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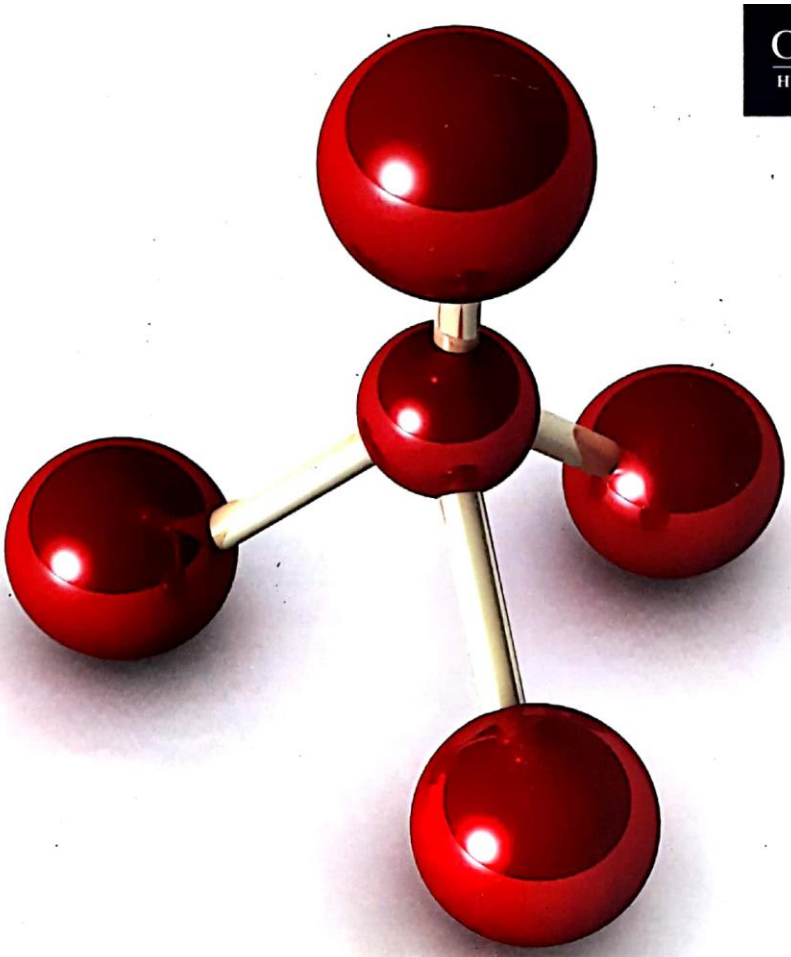

Problems and Solutions in Organic Chemistry

Subrata Sen Gupta

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Preface

Though chemical compounds are visible to the naked eye, their constituent atoms and bonds are invisible even under a very powerful microscope. When one tries to visualize the formation of a compound, one has to depend on the information available in related literature, confirmed through time-tested experiments. Therefore, when a student comes across a new problem, the solution can only be rationalized as a 'plausible' explanation or by concluding that 'results have to be confirmed by experiments and investigations'. Organic chemistry is a mind-boggling field of chemistry, in the sense that nature has produced thousands of organic molecules with unimaginable complexities. Fascinated by this area of study, chemists are observing and following nature to synthesize many new compounds in their laboratories, many of which have changed our lifestyle in unimaginable ways.

Young learners must realize that to excel in any science course, they must develop the habit of solving problems. To gain confidence in this, they would initially need the assistance of books that contain a large number of solved problems. It is with this objective in mind that *Problems and Solutions in Organic Chemistry* was conceived. The book is designed as a self-study material, to expose students to the various facets of organic chemistry.

ABOUT THE BOOK

Problems and Solutions in Organic Chemistry is primarily written for undergraduate students who have opted for an Honours course in chemistry. It will also be useful for students pursuing postgraduation in chemistry and those preparing for competitive examinations such as the Joint Admission Test for Masters (JAM), National Eligibility Test (CSIR–UGC NET), and Graduate Aptitude Test in Engineering (GATE).

Most problems in each chapter have been discussed on the basis of traditional functional groups present in organic compounds. This will help students get an idea of the types of problems based on a particular class of compounds. For example, alcohols can participate in elimination reactions, etherification reactions, esterification reactions, and are reagents in nucleophilic substitutions as well. Therefore, if we separately discuss the problems on alcohols, we can get an idea of the different types of reactions these compounds take part in. Similarly, the properties of aliphatic carbonyl compounds and aromatic carbonyl compounds differ in many reactions. Therefore, if problems on these compounds are individually discussed, students would get specific information on the types of reactions these two different classes of carbonyl compounds take part in. Such an approach to learning the subject is more pragmatic as it helps readers get acquainted with the relevant reactions within a class of organic compounds.

KEY FEATURES

- Problems on the nomenclature of the different classes of organic compounds based on IUPAC rules, and the answers to these
- A plethora of problems on the classes of compounds with plausible mechanisms and rationalization, where necessary
- Illustrative reaction mechanisms through well-drawn diagrams with supportive explanations and comments wherever needed
- Problems on stereochemistry, spectroscopy, and pericyclic reactions
- Over 1500 solved problems addressing various topics on the subject
- Includes 700 chapter-end exercise problems to aid self-evaluation

CONTENTS AND COVERAGE

The book has 21 chapters. A short description of the nature of problems included in each chapter is given here.

Chapter 1, *Nomenclature of Organic Compounds*, provides problems on the naming of various aliphatic, alicyclic, aromatic, fused polynuclear, spiro, heterocyclic, and bridged compounds. The nomenclature of many unique unsaturated aliphatic compounds and compounds with a variety of functional groups have been discussed. End-chapter exercises discussing certain interesting chemical structures have also been included.

Chapter 2, *Physical Organic Chemistry*, deals with problems based on the concepts and theories in organic chemistry, such as acid–base reactions, dipole moments, reaction rates, tautomerism, reaction kinetics, and aromaticities.

Chapter 3, *Stereochemistry*, includes a large number of problems on various aspects of stereochemistry involving organic molecules. Problems on both static and dynamic stereochemistry have been demonstrated.

Chapter 4, *Aliphatic and Alicyclic Hydrocarbons and their Halides*, elucidates problems on both saturated and

unsaturated compounds in addition to those on aliphatic and alicyclic hydrocarbons.

Chapter 5, *Alcohols and Ethers*, throws light on typical problems on alcohols and aliphatic ethers.

Chapter 6, *Aliphatic Carbonyl Compounds*, deals with a wide array of interesting problems on aliphatic aldehydes and ketones.

Chapter 7, *Aliphatic Acids and their Derivatives*, describes problems on aliphatic acids and their derivatives, such as esters, amides, and acid halides.

Chapter 8, *Aliphatic and Alicyclic Amines, Nitriles, Isocyanides, Ylides, Diazocompounds, and Organometallic Compounds*, discusses a host of interesting problems on these classes of compounds.

Chapter 9, *Aromatic Carbonyl Compounds*, explores the typical problems associated with these compounds.

Chapter 10, *Aromatic Acids, Amines, Nitro-compounds, and Diazo-compounds*, comprises a large number of problems on these staggering classes of compounds.

Chapter 11, *Phenolic Compounds, Benzoquinones, and Aromatic Ethers*, deals with specific and interesting problems on these compounds to understand their reactions better.

Chapter 12, *Benzenes, Polynuclear and Alicylic Hydrocarbons*, explains problems on benzene and substituted benzenes, polynuclear aromatic hydrocarbons, and some additional problems on alicyclic compounds, which have not been discussed in Chapter 4.

Chapter 13, *Pericyclic Reactions*, deals with problems on this special class of organic reactions. These include reactions such as electrocyclic reaction, cycloaddition reaction, sigmatropic reaction, and ene-reaction.

Chapter 14, *Problems on the Uses of Spectroscopic Methods in Organic Chemistry*, illustrates the problems on the application of ultraviolet (UV), infrared (IR), nuclear magnetic resonance (NMR), and mass spectroscopic methods in the identification and determination of structures of organic molecules.

Chapter 15, *Heterocyclic Compounds*, has a large array of problems on monocyclic and bicyclic heterocycles with N, O, and S as heteroatoms.

Chapter 16, *Carbohydrates*, has problems dealing with naturally occurring typical monosaccharides, disaccharides, and polysaccharides.

Chapter 17, *Amino Acids, Proteins, and Nucleic Acids*, deals with a variety of problems on important biomolecules such as amino acids, proteins, and nucleic acids.

Chapter 18, *Molecular Rearrangements*, analyses problems associated with molecular rearrangements encompassing all the classes of organic compounds.

Chapter 19, *Conversions and Syntheses of Organic Compounds*, gives a clear picture on the mechanisms related to conversions among organic molecules and also talks about the synthesis of organic molecules from typical compounds and reagents.

Chapter 20, *Constitutional Problems on Organic Compounds*, has a diverse range of problems on the identification of compounds based on a sequence of reactions.

Chapter 21, *Miscellaneous Problems*, presents a large number of interesting problems based on the different classes of organic compounds and a variety of organic reactions we encounter in organic chemistry.

Appendix A, *Abbreviations of a Few Reagents Used in Chemical Literature*, lists out the abbreviations and the corresponding chemical structures of some frequently used reagents in organic reactions.

Appendix B, *Reducing and Oxidizing Agents Commonly Used in Organic Chemistry*, lays emphasis on the various reducing and oxidizing agents, along with their chemical composition, preferred solvent, and reaction mixture.

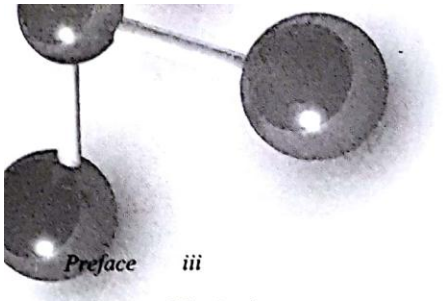
ACKNOWLEDGEMENTS

I express my deepest gratitude to Oxford University Press India for accepting this book for publication. I am particularly thankful to the members of the editorial team for their diligent guidance and cooperation in this endeavour.

I also appreciate the support and encouragement I received from my wife, Mrs Arundhati Sen Gupta, and my son, Dr Anirban Sen Gupta, during the preparation of this book.

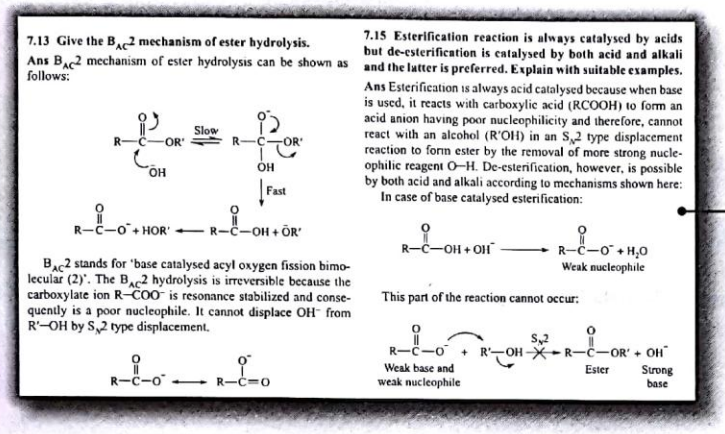
Suggestions and feedback are welcome and can be sent to me at pushpal_@hotmail.com and pushpal314@data-one.in.

Subrata Sen Gupta



Contents

FEATURES OF



7.13 Give the $B_{AC}2$ mechanism of ester hydrolysis.

Ans $B_{AC}2$ mechanism of ester hydrolysis can be shown as follows:

$B_{AC}2$ stands for 'base catalysed acyl oxygen fission bimolecular (2)'. The $B_{AC}2$ hydrolysis is irreversible because the carboxylate ion $R-\overset{O}{\overset{\|}{C}}-O^-$ is resonance stabilized and consequently is a poor nucleophile. It cannot displace OH^- from $R'-OH$ by S_N2 type displacement.

7.15 Esterification reaction is always catalysed by acids but de-esterification is catalysed by both acid and alkali and the latter is preferred. Explain with suitable examples.

Ans Esterification is always acid catalysed because when base is used, it reacts with carboxylic acid (RCOOH) to form an acid anion having poor nucleophilicity and therefore, cannot react with an alcohol (R'OH) in an S_N2 type displacement reaction to form ester by the removal of more strong nucleophilic reagent O—H. De-esterification, however, is possible by both acid and alkali according to mechanisms shown here:

In case of base catalysed esterification:

This part of the reaction cannot occur:

Over 1500 Problems with Solutions

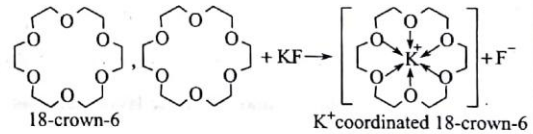
The book contains more than 1500 problems with solutions to reinforce learning through the question-and-answer format.

Illustration of Structural Formulae

The book is loaded with many structural formulae to enable visualization of the organic compounds.

Ans

(a) The structure of 18-crown is given here.



$$CH_3(CH_2)_6CH_2Br + F^- \longrightarrow CH_3(CH_2)_6CH_2F$$

EXERCISES

5.1 Draw the structures and IUPAC names of the isomeric 2° heptanols containing one methyl side chain.

5.2 What is Lucas reagent? How is it used to distinguish three classes of alcohols?

5.3 Alcohols are neutral towards alkali but readily forms alkoxides with alkali metals such as Na and K. Offer an explanation.

5.4 Potassium *t*-butoxide is a widely used base in organic reactions but the corresponding sodium compound is unknown. Give reason.

5.5 The dehydration of *n*-BuOH with acid gives two isomeric alkenes. What are they? Which one would be the major compound?

5.6 What are three isomeric alcohols having the molecular formula $C_4H_{10}O$? Which of them will react first when a mixture of them is treated with one equivalent of acetic acid?

5.7 Identify the compounds A and B in the following reactions. Comment on the stereochemical aspects where necessary.

5.8 How can you use CH_3CH_2OH to get CH_3CH_2OD and CH_3CH_2D?

5.9 How can you convert $(CH_3)_3CCH{=}O$ to neopentyl alcohol using $HCH{=}O$ as reducing agent?

5.10 What are the compounds formed when vapour of each of the following compounds is passed through the hot copper tube? (a) Butan-1-ol, (b) Butan-2-ol (c) 2-Methylbutan-2-ol.

5.11 Describe the action of an oxidizing agent on primary, secondary, and tertiary alcohols.

5.12 Write down the action of the following reagents on ethyl and isopropyl alcohol.

(a) Na
(b) $POCl_3$
(c) Hot H_2SO_4
(d) CH_3COOH in presence of a few drops of H_2SO_4
(e) CH_3COCl

5.13 How can you distinguish between (a) methanol and ethanol (b) propan-1-ol and propan-2-ol.

5.14 Outline the synthesis of each of the following compounds:

Numerous Exercises

There are more than 700 exercise questions spread across chapters for self-evaluation of concepts.

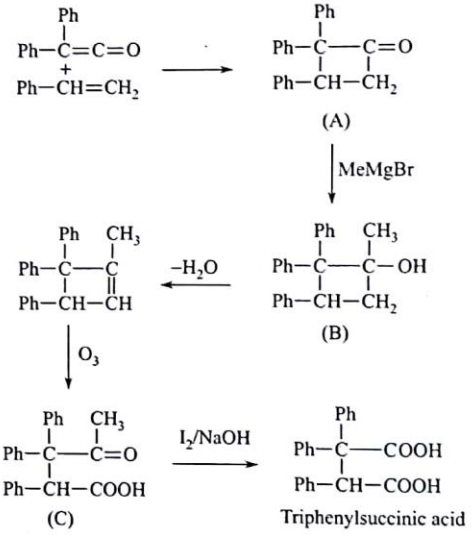
THE BOOK

Exclusive Chapter on Constitutional Problems

This chapter trains students to analytically think and deduce organic compounds which are represented as unknown variables in a given reaction description.

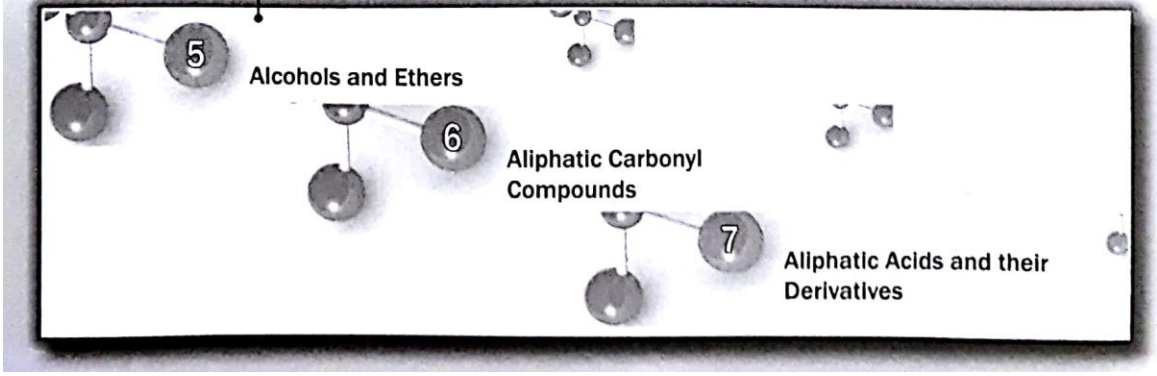
20.6 The interaction of diphenylketene and styrene results in a compound 'A', $C_{22}H_{18}O$. 'A' reacts with methylmagnesium bromide to give 'B', $C_{23}H_{22}O$. Dehydration of 'B' followed by ozonolysis gives a ketoacid 'D', which with alkaline hypoiodite forms triphenylsuccinic acid. Identify the compounds 'A', 'B', and 'D' and show the reactions.

Ans



Presentation Based on Various Classes of Compounds

The text exemplifies the subject matter according to the various classes of organic compounds and their associated reactions.

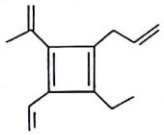


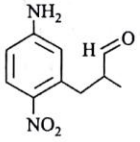
1 Nomenclature of Organic Compounds

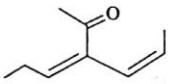
1.1 Give the structures of the following IUPAC names:

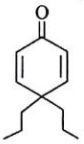
(a) 1-Allyl-2-ethyl-4-(prop-1-en-2-yl)-3-vinylcyclobuta-1,3-diene
(b) 3-(5-Amino-2-nitrophenyl)-2-methylpropanal
(c) 3-(Prop-1-enyl)hex-3-en-2-one
(d) 4,4-Dipropylcyclohexa-2,5-dienone
(e) 8-Methyl-6,7-dimethylene-4-oxononanoic acid
(f) 2-(Prop-1-en-2-yl)-7-vinyl-1,2,3,4,5,6,6,8-octahydronaphthalene
(g) 2-(1-Methyl-7-vinyl-1,2,3,4-tetrahydronaphthalene-2-yl)acrylic acid
(h) 5-Ethyl-2,9,12-trimethyl-10-methylenetridec-1-en-6-one
(i) Octa-2,4-dienedial
(j) 4,8,9,11-Tetramethyl-5-oxododecanal

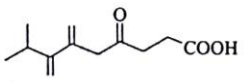
Ans

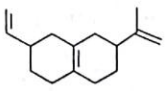
(a) 

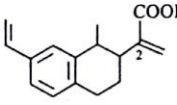
(b) 

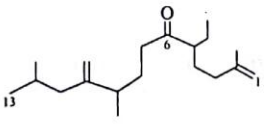
(c) 

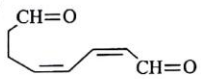
(d) 

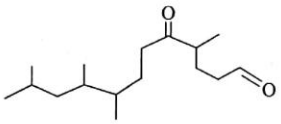
(e) 

(f) 

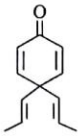
(g) 

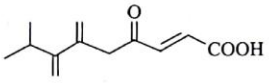
(h) 

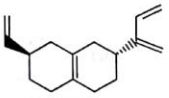
(i) 

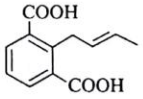
(j) 

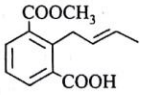
1.2 Give IUPAC names of the following compounds along with the stereochemical descriptors.

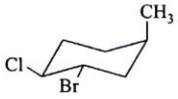
(a) 

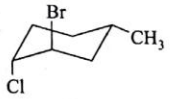
(b) 

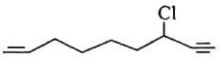
(c) 

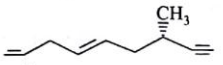
(d) 

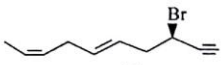
(e) 

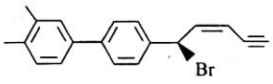
(f) 

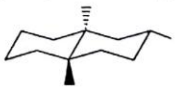
(g) 

(h) 

(i) 

(j) 

(k) 

(l) 

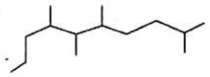
Ans

(a) 4,4-Di((*E*)-prop-1-enyl)cyclohexa-2,5-dienone
(b) (*E*)-8-Methyl-6,7-dimethylene-4-oxonon-2-enoic acid
(c) (2*R*,7*R*)-2-(*s*-*cis*(But-1,3-dien-2-yl)-7-vinyl-1,2,3,4,5,6,7,8-octahydronapthalene
(d) (*E*)-2-(But-2-enyl)benzene-1,3-dicarboxylic acid
(e) (*E*)-2-(But-2-enyl)-3-(methoxycarbonyl)benzoic acid

(f) (1*S*,2*S*,4*R*)-2-Bromo-1-chloro-4-methylcyclohexane
(g) (1*R*,2*R*,4*S*)-2-Bromo-1-chloro-4-methylcyclohexane
(h) 7-Chloronon-1-en-8-yne
(i) (*S*,*E*)-7-Methylnona-1,4-dien-8-yne
(j) (*R*,5*E*,8*Z*)-3-Bromodeca-5,8-dien-1-yne
(k) (*R*,*Z*)-4/-(1-Bromopent-2-en-4-ynyl)-3,4-dimethylbiphenyl
(l) (2*R*,4a*S*,8a*S*)-2,4a,8a-Trimethyldehydronaphthalene

1.3 Give IUPAC names of the following compounds along with the stereochemical descriptors wherever applicable.

(a)



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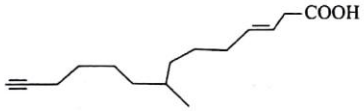

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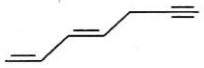

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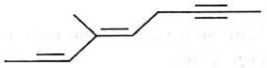
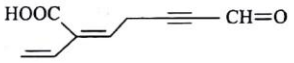


(e)



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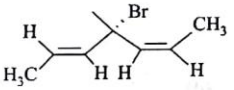

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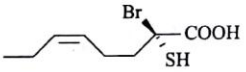

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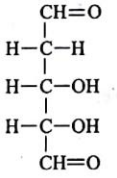

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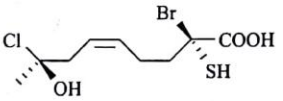

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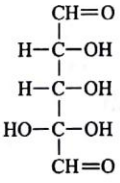

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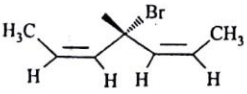

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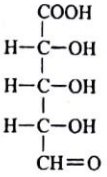

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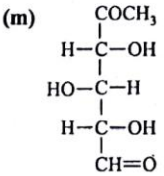

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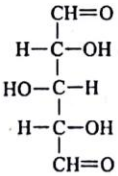

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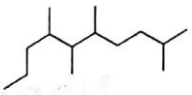

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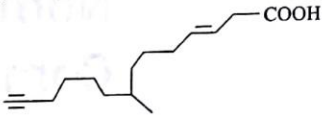

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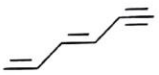

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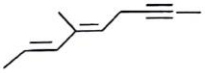
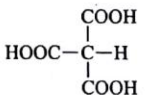


Ans

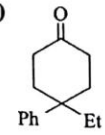
(a) 2,5,6,7-Tetramethyldecann
(b) (*E*)-8-Methyltetradec-3-en-13-ynoic acid
(c) (*E*)-Hepta-1,3-dien-6-yne
(d) (4*E*)-4-Methylnona-2,4-dien-7-yne
(e) (2*Z*)-7-Oxo-2-(prop-1-enyl)hept-2-en-5-ynoic acid
(f) (*S*,2*Z*,5*E*)-4-Bromo-4-methylhepta-2,5-diene
(g) (*R*,*Z*)-2-Bromo-2-mercaptooct-5-enoic acid
(h) (2*R*,3*r*,4*S*)-2,3,4-Trihydroxypentanedial
(i) (2*R*,8*S*,*Z*)-2-Bromo-8-chloro-8-hydroxy-2-mercaptonon-5-enoic acid
(j) (2*R*,4*R*)-2,3,4-Trihydroxypentanedial
(k) (2*Z*,5*Z*)-4-Bromo-4-methylhepta-2,5-diene
(l) (2*R*,3*R*,4*S*)-2,3,4-Trihydroxy-4-formylpentanoic acid
(m) (2*S*,3*S*,4*R*)-2,3,4-Trihydroxy-5-oxohexanal
(n) (2*R*,3*s*,4*S*)-2,3,4-Trihydroxypentanedial
(o) 2,5,6,7-Tetramethyldecane
(p) (*E*)-8-Methyltetradec-3-en-13-ynoic acid
(q) (*E*)-Hexa-1,3-dien-6-yne
(r) (2*E*,4*E*)-4-Methylocta-2,4-dien-6-yne

1.4 Write the IUPAC names of the following compounds.

(a)



(b)



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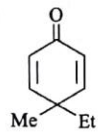

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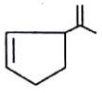

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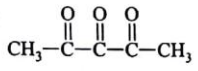

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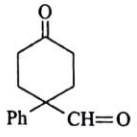
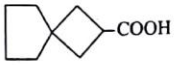


(g)

(h)



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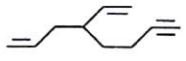

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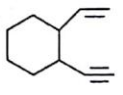

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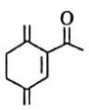

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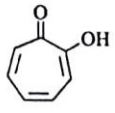

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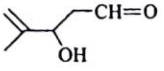

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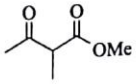
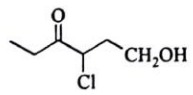


(o) 

Ans

(a) Methanetricarboxylic acid
(b) 4-Ethyl-4-phenylcyclohexanone
(c) 4-Ethyl-4-methylcyclohexa-2,5-dienone
(d) 3-(Prop-1-en-2-yl)cyclopent-1-ene
(e) Pentane-2,3,4-trione
(f) 4-Oxo-1-phenylcyclohexanecarbaldehyde
(g) Bicyclo[2.2.2]octan-2-one
(h) Spiro[3.4]octane-2-carboxylic acid
(i) 4-Vinyloct-1-en-7-yne
(j) 1-Ethynyl-2-vinylcyclohexane
(k) 1-(3,6-Dimethylenecyclohex-1-enyl)ethanone
(l) 2-Hydroxycyclohepta-2,4,6-trienone
(m) 3-Hydroxy-4-methylpent-4-enal
(n) Methyl 2-methyl-3-oxobutanoate
(o) 4-Chloro-6-hydroxyhexan-3-one

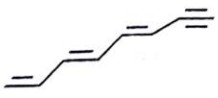
1.5 Are the following IUPAC names correct? If not, give their correct IUPAC names.

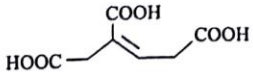
(a) 1,3,4,5,6-Pentabromo-1,2,6-trichlorohexane
(b) 5-Ethoxy-2-methyl-5-oxopentanoic acid
(c) 2-Methyl-4,6-dioxoheptanal
(d) Biacetyl
(e) Butane-1,3-dione
(f) Diethyl oxalate
(g) 4-Nitropentanenitrile
(h) Octa-5,7-dien-1,3-diyne
(i) Butane-1,2,4-tricaboxylic acid
(j) 4-Cyano-2-(2-cyanoethyl)butanoic acid
(k) 3-Propylidenepent-1-en-5-yne

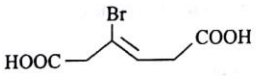
Ans

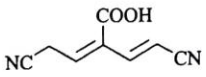
(a) Incorrect (Correct name: 1,2,3,4,6-Pentabromo-1,5,6-trichlorohexane)
(b) Incorrect (Correct name: 4-Carbethoxy-2-methylbutanoic acid)
(c) Correct
(d) Incorrect (Correct: Butane-2,3-dione)
(e) Incorrect (Correct: 3-Oxobutanal)
(f) Incorrect (Correct: Diethyl ethanedioate)
(g) Correct
(h) Incorrect (Correct: Octa-1,3-diene-5,7-diyne)
(i) Correct
(j) Correct
(k) Incorrect (3-Ethynylhexa-1,3-diene)

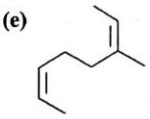
1.6 Give the *E,Z* nomenclature of the following compounds.

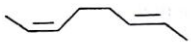
(a) 

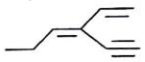
(b) 

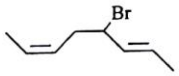
(c) 

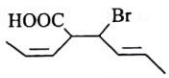
(d) 

(e) 

(f) 

(g) 

(h) 

(i) 

Ans

(a) (3*E*,5*E*)-Octa-1,3,5-trien-7-yne
(b) (*E*)-But-2-ene-1,2,4-tricarboxylic acid
(c) (*Z*)-4-Bromohex-2-enedioic acid
(d) (*Z*)-4-Cyano-2-[(*E*)-2-cyanovinyl]but-2-enoic acid
(e) (2*Z*,4*Z*)-3-Methylocta-2,6-diene
(f) (2*Z*,6*E*)-Octa-2,6-diene
(g) (*Z*)-3-Ethynylhexa-1,3-diene
(h) (2*E*,6*Z*)-4-Bromoocta-2,6-diene
(i) (*E*)-3-Bromo-2-[(*Z*)-prop-1-enyl]hex-4-enoic acid

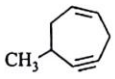
1.7 Give the IUPAC names of the following monovalent radicals.

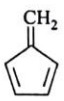
(a) $CH{\equiv}C-$ **(b)** $CH{\equiv}CCH_2-$ **(c)** $CH_3CH{=}CH-$
(d) $CH_3CH{=}CHCH_2-$ **(e)** $CH_3CH_2CH{=}CHCH_2-$
(f) $CH_2{=}CHCH{=}CH-$ **(g)** $HC{\equiv}CCH{=}CHCH_2-$

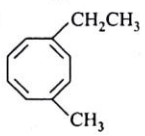
Ans

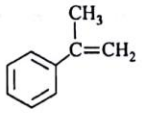
(a) Ethylnyl
(b) Prop-2-ynyl
(c) Prop-1-enyl
(d) But-2-enyl
(e) Pent-2-enyl
(f) Buta-1,3-dienyl
(g) Pent-2-en-4-ynyl

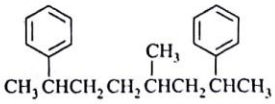
1.8 Give the IUPAC names of the following structures.

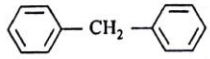
(a) 

(b) 

(c) 

(d) 

(e) 

(f) 

Ans

(a) 6-Methylcyclohepta-1-en-4-yne
(b) 5-Methylidenecyclopenta-1,3-diene
(c) 1-Ethyl-4-methylcycloocta-1,3,5,7-tetraene
(d) Prop-1-en-2-ylbenzene
(e) 4-Methyl-2,7-diphenyloctane
(f) Diphenylmethane

1.9 Give the structures of the following names.

(a) Perfluorohexane
(b) Perchloro(2-methylpentane)
(c) Perbromocyclohexane
(d) 4′-Chloro-*m*-terphenyl
(e) 4-(1-Propyl)octan-2-ol
(f) 4-(2-Butyl)heptane-2,6-diol
(g) 2-(Hydroxymethyl)heptane-1,6-diol

Ans

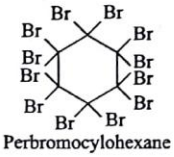
(a) $CF_3-CF_2-CF_2-CF_2-CF_2-CF_3$

Perfluorohexane

(b) $CCl_3-\underset{\displaystyle CCl_3}{\underset{|}{C}}Cl-CCl_2-CCl_2-CCl_3$

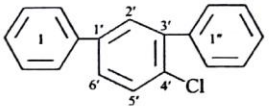
Perchloro(2-methylpentane)

(c)



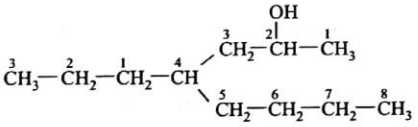
Perbromocylohexane

(d)



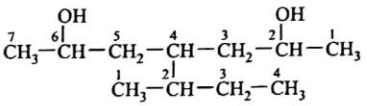
4′-Chloro-*m*-terphenyl

(e)



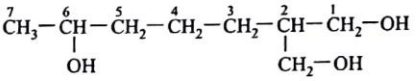
4-(1-Propyl)-octan-2-ol

(f)



4-(2-Butyl)heptane-2,6-diol

(g)



2-(Hydroxymethyl)heptane-1,6-diol

1.10 Give the structure of the following IUPAC names.

(a) 3,6-Dioxaoctane
(b) 3,6-Dioxaoctane-1,8-diol
(c) 1,2-Epoxy-2-methylbutane
(d) 1,3-Epoxy-2,2-dimethylpropane
(e) 1-Oxaspiro[4.5]decane
(f) 9-Oxa-6-azaspiro[4.5]decane
(g) 3-Vinylhept-2-en-6-ynal
(h) Heptanedial
(i) 3-Ethyl-2-methylbutanedial
(j) Naphthalene-1,2-dicarbaldehyde
(k) Thiazolidine-2-carbaldehyde
(l) Pyridine-2-carbaldehyde
(m) Pent-1-en-4-yn-3-one

Ans

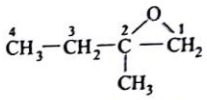
(a) $CH_3-CH_2-O-CH_2-CH_2-O-CH_2-CH_3$

3,6-Dioxaoctane

(b) $HOCH_2-CH_2-O-CH_2-CH_2-O-CH_2-CH_2OH$

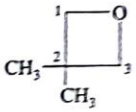
3,6-Dioxaoctane-1,8-diol

(c)



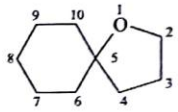
1,2-Epoxy-2-methylbutane
(2-Ethyl-2-methyloxirane)

(d)



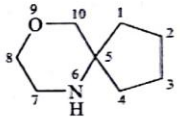
1,3-Epoxy-2,2-dimethylpropane
(3,3-Dimethyloxetane)

(e)



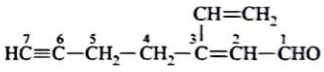
1-Oxaspiro[4.5]decane
(Not 4-Oxaspiro[4.5]decane)

(f)



9-Oxa-6-azaspiro[4.5]decane
not 7-Oxa-10-azaspiro[4.5] (6,9 is lower than 7,10)

(g)

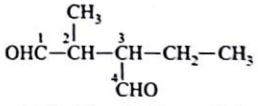


3-Vinylhept-2-en-6-ynal

(h) $OHC-CH_2-CH_2-CH_2-CH_2-CH_2-CHO$

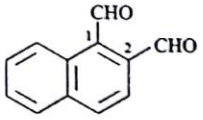
Heptanedial

(i)



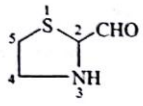
3-Ethyl-2-methylbutanedial

(j)



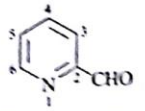
Naphthalene-1,2-dicarbaldehyde

(k)



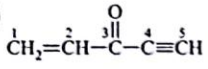
Thiazolidine-2-carbaldehyde

(l)



Pyridine-2-carbaldehyde

(m)



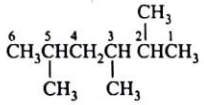
Pent-1-en-4-yn-3-one

1.11 Give the structures of the following names.

(a) 2,3,5-Trimethylhexane
(b) 2,7,8-Trimethyldecane
(c) 4-Ethyl-5-methylnonane
(d) 5-Ethyl-2,2-dimethylheptane
(e) 7-(1,2-dimethylpentyl)-5-ethyltetradecane
(f) 4-Ethyl-5-methyloctane
(g) 4-Isopropyl-5-propyloctane
(h) 5-(1-Methylbutyl)-7-(2-methylbutyl)tridecane
(i) 5,5-Bis-(1,1-dimethylpropyl)-2-methyldecane
(j) 2,3,5-Trimethyl-4-propylheptane
(k) 7,7-Bis-(2,4-dimethylhexyl)-3-ethyl-5,9,11-trimethyltridecane
(l) 4-(1-Isopropylbutyl)-3-propylundecane
(m) 3,4-Diethylhexa-1,3-dien-5-yne
(n) 3-Propylhex-1-en-4-yne

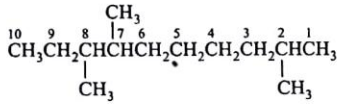
Ans

(a)



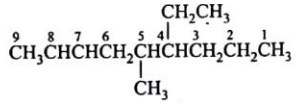
2,3,5-Trimethylhexane

(b)



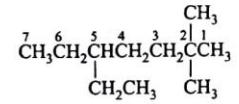
2,7,8-Trimethyldecane

(c)



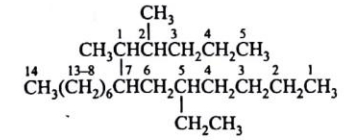
4-Ethyl-5-methylnonane

(d)



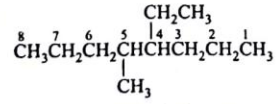
5-Ethyl-2,2-dimethylheptane

(e)



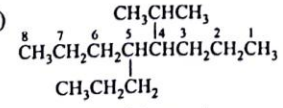
7-(1,2-Dimethylpentyl)-5-ethyltetradecane

(f)



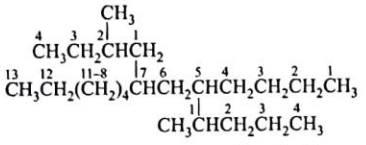
4-Ethyl-5-methyloctane

(g)



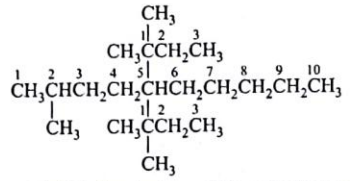
4-Isopropyl-5-propyloctane

(h)



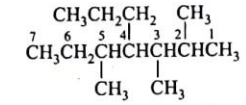
5-(1-Methylbutyl)-7-(2-methylbutyl)tridecane

(i)



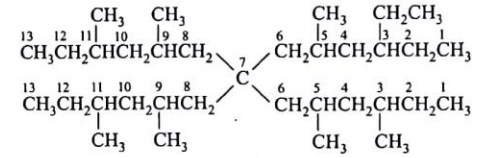
5,5-Bis(1,1-dimethylpropyl)-2-methyldecane

(j)



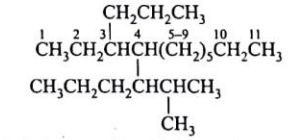
2,3,5,-Trimethyl-4-propylheptane

(k)



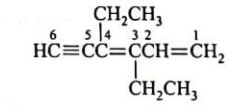
7,7-Bis-(2,4-dimethylhexyl)-3-ethyl-5,9,11-trimethyltridecane

(l)



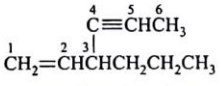
4-(1-Isopropylbutyl)-3-propylundecane

(m)



3,4-Diethylhexa-1,3-dien-5-yne

(n)

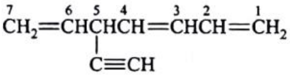


3-Propylhex-1-en-4-yne

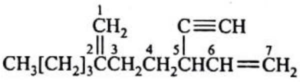
1.12 Give the structures of the following names.

(a) 5-Ethylhepta-1,3,6-triene
(b) 2-Butyl-5-ethynylhepta-1,8-diene
(c) 7-Methyltrideca-1,10-diene-4,8-diyne
(d) 4-Vinylhept-2-en-5-yne
(e) 6-Methylcyclohept-1-en-4-yne
(f) 5-Methylidenecyclopenta-1,3-diene
(g) 1-Ethyl-4-methylcycloocta-1,3,5,7-tetraene

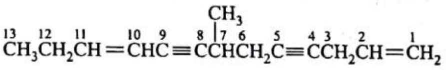
Ans

(a) 

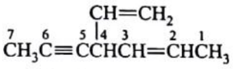
5-Ethynylhepta-1,3,6-triene

(b) 

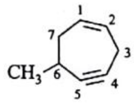
2-Butyl-5-ethynylhepta-1,6-diene

(c) 

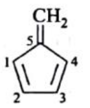
7-Methyltrideca-1,10-diene-4,8-diyne

(d) 

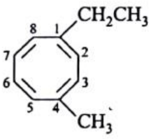
4-Vinylhept-2-en-5-yne

(e) 

6-Methylcyclohept-1-en-4-yne

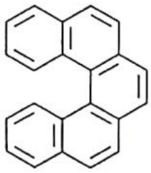
(f) 

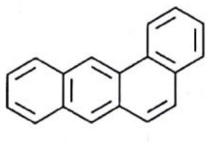
5-Methylidenecyclopenta-1,3-diene (Trivial name: Fulvene)

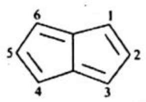
(g) 

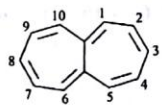
1-Ethyl-4-methylcycloocta-1,3,5,7-tetraene

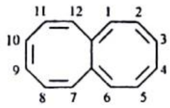
1.13 Give the names of the following fused ring hydrocarbons.

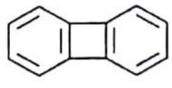
(a) 

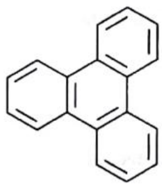
(b) 

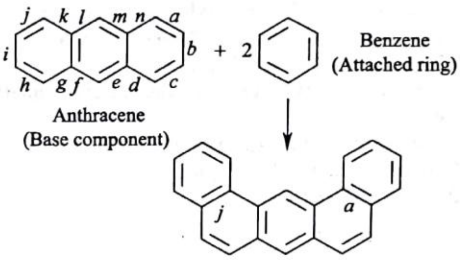
(c) 

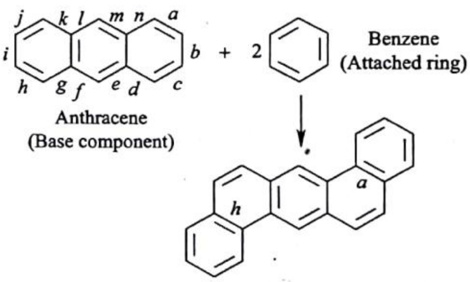
(d) 

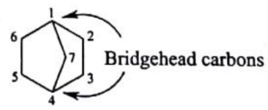
(e) 

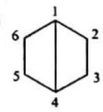
(f) 

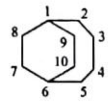
(g) 

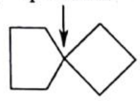
(h) 

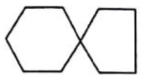
(i) 

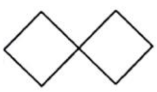
(j) 

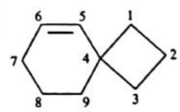
(k) 

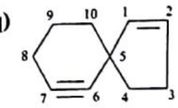
(l) 

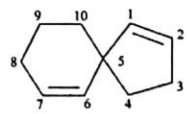
(m) 

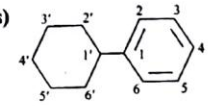
(n) 

(o) 

(p) 

(q) 

(r) 

(s) 

Ans

(a) Dibenzophenanthrene
(b) Benzanthracene
(Not Benzoanthracene)
(c) Pentalene
(d) Heptalene
(e) Octalene
(f) Biphenylene
(Not Diphenylene; two benzene ringsare ortho-fused to the central ring of four carbon atoms)
(g) Triphenylene
(Three benzene rings are ortho-fused to the central ring of six carbon atoms)
(h) Dibenzo[a,j]anthracene
(i) Dibenzo[a,h]anthracene
(j) Bicyclo[2.2.1]heptane
(k) Bicyclo[2.2.0]hexane
(l) Bicyclo[4.2.2]decane
(m) Spiro[3.4]octane
(Total number of carbons is eight)
(n) Spiro[4.5]decane
(Not Spiro[5.4]decane; total number of carbons is ten)
(o) Spiro[3.3]heptane
(Total number of carbons is seven)
(p) Spiro[3.5]non-5-ene
(q) Spiro[4.6]dec-1-en-6-yne
(r) Spiro[4.5]deca-1,6-diene
(Not Spiro[4.5]deca-1,9-diene; 1,6 is lower than 1,9)
(s) Cyclohexylbenzene

1.14 Are the following IUPAC names correct? If not, give the correct name along with the structures. Give your reasons in brief.

(a) 1,5-Dibromohexa-3,5-dien-1-yne
(b) Hexane-1,6-dicarboxylic acid
(c) 3-Ethynylhexa-1,4-diene
(d) 4- Formylbutan-2-one
(e) Hepta-2-en-5-ynedioic acid
(f) 5-Formyl-2-oxohexanedioic acid
(g) Propane-1,2,3-tricarboxylic acid
(h) 3-Isocyanatopropylcyanate
(i) Isopropanol
(j) Diaziridine-1-carboxylic acid
(k) 7-Bromo-hept-4,6-dien-2-ynoic acid
(l) Octa-4,6-dien-2-yndioic acid

Ans

(a) Incorrect	(e) Correct	(i) Incorrect
(b) Correct	(f) Incorrect	(j) Incorrect
(c) Correct	(g) Correct	(k) Correct
(d) Incorrect	(h) Correct	(l) Incorrect

The correct names and the corresponding structures are given here, with explanations as necessary.

(a) $Br-CH=CH-CH=CH-C\equiv C-Br$

1,6-Dibromo-2,3-dien-5-yne
(Numbering should start from the left-hand side according to IUPAC rule)

(b) $HOOC-CH_2-CH_2-CH_2-CH_2-COOH$

Hexanedioic acid
(In the case of saturated dicarboxylic acid with no branching, one need not give any number to indicate the positions of COOH groups)

(c) $CH_3-CH=CH-\underset{\displaystyle CH=CH_2}{\underset{|}{CH}}-C\equiv CH$

3-Ethynylhexa-1,4-diene
(In the case of compounds having double bonds and triple bonds, the base name should include the maximum number of double bonds)

(d) $CH_3-\overset{\displaystyle O}{\overset{\|}{C}}-CH_2-CH_2-CH=O$

4-Oxopentanal
(−CH=O group gets preference over C=O group in numbering the chain. The position of the terminal −CH=O group need not be given any number)

(e) $HOOC-CH=CH-CH_2-C\equiv C-COOH$

Hept-2-en-5-ynedioic acid
(Since we have the option of numbering the carbon chain, the double bond gets a lower number)

(f) $HOOC-\underset{\displaystyle CH=O}{\underset{|}{CH}}-CH_2-CH_2-\overset{\displaystyle O}{\overset{\|}{C}}-COOH$

2-Formyl-5-oxohexanedioic acid
(−CH=O group gets preference in citation over C=O group, when there is an option)

(g) $NC-CH_2-\underset{\displaystyle CN}{\underset{|}{CH}}-CH_2-CN$

Propane-1,2,3-tricarbonitrile
(−CN group is named as carbonitrile when they are supposed to yield carboxylic acid on hydrolysis in an aliphatic chain)

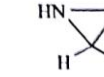
(h) $NCO-CH_2-CH_2-CH_2-NCO$

3-Isocyanatopropylcyanate
[−NCO group (cyanate) gets preference over −OCN (isocyanate group)]

(i) $CH_3-\underset{\displaystyle OH}{\underset{|}{CH}}-CH_3$

Propan-1-ol
(Isopropanol is a wrong name because there is no hydrocarbon like isopropane)

(j)



Diaziridine-3-carboxylic acid
(Numbering should start from the nitrogen atoms of the ring)

(k) Br—=—=—≡—COOH

7-Bromohepta-4,6-dien-2-ynoic acid
(Numbering should start from the side of the —COOH group which is the principle functional group)

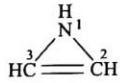
(l) HOOC—=—=—≡—COOH

Octa-2,4-dien-6-ynedioic acid
(Since there is a choice, numbering should start from the double bond end)

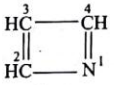
1.15 Give the names of the following heterocyclic compounds based on the Hantzsch–Widmann system.

(a) 1H-Azirene
(b) Azete
(c) Oxirane
(d) Oxetene
(e) 2-Ethyl-3-methylaziridine
(f) 1,4-Diphenylazetidine
(g) 1,3-Dithiolane
(h) 1,3,5,7-Tetroxocane
(i) 2*H*,4*H*-1,3-Dioxine
(j) 1,2,4-Trazine
(k) 4*H*-1,3-Diphosphepine
(l) 1,3-Oxathiolane
(m) 1,3-Thiazole
(n) 6*H*-1,2,5-Thiadiazine
(o) 2*H*,6*H*-1,5-2-Dithiazine
(p) 1,3,2-Diazarsetidine
(q) 1,4,2-Oxazaphospholidine
(r) 1,2,4,3-Triazasilolidine

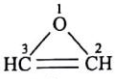
Ans The structures of the aforementioned compounds are given here.

(a) 

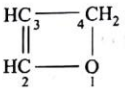
1*H*-Azirene
1*H*-Azirine (Traditional)

(b) 

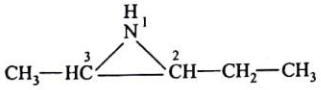
Azete

(c) 

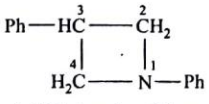
Oxirane

(d) 

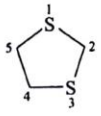
Oxetene

(e) 

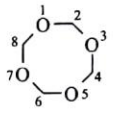
2-Ethyl-3-methylaziridine
(Substituents are cited in alphabetical order)

(f) 

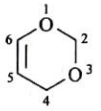
1,4-Diphenylazetidine

(g) 

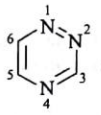
1,3-Dithiolane
(The locant set '1,3' is lower than '1,4')

(h) 

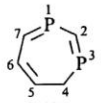
1,3,5,7-Tetroxocane

(i) 

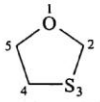
2*H*,4*H*-1,3-Dioxine
(Or simply 4*H*-1,3-Dioxine)

(j) 

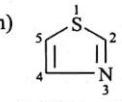
1,2,4-Triazine
(The locant set '1,2,4' is lower than other possible sets '1,2,5'; '1,3,5'; or '1,4,5')

(k) 

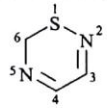
4*H*-1,3-Diphosphepine
(Hetero atoms get preference to indicate hydrogen for the lowest locants)

(l) 

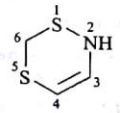
1,3-Oxathiolane
(1-Oxa-3-thiolane is incorrect)

(m) 

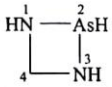
1,3-Thiazole

(n) 

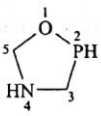
6*H*-1,2,5-Thiadiazine
(Numbering begins with the sulfur atom and the set '1,2,5' is lower than the set '1,3,6')

(o) 

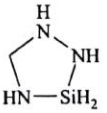
2*H*,6*H*-1,5,2-Dithiazine
(Numbering begins with the sulfur atom. 'Thia' prefix gets preference over 'aza' and that is why the order of locants is '1,5,2' and not '1,2,5'.)

(p) 

1,3,2-Diazarsetidine

(q) 

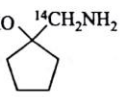
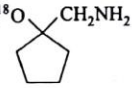
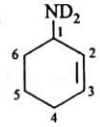
1,4,2-Oxazaphospholidine
(Not 1,4,2-Oxaazapholidine)

(r) 

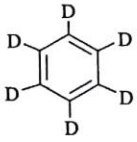
1,2,4,3-Triazasilolidine

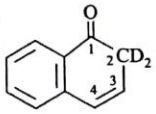
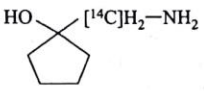
1.16 Give the names of the following isotope labelled compounds.

(a) $^{14}CH_4$ (b) CH_3D (c) CD_2Cl_2

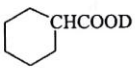
(d)  (e)  (f) 

(g) $^{14}CH_2COOC_2H_5$ / $^{14}CH_2COONa$ (h) $CH_3-CH_2-CH(CH_3)-CH=C[^2H_2]$

(i) $CH_3-CH_2-O[^2H]$ (j) 

(k)  (l) 

(m) CH_2DCOOH (n) CH_3-COOD

(o) $CH_3-CH_2-CH_2-CH_2[^{14}C]OOD$ (p) 

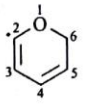
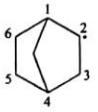
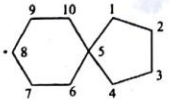
(q) $[^{14}C]H_3-CH_2-C_6H_4-COOH$ (r) $H[^{14}C]OONa$

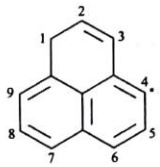
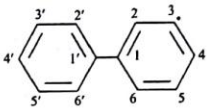
Ans

(a) (^{14}C)Methane
(b) ($^2H_1$)Methane
(c) Dichloro($^2H_2$)methane
(d) 1-[Amino(^{14}C)methyl]cyclopentanol
(e) 1-(Aminomethyl)cyclopentan(^{18}O)ol or 1-(Aminomethyl)(^{18}O)cyclopentanol
(f) (*N*,*N*-$^2H_2$)Cyclohex-2-en-1-amine
(g) Sodium ethyl(2,3-$^{14}C_2$)succinate
(h) 3-Methyl[1,1-$^2H_2$]pent-1-ene (Here the locant is part of the parent hydrocarbon name)
(i) Ethan[^2H]ol or [*O*-^2H]Ethanol
(j) [$^2H_6$]Benzene
(k) [2,2-$^2H_2$]-1-(2*H*)-Naphthalenone
(l) 1-(Amino[^{14}C]methyl)cyclopentanol
(m) [2-$^2H_1$]Acetic acid
(n) [*O*-^2H]Acetic acid or Acetic[^2H]acid
(o) [1-^{14}C]Pentan[^2H]oic acid or [1-^{14}C, *O*-^2H]pentanoic acid
(p) Cyclohexane[^2H]carboxylic acid
(q) 4-([2-^{14}C]Ethyl)benzoic acid
(r) Sodium [^{14}C]formate

1.17 Give the names of the following radicals and ions.

(a) $CH_3CH_2\dot{C}H_2$ (b) $CH_3\dot{C}HCH_2$ (c) 

(d)  (e)  (f) 

(g)  (h) 

(i) $\overset{+}{C}H_3$ (j) $CH_3CH_2\overset{+}{C}H_2$ (k) $CH_3\overset{+}{C}HCH_3$

(l)  (m)  (n) $\overset{+}{C}H_2-\overset{+}{C}H_2$

(o)  (p)  (q) $\overset{+}{C}H_2-\overset{+}{C}H-\overset{+}{C}H_2$

(r) $\overset{+}{C}H_2-CH_2-CH_2-\overset{+}{C}H_2$ (s) CH_3^- (t) $\overset{3}{C}H_3-\overset{2}{\underset{-}{C}}H-\overset{1}{C}H_3$

(u) $\overset{4}{C}H_3-\overset{3}{C}H_2-\overset{2}{C}H_2-\overset{1}{C}H_2^-$ (v) $\overset{4}{C}H_3-\overset{3}{C}H_2-\overset{2}{C}-\overset{1}{C}^-$

Ans

(a) Propyl
(b) Propan-2-yl or 1-Methylethyl or Isopropyl (Traditional)
(c) Cyclopenta-2,4-diene-1-yl
(d) 2*H*-Pyran-6-yl
(e) Bicyclo[2.2.1]heptan-2-yl
(f) Spiro[4.5]decan-8-yl
(g) 1*H*-Phenalen-4-yl
(h) 1,1′-Biphenyl-3-yl
(i) Methylium *Methyl cation
(j) Propylium *Propyl cation
(k) Propyl-2-ylium *Propan-2-yl cation
(l) Cyclobutylium *Cyclobutyl cation
(m) Furan-2-ylium *Furan-2-yl cation
(n) Ethane-1,2-bis(ylium)
(o) Cyclobut-3-ene-1,2-bis(ylium)
(Note that the charged carbon gets priority in numbering)
(p) Cyclohexane-1,1-bis(ylium) *Cyclohexylidene dication
(q) Propane-1,2,3-tris(ylium)
(r) Butane-1,4-bis(ylium)
(s) Methanide *Methyl anion
(t) Propan-2-ide 1-Methylethanide
*Propan-2-yl anion
*1-Methylethyl anion
(u) Butan-1-ide *Butan-1-yl anion
(v) But-1-yn-1-ide *But-1-yn-1-yl anion

1.18 What is meant by λ, δ, and Δ conventions in naming organic compounds? Give examples.

Ans *λ-convention*: It is a method of describing non-standard bonding numbers of skeletal atoms in parent hydrides. A non-standard bonding number of a neutral hetero atom in a structure is denoted by the symbol λ^n, where n is the number of non-standard bonds. A few examples are given here.

CH_3-SH_5

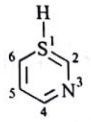
Methyl-λ^6-sulphane
(Sulphur atom has non-standard bonding number 6)

$(C_6H_5)_3PH_2$

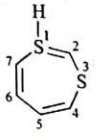
Triphenyl-λ^5-phosphane
(Phosphorus atom has non-standard bonding number 5)

$H_2\overset{3}{P}\overset{2}{P}H_3\overset{1}{P}H_2$

$2\lambda^5$-Triphosphane

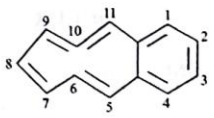


$1\lambda^4$-Thiazine
(Sulphur atom has non-standard bonding number 4)

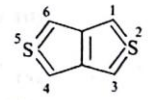


$1\lambda^4$,3-Dithiepin (IUPAC)
$1\lambda^4$-,1,3-Dithiepin (CAS)
(CAS stands for chemical abstract service)

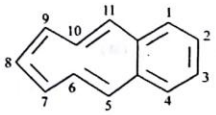
δ-convention: The presence of contiguous formal double bonds at a skeletal atom in a cyclic parent compound whose name normally represents the structural unit having maximum number of non-cumulative double bonds is described by the symbol 'δ^c', where 'c' is an Arabic numeral denoting the number of contiguous double bonds attached to that particular skeletal atom. The symbol 'δ^c' is always preceded by the concerned locant. The hetero atom exhibiting a non-standard bonding number can be associated with contiguous formal double bonds in a cyclic parent hydride. In such cases the symbol for the non-standard bonding number is also to be incorporated in the name. Illustrative examples are given here.



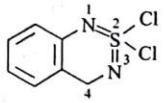
$10\delta^2$-Benzo[9]annulene



$2\lambda^4\delta^2,5\lambda^4\delta^2$-Thieno[3,4-c]thiophene

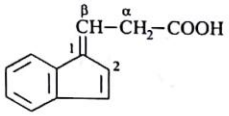


$8\delta^2$-Benzo[9]annulene



2,2-Dichloro-4*H*-$2\lambda^6\delta^2$-1,3-benzothiadiazine

Δ-convention: If the cyclic component and the side chain are linked together through a double bond, the locants of this bond are placed as superscripts to a Greek capital delta (Δ). The symbol is inserted between the cyclic and the acyclic component. The locant for the cyclic part is placed earlier.



Indene-$^{1,\beta}\Delta$-propionic acid

EXERCISES

1.1 In the following pairs, state which name is correct and which isn't.

(a) Pentan-2-ol and Pentane-2-ol
(b) Pentane-2,4-dione and Penta-2,4-dione
(c) 1,2,*N*,*N*-Tetraaminobenzene and *N*,*N*,1,2-Tetraminobenzene
(d) 1,3,5,7-Tetroxocane and 1,3,5,7-Tetraoxacane
(e) Thialdehyde and Thioaldehyde
(f) Imidoamidic acid and Imidamidic acid
(g) Carboximidic acid and Carboximidoic acid
(h) Cyclohehexaneethanol and Cyclohexethanol
(i) Dibenz[*b*,*e*]oxepine and Dibenzo[*b*,*e*]oxepine
(j) Benzilmonoxime and Benzilmonooxime
(k) Benzophenone and Benzphenone

1.2 Answer these questions.

(a) In the following sets of combinations of locants, which set will get preference in numbering the carbon atoms of a chain.
  (i) (2,3,6,8)-, (2,4,5,7)-, (3,4,5,6)
  (ii) 2, 2′ and 1′, 2
  (iii) (*N*, α, 1,2) and (1,2,4,6)
(b) What does the following letter/letters or combination of letters indicate in a structure of an organic compound?
peri, *s*, *rac*, *m*, *abeo*, *seco*, *nor neo*, *friedo*, *vic*, *as*.
(c) Decide which on of the following names are correct or incorrect in each pair according to IUPAC rules of naming organic compounds. Give reasons wherever necessary.
  (i) Neo-pentane and Neopentane
  (ii) Isopropanol and Propan-2-ol
  (iii) N-Acetylated aniline and *N*-acetylated aniline
  (iv) Spiro[5.4]decane and Spiro[4.5]decane
  (v) Methanoic acid and Methanoic-acid.
  (vi) Ethylethanoate and Ethyl ethanoate
  (vii) Ethylmethyl ketone and Ethyl methyl ketone
  (viii) Styrene oxide and Stryreneoxide
  (ix) Biphenyl and Diphenyl

(x) Bis-2-chloromethylamine and Bis-(2-chloromethyl) amine
(xi) (*R*)-Lactic acid and *R*-Lactic acid

1.3 Give structures to demonstrate the following ways of naming organic compounds.

(a) Trivial name
(b) Semi-trivial name
(c) Fusion name
(d) Substitutive name
(e) Replacement name
(f) Conjunctive name
(g) Radicofunctional name
(h) Additive name
(i) Subtractive name
(j) Hantzsch–Widman name of hetercycles

1.4 Give the IUPAC names of the following compounds.

(a) $CH_3CH{=}CHCHCH_2CH{=}CH_2$ with $CH{=}CH_2$ branch

(b) $CH_2{=}CHCHCH{=}CHCH{=}CH_2$ with $C{\equiv}CH$ branch

(c) $CH_3[CH_2]_2C(CH_2)CH_2CH_2CH(C{\equiv}CH)CH{=}CH_2$

(d) $CH_3[CH_2]_3C(CH_3)CH_2CH_2CH(C{\equiv}CH)CH{=}CH_2$

(e) $CH_3CH_2CH{=}CHC{\equiv}CCHCH_2C{\equiv}CCH_2CH{=}CH_2$ with CH_3 branch

(f) $CH_3C{\equiv}CCHCH{=}CHCH_3$ with $CH{=}CH_2$ branch

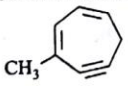
(g) $CH_3[CH_2]_4CH_2{-}C(C(CH_3)_2CH_2CH_2CH_3)(CH_2[CH_2]_4CH_3){-}CH_3[CH_2]_2CH_2{-}C(CH_3)_2$

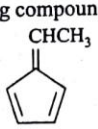
(h) $CH_2{=}C{=}C{=}C{=}CH_2$

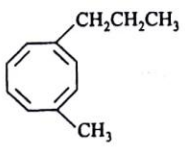
(i) $CH_3CH_2CH_2C{=}CHCH_3$ with $CH{=}CH_2$ branch

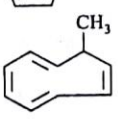
1.5 Answer these questions on structures.

(a) Give the IUPAC names of the following compounds.

(i) 

(ii) 

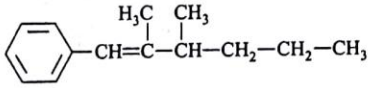
(iii) 

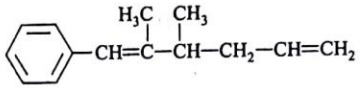
(iv) 

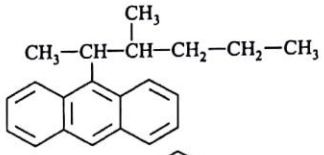
(b) Draw the structures of the following compounds.

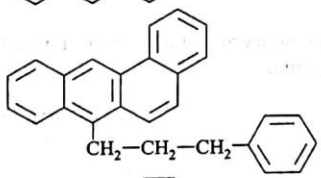
(i) Triapentafulvalene
(ii) Azulene
(iii) 14[Annulene]
(iv) Benzo[8]annulene
(v) 6[Annulene]

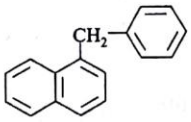
1.6 Give the IUPAC names of the following compounds.

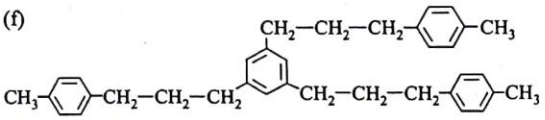
(a) 

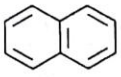
(b) 

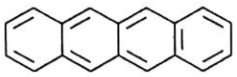
(c) 

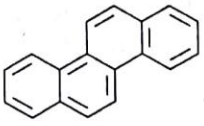
(d) 

(e) 

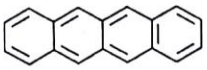
(f) 

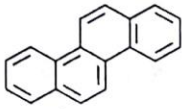
(g) 
Naphthalene
(*ortho*-fused)

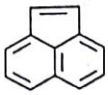
(h) 
Naphthacene
(*ortho*-fused)

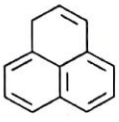
(i) 
Chrysene
(*ortho*-fused)

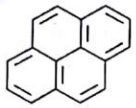
1.7 Give the trivial names of the following compounds.

(a) 

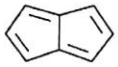
(b) 

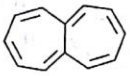
(c) 

(d) 

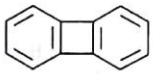
(e) 

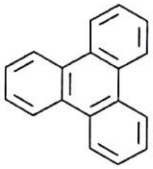
(f) 

(g) 

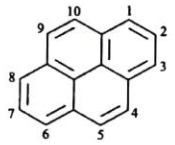
(h) 

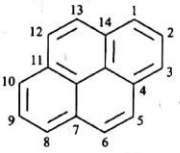
(i) 

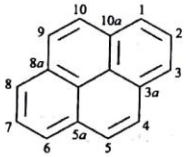
(j) 

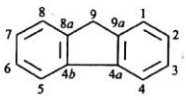
(k) 

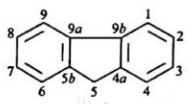
1.8 Identify the correct numbering of the carbon atoms of the following sets of compounds.

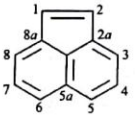
(a) 

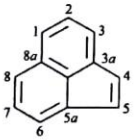
(b) 

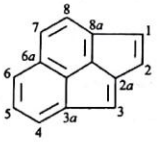
(c) 

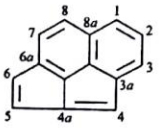
(d) 

(e) 

(f) 

(g) 

(h) 

(i) 

1.9 Answer these questions on the naming of structures.

(a) Number the carbons and give the correct name of each of the following bridged hydrocarbons.

(i) 

(ii) 

(iii) 

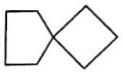
(iv) 

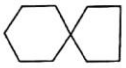
(v) 

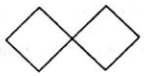
(vi) 

(vii) 

(b) Give the IUPAC names of the following spiro hydrocarbons. Show the numbering of the carbon atoms.

(i) 

(ii) 

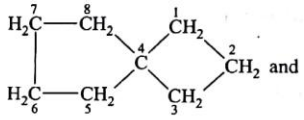
(iii) 

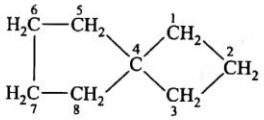
(iv) 

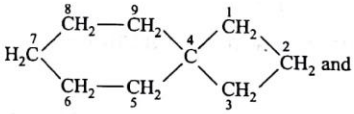
(v) 

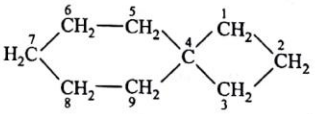
(vi) 

1.10 Identify the correct numbering of the following pairs of *spiro* compounds and give its IUPAC names.

(a)  and



(b)  and

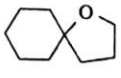


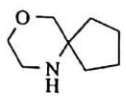
1.11 Answer these questions on IUPAC names and structures.

(a) Give the structure of the following compounds.
- (i) 1,1′-Bicyclopentadienylidene
- (ii) Bi(cyclopentylidene)
- (iii) Biphenyl
- (iv) Tercyclopropane

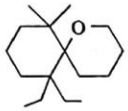
(b) Give the structures of *alternate* acylic and cyclic hydrocarbons and *non-alternate* cyclic hydrocarbons and mention the necessary rules for such definitions.

(c) Give the IUPAC names of the following hetercyclic spiro compounds.

(i) 

(ii) 

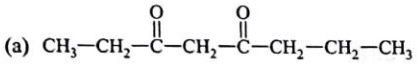
(iii) 

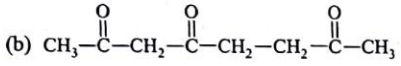
(iv) 

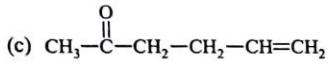
1.12 Draw the structures of the following compounds.

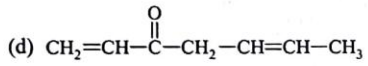
(a) Perchloro(2-methylpentane)
(b) 2-(Hydroxymethyl)heptane-1,6-diol
(c) Aluminium tri(2-propanolate)
(d) Ethoxyethylene
(e) Bis(2-bromoethyl) ether
(f) 2,2′-Oxydiethanol
(g) 3-Formylhept-2-enedial
(h) 3-Vinylhept-2-en-6-ynal
(i) Pyridine-2-carbaldehyde
(j) Benzenecarbothialdehyde
(k) Benzenehexol

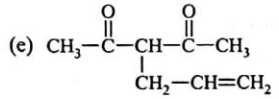
1.13 Give the IUPAC names of the following compounds.

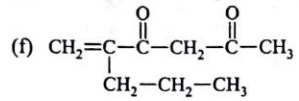
(a) 

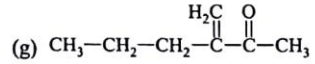
(b) 

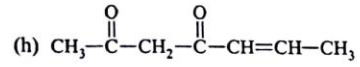
(c) 

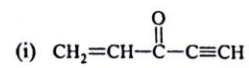
(d) 

(e) 

(f) 

(g) 

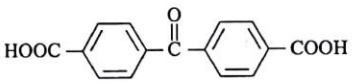
(h) 

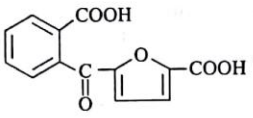
(i) 

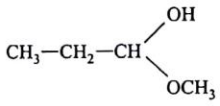
1.14 Draw the structures of the following compounds.

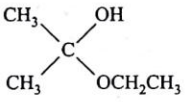
(a) Hepta-2,5-dienoic acid
(b) Hex-2-en-4-ynedioic acid
(c) Pent-4-en-2-ynoic acid
(d) 3-(carboxymethyl)heptanedioic acid
(e) Biphenyl-3-carboxylic acid
(f) Naphthalene-1,3,5-tricarboxylic acid
(g) *o*-(2-Oxobutyl)benzoic acid
(h) *p*-Benzoylbenzoic acid
(i) 4-Methylbenzene-1,3-disulphonic acid

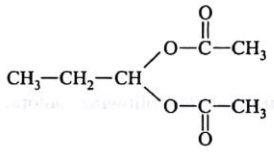
1.15 Give the IUPAC names of the following compounds.

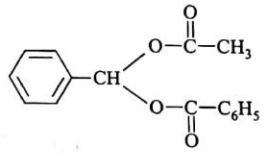
(a) 

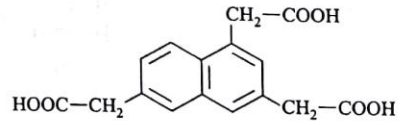
(b) 

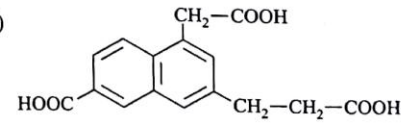
(c) 

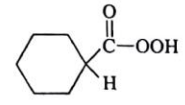
(d) 

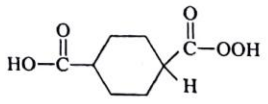
(e) 

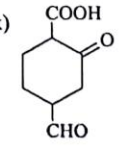
(f) 

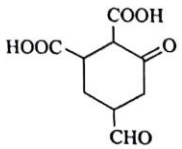
(g) 

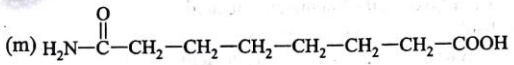
(h) 

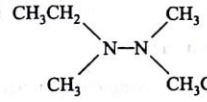
(i) 

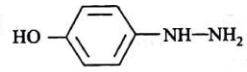
(j) 

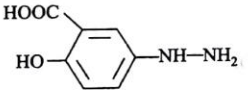
(k) 

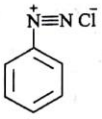
(l) 

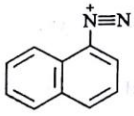
(m) 

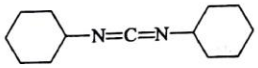
(n) 

(o) 

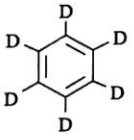
(p) 

(q) 

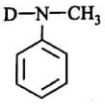
(r) 

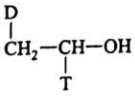
(s) 

1.16 Give the IUPAC names of the following isotopically labelled compounds.

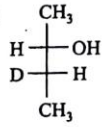
(a) 

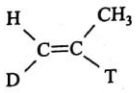
(b) CH_3COOD

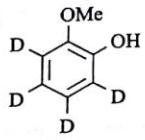
(c) 

(d) 

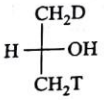
(e) $CH_3-\overset{18}{O}-D$

(f) 

(g) 

(h) 

(i) $CH_3CD_2\overset{14}{C}H_2CH_3$

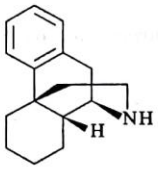
(j) 

(k) CD_3CN

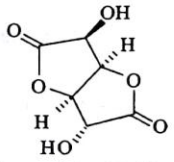
D = Deuterium, T = Tritium

(l) $DO-CH_2-CH_2-OD$

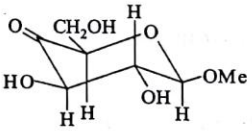
1.17 Give the method of numbering the carbon atoms in the following compounds.

(a) 

Morphinan

(b) 

D-Glucaro-1,4 : 6,3-dilactone

(c) 

Methyl β-D-*xylo*-Hexopyranoside-4-ulose

1.18 Draw the Fischer projection formula of (a) 4-*O*-α-D-Glucopyranosyl-α-D-glucopyranose and Haworth structure of (b) β-D-Galactopyranosyl(1→4)-α-D-glucopyranose.

1.19 Draw the structures of (a) [(*Z*,*Z*,*Z*,*Z*)-Eicosa-5,8,11,14-tetraenoic acid] and (*Z*)-Octadec-9-enoic acid. What are the trivial names of these two compounds?

2 Physical Organic Chemistry

2.1 State whether the following molecular formulae are correct to represent stable neutral organic compounds. State the reason.

(a) $C_4H_4Cl_2$ **(d)** $C_5H_{11}NO_2$ **(g)** $C_{12}H_{18}N_2FCl$
(b) C_5H_9OBr **(e)** $C_{10}H_{18}NCl_2$ **(h)** $C_5H_9O_2$
(c) $C_6H_{11}N_2O$ **(f)** C_4H_5ClBr

Ans Amongst the aforementioned molecular formulae, formulae (a), (b), (d), and (g) are possible. However, (c), (e), (f), (h) are not valid formulae. The argument is that, for stable organic compounds the total number of odd-valenced atoms is even.

2.2 Calculate the double bond equivalent of the following molecular formulae and give at least one reasonable structure for each.

(a) $C_8H_6O_4$ **(b)** C_3H_3N **(c)** $C_{11}H_{10}O$ **(d)** $C_{10}H_9NO$

Ans Double bond equivalent of a compound having the molecular formula, $C_aH_bX_cN_dO_e$ is given by the equation, $\text{DBE} = \frac{2\times a+2-(b+c-d)}{2}$. Note that the atoms of oxygen have not been included in the equation because it has an even numbered valency. On the basis of this equation,

$$\text{DBE of (a)} = \frac{2\times 8+2-(6+0-0)}{2} = 6$$

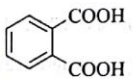
$$\text{DBE of (b)} = \frac{2\times 3+2-(3+0-1)}{2} = 3$$

$$\text{DBE of (c)} = \frac{2\times 11+2-(10+0-0)}{2} = 7$$

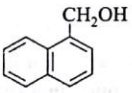
$$\text{DBE of (d)} = \frac{2\times 10+2-(9+0-1)}{2} = 7$$

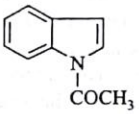
Note: It is to be noted that the value of DBE cannot be a fraction. The value should be zero or any positive integer. Any triple bond is equivalent to two double bonds.

Based on the DBE values of (a), (b), (c) and (d), the following structures may be suggested but other structures may also fit into these values.

(a) 

(b) $CH_2=CH-C\equiv N$

(c) 

(d) 

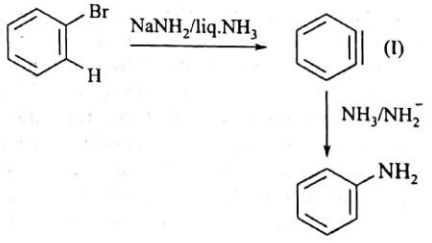
2.3 A good base is not necessarily a good nucleophile. Explain.

Ans The basicity of an anion is defined by its ability to accept a cation (usually a proton) from a reaction medium. Usually, the anion having higher electron density represents a stronger base.

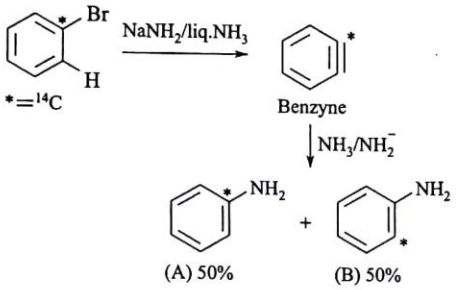
By the term nucleophilicity, we mean the ability of an anion or a Lewis base to release its electron to form a covalent bond with an electron deficient atom or group by S_N2 type substitution. It is measured in terms of polarizability of the electron-pair and not by the charge density. For example, F^- is a very strong base but a poor nucleophile. On the other hand, I^- is a weak base but a strong nucleophile. Similarly, OH^- is a stronger base than HS^- but the latter is a stronger nucleophile.

2.4 What is benzyne? Give chemical evidence in favour of the formation of benzyne as a reactive intermediate.

Ans Benzyne is dehydrobenzene. Several structures have been suggested for this reactive intermediate but the structure represented (I), shown below is commonly used to explain the reactions of benzyne. It is normally formed when an aryl halide with at least one hydrogen atom at the *ortho* position is treated with a strong base.



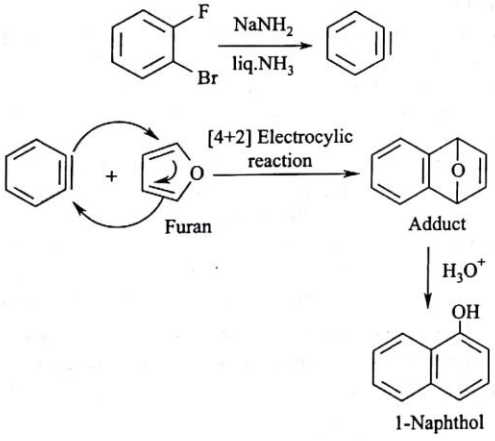
That benzyne is the intermediate in the aforementioned reaction is confirmed by the fact that when a ^{14}C labelled compound, as shown here, is taken, then a 50:50 mixture of two compounds is obtained differing in the position of the labelled carbon.



Direct substitution should have given 100% of (A) only.

2.5 Give an example where the benzyne intermediate has been trapped in a reaction product.

Ans When bromofluorobenzene is treated with sodamide in liquid ammonia in the presence of furan then an adduct is obtained. This adduct finally gives 1-naphthol on treatment with an acid. This is accountable if a benzyne intermediate is formed to react with furan.



2.6 The basicity and nucleophilicity of an anion sometimes do not run parallel but in certain cases they do. Explain.

Ans The basicity of an electron rich species is dependent on its electron density and not on the degree of polarizability of the electrons. Nucleophilicity of an electron reach species depends on the polarizability of the electron, usually a non-bonded electron pair in the valence shell. Therefore, basicity and nucleophilicity do not always run parallel, that is, a good base is not necessarily a good nucleophile and vice versa. For example, between F^- and I^-, F^- is a stronger base but I^- is a stronger nucleophile. Similarly, between HS^- and OH^-, the former is a better nucleophile but OH^- is a stronger base. It is to be noted that an electron pair residing on a large but less electronegative atom is more polarizable than the electron pair on a smaller atom having higher electronegative value.

When, in a set of anions, the negative charge resides on the same atom, then their basicities and nucleophilicity run parallel.

2.7 Arrange the following oxyanions in order of increasing basicity as well as increasing nucleophilicity with reasoning.

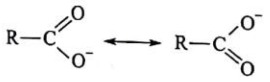
(a) CH_3O^- **(d) HO^-**
(b) PhO^- **(e) $(CH_3)_3CO^-$**
(c) $(CH_3)_2CHO^-$ **(f) CH_3COO^-**

Ans In all the aforementioned oxyanions, negative charge resides on the oxygen atom. Therefore, their basicities and nucleophilicity run parallel. Basicities can be easily determined on the basis of the acidities of their conjugate acids. Conjugate acids are shown within brackets:
CH_3O^- (CH_3OH), PhO^- (PhOH), $(CH_3)_2CHO^-$ [$(CH_3)_2CHOH$)], HO^- (H_2O), $(CH_3)_3CO^-$[$(CH_3)_3CO^-$ [$(CH_3)_3COH$)], CH_3COO^- (CH_3COOH).

The increasing order of acidity is as follows: $(CH_3)_3COH < (CH_3)_2CHOH < CH_3OH < H_2O < PhOH < CH_3COOH$. Therefore, the increasing order of basicity is as follows: $CH_3COO^- < PhO^- < HO^- < CH_3O^- < (CH_3)_2CHO^- < (CH_3)_3CO^-$ and this order also represents the nucleophilicity order.

2.8 In R—C(=O)—OH, C=O and C—O bond distances are different but in R—C(=O)—O⁻, they are the same. Give your reason.

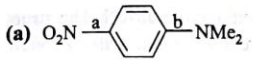
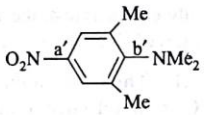
Ans In case of R—C(=O)—OH, two C—O bonds are non-equivalent and that is why C—O bond distances are different. In case of R—C(=O)—O⁻, resonating structures are possible where the C—O bonds become equivalent in all respects. That is why we get identical bond distances in case of C—O bonds.



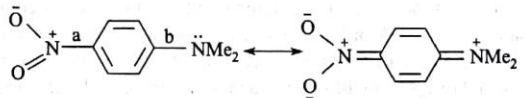
2.9 The C—C bond length in propylene is 1.50Å and not 1.54 Å. Explain.

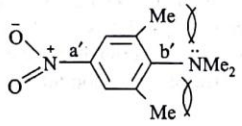
Ans Due to hyperconjugative resonance, the nature of the entire carbon–carbon bond distance changes. The original C—C bond distance becomes shorter and C=C bond becomes longer.

2.10 Compare the C—N bond length (a vs a′) and (b vs b′) in the following compounds with reasoning.

(a)  (b) 

Ans In case of compound (a), extended resonance is possible. Due to this, 'a' and 'b' bonds assume some double bond character. Consequently, bond lengths of these bonds decrease. In case of compound (b) reasonane is not possible due to steric inhibition. Therefore, a′ and b′ bonds remain as single bonds. Thus, (a′ > a) and (b′ > b).

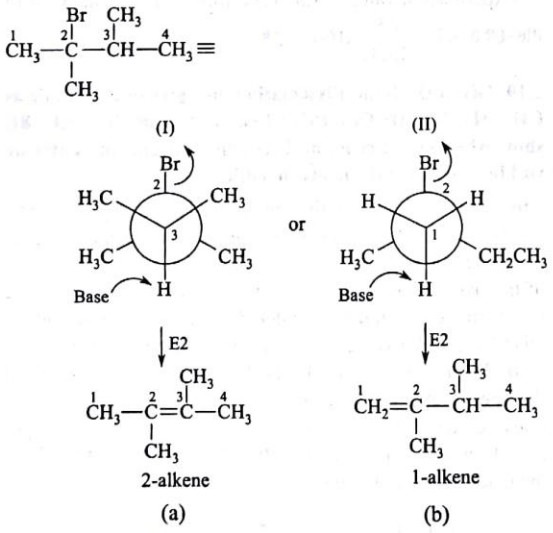




Stereic inhibition of resonance

2.11 Account for the increase in the ratio of 1-alkene to 2-alkene products as the base is changed from MeO^- to Me_3CO^- to Et_3CO^- in the dehydrobromination of 2-bromo-2,3-dimethylbutane.

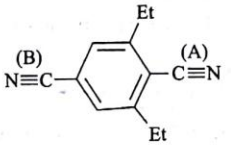
Ans The reaction is E2 elimination. Steric factor plays a role here to decide the product compositions. When a bulkier base is used, less crowded hydrogen from the β position is eliminated. The course of the reaction is shown here.



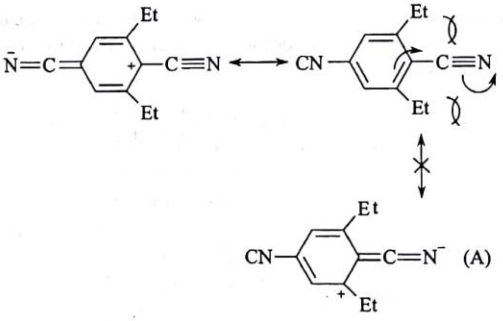
In case of (I), the less bulky MeO^- can approach from behind to abstract the β-hydrogen and that leads to the formation of the more stable 2-alkene.

As the size of the base increases, this approach becomes more difficult due to steric factor and E2 elimination takes place through the conformation represented by (II) where steric factor is minimum. In this case, 1-alkene is formed as the major product.

2.12 The bond energy of which C—CN bond, A or B, is greater?



Ans In this compound, delocalization of π-electrons of the aromatic system with the CN (A) is not possible due to non-planarity of CN group with the benzene ring due to steric interaction offered by the *ortho* Et groups. However, CN (B) can take part in resonance. This makes the C—CN (B) bond assume some double bond character. Consequently, this bond has higher bond energy.



2.13 Differentiate between polarization and polarizability of a covalent bond with suitable examples.

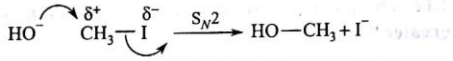
Ans The term polarization of a covalent bond means its permanent distortion to a state of partial bipolar character due to difference in eletronegativity values of the atoms and groups joined by the concerned bond. For example, C—F, is permanently polarized to positive and negative poles due to difference in the electronegativities of carbon and fluorine atoms, $\overset{\delta^+}{H}\!\!-\!\!\overset{\delta^-}{F}$.

The term polarizability of a covalent bond, on the other hand, means temporary polarization of the bond due to the proximity of a reagent. For example, C—I bond becomes very much distorted compared to C—F bond in the presence of a nucleophilic reagent. Thus, we can conclude that C—I bond is more polarizable than C—F bond although the latter is more polarized.

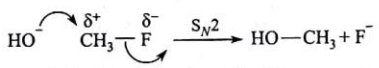
2.14 Between bond polarity and bond polarizability, which one is of greater importance in S_N2-type substitution reaction and why?

Ans In case of S_N2 type substitution reaction, polarizability of a bond is more important than that of permanent polarization. For example, when CH_3F and CH_3I are treated separately with OH^-, it is the CH_3I that undergoes substitution at a faster rate and not the CH_3F. In this case C—F bond is more polarized

but C—I bond is more polarizable. Polarizability of a bond can create a more electron deficient centre during S_N2-type substitution and thus needs less activation energy to react.



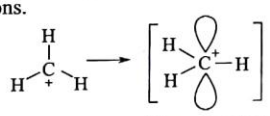
Less polarized but more polarizable (Faster reaction)



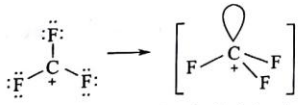
More polarized but less polarizable (Slower reaction)

2.15 $^+CH_3$ has a planar structure whereas $^+CF_3$ appears to have a tetrahedral-like structure. Discuss.

Ans In the case of $^+CH_3$, there is no lone pair associated with hydrogen atoms and consequently no bond pair–lone pair repulsion force operating here. However, in the case of $^+CF_3$, each F atom has three pairs of lone-pair electrons. Therefore, in this case bond pair–lone pair repulsion force is very effective and decreases the C—F—C angle to nearly the tetrahedral angle. This is the reason for the difference in the shapes of the two carbocations.



Planar structure

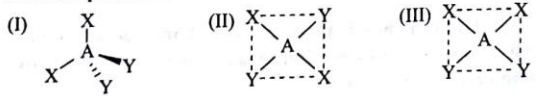


Tetrahedral structure

Alternatively, more electronegative fluorine atoms will try to form covalent bonds with the less electronegative sp^3 hybridized carbon (Bent's rule)

2.16 In AX_2Y_2, X and Y are bonded to A. Electronegativity order is A > X > Y. Draw the structure of possible stereoisomers, if A occupies the centre of a tetrahedron and square. In addition, comment on the polarity of the possible isomers.

Ans In the case of a tetrahedral structure, only one structure is possible because the structure of the molecule of the type AX_2Y_2 would be a symmetrical one. Resultant vector of one X–A–Y system will be balanced by another. In the case of square planar structure two stereoisomers are possible having different polarities.

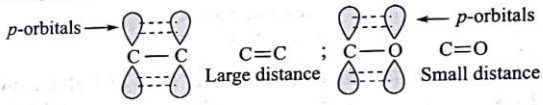


The tetrahedral structure (I) is non polar because it is symmetric and the electronegativity order of the concerned atoms is A > X > Y.

Between the square planar structures, (II) is non-polar because the bond polarities of A–X and A–Y bonds are mutually compensated, the structure being symmetrical. The structure (III) is polar, because bonds are not symmetrically oriented.

2.17 The C=C bond energy is less than twice that of the C–C bond energy but the C–O bond energy is slightly greater than twice that of the C–O bond energy. Account for this.

Ans When two atoms with different electronegativities are joined by a covalent bond then the bond distance is shortened when the electronegativity difference is large and as the bond distance decreases, bond strength increases. In the case of the C=C bond, one is a strong sigma bond and the other is comparatively a weak pi bond. The electronegativity difference is nil. In the case of C=O, the electronegativitity values of carbon and oxygen are different and their difference is large. Consequently, C—O sigma bond becomes closure and as a result of which the orthogonal *p*-orbitals also become closure. This makes the overlapping of *p*-orbitals more effective and bond strength increases. This is the reason for the result as stated in the question.



2.18 The observed dipole moment of Ph—Cl is 1.55D. The Ph—Cl bond distance is 2.8Å. Estimate % ionic character of Ph—Cl.

Ans The theroretically calculated value of the dipole moment is

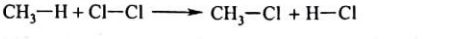
$$2.8\times10^{-8}\text{cm}\times4.81\times10^{-10}\text{esu}=13.47\times10^{-18}\text{esu.cm}=13.47\text{D}$$

Experimental value is 1.5. Therefore, % ionic character of Ph—Cl bond is $\frac{1.55}{13.47}\times100=1.2\%$

2.19 Given the bond dissociation energies in kcal/mole as CH_3—H = 102, H—Cl = 103, Cl—Cl = 58, and CH_3—Cl = 81, show whether the reaction between methane and chlorine will be endothermic or exothermic?

Ans It is the convention that bond breaking energy is always endothermic and has a positive sign. Bond formation energy is exothermic and is negative in sign. If the enthalpy change of the overall chemical change (ΔH) is found to have a +ve sign then the reaction is considered to be endothermic. On the other hand if ΔH value is –ve then the reaction is exothermic.

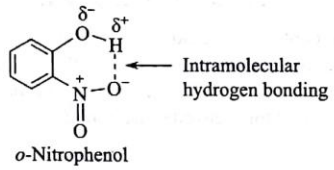
In the present case, C—H and H—Cl bonds are broken and the energy change is +(102 + 58) = 160 kcal/mol. Energy released due to the bond formation is –(103 + 81) = 184 kcal/mol. Therefore, ΔH value is (+160–184) = –24 kcal/mol. Thus the reaction is exothermic.



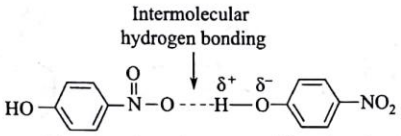
2.20 *o*- and *p*-Nitrophenol can be separated by steam distillation. Explain.

Ans *o*-Nitrophenol can form intramolecular hydrogen bonding and consequently is extremely volatile to come out with

steam. *p*-nitrophenol, on the other hand, cannot form intramolecular hydrogen bonding but can form intermolecular hydrogen bonds and, therefore, much less volatile to come out with steam.



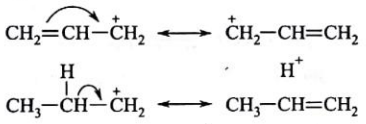
o-Nitrophenol



p-Nitrophenol *p*-Nitrophenol

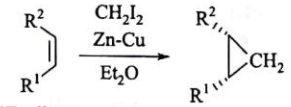
2.21 Which of the two carbocations $CH_2{=}CH{-}CH_2^+$ and $CH_3CH_2CH_2^+$ is more stable and why?

Ans $CH_2{=}CH{-}CH_2^+$ is an allylic carbocation and is stabilized by delocalization. $CH_3CH_2CH_2^+$ is a primary carbocation and is stabilized by hyperconjugative resonance. Since resonance involving delocalization of pi-electrons is a more stabilizing phenomenon, $CH_2{=}CH{-}CH_2^+$ is more stable than $CH_3CH_2CH_2^+$.

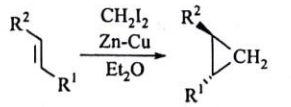


2.22 What is a carbenoid? Give an example of a reaction where such compounds are used in synthesis.

Ans A combination of methylene iodide (CH_2I_2) and zinc–copper couple is referred to as *Simons–Smith* reagent. The active species is iodomethylzinc iodide (ICH_2ZnI). Since (ICH_2ZnI) gives a methylene (carbene), it is commonly called carbenoid. The reaction is a general method of creating a cyclopropane system from alkenes. The reaction is stereospecific.



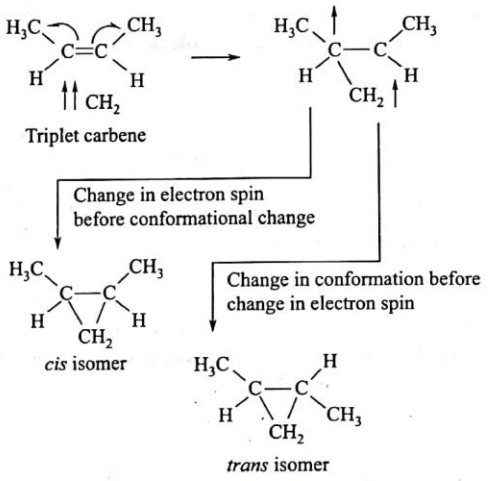
(*Z*)-alkene 1,2-*cis*-Disubstituted cyclopropane



(*E*)-alkene 1,2-*trans*-Disubstituted cyclopropane

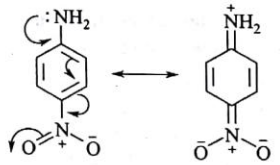
2.23 Triplet carbenes add to *E* or *Z*-alkenes with the loss of stereochemical integrity. Explain.

Ans Triplet carbenes react with alkenes in a non-stereoselective manner and form both *cis* and *trans* cyclopropanes irrespective of the stereochemistry (*E* or *Z*) of alkenes. The reaction proceeds through the following mechanism.



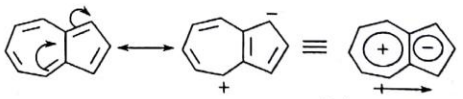
2.24 The dipole moment of aniline is 1.53D and that of nitrobenzene is 3.95D. However, the dipole moment of *p*-Nitroaniline is not 5.48D but 6.1D. Explain.

Ans Due to extended resonance involving $-NH_2$ and NO_2 groups, the distance between the poles increases and since the value of dipole moment is a product of charge and distance, the dipole moment value is enhanced.



2.25 Azulene has an unexpectedly high dipole moment. Explain.

Ans Azulene is a bycyclic compound with 10 π-electrons. Distribution of these electrons between the two rings generates an aromatic system comprising a cycloheptatrienyl cation (tropylium ion) and a cyclopentadienide ion. Since this aromatic system is quite stable, azulene remains mostly in bipolar form and shows high dipole moment value.



Polar aromatic form of azulene

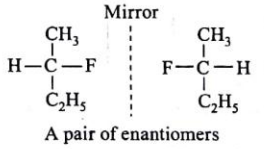
2.26 Explain whether the following statements are true or false.

(a) Enantiomers can be distinguished from their dipole moment values.

(b) π- and ring diastereoisomers can be differentiated from their dipole moment values.

Ans

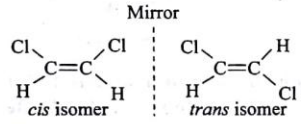
(a) The statement is false. Since enantiomers are mirror images of each other with the same bond connectivities, they have the same value of dipole moments. An example is given here.



A pair of enantiomers

These two enantiomers cannot be differentiated by dipole moment values. They have got the same value of dipole moment.

(b) This statement is true. Diastereoisomers have the same bond connectivities but they are not mirror images of each other. Therefore, they have different dipole moment values. An example is given here.



A pair of diastereoisomers

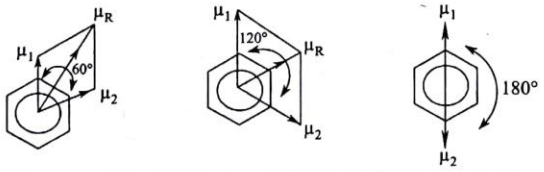
These two diastereoisomers can be differentiated from their dipole moment values, since their dipole moment values are different.

2.27 Dichlorobenzenes can be distinguished by the measurement of their dipole moments. Explain.

Ans *o*-, *m*-, and *p*-dichlorobenzenes can be distinguished from their dipole moment values. Dipole moment values can be calculated using cosine law as follows.

Dipole moments of disubstituted benzenes may be calculated by using 'law of cosine' as given here. If μ_1 and μ_2 are individual dipole moments associated with the two substituents on the benzene ring and if the angle between the two bonds linked to the ring is ϕ, then the resultant dipole moment, μ_R, is given by the equation,

$$\mu_R = \sqrt{\mu_1 + \mu_2 + 2\mu_1\mu_2\cos\phi}$$



For *o*-isomer: $\mu_R = \sqrt{\mu_1 + \mu_2 + \mu_1\mu_2}$ $\because \cos 60° = \frac{1}{2}$

($\phi = 60°$)

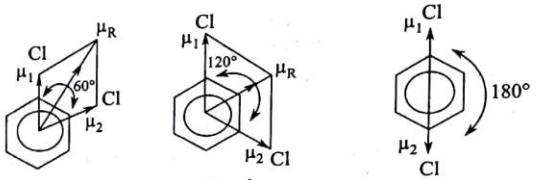
For *m*-isomer: $\mu_R = \sqrt{\mu_1 + \mu_2 - \mu_1\mu_2}$ $\because \cos 120° = -\frac{1}{2}$

($\phi = 120°$)

For *p*-isomer: $\mu_R = \sqrt{\mu_1 + \mu_2 - 2\mu_1\mu_2\cos\phi}$ $\because \cos 180° = -1$

($\phi = 180°$) $= \mu_1 - \mu_2 = 0$, when $\mu_1 = \mu_2$

The aforementioned method has been used to find out the structures of dichlorobenzenes. The method is useful when the substituents are the same. The dipole moment values of three isomeric dichlorobenzenes are found to be very close to calculated values.



o-Dichlorobenzene (μ = 2.25D)

m-Dichlorobenzene (μ = 1.48D)

p-Dichlorobenzene (μ = 0.0D)

2.28 α-Aminoacids have greater dipole moments than expected. Explain.

Ans An α-amino acid remains as a dipolar zwitter ion and that enhances polarity. That is why amino acids have higher dipole moments than expected.

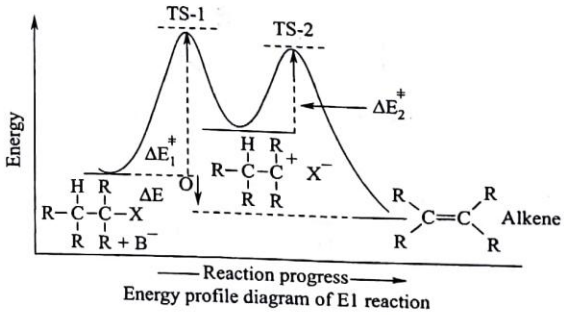
$$H_2\ddot{N}-CH_2-COOH \rightleftharpoons H_3\overset{+}{N}-CH_2-COO^-$$

Glycene — Zwitter ion (More polar)

2.29 Draw the energy profile diagrams of E1, E2, and $E1_{CB}$ mechanisms of β-elimination.

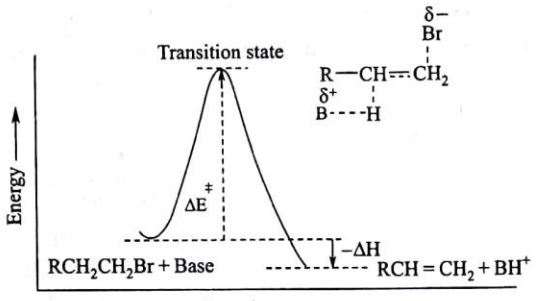
Ans The energy profile diagrams of E1, E2, and $E1_{CB}$ are given here.

E1: E1 elimination is a two-step reaction. The formation of the carbocation intermediate is the rate determining step. The over all reaction is exothermic.



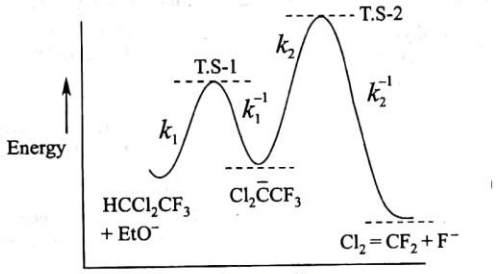
Energy profile diagram of E1 reaction

E2: E2 reaction is a one-step reaction with a transition state comprising the substrate and the base.



Energy profile diagram of E2 reaction

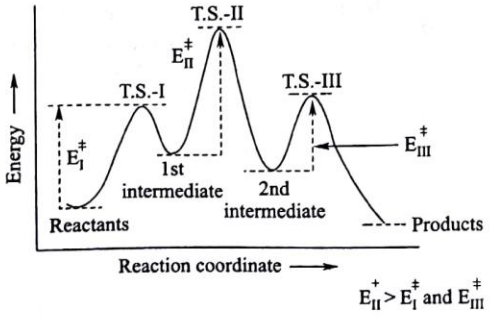
$E1_{CB}$: $E1_{CB}$ reaction is a two-step process. The rate determining step is the formation of alkene from the intermediate carbanion. The carbanion formation step is fast.



Energy profile diagram of $E1_{CB}$ reaction

2.30 Draw an energy profile diagram of a three-step exothermic reaction in which the second step is the rate determining step and the second intermediate is more stable than the first.

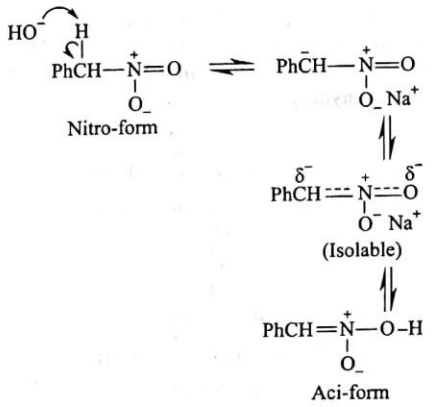
Ans The energy profile diagram is given here based on the conditions just mentioned.



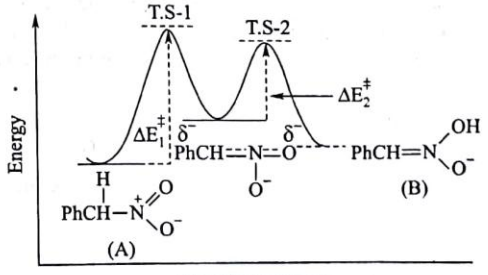
The activation energy of the second step is the highest; therefore, it is the rate determining step of the whole reaction. The second intermediate is more stable because its position is lower than that of the first intermediate in the energy profile diagram. Nothing has been mentioned about the rates between the first and the third steps. Their positions in the diagram have been placed arbitrarily.

2.31 $PhCH_2NO_2$ is a liquid that dissolves in NaOH. On acidification with HCl, initially a solid tautomer is precipitated. However, this slowly reverts to the original liquid. Explain this with a suitable energy profile diagram.

Ans It is a unique example to explain how kinetically controlled and thermodynamically controlled processes determine the nature of the final product composition.



In the aforementioned examples, the composition of the equilibrium mixture is, of course, governed by the relative thermodynamic stability of the forms under the particular conditions being studied. In this case the nitro-form, a yellow oil, is the more stable of the two and at equilibrium, predominates to the almost total exclusion of the aci-form. Despite this fact, acidification of the isolable sodium salt of the carbanion intermediate yields only the less stable aci-form (B). This happens because more rapid protonation takes place on the oxygen atom having a higher electron density, that is, a kinetically controlled reaction. The energy profile diagram of the process is shown here.



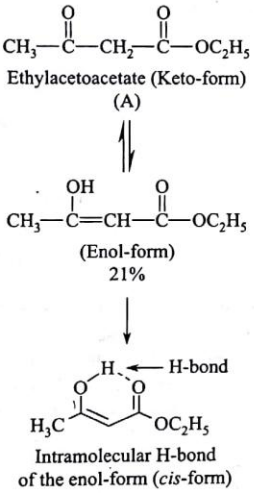
Energy profile diagram of E1 reaction

Between the activation energies to reach the transition states TS-2 requires less energy, reflecting the greater ease of cleavage of O—H bond than a C—H bond. Although the immediate result of the acidification of the intermediate sodium salt

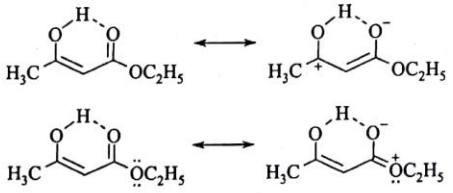
is the formation of aci-form, it spontaneously gets reionized. Thus aci-form will lose its proton faster to form the intermediate and then reprotonation produces the more stable nitro-form. When the equilibrium condition is allowed to set in, the thermodynamically control product (A) would be the major product again.

2.32 Predict the enol content of the following compounds and explain: Ethyl acetoacetate (A), Acetylacetone (B), Diethylmalonate (C), and 3-Ethylexane-2,4-dione (D).

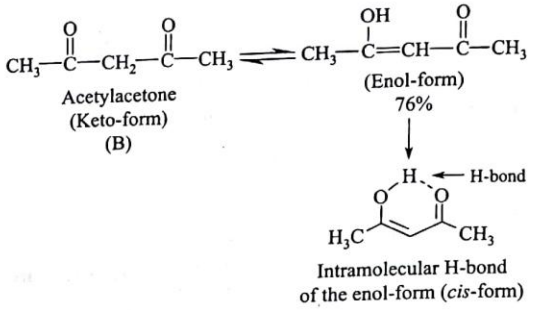
Ans In the aforementioned cases, the decreasing order of enol content is B > A > C > D. In the case of (A), +I effect of the marked (bold) CH_3 group increases the electron densities of ketonic oxygen atom and thereby strengthens the intramolecular hydrogen bond.



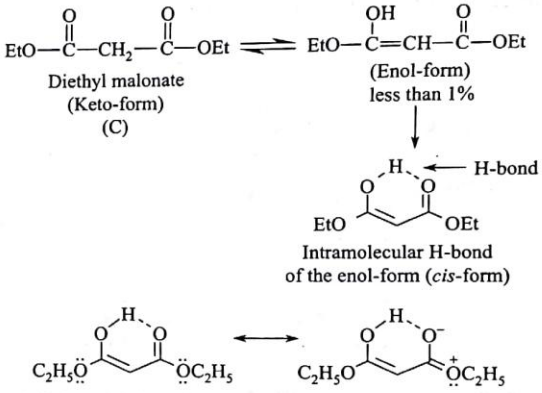
On the other hand, the marked –OEt group has –I effect and weakens the intramolecular hydrogen bonding. In totality the enol content decreases. Another factor important here is cross conjugation between the ester group and the enol structure. This resonance inhibits the resonance of the αβ-unsaturated system within the ring. This destabilizes the enol-form with respect to the keto tautomer and shifts the equilibrium towards the ketone.



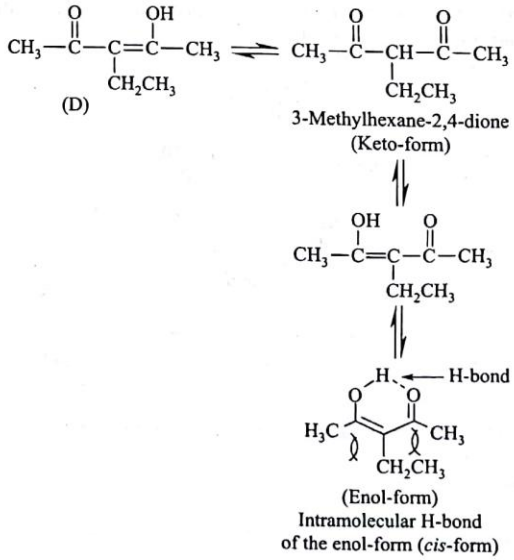
In the case of (B), the marked CH_3 group has +I effect and strengthens the intramolecular hydrogen bonding. Consequently, the enol content increases. Moreover, resonance stabilization of the enol-form has some role in increasing the amount of enol-form.



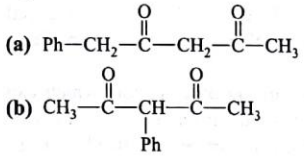
In (C), the marked –OEt groups have –I effect and make the intramolecular hydrogen bond very weak and enol content decreases further. Moreover, resonance involving the –OEt group also destabilizes the enol-form.



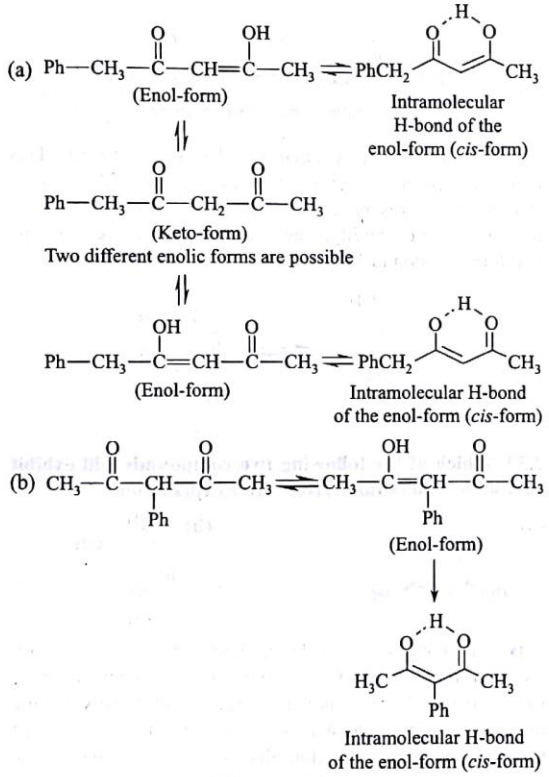
In the case of (D), the enol content is minimum because the strong steric interactions amongst the alkyl groups on the carbon atoms prevent the formation of enolic form.



2.33 Of the following two compounds, which one has higher enol content?

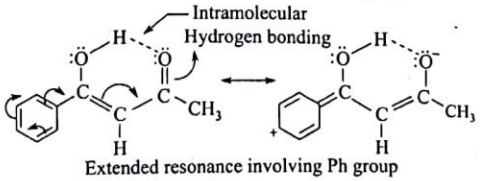


Ans In this case, the compound (b) has greater enol content because the Ph group is conjugated to the double bond generated in the process of enolization and gets stabilized by resonance. In the case of (a) the Ph group is not conjugated to a similar double bond generated through enolization.



2.34 $PhCOCH_2COCH_3$ and $PhCOCH_2COPh$ have very high enol content. Account for this.

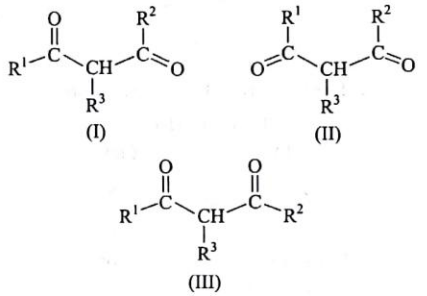
Ans In both these compounds, the enolic form becomes stabilized by extended resonance involving the Ph ring. The resonating structure of the hydrogen-bonded enolic form of the first compound is given here.



In the second compound, there are two benzene rings and both of them can participate in a similar resonance. Therefore, its enol-form is more stabilized and consequently enol content is more than that of the first.

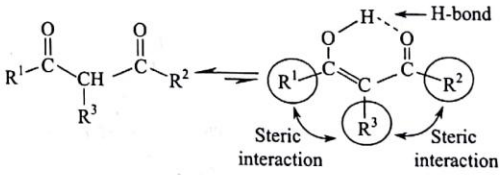
2.35 In a substituted β-diketone like R^1-CO-CHR^3-CO-R^2, the size of the substituents R^1, R^2, and R^3 has a role in the enol content of the compound. Discuss.

Ans The β-diketone shown here can have different conformations having different orientations of C=O groups. These are shown here.



The carbon bearing the R^3 group is sp^3 hybridized, having tetrahedral geometry demanding more space for R^1 and R^2. Therefore, as the sizes of the R^1 and R^2 increase, the keto-form becomes less stable. In enol-form, the said carbon becomes sp^2 hybridized, the spatial demand for R^1 and R^2 decreases and the steric strain is released to some extent and the enol-content increases. Keto-form of (III) is further destabilized due to dipole–dipole repulsion. For example, in case of the structure R–CO–CH_2–CO–R, the enol/keto ratio is 1.4 when R = Me, but the said ratio is 6.1 when R = *t*-Bu.

When in a compound like R^1–CO–CHR^3–CO–R^2, R^1, R^2, and R^3, are all bulky, the effect is opposite, that is, the keto-form predominates over the enol-form. This is because of the fact that the three groups become closure in enolic form and steric interaction among the three groups increases sharply and destabilizes the enol-form. Enolic form of (III) is shown now to demonstrate this steric interaction.

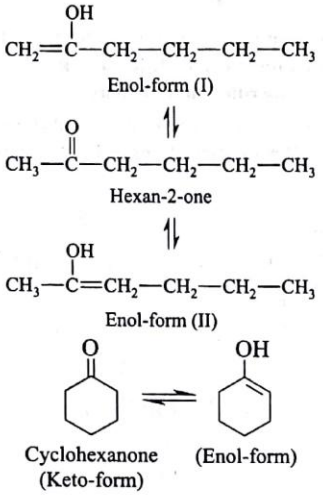


2.36 The enol content of hexan-2-one is 0.11% but that of cyclohexanone is 1.18. Offer an explanation.

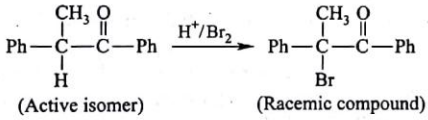
Ans This difference in the enol content between an open chain ketone and cyclic analogue has been attributed to the loss of entropy. The double bond in open-chain enol locks part of the chain in a rigid orientation so that the enolization is accompanied by partial loss of freedom of rotation of the chain. This loss of entropy due to enolization favours the retention of the keto-form.

On the other hand, cyclohexanone already has a semi-rigid structure; therefore, due to enolization, the loss of entropy is

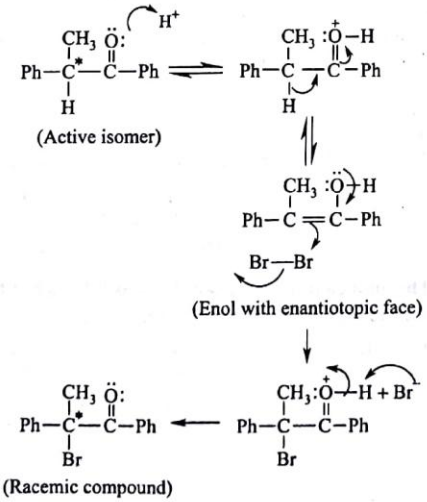
much less. In the absence of other factors such as bond-angle strain and non-bonding repulsive interactions, cyclohexanone shows higher enol-content compared to hexan-2-one.



2.37 When an acid-catalysed bromination is carried out on an active isomer of the following compound, then a racemic α-bromo compound is obtained. Explain the reaction.



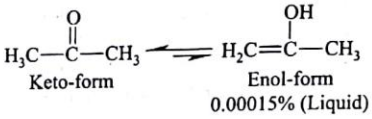
Ans In this case, α-bromination takes place through the formation of enol, being catalysed by an acid. The chiral centre in the active compound is converted into an enantiotopic face and bromine gets substituted from *Re*-and *Si*-face equally well to give a racemic compound.

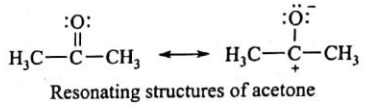


2.38 Acetone remains almost exclusively in keto-form but phenol is always in 100% enolic form. Explain.

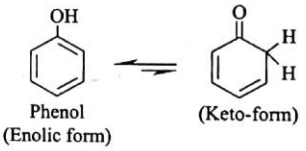
Ans Bond energy calculation shows that the keto-form of a carbonyl compound is more stable by about 18 kcal/mole, compared to its enolic form. The energy difference is reduced if enol-form gets stabilized by other factors like intramolecular hydrogen bonding.

In case of acetone, there are no other factors which can stabilize the enol-form. That is why, it remains almost exclusively in keto-form. Keto-form is further stabilized by resonance of the C=O group itself.

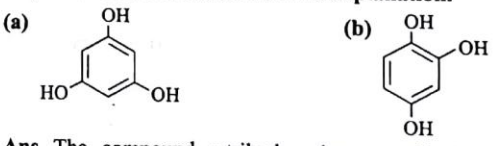




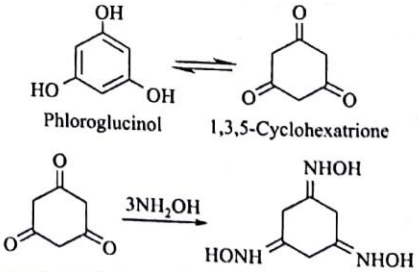
In case of phenol, it remains in 100% enolic form. This is because, phenol contains a benzene nucleus with aromatic stability due to resonance. Its keto-form is less stable due to loss in aromatic stability. The energy difference between the two forms is around 15 kcal/mole.



2.39 Which of the following two compounds will exhibit easy keto–enol tautomerism? Give explanation.

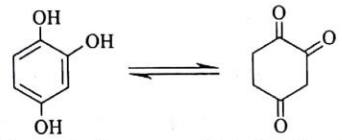


Ans The compound *s*-trihydroxybenzene (a) is trivially known as phloroglucinol. It exhibits easy keto–enol tautomerism. Its triketo-form is known and reacts with hydroxylamine to give a trioxime. The loss of aromatic resonance energy of the benzene nucleus in phloroglucinol is counterbalanced by the resonance energy of three C=O groups, which is around 18 kcal/mole for each C=O group.



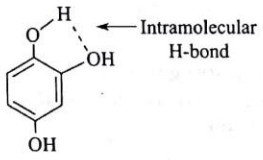
The compound (b) can also exhibit keto–enol tautomerism but the keto-form is very unstable due to the two C=O groups

on adjacent carbon atoms. The enol-form is stabilized by intramolecular hydrogen bonding. The structures are shown here.



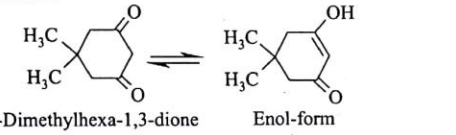
Hydroxyquinol
Enol-form (More stable)

(Keto-form less stable)

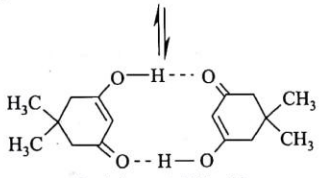


2.40 Give an example where intermolecular hydrogen bonding is responsible in giving stable enolic form.

Ans It has been observed that in certain cases, intermolecular hydrogen bonding can stabilize the enolic form. An example is given here.

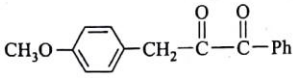


5,5-Dimethylhexa-1,3-dione Enol-form

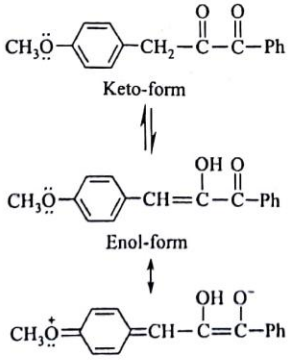


Enol-form stabilized by
intermolecular hydrogen bond

2.41 The following compound remains almost in 100% enolic form. Offer an explanation.



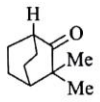
Ans This compound is an α-diketone. It can also exhibit keto–enol tautomerism and the enol-form remains almost in 100%, due to extended resonance. The conversion is given here.

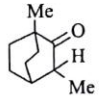


Keto-form

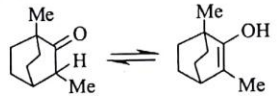
Enol-form

2.42 Which one of the following bridged bicyclic compounds will exhibit keto–enol tautomerism?

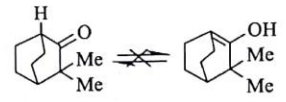
(a) 

(b) 

Ans Between these two compounds, compound (b) can exist as keto and enol tautomeric forms. However, compound (a) cannot, because the formation of enol involving the bridgehead hydrogen will violate the so called Bredt's rule.

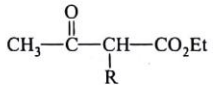
(a) 

Keto-form Enol-form

(b) 

Keto-form Enol-form with bridgehead double bond

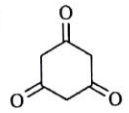
2.43 In the following chart, β-keto esters with different substituents on the α-carbon along with the % enol content in each case is given. Account for these differences in enol contents.

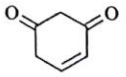


R	% enol content (liquid)
Et	3
Me	4
H	7.5
Ph	30
CO_2Et	44

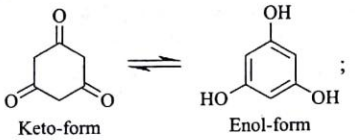
Ans It has been observed that as the α-H becomes more labile, the enol content increases. Now when the elactronegativity of the 'R' group increases, the αC—H bond becomes weaker and consequently enol content increases.

2.44 Which one of the following has higher enol content? Give reasons for your answer.

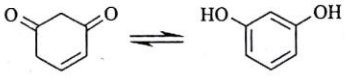
(a) 

(b) 

Ans The compound (a) is the triketo-form of phloroglucinol which is its enolic form. The enolic form of the compound (b) is resorcinol. Now, phloroglucinol can readily form its triketo-form. However, resorcinol cannot readily form its diketo-form. Therefore, it can be concluded that enol-content of the compound (b) is higher than that of (a).

(a) 

Keto-form Enol-form

(b) 

2.45 How do the polar and non-polar solvents affect the enol content of a keto–enol tautomeric system in 1,3-diketo compounds?

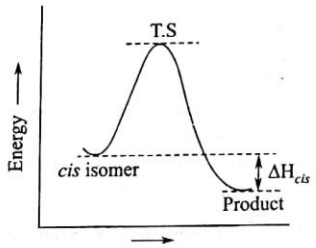
Ans The enolic form of a keto–enol tautomeric system is less polar due to H-bonding. Consequently, polar solvents stabilize the ketonic form, and the enol content should be higher in non-polar solvents.

For example, in case of CH_3—CO—CH_2—CO—CH_3, the percentage of ketonic form in polar solvents is as high as 92% but in water it is only 15%. Again, in the case of CH_3—CO—CH_2—CO_2 Et, enolic form is only 5.7% in acetic acid, whereas the ketonic form is as high as 94%.

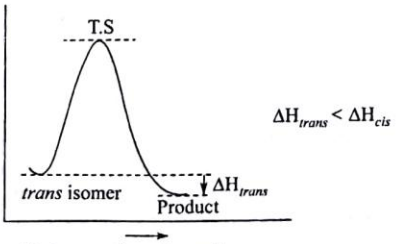
In addition, hydroxylic solvents would form hydrogen bonds with the solute oxygen atom to compete with the intramolecular hydrogen bonding in the enol. This would further decrease the enol content of 1,3-diketones.

2.46 The heat of hydrogenation of *cis*-but-2-ene is greater than that of *trans*-but-2-ene. Explain.

Ans Heat of hydrogenation is equivalent to the enthalpy change in the hydrogenation reaction. The more stable the alkene is, less would be the enthalpy change. Between *cis*-but-2-ene and *trans*-but-2-ene, *trans* isomer is more stable and consequently, has less heat of hydrogenation compared to the *cis* isomer. Energy profile diagrams of heats of hydrogenation of *trans* and *cis* isomers are shown here, assuming the reactions to be a one-step process.

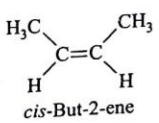


Hydrogenation of *cis* isomer

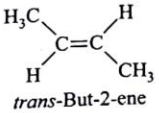


Hydrogenation of *trans* isomer

The structures of *cis*- and *trans*-Bu-2-ene are given here.



cis-But-2-ene

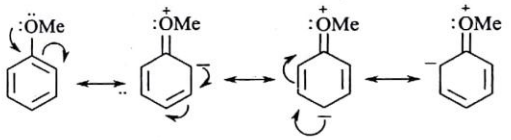


trans-But-2-ene

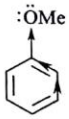
trans-But-2-ene is more stable than the *cis* isomer because the two large methyl groups are located far apart compared to the *cis* isomer where methyl groups are closure. Hence *trans* isomer is less crowded and has lesser van der Waals strain (steric strain).

2.47 OMe group strongly activates the *o*- and *p*-positions of the benzene nucleus but weakly deactivates the *m*-position. Explain.

Ans OMe group has pairs of non-bonded electrons. A pair of electrons can delocalize with the pi-electrons of the benzene electrons and thereby increases the electron densities of *o*- and *p*- positions to it. *m*-position cannot get electro-rich by this delocalization. On the contrary, OMe group has –I effect and that operates through bonds to deactivate the *m*-position.



Ortho and *para* positions are activated



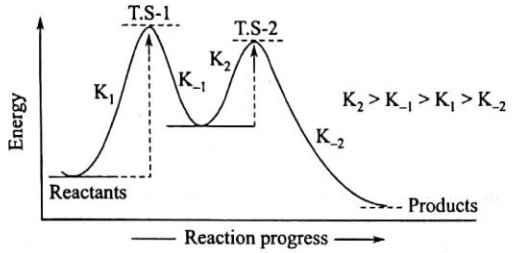
Meta position is deactivated

2.48 Halogens are deactivating, yet *o/p*-directing. Explain.

Ans Halogen atoms have non-bonded electron pairs in its valance shell. A pair of these electrons can participate in the delocalization process along with the pi-electrons of the benzene nucleus. This delocalization increases the electron density at the *ortho* and *para* position with respect to the halogen atom. This delocalization becomes effective at the requirement of an electrophilic reagent during an electrophilic substitution. However, halogen atoms are highly electronegative and, therefore, have a deactivating effect on the benzene nucleus.

2.49 Construct a reaction coordinate diagram for a reaction A → B → C in which the relative stabilities are C > A >B and for which the relative four rate constants are $K_2 > K_{-1} > K_1 > K_{-2}$. Which one is the rate determining step in your diagram?

Ans In the aforementioned reaction condition, K_1 and K_2 are rate constants of the forward reactions and K_{-1} and K_{-2} are the corresponding reverse reactions. The energy profile diagram can be shown as follows.



It is to be noted that greater the value of the rate constant, the faster would be the rate and vice versa. In this energy profile diagram, the rate determining step is the formation of T.S-1 in the forward reaction and the formation of T.S-2 in the reverse reaction.

2.50 Bromine can be displaced by iodine in H_2O medium but iodine can be displaced by bromine in acetone medium. Explain.

Ans The nucleophilicity of an anion or electron rich neutral species is found to be solvent dependent. In the case of a polar solvent like H_2O, the smaller anion with high electron density gets more solvated and its mobility and availability decreases. In H_2O medium, Br^- is more solvated than I^-. Consequently, in that medium I^- is a better nucleophile to displace Br^-. When the medium is changed to acetone, none of the halogen ions are solvated effectively and the Br^-, being smaller in size, has greater mobility compared to I^- and behaves as a better nucleophile. Therefore, in acetone medium Br^- can displace I^-.

$$I^- + CH_3{-}Br \xrightarrow[S_N2]{H_2O} I{-}CH_3 + Br^-$$

$$Br^- + CH_3{-}I \xrightarrow[S_N2]{H_2O} Br{-}CH_3 + I^-$$

$$I^- + CH_3{-}Br \xrightarrow[S_N2]{(CH_3)_2C=O} I{-}CH_3 + Br^-$$

$$Br^- + CH_3{-}I \xrightarrow[S_N2]{(CH_3)_2C=O} Br{-}CH_3 + I^-$$

2.51 CH_3CH_2OH does not react with aqueous NaBr to form CH_3CH_2Br but readily reacts with HBr to form CH_3CH_2Br. Explain.

Ans In the case of an S_N2-type displacement reaction, a better nucleophile can displace a weaker nucleophile. In the case of the reaction between CH_3CH_2OH and NaBr solution, Br^- being a weaker nucleophile, cannot displace a better nucleophile OH^- and the reaction does not occur.

In the case of the reaction between CH_3CH_2OH and HBr, CH_3CH_2OH is protonated to form $CH_3CH_2OH_2^+$. In this case, Br^- displaces the weaker nucleophile H_2O.

$$CH_3CH_2OH + NaBr \longrightarrow \text{No reaction}$$

$$CH_3CH_2OH + HBr \longrightarrow CH_3CH_2\overset{+}{O}H_2 + Br^-$$

$$Br^- + CH_3CH_2{-}\overset{+}{O}H_2 \longrightarrow CH_3CH_2Br + H_2O$$

In addition, OH^- is a bad leaving group but H_2O is a good leaving group.

2.52 The reaction of $PhCH{=}CH_2$ with H_2O/H_2SO_4 (dil), and with D_2O/D_2SO_4 (dil) shows $K_{H,O}/K_{D,O} = 3$. Explain this observation.

Ans The given reactions are acid catalysed hydration of styrene. The reaction is an electrophilic addition and takes place in two steps. The first step is the rapid formation of a carbocation and the second step is the slow attack by H_2O (D_2O). The course of the reaction is shown here.

$$PhCH{=}CH_2 \overset{H^+,\ H_2SO_4}{\underset{\text{Fast}}{\rightleftharpoons}} PhCH{-}CH_3 \xrightarrow{\text{Slow}} \left[PhCH(-CH_3)-\overset{+}{O}H_2\right] \xrightarrow{H_2O} PhCH(OH){-}CH_2$$

Since the slow step involves the attack by H_2O with concomitant loss of a proton, in case of D_2O, this step would be slower because the O—D bond is about four times stronger than the O—H bond. That is why the reaction shows deuterium isotope effect.

2.53 What is a nucleophilic catalyst. Give an example.

Ans Nucleophilic catalysts are those nucleophilic species that accelerate the rate of an S_N2-type displacement reaction which is otherwise extremely slow. At the end of the reaction, the nucleophilic catalyst is recovered. I^- is such a catalyst. For example, the reaction between an alcohol and HCl is quite slow but the reaction rate is enhanced in the presence of NaI. The course of the reaction is shown. I^- is a strong nucleophile and at the same time a good leaving group. These are the basic requirement for a nucleophile to act as a 'nucleophilic catalyst'.

$$CH_3CH_2OH + HCl \longrightarrow CH_3CH_2\overset{+}{O}H_2 + Cl^-$$

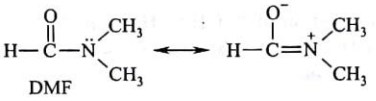
$$CH_3CH_2\overset{+}{O}H_2 + Cl^- \xrightarrow{\text{Slow}} CH_3CH_2Cl + H_2O$$

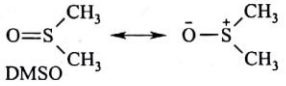
$$I^- + CH_3CH_2{-}\overset{+}{O}H_2 \xrightarrow{\text{Fast}} CH_3CH_2I + H_2O$$

$$Cl^- + CH_3CH_2{-}I \xrightarrow{\text{Fast}} CH_3CH_2Cl + I^-$$

2.54 DMF and DMSO favours S_N2 reaction although they are polar solvents. Explain.

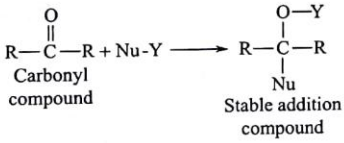
Ans DMF and DMSO are polar molecules. However, they fail to solvate an electron rich nucleophile through their +ve end because of strong steric factor. On the other hand, because of their high dielectric constant values, they can cause polarization of the substrate molecule and can facilitate facile nucleophilic attack. For these two reasons, DMF and DMSO support S_N2 substitution in spite of their polar character.

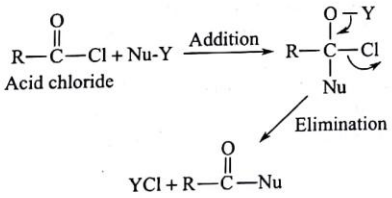




2.55 The addition of a nucleophile to a carbonyl compound leads to addition, whereas the addition of the same to an acid chloride leads to substitution. Explain.

Ans The addition of a nucleophile to a carbonyl compound leads to a stable addition compound because there is no good leaving group attached to the carbonyl carbon atom. When a nucleophilic reagent adds to an acid chloride, an initial addition compound is formed but it undergoes further elimination because the carbonyl carbon contains a chlorine atom which is a good leaving group.

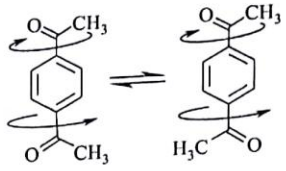




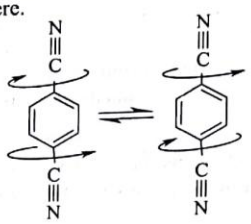
2.56 Which of the following compounds have resultant dipole moment?

(a) C_2H_5—OH **(d) CCl_4**
(b) Me—O—Me **(e) *p*-Diacetylbenzene**
(c) Me_2NH **(f) *p*-Dicyanobenzene**

Ans CH_3OH, Me_2NH, and *p*-Diacetylbenzene have resultant dipole moment. *p*-Diacetylbenzene has a resultant dipole moment because the C—C bond joining the benzene nucleus and the acetyl group has free rotation and the two acetyl groups can have non-symmetrical orientations, as a result of which, bond moments are not mutually neutralized.



In the case of *p*-dicyanobenzene, the resultant dipole moment value is zero, because rotation of CN groups about the C—CN bond does no change the symmetry of the molecule. This is shown here.



2.57 Compare the dipole moments of compounds in each of the following pairs.

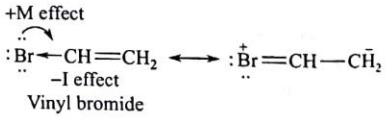
(a) *p*-Toluidine and *p*-Anisidine
(b) Vinyl bromide and Ethyl bromide
(c) 2,3-Diphenylcyclopropenone and Acetophenone
(d) MeCl and MeF
(e) *p*-Chlorophenol and *p*-Fluorophenol
(f) Tropolone and 2-Hydroxytropolone

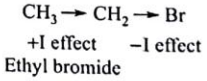
Ans

(a) *p*-Anisidine has greater dipole moment than *p*-Toluidine because in case of *p*-anisidine, delocalization (+M) effect is more pronounced due to the presence of an $-NH_2$ group having a lone pair of electrons on the nitrogen atom.

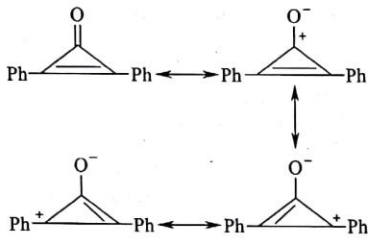
(b) CH_3Cl has higher dipole moment than CH_3F, because the C—Cl bond distance is much larger than the C—F bond distance in CH_3F, although CH_3F is more polar due to greater electronegativity of F atom. We know that dipole moment = charge × distance.

(c) Vinyl bromide has less dipole moment than ethyl bromide. In the case of vinyl bromide the –I effect of bromine atom is opposed by the +M effect due to pi-electrons delocalization. In case of ethyl bromide, –I effect of the bromine atom is reinforced by the +I effect of CH_3 group.

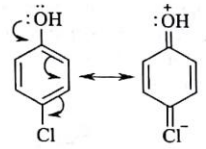




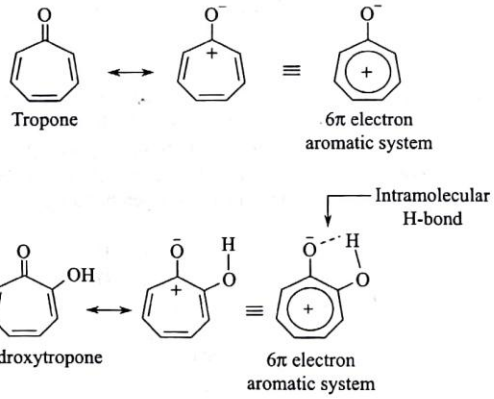
(d) 2,3-Diphenylcyclopropenone has higher dipole moment than acetophenone. Cyclopropenone system can assume aromatic stability due to delocalization. The generated cyclopropenium ion is further stabilized by the resonance involving benzene nucleus.



(e) *p*-Chlorophenol has higher dipole moment than *p*-fluorophenol. The reason is that in case of *p*-chlorophenol, extended resonance is possible due to the available vacant *d*-orbital with the chlorine atom. In case of *p*-fluorophenol, extended delocalization is not possible due to the absence of the *d*-orbital with the fluorine atom.

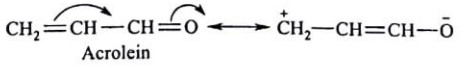


(f) Tropone exhibits aromatic character in its ionic form and hence has dipole moment. 2-Hydroxytropone also exhibits its dipole moment because of its aromatic ionic form but that ionic form is further stabilized by intramolecular hydrogen bonding.



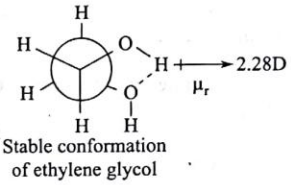
2.58 Acrolein has greater dipole moment than propanal. Explain.

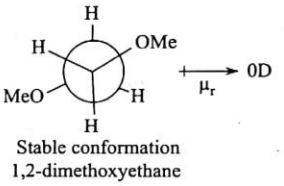
Ans Acrolein is a resonance hybrid involving the double bond and the aldehydic group. This enhances the polarity and consequently, it has greater dipole moment compared to propanal.



2.59 Ethylene glycol has a higher dipole moment value than 1,2-dimethoxy ethane. Explain.

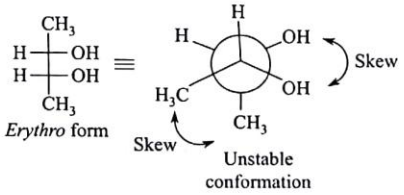
Ans Ethylene glycol can assume a very stable conformation where the two —OH groups are in skew position due to strong intramolecular hydrogen bonding. This makes the C—O bond moments to reinforce in the same direction and thereby causes increase in the dipole moment value. In the case of 1,2-dimethoxy ethane, the maximum contribution of that conformation is possible where the two —OMe groups are in *anti* position. As a result of this, the C—O bond moments cancel each other. Therefore, ethylene glycol has higher dipole moment than 1,2-dimethoxyethane.

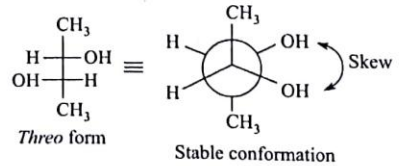




2.60 *Erythro* and *threo* isomers of Butane-2,3-diol can be distinguished from their Dipole moment values.

Ans *Erythro* and *threo* isomers can assume conformaions where stability is achieved through intramolecular hydrogen bonding when the —OH groups are in skew position. In case of *erythro* isomer, stability is less because when the —OH groups are in skew position, two $-CH_3$ groups are also in skew position and causes strong stereic interactions. Therefore, this conformation has lesser contribution compared to a completely staggered conformation. Thus it shows less dipole moment value. In case of *threo* isomer, skew position of —OH groups is more stable because in that condition the two $-CH_3$ groups are in *anti* position. Therefore, *threo*-form can form very stable intramolecular hydrogen bonding. Thus the *threo* form has higher dipole moment value.

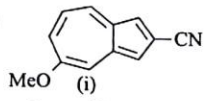
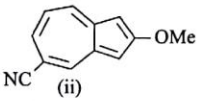


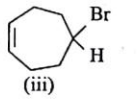
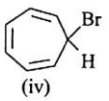


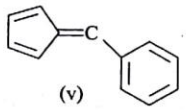
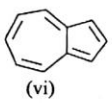
2.61 The dipole moment of $CH_2Cl–CH_2Cl$ increases as the temperature is raised. Explain.

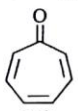
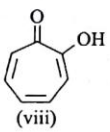
Ans $CH_2Cl–CH_2Cl$ can have a large number of conformations having different orientations of two C–Cl bonds. At low temperature, they remain in *anti* position to avoid dipole interaction, as much as possible. Under this conformational state, the dipole moment value is low. However, as the temperature is increased, the energy barrier arising out of dipole–dipole interaction is crossed and conformational compositions can contain more skew and eclipsed forms and these forms have higher dipole moments. This is why the average dipole moment value of $CH_2Cl–CH_2Cl$ increases as the temperature is raised.

2.62 Compare the dipole moments of the following compounds with reasons.

(a)  (i) **and**  (ii)

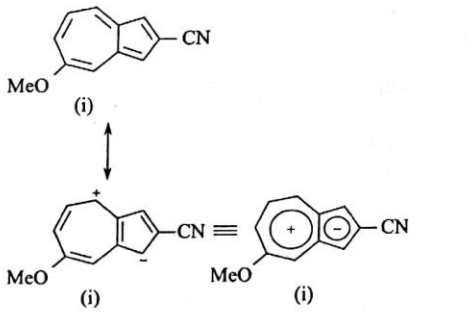
(b)  (iii) **and**  (iv)

(c)  (v) **and**  (vi)

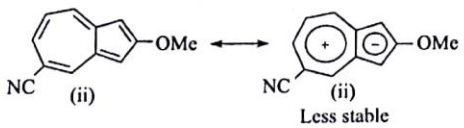
(d)  (vii) **and**  (viii)

Ans (a) These two are substituted azulenes. Due to redistribution of pi-electrons, the seven-membered ring becomes electron deficient and the five-membered ring becomes electron rich. In this form, azulene exhibits aromatic stability. Therefore, –OMe group can more stabilize the electron deficient ring and –CN can more stabilize the electron rich ring. Therefore, compound (i) has higher dipole moment than compound (ii).

(a)

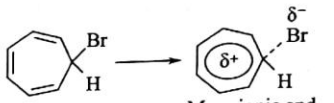


Stabilized molecule



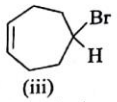
Less stable

(b) Between the compounds (iii) and (iv), (iv) is more polar and stable. Therefore, it has greater dipole moment.



(iv)

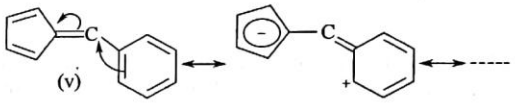
More ionic and stable due to some aromatic nature



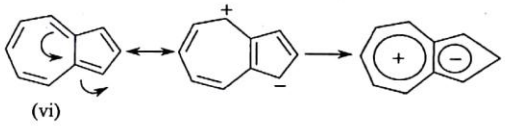
(iii)

Less ionic

(c) In this case, the compound (v) has higher dipole moment. In compound (v), extended resonance is possible along with the developement of aromatic character to the five membered-ring. The compound (vi) is azulene and is also ionic due to delocalization of p-electrons; however charge separation is less.

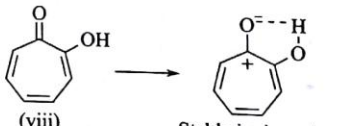


(v)



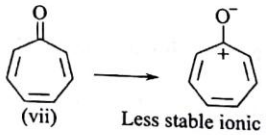
(vi)

(d) In this case, the compound (viii) has higher dipole moment value. The ionic forms of both the compounds have an aromatic system comprising cycloheptatrienyl carbonium ion. However, in the case of (viii), it is further stabilized by intramolecular hydrogen bonding.



(viii)

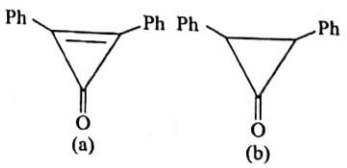
Stable ionic system



(vii)

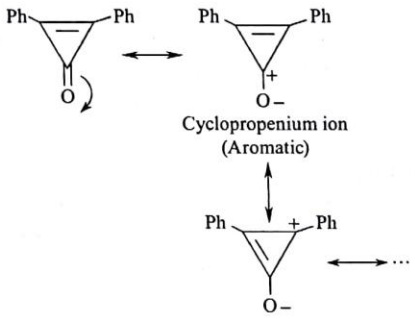
Less stable ionic system

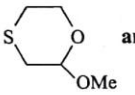
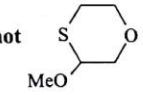
2.63 Which of the following two compounds has higher dipole moment?



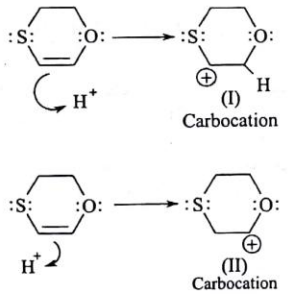
(a) (b)

Ans Compound (a) has higher dipole moment than compound (b). Compound (a) can assume ionic aromatic character due to delocalization and that state is further stabilized by the conjugated Ph group. This is not possible in case of compound (b). Since the compound remains in more ionic form, it has a higher dipole moment value.

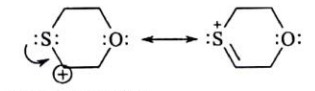


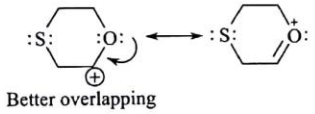
2.64 Acid catalysed addition of methanol to  **produces**  **and not**  **Give an explanation and the necessary mechanism.**

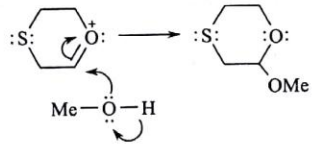
Ans Protonation of the parent compound can produce two cations (I) and (II).



Of the two carbocations shown, it apparently seems that (I) should be more stable because the lone pair of electrons on the S atom is more polarizable but the product obtained by the acid catalysed methanol addition shows that carbocation (II) is the reactive intermediate. This stability of (II) compared to (I) may be poor overlapping of the lone pair of electrons on S, which resides in an sp^3 hybrid orbital arising from principal quantum level '3', but in case of O in the carbocation (II) the lone pair is in sp^3 orbital involving principal quantum level 2. Therefore, in case this carbocation (II) is more stabilized by delocalization; consequently this carbocation takes part in the reaction. The bigger size of sulphur atom and greater bond distance of the C–S bond might also be partly responsible for this poor overlapping.

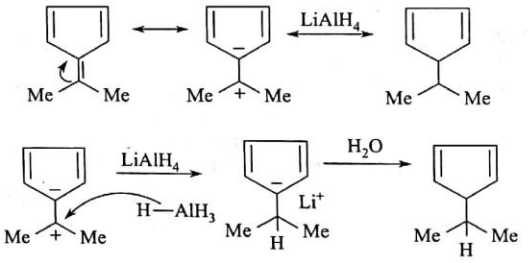






2.65 Rationalize that  **reacts with $LiAlH_4$, whereas $Et_2C{=}CMe_2$ does not.**

Ans $LiAlH_4$ normally does not reduce olefinic double bond. However, this cyclic compound is found to be reduced because it generates a strong carbocationic centre due to delocalization of the exocyclic double bond leading to the formation of an aromatic cyclopentadienide system. However, in case of $Et_2C{=}CMe_2$, this type of activation is not possible and reduction does not occur in this case.



2.66 Arrange the compounds in each group in the decreasing order of the properties mentioned in parenthesis, giving reasons.

(a) CH_3Cl, Cl_2CH_2, $CHCl_3$, CCl_4 (Dipole moment)

(b) Benzyl chloride, Chlorobenzene, Cyclohexyl chloride, Neopentyl chloride (Affinity towards S_N2 nucleophilic substitution)

(c) Benzene, Nitrobenzene, Toluene, Anisole (Affinity towards electrophilic substitution)

Ans

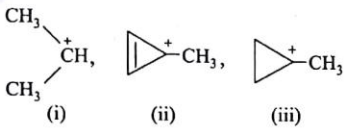
(a) Dipole moment order is $CH_3Cl > Cl_2CH_2 > CHCl_3 > CCl_4$.

(b) Nucleophilic substitution order (S_N2) is Benzyl chloride > Cyclohexyl chloride > Neopentyl chloride, Chlorobenzene.

(c) Anisole > Toluene > Benzene > Nitrobenzene

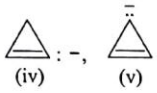
2.67 Arrange the following ions in order of decreasing stability.

(a)



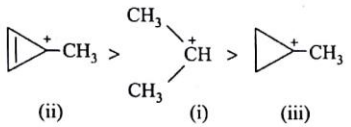
(i) (ii) (iii)

(b)



(iv) (v)

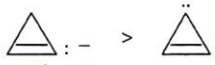
Ans In the case of compounds in (a), the decreasing stability order is



(ii) (i) (iii)

Here, (ii) is a stable 2π-electron Huckel's aromatic system. (i) has the stability due to +I and hyperconjugative resonance involving two $-CH_3$ groups.

In case of (b)

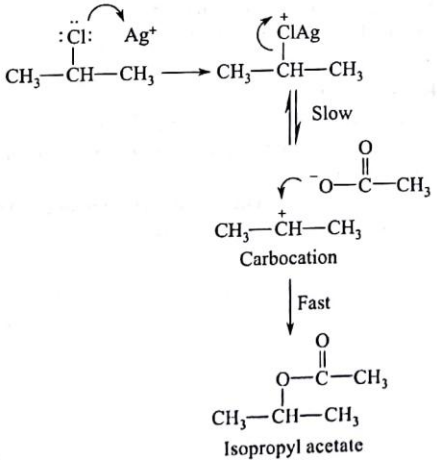


Antiaromatic system

In this case, (iv) represents an anti-aromatic system according to Huckel's rule. Therefore, it is less stable than (v).

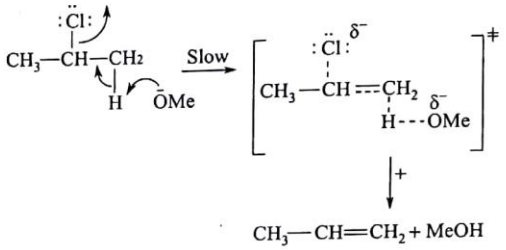
2.68 $CH_3CHClCH_3$ and $CD_3CHClCD_3$ show kinetic isotope effect during (a) substitution reaction using CH_3COOAg/CH_3COOH and (b) elimination reaction using NaOMe/DMSO. Indicate the primary/secondary nature of the kinetic isotope effect in the aforementioned reactions explaining the variation of the rate.

Ans (a) Reaction with CH_3COOAg gives an ester through S_N1 mode of substitution. The course of the reaction can be shown as follows.



In this case the stability of the intermediate carbocation is partly due to +I effects of CH_3 groups and primarily due to hyperconjugation involving the cleavages of C—H bonds of methyl groups. Since carbocation formation is the rate determining step of the reaction, $CD_3CHClCD_3$ would react at a slower rate because C—D bond is about seven times more strong when compared to C—H bond. Therefore, the reaction will exhibit strong secondary kinetic isotope effect.

(b) This is a case of base catalysed E2 reaction. The mechanism can be shown as follows.



The reaction is a one-step process through a transition step. This the slow step. If the substrate molecule is $CD_3CHClCD_3$, then the reaction rate will be slowed down because the slow step involves the cleavage of C—H bond and C—D is stronger. Therefore, this reaction will exhibit primary kinetic isotope effect.

2.69 Compare the basicities and nuclephilicity of the following compounds. Explain your answer.

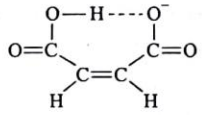
$$\ddot{N}H_3,\ H_2\ddot{N}—\ddot{N}H_2,\ \ddot{N}H_2\ddot{O}H$$

Ans The decreasing orders of nucleophilicity and basicity are $H_2N—NH_2 > NH_2OH > NH_3$ and $NH_3 > NH_2NH_2 > NH_2OH$ respectively. In all these cases, nucleophilicity is due to the lone pair of electrons on the nitrogen atom. In case of $H_2N—NH_2$ and NH_2OH, nucleophilicity is enhanced due to α-effect of the lone pair of electrons on the adjacent atom. α-effect is more effective in case of $H_2N—NH_2$ because the lone pair of electrons on the nitrogen atom is more polarizable compared to that on the oxygen atom. Oxygen atom has higher electronegativity than nitrogen atom.

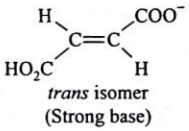
On the other hand, basicity depends on the electron density on the nitrogen atom. Electron density of the nitrogen atom in NH_3 is higher than the in case of $H_2N—NH_2$ and NH_2OH, because of strong $-I$ effects of the adjacent N and O atom respectively, where oxygen is more electronegative than nitrogen.

2.70 (*E*)-isomer of $HO_2C—CH=CH—\overset{-}{C}O_2\overset{+}{N}a$ is a stronger base than its corresponding (*Z*)-isomer. Explain. Further, comment on their relative acidities.

Ans In the case of (*E*)-isomer, the carboxylate anion cannot form an intramolecular hydrogen bonding, but (*Z*)-can. That is why (*E*)-isomer can behave as a stronger base.



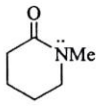
cis isomer (Weak base)

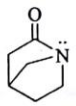


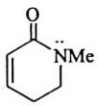
trans isomer
(Strong base)

Since (*Z*)-isomer forms intramolecular H-bonding, it cannot release H^+ easily. However, (*E*)-isomer cannot form intramolecular H-bonding and can release H^+ more readily. Hence (*E*)-isomer is more acidic than (*Z*)-isomer.

2.71 Arrange the following amides in increasing order of basicity. Explain your answer.

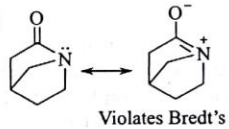
(a) 

(b) 

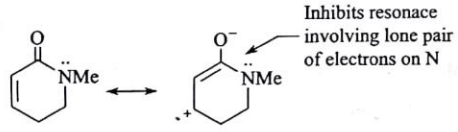
(c) 

Ans In these compounds, basicity is determined on the basis of electron density on nitrogen atom. Based on this fact, the decreasing basicity order is (b) > (c) > (a). In case of (b), line pair of electrons on the nitrogen atom cannot delocalize, because in that case a double bond has to be placed with the bridgehead atoms violating Bredt's rule.

In case of (c), resonance involving αβ-unsaturated ketonic system partially inhibits the delocalization of the electron pair on the nitrogen atom. In case of (a), no such incidents inhibit the delocalization of the electron pair on the nitrogen atom.

(b) 

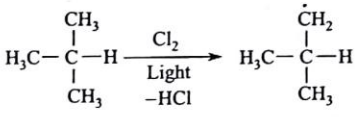
Violates Bredt's rule

(c) 

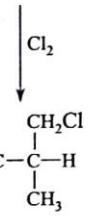
2.72 Me_3CH on chlorination using Cl_2 in diffused sun light gives primary halide as major monosubstituted product, whereas bromination by heating with bromine produces a tertiary halide as the major compound. Justify the observation.

Ans A probable explanation may be that when a reaction with chlorine is carried out in the presence of light, the reaction proceeds according to free radical mechanism. Now the compound Me_3CH contains nine primary hydrogens and one tertiary hydrogen. Therefore, probability of the formation of primary free radical is much greater compared to the formation of tertiary free radical, although tertiary free radical is more stable by hyperconjugation, but not by any inductive effects.

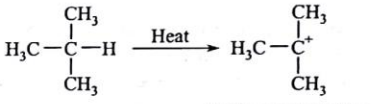
In the reaction of Me_3CH with bromine, when it proceeds thermally, ionic mechanism is more probable, because tertiary cation can be formed thermally more easily than that of the formation of tertiary radical. This tertiary carbocation is much more stable compared to the possible primary carbocation, because the former is stabilized by +I effects of the CH_3 groups as well as hyperconjugative delocalization. Thus, photochemical chlorination gives a primary chloride as the major product but reaction with bromine under thermal condition gives a tertiary bromide as the major product.



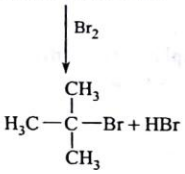
Primary radical



Primary halide



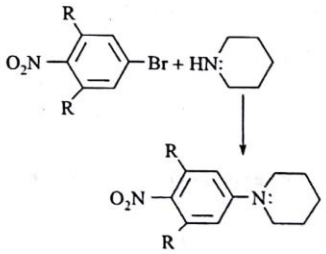
Tertiary carbocation



Tertiary bromide

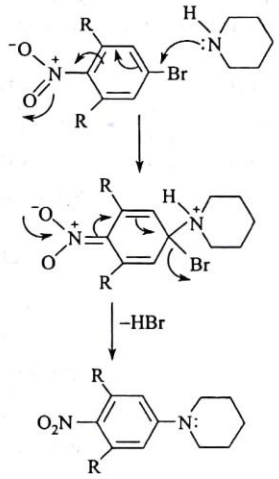
Alternatively, it can be concluded that if we assume the formation of both primary and tertiary radicals from Me_3CH, then the $Cl^\cdot$ being more reactive and less selective can readily react with a primary radical because of its higher concentration. On the other hand, $Br^\cdot$ is less reactive and more selective, and reacts with the more stable tertiary radical.

2.73 Write down the mechanism of the following reaction.



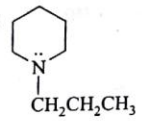
Account for the fact that the compound that has R=H reacts 35 times as fast as the one that has R=CH_3.

Ans It is a case of activated nucleophilic substitution where piperidine is the nucleophile. The course of the reaction can be shown as follows.



In R=H, this extensive resonance involving $-NO_2$ group is facile, but in R=CH_3, the steric interaction causes the $-NO_2$ group to move out of the plane of the benzene ring and inhibits its resonance and consequently slows down the rate of the reaction.

2.74 Explain the relative order of reactivity of the following amines with Me_3B.

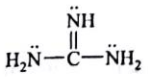
(a) 

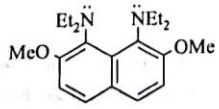
(c) 

(b) $(CH_3CH_2CH_2)_3N$:

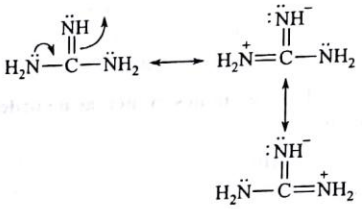
Ans The relative order of reactivity is (c) > (a) > (b). Compound (c) is a rigid bridged bicyclic compound and the lone pair of electrons on the nitrogen atom is more exposed to react with the bulky Lewis acid, Me_3B. In case of (b), three propyl groups bonded to the central nitrogen atom envelope the lone pair of electrons on the nitrogen atom in such a way that the bulky Me_3B cannot get close enough to react with the compound. Compound (a) is partially rigid and only one propyl group is attached to the nitrogen atom bearing the nitrogen atom. Therefore, it is more reactive than (b) but less reactive than (c).

2.75 The following compounds are extremely strong bases towards H^+. Give reasons.

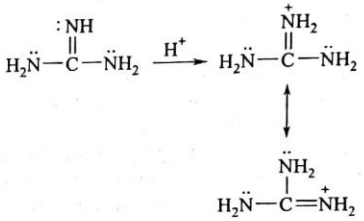
(a) 

(b) 

Ans The compound (a) is trivially known as guanidine. It is a very strong organic base because of the fact that its protonated form is stabilized by resonance involving three equivalent mono-positive resonating structures. A neutral molecule can also give a resonating structure but it is less stable because of bipolar structures.

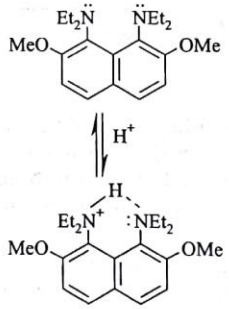
(a) 

Resonating structures of neutral molecule



Resonating structures of monoprotonated cation

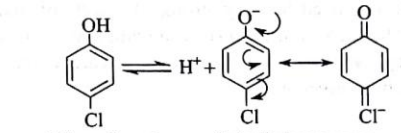
In case of the compound (b), monoprotonated form gets very much stabilized by intramolecular hydrogen bonding. That is why it functions as a strong base towards H^+, but cannot do so against Lewis acids such as BH_3 or $AlCl_3$.

(b) 

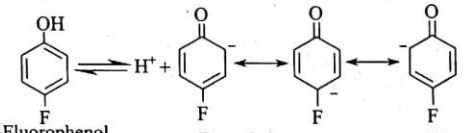
Stabilized by intramolecular hydrogen bonding

2.76 Compare the acidity of *p*-chlorophenol and *p*-fluorophenol.

Ans Between *p*-chlorophenol and *p*-fluorophenol, the former is more acidic. In case of *p*-chlorophenol, the corresponding phenoxide ion is more stabilized by extended resonance involving the vacant 3*d*-orbital on the chlorine atom. In case of *p*-fluorophenol, this type of extended resonance is not possible because the fluorine atom has no such *d*-orbital.

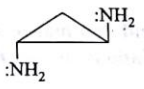


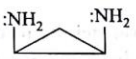
p-Chlorophenol Extended resonance (More stable)



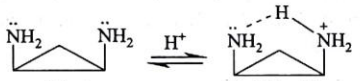
p-Fluorophenol Extended resonance not possible (Less stable)

2.77 Which one of the following two compounds is more basic and why?

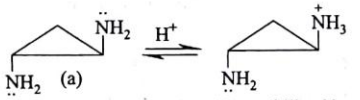
(a) 

(b) 

Ans The aforementioned compounds are rigid molecules. The compound (b) is more basic, because its monoprotonated form gets stabilized by intramolecular hydrogen bonding. In the case of compound (a), such intramolecular hydrogen bonding is not possible after monoprotonation.

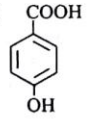


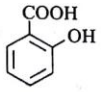
(b) Stabilized by intramolecular hydrogen bonding

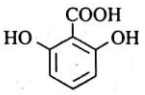


Not stabilized by intramolecular hydrogen bonding

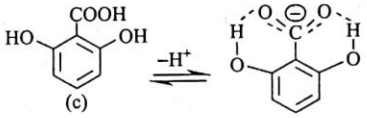
2.78 Arrange the following compounds in order of increasing acid strength with explanations.

(a) 

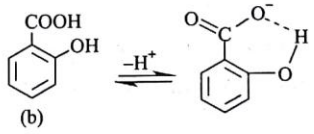
(b) 

(c) 

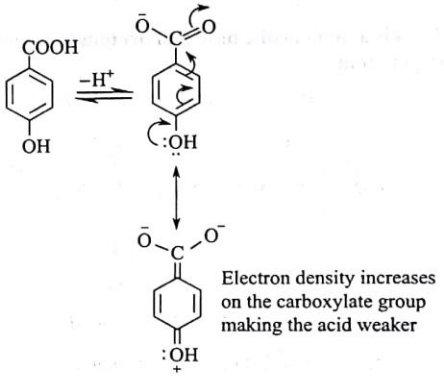
Ans The decreasing acidity order is (c) > (b) > (a). In case of (c), the corresponding carboxylate anion is stabilized by intramolecular hydrogen bonding from two *ortho* —OH groups. In case of (b), the stabilization comes from intramolecular hydrogen bonding from one *ortho* —OH group. In case of (a), carboxylate ion is destabilized by resonance involving *p*—OH group.



(c)



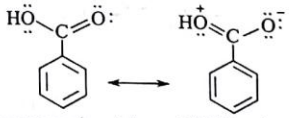
(b)



Electron density increases on the carboxylate group making the acid weaker

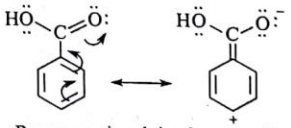
2.79 What is *ortho*-effect on the acidity of substituted benzoic acid. Explain with a suitable example.

Ans Benzoic acid can have two sets of resonance. One is within the —COOH group and the other involving benzene ring along with the —COOH group. These are shown here.



Resonance involving —COOH only

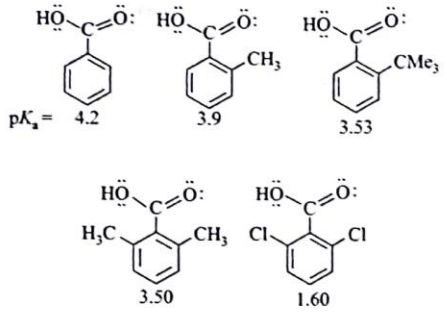
(I)



Resonance involving benzene ring

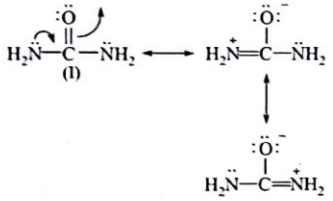
(II)

Resonance (I) has no apparent role on the acidity strength in case of substituted benzoic acids but the resonance (II) with substitution at the *ortho*-position can inhibit this resonance due to non-planarity of —COOH group. This enhances the resonance (I) and increases the acidity. This enhancement in the strength of *ortho*-substituted benzoic acids compared to benzoic acid itself is called '*ortho*-effect'. A few examples are given here.



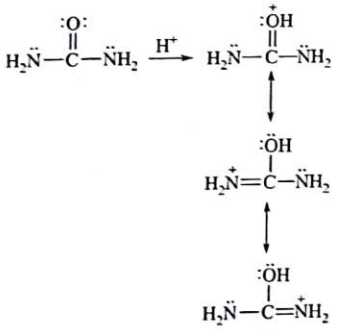
2.80 Urea is a monoacidic base and protonation occurs on the oxygen atom.

Ans Urea has the following resonating structures.



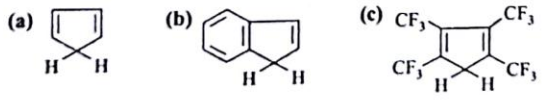
Resonating structures of neutral molecule

From the given resonating structures, it is evident that electron density is maximum on the oxygen atom. Therefore, protonation occurs on the oxygen atom and the protonated form is also stabilized by equivalent resonating structures.

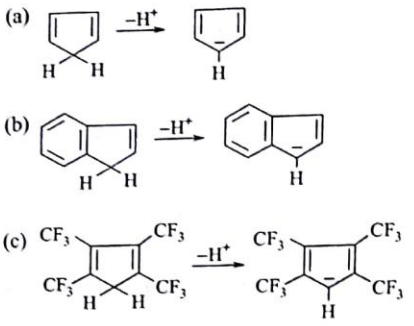


Resonating structures of monoprotonated cation

2.81 Arrange the following compounds in order of increasing pK_a values.

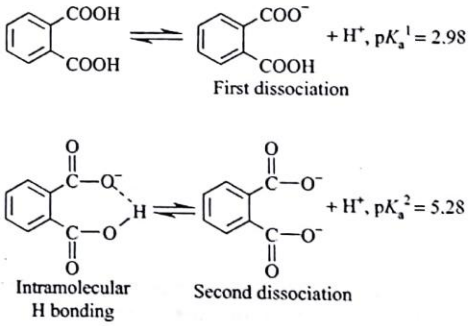


Ans The decreasing order of acidity of the three compounds is (c) > (b) > (a). All the three compounds produce stable aromatic cyclopentadienide ion. However, in the case of (c), this is further stabilized by very strong –I effects of four $-CF_3$ groups. The carbanion from (b) is a combination of two aromatic ring systems. The corresponding carbanion, in each case, has been given here.

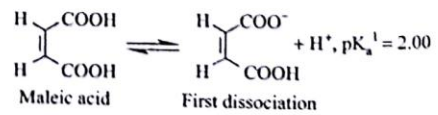


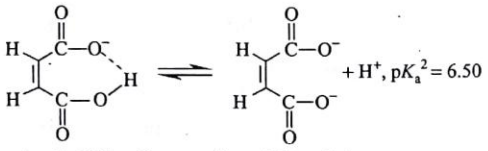
2.82 Discuss the acidity of phthalic acid and maleic acid based on the first and second dissociations of —COOH groups.

Ans Phthalic acid is benzene-1,2-dicarboxylic acid and maleic acid is *cis*-butenedioic acid. Two carboxylic groups exhibit different acidities. In case of phthalic acid, pK_a of first dissociation is 2.98 and pK_a of second dissociation is 5.28. This difference has been attributed to the intramolecular hydrogen bonding in case of second dissociation. This causes second dissociation difficult. The first dissociation of the —COOH group is normal.



In the case of maleic acid (*cis*-butenedioic acid), the same argument is applicable in case of difference in acidities due to the first dissociation and second dissociation. Due to the double bond, the molecule is rigid and after the first dissociation, intramolecular hydrogen bonding is possible. This makes the second dissociation difficult.

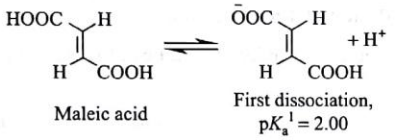




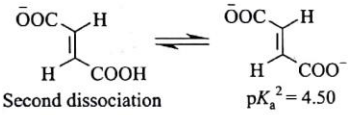
Intramolecular H-bonding Second dissociation

2.83 Compare the acidity of *cis*- and *trans*-butenedioic acid.

Ans *Trans*-butenedioic acid is trivially called fumaric acid. It also gives two dissociation constants for two —COOH groups. However, the difference in acidities is not very large. After the first dissociation, intramolecular hydrogen bonding is not possible, as in the case of *cis* isomer.



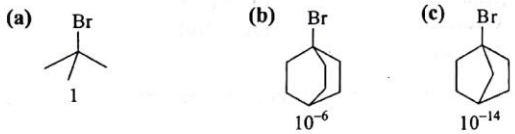
Maleic acid First dissociation, $pK_a^1 = 2.00$



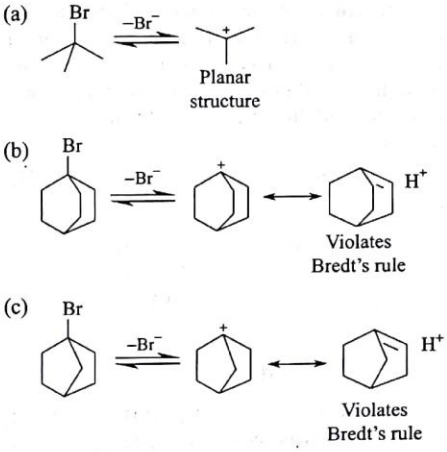
Second dissociation $pK_a^2 = 4.50$

For a discussion on the acidity of *cis*-butenedioic acid, see 2.82.

2.84 Rates of sovolysis of the bromides (a), (b), and (c) in 80% ethanol at 25°C are $1:10^{-6}:10^{-14}$. Explain the reason for these relative rates.

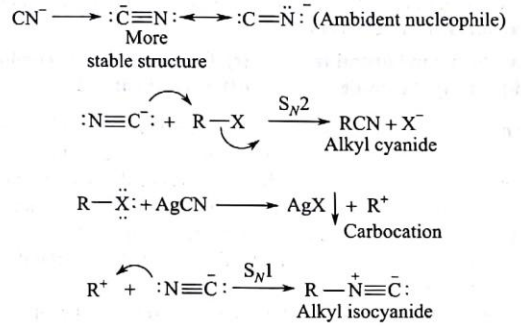


Ans All these three bromides are tertiary halides and undergo solvolysis by S_N1 pathway. This means, a tertiary carbocation is formed as the intermediate determines the rate of solvolysis; therefore rates are related to the stability of the carbocations. In case of (a), carbocation formation and its stability is maximum because the carbocation can assume planarity which is necessary for giving it stability by hyperconjugation. In case of (b), the resultant tertiary cation can assume partial planarity because of 2-carbon-bridge which gives it some flexibility. In case of (c), the bridge compound becomes more rigid because of smaller rings and the corresponding tertiary carbocation fails to assume planarity. Therefore, carbocations (b) and (c) have different stabilities although both of them violate Bredt's rule when exhibiting hyperconjugation.



2.85 Alkyl halides with aqueous ethanol KCN mainly produce cyanides, whereas with AgCN, isocyanides are the main products. Explain this observation.

Ans CN^- ion is an ambident nucleophile. It can take part in substitution reaction through its carbon end as well as nitrogen end. In case of reaction with KCN in aqueous medium, reaction occurs according to S_N2 mechanism and the more polarizable electron pair on the carbon atom of CN^- takes part in the reaction and cyanides are formed as the major product. When the reaction is carried out with AgCN, then Ag^+ initiates the formation of a carbocation from alkyl halides and thus the reaction is shifted to S_N1 pathway. In this case the more electron rich nitrogen end takes part in the reaction and isocyanides are formed as the major product.



2.86 Explain why the halogen atom of vinyl chloride is less reactive than that of ethyl chloride.

Ans In the case of vinyl chloride, resonance involving the lone pair of electrons on the chlorine atom makes the C—Cl bond to assume some double bond character and consequently the C—Cl bond becomes stronger and requires more energy to react. No such resonance is possible in case of ethyl chloride.

Vinyl chloride

2.87 Give the structures of the isomeric alkenes having the molecular formula C_5H_{10} and arrange them in order of decreasing heats of hydrogenation. What is the relationship between stability and heats of hydrogenation? When can we compare the stabilities of alkenes from their heats of hydrogenation.

Ans The isomeric alkenes from the molecular formula C_5H_{10} are given here.

$CH_2{=}CHCH_2CH_2CH_3$ Pent-1-ene (I)

$CH_3CH{=}CHCH_2CH_3$ Pent-2-ene (II)

$(CH_3)_2CHCH{=}CH_2$ 3-Methylbut-1-ene (III)

$CH_2{=}C(CH_3){-}CH_2CH_3$ 2-Methylbut-1-ene (IV)

$(CH_3)_2C{=}CHCH_3$ 2-Methylbut-2-ene (V)

The decreasing order of heat of hydrogenation between (I) and (II) is (I) > (II) and that amongst (III), (IV), and (V) is (III) > (IV) > (V). In case of isomeric alkenes leading to the formation of same alkane on hydrogenation, the most stable alkene has the least heat of hydrogenation and vice versa.

If hydrogenation produces different alkenes then 'heat of hydrogenation' method cannot be used to compare their stabilities. In the present case, stabilities of (I) and (II) cannot be compared with methyl substituted butuenes, because (I) and (II) gives n-pentane as the hydrogenated compound but (III), (IV), and (V) give 2-methylbutane as the hydrogenated compound.

2.88 Arrange the following compounds in order of decreasing rate of solvolysis in methanol. Give reasons in favour of your answers.

(a) Isopropyl bromide
(b) *t*-Butyl bromide
(c) Diphenylmethyl bromide
(d) *t*-Butyl chloride

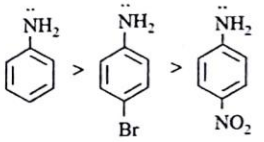
Ans These allyl bromides are likely to undergo solvolysis by S_N1 pathway. In S_N1 mechanism of substitutions, the reaction rates are dependent on the stabilities of the intermediate carbocations. On the basis of this fact, the increasing order of rates of reactions of the aforementioned compounds is

Isopropyl bromide < *t*-Butyl chloride < *t*-Butyl bromide < Diphenylmethyl bromide.

Between *t*-Butyl chloride and *t*-Butyl bromide, the latter is more reactive because it contains a better leaving group (Br^-) compared to Cl^- in *t*-Butyl chloride.

2.89 Arrange the following compounds in order of decreasing nucleophilicity giving reasons: (a) Aniline, (b) Ethylamine, (c) 4-Nitroaniline, and (c) 4-Bromoaniline.

Ans In these compounds, basicities and nucleophilicity run parallel because the lone pair of electrons, necessary for the exhibition of both basicity and nucleophilicity, resides on the nitrogen atom in each case. The basicities of these compounds in decreasing order are

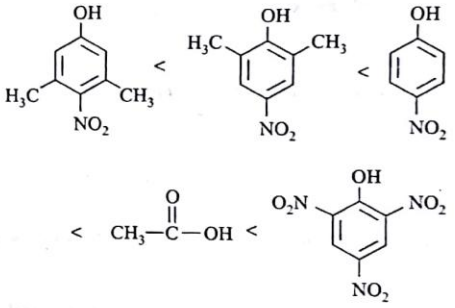
$CH_3CH_2\ddot{N}H_2$ >  >

The decreasing nucleophilicity is also in the same order, as shown. 4-Bromoaniline is less basic and less nucleophilic than aniline because of mesomeric and inductive effect. Ethylamine is the most basic and nucleophilic because the lone pair of electrons on the nitrogen atom cannot delocalize.

2.90 Arrange the following compounds in order of increasing acid strength.

(a) 4-Nitrophenol
(b) 3,5-Dimethyl-4-nitrophenol
(c) 2,4,6-Trinitrophenol
(d) Acetic acid
(e) 2,6-Dimethyl-4-nitrophenol.

Ans The increasing order of acidities of these compounds is as follows:



2.91 Arrange the following reagents in order of decreasing basicity. Give your justification.

(a) *t*-BuOK
(b) $NaNH_2$
(c) Ph_3CNa
(d) NaOEt
(e) *n*-BuLi

Ans The decreasing basicity order of these reagents is given here.

$$n\text{-BuLi}(n\text{-Bu}^-) > Ph_3CNa(Ph_3C^-) > NaNH_2(NH_2^-) > t\text{-BuOK}(t\text{-BuO}^-) > NaOEt > (EtO^-)$$

It is to be noted that weaker the conjugate acid, stronger would be the conjugate base and vice versa. The decreasing order of acidities of the corresponding conjugate acids of the bases shown is given here.

$$EtOH > t\text{-BuOH} > NH_3 > Ph_3CH > n\text{-BuH}$$

2.92 Arrange the following ions in the decreasing order of S_N2 reactivity towards MeI in MeOH. Give arguments in support of your answer.

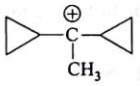
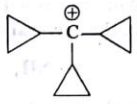
(a) F^-
(b) I^-
(c) PhO^-
(d) CH_3O^-
(e) EtO^-

Ans In the case of S_N2 substitution, the nucleophilicity of an anion or Lewis base is measured on the basis of the polarizability of the pair of electrons responsible for exhibiting nucleophilicity. On the basis of this fact, the aforementioned ions can be arranged in decreasing order of nucleophilicity as follows.

$$I^- > EtO^- > MeO > PhO^- > F^-$$

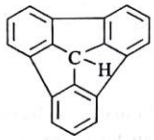
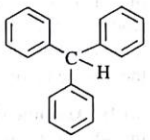
When the size of the atom bearing the lone pair of electrons is larger and electronegativity value is lower, then the lone pair of electrons is more polarizable. When the lone pair of electrons resides on the identical atom in several anions, then the more basic anion is more nucleophilic.

2.93 Which of the following two carbocations is more stable and why?

(a)  or (b) 

Ans Between the compounds (a) and (b), (b) is more stable. According to Walsh model of cyclopropane, the ring behaves like a substituent having a π-electron system. Therefore three cyclopropyle rings will stabilize the carbocation more effectively than two cyclopropyl rings and a methyl group.

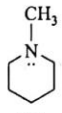
2.94 Which compound in the following pair is more acidic and why?

(a)  or (b) 

Ans Compound (a) is more acidic than compound (b). After deprotonation of the central carbon atom of (a), the corresponding carbocation can assume an almost planar structure because the rigid nature of its structure and resonance involving benzene rings become more effective. In case of (b), the carbocation formed by deprotonation becomes partly non-planar due to non-rigidity of its structure.

2.95 Predict with proper reasoning which member of the following pairs behaves as a better base towards BMe_3.

(a) $Et_2\ddot{N}H$ (i) **and**  (ii)

(b)  (iii) **and**  (iv)

Ans In the case of (a), pyrrolidine (ii) is a stronger base compared to diethylamine (i). In the case of diethylamine, steric interaction between Me groups of BMe_3 and ethyl group of the amine will prevent reactants to come close enough for coordination.

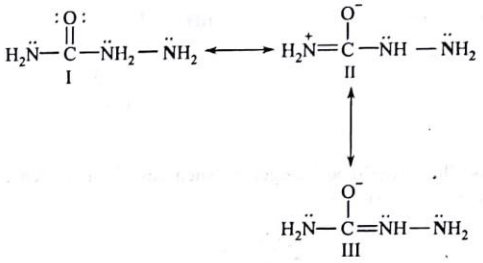
In the case of (b), compound (iii) is more basic, because the lone pair of electrons on the nitrogen atom is more exposed to coordinate with BMe_3. In compound (iv), the lone pair of electrons on the nitrogen atom is somewhat masked by the methyl group and some steric interaction may occur with the methyl groups of BMe_3.

2.96 What do you mean by nucleofugality? Explain with suitable example.

Ans The leaving group that carries away the bonding electron pair in a substitution reaction is called nucleofuge and the tendency of atoms or groups to depart with the bonding electron pair is called nucleofugality. For example, in the hydrolysis of an alkyl chloride, Cl^- is the nucleofuge.

2.97 Which of the nitrogen atoms in semicarbazide is involved in the semicarbazone formation. Explain.

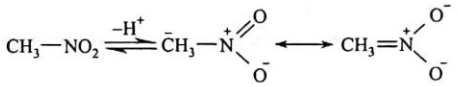
Ans In the case of semicarbazide, we can show the following resonation structures.

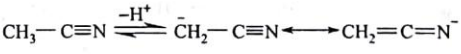


From these resonating structures, it is evident that the lone pair of electrons on the marked nitrogen (bold) cannot take part in the resonance. Therefore, it is more available and a more polarizable electron pair to participate in the reaction of the formation of semicarbazone.

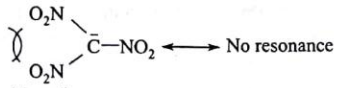
2.98 Nitromethane is a stronger acid than methyl cyanide but trinitromethane is a weaker acid than tricyanomethane. Give an explanation for this.

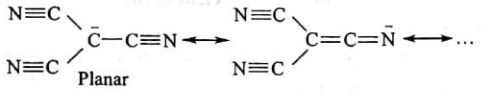
Ans It is to be noted that $-NO_2$ group is a much stronger negative group (electron withdrawing group) compared to —CN group. That is why, CH_3NO_2 is a stronger acid than CH_3CN.



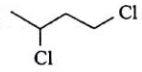


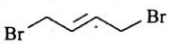
In case of trinitromethane, carbanion cannot become stabilized by resonance because planarity cannot be achieved due to interaction among the three nitro groups on a single carbon. In case of tricyanomethane, CN group is linear and steric factor is not inhibiting resonance. This is why, tricyanomethane behaves as a stronger acid compared to trinitromethane.

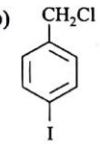




2.99 Each of the following molecules contains two halogens at different positions in the molecule. For each one, explain which of the two halogens will be more reactive in the S_N1 reaction.

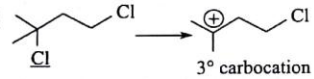
(a) 

(c) 

(b) 

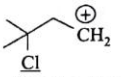
(d) 

Ans The underlined halogen in each case is more reactive towards S_N1 reaction.

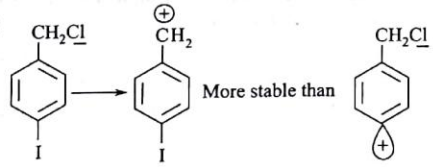
(a) 

3° carbocation

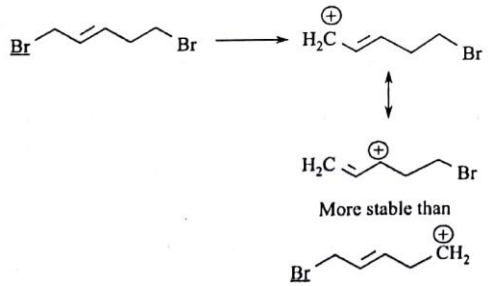
More stable than

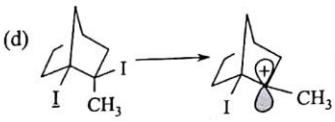


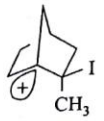
1° carbocation

(b) 

Resonance stabilized ⊕–ve charge on sp^2 orbital

(c) 

(d) 



Bridged bicyclic compound prevents + –ve sp^2 carbon at the bridgehead

2.100 The equilibrium constants for the complex formation of amines with Me_3B increase in the following order. Give the necessary explanation.

$$NH_3 < Me_3N < MeNH_2 < Me_2NH$$

Ans Me_3B is a Lewis acid and the amines in the question are all Lewis bases. The two important factors that will determine the equilibrium position in each case are electron density on the nitrogen atom of the bases and steric factor.

As the number of Me groups increases on the nitrogen atom in a base, electron density increases but at the same time steric interaction tends to increase. In case of Me_3N, steric interaction with the methyl groups of Me_3B causes the slowing down of its reaction as an electron donor. However, Me_2NH is most reactive because it behaves as a strong base and steric interaction is less due to the lesser number of Me groups attached to the nitrogen atom.

2.101 Arrange the compounds in (a) in order of decreasing –I effect and compounds in (b) in order of increasing +I effect.

(a) $-CN, -CO_2H, -NR_3, -OMe$ (b) Me_3C, Me_2CH, Me

Ans (a) The order of decreasing –I effect is $-CN > -CO_2H > -OMe > -NR_3$ and (b) the order of increasing +I effect is $Me < Me_2CH < Me_3C$.

2.102 Write resonance structures for the following, indicating major and minor contributors (C_6H_5 is the phenyl ring).

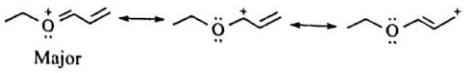
(a) $[CH_3CHOCHCH_2]^+$ (c) $[CH_3COCH_2^-]^-$

(b) $[CH_3CH_2OCHCHCH_2]^+$ (d) $[C_6H_5CHNH_2]^+$

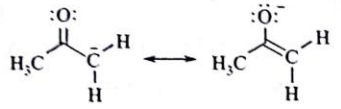
Ans

(a) 

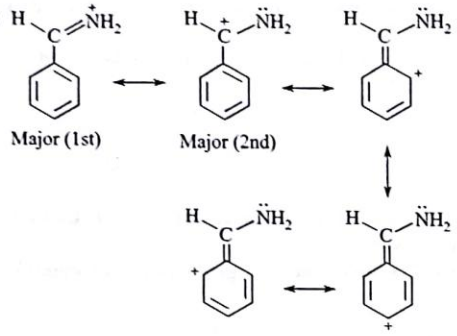
Major

(b) 

Major

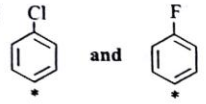
(c) 

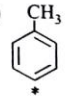
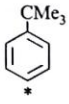
Major

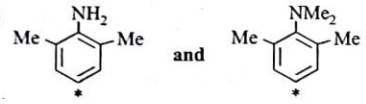
(d) 

Major (1st) Major (2nd)

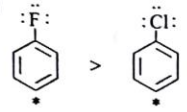
2.103 Which compound among the following pairs will have a higher electron density at the marked carbon atom?

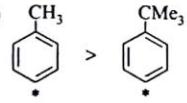
(a)  and

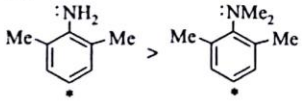
(b)  and 

(c) 

Ans

(a)  Fluorine has greater + M effect compared to chlorine

(b)  C—H hyperconjugation is more effective than C—C hyperconjugation

(c)  Steric inhibition of resonance decreases the electron density in *N*,*N*,2,6-tetramethylaniline

2.104 Arrange the following ions in decreasing order of nucleophilicity in protic and aprotic solvents.

$$Cl^{\ominus}, Br^{\ominus}, I^{\ominus}, F^{\ominus}$$

Ans In a protic solvent like water, the decreasing nucleophilicity order is $I^- > Br^- > Cl^- > F^-$. In case of an aprotic solvent, the order is reversed and is $F^- > Cl^- > Br^- > I^-$.

2.105 Write the following compounds in order of decreasing acidity, and explain the reason for the order.

(a) CH_3CO_2H **(c)** $ClCH_2CO_2H$

(b) HCO_2H **(d)** $ClCH_2CH_2CO_2H$

Ans The order of decreasing acidity is as follows:

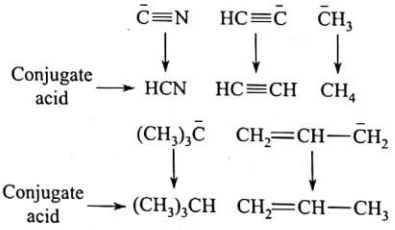
$$ClCH_2CO_2H > HCO_2H > ClCH_2CH_2CO_2H > CH_3COOH$$

In case of α-chloroacetic acid, –I effect of chlorine atom is more pronounced because of its proximity to $-CO_2H$. This is why it is more acidic than HCO_2H. Now, –I effect of chlorine atom in β-chloroacetic acid is not very important on the acidity of the compound, because it is two carbon atoms away from the CO_2H group. In case of acetic acid, +I effect decreases the acidity by electron pushing towards the $-CO_2H$ group.

2.106 Arrange the following carbanions in order of decreasing nucleophilicity.

$$\bar{C}\equiv N,\ HC\equiv\bar{C},\ \bar{C}H_3,\ (CH_3)_3\bar{C},\ CH_2=CH-\bar{C}H_2$$

Ans In these anions, the negativity resides on the carbon atom. Therefore, their nucleophilicities run parallel with their basicities. Now stronger the conjugate acid, weaker would be the corresponding base and vice versa. Therefore, let us find out the corresponding conjugate base in each case.



Now the increasing acidity order of the conjugate acids is

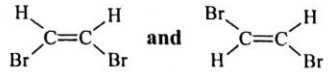
$$(CH_3)_3CH < CH_4 < CH_2=CH-CH_3 < HC\equiv CH < HCN$$

Therefore, decreasing basicity order is

$$(CH_3)_3\bar{C} > \bar{C}H_3 > CH_2=CH-\bar{C}H_2 > HC\equiv\bar{C} > \bar{C}\equiv N$$

The decreasing basicity order is also the decreasing nucleophilicity order.

2.107 Which one of the following pairs has higher boiling point and why?

(a) 

(b) $CH_3CH_2CH_2CH_3$ **and** $CH_3\underset{\displaystyle CH_3}{\underset{|}{C}}HCH_3$

Ans The explanations are as follows:

(a) Between *cis*-and *trans*-1,2-dibromoethylene, *cis* isomer has greater dipole moment and consequently, intermolecular

dipole–dipole interactions is also more. Therefore, *cis* isomer has a higher boiling point. *trans*-1,2-Dibromoethylene has zero dipole moment.

(b) Between n-butane and isobutene, n-butane has higher boiling point. The probable reason is that n-butane, being a straight-chain hydrocarbon, its molecules can come close to each other and van der Waals attractive force could operate more effectively to keep the molecules together. In the case of isobutane, it being a branched hydrocarbon, the molecules cannot come close enough and van der Waals forces of attraction are very feeble. Consequently, the molecules of isobutane remain less associated and it has a lower boiling point.

2.108 Based on HSAB theory, identify the following ions and molecules as hard and soft acids and bases.

H^+, BF_3, Pd^{2+}, CH_3COO^-, Cd^{2+}, BH_3, H^-, SCN^-, OH^-, $Pt^{4}+$, CO_3^{2-}, Cr^{3+}, NH_3

Ans Hard acids: H^+, BF_3, Cr^{3+}
Soft acids: Pd^{2+}, Cd^{2+}, BH_3, Pt^{4+}
Hard bases: CH_3COO^-, OH^-, CO_3^{2-}, NH_3
Soft bases: H^-, SCN^-

2.109 Show the direction (LHS or RHS) that you would expect the following equilibria to lie in. Give reasons.

(a) $CH_3C{\equiv}N + C_6H_5^- \rightleftharpoons CH_2C{\equiv}N^- + C_6H_6$

(b) $CH_2{=}CH_2 + OH^- \rightleftharpoons CH_2CH^- + H_2O$

(c) $OH^- + CH_3NH_2 \rightleftharpoons CH_3NH^- + H_2O$

(d) $CH_3SH + CH_3^- \rightleftharpoons CH_3S^- + CH_4$

(e) $CH_3CH_2O^- + C_6H_6COOH \rightleftharpoons CH_3CH_2OH + C_6H_5COO^-$

(f) $(C_2H_5)_2\overset{+}{N}H_2 + HCO_2^- \rightleftharpoons (C_2H_5)_2NH + HCOOH$

Ans

(a) RHS. Acetonitrile ($pK_a = 35$) is a stronger acid than benzene ($pK_a = 43$) and will, therefore, protonate the benzene conjugate base, phenyl anion.

(b) LHS. Water ($pK_a = 15.7$) is a much stronger acid than ethane ($pK_a = 36$) and will protonate the conjugate base, ethyl anion.

(c) LHS. Water ($pK_a = 15.7$) is a much stronger acid than the N–H proton of methylamine ($pK_a \sim 35$) and will, therefore, protonate the methylamide anion.

(d) RHS. Mercaptomethane (CH_3SH; $pK_a \sim 10$) is a very much stronger acid than methane ($pK_a \sim 50$) and will thus protonate the methyl anion.

(e) RHS. Benzoic acid ($pK_a = 4.2$) is a stronger acid than ethanol ($pK_a = 15.9$) and will protonate ethoxide anion.

(f) LHS. Formic acid ($pK_a = 3.75$) is a stronger acid than the diethylammonium cation ($pK_a \sim 11$), and will thus pronate diethylamine.

2.110 In the following equilibria, the right-hand side components are preferred in each equation. Explain.

$$NH_2^- + CH_3COOCH_3 \rightleftharpoons NH_3 + {}^-CH_2COOCH_3$$

$$^-CH_2COOCH_3 + CH_3COCH_3 \rightleftharpoons CH_3COOCH_3 + {}^-CH_2COCH_3$$

$$^-CH_2COCH_3 + CH_3OH \rightleftharpoons CH_3COCH_3 + CH_3O^-$$

$$CH_3O^- + CH_3NO_2 \rightleftharpoons \bar{C}H_2NO_2 + CH_3OH$$

From the aforementioned equilibria, answer the following questions.

(a) Identify which compounds are weaker acids than methanol.

(b) Identify which compounds are weaker bases than methoxide ion.

(c) Identify which compounds are weaker acids than acetone.

(d) Identify which compounds are weaker bases than acetone anion.

(e) Identify which is the strongest acid and strongest base.

Ans

(a) Methanol is able to donate a proton to acetone to acetone anion ($CH_3COCH_2^-$) and is, therefore, a stronger acid than acetone. Likewise, it is stronger acid than methyl acetate because; acetone is a stronger acid than methyl acetate and ammonia.

(b) Methoxide ion is involved in only one equilibrium which lies on the right (the last one). Thus methoxide anion is a stronger base than nitromethane anion ($^-CH_2NO_2$). All the others are stronger bases than methoxide anion.

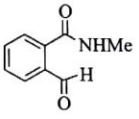
(c) From the arguments in (a) above, propanone is a stronger acid than methyl acetate and ammonia.

(d) Propanone –anion is a stronger base than methoxide anion and nitromethane anion.

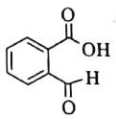
(e) The strongest acid is nitromethane. The strongest base is amide-anion (NH_2^-).

2.111 Give the nature of tautomeric forms present in the following compounds.

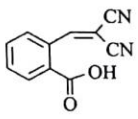
(a)



(b)

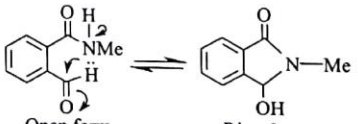


(c)



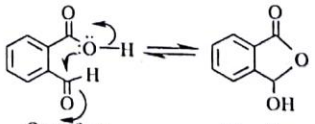
Ans All the three compounds exhibit ring-chain tautomerism. This is shown here.

(a)



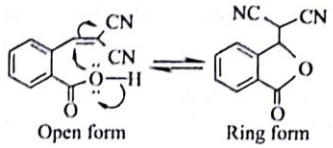
Open form Ring form

(b)



Open form Ring form

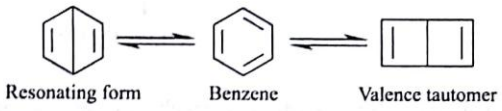
(c)



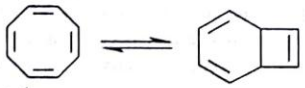
Open form Ring form

2.112 What is the common factor and what is the difference between resonance and valence tautomerism? Give your answer with suitable examples.

Ans The common factor in the case of valence tautomerism and resonance is that in both the cases electrons are shifted from one position of a molecule to another. However, in valence tautomerism, sigma framework of the molecule changes but in resonance, sigma framework remains unchanged. Valence tautomerism is exhibited by neutral molecules only but resonance can be exhibited both by neutral molecule as well as ions.



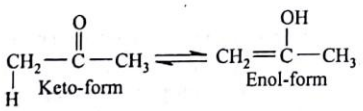
Resonating form Benzene Valence tautomer



Cyclooctatetraene Valence tautomer

2.113 In a normal case, thermodynamically, keto-form is more stable from the corresponding enol-form. Justify this statement from the bond energy calculations.

Ans This can be shown taking acetone as an example. Tautomeric forms of acetone can be shown as follows.



Keto-form Enol-form

The keto-form has a C–H, C–C, and a C=O bond, which are transformed into C=C, C–O, and O–H bond in the corresponding enol-form. The approximate total bond energy of the bonds mentioned in keto-form is 359 kcal mol^{-1} (1500 kJ mol^{-1}) and of that in enol-form is 347 kcal mol^{-1} (1452 kJ mol^{-1}). The keto-form is, therefore, thermodynamically more stable over the enol-form by ~12 kcal mol^{-1} (48 kJ mol^{-1}). Therefore, normally, transformation of a keto-form to enol-form is an endothermic process.

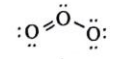
2.114 What to you mean by formal charge on an atom in a molecule or in an ion? Write down the equation that is normally used to calculate formal charge. Calculate the formal charges on O_3 and NO_2^- based on this equation.

Ans In chemistry, formal charge (FC) is the charge assigned to an atom in a molecule or in an ion, assuming that electrons in a chemical bond are shared equally between atoms, regardless of relative electronegativity. The formal charge of any atom in a molecule or in an ion is calculated using the following equation:

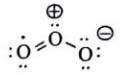
$$FC = V - N - \frac{B}{2}$$

where, V is the number of valence electrons of the atom in isolation in its ground state, N is the number of non-bonding valence electrons on this atom in the molecule or in the ion, and B is the total number of electrons shared in covalent bonds with other atoms in the molecule or in the ion. During the calculation of the formal charge, the correct Lewis structure or predominant resonance is to be considered.

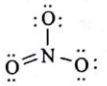
The formal charges on the oxygen atoms of O_3 molecule are as follows. The correct stable resonating structure of O_3 molecule is shown.



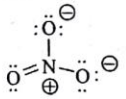
Left-hand oxygen: FC = 6 – 4 – (4 ÷ 2) = 0, centre oxygen: FC = 6 – 2 – (6 ÷ 2) = +1, and right-hand oxygen: FG = FC = 6 – 6 – (2 ÷ 2) = –1. Therefore, the formal charges on the oxygen atoms of the aforementioned structure are



The formal charges on the atoms of NO_2^- ion having a stable Lewis structure is as follows:



Nitrogen atom: FC = 5 – 2 – (6 ÷ 2) = 0; Double-bonded oxygen atom: FC = 6 – 4 – (4 ÷ 2) = 0; Single-bonded oxygen atoms: FC = 6 – 6 – (4 ÷ 2) = –1. Therefore, the formal charges on the atoms of the NO_2^- ion are as follows:



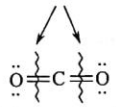
2.115 Justify with an example that formal charges on atoms of a molecule and oxidation states of the same atoms in the same molecules are different aspects.

Ans Formal charges and oxidation states of atoms of a molecule are different. The reasons for the difference between these values are that formal charges and oxidation states are different ways of looking at the distribution of electrons among the atoms in the molecule.

With formal charge, the electrons in each covalent bond are assumed to be split exactly evenly between the two atoms in the bond.

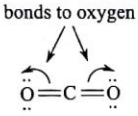
With the oxidation state formalism, the electrons in the bonds are awarded to the atom with greater electronegativity. Thus, formal charges and oxidation states of atoms of CO_2 can be shown as follows.

Formal charges: 'Split' electrons in covalent bonds evenly



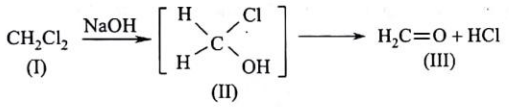
Formal charge on carbon and oxygen atoms are zero

Oxidation states: 'Award' electrons in bonds to oxygen



Oxidation state of carbon: 4 +
Oxidation state of each oxygens: 2 –

2.116 Explain why the following reaction is not a case of oxidation–reduction.

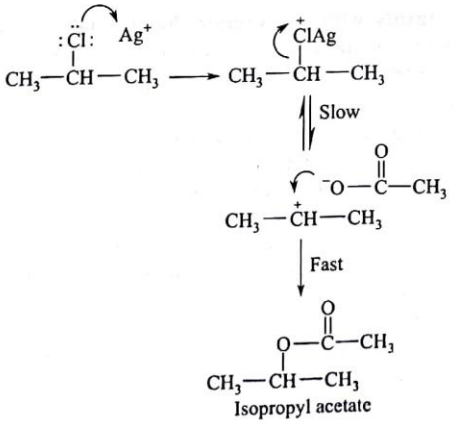


Ans In these reactions, in all the compounds, that is, (I), (II), and (III), the carbon is in zero oxidation state. Therefore, there is no change in the oxidation state of the carbon atom at any stage of the reaction. Therefore, this reaction is not a case of an oxidation–reduction reaction.

2.117 $CH_3CHClCH_3$ and $CD_3CHClCD_3$ show kinetic isotope effect during (a) substitution reaction using CH_3COOAg/CH_3COOH and (b) elimination reaction using NaOMe/DMSO. Indicate the primary/secondary nature of the kinetic isotope effect in the aforementioned reactions explaining the variation of the rate.

Ans The explanations are as follows:

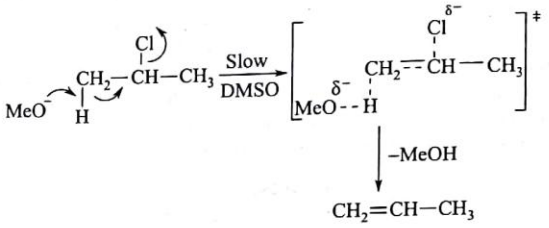
(a) Reaction with CH_3COOAg gives an ester through an S_N1 mode of substitution. The course of the reaction can be shown as follows.



Isopropyl acetate

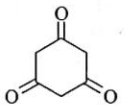
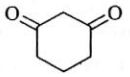
In this case, the reaction shows secondary kinetic isotope effect, because the intermediate carbocation is stabilized by hyperconjugation, involving the cleavage of C–H bond. Since C–D bond is stronger, the reaction rate slows down when deuterium replaces hydrogen atoms of $-CH_3$ groups.

(b) In the case of elimination reaction, the reaction is presumed to occur through E2 mechanism. The mechanism is shown here.

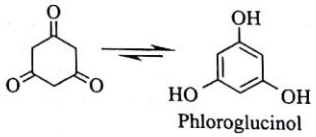


In this case also, when deuterium replaces hydrogen atoms of CH_3 group, the reaction slows down. This reaction shows primary kinetic isotope effect because isotopic replacement involves the reaction centre directly.

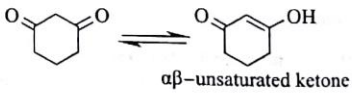
2.118 Which one of the following has higher enol content? Give reasons for your answer.

(a)  **and** **(b)** 

Ans Compound (a) has higher enol content. Through enolization, it forms a highly aromatized phenolic compound, trivially called phloroglucinol. However, the compound (b) forms a less stable αβ-unsaturated carbonyl compound through enolization.



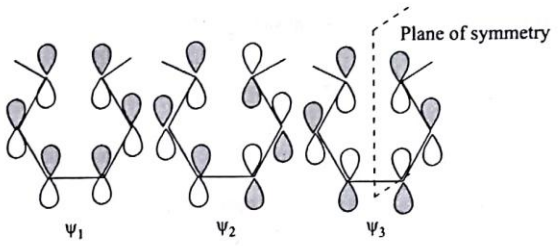
Phloroglucinol



αβ–unsaturated ketone

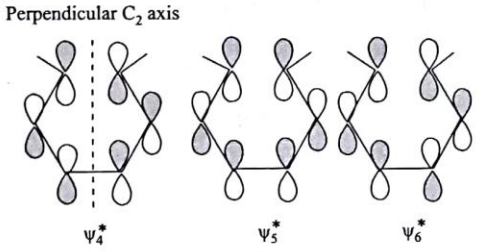
2.119 Draw the π-molecular orbitals of (2*E*,4*Z*,6*E*)-octa-2,4,6-triene. Arrange them in order of increasing energy level, designating HOMO and LUMO in the ground state.

Ans In the case of (2*E*,4*Z*,6*E*)-octa-2,4,6-triene, the bonding and anti-bonding molecular orbitals arising out of *p*-atomic orbitals are shown. The shaded and unshaded parts show different phases.



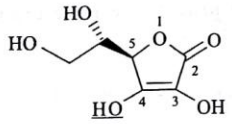
ψ_1, ψ_2, and ψ_3 are bonding π-molecular orbitals. The order of decreasing energy is $\psi_3 > \psi_2 > \psi_1$. Therefore, HOMO is ψ_3 having a plane of symmetry.

ψ_4^*, ψ_5^*, and ψ_6^* are antibonding π-molecular orbitals. The order of decreasing energy is $\psi_6^* > \psi_5^* > \psi_6^*$ Therefore, LUMO is ψ_4^* having a C_2 axis as the element of symmetry.

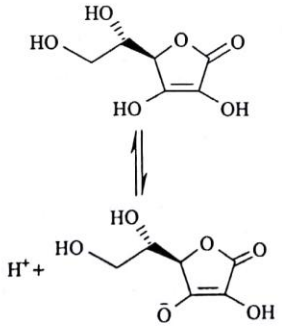


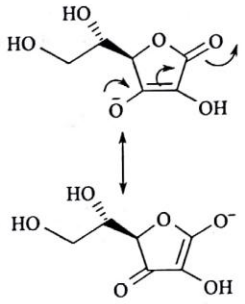
2.120 What is the structure of ascorbic acid. Comment on the acidity of the compound. What is its IUPAC name?

Ans The structure of ascorbic acid is given here.



In this case, the acidic hydrogen is with the marked 'OH' group (underlined) and this is due to vinylogous effect. The ionization leads to an alkoxy ion which is stabilized by resonance.

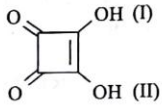




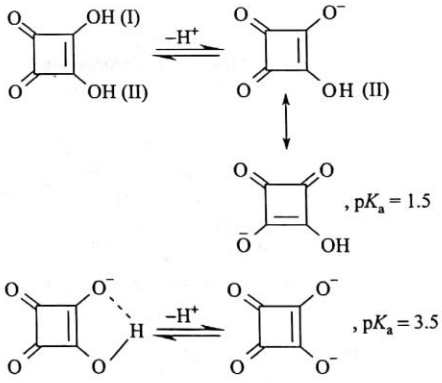
The acidity of the ascorbic acid involving the marked 'OH' group is quite strong, having a pK_a value = 4.17. The IUPAC name of the ascorbic acid is (*R*)-5((*S*)-1,2-Dihydroxyethyl)-3,4-dihydroxyfuran-2(5H)-one.

2.121 What is squaric acid. Why is it a very strong acid?

Ans The structure of squaric acid is given here.

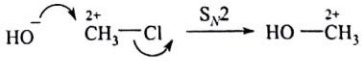


Structurally it is symmetrical. Its two acidic hydrogen atoms are associated with two OH groups identified as (I) and (II). The first ionization is found to give a more acidic hydrogen ion, because of vinylogous effect. Second ionization becomes slightly difficult because of the formation of a weak intramolecular hydrogen bonding.



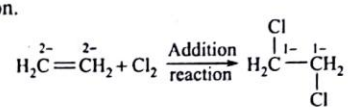
2.122 What are isohyptic and non-isohyptic reactions? Explain with reactions.

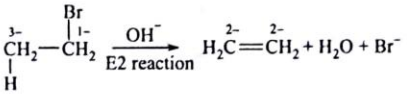
Ans Isohyptic reactions are those reactions in which there is no change in the oxidation states of the carbon atoms participating in the reactions. Substitution reactions are found to be isohyptic reactions.



In this reaction, the oxidation state of the carbon atom has not changed after the reaction. Therefore, it can be identified as an 'isohyptic reaction'.

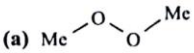
In the case of addition and elimination reactions, there are changes in the oxidation state of the carbon atoms involved in the reaction.

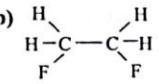




The aforementioned two reactions, namely addition and elimination, may be considered as isohyptic reactions because they involve a change in the oxidation levels of the carbon atoms involved in the reactions.

2.123 For each of the following molecules shown, hyperconjugative, rather than steric factors, dictate the geometry of the structures. Draw the most stable conformation or geometric isomer and clearly label all dominant hyperconjugative interactions, for example, σ C—C and σ*C—O.

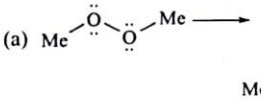
(a) 

(b) 

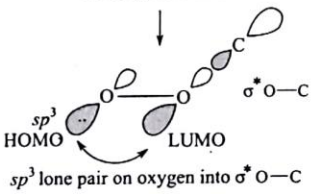
(c) 

(d) 

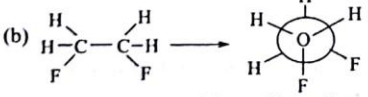
Ans

(a) 

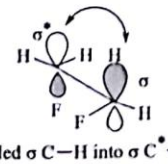
Most stable conformation due to *gauche* effect



sp^3 lone pair on oxygen into σ* O—C

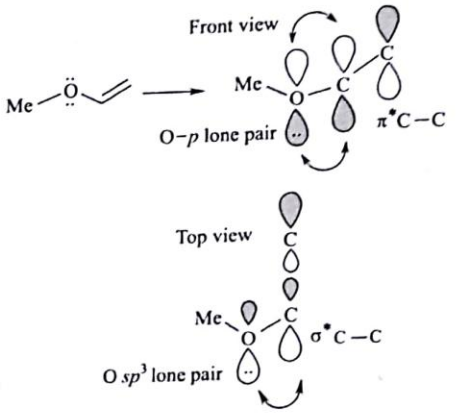
(b) 

Most stable conformation due to *gauche* effect



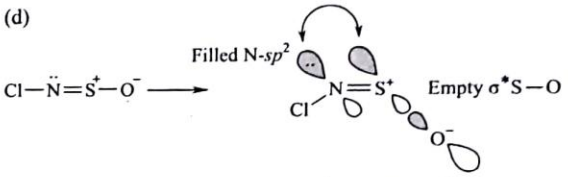
Filled σ C—H into σ C*—F
there are two such interactions

(c)



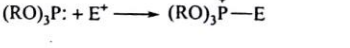
p-orbital lone pair on oxygen into π* C—C makes the molecule planar, sp^2 lone pair on oxygen into σ* C—C causes methyl and double bond to be on the same side of the central O—C bond.

(d)

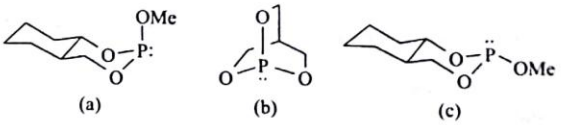


Filled N-sp^2 into empty σ*S—O
In addition, filled S-sp^2 into σ* N—Cl

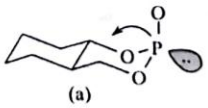
2.124 The three phosphites illustrated in this question exhibit a 750-fold span in reactivity with a test electrophile (Eq. 2.1). Rank the phosphites from the least to the most nucleophilic and provide a concise explanation for your predicted reactivity order.



(2.1)



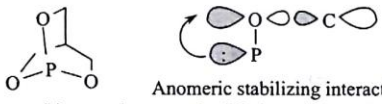
Ans



(a)

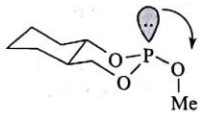
Phosphate (a) has two anomeric interactions between the filled *p*-orbital and s* C—O if the OMe substituent is directed (axial) away from the ring.

Phosphate (b) has three anomeric interactions between the filled *p*-orbital and s* C—O. This structure should be the weakest nucleophile.



(b) Anomeric stabilizing interactions between the filled *p*-orbital and σ* C—O

Phosphate (c) has one anomeric interaction between the filled *p*-orbital and the σ* C—O, if the OMe substituent is oriented in the conformation just shown. Otherwise there are no anomeric interactions.



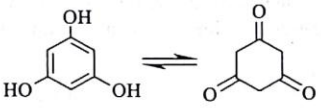
(c)

This phosphate should be the strongest nucleophile.

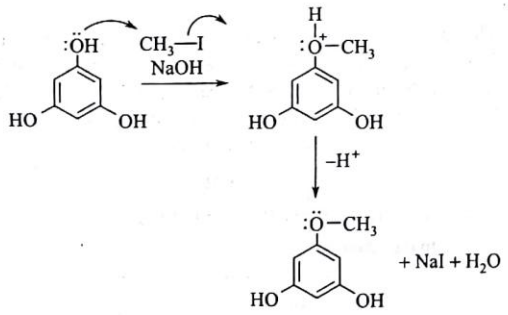
Therefore, relative reactivities of (a), (b), and (c) are found to be 125:1:750.

2.125 'Phloroglucinol can behave as an ambident nucleophile but phenol cannot.' Justify this statement with examples.

Ans Phloroglucinol can have both enolic form (phenolic structure) as well as triketo-form.

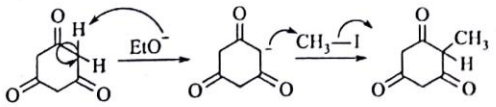


In enolic form (phenolic), phloroglucinol can react as a nucleophile through the lone pairs of electrons on oxygen atoms.



The other two –OH groups can also undergo a similar reaction.

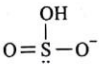
In triketo-form, phloroglucinol behaves like a β-diketone with active methylene group. The hydrogen atom from these active methylene groups can be lost as H^+ in the presence of a strong base forms a very stable carbanion. Therefore, C-alkylation is also possible, as shown here.



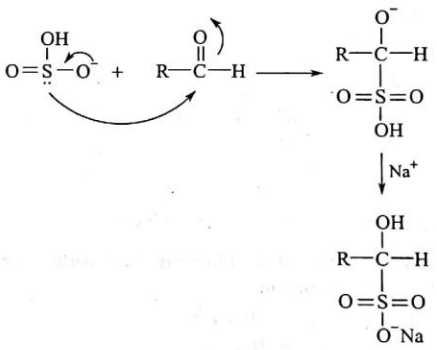
In this way, all the six active hydrogens can be substituted by alkyl group. Thus, phloroglucinol can undergo O-alkylation as well as C-alkylation through nucleophilic attack. Therefore, phloroglucinol can function as an ambident nucleophile. Keto-form of phenol is not observed because of its extreme instability.

2.126 When an aldehyde reacts with $NaHSO_3$, a bisulphite addition compound is formed. HSO_3^- is the necessary nucleophile in this reaction. Is it an ambident nucleophile? Give the reaction and structure of the product. Is HSO_4^- an ambident nucleophile?

Ans HSO_3^- is an ambident nucleophile. Its structure is shown here.



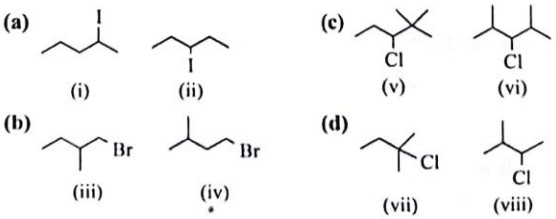
It can take part in a nucleophilic substitution reaction (S_N2) through oxygen atom as well as sulphur atom. Since the lone pair of electrons on sulphur atom is more polarizable, this lone pair of electrons takes part in the formation of sodium bisulphite addition product. The course of the reaction is shown here.



Bisulphite addition product

HSO_4^- is not an ambident nucleophile. It always attacks through oxygen atom.

2.127 For each of the following pairs of alkyl halides, indicate which member in each is more reactive in S_N2 reactions.



Ans In (a), (i) is more reactive. Compound (ii) is sterically hindered for S_N2.

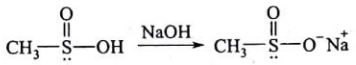
In (b), (iv) is more reactive. (iii) has got a β–branching.

In (c), (vi) is more reactive. (v) is a neopentyl-like compound.

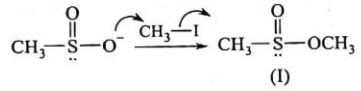
In (d), (viii) is more reactive. (vii) is a tertiary halide and therefore, reluctant to undergo S_N2 reaction.

2.128 The sodium salt of methylsulphinic acid reacts with methyl iodide in methanol to give a mixture of two isomeric products. What are the structures of these two products?

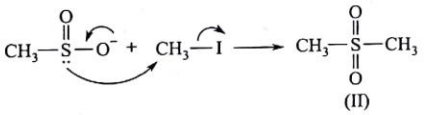
Ans Sodium salt of methylsulphinic acid is an ambident nucleophile. It can attack through oxygen atom as well as through sulphur atom. The reaction and products are shown here.



Methylsulphinic acid



(I)



(II)

(I) and (II) are the two isomeric products.

2.129 Explain whether the following substitution reactions (S_N2) will occur or not.

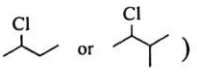
(a) $Nu^- + R{-}CN \longrightarrow Nu{-}R + CN^-$

(b) $Nu^- + R{-}N_3 \longrightarrow Nu{-}R + N_3^-$

Ans In the case of (a), CN^- is the conjugate base of a very weak (HCN) acid ($pK_a = 10$). Therefore, CN^- is a strong base and consequently is a bad leaving group. Therefore reaction (a) will not take place.

In the case of (b) N_3^- is also a conjugate base of a weak acid HN_3 ($pK_a = 5.8$). Therefore, it is also a bad leaving group and the reaction shown in the problem will not occur.

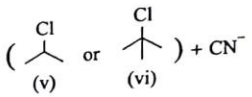
2.130 In each of the following pairs of reactions, which gives more of the elimination product?

(a) I^- + 

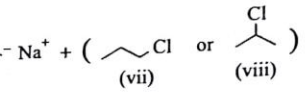
(i) (ii)

(b) $(CH_3CO_2^-$ or $CH_3CH_2O^-)$ + 

(iii) (iv)

(c) 

(v) (vi)

(d) 

(vii) (viii)

Ans In the case of (a), the compound (b) will undergo better elimination reaction because β-branching slows down S_N2 reaction.

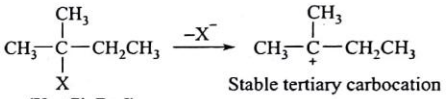
In the case of (b), ethoxide ion is a stronger base than acid anion. Therefore, (iv) would be more effective for elimination reaction.

In the case of (c), (vi), being a tertiary halide, undergoes slower S_N2 but better E2.

In the case of (d), secondary halide (viii) is slower in S_N2 but better in elimination reaction than the primary halide (vii).

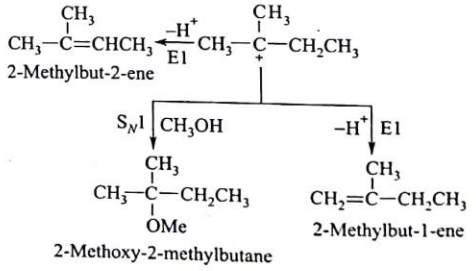
2.131 2-Bromo, 2-chloro, and 2-iodo-2-methylbutanes react at different rates with pure methanol but produce the same mixture of 2-Methoxy-2-methylbutane and alkenes as products. Explain these results in terms of the reaction mechanism.

Ans The reaction occurs through the formation of a common stable carbocation and this is why the product composition is the same.



(X = Cl, Br, I) Stable tertiary carbocation

The rates of formation of the stable carbocation from the tertiary halides is I > Br > Cl, because I^- is a better leaving group than Br^- and Br^- is a better leaving group than Cl^-. The carbocation can undergo elimination (E1) and (S_N1), as shown, to give a mixture of the same compounds.



2-Methylbut-2-ene

2-Methoxy-2-methylbutane 2-Methylbut-1-ene

2.132 For each of the following pairs of reactions, predict which one is faster and explain why.

(a) $(CH_3)_2CHCH_2Cl + \bar{N}_3 \longrightarrow (CH_3)_2CHCH_2N_3 + Cl^-$

and $(CH_3)_2CHCH_2I + N_3 \longrightarrow (CH_3)_2CHCH_2N_3 + I^-$

(b) $CH_3CH_2\underset{|}{\overset{CH_3}{C}}HCH_2Br + SH^- \longrightarrow CH_3CH_2\underset{|}{\overset{CH_3}{C}}HCH_2SH + Br^-$

and

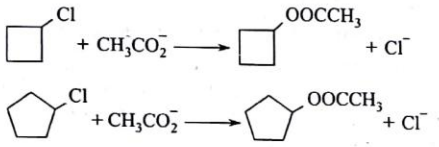
$CH_3CH_2CH_2CH_2Br + SH^- \longrightarrow CH_3CH_2CH_2CH_2SH + Br^-$

(c) $CH_3CH_2Br + CN^- \xrightarrow{CH_3OH} CH_3CH_2CN + Br^-$

and $CH_3CH_2Br + CN^- \xrightarrow{(CH_3)_2NCHO} CH_3CH_2CN + Br^-$

(d) $CH_3Br + (CH_3)_3N: \longrightarrow (CH_3)_4\overset{+}{N}Br^-$

and $CH_3Br + (CH_3)_3P: \longrightarrow (CH_3)_4\overset{+}{P}Br^-$

(e) 

Ans The explanations are as follows:

(a) $(CH_3)_2CHCH_2I$ reacts faster because I^-, being a weaker base, is a better leaving group

(b) In this case, $CH_3CH_2CH_2CH_2Br$ will react faster, because in the other case β-substitution slows down S_N2 reaction.

(c) In this case, the reaction carried out in DMF would be faster, because hydroxylic solvent CH_3OH will solvate CN^- more effectively and will reduce its effective concentration as nucleophile.

(d) In this pair of reactions, triphenylphosphine will react at a faster rate, because the lone pair on phosphorus atom is more polarizable. In general, third period atoms are more nucleophilic than their second period counterparts.

(e) In the transition state of substitution reaction, the carbon atom undergoing substitution changes hybridization from sp^3 (bond angle 109°) to sp^2 (bond angle 120°). Ring strain will oppose this change in bond angle (spreading process). In case of lower ring, the opposing process is more compared to the larger ring. Therefore, cyclobutyl chloride will react at a slower rate compared to cyclopentyl chloride.

2.133 Of the following nucleophilic substituition reactions, which of these will probably occur and which will probably not occur or be very slow? Explain your answer.

(a) $CH_3CN + I^- \longrightarrow CH_3I + CN^-$

(b) $(CH_3)_3COH + NH_2^- \longrightarrow (CH_3)_3CNH_2 + OH^-$

(c) $CH_3OSO_2OCH_3 + Cl^- \longrightarrow CH_3Cl + CH_3OSO_3^-$

(d) $CH_3CH_2I + N_3^- \longrightarrow CH_3CH_2N_3 + I^-$

Ans

(a) The reaction (a) will not occur because CN^- is a poor leaving group (conjugate base of a weak acid HCN).

(b) In the case of (b), there will be no substitution reaction because OH^- is a very poor leaving group (conjugate base of a very weak acid H_2O). However, there is a possibility of acid–base reaction in this case with the formation of an alkoxide and NH_3.

$$(CH_3)_3COH + NH_2^- \longrightarrow (CH_3)_3CO^- + NH_3$$

(c) This reaction will take place because $CH_3OSO_2^-$ is a good leaving group, being a conjugate base of a strong acid, CH_3OSO_2H, comparable to H_2SO_4.

(d) The reaction will occur. I^- is a good leaving group.

2.134 Give a specific example of two related reactions having different rates for which each of the following is the principal reason for the relative reactivity.

(a) The less basic leaving group is more reactive.

(b) A nitrogen anion is hydrogen bonded more strongly than a sulphur anion.

(c) Steric hindrance

(d) Protic solvent can form hydrogen bonds.

Ans

(a) $N_3^- + CH_3Cl \xrightarrow{Slower} CH_3N_3 + Cl^-$ ← More basic leaving group

$N_3^- + CH_3I \xrightarrow{Faster} CH_3N_3 + I^-$ ← Less basic leaving group

(b) $CH_3Br + SCN^- \xrightarrow{Protic\ solvent} \underset{(Major)}{CH_3SCN} + \underset{(Minor)}{CH_3NCS}$

$CH_3Br + SCN^- \xrightarrow{Aprotic\ solvent} \underset{(Minor)}{CH_3SCN} + \underset{(Major)}{CH_3NCS}$

(c) $CH_3CH_2CH_2I + CH_3S^- \longrightarrow CH_3CH_2CH_2SCH_3 + I^-$ (Faster)

$(CH_3)_2CHI + CH_3S^- \longrightarrow CH_3CH_2CH_2SCH_3 + I^-$ (Slower)

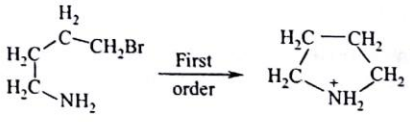
(d) $CH_3CH_2I + F^- \xrightarrow{H_2O} CH_3CH_2F + I^-$ (Very slow)

$CH_3CH_2I + F^- \xrightarrow{Acetone} CH_3CH_2F + I^-$ (Faster)

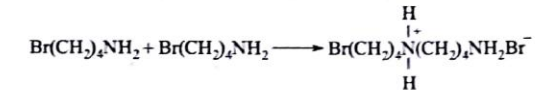
2.135 The reaction of methyl bromide with methylamine to give dimethylammonium bromide is a typical S_N2 reaction that shows a second-order kinetics.

$$CH_3Br + CH_3NH_2 \xrightarrow[order]{Second} (CH_3)_2\overset{+}{N}H_2Br^-$$

However, the analogous cyclization of 4-bromobutylamine shows first-order kinetics. Explain.



This intramolecular displacement reaction is a useful method for making cyclic amines. However, a competing side reaction is the intermolecular displacement,



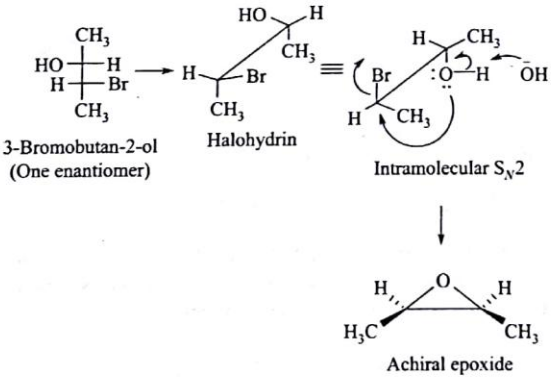
Suggest the experimental conditions to minimize this side reaction.

Ans Reaction between a primary alkyl halide and an amine is a typical S_N2 substitution reaction. In case of cyclization, the reaction must be first order and intramolecular. Therefore, its rate equation would be, rate = $k[NH_2(CH_2)_4Br]$, that is, unimolecular, k = rate constant.

Competitive reaction is intermolecular and second order. Its rate equation is rate = $k[NH_2(CH_2)_4Br]^2$. If the concentration is high, then reacting centres are closure to each other and intermolecular reaction is favoured. If the concentration is low, then the reacting centres are comparatively more close and intramolecular reaction leading to cyclic compound is more favoured. This is called high-dilution technique for the synthesis of cyclic compounds.

2.136 Optically active 3-bromobutan-2-ol is treated with KOH in methanol to obtain an optically inactive product having the formula C_4H_8O. What is the structure of this compound? Explain.

Ans The reaction amounts to formation of an epoxide (oxirane derivative) from a bromohydrin by intramolecular S_N2 reaction, being catalysed by a base. The course of the reaction is shown here.



Intramolecular S_N2 reaction takes place in that conformation where the nucleophile and the leaving group are *anti* to each other. The other enantiomer of the bromohydrin gives the same result.

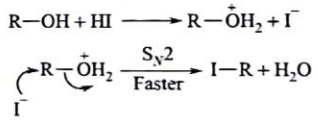
2.137 In contrast to S_N2 reactions, S_N1 reaction show relatively little nucleophilic selectivity. That is, when more than one nucleophile is present in the reaction medium, S_N1 reactions show only a slight tendency to discriminate between weak nucleophile and strong nucleophiles, whereas S_N2 reactions show a marked tendency to discriminate. (a) Provide an explanation for this behaviour. (b) Show how your answer accounts for the fact that $CH_3CH_2CH_2CCl$ reacts with 0.01M NaCN in ethanol to yield primarily $CH_3CH_2CH_2CN$, whereas under the same conditions, $(CH_3)CCl$ reacts to give primarily $(CH_3)_3COCH_2CH_3$.

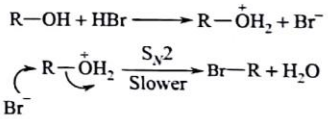
Ans The explanations are as follows:

(a) The rate equation of an S_N2 substitution is given by the following expression:

Rate = k[Substrate] [Nucleophile], k = Rate constant

Thus the reaction is second order and bimolecular. The reaction is found to be dependent on the concentration as well as nucleophilicity of the nucleophile. If the reaction medium contains two different nucleophiles differing in their nucleophilicity, then a stronger nucleophile will react preferably. Thus, when ROH is treated with a mixture of HI and HBr, the major product would be RI and not RBr. This is because I^- is a stronger nucleophile compared to Br^-.



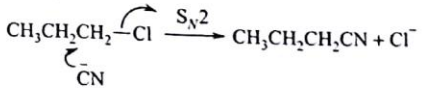


In case of S_N1 reaction, the rate equation is found to follow the expression given here.

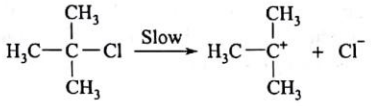
Rate = k[Substrate], k = Rate constant

Thus, the rate of S_N1 substitution is independent of the nature of the nucleophile and its concentration in the reaction medium. Therefore, S_N1 reaction is less discriminating towards nucleophiles.

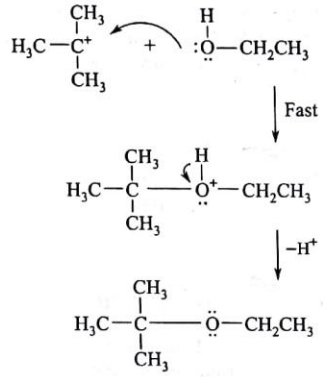
(b) In the case of a reaction between $CH_3CH_2CH_2Cl$ and NaCN in ethanol, the reaction proceeds according to S_N2 pathway. Here two nucleophilic species are CN^- and EtOH. Since CN^- is a stronger nucleophile compared to EtOH, the major product is $CH_3CH_2CH_2CN$.



On the other hand $(CH_3)CCl$ reacts by S_N1 mechanism, where the formation of the *t*-butyl cation is the rate determining step.

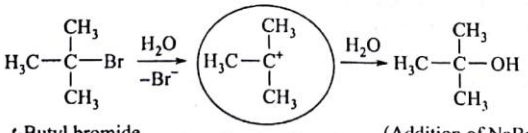


t-Butyl cation then competes for CN^- and EtOH to form a stable product. Since the concentration of EtOH (reaction medium) is larger compared to CN^-, the predominant substituted product is $(CH_3)_3COCH_2CH_3$.



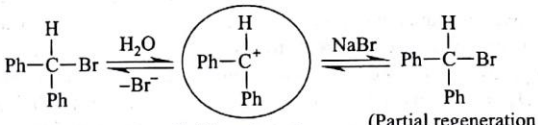
2.138 When $(CH_3)_3CBr$ undergoes S_N1 hydrolysis, adding a 'common ion' (i.e., NaBr) to the aqueous solution has no effect on the rate. On the other hand, when $(C_6H_5)_2CHBr$ undergoes S_N1 hydrolysis, addition of NaBr retards the reaction. Given that the $(C_6H_5)_2\overset{+}{C}H$ cation is known to be much more stable than $(CH_3)_3C^+$ cation, provide an explanation for the different behaviour of the two compounds.

Ans In case of S_N1 solvolysis, the stability of carbocation plays a very important role. A carbocation, during its rather short life time, is surrounded by a 'salvation cage' consisting of largely water molecules (in case of hydrolysis). Such a solvated carbocation persists until it pulls a water molecule out of its salvation cage forming a molecule of alcohol and causing the remainder of the cage to collapse, or until a halide ion pushes through the salvation cage to attack positively charged carbon. In case of relatively less stable $(CH_3)_3C^+$ carbocation with high concentration of positive charge on a carbon, the solvent cage collapses quickly and reacts with a nucleophilic solvent molecule, before an external bromide ion can attack. Therefore, the reaction is not affected by the addition of NaBr to the reaction medium.



t-Butyl bromide — Short-lived carbocation within the solvent cage — (Addition of NaBr has no effect)

As the stability, and hence the average lifetime, of the carbocation increases, halide ion (in this case bromide ion) finds a chance to react with the carbocation and the reversal of the ionization step becomes possible and the effective concentration of carbocation decreases (mass law effect). That is why addition of NaBr to the aqueous medium containing $(C_6H_5)_2CHBr$ retards the solvolysis reaction.



Stable carbocation within solvent cage — (Partial regeneration of the substrate molecule)

2.139 The order of bond lengths in the halogen hydracids is HI > HBr > HCl > HF; the order of their dipole moment is HF > HCl > HBr > HI. Offer an explanation.

Ans Dipole moment (μ) = magnitude of charge × distance between the centre of the positive and negative poles (i.e., $\mu = e \times d$). The value of 'e' is determined by the electronegativity of X (halogen atom). The order of electronegativities is F (4.0) > Cl (3.0) > Br (2.8) > I (2.5). If 'e' increases sufficiently more rapidly from I to F than 'd' decreases from HI to HF, then the product of $e \times d$ increases from HI to HF. The experimental dipole moment values of HF, HCl, HBr, and HI are 1.86, 1.05, 0.82, and 0.38D respectively.

2.140 Arrange the four halide ions in order of decreasing basicity. Explain your answer.

Ans The decreasing order of acidity of the four halogen hydracids is HI > HCl HBr > HF. It is known that stronger the acid, weaker is the corresponding conjugate base (and vice versa). Therefore, it follows that the order of decreasing basicity of the halide ions is (conjugate bases of halogen hydracids): $F^- > Cl^- > Br^- > I^-$.

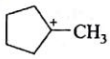
2.141 Arrange the acids with the following pK_a values in order of increasing strength: 6.3, 4.7, 9.5, –2.1, 15.8. Do the same with bases having pK_a values 8.1, 4.2, 16, 10, and 25, and order of acidity for the bases with pK_b values 7, 11.4, 9.2, 12.8.

Ans The general rules of relations of strengths of acids and bases with respect to pK_a and pK_b are (a) stronger the acid, smaller the pK_a values (and vice versa); (b) stronger the base, smaller the pK_b (and vice versa). On the basis of these, we conclude the following:

Acids, pK_a: 15.8, 9.5, 6.3, 4.7, –2.1 (strength increases from left to right)

Bases, pK_a: 4.2, 8.1, 10, 16, 25 (base strength increases from left to right); pK_b: 12.8, 11.4, 9.2, 7, 4.7 (acid strength increases from left to right).

2.142 Comment on the relative stabilities of the following carbocations.

(a)  (b) $(CH_3)_3\overset{+}{C}$ (c) $(CH_3)_2\overset{+}{C}$—Ph

Ans The increasing stability of order is (a) < (b) < (c). The carbocation (a) is partially non-planar because of the five-membered saturated ring. Consequently, hyperconjugation involving CH_2 groups of the ring would be difficult. In the case of (c), carbocation is almost planar and hyperconjugative resonance involving CH_3 groups as well as delocalization involving π-electrons of the Ph ring stabilize it considerably. (b) is stabilized by hyperconjugative resonance involving CH_3 groups. In all the cases +I effect also has some stabilizing effect but this effect is less compared to hyperconjugation and delocalization of π-electrons.

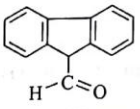
2.143 Nucleophilicity and basicity order of NH_2, H_2N—NH_2, and H_2N—OH are in reverse to each other. Explain.

Ans All the three compounds show their basicity due to the presence of lone pair of electrons on the nitrogen atom. In case of N_2H_4, basicity is partly decreased due to –I effect of the other nitrogen atom. Since oxygen atom is more electronegative than nitrogen, basicity of NH_2OH is less than that of H_2N—NH_2 Therefore, basicity order of the three compounds is $NH_3 > N_2H_4 > NH_2OH$.

In this case, nucleophilicity does not run parallel with the basicity. In both H_2N—NH_2, and H_2N—OH, nucleophilic attack by lone of electrons is enhanced by the lone pair of electrons on the adjacent atom. The phenomenon is called 'α-effect'. This effect is more pronounced in case of H_2N—NH_2 compared to H_2N—OH, because lone pair on N is more polarizable than the lone pair of electrons on O atom. Therefore, the nucleophilicity order is H_2N—NH_2 > H_2N—OH > NH_3

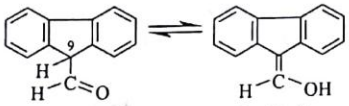
2.144 Enol-form of 9-formylfluorene is favoured in its equilibrium system. Explain.

Ans The structure of 9-formylfluorene is given here.



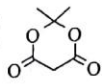
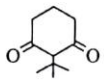
9-Formylfluorene

The hydrogen atom attached to C-9 is doubly benzylic and considerably acidic. Therefore, it enolizes readily and the planar enolic form is stabilized by delocalization involving extended conjugation.

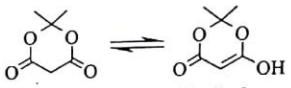


Enolic form
(Stabilized by extented conjugation with a Ph group)

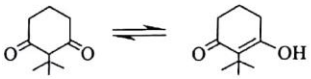
2.145 Of the following two compounds, one remains almost exclusively in the enolic form but the other as ketonic form. Identify the compounds and give reasons.

(a)  (b) 

Ans Both the compounds are β-diketones. The compound (a) can remain exclusively in enolic form because the enolic form can assume an αβ-unsaturated ketonic form. Compound (b) is reluctant to form enolic form because of the excessive strain that is developed due to the *t*-butyl group.

(a) 

Enolic form

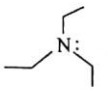
(b) 

Enolic form
(Strained molecule)

2.146 How can you separate a mixture of CH_3COOH and PhOH from an aqueous solution? Give reasons in favour of your answer.

Ans Between CH_3COOH and PhOH, the former is more acidic and consequently when a weaker base like $NaHCO_3$ is added to the mixture, CH_3COOH will make the sodium salt and remains in the solution. Unreacted PhOH can be distilled out from the reaction mixture. When the aqueous solution is acidified with a more strong acid like HCl, then free CH_3COOH is obtained. It can be distilled out or can be extracted with organic solvents such as chloroform or ether.

2.147 Quinuclidine is a better nucleophile than triethylamine. Explain.

Quinuclidine Triethylamine

Ans Quinuclidine is a rigid bicyclic bridged compound and the lone pair of electrons on the nitrogen atom is exposed for easy co-ordination with an electrophilic species. In case of triethylamine, three ethyl groups encompass the lone pair of electrons on the nitrogen atom in such a way that it fails to coordinate with an electrophilic species.

2.148 In a non-protic solvent like acetone, nucleophilicity of F^- increases in the order LiF < KF < CsF. Give an explanation.

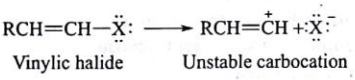
Ans In non-protic solvents, cations and anions are not solvated and consequently they almost remain as free ions. The ionic attraction is maximum in case of LiF, because Li^+ is small in size with higher charge density, and ionic attraction is minimum in case of CsF because Cs^+ has a large size with lesser charge density. That is why, in non-polar solvents, the reactivity order of F^-, as nucleophile, is CsF > KF > LiF.

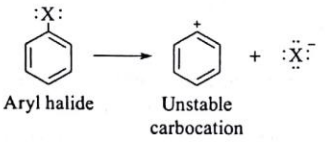
2.149 For the reaction KCN + R–X ⟶ RCN + KX, which solvent, methanol, acetone, or dimethyl sulphoxide would be more important?

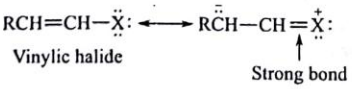
Ans The mode of reaction is S_N2 substitution. The rate equation of S_N2 substitution is as follows: Rate=k[Substrate][Nucleophile], k=rate constant. This means, the rate is dependent on the concentration of the nucleophilic species. In a protic solvent like MeOH, the nucleophilic species CN^- gets solvated due to the formation of hydrogen bonding and its effective concentration decreases. In acetone, ionization is minimum. DMSO is a polar solvent but it cannot solvate anionic species CN^- due to steric factor but at the same time the substrate molecule becomes more polarized. Consequently, rate of S_N2 substitution is accelerated considerably in DMSO [$(CH_3)_2S{=}O$)].

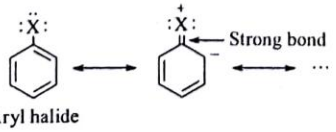
2.150 Why are vinylic and aryl halides unreactive towards both S_N1 and S_N2 reactions?

Ans Vinylic and aryl halides do not form stable carbocations through ionization; therefore, they fail to give S_N1 substitutions. On the other hand, resonance involving the lone pair of electrons on the halogen atom makes the carbon–halogen bond very strong (double bond character) and thereby appreciably increases the bond strength of C–X bond and prevents S_N2 reactions.



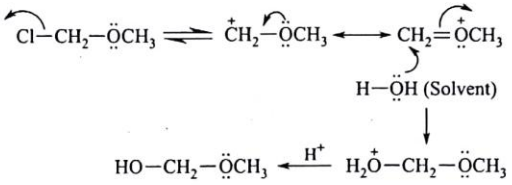






2.151 $ClCH_2OCH_3$ undergoes S_N1 solvolysis even though it is a primary halide. Explain.

Ans In this case formation of the intermediate carbocation through the heterolysis of C–Cl bond is stabilized by the delocalization of the lone pair of electrons on the oxygen atom (analogous to NGP). Thus the formation of carbocation requires less activation energy and the solvolysis reaction by S_N1 mechanism occurs smoothly.



2.152 Consider the following data for a simple displacement reaction:

$$HO^- + R{-}Br \longrightarrow R{-}OH + Br^-$$

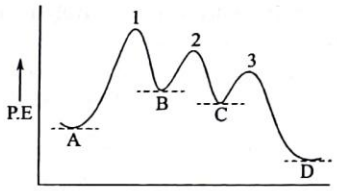
Experiment no.	Initial concentration (Moles/litre)		Relative intial reaction rate
	HO^-	RBr	
1	0.05	0.05	1
2	0.10	0.05	1
3	0.05	0.10	2

What is the mechanism of the reaction?

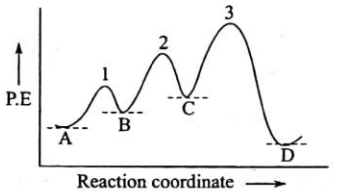
Ans In the reaction, doubling the concentration of hydroxide ion (nucleophile) does not affect the rate of the reaction. Doubling the concentration of RBr doubles the rate of the reaction. The reaction is, therefore, first order in RBr and zero order in HO^-. This fact suggests that the reaction is a case of S_N1 substitution. It occurs in two steps. The first step is the slow ionization of RBr to R^+ and Br^-. In the second step HO^- rapidly combines with the carbocation to form the product.

2.153 Draw the energy profiles for a three-step reaction in which (a) the first step is the slowest and the last step is the fastest; (b) the first step is the fastest and the last step is the slowest; (c) the second step is the slowest and the last step is the fastest.

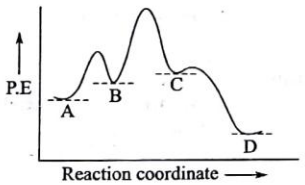
Ans The three-step reaction can be depicted as $A \xrightarrow{1} B \xrightarrow{2} C \xrightarrow{3} D$. Let us assume that the overall reaction is exothermic. The three energy profile diagrams can be written as follows. In all these energy profile diagrams, 'D' has lower energy content than 'A'. In the diagram (a), the first step is the R.D. step and the last step is the fastest (lowest activation energy). In the diagram (b), the first step is the fastest and the last step is the slowest, that is, rate determining step. In the diagram (c), the second step is the slowest and the last step is the fastest.



(a)



(b)



(c)

2.154 Consider the reaction A $\rightleftharpoons$ B.

	$\Delta Hf^{\ominus}$ kJ	$S^{\ominus}$ JK^{-1}
A	−24.27	246.4
B	−25.44	252.3

What is the composition of the equilibrium mixture at 25°C?

Ans Since this problem requires an answer to an equilibrium constant, it will be necessary to determine the value of ΔG^{θ}. Since k is positive for a negative ΔG^{θ}, the necessary equation would be $-RT\ln K = \Delta G^{\theta} = \Delta H^{\theta} - T\Delta S^{\theta}$.

Therefore, $\Delta G^{\theta} = (-25.44 + 24.27) - 298(252.3 - 246.4)\times 10^{-3}$

$$= -1.17(298\times 5.9\times 10^{-3})$$

$$= -1.17 - 1.76 = -2.93 \text{ KJ}$$

Now, $\Delta G^{\theta} = -RT\ln K = 5.7\log K$ kJ, therefore, $5.7\log K = 2.93$.

$\therefore \log K = 2.93/5.7 = 0.51$, $\therefore K = 3.24$

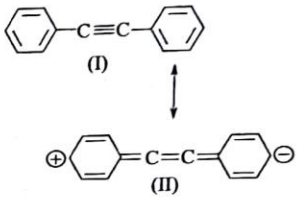
In the equilibrium, A $\rightleftharpoons$ B, $\dfrac{[B]}{[A]} = 3.24$, or for 3.24 parts B there is 1 part A.

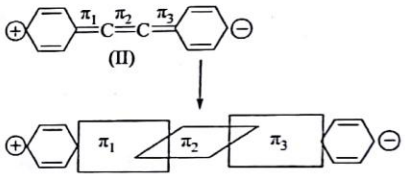
$\therefore$ % A $= \dfrac{1}{4.24}\times 100 = 23.6$ and % B $= \dfrac{3,24}{4.24}\times 100 = 76.4$

Thus in the equilibrium mixture, 23.6% A and 76.4% B will be the composition.

2.155 One of the resonating structures of diphenylacetylene is a cumulene. Identify the structure with explanation. Show the π-planes of the cumulene-type resonating structure.

Ans The required resonating structure is shown here. The structure (II) has three consecutive double bonds; therefore, it represents a cumulene with odd number of double bonds.

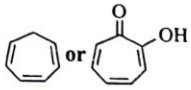




The π-planes of the structure of the consecutive double bonds are shown.

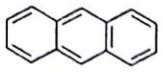
2.156 Predict which member of each of the following pairs of compounds has higher resonance energy and justify your choice.

(a) Anthracene or phenanthrene
(b) Ammonium acetate or acetamide
(c) Cyclooctatetraene or styrene
(d) Benzene or hexamethylbenzene
(e) *p*-benzoquinone or benzaldehyde
(f) Furan or thiophene
(g)

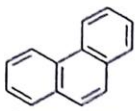


Ans It is known that the more stable a resonating structure the more would be its resonance energy and vice versa. Therefore, we will have to find out the more stable structure in each case of the compound in the aforementioned pairs of compounds.

(a) Between anthracene and phenanthrene, phenanthrene has higher resonance energy. It has got the maximum number of benzenoid rings and can have greater number of resonating structures. Structures of anthracene and phenanthrene are given here.

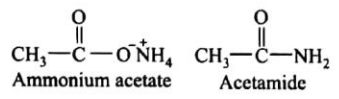


Anthracene



Phenanthrene

(b) Between ammonium acetate and acetamide, resonance is more effective in case of acetamide. In case of ammonium acetate, the negative charge on the oxygen atom of the acetate ion is not sufficiently free because of ammonium ion and, therefore, resonance is inhibited. Therefore, acetamide has higher resonance energy.

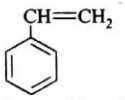


Ammonium acetate Acetamide

(c) Cyclooctatetraene almost always remains in non-planar tub-like structure with little scope for resonance. Planar structure of cyclooctatetraene is an unstable *anti*-aromatic system. Styrene is a planar molecule with an olefinic double conjugated to a phenyl ring and gives a large number of resonating structures. Therefore, styrene has higher resonance energy.

Cyclooctatetraene
(Tub-like non-planar structure)

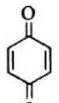
Cyclooctatetraene
(Planar, anti-aromatic structure)



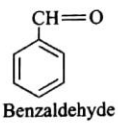
Styrene (Planar)

(d) Between benzene and hexamethylbenzene, hexamethylbenzene is more stable due to hyperconjugation. Therefore, it has higher resonance energy.

(e) *p*-Benzoquinone is a crossed-conjugated system and has no aromatic stability. Benzaldehyde is an aromatic compound with an extended conjugation. Therefore, benzaldehyde is a very stable molecule having higher resonance energy.

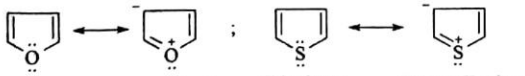


p-Benzoquinone



Benzaldehyde

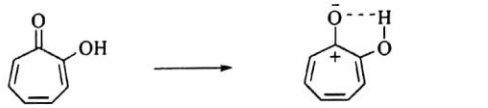
(f) Between furan and thiophene, thiophene has higher aromatic character due to greater polarizability of the electron pair on the sulphur atom. Therefore, thiophene is more stable and has higher resonance energy.



Furan (Less effective resonance) Thiophene (More effective resonance)

(g) Between cyclohepta-1,3,5-triene and 2-hydroxycyclohepta-2,4,6-trienone, the latter is more stable, because it can form a stable aromatic system by the ionization of the ketonic group followed by intramolecular hydrogen bonding. Therefore, 2-hydroxycyclohepta-2,4,6-trienone has higher resonance energy.

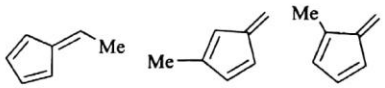
Cyclohepta-1,3,5-triene



2-Hydroxycyclohepta-2, 4,6-trienone

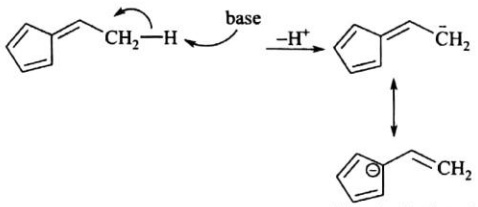
Cycloheptatrienyl cation form (Very stable due to the formation of aromatic system)

2.157 Which of the following hydrocarbons is expected to be the most acidic?



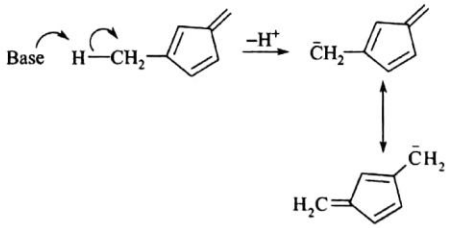
(a) (b) (c)

Ans Methyl hydrogen of compound (a) is the most acidic, because the corresponding conjugate base is a vinyl-substituted Huckel 6π-electron anion, that is, cyclopentyldienide ion.

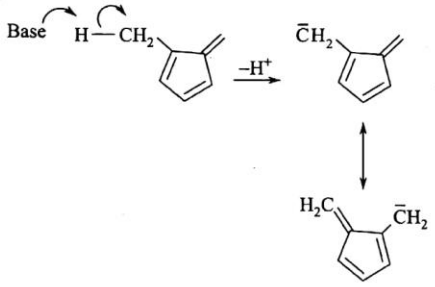


Vinyl-substituted aromatic anion

In the case of (b) and (c), the corresponding conjugate bases cannot achieve such aromatic stabilities.



Conjugate base cannot assume 6π-electron Huckel aromatic system

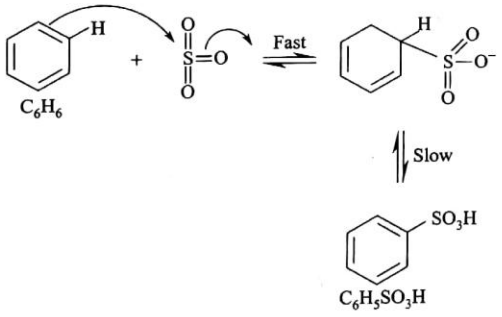


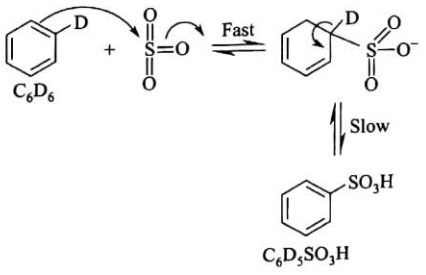
Conjugate base cannot assume 6π-electron Huckel aromatic system

2.158 Sulphonation of benzene exhibits primary kinetic isotope effect. Explain.

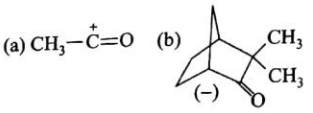
Ans Sulphonation of benzene is an electrophilic substitution involving two steps. The first step is electrophilic attack by SO_3 molecule to form a σ-complex. It then loses a proton from sp^3 carbon to give the sulphonated compound.

Study with deuterium-labelled compound (C_6D_6) shows the reaction rate slows down about four times. This confirms that sulphonation reaction exhibits primary kinetic isotope effect and the rate determining step is the loss of proton in the second step.





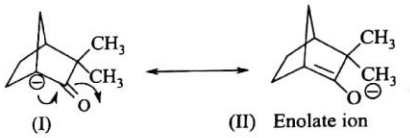
2.159 Draw the resonance structures of the following intermediates and indicate the most important contributor to the resonance hybrid in each case.



Ans For the ion (a), the resonating structures are as follows:

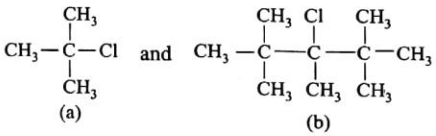
Of these two structures, (II) is more contributing because it has got maximum covalency and the octet of each of the atoms is completely filled up. Although, in this case, O bears positive charge.

For the ion (b), the resonating structures are as follows:



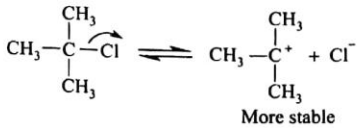
Of these two structures, (I) is a more contributing resonating structure because in (II), we need to put a double bond with the bridgehead carbon and that violates the Bredt's rule, making the system extremely strained.

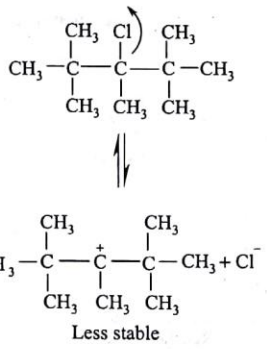
2.160 Compare with reasons, the ease of S_N1 reaction of the following compounds.



Ans Between the compounds (a) and (b), the compound (a) is more reactive towards S_N1 substitution, because it gives more stable *t*-butyl cation where nine conjugated H-atoms can take part in hyperconjugation.

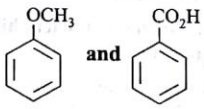
In the case of (b), the corresponding *tert*-cation is stabilized by only three hyperconjugative resonating structures. The cations are also partially stabilized by +I effect of the alkyl groups but hyperconjugative resonance is more important in this case. Hyperconjugation involved in C—C is almost negligible.



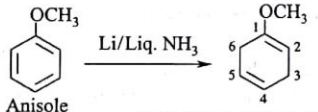


Less stable

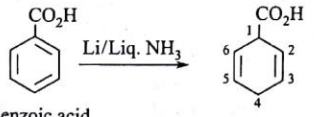
2.161 Compare, with reasons, the ease of Birch reduction (Li/liq. NH_3, C_2H_5OH) to the following compounds.



Ans Benzoic acid is more reactive towards Birch reduction compared to anisole. Birch reduction is, in fact, a nucleophilic reaction where solvated electrons are the nucleophile. Benzoic acid is more electron deficient due to –I effect of $-CO_2H$ group. Therefore, it will undergo easy nucleophilic attack.



Anisole — 1-Methoxycyclohexa-1,4-diene



Benzoic acid — Cyclohexa-2,5-dieneoic acid

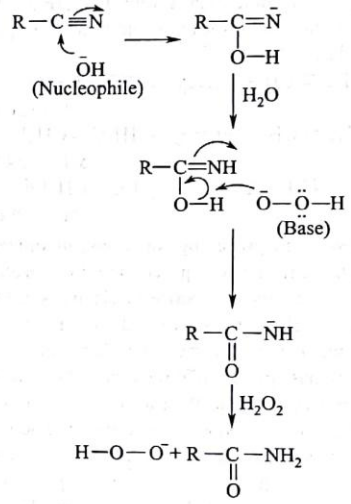
2.162 Chloride ion in $Bu_4N^+Cl^-$ in acetone is a better nucleophile than that in LiCl in the same solvent. Explain.

Ans $Bu_4N^+Cl^-$ and LiCl are both ionic compounds. In $Bu_4N^+Cl^-$, the positively charged nitrogen atom is surrounded by bulky butyl groups and the approach of the halide ion to the positively charged ion is difficult. Thus the attraction between the bulky cation Bu_4N^+ and Cl^- is much weaker compared to that in LiCl where Li^+ is a small cation with high charge density. Therefore, Cl^- ion from the quaternary salt is more free and available for nucleophilic attack and that is why $Bu_4N^+Cl^-$ is a better nucleophile than LiCl.

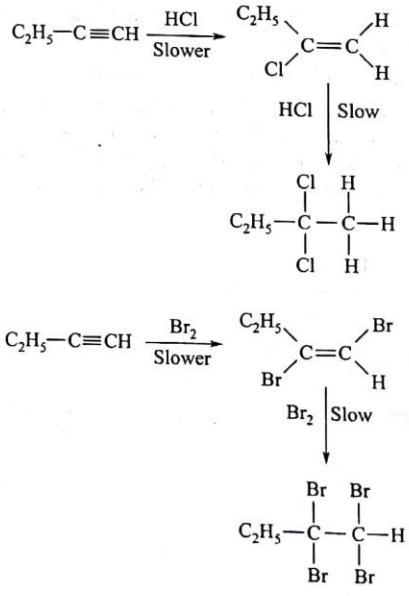
2.163 Which one is the better nucleophile of the following pair of oxy-anions: OH^- or HOO^-? Explain. Discuss the roll of these anions in the hydrolysis of RCN to $RCONH_2$ when H_2O_2 is added to the alkaline aqueous-ethanolic solution of RCN.

Ans When in a nucleophile, a lone pair of electrons exist on an adjacent atom to the atom bearing the negative charge, then the nucleophilicity of the anion is enhanced by the lone pair of electrons on the adjacent atom. This fact is called α-effect. Therefore, HOO^- is a stronger nucleophile reagent compared to OH^-.

In the hydrolysis of $R-CONH_2$ by the condition just stated, OH^- is the nucleophile because it is added before the addition of H_2O_2, and $H^-O^-O^-$ is the base in this reaction. The mechanism of the reaction can be shown as follows:



2.164 Explain why alkynes are less reactive than alkenes towards electrophilic addition reactions?



$$H-C\equiv C-H \xrightarrow[\text{Slow}]{I_2} \underset{I}{\overset{H}{\diagdown}}C=C\underset{H}{\overset{I}{\diagup}}$$

Ans First of all, addition reactions to alkynes are generally more exothermic than additions to alkenes, and there would seem to be a higher π-electron density about the triple bond (two π-bonds versus one).

Two factors are significant in explaining this apparent paradox. First, although there are more π-electrons associated with the triple bond, the *sp*-hybridized carbons exert a strong attraction for these π-electrons, which are consequently bound more tightly to the functional group than are the π-electrons of a double bond. This is seen in the ionization potentials of ethylene and acetylene.

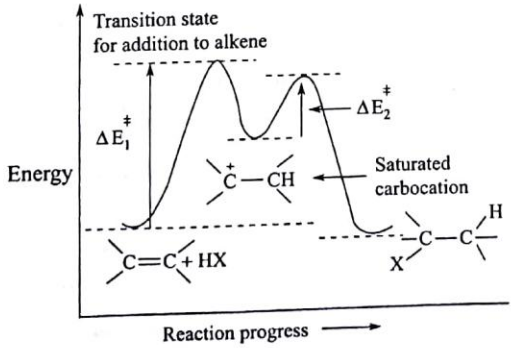
Acetylene: $HC\equiv CH + \text{Energy} \rightarrow [HC\equiv CH]^{\bullet(+)} + e^{(-)}$
$\Delta H = +264$ kcal/mole

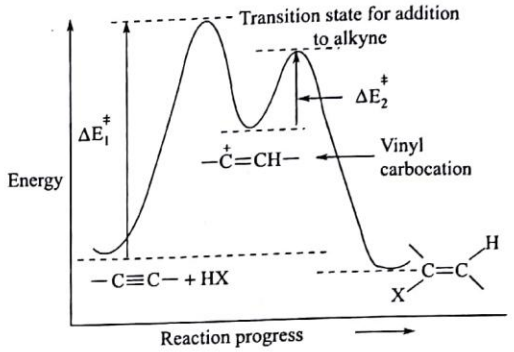
Ethylene: $H_2C=CH_2 + \text{Energy} \rightarrow [H_2C=CH_2]^{\bullet(+)} + e^{(-)}$
$\Delta H = +244$ kcal/mole

Ethane: $H_3C-CH_3 + \text{Energy} \rightarrow [H_3C-CH_3]^{\bullet(+)} + e^{(-)}$
$\Delta H = +296$ kcal/mole

As defined by the preceding equations, an ionization potential is the minimum energy required to remove an electron from a molecule of a compound. Since pi-electrons are less tightly held than sigma-electrons, we expect the ionization potentials of ethylene and acetylene to be lower than that of ethane, as is the case. Gas-phase proton affinities show the same order, with ethylene being more basic than acetylene, and ethane being less basic than either. Since the initial interaction between an electrophile and an alkene or alkyne is the formation of a pi-complex, in which the electrophile accepts electrons from and becomes weakly bonded to the multiple bond, the relatively slower reactions of alkynes becomes understandable.

The second factor is the stability of the carbocation intermediate generated by sigma-bonding of a proton or other electrophile to one of the triple bond carbon atoms. This intermediate has its positive charge localized on an unsaturated carbon, and such vinyl cations are less stable. Thus, $R\overset{+}{C}HCH$ is more stable than $R\overset{+}{C}=CH_2$. Application of the Hammond postulate then suggests that the activation energy for the generation of such an intermediate would be higher than that for a lower energy intermediate. This is illustrated by the following energy diagrams.





Comparison of energy profiles for electrophilic addition to alkenes and alkynes

2.165 Answer the following.

(a) $(CH_3)_3N$: is a stronger nucleophile than $(CF_3)_3N$: Comment on their basicities.

(b) The order of reactivity of $I^- > Br^- > Cl^- > F^-$ towards CH_3Br in water is reversed in DMF solution. Explain.

(c) Explain the effect of increase in solvent polarity on the following reactions.

(i) $R-\overset{+}{L} \xrightarrow{S_N1} R^+ + L;\quad R^+ + Nu^- \longrightarrow Nu-R$

(ii) $Nu: + R-L \xrightarrow{S_N2} \overset{+}{Nu}-R + L^-$

(iii) $Nu^- + R-\overset{+}{L} \xrightarrow{S_N2} Nu-R + L^-$

Ans The following are the explanations:

(a) Polarizability of the lone pair of electrons on the nitrogen atom decides the strength of the two compounds mentioned in the problem. Now the strong –I effects of three CF_3 groups in $(CF_3)_3N$: decrease the polarizability of the lone pair of electrons and consequently makes it a weaker nucleophile. On the other hand +I effects of CH_3 groups in $(CH_3)_3N$: increases the polarizability of the lone pair of electrons on the nitrogen and causes enhanced nucleophilicity. Since the lone pair of electrons resides on the nitrogen atom in both the cases, nucleophilicity order and basicity order run parallel. Therefore, $(CH_3)_3N$: is also a stronger base compared to $(CF_3)_3N$:.

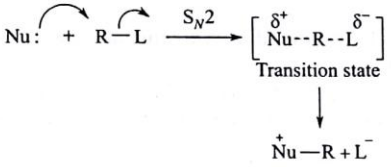
(b) In water, the reactivity order of halide ions as nucleophile towards CH_3Br is $I^- > Br^- > Cl^- > F^-$, the reaction being taken as S_N2. The reason is the increasing size of the halide ions in the order $F^- < Cl^- < Br^- < I^-$. Consequently, the decreasing order of charge density is $F^- > Cl^- > Br^- > I^-$. Water, being a polar solvent, solvates the smallest F^- ion, with high charge density, considerably through hydrogen bonding. The least solvated ion is I^-, because of its large size and least charge density. Thus, the availability and mobility of halide ions as nucleophiles make their reactivities towards CH_3Br in the order $I^- > Br^- > Cl^- > F^-$.

In the case of DMF ($HCONMe_2$), solvation is sterically inhibited because of two Me groups attached to the

positive carbon of the polar molecule. Therefore, desolvation effect on the halide ions makes F^- ion most free and turns it into the most effective nucleophile because of its high charge density and greater mobility. This is why the decreasing reactivity order of halide ions in DMF is found to be in the order $F^- > Cl^- > Br^- > I^-$.

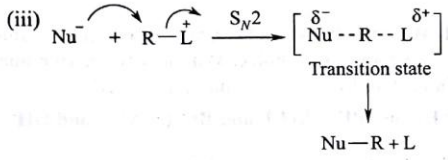
(c) Solvent effects on rates of nucleophilic substitutions on aliphatic compounds is governed by the following facts.

If the activation step is accompanied by an increase in electrical charges on the reactants in the transition state, a change to a mere solvent will cause a large increase in rate. This is the case in reaction (ii).

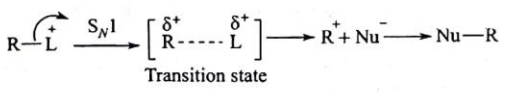


The charged transition state will be more stabilized as the polarity of the solvent is increased. Therefore, in this case a change to the higher polarity of the solvent will largely increase the rate of the reaction.

If the activation step is accompanied by a decrease in electrical charge on the reactants, a change to a more polar solvent will cause a large decrease in rate. This has been observed in the reaction of the type (iii). In this case, charges on the reactants decrease in the transition state and therefore overall rate will decrease considerably as the polarity of the solvent is increased.



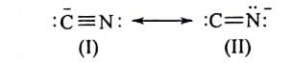
If the activation step of a reaction is accompanied by a dispersion of electrical charge, a change to a more polar solvent will cause a small decrease in the rate. This is the case with reaction (i).



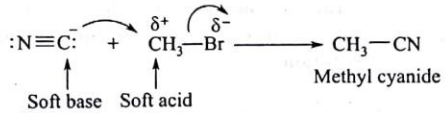
The positive charge is dispersed among the reactants in the transition state. Therefore, the transition state will not be sufficiently stabilized as reactant. Hence, increased polarity of the solvent will cause a small decrease in rate.

2.166 On the basis of the soft and hard acid base theory (SHAB), give an example of a reaction of CH_3Br with an ambident nucleophile of your choice.

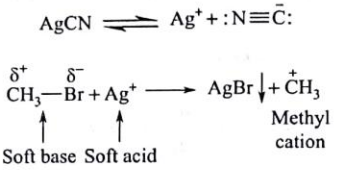
Ans CN^- is an ambident nucleophile. Its structure can be shown as follows. Structure (a) is more contributing and takes part in the reactions.



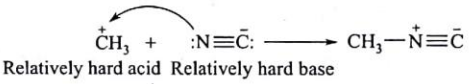
In the case of $:\bar{C} \equiv N:$ the carbon end represents a soft base and when it reacts with CH_3Br, it reacts with partially electron deficient carbon of the methyl bromide, which is a soft acid. The net result is the predominant formation of methyl cyanide.



When the reaction is carried out with AgCN, initially, a methyl cation is formed along with AgBr.



Now methyl cation is a relatively hard acid and the nitrogen end of the cyanide ion is a relatively hard base. Therefore, in this case the major reaction product is methyl isocyanide and not methyl cyanide.



2.167 The rate equation of the S_N2 reaction, $CH_3Br + OH^- \longrightarrow CH_3OH + Br^-$ is, rate = $k[CH_3Br][OH^-]$. What type of changes are expected in the rates of the reaction if (a) the concentration of each of the reactants is made double and (b) the concentration of CH_3Br is made half.

Ans In the case of S_N2 reaction, the rate of a reaction is dependent both on the concentration of the substrate molecule and the concentration of the nucleophile. The rate equation is given by the following expression.

Rate = K[Substrate][Nucleophile], where K = rate constant

(a) In the present case the rate equation should be as follows:

Rate = $K[CH_3Br][OH^-]$, where K = rate constant

When the concentrations of both the substrate and the nucleophile are doubled, we get

Rate = $K2[CH_3Br]2[OH^-]$, where K = rate constant

Rate = $4K[CH_3Br][OH^-]$; therefore rate of the reaction will be four times faster.

(b) When the concentration of CH_3Br is made half, the rate equation would be as follows:

$K[CH_3Br]1/2[OH^-] = \frac{K}{2}[CH_3Br][OH^-]$; therefore, rate will be half of the original rate.

2.168 We get the following thermodynamic parameters for the reaction.

$$CH_3CH_2CH_2CH_3 \underset{}{\overset{AlCl_3}{\rightleftharpoons}} CH_3\overset{CH_3}{\overset{|}{C}}HCH_3$$

n-Butane Isobutane

$\Delta H = -2000$ cal/mole

$\Delta S = -3.69$ cal/mole-°K

Account for the observation that at 25°C isobutane is the predominating isomer, but at 269°C both isomers are present in equal concentration. Assume one starts with 1mole/litre of *n*-butane

Ans We can calculate ΔG at 25°C and 269°C from the expression, $\Delta G = \Delta H - T\Delta S$.

$$\text{At } 25°C,\ \Delta G = -2000\frac{\text{cal}}{\text{mole}} - (298°K)\left(-3.69\frac{\text{cal}}{\text{mole} - °k}\right)$$

$$= -900\frac{\text{cal}}{\text{mole}}$$

$$\text{At } 269°C,\ \Delta G = -2000\frac{\text{cal}}{\text{mole}} - (542°K)\left(-3.69\frac{\text{cal}}{\text{mole} - °k}\right)$$

$$= 0\frac{\text{cal}}{\text{mole}}$$

At 25°C, from the relation $\Delta G = -2.303\,RT\log K_e$, K_e

$$= \frac{[\text{isobutane}]}{[n\text{–butane}]}, \text{ would be}$$

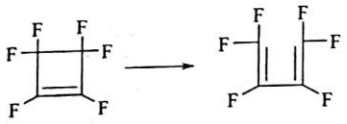
$-900 = -2.303(1.987)(298)\log K_e$, where $K_e = 33$; therefore,

$$\frac{x}{1-x} = 33$$

where, x = isobutane, and $1 - x$ = *n*-butane. Solving for x from the aforementioned equation, one finds x=0.97. Thus, 97% of the mixture is isobutene. At 269°C, $\Delta G = 0$ and therefore, $\log K_e = 0$ and $K_e = 1$. In this case, we shall get a 1:1 mixture of isobutane and butane. At a temperature higher than 269°C, *n*-butane is more stable because ΔG = positive.

If we use the equation, $\Delta G = -2.303RT\log K$, then we can calculate ΔG at 25°C and 269°C.

2.169 Will the following reaction occur at 300°C if ΔS = 9.6 and ΔH = + 11.7 kcal / mole? Why is ΔS positive?



Ans

$$\Delta G = 11.7\frac{\text{cal}}{\text{mole}} - (573°K)\left(\frac{9.6\,\text{cal}}{\text{mole} - °K}\frac{1\,\text{kcal}}{1000\,\text{cal}}\right) = 6.2\frac{\text{kcal}}{\text{mole}}$$

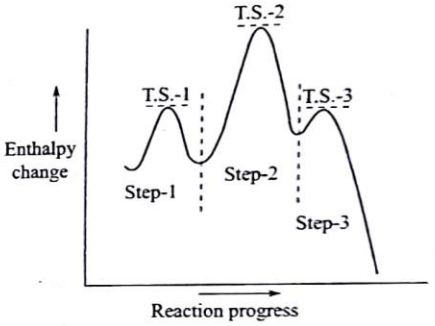
Since ΔG is positive, the reaction is thermodynamically not viable. Therefore, at 300°C, this ring opening will not occur. In this case, ΔS is positive because the rigid ring opens to form a more flexible chain.

2.170 Consider the following sequence of steps:

$$A \longrightarrow B \qquad B + C \xrightarrow{\text{Slow}} D + E \qquad E + A \longrightarrow 2F$$

(a) Which species may be described as reactant, product, and intermediate?
(b) Write the chemical reaction.
(c) Indicate the molecularity of each step.
(d) What is the rate determining step? Write the rate expression.
(e) Draw a possible reaction–enthalpy diagram.

Ans
(a) Reactants: A and C; Products: D, F; Intermediates: B, E.
(b) $2A + C \longrightarrow D + 2F$
(c) Step-1: unimolecular; step-2: bimolecular; step-3: bimolecular.
(d) Rate = k[C][A], since A is needed to make the intermediate B
(e) A possible reaction–enthalpy diagram is shown here.



2.171 Which is the stronger base in each of the following pairs? Explain your choice. Which is the better nucleophile in each of the following pairs and why?

(a) :NH_3 and :PH_3 (b) Cl^- and Br^- (c) NH_2^- and OH^-

Ans The explanations are as follows:
(a) Between :NH_3 and :PH_3, the former is a stronger base because N is smaller in size and higher in electronegativity.
(b) Between Cl^- and Br^-, Cl^- is the stronger base. Cl is smaller in size with greater electronagetivity.
(c) NH_2^- is a stronger base compared to OH^-. In NH_2^-, electron density is less dispersed than in the case of OH^-.

NH_2 is more nucleophilic because N is bigger in size and less electronegative compared to O. Between :NH_3 and :PH_3, the latter is a better nucleophile because the lone pair of electrons on P is more polarizable. P is less electronegative and bigger in size compared to N.

Br^- is a better nucleophile because the electron pair on Br^- is more polarizable as the Br atom is bigger in size and less electronegative.

2.172 If ethanol is the solvent, which reagent in each of the following pairs would be a better nucleophile and why?

(a) CH_3NH^- and CH_3NH_2 (c) I^- and Br^-
(b) NH_2^- and $NH_2{-}NH^-$ (d) PhO^- and $PhCH_2O^-$

Ans The following is an explanation:

(a) CH_3NH^- is a better nucleophile than CH_3NH_2. Here the negatively charged species requires less activation energy to react with an electron deficient centre.

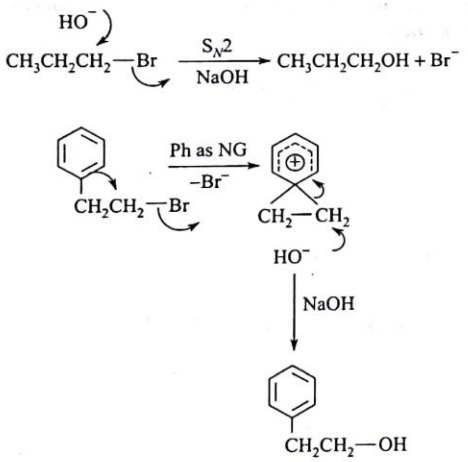
(b) $NH_2—NH^-$ is a better nucleophile than NH_2^- due to α-effect.

(c) I^- is a stronger nucleophile compared to Br^-. Because of the large size and lesser electronegativity of I, electron pair on I^- is more polarizable and hence more nucleophilic.

(d) $PhCH_2O^-$ is a better nucleophile compared to PhO^-. In case of phenoxide ion, resonance (+M effect) decreases the electron density on the oxygen atom. This is not possible in case of $PhCH_2O^-$

2.173 Define 'anchimeric assistance' with suitable examples.

Ans When in a bimolecular nucleophilic substitution reaction involving the participation of a neighbouring group, the rate of the reaction is enhanced by the participation of the neighbouring group then that phenomenon is called 'anchimeric assistance'. For example, when $CH_3CH_2CH_2Br$ and $PhCH_2CH_2Br$ are separately treated with NaOH, rate of substitution of Br by —OH group is much faster than that in $CH_3CH_2CH_2Br$.



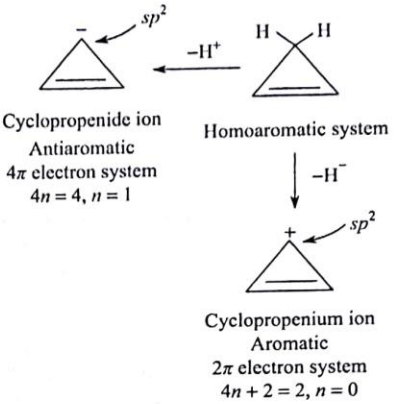
Conversion of $PhCH_2CH_2Br$ to $PhCH_2CH_2OH$ is much faster than in the case of $CH_3CH_2CH_2Br$ to $CH_3CH_2CH_2OH$.

2.174 Convert cyclopropene to an aromatic and antiaromatic system.

Ans When a cyclic conjugated planar system contains $(4n+2)$ π-electrons where $n = 0, 1, 2, 3, ...$, it exhibits so-called aromatic character. On the other hand, a cyclic conjugated planar system containing $4n\pi$-electrons where $n=1, 2, 3, ...$, represents antiaromatic character.

When cyclopropene loses an H^- ion, cyclopropenium ion is formed which is aromatic because it contains 2π electrons in a planar cyclic system where the value of $n=0$.

On the other hand, when cyclopropene loses a proton, H^+, cyclopropenide ion is obtained. It is also a planar system with 4π electrons. Therefore, it represents an antiaromatic system.



2.175 What do you mean by antiaromaticity? Give examples. Define them in terms of Huckel's rule.

Ans The term aromaticity implies some extra stability of a compound with respect to some apparently similar aliphatic, alicylic, or heterocyclic compound. The term antiaromaticity, on the other hand, indicates that a compound is less stable than a similar type of compound. For example, benzene, being an aromatic compound, is more stable than the isomeric hexa-2,4-diyne or bicyclo[2.2.0]hexane.

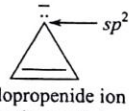
On the other hand, cyclopropenenide ion is less stable than cyclopropene itself. Therefore, the former one is considered to be antiaromatic with respect to cyclopropene. The carbon bearing the negative charge must be sp^2 hybridized to exhibit antiaromatic character. However, cyclopropenium ion is more stable than cyclopropene. Therefore, cyclopropenium ion is aromatic.

According to Huckel's rule, cyclic, planar systems with $4n$ number of electrons (n=positive integer) are considered to be antiaromatic.

Benzene
(Aromatic)

$CH_3—C\equiv C—C\equiv C—CH_3$
Hexa-2,4-diyne
(Not aromatic)

Bicyclo[2.2.0]hexane
(Not aromatic)



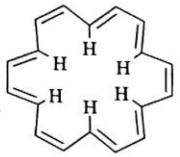
Cyclopropenide ion
(Antiaromatic)

Cyclobuta-1,3-diene

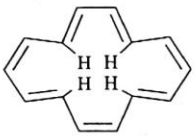
Cycloocta-1,3,5,7-tetraene (Planar)
(Antiaromatic)

2.176 Why is [18]annulene more stable than [14]annulene?

Ans The structures of [18]annulene and [14]annulene are given here.



[18]Annulene



[14]Annulene

Both [18]annulene and [14]annulene are aromatic in the sense that both of them satisfy the so called Huckel's rule for exhibiting aromatic character. However, because of a greater number of carbon atoms in the [18]annulene ring system, interannular space is more and as a result of which interannular steric interactions of hydrogen atoms is minimum and the system can assume almost complete planarity, showing greater aromatic character. In case of [14]annulene, interannular steric interactions of hydrogen atoms is large and the system assumes some non-planarity. This inhibits delocalization of the π-electron system and reduce aromatic character.

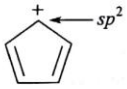
2.177 Explain the following facts.

(a) Cyclopentadiene is non-aromatic.
(b) Cyclopentadienyl cation is antiaromatic.
(c) Cyclopentadianide ion is aromatic.
(d) Cycloheptatriene is homoaromatic.

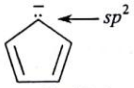
Ans The following are the explanations:

(a) Cyclopentadiene is a non-planar cyclic molecule with $4n$ number of π-electrons where $n=1$. That is why it represents a non-aromatic system according to Huckel.
(b) Cyclopentadienyl cation is antiaromatic because it is a cyclic planar system with $(4n+2)$ number of π-electrons where the value of $n=0$.
(c) Cyclopentadienide ion is aromatic according to Huckel's rule. It is a cyclic planar system with $(4n+2)$ number of π-electrons, where $n=1$.
(d) Cycloheptatriene is homoaromatic. It is a cyclic planar molecule with $(4n+2)$ number of π-electrons, where $n=1$.

Cyclopentadiene



Cyclopentadienyl ion



Cyclopentadienide ion

2.178 Give example of molecules or ions which corroborate the following facts.

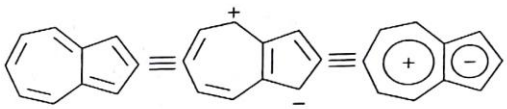
(a) A molecule with $4n$ π-electrons and antiaromatic ($n=1$, 2, 3, ...)
(b) A dianion system having aromatic character
(c) A non-benzenoid bicyclic hydrocarbon having aromatic characcter in ionic form.

Ans The example are as follows:

(a) Cyclobuta-1,3-diene is an antiaromatic molecule with $4n$ number of π-electrons, where $n=1$.
(b) Cycloocta-1,3,5,7-tetraenyl dianion is aromatic. It contains 10 π-electrons with cyclic planar structure.
(c) Azulene is a bicyclic non-benzenoid hydrocarbon which exhibits aromatic character in its bipolar ionic form.

Cyclobuta-1,3-diene

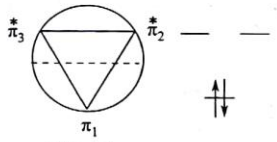
Cycloocta-1,3,5,7-tetraenyl dianion



Azulene

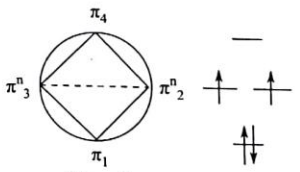
2.179 Cyclic unsaturated compounds A, B, C, D, E, and F have the following Frost–Musulin M.O picture for their π-orbitals. Identify them as aromatic, antiaromatic, or non-aromatic.

(a)



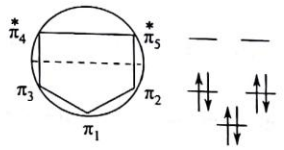
(Planar)

(b)

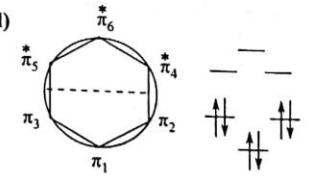


(Planar)

(c)

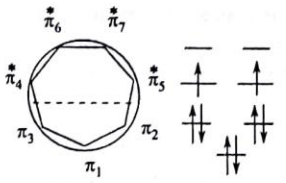


(d)



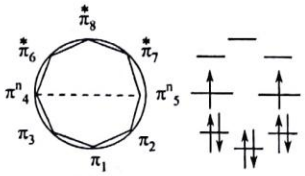
(Planar)

(e)



(Planar)

(f)



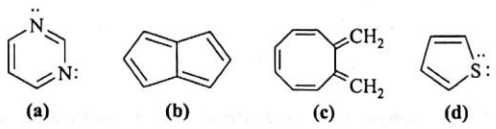
(Planar)

Ans According to the Frost–Musulin diagram,

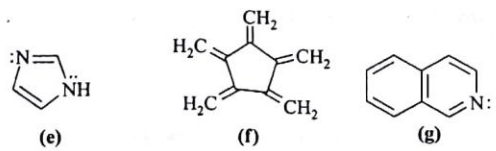
- if all the bonding M.O.'s are fully occupied and the molecule/ion is planar then the compound is aromatic;
- if all the bonding M.O.'s and non-bonding M.O.'s (if available) are fully occupied and the molecule/ion is planar then the compound is aromatic;
- a planar molecule/ion is antiaromatic if (i) antibonding M,O.'s also contain electrons along with electrons in bonding M.O.'s, (ii) bonding M.O.'s are fully occupied and non-bonding M.O.'s are half-filled;
- a non-planar molecule/ion is designated as non-aromatic if bonding M.O.'s are occupied but non-bonding M.O.'s are half-filled; and
- a non-planar molecule/ion is designated as homoaromatic if bonding M.O.'s are occupied but non-bonding M.O.'s (if available) and anti-bonding M.O.'s are empty.

On the basis of these observations, the diagram (a) represents planar cyclopropenium ion and is aromatic, the diagram (b) represents planar cyclobutadiene and is antiaromatic, the diagram (c) represents planar cyclopentadienyl anion and is aromatic, the diagram (d) represents planar cyclohexatriene and is aromatic, the diagram (e) represents cycloheptatrienyl anion and antiaromatic when planar, the diagram (f) represents planar cyclooctatetraene and is antiaromatic.

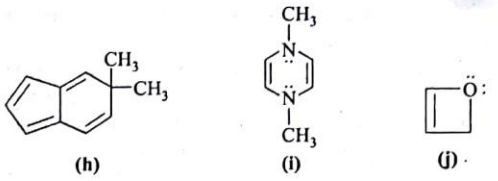
2.180 Identify the aromatic systems among the following structures based on Huckel's rule.



(a) (b) (c) (d)



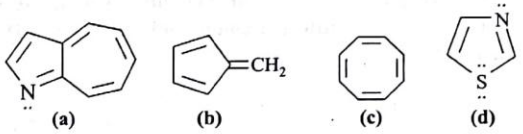
(e) (f) (g)



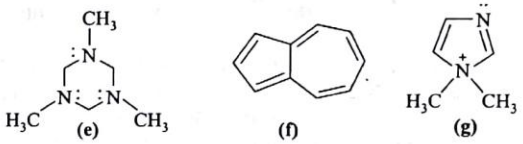
(h) (i) (j)

Ans Among the structures shown, (a), (d), (e), and (g) are aromatic according to Huckel's rule.

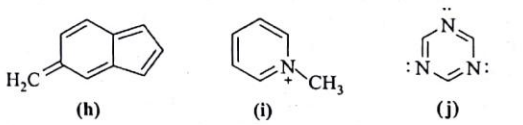
2.181 Identify the aromatic systems among the following structures based on Huckel's rule.



(a) (b) (c) (d)



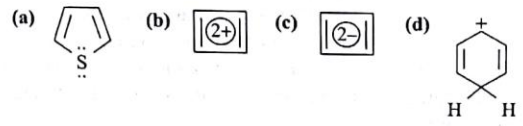
(e) (f) (g)



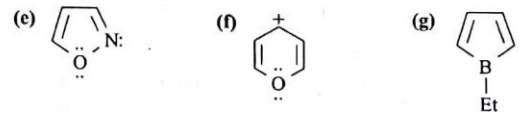
(h) (i) (j)

Ans Among the structures shown, the structures (a), (d), (f), (i), and (j) are aromatic systems according to Huckel's rule.

2.182 Which of the following species should be aromatic by the Huckel's $4n + 2$ rule?



(a) (b) (c) (d)



(e) (f) (g)

Ans The aromatic systems among the structures shown here are (a), (b), (c), (d), and (f). The compound (a) is called thiophene. It is a planar system with six π-electrons. Sp^2 hybridized sulphur atom provides two π-electrons.

The ions (b) and (c) are both aromatic systems. The dication (b) is a planar cyclic system with two π-electrons ($n=0$ for Huckel's $4n+2$ rule).

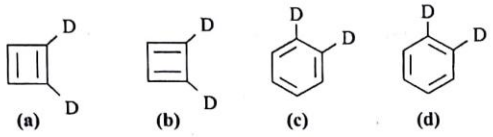
The dianion (c) represents a planar cyclic system with six π-electrons ($n=1$ for Huckel's $4n+2$ rule).

The compound (e) is called isoxazole and is a planar system with six π-electrons. Sp^2 hybridized oxygen atom provides two π-electrons. Lone pair on the nitrogen atom is not involved in the formation of aromatic sextet.

Ion (f) exhibits aromatic character where sp^2 hybridized oxygen atom provides two p-electrons. It obeys Huckel's rule where $n = 1$.

The structures (d), and (g) do not represent aromatic systems because they do not obey Huckel's condition for aromaticity.

2.183 Using the theory of aromaticity, explain the fact that A and B are different compounds, but C and D are identical?



Ans According to the condition of aromaticity, the contributing structures should not differ in σ-framework. Now in case of compounds A and B, they differ in σ-framework and antiaromatic system and one cannot be transformed into another by delocalization of π-bonds. Two deuterium atoms are differently attached to the cyclobutadiene systems. Both A and B represent antiaromatic systems but are not the same compounds.

The compounds C and D represent aromatic systems and are interconvertible by delocalization. Therefore, they represent the same compound.

2.184 Cyclooctatetraene (COT) is more stable in tub-like structure compared to planar structure. Give reasons.

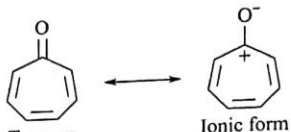
Ans According to the Huckel's rule, a planar cyclic conjugated system with $4n$ π-electrons ($n=1, 2, 3, ...$) would be antiaromatic in properties and becomes destabilized. However, the same system is considered to be non-aromaic and more stable compared to antiaromatic system. Therefore, cyclooctatetraene tries to switch over to a tub-like structure to gain more stability.

Cyclooctatetraene (Planar form) 8π-electron system Antiaromatic

Tub-like structure (Non-planar form) 8π-electron system Non-aromatic

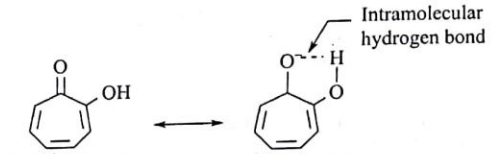
2.185 Between tropone and 2-hydroxytropone, the latter is found to be more stable. Offer an explanation.

Ans Tropone exhibits aromatic character in its charged structure. If that charged structure can become stabilized by some factor then the stability is further enhanced. In the case of 2-hydroxytropone, intramolecular hydrogen bonding stabilizes the aromatic system of bipolar character. The structures of tropone and 2-hydroxytropone are given here.



Tropone

Ionic form more stable due to the formation of a trotylium ion system



2-Hydroxytropone 2-Hydroxytropone

2.186 Give examples of so called pseudoaromatic compounds. Why are they so called?

Ans This term is used to identify certain highly unstable cyclic conjugated hydrocarbons possessing two or more rings. This nomenclature is not widely used in recent literature. Examples of pseudoaromatic molecules are pentalene and heptalene. Although both of these ring systems can be written in two equivalent neutral resonance structures, neither resonance structure can be written with a central double bond and consequently both the rings possess $4n$ number of π-electrons ($n=1, 2, 3, ...$). These compounds then resemble a cyclic conjugated polyene and presumably that accounts for their instability.

Pentalene Pentalene

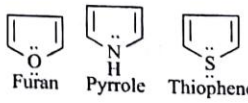
(Pseudoaromatic system)

Heptalene Heptalene

(Pseudoaromatic system)

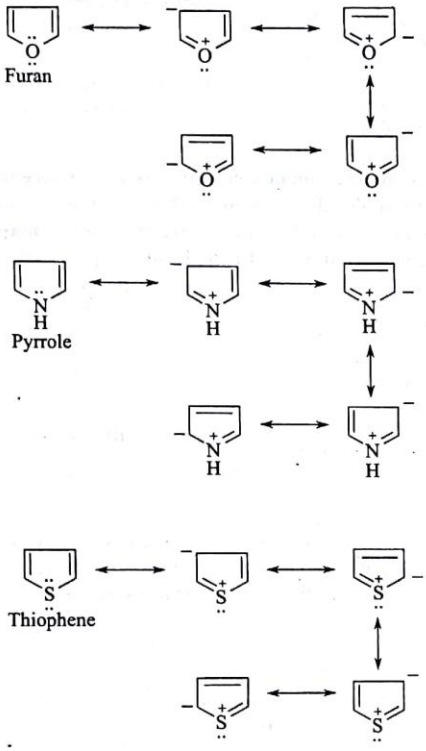
2.187 Compare the aromatic characters of furan, pyrrole, and thiophene.

Ans The structures of furan, pyrrole, and thiophene are given here.



Furan Pyrrole Thiophene

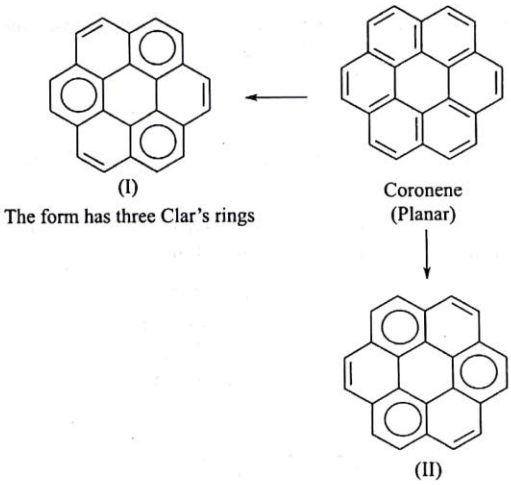
In all the three compounds, hetero atoms are sp^2 hybridized and in each case contain a lone pair of electrons in a *p*-orbital. These compounds exhibit aromatic character obeying Huckel's 6π electron cyclic system. Each of them can be represented by a set of resonating structures as shown here.



Mesomeric effect (+M) involving the lone pair of electrons on the hetero atom is mostly responsible for their aromatic character. Decreasing polarizability order of the lone pair of electrons on the hetero atom is S > N > O. Therefore, the decreasing order of aromatic character of these heterocycles is thiophene > pyrrole > furan.

2.188 Coronene has the following structure containing 24 π-electrons. Yet it exhibits strong aromatic character. Offer an explanation.

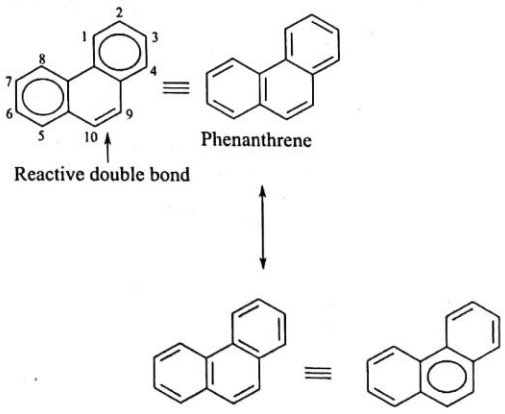
Ans Huckel'rule applies only to monocyclic systems. It cannot be applied to the polycyclic aromatic hydrocarbon, commonly called PAH. Therefore, a PAH does not necessarily obey the Huckel's so called $4n+2=\pi$-electrons ($n=0$ to any positive integer). Coronene has got the following planar structure, where six benzene units are fused. PAHs clearly are aromatic compounds, the degree of aromaticity can be different for each ring segment. According to Clar's rule (formulated by Erich Clar in 1964) for PAHs the resonance structure with the most disjoint aromatic π-sextets, that is, benzene-like moieties are the most important for the characterization of the properties. When the Clar's rule is applied to coronene, we get the following structure.



It is evident from the diagram that each individual ring of coronene can assume Clar's structure obeying Huckel's rule. This is the reason why coronene exhibits aromatic character inspite of the presence of 24 π-electrons.

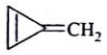
2.189 Based on Clar's method, show that the outer rings of phenanthrene are the most aromatic in nature and hence find out the most reactive centres of phenanthrene.

Ans According to Clar's method of determining aromatic character of an individual ring in a polycyclic aromatic hydrocarbon phenanthrene, in one structure two outer rings can individually satisfy Huckel's $4n+2=\pi$-electrons. However, in another resonating form, only the middle ring can do so. Therefore, the former structure is more stable and outer rings are more stable and less reactive compared to the inner ring.

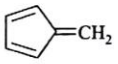


2.190 The directions of dipole moments of 3-methylenecycloprop-1-ene and 5-methylenecyclopenta-1,3-diene are opposite to each other. Offer an explanation.

Ans The structures of 3-methylenecycloprop-1-ene and 5-methylenecyclopenta-1,3-diene are shown here.



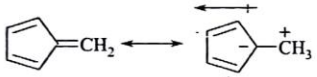
3-Methylenecycloprop-1-ene



5-Methylenecyclopenta-1,3-diene (Fulvene)

Both the structures are found to be polar in nature because in polar forms they exhibit aromatic stability.

(Aromatic) Cylopropenium ion



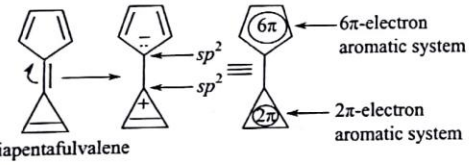
(Aromatic) Cyclopentadienide ion

2.191 Draw the structures of (a) triapentafulvalene, (b) triafulvalene and (c) pentaheptafulvalene. Which of these have stable polar structures and why?

Ans The structures of the compounds are given here.

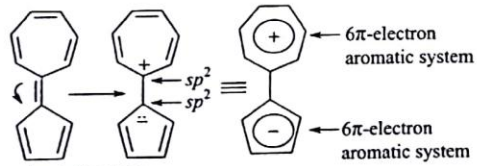
Triafulvalene Triapentafulvalene Pentaheptafulvalene

Of the three compounds, triapentafulvalene and pentaheptafulvalene exhibit aromatic stability in their polar structures.



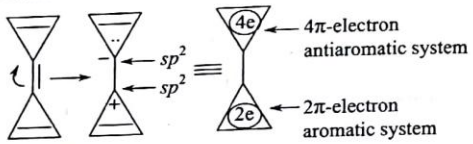
Triapentafulvalene

Similarly, pentaheptafulvalene can become stabilized by delocalization of π-electrons resulting in the formation of a combination of aromatic ions.



Pentaheptafulvalene

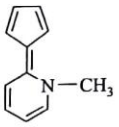
Triafulvalene is not a stable molecule and neither it nor any of its derivatives have been prepared. Delocalization of the π-bond causes a combination of a cyclopropenium ion (aromatic) and cyclopropenide ion (antiaromatic). Thus the combination is a non-existence system.



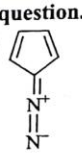
Triafulvalene

2.192 A single resonance structure is shown here for each of several molecules. Consider other resonance structures. Comment on those that would expect to make major stabilizing contributions to the molecule in question.

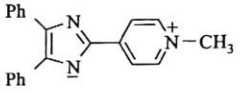
(a)



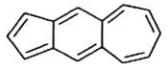
(c)



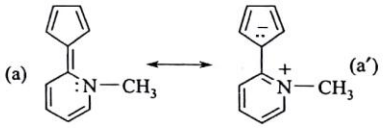
(b)



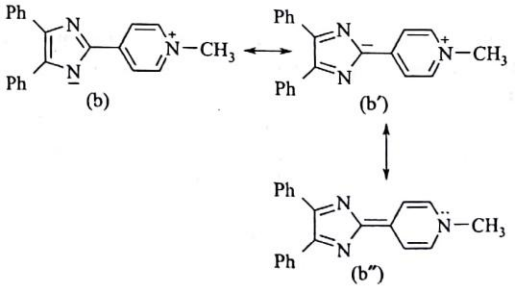
(d)



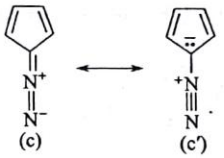
Ans The following resonating structure has a major contribution, because it is a combination of cyclopropadiene anion and pyridinium ions. Both are aromatic rings according to Huckel's rule.



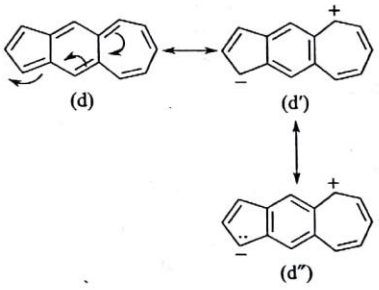
In the case of (b), two major contributing structures are shown. Of these two (b) is more contributing, because both the rings of the structure can assume aromatic stabilities according to Huckel's rule and the negative charge resides on the more electronegative nitrogen atom.



In the case of the compound (c), the major contributing resonating structure would be (c′), because it has one aromatic ring, that is, cyclopenta-1,3-dienyl cation and a less strained molecule.

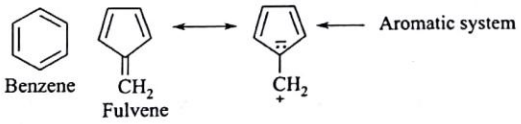


The compound (d) can have two major contributing resonating structures where delocalization of π-electrons can result in the formation of an aromatic ring system. Major contributing structures are given here. Both (d′) and (d″) have two rings showing aromatic stability individually.



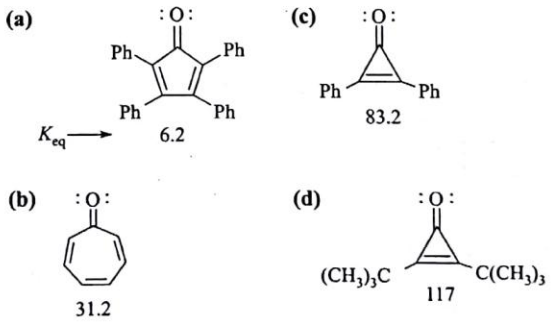
2.193 Two compounds have the same molecular formula, C_6H_6. Both of them show aromatic character, but one in neutral form and the other in polar form. Identify the compounds and give reasons.

Ans The two compounds are benzene and fulvene. Fulvene exhibits aromatic character in its polar form.

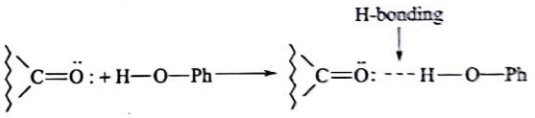


Fulvene has a dipole moment value of only 0.42D, showing that polar structure has some contribution but not very much.

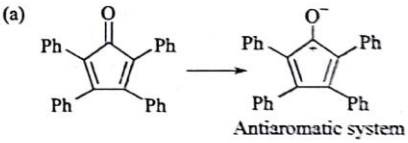
2.194 The relative basicity of the carbonyl oxygen atoms can be measured by studying the strength of hydrogen bonding between the carbonyl compound and a hydrogen donor like phenol. In carbon tetrachloride, values of K_{eq} for 1:1 complex formation for the compounds shown have been measured. Rationalise the observed order of basicity.

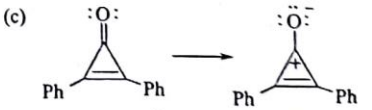


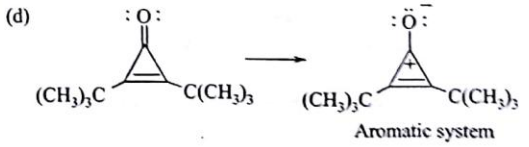
Ans The hydrogen bond mentioned can be depicted as follows:



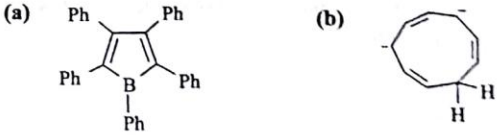
If the electron density on the oxygen atom is enhanced, the hydrogen bond would be stronger and the value of K_{eq} would be higher. Among the molecules shown, electromerization of the C=O bond in (b), (c), and (d) generates ions having aromatic stability. Similar electromerization in (a) produces an antiaromatic system. Therefore, (a) is the least basic. The compound (b), called tropone, exhibits aromatic stability due to the formation of cyclohepatrienyl cation moiety called tropylium ion. Therefore, its basicity increases. The compound (c) forms cyclopropenium ion which is further stabilized by two phenyl rings. However, the stability of cyclopropenium ion is partly opposed by the resonance involving the double bond of the cyclopropene ring and the benzene rings. In case of (d), the resultant cyclopropenium ion is most stable because there are no other factors to oppose electromerization.

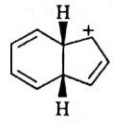


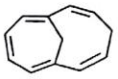


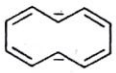


2.195 Identify the following compounds as aromatic, homoaromatic, non-aromatic, or antiaromatic. Give reasons in each case.



(c) 

(f) 

(d) 

(g) 

(e) 

Ans According to HMO calculation, a planar cyclic system with $4n+2\pi$-electrons ($n=0, 1, 2, ...$) is an aromatic, non-planar cyclic system with $4n+2\pi$-electrons ($n=0, 1, 2, ...$) is homoaromatic, planar cyclic system with $4n$ π-electrons ($n=1, 2, 3, ...$), is antiaromatic, and non-planar cyclic system with $4n$ π-electrons ($n=1, 2, 3, ...$) is non-aromatic. These rules are applicable to monocyclic systems only. In case of polycyclic fused systems, these properties are applied to each individual ring to find out the outcome.

In the present case, compound (a) is antiaromatic on the basis of cyclopentadiene system. Boron atom is sp^2 hybridized and planar.

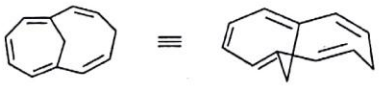
The compound (b) is non-planar with 10π-electrons. Therefore, it is homoaromatic.

In (c), the molecule itself is non-planar and each ring contains $4n\pi$-electrons. Therefore, it is a non-aromatic system.

The compound (d) is antiaromatic with 12π-electrons ($4n\pi$-electrons, $n=3$). The carbon atoms bearing the negative charges are considered to be sp^2 hybridized.

The compound (e) is an antiaromatic ion with 8π-electrons. The positively charged nitrogen atom bearing a lone pair of electrons is sp^2 hybridized (planar).

Compound (f) is a bridged bicyclic compound and since it is not a fused system, it can be treated as a monocylic system as shown here.

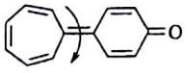


It is a non-planar system with 10π ($4n+2\pi$-electrons, $n=2$). Thus it represents a homoaromatic system.

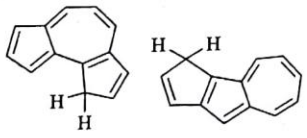
The compound (g) is a planar system with 12p-electrons. Therefore the molecule is antiaromatic.

2.196 Account for the following observations.

(a) The barrier for rotation about the marked bond in the following compound is only about 14 kcal/mol.



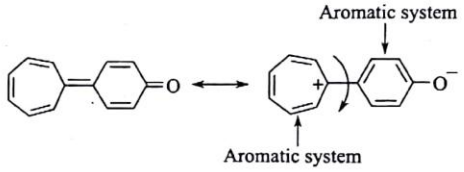
(b) Hydrocarbon A ($pK \sim 14$) is much more acidic than B ($pK \sim 22$).



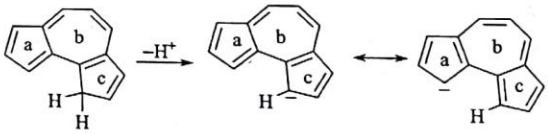
(A) (B)

(c) Cyclopentadienone is a kinetically unstable molecule.

Ans In the case of (a), delocalization of π-electrons gives a stable aromatic system and concomitantly the double bond joining the two rings becomes a single bond appreciably. This is why rotational barrier between the two rings is only 14 kcal/mole.



In problem (b), the acidity of compounds depends on the stabilities of the conjugate base (carbanion) after the loss of a proton.



(I)

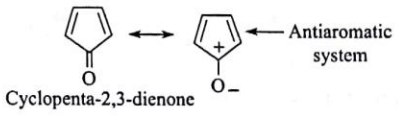
In compound (I), the terminal five-membered rings (a, c) can assume stable cyclopentadienyl anion (aromatic anion) by delocalization, after deprotonation from the sp^3 carbon.

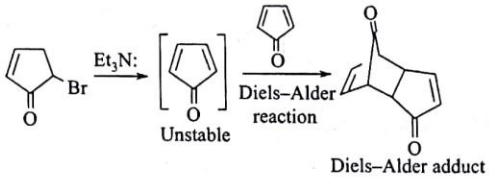
In compound (II), only one terminal ring (d) can have aromatic stability after deprotonation, being converted into cyclopentadienide ion. Further delocalization makes the cyclohetptatrienyl ring antiaromatic.

(II)

This is why, (I) is more acidic than (II).

(c) Cyclopen-2,3-dienone is a very unstable compound because by electromerization of the C=O group, the ring becomes an antiaromatic system and consequently its reactivity is enhanced requiring less activation energy (kinetic instability). In fact, attempt to prepare cyclopentadienone by treatment of 5-bromocyclopentadienone with Et_3N: gave virtually a quantitative yield of Diels-Alder adduct showing extreme instability of the cyclopentadienone compound.





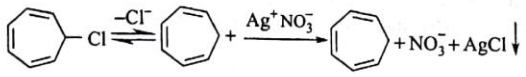
2.197 Which of the following ring compounds obey Huckel's rule? $C_{10}H_{10}^{+}$, $C_{10}H_{10}$, $C_{12}H_{12}$, $C_{12}H_{12}^{2-}$, $C_{12}H_{12}^{2+}$, $C_{20}H_{20}$, $C_{20}H_{20}^{2-}$, $C_{20}H_{20}^{+}$, $C_{20}H_{20}^{2+}$

Ans Huckel'rule requires a monocyclic planar ring compound or ion to contain $(4n+2)$ π-electrons for it to exhibit aromaticity. Assuming that all the compounds and ions mentioned in the question are planar and number of π-electrons in neutral molecules is equal to the number of carbon atoms, we can use Huckel's rule to ascertain their aromatic characters.

$C_{10}H_{10}$: 10 π-electrons, $(4n+2)$, $n=2$, aromatic
$C_{12}H_{12}$: 12 π-electrons, $(4n)$, $n=3$, not aromatic (if planar – antiaromatic)
$C_{12}H_{12}^{2-}$: 14 π-electrons, $(4n+2)$, $n=3$, aromatic
$C_{12}H_{12}^{2+}$: 10 π-electrons, $(4n+2)$, $n=2$, aromatic
$C_{20}H_{20}$: 20 π-electrons, $(4n)$, $n=5$, not aromatic (if planar – antiaromatic)
$C_{20}H_{20}^{-}$: 21 π-electrons, $(4n+1)$, $n=5$, not aromatic
$C_{20}H_{20}^{2-}$: 22 π-electrons, $(4n+2)$, $n=5$, aromatic
$C_{20}H_{20}^{+}$: 19 π-electrons, $(4n+3)$, $n=4$, not aromatic
$C_{20}H_{20}^{2+}$: 18 π-electrons, $(4n+2)$, $n=4$, aromatic

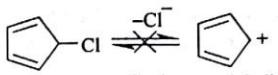
2.198 7-Chlorocyclohepta-1,3,5-triene readily forms white AgCl precipitate when boiled with AgNO3 solution but 5-chlorocyclopenta-1,3-diene does not. Give reasons.

Ans 7-Chlorocycloheptа-1,3,5-triene undergoes easy heterolysis to form cycloheptatrienyl cation, commonly called tropylium ion and chloride ion. Tropylium is stable because it exhibits aromatic character following Huckel's $(4n+2)$ π-electrons, $n=1$. The free chloride ion reacts with Ag^{+} from $AgNO_3$ to give an insoluble white precipitate of AgCl.



Tropylium ion
(Aromatic cation)

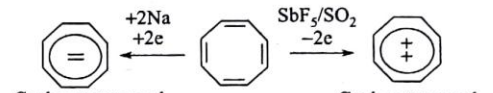
On the other hand, 5-chlorocyclopenta-1,3-diene fails to undergo heterolysis to produce chloride ion because the corresponding cyclopentadienyl cation is an anti-aromatic system. Consequently it fails to react with AgNo3 to form AgCl precipitate.



Cyclopenta-1,3-dienyl ion
(Antiaromatic system)

2.199 Both dianion and dication of a monocyclic hydrocarbon C_8H_8 show aromatic stabilization. Identify the compound and give your answer.

Ans The monocyclic hydrocarbon, C_8H_8 is cyclooctatetraene, generally abbreviated to COT. Its dianion contains 10π-electrons obeying Huckel's rule of $4n$ π-electrons $(n=2)$ and its dication contains 6π-electrons and that also obeys Huckel's rule of $(4n+2)$ π-electrons $(n=1)$. Structures are shown here. In planar form 'Cot' is antiaromatic and normally remains in tub-like puckered form.



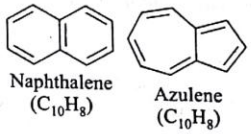
Cyclooctatetraenyl dianion
10π-electron aromatic system

COT

Cyclooctatraenyl dication
6π-electron system

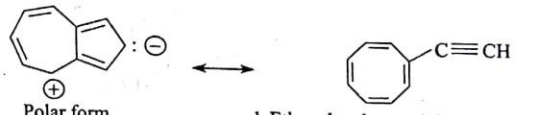
2.200 Two bicyclic hydrocarbons have the same molecular formula, $C_{10}H_8$, Both of them have aromatic stability but one is neutral and the other is polar. Identify the compounds and offer an explanation. Give an isomeric cyclic compound having four double bonds and a triple bond

Ans The neutral compound is naphthalene. The polar compound is azulene and the isomeric cyclic compound is cycloocta-1,3,5-triene derivative.



Naphthalene ($C_{10}H_8$)

Azulene ($C_{10}H_8$)

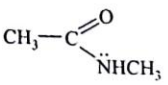


Polar form

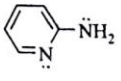
1-Ethenylcycloocta-1,3,5,7-tetraene ($C_{10}H_8$)

2.201 Predict the energetically preferred site of protonation for each of the following molecules and explain the basis of your prediction.

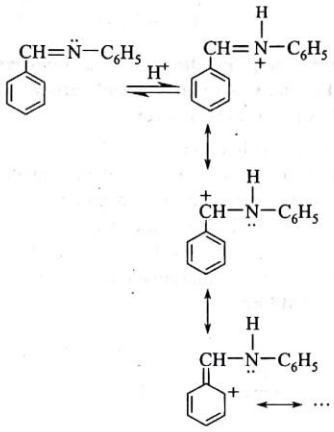
(a) $C_6H_5CH{=}\ddot{N}{-}C_6H_5$

(c) 

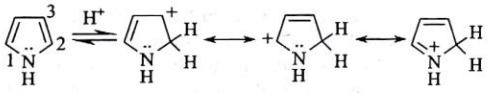
(b) 

(d) 

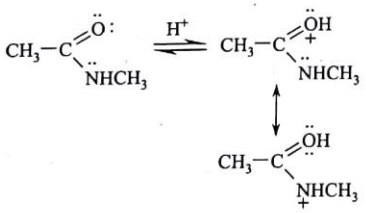
Ans In (a), protonation takes place on the nitrogen atom bearing the lone pair of electrons. The resultant ammonium salt is stabilized by resonance.



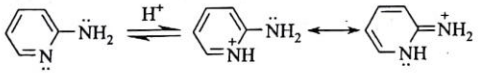
In (b), protonation takes place on the C-2 carbon atom and not on the nitrogen atom bearing the lone pair of electrons. C-2 protonation gives a carbocation which is stabilized through maximum number of resonating structures.



In (c), protonation takes place on the oxygen atom and not on the nitrogen atom. Protonation on the oxygen atom can give resonance stabilization. Protonation on the nitrogen atom does not give resonance stabilization.

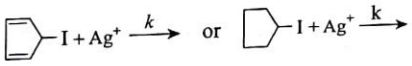


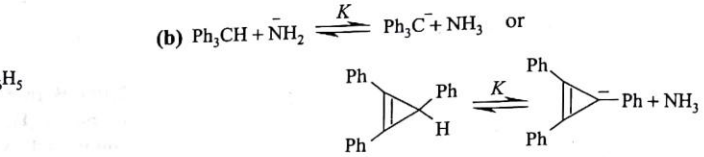
In (d), protonation will occur on the ring nitrogen atom, because in that case we get resonance stabilizied cation involving all the atoms of the molecule.

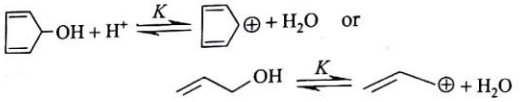


If protonation takes place on NH_2 then resonance is not possible.

2.202 Predict which would give the faster (*k*) or more complete (*K*) reaction. Explain the basis for your prediction.

(a) 

(b) 

(c) 

Ans In case of (a), 5-iodocyclopenta-1,3-diene will react extremely slowly because the corresponding carbocation is antiaromatic. Cyclopentyl iodide will react faster.

In case of (b), the triphenylmethane will react with NH_2^- almost to completion. The triphenylcyclopropene cannot afford to lose a proton because the corresponding carbanion is an antiaromatic system (planar $4n$ system with $n=1$).

In case of (c), allyl alcohol will form the resonance stabilized allyl cation. Cyclopenta-1,3-dien-5-ol will not react because the corresponding cyclopentadienyl ion is an antiaromatic system.

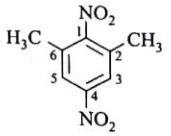
2.203 Explain each of the following.

(a) *n*-Butyric acid is slightly stronger than *i*-butyric acid in aqueous medium.

(b) Acetylacetone is a stronger acid than acetonylacetone.

(c) A bromine atom raises the acidity of phenol more effectively when substituted at *meta*-position, but the reverse is true when bromine atom is in *para*-position.

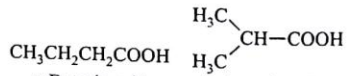
(d) When the dinitro compound is treated with a base, the nitro group in the 1-position, although more 'hindered', is more easily displaced than that at the 4-position.



(e) Anthracene-9-carboxylic acid is six times as strong an acid in water compared to anthracene-2-carboxylic acid.

Ans The explanations are as follows.

(a) The structures of *n*-butyric acid and isobutyric acid are given here.

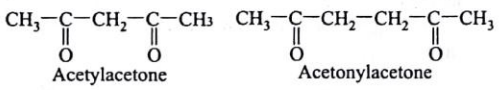


n-Butyric acid Isobutyric acid

In this case, the inductive effect (+I) of two CH_3 groups increases the electron density on the oxygen atom and inhibits dissociation of —COOH group. Moreover, acid-anion from isobutyric acid is less solvated due to its

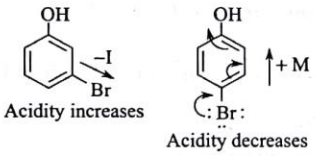
branched structure. This is why, *n*-butyric acid is slightly more acidic than *n*-butyric acid.

(b) Structures of acetylacetone and acetonylacetone are given here.

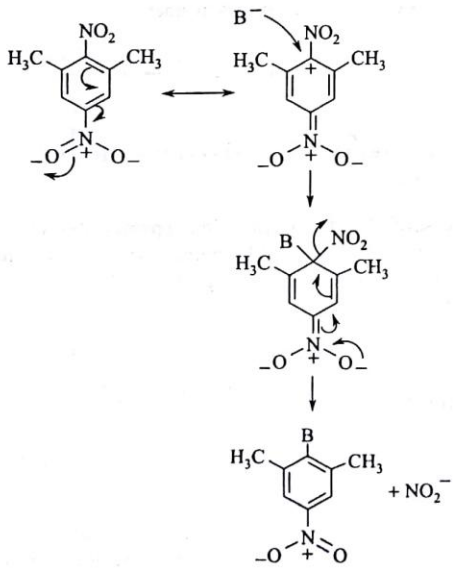


Acetylacetone is a β-diketone and acetonylacetone is a γ-diketone. In case of acetylacetone, the $-CH_2-$ group is flanked by two carbonyl groups and consequently the hydrogen atoms exhibit greater acidity.

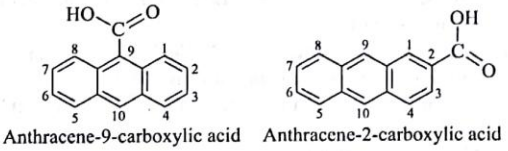
(c) In case of *m*-bromophenol, Br atom cannot take part in resonance, that is, cannot exhibit +M effect. It exhibits –I effect and consequently enhances the acidity of phenol. In case of *p*-isomer, +M effect is prominent compared to –I effect. Consequently, acidity of phenol decreases.



(d) In case of the dinitro compound, the nitro group at C-4 position can take part in delocalization involving the benzene ring. This generates a cationic centre to be attacked by a base (nucleophile). In fact, this is a case of activated nucleophilic substitution. In case of C-1 nitro group, steric interaction with *ortho* CH_3 groups makes the nitro group out of the plane of the benzene ring and consequently delocalization is inhibited. This is why, C-4 nitro group cannot be displaced by a base (nucleophile)

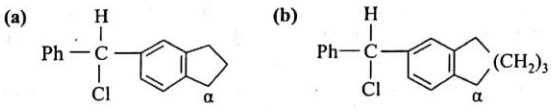


(e) Structures of anthracene-9-carboxylic acid and anthracene-2-carboxylic acid are shown here.

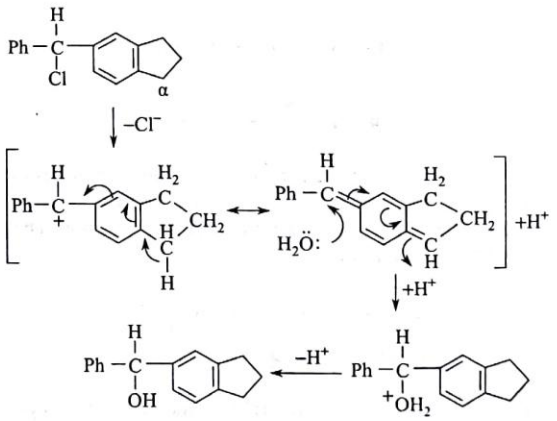


The higher acidity of anthracene-9-carboxylic acid compared to anthracene-2-carboxylic acid may be attributed to the so called *peri interaction*. In case of anthracene-9-carboxylic acid, interactions between-COCH group and hydogen atoms at C-1 and C-8 force the –COOH group to move out of the plane of the anthracene ring system and the resonance involving the π-electrons of the rings is inhibited. This enhances the acidity of the anthracene-9-carboxylic acid. There are no such *peri-interactions* in case of anthracene-2-carboxylic acid.

2.204 Which of the following two compounds will undergo hydrolysis more easily? Give reasons.



Ans The mechanism of the hydrolysis of (a) can be shown as follows. Both hydrolyses are thought to proceed through carbocation formation by the loss of chloride ion.



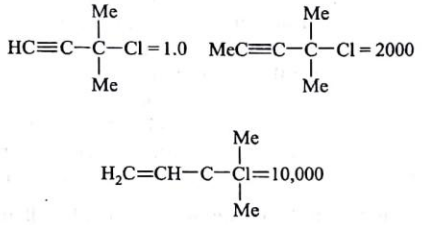
The carbocation is presumably stabilized by hyperconjugation involving hydrogen atom at the α-position, as shown in the mechanism. In compound (a), this hyperconjugation is more effective because the five-membered ring is almost planar with the benzene ring. In the case of compound (b), the seven-membered ring is more puckered and non-planar with the benzene ring. Thus the stability of the intermediate carbocation governs the rate of hydrolysis and the compound (a) reacts at a faster rate.

2.205 Explain each of the following.

(a) BF_3 accelerates the unimolecular substitution of alkyl fluorides but not those of alkyl chlorides. The reverse is true for AgF.

(b) The ethanolysis of benzhydryl chloride is accelerated by addition of small quantities of water, but there is no significant increase in the ratio of Ph_2CHOH/Ph_2CHOEt in the product.

(c) The relative specific rates of unimolecular solvolysis of the following chlorides in ethanol are



Ans Alkyl fluoride can generate a carbocation on reaction with BF_3. The reaction produces stable anion BF_4^-. However alkyl chloride fails to react with BF_3 as BF_3Cl^- is not a stable anion, because of poor overlapping between the vacant $2p$ orbital of boron in BF_3 and electron pair in the $3p$-orbital of chlorine. This why, the reaction between RF and BF_3 accelerates the rate of unimolecular substitution (S_N1) but not in the case of RCl.

$$R{-}F + BF_3 \longrightarrow R^+ + BF_4^-$$

$$R{-}Cl + BF_3 \not\longrightarrow R^+ + BF_3Cl^-$$

$$R^+ + Nu^- \xrightarrow{S_N1} R{-}Nu$$

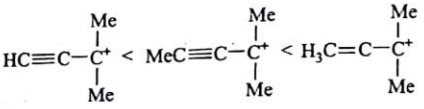
When an alkyl chloride is treated with AgF, Ag^+ ion is the reacting Lewis acid and has a strong affinity for Cl^- ion. AgCl is precipitated and the reaction produces a carbocation. Then normal S_N1 reaction occurs.

$$R{-}Cl + AgF \longrightarrow R^+ + AgCl\downarrow + F^-$$

$$R^+ + Nu^- \xrightarrow{S_N1} R{-}Nu$$

(b) Benzydril chloride (Ph_2CHCl) undergoes ethanolysis through ionization into Ph_2CH^+ and Cl–. This ionization will be more effective in solvents with high dielectric constant. When small amount of water is added, ionization will be facilitated but the medium now contains a large quantity of EtOH and a small quantity of H_2O. Both are nucleophilic molecules and give both Ph_2CHOH and PH_2CHOEt. However, the carbocation Ph_2CH^+ is a stable cation and is subjected to mass effect. Since EtOH is present in large quantity, PH_2CHOEt will be formed in appreciable amount compared to Ph_2CHOH. Therefore, there will be no appreciable change in the ratio of Ph_2CHOH/Ph_2CHOEt.

(c) Solvolysis takes place through the formation of the respective carbocation and the rates of solvolysis are dependent on their stabilities. The increasing stability order of carbonations are shown here, which explains the rates of reactions.



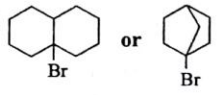
2.206 Decide which compound in each of the following pairs reacts more rapidly with AgOAc in acetic acid. Give reasons in each case.

(a) CH_3OCH_2Cl **or** $CH_3OCH_2CH_2Cl$

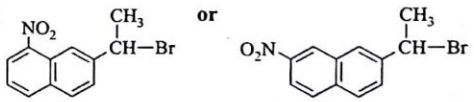
(b) $(CH_3)_2CDBr$ **or** $CH_2D{-}CH(CH_3){-}Br$

(c) $CH_2{=}C(CH_3)CH_2Cl$ **or** $CH_3CH{=}CH{-}CH_2Cl$

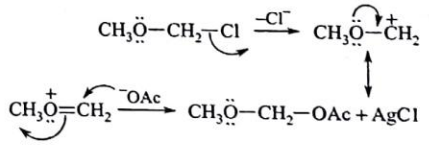
(d)



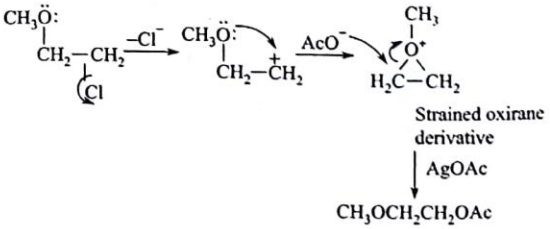
(e)



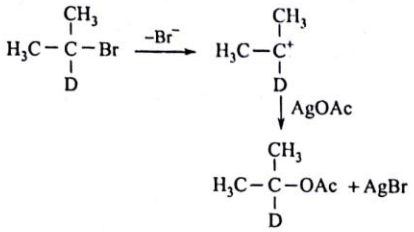
Ans In the case of (a), the compound CH_3OCH_2Cl reacts at a faster rate. Here the reactions occur through carbocations and the formation of carbocation is accelerated by NGP of $-OCH_3$. This has been shown step-wise. Formation of cation can also occur in a synchronous manner.



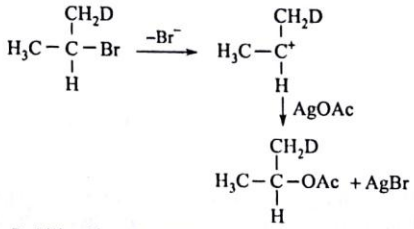
In case of $CH_3OCH_2CH_2Cl$, similar participation of $-OCH_3$ requires formation of a highly strained oxirane compound and consequently the activation energy will be large to slow down the rate of the reaction.



(b) The reaction occurs according to S_N1 mechanism.



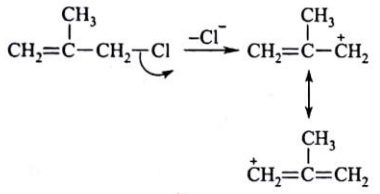
Stabilized by +I effects of CH_3 groups and hyperconjugation



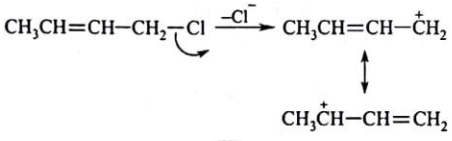
Stabilized by +I effects of CH_3 and CH_2D groups and hyperconjugation

It is to be noted that the +I effects of $-CH_3$ and $-CH_2D$ groups is almost same but in case of hyperconjugation, one C–D bond will be slowly cleaved compared to C–H bond. Therefore, CH_2D–$CH(CH_3)Br$ will react at a slower rate.

(c) In this case both compounds can form allylic carbocation. Reactivity depends on the stability of each carbocation.



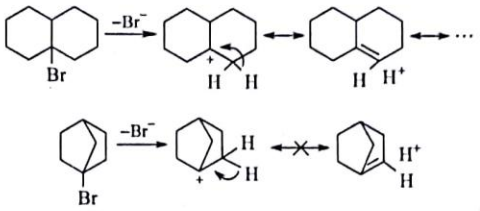
(I)

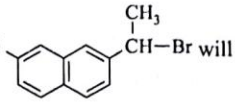
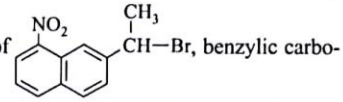


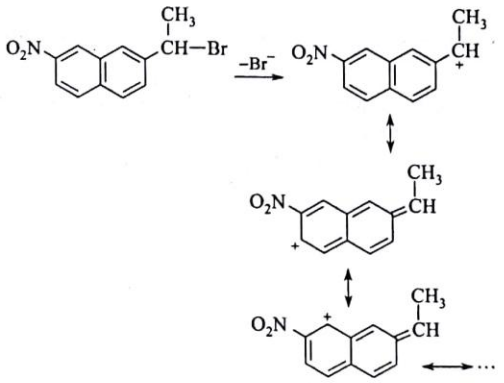
(II)

Of the two allylic carbocations, the cation (I) is more stable, because it gives two identical resonance structures and the double bond can participate in hyperconjugation with the CH_3 group. The allylic carbocation (II) gives non-equivalent resonance structures. Therefore, $CH_2=C(CH_3)CH_2Cl$ will react at a faster rate.

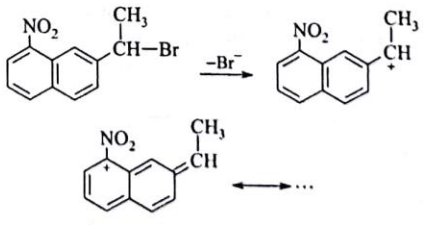
(d) In this case, decalin derivative is a fused bicyclic system and the resultant carbocation formed by the loss of bromide ion can become stabilized by hyperconjugation. The other compound is a bridged bicylic compound. The carbocation from this compound cannot become stabilized by hyperconjugation because of violation of the so called Bredt's rule. Therefore, decalin derivative will react at a faster rate.



(e) In this pair of compounds,  will react at a faster rate, because the benzylic carbocation formed by the loss of bromide ion can be stabilized by delocalization more effectively where the +ve charge cannot be placed on the carbon atom bearing the $-NO_2$ group. In the case of  , benzylic carbocation is less stable because delocalization needs to put a +ve charge on the carbon atom bearing the nitro group. The structures are shown here.

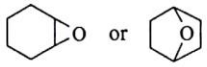
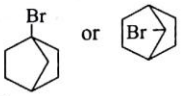


More stable resonating structure

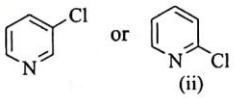


Less stable resonating structure

2.207 Predict which compound in each of the following pairs reacts more rapidly with sodium ethoxide in ethanol.

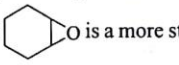
(a)  (b) 

(c) 

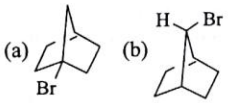
(d) 

(ii)

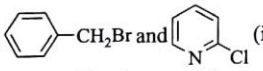
Ans The following is the explanation:

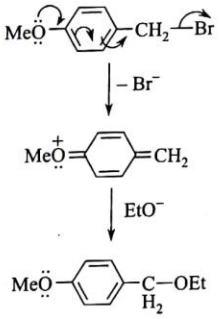
(a) The compound  is a more strained molecule compared to  . Therefore, the former is more reactive.

(b) The conformational structures of these compounds can be shown as follows.

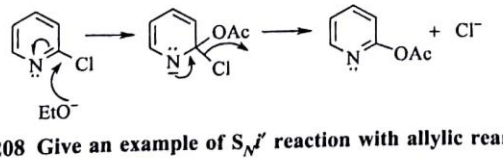


Since in the first compound (a), Br atom is at the bridgehead carbon atom, it is difficult to be substituted by substitution reactions. Consequently, the second one (b) where the bromine atom is at the apex of the bridge can be substituted more easily.

(c) Between,  (i) (ii) (ii) is more reactive due to anchimeric assistance by *p*-OCH_3 group. This is shown here.

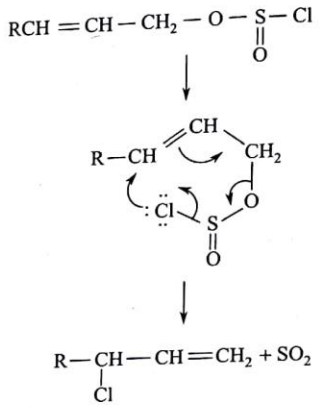


(d) Pyridine behaves like nitrobenzene in case of activated nucleophilic substitutions. Therefore, *o*-chloropyridine will react more easily compared to *m*-chloropyridine.



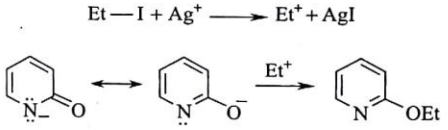
2.208 Give an example of S_Ni' reaction with allylic rearrangement.

Ans When a chlorosulphite derivative from an allylic alcohol is heated then a chloro-compound is obtained with allylic rearrangement. This reaction can be considered mechanistically as S_Ni'. The reaction is shown here.

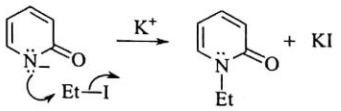


2.209 What happens when α-pyridone is separately treated with (a) EtI in presence of Ag^+ (silver salt) and (b) EtI in presence of K^+ (KOH). Explain the reaction.

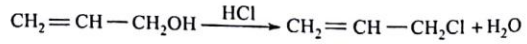
Ans α-Pyridone is an ambident nucleophile having nucleophilic centres on the nitrogen atom as well as on the oxygen atom. When the reaction is carried out in presence of Ag^+ ion (Lewis acid) then a carbocation is generated from EtI, because of strong affinity of silver ion for the iodide ion. This carbocation then reacts with the more electron-rich oxygen centre. Reaction is more like S_N1 substitution.



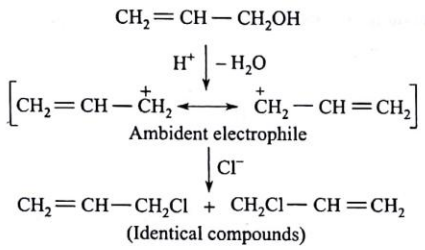
When the reaction is carried out in presence of K^+ then carbocation is not formed from EtI and the reaction is switched over to S_N2-like substitution and more polarizable lone pair of electrons on the nitrogen atom takes part in the reaction and *N*-alkyl compound is formed.



2.210 How can you demonstrate that the following reaction occurs through S_N1' mechanism?



Ans S_N1' mechanism involves unimolecular nucleophilic substitution with the shift of a double bond. Hence a carbocation intermediate is formed and that is stabilized by resonance. Thus two reactive sites are generated and this functions as an ambident electrophile. This is shown here.

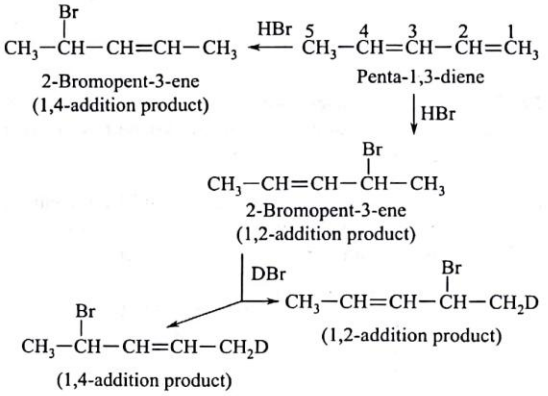


Since the two resonating structures are structurally identical, allyl chlorides formed from them are also identical. Therefore, to demonstrate that this is the case of S_Ni' reaction, we require an experiment with an isotopically labelled compound.

If we start from $CH_2{=}CH{-}\overset{14}{C}H_2OH$ then the final products would be, $CH_2{=}CH{-}\overset{14}{C}H_2Cl$ and $CH_2Cl{-}CH{=}\overset{14}{C}H_2$. Therefore, if we can identify the product containing $-CH_2Cl$ in this reaction then we can conclude that S_Ni' mechanism must be operating.

2.211 The following compound undergoes both 1,2- and 1,4-additions with HBr to give the same compound. How can you prove that both types of addition reactions are taking place?

Ans Although 1,2- and 1,4-addition of HBr give the same product, the mode of addition can be differentiated by using DBr in place of HBr. In case of DBr, the 1,2- and 1,4-additions give products differing in the position of D. Ozonolysis can be used to differentiate them.



EXERCISES

2.1 Give an explanation for the following observations.

(a) Amides are protonated on oxygen rather than on nitrogen.
(b) Ethers are better Lewis bases than ketones.
(c) Tetramethylguanidine is a much stronger base than *N*, *N*-dimethylacetamide.
(b) BF_3 is a stronger Lewis acid than $(CH_3O)_3B$.
(e) Piperidine is a much stronger Lewis base than Pyridine.
(f) *o*-Chloroaniline is a weaker base than *p*-chloroaniline
(g) $NaBH_4$ in alcohol does not reduce imines effectively. If BF_3 is added to the mixture, however, the reduction proceeds rapidly and efficiently.

2.2 Consider the equilibrium of the following reactions:

$$C_4H_{10} \rightleftharpoons C_2H_6 + C_2H_4$$

(a) At 25°C, $\Delta H^\circ = -22.2$ kcal mole^{-1} and $\Delta S^\circ = 33.5$ eu. What is ΔG°? On which side does the equilibrium lie?
(b) Calculate ΔG° at 800K and determine the position of equilibrium.

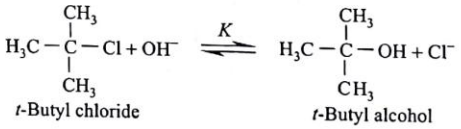
2.3 Consider the following reaction sequence in which 'B' is an intermediate. Draw energy profiles for each of the possible relationships among the rate constant.

$$A \underset{k_2}{\overset{k_1}{\rightleftharpoons}} B \quad B \xrightarrow{k_3} C$$

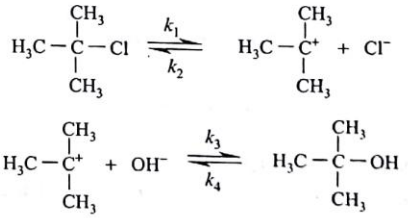
The back reaction from C is negligible.
(a) k_1 and k_2 large, k_3 small
(b) k_1 large, k_2 and k_3 large, but $k_2 > k_3$
(c) k_1 and k_3 large, k_2 small
(d) k_1 small, k_2 and k_3 large, but $k_3 > k_2$

Identify the rate determining transition state for each of the four cases.

2.4 *t*-Butyl chloride reacts with NaOH according to the following equation.

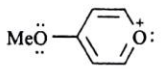


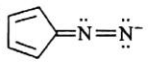
The reaction is believed to proceed by the following mechanism.

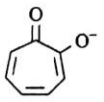


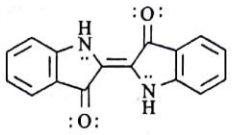
The order of the rate constants is $k_3 > k_2 > k_1 >> k_4$
(a) Construct a reaction coordinate for the reaction.
(b) Is the first step exothermic or endothermic?
(c) Is the overall reaction exothermic or endothermic?
(d) Does the first or second step govern the rate of disappearance of *t*-butyl chloride?

2.5 Write the principal resonance forms stabilizing the following structures.

(a) 

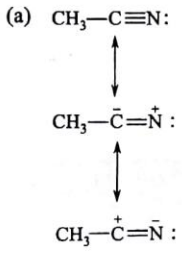
(b) 

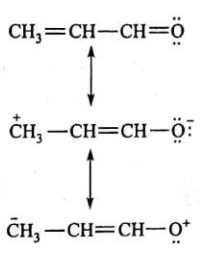
(c) 

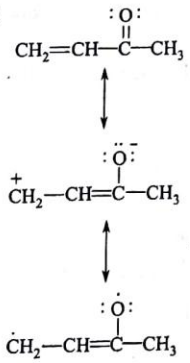
(d) 

2.6 2,3-Dimethylcyclohex-2-one and 2,3-dimethylcyclohex-3-one are much more readily interconvertible than 1,2-dimethylhexene and 2,3-dimethylhexene. Explain.

2.7 Examine the following structures as significant contributors to the resonance hybrid of the molecule. Mention if each of the sets has isovalent or heterovalent interactions.

(a) 

(b) 

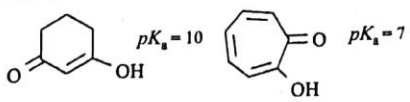
(c) 

(d) 

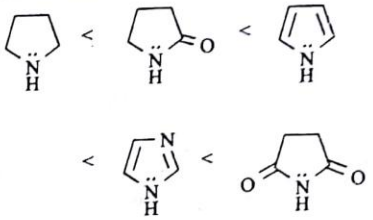
2.8 Answer the following.

(a) Furan-2-carboxylic acid is a stronger acid than acetic acid. Explain.

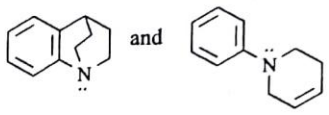
(b) Account for the acidity difference between the following two compounds.

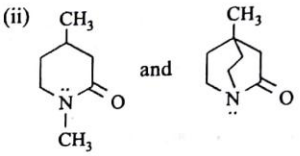


(c) Account for this increase in acidity loss of proton.



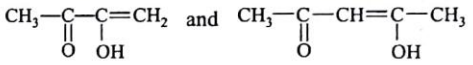
(d) Which compound in each pair of the following is more basic? Give reasons.

(i) 

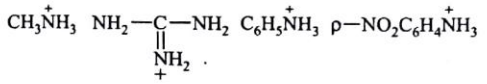
(ii) 

2.9 Answer these questions.

(a) Which of the following two enols would you expect to be a stronger base, and why? Which is a stronger acid and why?



(b) Arrange the following acids in decreasing order of acid strength.



2.10 1-Bromo-1-phenylbutane may be converted to the acetate (ester) of 1-phenyl-butan-1-ol either by refluxing in acetic acid or by the action of sodium acetate in an inert solvent such as DMF.

(a) Write a detailed mechanism of each procedure and draw a qualitative energy diagram for each one.

(b) What stereochemistry would you expect in the product ester in each case and why?

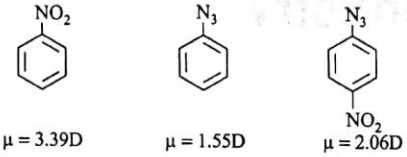
(c) What effects on the rates of reaction would be observed on adding silver salt in the first case, or adding excess potassium acetate in the second case?

(d) What effect on the rates of reaction would occur by use in the first case of (i) the π-nitrophenyl analogue, (ii) π-hydroxyphenyl analogue?

(e) What effect on the two cases would be caused by substitution of extra methyl at the 1-position or the 2-position.

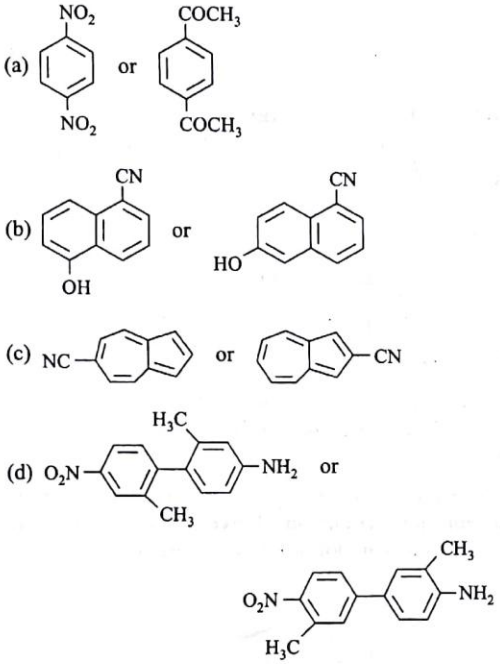
(f) If 1-phenylbutan-1-ol itself was desired (instead of the ester), could sodium hydroxide be used instead of sodium acetate in the second case, and what effect would you expect on the stereochemistry and yield?

2.11 Given the following moments, and assuming that the N_3 group is linear, calculate the angle between the N_3 group and the C—N bond in *p*-nitrophenyl azide.

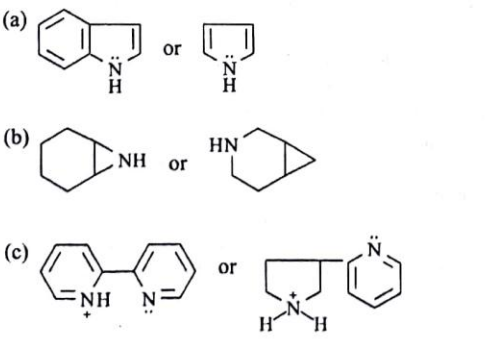


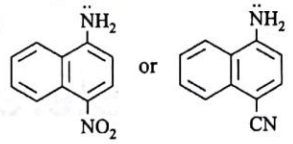
$\mu = 3.39D$ $\mu = 1.55D$ $\mu = 2.06D$

2.12 Predict which compound in each of the following pairs has the higher dipole moment and justify your guess in each case.



2.13 Predict which base in each of the following pairs is stronger if the reference acid is the proton H^+. Indicate, in each case, if a reversal in order would result if $(i\text{-Pr})_3B$ is taken as the reference acid.





2.14 Explain the following.

(a) Cyclopentadiene is a stronger acid than benzene.

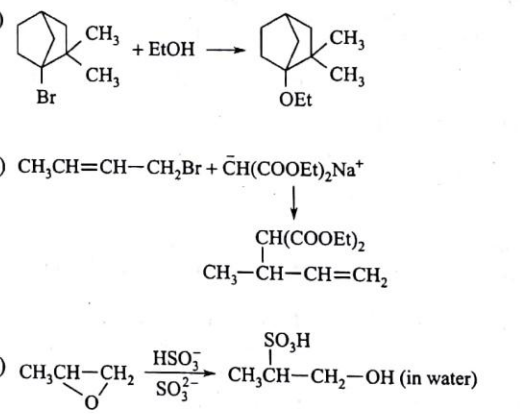
(b) The loss of Cl^- from $C_6H_5C(CH_2)_2Cl$ in aqueous alcohol is accelerated by *p*-Cl substitution but retarded by *o*-Cl substituent.

(c) *trans*- 2-Hydroxycyclohexanecarboxylic acid is a stronger acid than its *cis* isomer in water, but in ethanol the reverse is true.

(d) The ratio of K_1/K_2 for 1,2-*cis*-cyclopropane dicarboxylic acid is raised by a factor of 600 by substituting two methyl groups for the hydrogens on the C-3 position.

(e) A bromine atom raises the acidity of phenol more effectively when substituted in the *meta* than in the *para* position, but the reverse is true for the $CH_3-\overset{\overset{O}{\|}}{S}-O^-$ substituent.

2.15 Suggest a mechanism for the following reactions.



2.16 Give examples of the following:

(a) Two aromatic systems with 2π-electrons

(b) Three aromatic carbocyclic systems with 6π-electrons

(c) An aromatic dianion and dication with 6 and 10π-electrons respectively

(d) A fulvalene with aromatic property in ionic form

(e) Two pseudoaromatic structures

2.17 Draw the structures of the following and find out whether they are aromatic. Give reasons in favour of your answers.

(a) Pyridine

(b) Imidazole

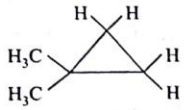
(c) Pyrilium ion

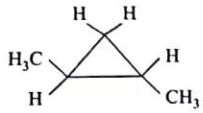
(d) Oxocycloheptatriene

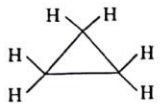
(e) Isoxazole.

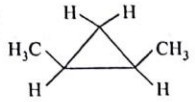
3 Stereochemistry

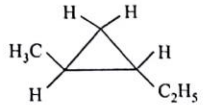
3.1 What are the elements of symmetry/symmetries in the following compounds? Comment on their chirality. Assume planar structure of the cyclopropane ring.

(a) 

(b) 

(c) 

(d) 

(e) 

Ans

(a) It has one C_2 simple axis and two C_v planes. The molecule is achiral.

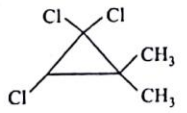
(b) It has only C_2 axis. The molecule is chiral.

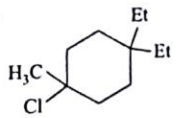
(c) It has one C_3 axis, three C_2 axes, one σ_h, and three σ_v planes. The molecule is achiral.

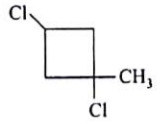
(d) It has only C_s axis. The molecule is chiral.

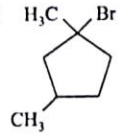
(e) It has only C_1 axis. The molecule is achiral.

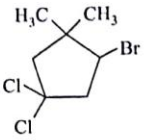
3.2 Among the eight compounds (A through H) drawn here, identify those that would exist as a pair of stereoisomers (enantiomers).

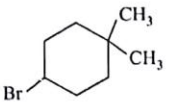
(a) 

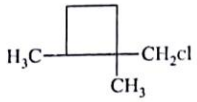
(b) 

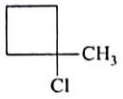
(c) 

(d) 

(e) 

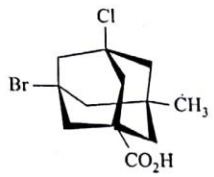
(f) 

(g) 

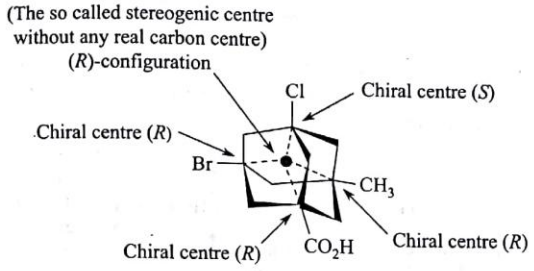
(h) 

Ans Among the compounds shown, the compounds C, D, E, and G are chiral and consequently can exist as a pair of enantiomers.

3.3 How many stereoisomers are theoretically possible for the following adamantane derivative? In practice only two stereoisomers are known. Give an explanation.

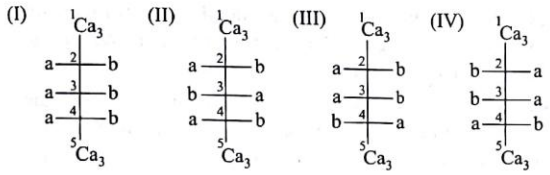


Ans Although four asymmetric carbon atoms are present in this compound, it exists in the form of only two stereoisomers (enantiomers) rather than the sixteen predicted by the 2^n rule. There is, in fact, only one stereogenic centre, shown by the black dot at the centre of the molecule (in the following diagram), and the configuration shown here is (*R*). The asymmetric carbon atoms are not stereogenic centres, because any two substituents on any of these bridgehead carbons cannot be exchanged without destroying the constitutional integrity of this rigid, highly bridged molecule. The configurations of the asymmetric bridgehead carbon units in this structure are (*R*), (*S*), (*R*) and (*R*) respectively, for the Br, Cl, CO_2H and CH_3 substituents. Its enantiomer would, of course, have the opposite configurations.



3.4 Draw the possible stereoisomers of the compound $Ca_3CabCabCabCa_3$ (a, b = substituents) in Fischer projection and designate each of the carbons as achirotopic, chirotopic, non-stereogenic, and stereogenic.

Ans The possible stereoisomers of the $Ca_3CabCabCabCa_3$ are as follows.



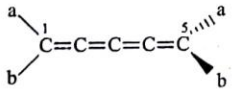
In (I), C-2 and C-4 are chirotopic (site symmetry C_1) but C-3 is achirotopic. However, C-2, C-3, and C-4 are stereogenic, that is interchange of position of substituents give new stereoisomers. C-1 and C-5 are non-stereogenic and achirotopic. In (II), situation is the same as in the case of (a).

In (III), C-1 and C-5 are achirotopic (site symmetry c_{3v}) and non-stereogenic. C-2 and C-4 are chirotopic and stereogenic. C-3 is unique in the sense that interchange of positions of a and b leads to an identical structure. This can be easily seen by turning the molecule 180° in plane, which is an allowed operation for the comparison of two Fischer projections. Therefore, C-3 in (III) is non-stereogenic. It is however chirotopic.

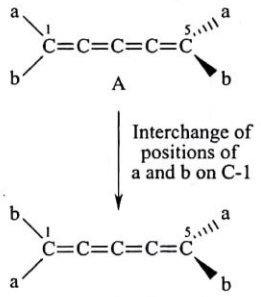
The character of (IV) is similar to that of (III), Here also C-1 and C-5 are achirotopic and non-stereogenic. C-2 and C-4 are chirotopic and stereogenic and C-3 is chirotopic but non-stereogenic.

3.5 Give examples of cumulenes where the terminal sp^2 carbon atoms represent (a) stereogenic–chirotopic and (b) stereogenic–achirotopic character respectively.

Ans Cumulenes with an even number of double bonds have stereogenic–chirotopic terminal sp^2 carbons when they possess non-identical substituents on each.

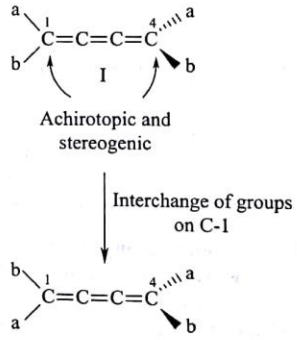


In this example C-1 and C-5 centres are stereogenic because mutual interchanges of positions of a and b either on C-1 or on C-5 produce a new stereoisomer (enantiomer). They are also chirotopic because the molecule belongs to the C_n point group and the site symmetry of C-1 and C-5 is C_1.



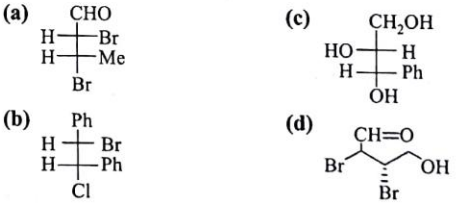
A and B are a pair of enantiomers

Cumulenes with an odd number of double bonds have terminal sp^2 carbons, which are stereogenic but achirotopic. In this case, the terminal carbon atoms with different substituents lie in the same plane (C_s point group) and consequently the terminal sp^2 carbons are achirotopic. However, interchange of positions of substituents on any of the terminal carbon atoms produces a new stereoisomer (diastereoisomer due to π-bonds). Therefore, their terminal centres are stereogenic.



I and II are *cis–trans* diastereoisomers

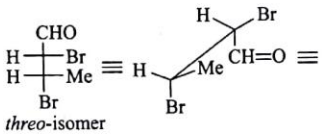
3.6 Do the following compounds represent *erythro* or *threo* isomers? How can *erythro* and *threo* terminologies be used in Newman projections?



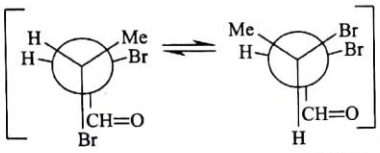
Ans The compounds (a) and (b) are *threo* isomers but the compound (c) is *erythro* isomer. The compound (d) is also *threo* isomer.

When applying Newman projections to decide *erythro* or *threo* isomers of a compound having two chiral centres, we should try to coincide the like or similar substituents in an eclipsed form of Newman projection. If two pairs of like

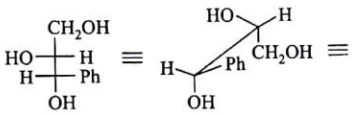
or similar substituents on the chiral centres can be made to coincide then that isomer represents *erythro*-form. If only one such pair can be made to coincide then that isomer represents *threo* isomer. Examples are given here.



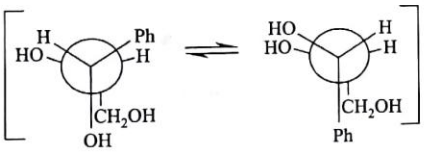
threo-isomer



(Only one like pair can be made to coincide)



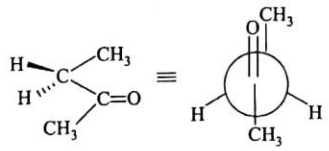
Erythro-isomer



(Two like pairs can be made to coincide)

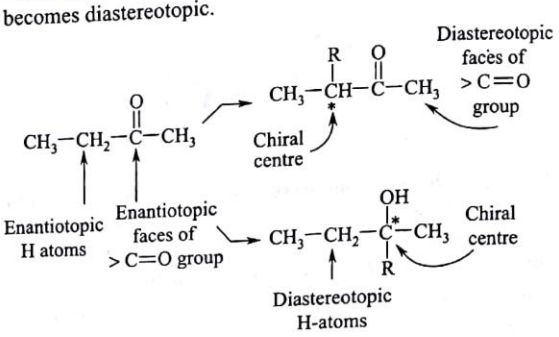
3.7 What is the point group of the molecule $CH_3CH_2COCH_3$ in its preferred conformation? What are the site symmetries of each carbon atom of the molecule? What are the topicities of H atoms of $-CH_2-$ group and faces of >C=O group? How are the topicities changed when carbon atoms of $-CH_2-$ and >C=O groups are separately converted into chiral centre?

Ans The preferred conformation $CH_3-CH_2-CO-CH_3$ is shown by the following perspective and Newman projections.



In the preferred conformation, the molecule has the point group C_s (has only one plane of symmetry). Each carbon centre of the molecule also has the same site symmetry C_s. In the molecule, H atoms of $-CH_2-$ group are enantiotopic because they are interchangeable by the operation of a symmetry plane. Similarly the two faces of the planar >C=O group are also enantiotopic because one face is the reflection-equivalent of the other.

When $-CH_2-$ group is desymmetrized to a chiral centre $-CH(R)-$, then the two opposite faces of >C=O group become diastereotopic. Similarly when >C=O group is converted into a chiral centre, H atoms of the $-CH_2-$ group becomes diastereotopic.

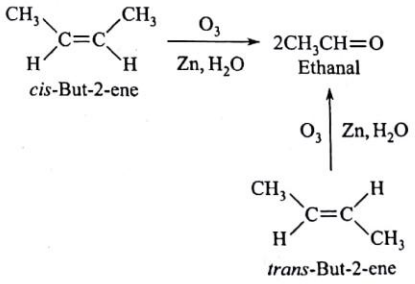


3.8 Predict the specific rotation of a mixture of 30% (–)-2-bromobutane and 70% (+)-enantiomer. $[\alpha]_D$ of pure enantiomer is (–)-23.13°.

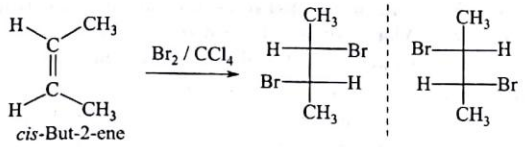
Ans 30% (–)-enantiomer will neutralize 30% (+)-enantiomer to form a 60% racemic mixture. Therefore, enantiomeric mixture contains 40% optically pure (+)-enantiomer. Because the racemic portion shows no resultant rotation, the observed rotation will be due to 40% of pure (+)-enantiomer. 100% pure (+)-enantiomer should exhibit $[\alpha]_D$ = (+) –23.13° [because pure(–)-enantiomer has an $[\alpha]_D$ = 23.13°]. Therefore, 40% of (+)-enantiomer should exhibit a specific rotation, 40 × 23.13/100 = (+) –9.25°.

3.9 How can you prove that *cis*- and *trans*-but-2-ene have the same constitutional structure but different configurational structures?

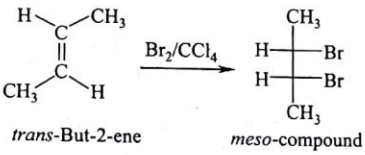
Ans When *cis*- and *trans*-but-2-ene are subjected to ozonolysis, then each of them gives the same product, namely two moles of ethanal. This reaction confirms that constitutionally they are identical.



However, when *cis*-but-2-ene is subjected to *trans* addition of bromine, the product is an equimolecular mixture of enantiomeric 2,3-dibromobutanes. Similarly when *trans*-but-2-ene is brominated, the compound is *meso*-2,3-dibromobutane. This is a case of diastereoface differenrentiation by stereospecific bromination. Therefore, *cis* and *trans* are configurationally different.



cis-But-2-ene



trans-But-2-ene *meso*-compound

3.10 Give examples which corroborate the following facts:

(a) A molecule which has enantiomers as well as diastereoisomers

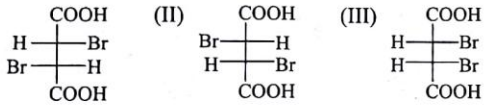
(b) A *meso*-compound having three chiral centres

(c) A molecule having only C_s symmetry

(d) A chiral molecule that cannot be resolved

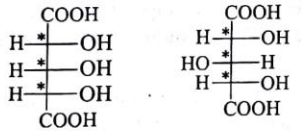
(e) A molecule having only S_4 as element of symmetry

Ans (a) 2,3-Dibromobutanoic acid is such an example. Structures are shown here.

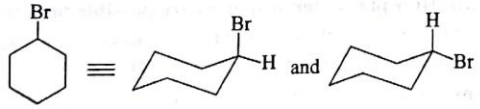


(I) and (II) represents a pair of enantiomers. (III) is diastereoisomeric to both (I) and (II).

(b) Following stereoisomers of 2,3,4-trihydroxypentanedioic acid are *meso*- compounds with three chiral centres.



(c) Monosubstituted cyclohexanes are compounds with one plane of symmetry. Their point group is C_s. Structures are shown here.

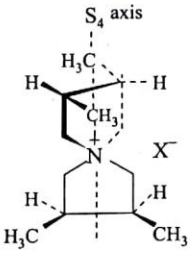


Bromocyclohexane

(d) Compounds like $R^1R^2R^3N$: are chiral tertiary amines but they cannot be resolved because of rapid configurational inversions. Two isomers remain in equilibrium state and are called invertomers.

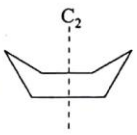
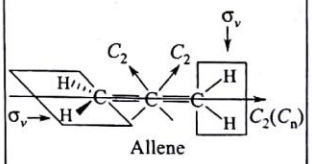
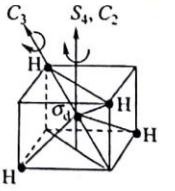
A pair of invertomers

(e) The following compound has only S_4 as elements of symmetry.



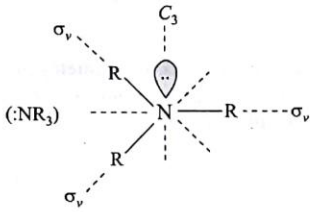
3.11 What are the elements of symmetry present in compounds belonging to the point groups C_{nv}, D_{nh}, D_{nd}, and T_d? Give an example in each case.

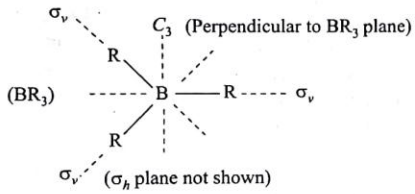
Ans

C_{nv} point group is equivalent to one C_n axis and n numbers of σ_v symmetry planes. A good example of C_{nv} compound is boat form of cyclohexane, shown on the right side. The compound has C_{2v} point group.	 Two planes of symmetry pass through the C_2 axis.
D_{nh} point group stands for the presence of a C_n axis, $n\sigma_v$ planes along with a horizontal plane bisecting the C_n axis. Benzene belongs to D_{6h} point group.	 It also has six σ_v and one σ_h bisecting the C_6 axis.
D_{nd} point group means the presence of a C_n axis, nC_2 axes supplemented by $n\sigma_v$ symmetry planes containing the C_n axis and bisecting the angle between the neighbouring two-fold axes. The allene molecule is an example of a point group of D_{2d}.	 Allene
T_d point group is encountered in regular tetrahedron of the type CX_4 with a regular tetrahedral structure. It has four C_3 axes, three C_2 axes, three S_4 axes and six σ_d planes. The structure of CH_4 molecule can be shown at the right side.	 Only a limited number of symmetry elements have been shown.

3.12 Why does :NR_3 belong to the C_{3v} point group but BR_3 belong to the D_{3h} point group?

Ans In :NR_3, nitrogen atom is sp^3 hybridized and nitrogen atom has a lone pair of electrons. It has a pyramidal structure but to determine the symmetry, it is treated as a trigonal structure with a lone pair of electrons in an sp^3 orbital perpendicular to the trigonal plane. Consequently it has a C_3 axis along with three σ_v planes but no σ_h. Therefore, its point group is $C_{3v} = C_3 + 3\sigma_v$.

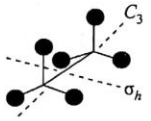
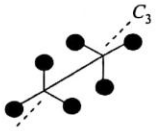




In case of BR_3, boron atom is sp^2 hybridized and, therefore, it has trigonal planar structure. It has a C_3 axis, three σ_v planes and a σ_h plane and three C_2 axes perpendicular to the C_3 axis. Therefore it belongs to D_{3h} point group which is equivalent to $C_3 + 3\sigma_v + \sigma_h + 3C_2$.

3.13 What are the elements of symmetry in eclipsed and staggered forms of ethane? Designate their point groups.

Ans

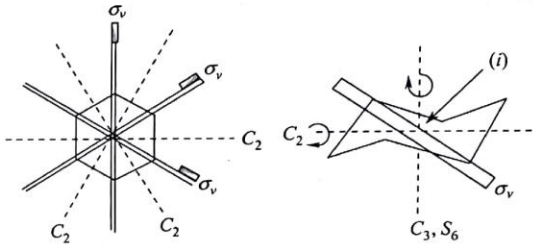
In case of eclipsed form of ethane, the elements of symmetry are C_3, $3C_2$ axes containing the C_3, $3\sigma_v$ planes (diagonal) bisecting the angle between the two neighbouring C_2 axes and a σ_h plane bisecting the C_3 axis. Therefore, its point group is D_{3h}. It also has an S_6 axis.	 Other elements of symmetry not shown
In case of staggered ethane, the elements of symmetry are C_3. It has $3C_2$ axes perpendicular to C_3 axis and $3\sigma_v$ planes (diagonal) bisecting the angle between the two neighbouring C_2 axes. Therefore, its point group is D_{3d}.	 Other elements of symmetry not shown

3.14 What is meant by operators in terms of elements of symmetry? What is order of symmetry operation? Show the symmetry operators of chair form of cyclohexane.

Ans If a structure of a molecule can be transformed into an identical or indistinguishable structure by the physical movement based on an element of symmetry, without breaking or deforming any part of the molecule, then that manipulation is called a symmetry operation

The order of a symmetry operation is the number of total operations that can be done to convert a structure to its equivalent/identical structure.

The chair form of cyclohexane belongs to the point group D_{3d}. Its elements of symmetry are C_3, $3C_2$, $3\sigma_v$ (diagonal) planes, i, S_6. Its operation of identity E (C_1) is also a symmetry operation. Moreover two times C_3 operation is an identity oeration (E). It can also be confirmed that five times operation of S_6 is also an operation of identity. Therefore, the order of symmetry operation of chair form of cyclohexane is 12. They are E, C_3^1, C_3^2, $3C_2$, $3\sigma_v$, i, S_6^1, S_6^5. The structure of the chair form of cyclohexane is as follows.

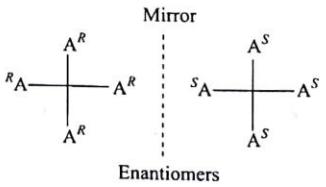


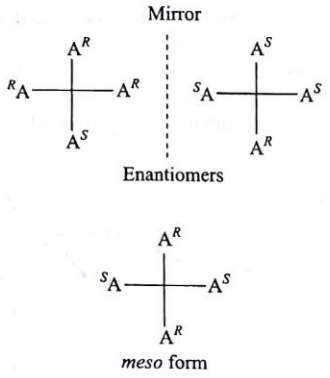
3.15 A molecule is not superimposable on its mirror-image structure. What could be the point group of that molecule?

Ans Since the molecule is not superimposable on its mirror image, the molecule as a whole is chiral. Consequently, it must have a point group that represents an asymmetric point group. Therefore, the molecule can possess any one of the following point groups: C_1, C_n, D_n

3.16 How many stereoisomers are possible for a molecule having the formula CA_4^* where A* represents an asymmetric centre. Are all of them optically active?

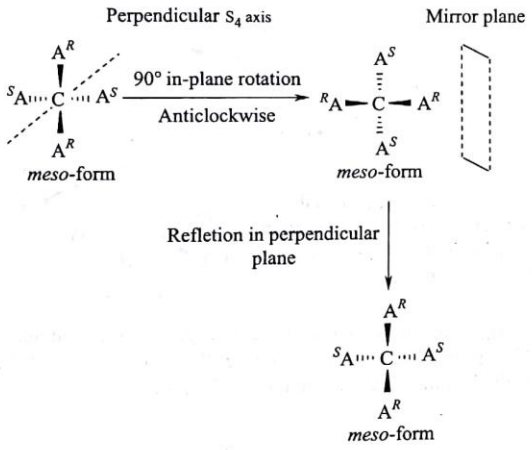
Ans The molecule represented as CA_4^* can have two pairs of enantiomers and one *meso*-compound. The asymmetric substituents can have both R and S configurations. The Fischer projection of stereoisomers in a perpendicular mirror plane can be shown as follows.



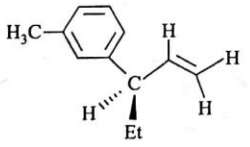


3.17 In question 3.15, the *meso* form is an achiral compound. What is the element of symmetry here for its achirality?

Ans The *meso*-form has a four-fold alternating axis of symmetry, that is, it has an S_4 alternating axis of symmetry perpendicular to the plane of the paper. This can be shown by the following Fischer projection.

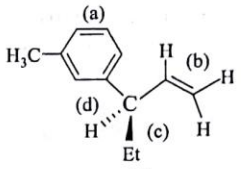


3.18 Give the chiral descriptor (*R*/*S*) of the chiral centre of the following compound. What are the products formed when it is subjected to bromination? Give the IUPAC names of the brominated compounds.



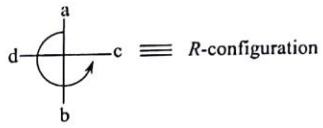
(I)

Ans The compound (I) shown has one chiral centre and the configuration is '*R*'. This can be readily understood by converting it into the corresponding Fischer projection.

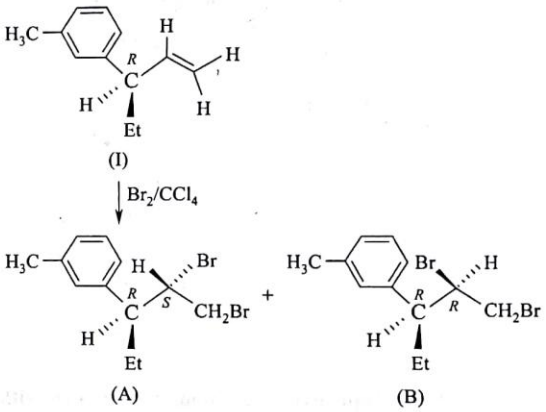


(I)

CIP priority shown by a, b, c, d



On bromination, we get two diastereoisomeric dibromo compounds, (A) and (B). The stereo structures of the compounds can be shown here.



(A) (B)

In (A), the new chiral centre has *S* configuration and in (B), it has *R* configuration. The IUPAC names of the compounds are as follows:

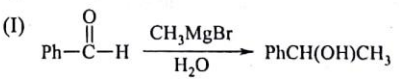
(I) is (*R*)-3-(3-Methylphenyl)pent-1-ene.

(A) is (2*S*,3*R*)-1,2-Dibromo-3-(3-methylphenyl) pentane.

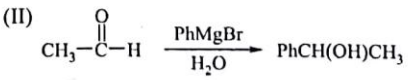
(B) is (2*R*,3*R*)-1,2-Dibromo-3-(3-methylphenyl) pentane.

3.19 $PhCH(OH)CH_3$ is obtained by Grignard reaction from two different aldehydes. If the chiral centre of the product has *R* configuration then how would you explain these reactions.

Ans The compound is a secondary alcohol. It can be obtained by the Grignard rection, as shown here.



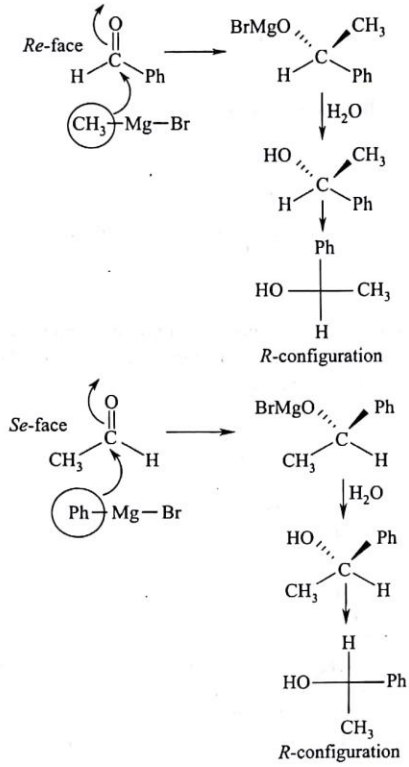
(I) $Ph-\overset{O}{\overset{\|}{C}}-H \xrightarrow[H_2O]{CH_3MgBr} PhCH(OH)CH_3$



(II) $CH_3-\overset{O}{\overset{\|}{C}}-H \xrightarrow[H_2O]{PhMgBr} PhCH(OH)CH_3$

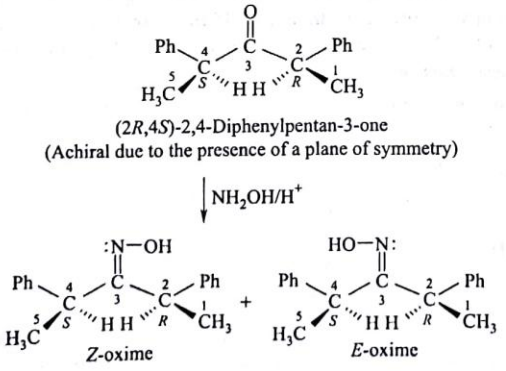
Since the chiral centre in $PhCH(OH)CH_3$ has the same configuration '*R*', it is obvious in case of (I), CH_3MgBr will react

with the *Re*-face of PhCH=O and in case of (II), PhMgBr will react with '*Se*' face of CH_3CH=O and vice versa. Reactions can be shown as follows.

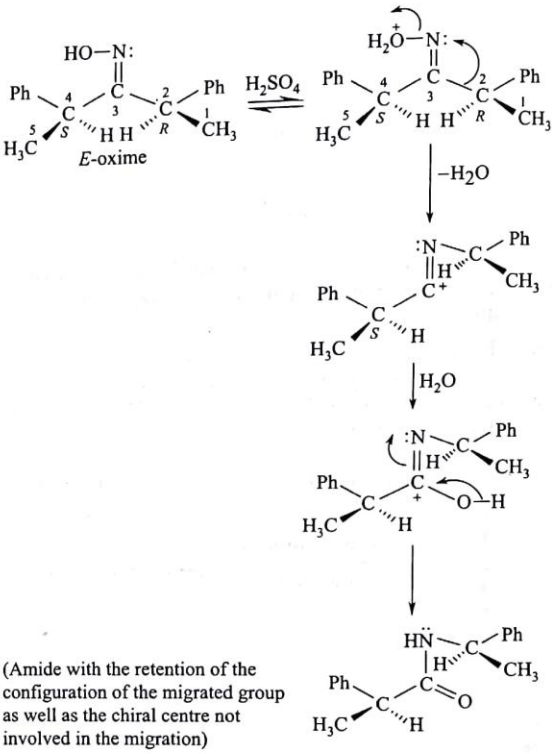


3.20 (2*R*,3*S*)-2,4-Diphenylpentan-3-one was treated with NH_2OH in the presence of dilute acid HCl. What are the products? What happens when they are subjected to the treatment of concentrated H_2SO_4? Discuss the stereochemical implications.

Ans (2*R*,3*S*)-2,4-Diphenylpentan-3-one reacts with NH_2OH to give diastereoisomeric *E*,*Z* oximes. The structures are shown here.

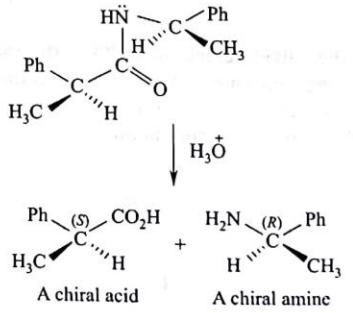


When oximes are treated with concentrated H_2SO_4, they undergo Beckmann rearrangement in a concerted manner with the retention of the configuration of the migrated group. Rearrangement is shown taking *E*-oxime as an example. In Beckmann rearrangement, *anti*-migration of group always takes place.



(Amide with the retention of the configuration of the migrated group as well as the chiral centre not involved in the migration)

When the amide is hydrolysed we get a chiral acid and a chiral primary amine. In each case, the configuration of the original chiral centres is retained in the product.



3.21 Trace the following conversions with three dimensional formulae as and where appropriate. Show appropriate reagents, catalysts, and solvents. Mention the characteristics of the steps involved.

(a) (*R*)-Butan-2-ol ⟶ *p*-Toluene sulfonate

NaBr | Acetone

Bromide $\xrightarrow{NMe_3}$ Salt

Bromide ↓ | Salt ↓ OH^-

Olefin + Alcohol | Products

(b)

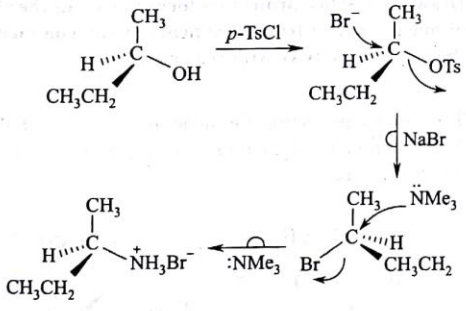
(*S*)-1-Phenylethanol $\xrightarrow[Ether]{SOCl_2}$ Alkyl chloride

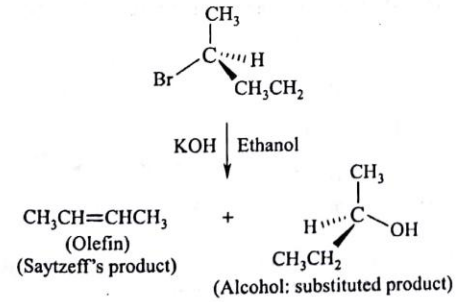
Alkyl chloride ↓ Acetate (Optically active) ⟶ Alcohol (Optically active) ↓

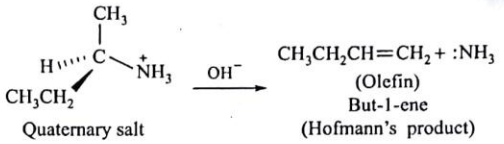
(*S*)-1-Phenylethyl iodide ⟵ *p*-Bromobenzene sulfonate

Ans

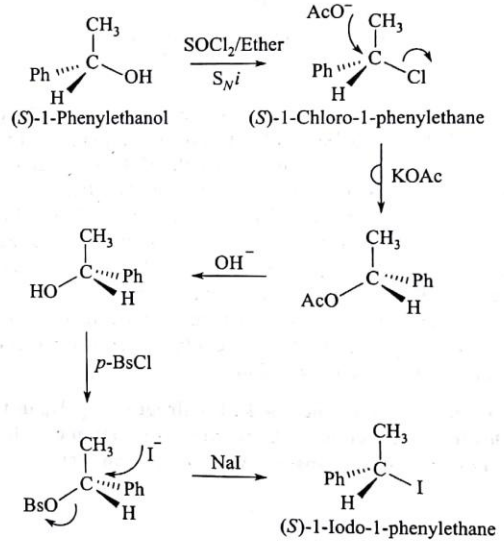
(a) (*R*)-Butan-2-ol is first converted into tosylate derivative with the retention of the configuration because the bonds that are directly attached to the chiral centre of the parent compound is not involved in the reaction. When *p*-toluene sulphonate is treated with NaBr, the corresponding bromide is obtained with the inversion of the configuration, because the step involved is an S_N2 substitution. When the bromide is treated with alcoholic KOH solution, an olefin is formed as the major product along with some alcohol. Treatment of the bromide with $:NH_3$ gives the corresponding quaternary ammonium salt, which when treated with an alkali gives an olefin along with a tertiary nitrogenous base. Reactions can be shown as follows.





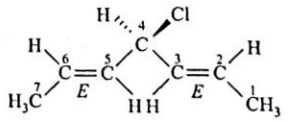


(b) In this case, the first reaction is a case of S_Ni reaction with the retention of the configuration. When alkyl chloride is treated with potassium acetate S_N2 reaction occurs with the inversion of the configuration. Hydrolysis of the acetate (ester) gives the corresponding chiral alcohol with the retention of the configuration. Treatment of the alcohol with *p*-bromosulfonyl chloride gives the corresponding brosylate with the retention of the configuration. Treatment of the *p*-bromobenzene sulphonate with NaI would give the corresponding iodide with the inversion of the configuration. The chronological reactions can be shown as follows.



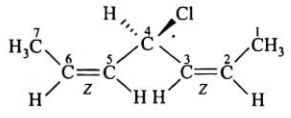
3.22 Draw all the possible stereoisomers of CH_3CH=CHCHClCH=$CHCH_3$ and mention whether they are *R* or *S* isomers.

Ans The compound has two olefinic double bonds capable of giving *E*,Z isomerism. Depending on their configurations, the carbon atom bearing the Cl atom (C-4) can be chiral or achiral. The structures of the possible stereoisomers are shown here.

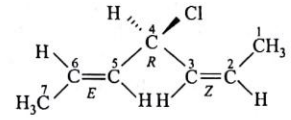


(1*E*, 5*E*)-4-Chlorohepta-2,5-diene

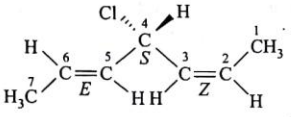
(A)



(1Z, 5Z)-4-Chlorohepta-2,5-diene
(B)



(1Z, 4R, 5Z)-4-Chlorohepta-2,5-diene
(C)

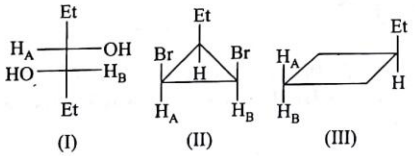


(1Z, 4S, 5Z)-4-Chlorohepta-2,5-diene
(D)

It is to be noted that in case of the stereoisomers (A) and (B), both the double bonds have identical configurations (both are *E* or both are *Z*). Consequently the C-4 carbon atom in these compounds does not represent a chiral centre.

In case of compounds (C) and (D), one double bond has *Z*-configuration and the other has *E*-configuration. In these cases, C-4 is a chiral centre and can have *R* or *S* configuration. In case of IUPAC naming, the group having *Z*-configuration gets preference over the group having *E*-configuration. Therefore, the compound (C) has (*R*)-configuration and the compound (D) has (*S*)-configuration.

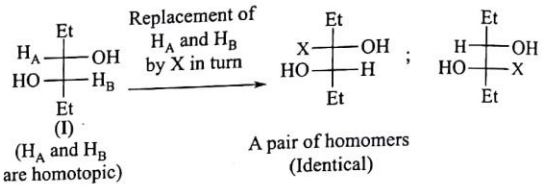
3.23 State whether the marked hydrogens H_A, H_B in the following compounds are homotopic, enantiotopic or diastereotopic. Give reasons in favour of your answer.



(I) (II) (III)

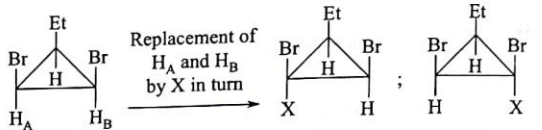
Ans The best way of ascertaining the topicity of a pair of identical ligands in a molecule is to carry out substitutions of the concerned ligands, one at a time, by a non-identical ligand. If those manipulations give same compounds, then the ligands in questions are homotopic. If enantiomers are formed, then the ligands are enantiotopic and if a pair of diastereoisomers is formed, ligands are diastereotopic.

On the basis of this argument, H_A and H_B in (I) are homotopic. H_A and H_B in (II) are enantiotopic and H_A and H_B in (II) are diastereotopic. These can be shown by the following substitutions.



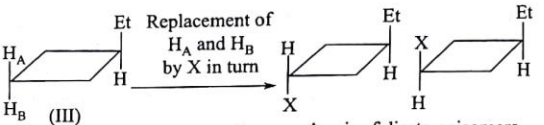
(I)
(H_A and H_B are homotopic)

A pair of homomers
(Identical)



(II)
(H_A and H_B are enantiotopic)

A pair of enantiomers



(III)
(H_A and H_B are diastereotopic)

A pair of diastereoisomers

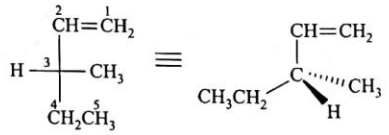
3.24 Answer the following:

(a) Write down a Fischer projection formula of each enantiomer of 3-methylpent-1-ene and specify the chiral centre as *R* or *S*. Draw corresponding flying wedge formula of each.

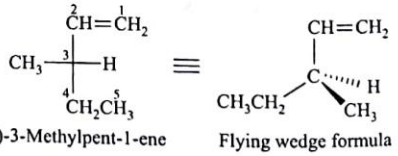
(b) Draw the Fischer projection formulae of all the stereoisomers of 2,3,4-trihydroxypentane and comment on their optical activity with reasons.

Ans

(a) The Fischer projection formulae as well as their flying wedge formulae of enantiomers of 3-methylpent-1-ene are shown here.

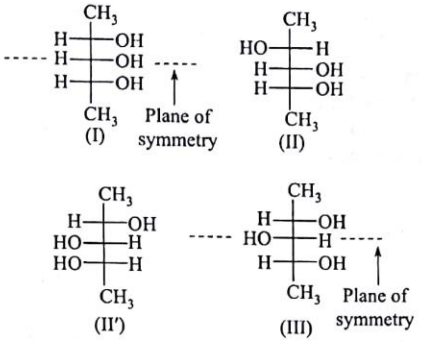


(*R*)-3-Methylpent-1-ene Flying wedge formula



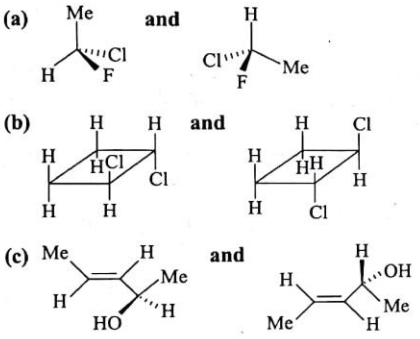
(*S*)-3-Methylpent-1-ene Flying wedge formula

(b) The Fischer projection formulae of stereoisomers of 2,3,4-trihydroxypentane are shown here.



Of the stereoisomers shown, (II) and (II') are chiral molecules and represent a pair of enantiomers. (I) and (III) are achiral *meso*-compounds. (I) and (III) have a plane of symmetry (as shown in Fischer projections).

3.25 Label the following pairs of molecules as homomers, enantiomers, or diastereoisomers.



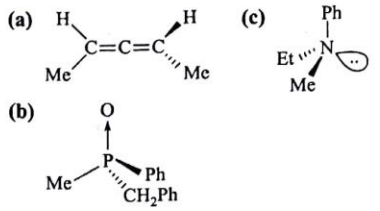
Ans The explanation is as follows:

(a) In this pair, molecules are constitutionally and configurationally same. They are (*R*)-isomer of 1-chloro-1-fluoroetane. Therefore, they are homomers.

(b) The molecules represent a pair of enantiomers because they are constitutionally identical but mirror image to each other.

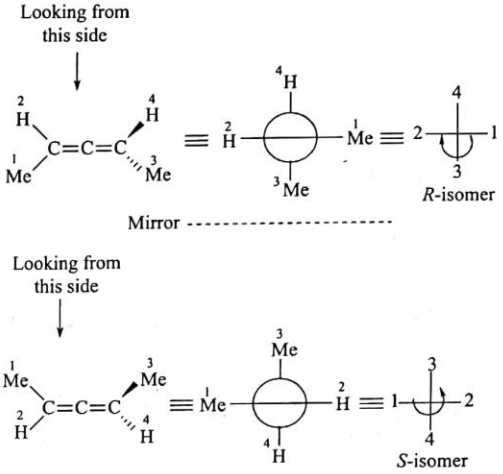
(c) The molecules have an olefinic double bond as well as a chiral centre. The chiral centre in each of the molecule has (*R*)-configuration and both are (*E*)-isomers. Therefore, the pair represents a pair of homomers.

3.26 Explain whether the following compounds are resolvable or not. Give *R,S*-descriptors wherever possible.

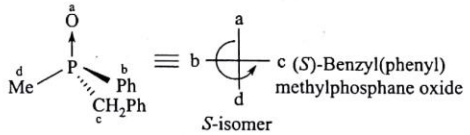


Ans The explanation is as follows:

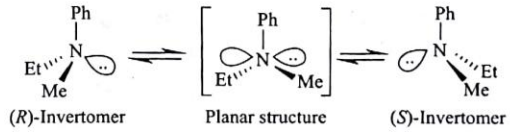
(a) The compound is a 1,3-disubstituted allene. Since the substituents on the terminal carbon atoms of an allene are perpendicular to each other, these types of allenes with each of the terminal carbons having different substituents represent chiral molecules. Fischer projections of the enantiomeric forms can be shown as follows.



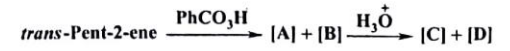
(b) The compound is a phosphane oxide. Here oxygen atom represents a substituent on the tetravalent phophorus atom. Since all the substituents on the phosphorus atom are different, the molecule is resolvable, that is, can exist as a pair of enantiomers.



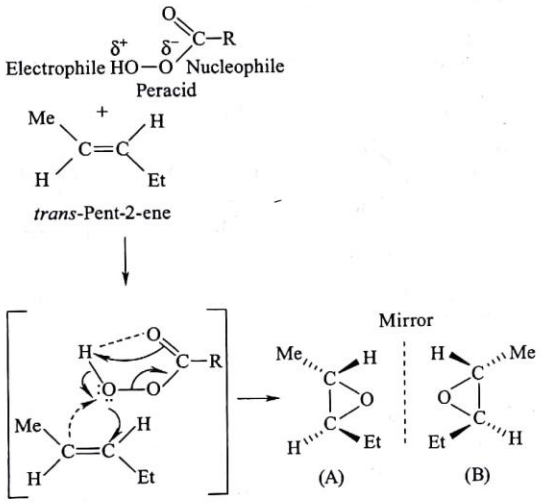
(c) The compound is a tertiary amine with a chiral nitrogen atom but is not resolvable. This is because, it undergoes rapid interconversion into enantiomeric forms due to the presence of a lone pair of electrons. Therefore, it always remains as a nonseparable *dl*-pair (invertomers). The process of inversion is shown here.



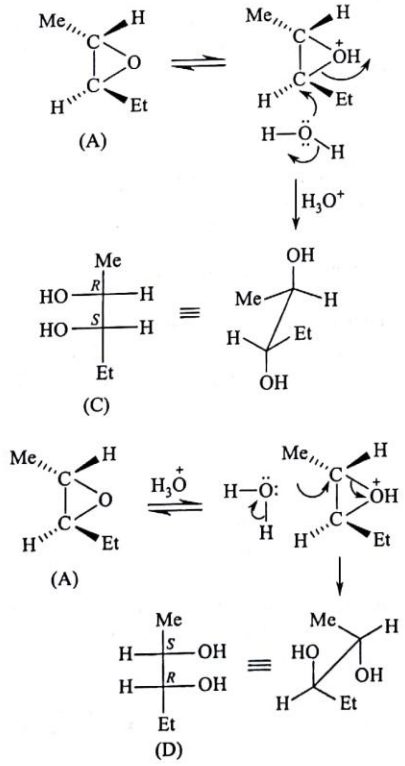
3.27 Write the products [A], [B], [C], and [D] in the following sequence of reactions. Discuss the mechanism and show the stereochemical courses of the reaction.



Ans *trans*-Pent-2-ene undergoes epoxidation when treated with $PhCO_3H$. The reaction is called Prileschieve reaction. Two stereoisomeric epoxides with enantiomeric relationship are formed. When epoxides are decomposed with dilute acid, enantiomeric diols are formed. The course of the reaction and the stereochemical course of the reactions are shown here.

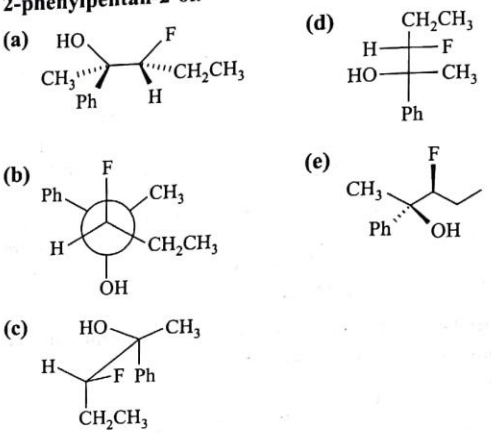


When either (A) or (B) is treated with dilute acid, the following reaction takes place.

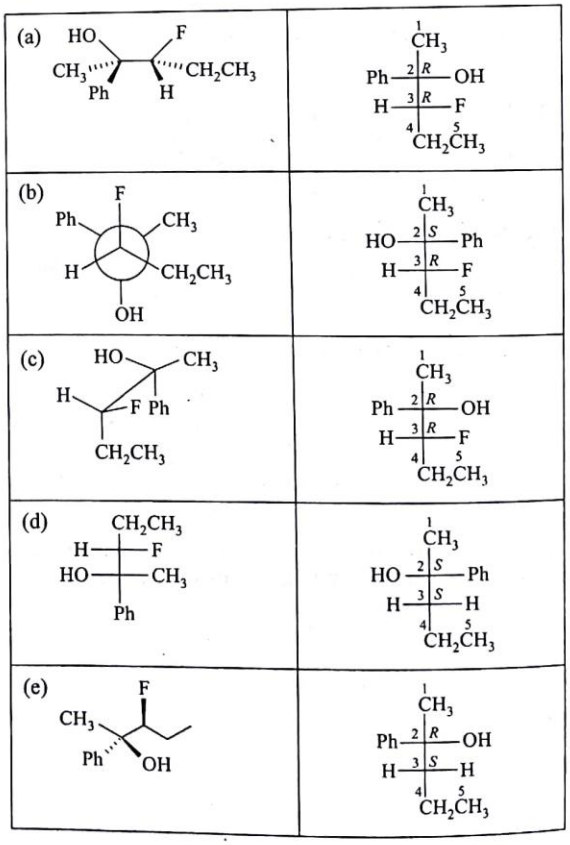


Compounds (C) and (D) are enantiomers. The same result is obtained when the compound (B) is hydrolysed.

3.28 The following structures are representations of 3-fluoro-2-phenylpentan-2-ol. Give the stereochemical relationship of each structure to (2*R*,3*R*)-3-fluoro-2-phenylpentan-2-ol.

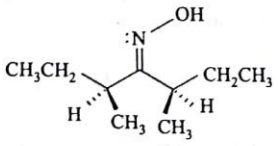


Ans The compounds (a) to (e) can be transformed into the following Fischer projection so that the absolute configuration can be ascertained easily.



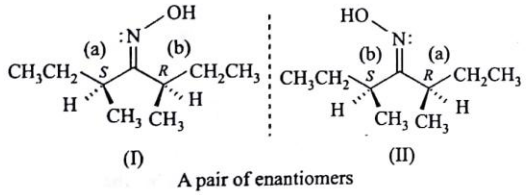
From the determination of the absolute configurations of the compounds for the compounds (a)–(e), it is evident that (a) is homomeric, (b) is diastereoisomeric, (c) is homomeric, (d) is enantiomeric, and (e) is diastereoisomeric to (2*R*,3*R*)-3-fluoro-2-phenylpentan-2-ol.

3.29 Suppose one made the following oxime. Then answer the following with suitable reasoning. (a) Is it resolvable? (b) Does it exhibit *E,Z*-isomerism? (c) Label the configurations of the chiral centres of the compound.



(A)

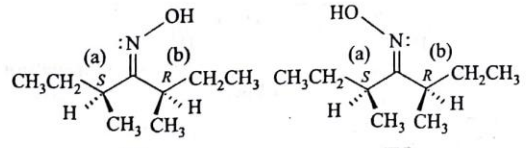
Ans The compound has two enantiomorphic groups having *R* and *S* configurations. The molecule has no elements of symmetry other than C_1 axis. Therefore it is a chiral molecule and capable of existing as enantiomers. Moreover, due to the presence of >C=N̈–OH, the molecule can exhibit *E,Z*-diastereoisomerism. The configurations of the chiral centres (a) and (b), in the following diagram, along with structures of the stereoisomers, are shown.



(I) (II)

A pair of enantiomers

Each of these stereoisomers can exist as a pair of diastereoisomers. *E,Z* isomers from the enantiomer (I) is shown here.



(III) (IV)

Z-isomer *E*-isomer

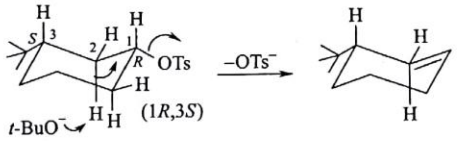
OH > .. OH > ..

R > *S* *R* > *S*

A pair of diastereoisomers

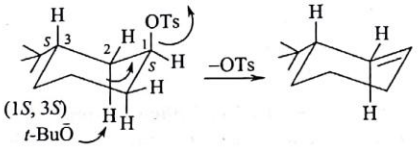
3.30 Explain why (1*R*,3S)-3-*tert*-butylcyclohexyl tosylate undergoes E2 elimination with potassium tertiary butoxide very slowly, whereas the (1*S*,3*S*) isomer reacts much more rapidly.

Ans The stereoelectronic requirement of E2 elimination is that the leaving group and the β-hydrogen must be antiperiplanar to each other. In case of (1*S*,3*R*)-3-*tert*-butylcyclohexyl tosylate, the leaving group –OTs and the β-hydrogen are not antiperiplanar in its most stable conformation, but in case of (1*S*,3*S*)-3-*tert*-butylcyclohexyl tosylate, they are antiperiplanar. That is why the reaction rates are different in these cases of diastereoisomeric compounds. The reactions are shown here.



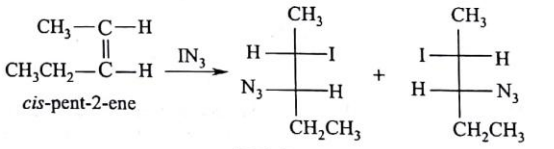
In the aforementioned compound, (1*S*,3*R*)-3-*tert*-butylcyclohexyl tosylate, H atom on the β-carbon and –OTs group are not antiperiplanar and therefore, the rate of E2 elimination is extremely slow.

In case of (1*R*,3*R*) isomer, –OTs group and β-hydrogen atom are antipriplanar and consequently E2 elimination takes place much more rapidly. The reaction is shown here.



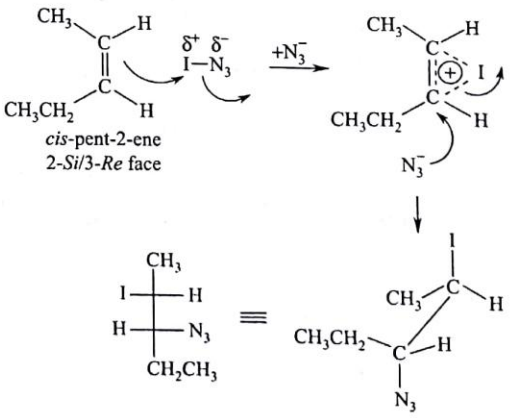
3.31 The reaction of *cis*-pent-2-ene with iodine azide in dichloromethane gives (2*S*,3*S*)-3-azido-2-iodopentane and (2*R*,3*R*)-3-azido-2-iodopentane as enantiomeric pair. Show the stereochemistry of the addition and give the curved arrow mechanism to account for it.

Ans The products and stereochemistry of this reaction is shown in Fischer projection.



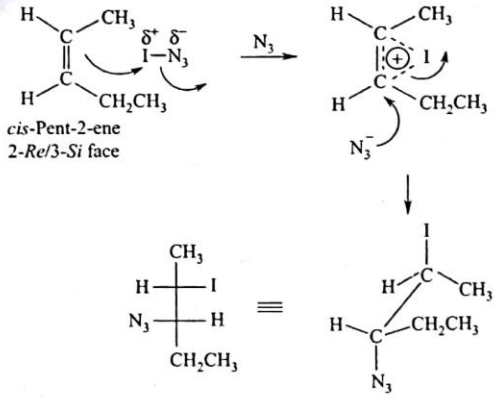
cis-pent-2-ene (2*S*,3*S*)-3-Azido-2-iodopentane (2*R*,3*R*)-3-Azido-2-iodopentane

The mechanism of the reaction is shown. *cis*-Pent-2-ene has enantiotopic faces and leads to the formation of a pair of enantiomers.



cis-pent-2-ene

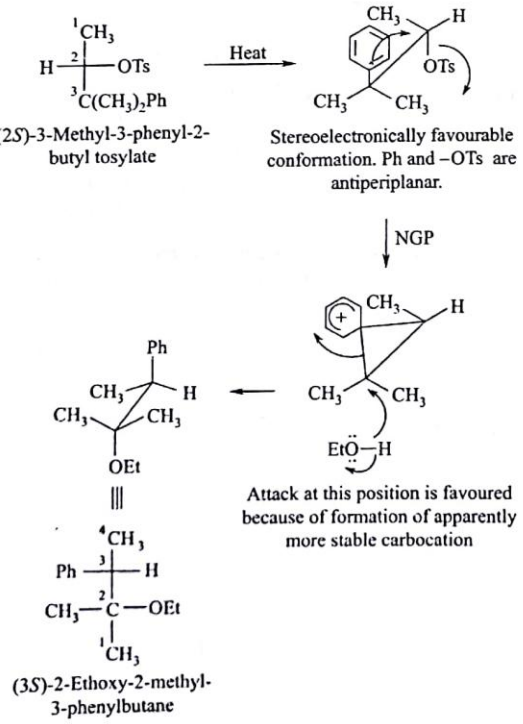
2-*Si*/3-*Re* face



The reaction can also give another pair of enantiomers, namely (2*S*,3*R*)-2-azido-3-iodopentane and (2*R*,3*S*)-2-azido-3-iodopentane, due to ring opening involving attack by N_3^- on the carbon bearing CH_3 group.

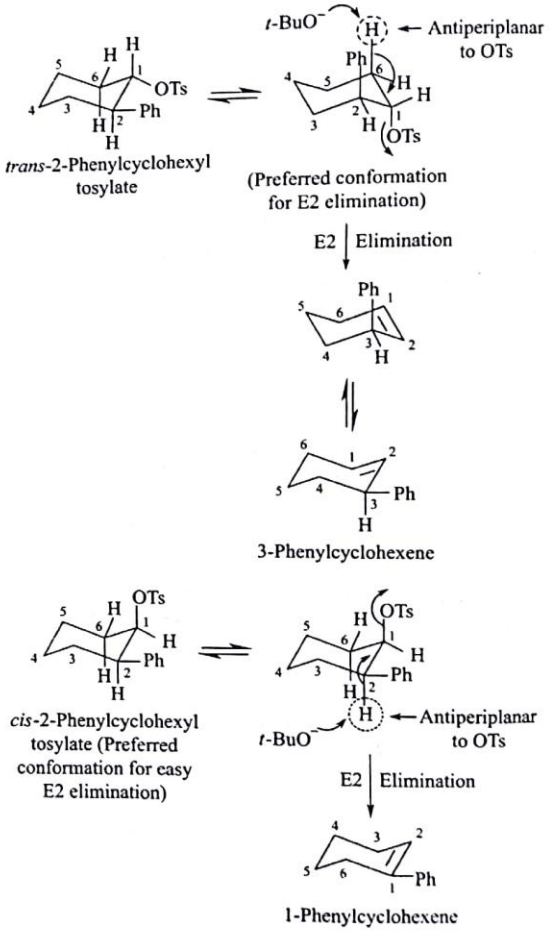
3.32 Heating (2*S*)-3-methyl-3-phenyl-2-butyl tosylate in ethanol leads to skeletal rearrangement and the formation of (3*S*)-2-ethoxy-2-methyl-3-phenylbutane. What does this information indicate about the stereoelectronic course of the skeletal rearrangement?

Ans It is a case of S_N2-type substitution with NGP. In this case Ph group in the substrate molecule is the neighbouring group. The mechanism of the reaction can be shown as follows.



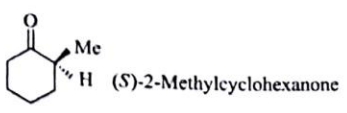
3.33 Treatment of *trans*-2-phenylcyclohexyle tosylate with potassium *tert*-butoxide gives mainly 3-phenylcyclohexene in a fairly slow process, whereas under the same conditions, *cis*-2-phenylcyclohexyl tosylate gives 1-phenylcyclohexene in a much shorter reaction time. Explain these observations.

Ans The reactions mentioned are E2 eliminations. The stereoelectronic requirements for E2 elimination are that the groups in this β-elimination must be antiperiplanar. This fact, when applied to these reactions, accounts for the regiospecificity. The reactions are shown here.

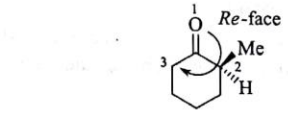


3.34 Draw the structure of (*S*)-2-methylcyclohexanone. What happens when *Re*-face of the C=O group reacts with $NaBH_4$?

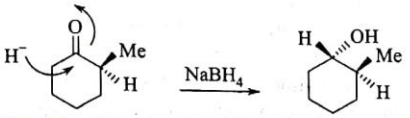
Ans The course and the stereochemistry of the reactions are shown here.



As we see the molecule from the top side of the paper, it represents the *Re*-face. Reduction of the ketone with $NaBH_4$ leads to a secondary alcohol. H^- from $NaBH_4$ attacks from the front side. The final product is (1*S*,2S)-2-methylcyclohexanol.



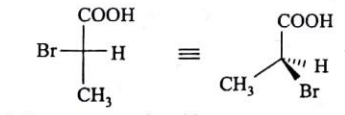
(*S*)-2-Methylcyclohexanone



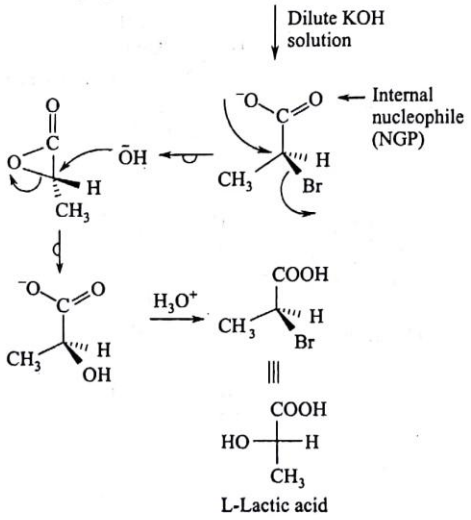
(*S*)-2-Methylcyclohexanone (1*S*,2*S*)-2-Methylcyclohexanol

3.35 In a method of reaction, (a) it is possible to prepare only L-lactic acid from (*S*)-2-bromopropanoic acid and in another reaction (b) pent-2-ene gives *dl*-mixture of 2,3-dibromopentane. Account for the stereospecificity of these reactions.

Ans (a) Formation of L-lactic acid from (*S*)-2-bromopropanoic acid involves a neighbouring group participation in an S_N2 reaction with hundred percent retention of configuration. The mechanism can be shown as follows.

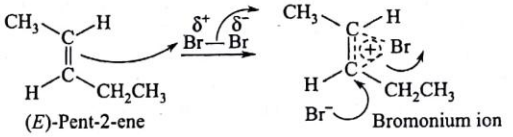


(*S*)-2-Bromopropanoic acid

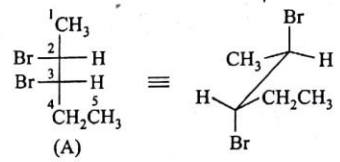


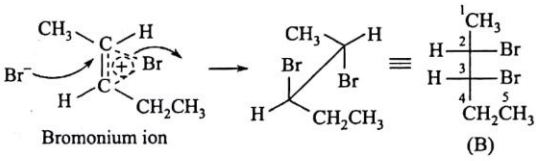
L-Lactic acid

(b) Bromination of an alkene is a case of *trans* electrophilic addition. In case of diastereoisomeric unsymmetrical alkenes, (*E*)-isomer gives *erythro-dl*-dibromo compound and (*Z*)-isomer gives *threo-dl*-dibromo compounds. The reaction with (*E*)-pent-2-ene with bromine is shown here.



(*E*)-Pent-2-ene Bromonium ion

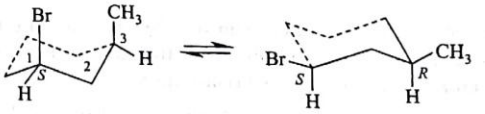




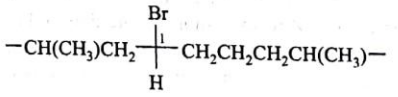
The compounds (A) and (B) are *erythro-dl*-pair of 2,3-dibromopentane.

3.36 Draw all possible chair conformations of (1*S*,3*R*)-1-bromo-3-methylcyclohexane and indicate the most stable conformer.

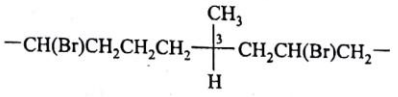
Ans The two possible chair conformations of (1*R*,3*S*)-3-bromo-1-methylcyclohexane are shown. The conformer in which Me and Br groups are equatorial is more stable. The other one has strong 1,3-diaxial interaction.



More stable conformation



C-3-configuration
S-configuration

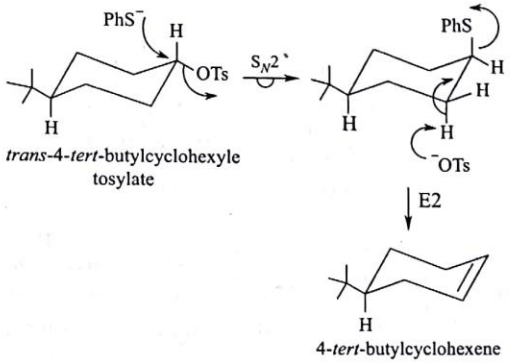


C-1-configuration
R-configuration

It is to be noted that conformational change through ring inversion of chair form of cyclohexane does change the absolute configurations of the chiral centres on the system.

3.37 Explain the fact that *trans*-4-*tert*-butylcyclohexyl tosylate undergoes bimolecular elimination with the bases bromide and thiophenolate, although not with the much stronger base ethoxide.

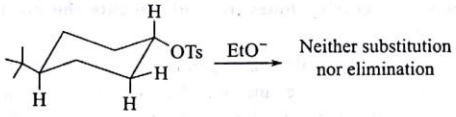
Ans This is a case of merged substitution–elimination reaction. During E2 elimination, the stereoelectronic requirement is that the groups on the α-carbon and the β-carbon must be periplanar to each other. Bromide and thiophenolate ions are good nucleophiles but weaker bases. Therefore, initially they cannot participate in the reaction as base but do so as nucleophiles. The sequential reactions are shown as follows.



trans-4-*tert*-butylcyclohexyle tosylate

4-*tert*-butylcyclohexene

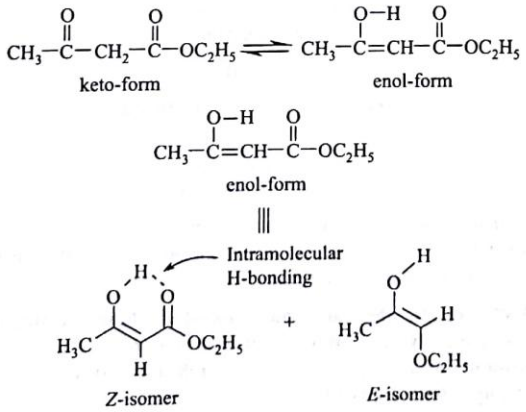
EtO^- is a strong base but poor nucleophile. Moreover, in *trans*-4-*tert*-butylcyclohexyle tosylate, β-hydrogen and OTs group are not antiperiplanar. Therefore E2 elimination is stereoelectronically not favourable



trans-4-*tert*-Butylcyclohexyle tosylate

3.38 Show that the enol-form of ethyl acetoacetate may exist as different diastereoisomers. Indicate, with reasons, the more stable of the diastereoisomers.

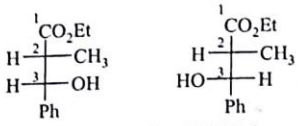
Ans The enol-form of ethyl acetoacetate can have *E,Z*-diastereoisomerism due to the formation of a differently substituted double bond. The *Z*-form is more stable due to the formation of six-membered cyclic system through the formation of intramolecular hydrogen bonding. Structures are shown here.



Z-isomer *E*-isomer

3.39 Delineate the structures of two different diastereoisomers (2*R*,3*S*) and (2*R*,3*R*) of the compound ethyl 3-hydroxy-2-methyl-3-phenylpropanoate. How will you assign these diastereoisomers as *erythro* and *threo* forms? Discuss how you will predict the preferred conformationof each of these diastereoisomers.

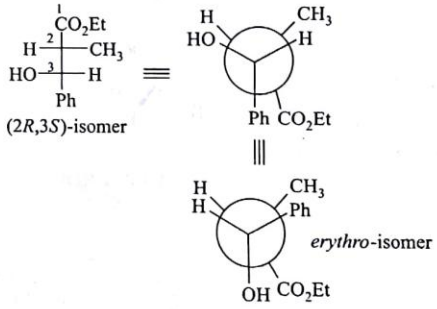
Ans The Fischer's projections of enantiomeric (2*R*,3*S*)- and (2*R*,3*R*)-2-ethyl-3-hydroxy-3-phenylpropaonate are shown here.

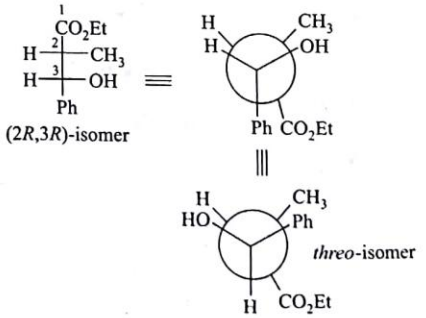


(2*R*,3*R*)-isomer (2*R*,3*S*)-isomer

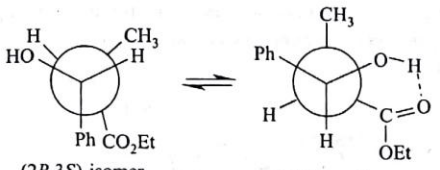
Ethyl 3-hydroxy-2-methyl-3-phenylpropaonate

Of these two isomers, (2*R*,3*R*)-isomer represents *threo* isomer and (2*R*,3*S*)-isomer represents *erythro* isomer. In these cases, like groups are considered to be (H/H), (CH_3/Ph), and (OH/CO_2Et). In Newman projections, two pairs of like groups can be made to coincide in case of (2*R*,3*S*)-isomer. Therefore, it represents *erythro*-form and in case of (2*R*,3*R*)-isomer, only one pair of like groups can be made to coincide in its Newman projection, It is therefore, the *threo*-form.



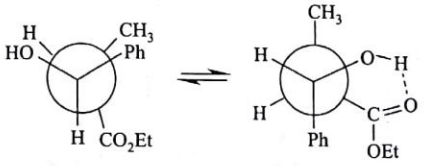


The preferred conformations in both the cases are those that get extra stability through intramolecular hydrogen bonding. The structures are shown here.



(2*R*,3*S*)-isomer
erythro isomer

Stable conformar

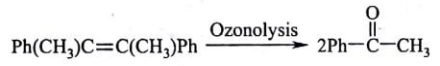


threo isomer
(2*R*,3*R*)-isomer

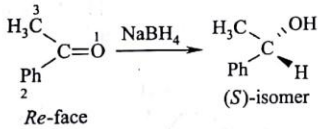
Stable conformar

3.40 Ozonolysis of $Ph(CH_3)=(CH_3)Ph$ gives two molecules of acetophenone. When this is reduced with $NaBH_4$, hydride transfer takes place from the *Re*-face of acetophenone molecules to produce (*S*)-1-methyl-1-phenylethanol. Find out the stereochemistry of the parent olefinic compound.

Ans The ozonolysis of $Ph(CH_3)=(CH_3)Ph$ gives two molecules of acetophenone.

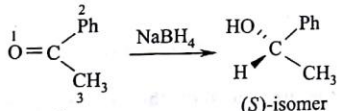


$NaBH_4$ reduction on the *Re*-face of the actophenone can be shown as follows.



Re-face

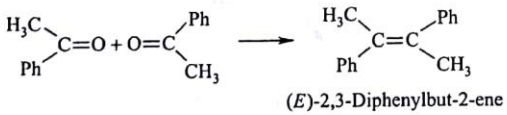
(*S*)-isomer



Re-face

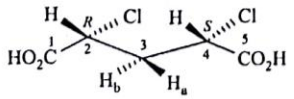
(*S*)-isomer

If we combine two units of acetophenone, each of them leading to the formation of (*S*)-alcohol, we find that the original olefinic compound must be (*E*)-diastereoisomers.

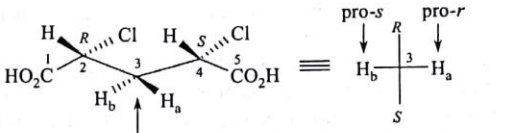


(*E*)-2,3-Diphenylbut-2-ene

3.41 Designate *pro-r* and *pro-s* hydrogen atoms marked as H_a and H_b in the following compound.



Ans This compound contains two homomorphic chiral centres, numbered as 1 and 4. C-3 is a pseudoasymmetric centre having two prochiral hydrogen atoms. The configuration of C-2 is (*R*) and that of C-4 is (*S*). When H_a is given higher priority over H_b, the absolute configuration of C-3 becomes (*r*). Therefore, H_a represents *pro-r* group. Consequently, H_b represents *pro-s* group.



Pseudoasymmetric centre

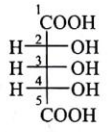
C-3 has (*R*) configuration when $H_a > H_b$

In C-3, priority order of groups are $R > S > H_a > H_b$ when H_a is given higher priority over H_b

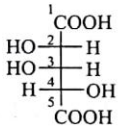
3.42 Draw the Fischer projection formula of all the possible stereoisomers of 2,3,4-trihydroxyglutaric acid. Comment on the stereogenicity and chirotopicity of carbon centres with reasons and find out the pseudoasymmetric centre, if any, in any of these isomers.

Ans Four stereoisomers of the compound are possible. The Fischer projection formulas of all the steroisomers of 2,3,4-trihydroxyglutaric acid are given below.

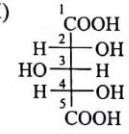
(I)



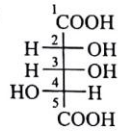
(III)



(II)



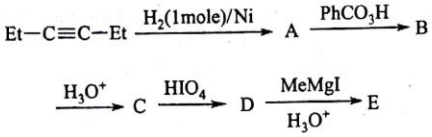
(IV)



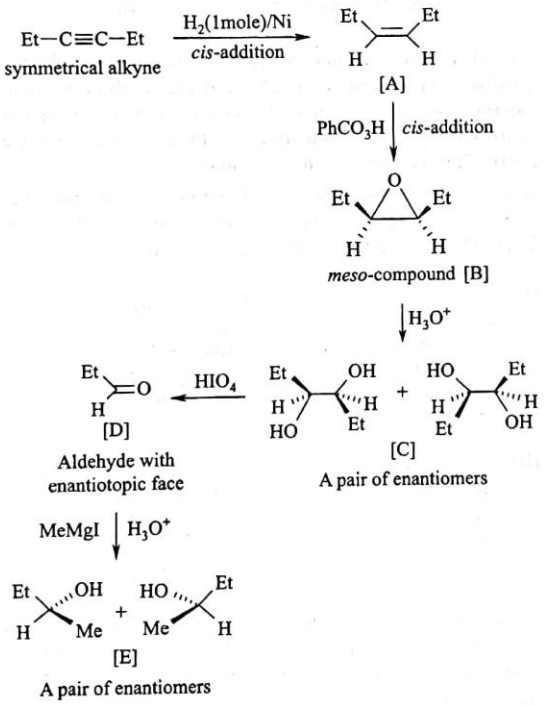
In compound (I), C-2 has (*R*)- configuration and C-4 has (*S*) configuration. The C-3 represents a pseudoasymmetric centre and its absolute configuration is (*r*). The C-3 carbon of the compound (II) is also a pseudoasymmetric centre having (*s*) configuration. Both (I) and (II) are *meso*-compounds and are, therefore achiral. Since the molecules (I) and (II) are not chiral, C-2, C-3, and C-4 are achirotopic but all of them are stereogenic, that is, exchange of any two substituents gives a new stereoisomer.

The isomers (III) and (IV) are chiral molecules. C-2, C-3, and C-4 centres are chirotopic and C-2 and C-4 centres are stereogenic. However, the pseudoasymmetric C-3 centre in (III) and (IV) is chirotopic but non-stereogenic, that is, exchange of any two substituents does not produce a new stereoisomer.

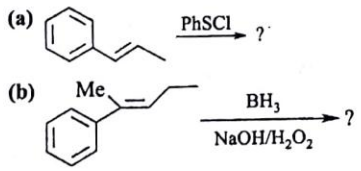
3.43 Give the products A, B, C, D, and E in the following sequence of reactions and comment on their stereochemistry.



Ans Metal/H_2 hydrogenation is stereospecifically *cis*-addition. Epoxidation of an alkene is also a *cis*-addition. When a symmetrical *cis*-olefine is subjected to epoxidation then a *meso*-compound is obtained. Acid catalysed ring opening is stereochemically *trans*-dihydroxylation. Periodic oxidation of a 1,2-diol leads to the formation of two molecules of carbonyl compounds, same or different, depending on the nature of the diol. Addition of Grignard reagent followed by hydrolysis gives an alcohol. The course along with the stereochemistry of the reactions is given here.

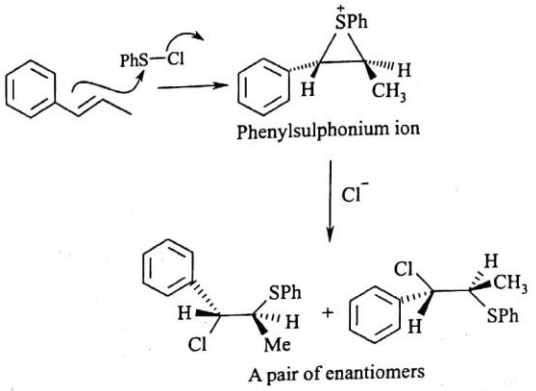


3.44 Give the products of the following reactions along with the stereochemical outcome.

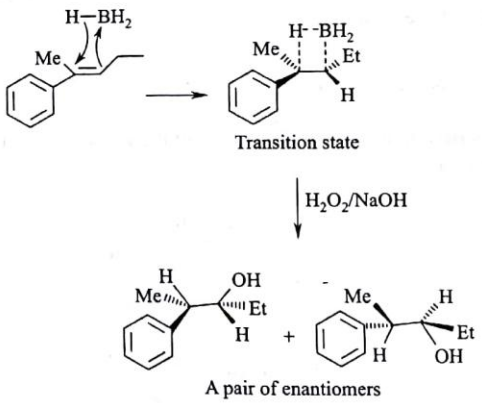


Ans The explanation is as follows:

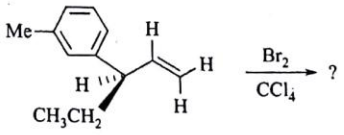
(a) Reaction takes place through a cyclic phenylsulphonium ion. Since the given olefinic compound is a *trans*-olefin and the addition is also *trans*, final products are a pair of *erythro* enantiomers. The course of the reactions is shown here.



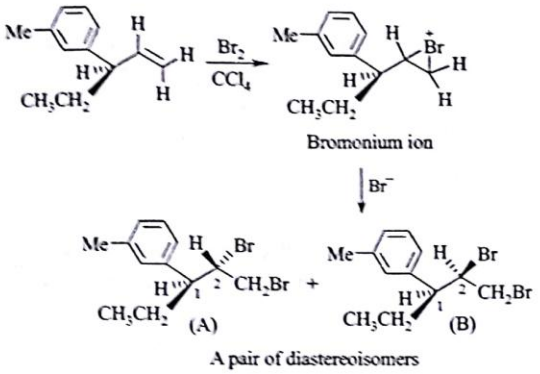
(b) It is a case of hydroboration–oxidation. The net result is *cis*-hydration to the olefinic double bond via a four-membered cyclic transition state. Addition of water molecule takes place in an *anti*-Markownikov way. The reactions and stereochemistry are shown here.



3.45 Give the products of the following reaction and assign *R*,*S*-configuration to each chiral centre of the product and comment on their stereochemical relationship.

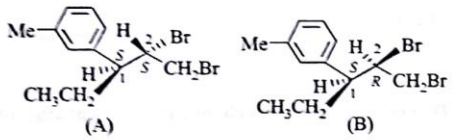


Ans Bromination of an olefinic compound is a *trans*-addition reaction. There is already a chiral centre present with a fixed configuration. Addition of bromine occurs through a cyclic bromonium ion and leads to the formation of another chiral centre in the present case. Therefore, final products would be a pair of diastereoisomers. The reaction and stereochemistry is shown here.



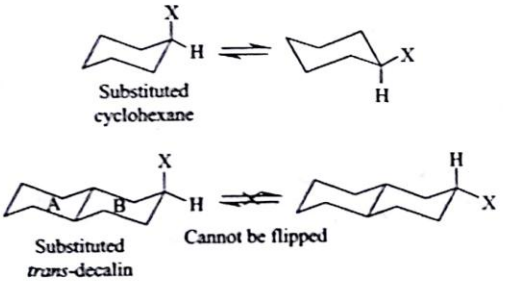
A pair of diastereoisomers

Since bromonium ion can have two different orientations, that is, up and down, the bromine atom at the newly formed chiral centre is up and down also. In the compound (A), chiral centre 1 has (*S*)-configuration and chiral centre 2 also has (*S*)-configuration. In compound (B), the configurations of the same chiral centres are (*S*) and (*R*) respectively. Therefore, one is (*S,S*) and the other is (*S,R*) isomers. That is they are diastereoisomers.



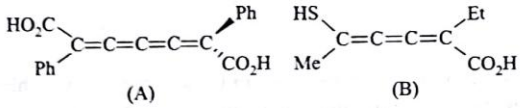
3.46 Reaction of substituted cyclohexanes having chair conformation cannot be investigated because of rapid ring inversion. However, comparable results are obtained when similarly substituted *trans*-decaline is taken. Explain this fact.

Ans Chair conformation of cyclohexane undergoes rapid ring inversion. In this process axial substituent becomes equatorial and vice versa. Therefore, the reactivities of this substituent cannot be studied properly. However, if this inversion can be prevented, then the properties of axial and equatorial substituent can be studied separately. In case of *trans*-decalin, two cyclohexane ring systems are *trans*-fused, and cannot undergo flipping due its conformationally locked structure. In this case axial and equatorial substitutents do not change their fixed position and consequently their properties can be investigated.

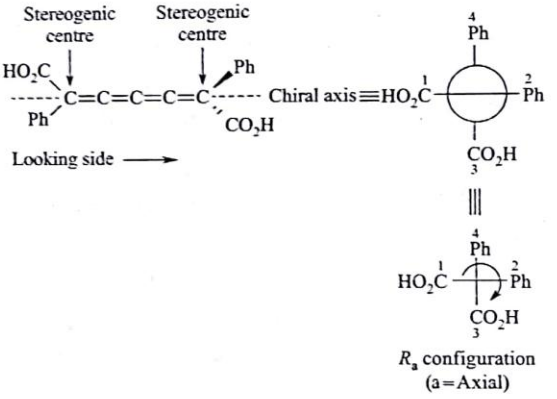


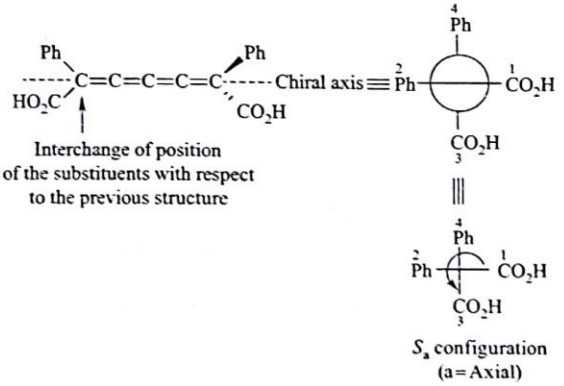
Unsubstituted second cyclohexane ring (A) in *trans*-decalin does not influence the reaction of the substituted cyclohexane ring (B), either electronically or sterically.

3.47 Which of the following compounds have both chiral axis and stereogenic centres and which of them has only one of them? In case of a compound having axial chirality, give their CIP configurational descriptors.



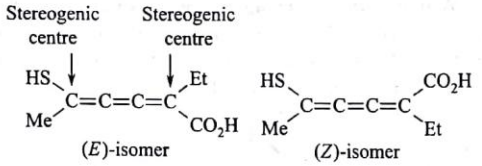
Ans The compound (A) has an even number of cumulated double bonds with different substituents on each of the terminal carbon atoms. Subsituents on the terminal carbon atoms are in perpendicular planes. Therefore, it has a chiral axis. Each of the terminal carbon atoms is stereogenic because interchange of the positions of the substituents will result in another stereoisomer. This is shown.





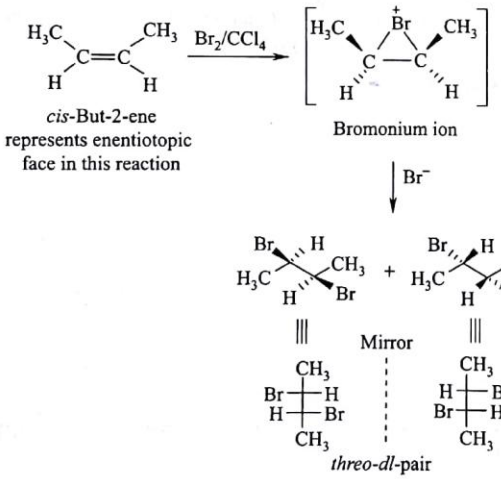
In case of the compound (A), the terminal carbon atoms along with their substituents lie in the same plane because the compound has an odd number of cumulated double bonds. There is no chiral axis in this compound; however,

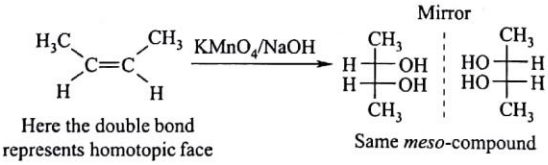
the terminal carbon atoms with different substitituents on each of them represent stereogenic centres. They can exhibit *E*/*Z* isomerism.



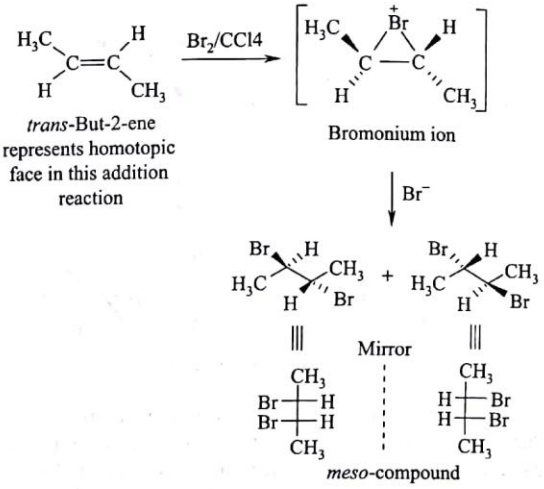
3.48 Between *cis*-but-2-ene and *trans*-but-2-ene, which one has an enantiotopic face and under what conditions? Give a suitable example in favour of your answer.

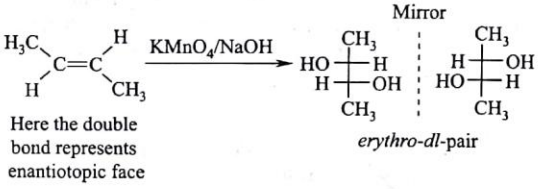
Ans Both *cis*- and *trans*-but-2-ene can demonstrate the presence of enantiotopic faces depending on the mode of addition reactions they undergo, that is, *cis*- or *trans*-addition. If *cis*-but-2-ene undergoes any *trans*-addition like bromination then a *threo-dl*-pair of dibromobutane is obtained. Under this condition, *cis*-but-2-ene represents an enantiotopic face. However, in the case of reaction with alkaline $KMnO_4$ (*cis*-hydroxylation), *meso*-2,3-dihydroxybutane is obtained. In this case, double bond of *cis*-but-2-ene represents a homotopic face.



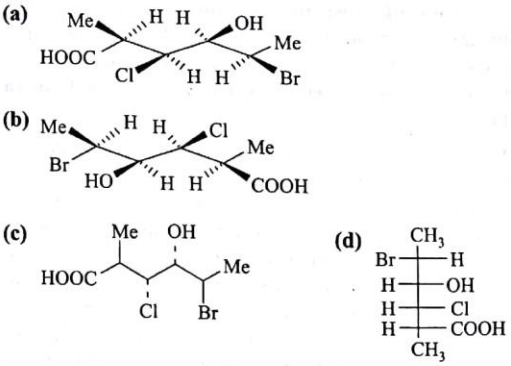


When *trans*-but-2-ene undergoes bromination, then only the *meso* compound is obtained via bromonium ion and the double bond, in this case, represents homotopic face. However, in the case of dihydroxylation with alkaline $KMnO_4$, the products are *threo-dl*-pair. Here the double bond represents enantiotopic face.

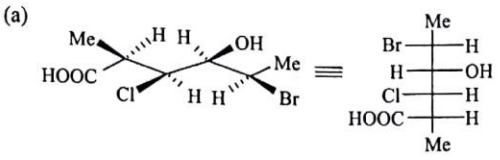


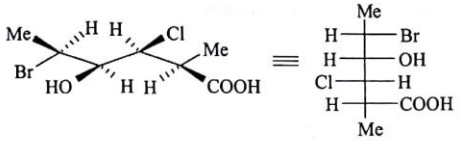


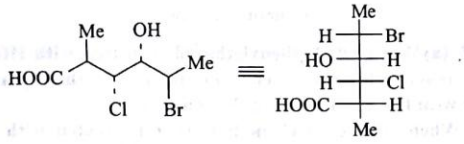
3.49 Determine the stereochemical relationships of the following compounds.

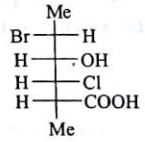


Ans Two different methods can be used to determine the stereochemical relationships of these four compounds: One, by converting all of them into identical type of Fischer projections and to see whether they are superimposable (homomers), or non-superimposable with mirror image relationship (enantiomers) or non-superimposable and not mirror images to any one (diastereoisomers). This method is shown.



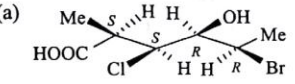
(b) 

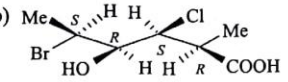
(c) 

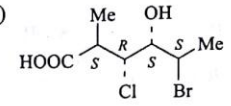
(d) 

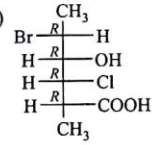
From the conversion of each stereoisomer to the corresponding Fischer projection, we find that (a), (b), (c), and (d) are all diastereoisomeric to each other.

Two, if we find out the absolute configuration of each chiral centre of each stereoisomer, we find the following absolute configurations.

(a) 

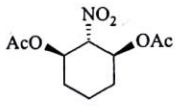
(b) 

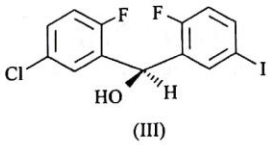
(c) 

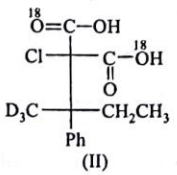
(d) 

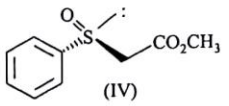
It is obvious therefore, that all are diastereoisomeric.

3.50 Find the absolute configuration of each chiral centre in each of the following compounds.


(I)

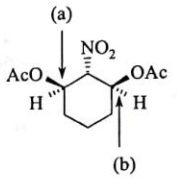

(III)


(II)

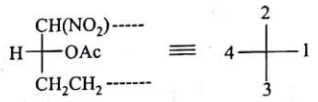

(IV)

Ans

(I) In case of compound (I), there are three chiral centres. The carbon atom bearing the $-NO_2$ group represents a pseudoasymmetric centre. Two carbon atoms bearing –OAc groups have (*R*) and (*S*) configurations. This is shown here.

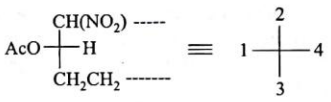


Chiral centre marked (a) has (*R*) configuration. Its Fischer Sprojection can be written as



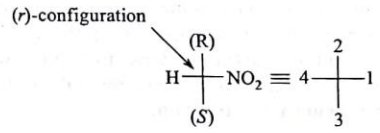
Chiral centre (a) (*R*)-configuration

Chiral centre marked (b) has (*R*) configuration. Its Fischer Sprojection can be written as

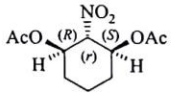


Chiral centre (b) (*S*)-configuration

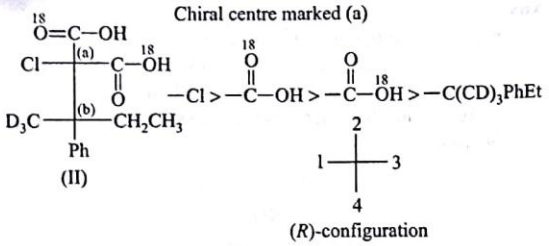
Since the chiral centres marked (a) and (b) are enantiomorphic, the carbon atom bearing $-NO_2$ group represents a pseudoasymmetric centre. Its configuration is found to be '*r*'. This is shown.



Therefore, the complete stereochemical descriptors of the compound is

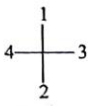


(II) The compound contains two chiral centres. These are marked as (a) and (b). The priorities of groups on each of these chiral centres, according to CIP rules, are shown. Based on these, the absolute configurations of both the chiral centres are found to be (*R*). These are shown.



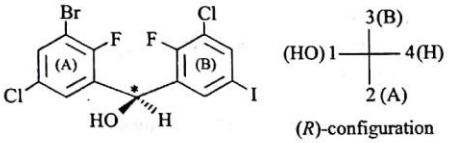
Chiral centre marked (b)

$-C(Cl)COOH > Ph > -Et > CD_3$



(*R*)-configuration

(c)

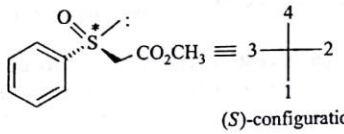


(*R*)-configuration

The priorities of groups on the chiral centre (*) is –OH > (A) > (B) > H.

This compound is (*R*)- enantiomer.

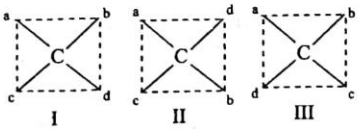
(IV) The compound has a chiral sulfur centre. The priorities of groups on the chiral centre, according to CIP rules, is $O > -Ph > -CO_2CH_3 > ...$ The absolute configuration of the chiral centre is shown here.



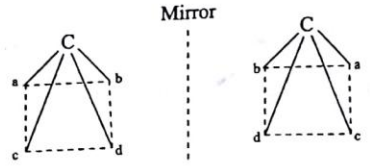
(*S*)-configuration

3.51 If the compound C_{abcd} is assumed to be square-planar, then how many stereoisomers are possible? What are the stereochemical relationships among them? If each of the square planar structure assumes pyramidal structure then how many stereoisomers are possible and what is their stereochemical relationship.

Ans When the compound C_{abcd} assumes square-planar structure then three stereoisomers are possible. Since all of them have planar structure, none of them is chiral. Stereochemically they are diastereoisomers. Structures are shown here.



When each of these square-planar structures is converted to pyramidal structure with C at the apex then three pairs of enantiomers are formed, that is, six stereoisomers are formed. Only one pair of enantiomers (transformed to pyramid form from I) is shown here.



A pair of enantiomers

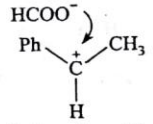
3.52 (a) When (*R*)-1-phenylethanol is heated with HCOOH, inactive formate ester is obtained. Give the explanation with the mechanism of the reaction.

(b) When (*R*)-sec-butyl methyl ether is treated with HI then the ether is transformed into the corresponding alcohol with the retention of the configuration. Explain the reaction.

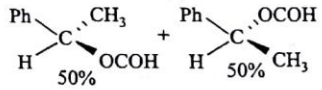
Ans

(a) In this case the reaction proceeds through S_N1 mechanism involving a stable benzylic carbocation. The course of the reaction is shown here.

(*R*)-1-Phenylethanol

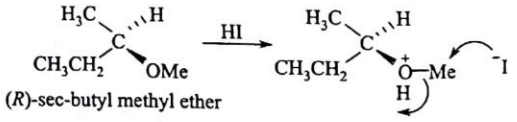


Carbocation with enantiotopic face

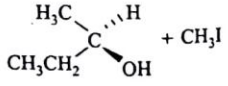


(Racemic inactive formate)

(b) It is a case of cleavage of an ether linkage without affecting the chiral centre. Therefore, the configuration of the ether is retained in the corresponding alcohol.



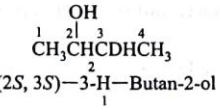
(*R*)-sec-butyl methyl ether



(*R*)-2-Methylbutanol
(retention of configuration)

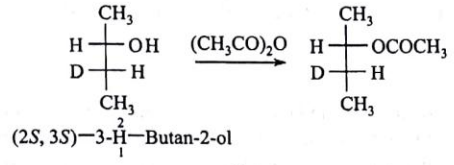
It is a case of S_N2 displacement and the strong nucleophilic iodide ion attacks the less hinderd methyl group.

3.53 Give the products formed when the following compound is converted into its acetate and then subjected to pyrolysis.

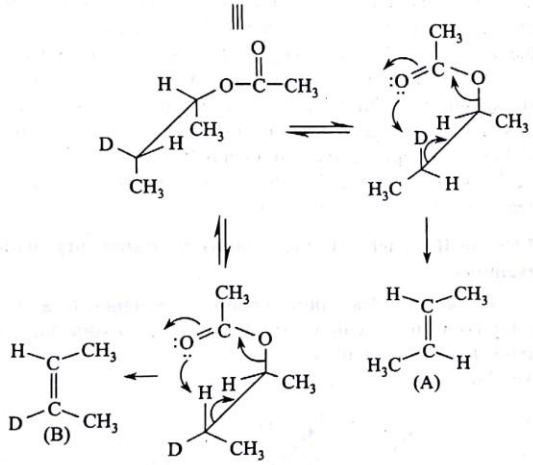


(2*S*, 3*S*)—3-H—Butan-2-ol

Ans The course of the reaction along with the products is shown here.

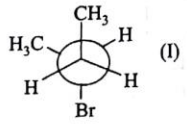


(2*S*, 3*S*)—3-H—Butan-2-ol



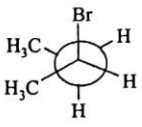
The reaction is pyrolytic *cis*-elimination of an acetate. Two products are possible due to the loss of β-hydrogen as well as β-deuterium. (A) and (B) are different compounds and not diastereoisomers because they are constitutionally different.

3.54 Given here is a Newman projection.

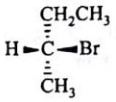


Is this structure (*R*) or (*S*)? Determine whether each of the following compounds is homomer or enantiomer to this Newman projection.

(a)

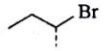


(b)



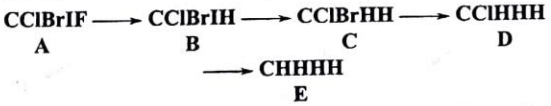
(c)

(d)



Ans The absolute configuration of (I) is (*R*). Here (I) is enantiomer of (I), (I) and (I) are homomers, (c) is enantiomer of (I) and (d) and (I) are also homomers.

3.55 Find out the change in point group and nature of elements of symmetry when the following symmetrization reactions are carried out stepwise.

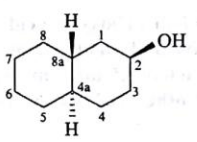


Ans 'A' is a chiral molecule with one asymmetric centre. Its point group is C_1. Replacement of F by H does not affect the asymmetry and consequently the point group of 'B' is also C_1. The compound 'C' is a prochiral molecule having C_s point, that is, a molecule with only one plane of symmetry.

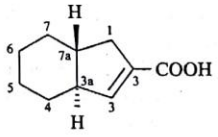
The compound 'D' belongs to point group C_{3v}. It has a C_3 proper axis and three s_v planes. The compound 'E' has T_d point group. Its elements of symmetry are three C_2 axes, four C_3 axes, three S_4 axes, and six s_d planes.

3.56 Give the stereochemical names of the following compounds.

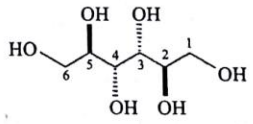
(a)



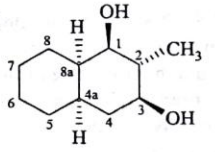
(b)



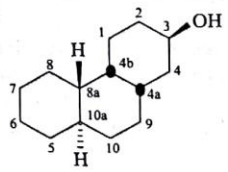
(c)



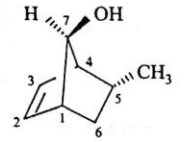
(d)



(e)



(f)



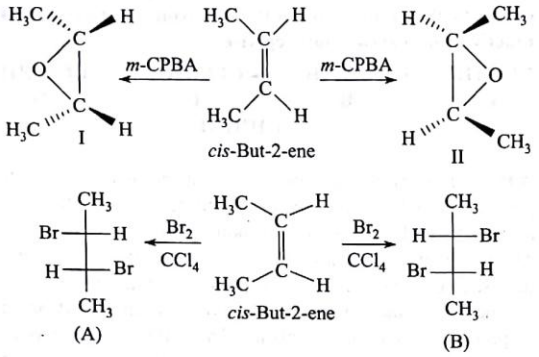
Ans The stereochemical names of the structures are given. Note the numbering of the carbon skeleton in each case.

(a) (2*S*, 4a*R*, 8a*R*)-Decahydronaphthalen-2-ol.
(b) (3a*R*, 7a*R*)-Octahydro-1-*H*-indene-2-carboxylic acid.
(c) (2*R*, 3*R*, 4*R*, 5*R*,)-Hexane-1,2,3,4,5,6-hexol.
(d) (1*R*, 2*R*,3*S*, 4a*R*, 8a*R*,)-2-Methyldecahydronaphthalene-1,3-diol.
(e) (3*R*,4a*R*,4b*R*,8a*S*,10a*S*)-Tetradecahydrohydrophenanthren-3-ol.
(f) (1*R*, 4*S*, 5*S*, 7*R*)-5-Methylbicyclo[2.2.1]hept-2-en-7-ol.

3.57 The topicity of faces RCH=CHR type molecule can be different depending on the nature of addition reactions carried out. Justify the statement with suitable examples.

Ans If we take but-2-ene as an alkene then two faces of *cis*-but-2-ene are homotopic when epoxidation reaction is carried

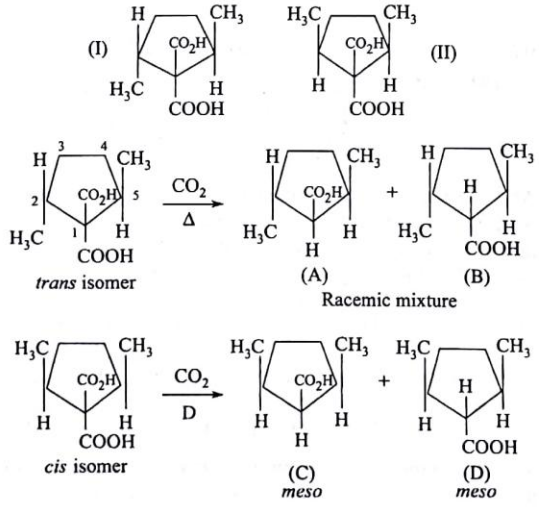
out with *m*-chloroperbenzoic acid. However, when bromination is carried out, we get equimolecular amount of *d*- and *l*-2,3-dibromobutane. Therefore, with respect to bromination, two faces of *cis*-but-2-ene are *enantiotopic*.



I and II are homomers, that is, superimposable, but (A) and (B) are enantiomers.. Therefore, *cis*-but-2-ene shows homotopic faces in case of epoxidation but enantiotopic faces in case of bromination.

3.58 2,5-dimethylcyclopentane-1,1-dicarboxylic acid has two diastereoisomers. One is active and another inactive. Upon heating, one of them yields active 2,5-dimethylcyclopentanecarboxylic acids and the other yields *meso* compounds. Explain.

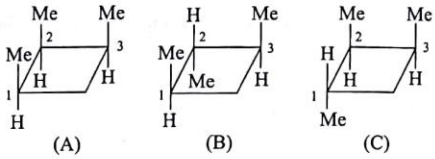
Ans (I) and (II) are *trans*- and *cis*-diastereoisomers of 2,5-dimethylcyclopentane-1,1-dicarboxylic acid respectively. The *trans* isomer is chiral (active) and *cis*-compound is achiral (*meso*). (I) on decarboxylation (*gem*-dicarboxylic acid easily decarboxylates on heating) gives a *racemic mixture* (A and B) but (II) gives *meso*-monocarboxylic acids.



(A) and (B) represent a pair of enantiomers, but (C) and (D) are diastereoisomeric *meso* compounds.

3.59 How many stereoisomers are possible for 1,2,3-trimethylcyclobutane? Discuss the nature of each carbon of each stereoisomer on the basis of (a) stereogenicity, (b) chirotopicity, and (c) pseudoasymmetry. (Assume planar structure.)

Ans 1,2,3-Trimethylcyclobutane can have three stereoisomers as shown.



The compounds (A) and (B) are achiral, that is, *meso* compounds due to the presence of plane of symmetry (point group C_s). The compound (C) is chiral (point group C_1). In compound (A) and (B) C-1, C-2, and C-3 are stereogenic but in the (C) C-1 and C-3 are stereogenic but C-2 is nonstereogenic.

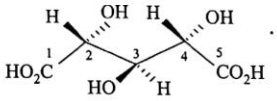
In (A) and (B) C-1 and C-3 are chirotopic because their site symmetry is chiral but C-2 is achirotopic because a plane of symmetry passes through it. In (C), all the C-1, C-2, and C-3 are chirotopic. In the compounds (A) and (B), C-2 centre is pseudoassymmetric. There is no pseudoassymmetric centre in (C).

3.60 Justify each of the following statements with examples.

CIP-chirality descriptors cannot be assigned to a chirotopic-nonstereogenic centre but that is possible for an achirotopic stereogenic centre.

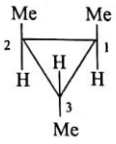
Ans Two examples (I) and (II) are given.

(I)



(2R,3r,4S)-2,3,4-Tryhydroxyglutaric acid

(II)

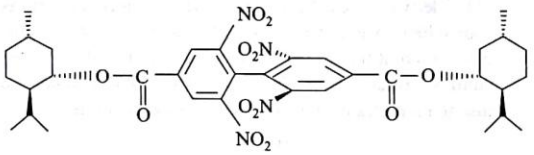


r-1,*c*-2,*t*-3-Trymethylcyclopropane

In I, C-2 and C-4 are asymmetric centres but C-3 is pseudoasymmetric. C-2 and C-4 have *R* and *S* configurations respectively. The C-3 centre has, therefore, an *r* configuration. The C-3 centre is *achirotopic* because its site symmetry is C_s but it is *stereogenic*. However, if we interchange the positions at H and OH at the C-2 chiral centre, C-3 centre becomes *chirotopic* and *non-stereogenic* and we cannot put any CIP configurational descriptor to this centre, because in that case both C-2 and C-4 have the same absolute configuration, *S*.

3.61 Give an example of a molecule, which lacks the usual symmetry elements and is yet achiral. Explain.

Ans Such a molecule is (–)-menthyl-(+)-menthyl 2,2′, 6,6′-tetranitro-4,4-diphenate.



(–)-Menthyl-(+)-menthyl-2,2′,6,6′-tetranitro-4,4′-diphenate is achiral because biphenyl moiety swivels easily between the carboxyl groups in spite of the hindrance for free rotation about the σ bond joining the two phenyl rings. The molecule is superimposable on its mirror image on the usual laboratory time scale, that is, there is no residual enantiomerism under the experimental condition. In this case symmetry of rotating system predominates over any of the contributing static arrangements that may lead to nonsuperimposability with the mirror image structure.

3.62 Give example in each case satisfying each of the following statements.

(a) A molecule having a pair of homomorphic ligands with *S*-configurations but one is *pro-R* and the other is *pro-S*

(b) A molecule with enantiomorphic groups along with *pro-r* and *pro-s* H atoms on a *pro-* pseudoasymmetric centre

(c) Enantiotopic ligands in a biphenyl molecule having prochiral axis

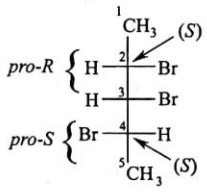
(d) Enantiotopic ligands in an allene having prochiral axis

(e) Chair conformation of a dimethylcyclohexane having three butane–gauche interactions

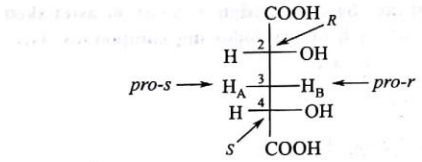
(f) A tertiary amine which can be resolved; explain

Ans

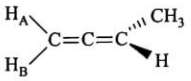
(a) In the molecule, C-2 and C-4 centres ($-CHBrCH_3$) are homomorphic ligands having *S* configuration. Therefore, C-3 represents a prochiral centre. The top $-CH(Br)CH_3$ group is *pro-R* and the bottom $-CH(Br)CH_3$ is *pro-S*.



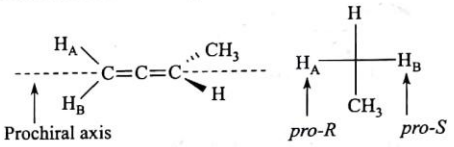
(b) The molecule shown by Fischer projection has enantiomorphic groups. C-2 and C-4 are chiral centres with *R* and *S*-configurations respectively. C-3 centre is pro-pseudoasymmetric. H_A is *pro-s* and H_B is *pro-s*.



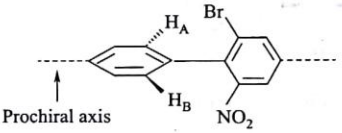
(c)



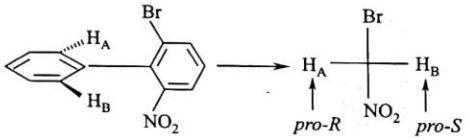
It has a prochiral axis. H_A is *pro-R* and H_B is *pro-S*. This can be easily understood from the so-called Fischer projection of the molecule, shown here.



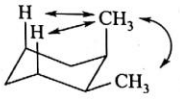
(d)



It has prochiral axis. In this case H_A is *pro-R* and H_B is *pro-S*. This is evident from the Fischer projection of the compound, shown here.



(e) *cis*-1,2-Dimethylcyclohexane has three butane–gauche interactions. This is shown by the following diagram.

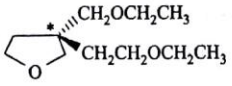


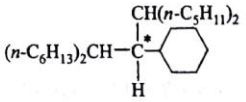
Three butane–gauche interactions have been shown by bold bonds and arrow-heads.

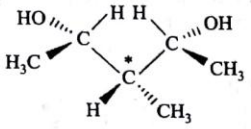
(f) Tertiary amines having the general formula $R^1R^2R^3N$: represent a chiral molecule where the lone pair on the nitrogen atom is equivalent to a substituent. However, this type of tertiary amines cannot be resolved because of rapid inversion of the structure due to rapid flipping of the lone pair of electrons. If this flipping is prevented structurally then tertiary amine can be resolved. An example of resolvable tertiary amine is given here.

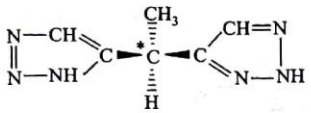
A pair of stable invertomers

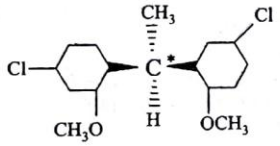
3.63 Find out the absolute configuration of the asterisked chiral centre of each of the following compounds. Give explanation in each case.

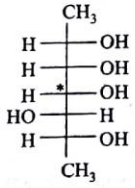
(a) 

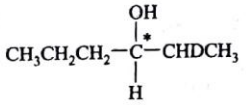
(b) 

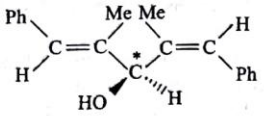
(c) 

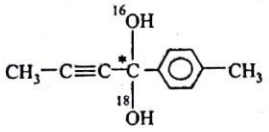
(d) 

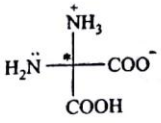
(e) 

(f) 

(g) 

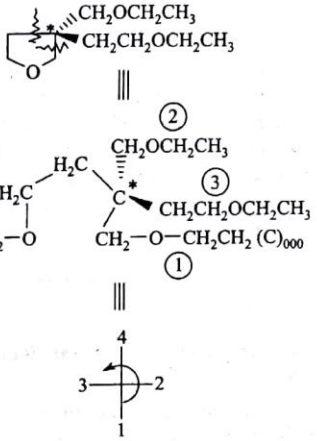
(h) 

(i) 

(j) 

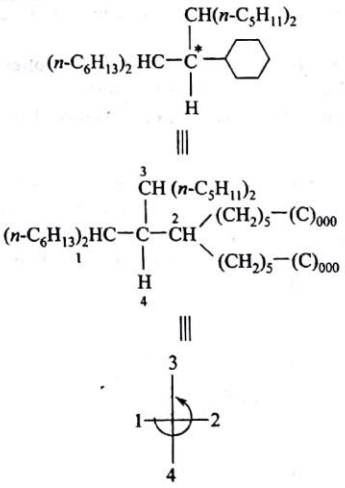
Ans

(a) Ligand complementation is required when there is a cyclic component to a ligand. In the present case, cyclic oxide ring (THF derivative) can be written in the disconnection form as shown here, where the chiral centre itself serves as a duplicated atom at the end of the expanded chains. Duplicated atom is written within the parentheses. Phantom atoms are inserted for tetra ligandation of the phantom atoms.



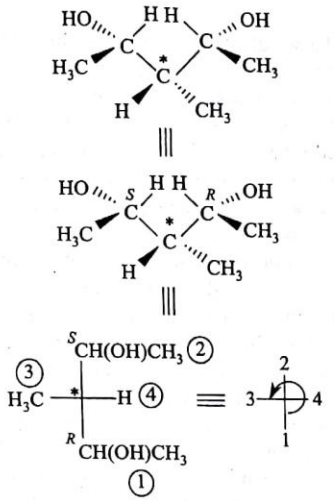
After opening the ring, CIP rules may be applied to find out the absolute configuration. In Fischer projection the compound is as just shown. Therefore the absolute configuration of the asterisked carbon atom is '*S*'.

(b) The compound can be written in the following disconnected form.

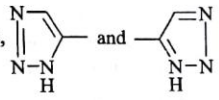


Applying CIP rules, the disconnected compound can be written in the Fischer form, as shown. Therefore, the absolute configuration of the chiral centre is *S*.

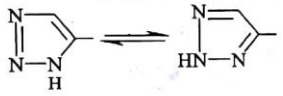
(c) In the compound, asterisked chiral centre is attached to two enantiomorphic groups. According to CIP rules, the enantiomorphic group having *R*-configuration has priority over the group having *S*-configuration.



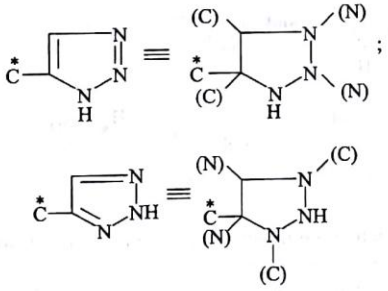
Therefore, the absolute configuration of the asterisked chiral centre is *R*. Lowest priority group (4) is on a horizontal bond.

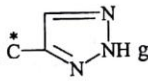
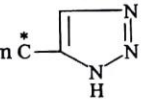
(d) In this example, the cyclic groups,  and

are interconvertible by tautomeric change.

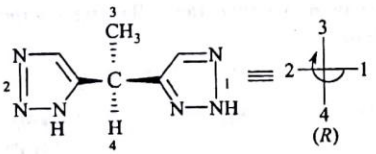


Both of these groups can be expanded as shown.

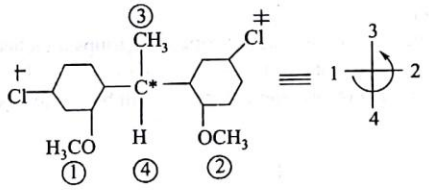


Therefore, the tautomeric form  gets priority over the form 

The absolute configuration of the chiral centre is (*R*).

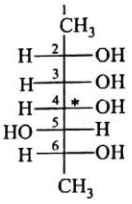


(e) In this case, we move along the *prior* branches following $-CH(OCH_3)CH_2-$ and find the first difference in the cyclohexane ring having Cl atom marked†. That is why the left-hand ring has priority. It is to be noted that the Cl† being on the junior branch, that is, less *prior* branch, does not in this case affect the result although it is closer to the branch point.

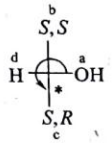


Configuration of the asterisked chiral centre is *S*.

(f)

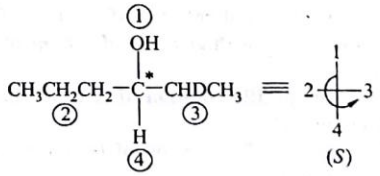


In this compound, chiral centres C-2, C-3, C-5, and C-6 have the configurational descriptors, *S*, *S*, *S*, and *R* respectively. Therefore, the compound can be written as shown in the figure. According to CIP rules (1966), (*S*, *S*) gets priority over (*S*, *R*). Therefore, the priority order of the ligands is in the Fischer projection, and the absolute configuration of the asterisked chiral centre is *R*.



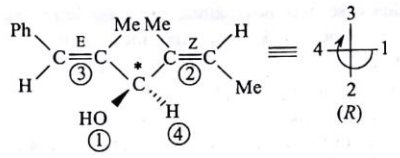
* = Chiral centre at C-4

(g) In this compound, the priority order of the substituents attached to the chiral centre is $-OH > -CH_2CH_2CH_3 > -CHDCH_3 > -H$. When isotopic atom is present in the group but not directly attached to the chiral centre then atomic number method (Rule 1) should be first tried out to determine the priorities of the groups. That is why, $-CH_2CH_2CH_3$ gets priority over $-CHDCH_3$.



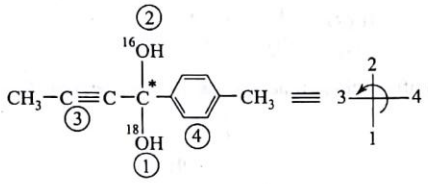
The absolute configuration of the compound is *S*.

(h) According to CIP rules (1966), between the two diastereomeric groups, one having *Z* configuration gets priority over the group having *E* configuration.



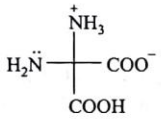
Therefore, the configuration of the asterisked chiral centre is *S*.

(i) In the compound, the priorities of groups attached to the chiral centre are $^{-18}OH > {}^{-16}OH > -C\equiv C-CH_3 > -C_6H_4-CH_3$. Therefore, the compound can be written as



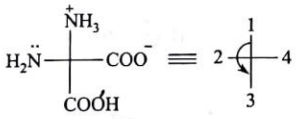
The absolute configuration is *R*. The lowest pririty group (4) is on a horizontal bond.

(j)



In the compound, the priority order is $-\overset{+}{N}H_3 > -NH_2 > -COOH > -COO^-$

This is because of the fact that according to CIP rules, H atom gets priority over lone pair of electrons (..). The charged atoms have no effect on the determination of priorities. Therefore, the compound can be written as



The configuration of the chiral centre is, therefore, *R*.

3.64 A 0.1M solution of a pure chiral compound X has an observed rotation (+)-0.2° in a 10cm cell. The molecular weight of the compound is 150.

(a) What is the $[\alpha]_D$ of X?

(b) What is the observed rotation if this solution is mixed with an equal volume of a solution that is 0.1M in (–)-enantiomer?

(c) What is the observed rotation of solution of X, if the solution is diluted with an equal of volume of the same solvent?

(d) What is the specific rotation of X after the dilution described in (c)?

(e) What is the specific rotation of (–)-enantiomer, the enantiomer of X?

(f) What is the observed rotation of 100mL of a solution that contains 0.01 mole of (+) and 0.005 mole of (–)-enantiomers? Assume a 1 dm polarimeter tube. What is the specific rotation?

Ans

(a) Molecular weight of X is 150, therefore, 0.1M solution = $0.1 \times 150/1000 = 0.015$g/mL.

(b) When 0.1M solution (–)-enantiomer is added, we get a racemate. The observed rotation is, therefore, ± 0°.

(c) Observed rotation 'α' is directly proportional to the concentration of an optically active compound. Hence, the observed rotation should be (+)-0.1°, as the concentration becomes half.

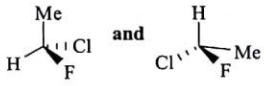
(d) Specific rotation, $[\alpha]$ is independent of the concentration of the solution. It depends on the nature of the solvent, length of the polarimeter tube, experimental temperature, and the wavelength of the plane polarized light used. Therefore, specific rotation will have the same value. (+)-13.3°.

(e) Since a pair of enantiomers have equal but opposite sign of rotation, the specific rotation of enantiomer is (–)13.3°.

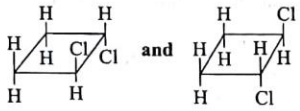
(f) When 0.005 mole of (–)- enantiomer is added to 0.01 mole of (+)-enantiomer, 0.005 mole of (+)-enantiomer forms racemate with 0.005 mole of (–) enantiomer. Therefore, rotation due to $(0.01 - 0.005) = 0.005$ mole of (+)-enantiomer will be observed. In this case $C = 7.5 \times 10^{-3}$g/mL, which is half of the value mentioned in (a). Therefore the observed rotation $\alpha = 0.1°$. The specific rotation will remain unaffected.

3.65 Label the following pairs of molecules as homomers, enantiomers, or diastereoisomers.

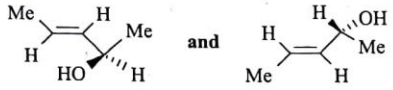
(a)



(b)



(b)



Ans

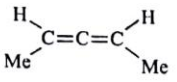
(a) This pair of compounds represents a pair of homomers. Both are (*R*)-isomers.

(b) This pair of compounds represents a pair of homomers. If we assume planar structures then the relative positions of Cl atoms are same in both the compounds. Therefore they are not diastereoisomers but one is the mirror image of the other and thus they are enantiomers (use model to undersatand).

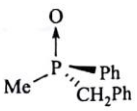
(c) These two compounds are homomers. The configuration of the identically substituted chiral centre in each case is (*R*). They are not diastreoisomers with respect to the double bond.

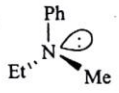
3.66 (a) Explain whether the following compounds are resolvable or not?

(i)



(ii)



(iii) 

(b) Justify the statement that S_2 and *i* are equivalent operations.

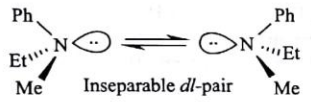
(c) (+)- EtCH(Me)COPh loses optical activity during deuteration with D_2O/NaOD. Explain.

Ans (a) The following is the explanation

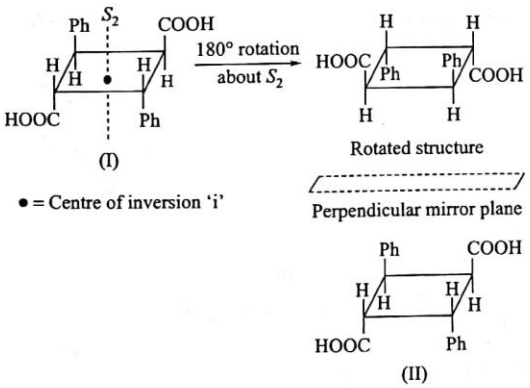
(i) It is a cumulene with even number of double bonds and each of the terminal carbons contains different substituents. Therefore, the compound is resolvable.

(ii) The compound is a phosphane oxide with tetrahedral geometry. Since all the substituents are different, like asymmetric carbon compounds, it is also an asymmetric phosphorus compound and is resolvable.

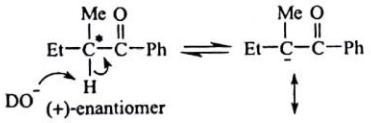
(iii) Although the tertiary amine is pyramidal (or tetrahedral) and represents an asymmetric molecule, it is not resovable owing to rapid interconversion between the enantiomers by inversion at the nitrogen. Therefore, it exits as a non-separable *dl*-pair.



(b) A molecule possessing S_2 means that we will get an indistinguishable structure of the molecule if we rotate the parent molecule about a chosen axis and then reflecting the rotated structure in a perpendicular mirror plane to that axis. This combined operation is equivalent to the presence of a centre of inversion in the said molecule. This can be demonstrated as follows.

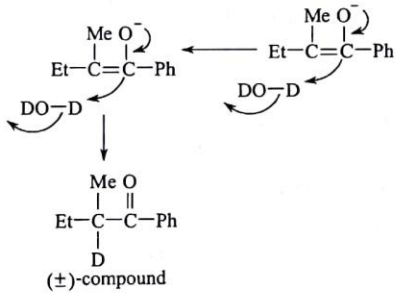


(c) Base catalysed α-deuteration involves the following mechanism.



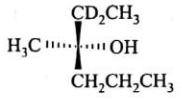
(Contd)

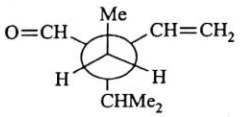
(Contd)



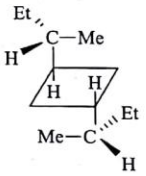
This mechanism shows that the initial chiral centre is transformed into a prochiral enantiotopic face and subsequent deutaration produces a racemic compound devoid of optical activity.

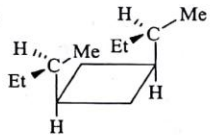
3.67 (a) Assign *R/S* descriptors for the chiral centre in the following compounds.

(i) 

(ii) 

(b) Indicate the elements of symmetry, if any, present in the following molecules. Find out the absolute configuration of the chiral centres in each case.

(iii) 

(iv) 

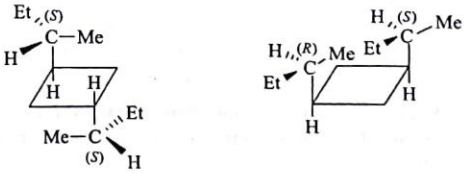
(c) The optical rotation of lactic acid disappears on treatment with a base. Explain.

Ans

(a) Absolute configurations of both (i) and (ii) are (*R*).

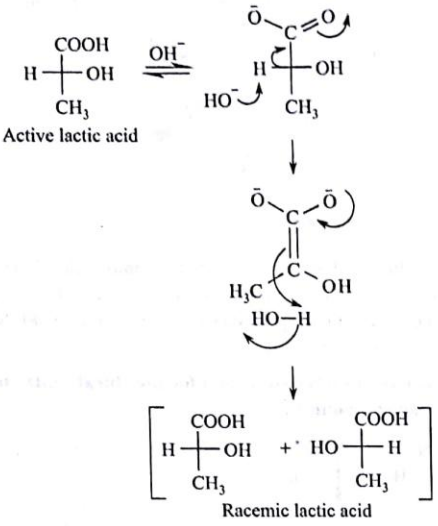
(b) The compound (iii) has no elements of symmetry and is chiral. The absolute configurations of two chiral centres in (iii) are (*S*).

The compound (iv) has a plane of symmetry and the molecule is achiral. The absolute configurations of the chiral cenres are (*R*) and (*S*), as shown here.



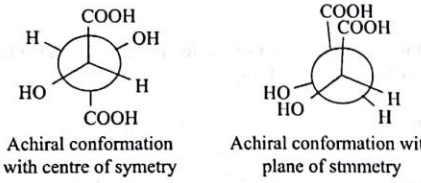
(c) Optical activity of lactic acid is lost when treated with a base and is due to the fact that the chiral centre is transformed into a prochiral enantiotopic face when treated with a base through deprotonation of the hydrogen atom attached to the chiral centre. During subsequent reversible

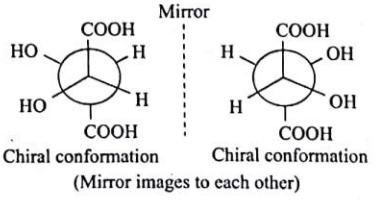
protonation, we get a *dl*-pare and optical activity disappears. The reaction is shown here.



3.68 Explain the statement that *meso*-tartaric acid can exist in many chiral conformations, yet it is optically inactive.

Ans *meso*-Tartaric acid can have an infinite number of conformations but only two of them have elements of symmetry, and the others have none. However, each chiral conformation has its mirror-image conformation due to free rotation. Therefore, meso-tartaric acid in fact can be considered as randomly racemized compound. Consequently, it always behaves as an optically inactive compound.

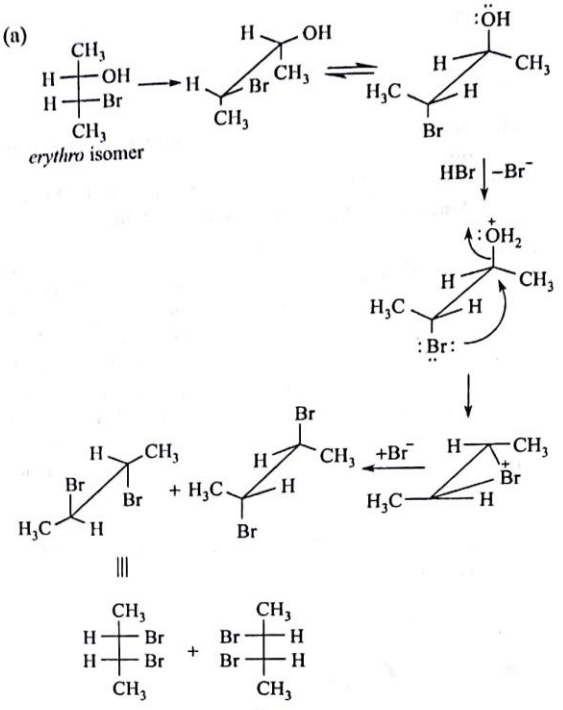




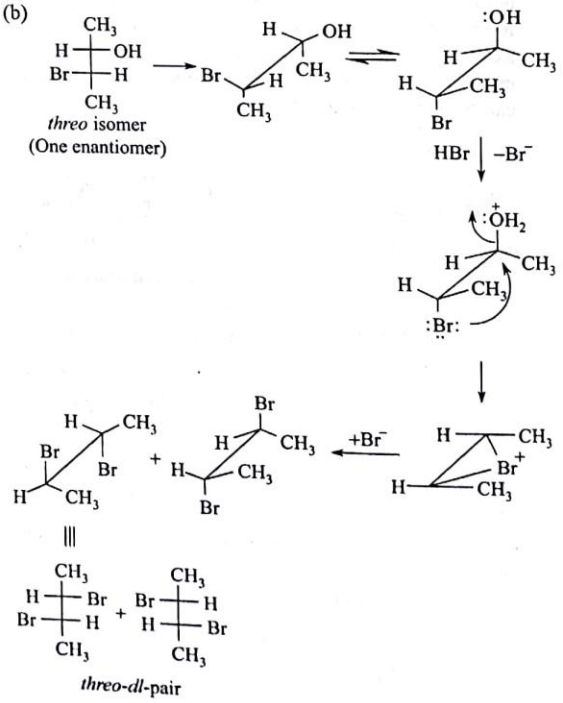
3.69 What products are obtained when *erythro*- and *threo*- forms of 3-bromobutan-2-ol are separately treated with HBr?

Ans Reactions are nucleophilic substitutions involving bromine atom as neighbouring group. *Erythro* isomer gives *meso*-2,3-dibromobutane and *threo* isomer gives *dl*-2,3-dibromobutane. The reactions are shown here.

(a)

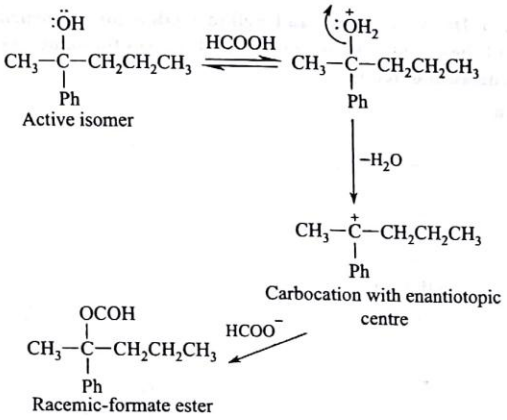


(b)



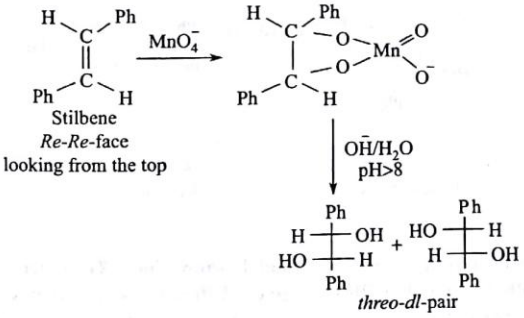
3.70 The optical rotation of (+)-2-Phenylpentan-2-ol goes down to 0° when boiled in formic acid. Explain.

Ans The reaction is a case of S_N1 reaction. Loss of optical activity is due to recemisation of the final product. The reaction is shown here.



3.71 PhCH=CHPh, in its *Re-Re* face, reacts with alkaline $KMnO_4$ solution. Give the product/products and the mechanism of the reaction. Do you expect the *Si-Si* face to react with alkaline $KMnO_4$ to give the same product?

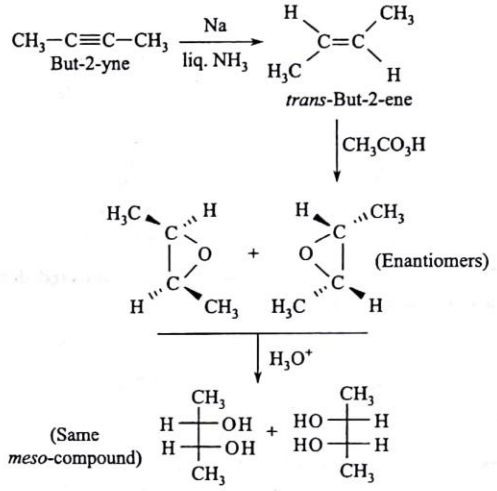
Ans *Re-Re* face of PhCH=CHPh represents *trans*-stilbene. 1,2-Dihydroxylation by alkaline $KMnO_4$ is a *cis*-addition. This combination will give *threo-dl*-pair of PhCH(OH) CH(OH)Ph. The reaction is shown here.



The *Si-Si*-face of stilbene is the mirror image of the *Re-Re* face and is also a *trans* isomer. Therefore, hydroxylation with alkaline KMnO4 will give the same *threo-dl*-pair of dihydroxy stilbene.

3.72 But-2-yne is first treated with sodium in liquid ammonia and the major product is made to react with peracetic acid and is then followed by decomposition with dilute hydrochloric acid. Identify the final product/products and designate the absolute configuration.

Ans Hydrogenation of alkyne with Na/liq. NH_3 gives *trans*-addition product. Peracetic acid oxidation of alkene gives epoxides and this is *cis*-addition. Decomposition of epoxides with dilute acid gives *trans* hydroxylation. In this case the final compound would be *meso*-butane-2,3-diol. The sequences of reactions are shown here.



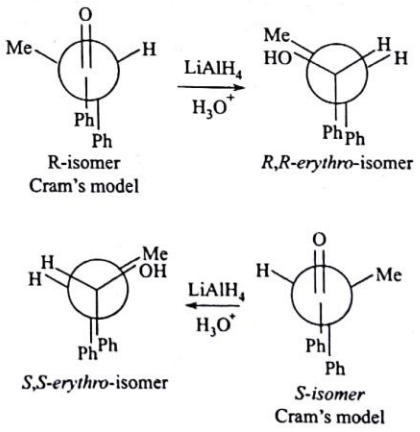
3.73 1,2-Diphenylpropan-1-ol may be prepared by either of the two ways:

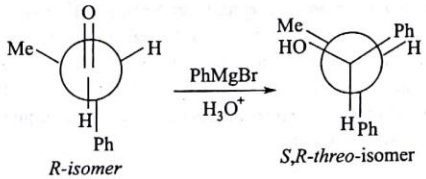
(a) $LiAlH_4$ reduction of $PhCH(CH_3)COPh$

(b) Reaction of $PhCH(CH_3)CHO$ with PhMgBr

Which method would you choose to prepare the *threo* isomer? Give reason in favour of your answer.

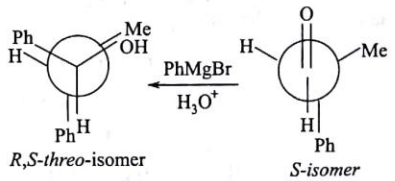
Ans When $PhCH(CH_3)COPh$ is subjected to reduction with $LiAlH_4$ then both *R* and *S*-isomers give *erythro* as the major product following Cram's rule. However, the *threo* isomer is possible in good yield from *R*-isomer of $PhCH(CH_3)CHO$ by reaction with PhMgBr. These facts have been explained here.





R-isomer
Cram's model

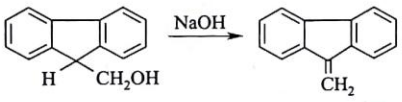
S,R-threo-isomer



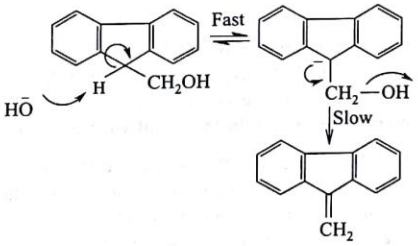
R,S-threo-isomer

S-isomer
Cram's model

3.74 How can you account for the base catalysed dehydration of the following compound.

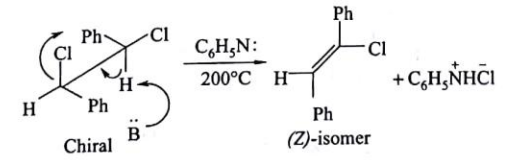


Ans It is a case of dehydration of an alcohol through $E1_{CB}$ pathway. The doubly benzylic hydrogen atom is quite acidic to be abstracted by the base to generate a carbanion.



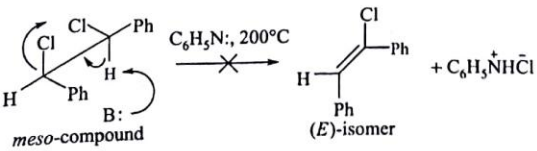
3.75 When dehydrochlorination of the *meso*- and chiral-1,2-dichloro-1,2-diphenylethane is carried out by heating with pyridine, only chiral substrate reacts to give (*Z*)-isomer. The *meso*- compound does not react. Explain this fact.

Ans



Chiral

(Z)-isomer



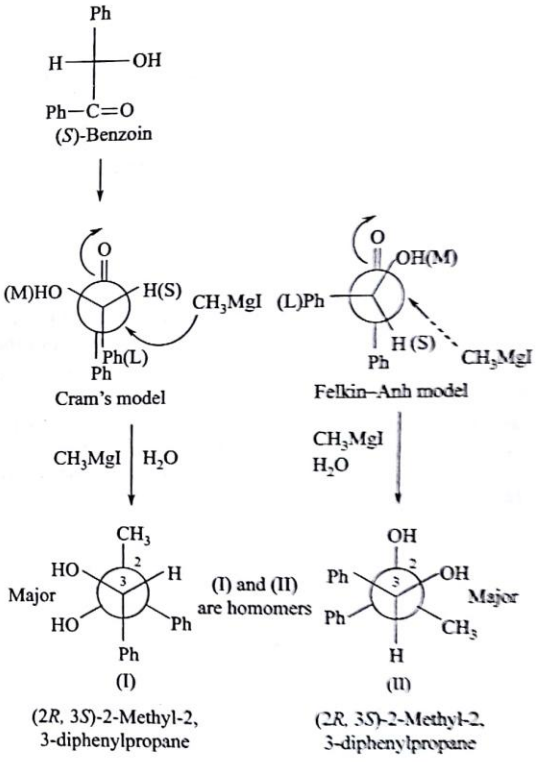
meso-compound

(E)-isomer

In this case, chiral compound undergo normal E2 elimination through a stable transition state having lower energy. The *meso*-compound does not undergo similar E2 elimination because its transition state conformation would be unstable where the Ph groups would be in *skew*. Approach of the C_5H_5N: would also be difficult due to steric hindrance.

3.76 Draw the Cram and Felkin models for (*S*)-benzoin and show that reaction with CH_3MgI gives the same stereochemical outcome.

Ans



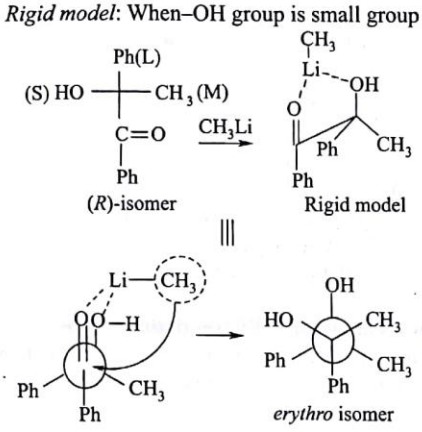
(2*R*, 3*S*)-2-Methyl-2, 3-diphenylpropane

(2*R*, 3*S*)-2-Methyl-2, 3-diphenylpropane

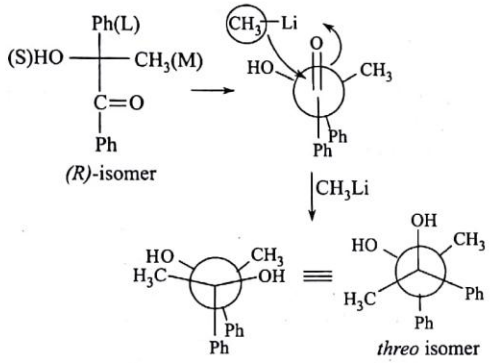
3.77 Based on Cram's model, show that (*R*)-isomer of Ph*C(OH)CH_3CPh=O give different stereochemical results in case of rigid cyclic model and the open-chain model, if OH group represents the smallest substituent on the chiral centre (*). Give the same compound when such a group is not a small group.

Ans If —OH, $—NH_2$, etc., is the medium sized (M) of the groups attached to the chiral centre then both *open-chain* model and *rigid model* give the same stereochemical result. However, if the —OH (or $—NH_2$) is the smallest (S) of the three groups, the use of open chain model gives erroneous conclusions. In this case diastereoselectivity can only be predicted by rigid model.

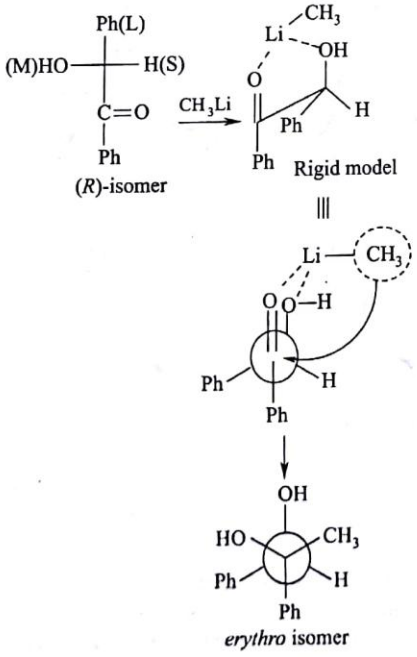
Rigid model: When–OH group is small group



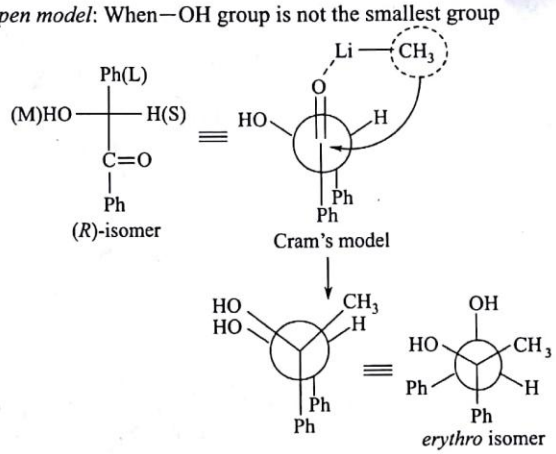
Open model: When—OH group is the smallest group



Rigid model: When—OH group is not the smallest group

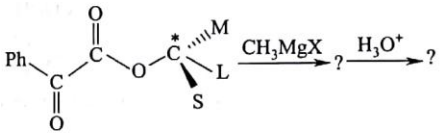


Open model: When—OH group is not the smallest group

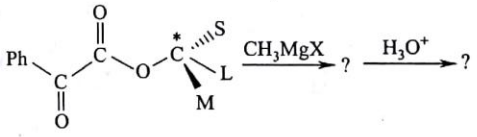


3.78 What would be the be absolute configurations of atrolactic acid from the following sequence of reactions.

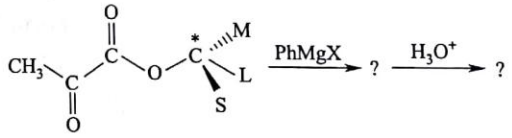
(a)



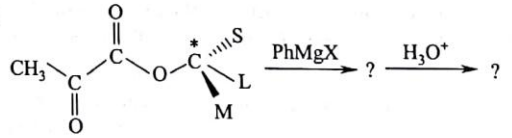
(b)



(c)

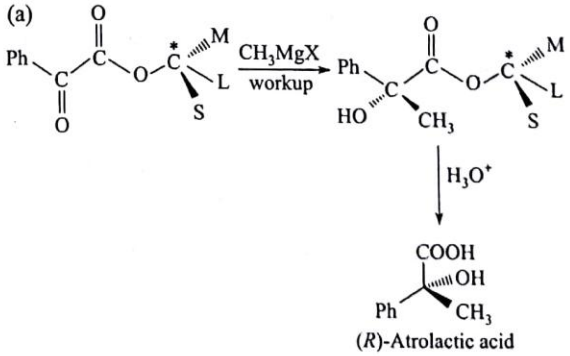


(d)



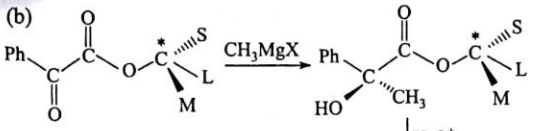
Ans The respective compounds in each case are shown.

(a)



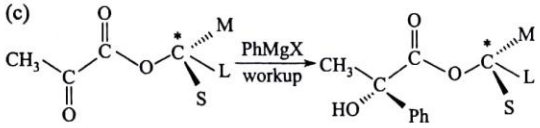
(*R*)-Atrolactic acid

(b)



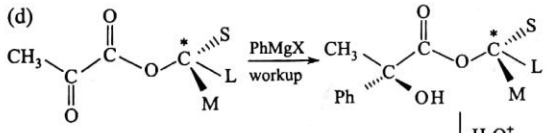
(*S*)-Atrolactic acid

(c)



(*S*)-Atrolactic acid

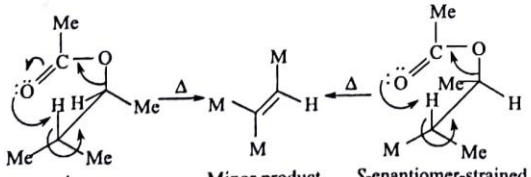
(d)



(*R*)-Atrolactic acid

3.79 What is the major product of the pyrolysis of Me_2CH-CH(Me)OAC? Give reasons in favour of your answer.

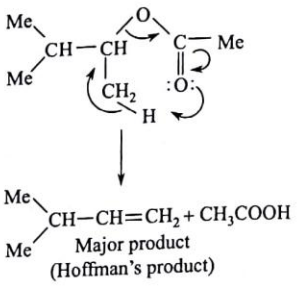
Ans It is a case of *syn*-elimination through the pyrolysis of ester. The given compound can have *R*- and *S*-enantiomers. During the formation of the Saytzeff product $Me_2C{=}CHMe$, the cyclic transition states from both *R* and *S* enantiomers suffer from strong steric and eclipsing strains and, therefore, its formation requires high activation energy. The formation of the Hoffman product, $Me_2CHCH{=}CH_2$ can occur easily through more stable cyclic transition state.



R-enantiomer-strained conformation

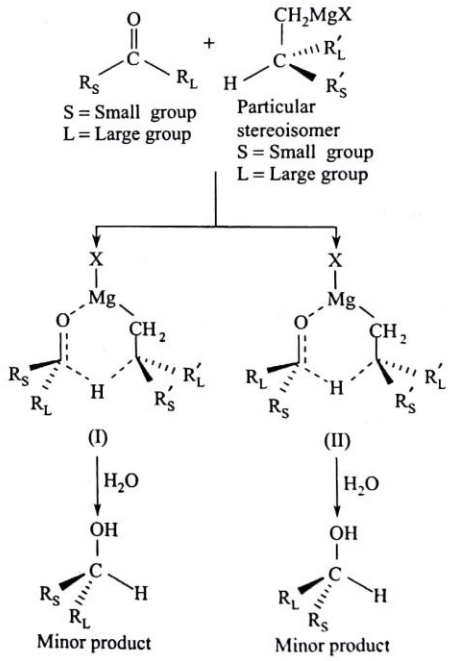
Minor product (Saytzeff's product)

S-enantiomer-strained conformation



3.80 Show how enantioface differentiation can be used to get enantioselective reduction of an achiral unsymmetrical ketone to alcohol using chiral Grignard reagent.

Ans An unsymmetrical ketone like R—CO—R′ has *Re* and *Si* faces. When a chiral Grignard regent like R^1—CH*(R^2) CH_2MgX reacts with the ketone, attack at *Re* and *Si* faces give two diastereoisomeric six-membered cyclic transition states having different energies. One which is sterically favoured is formed at a faster rate than the other having steric crowding. The final result is the formation of unequal amounts of enantiomers. Transition states of this enantioselective reaction can be shown as follows.



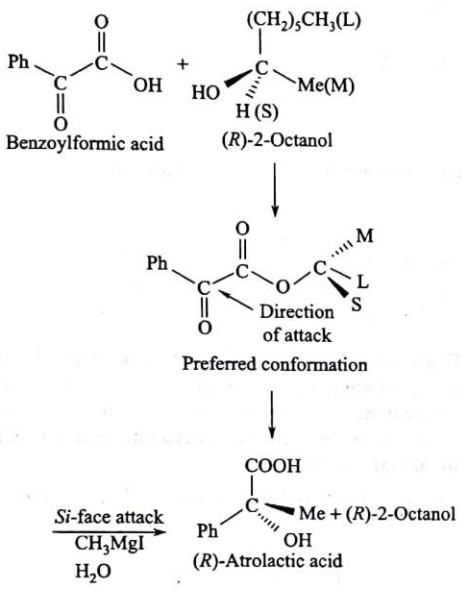
In these diagrams, (II) is a more stable transition state because bulky groups R_L and R'_L are almost *anti* to each other. In (I), they are in *syn* position.

3.81 What is the configuration of the atrolactic acid which is formed when (a) ester of $PhCOCO_2H$ and (*R*)-2-octanol and (b) ester of $PhCOCO_2H$ and (*S*)-2-octanol are

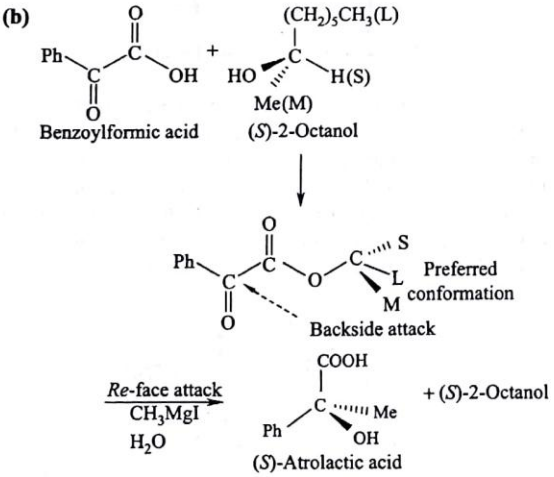
separately treated with CH_3MgI and then the product in each case is hydrolysed. What would be the configuration of the atrolactic acid when CH_3COCO_2H replaces $PhCO-CO_2H$ and PhMgI replaces CH_3MgI?

Ans

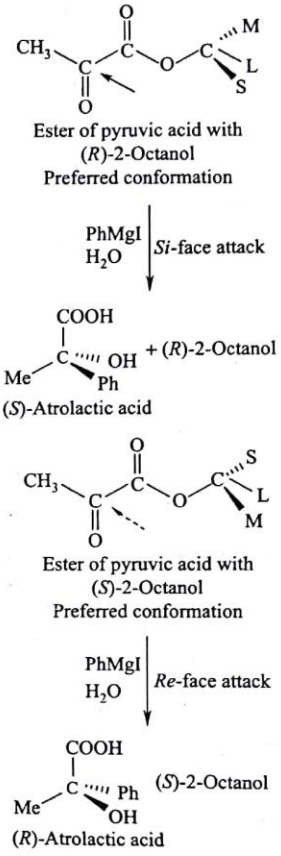
(a)



(b)

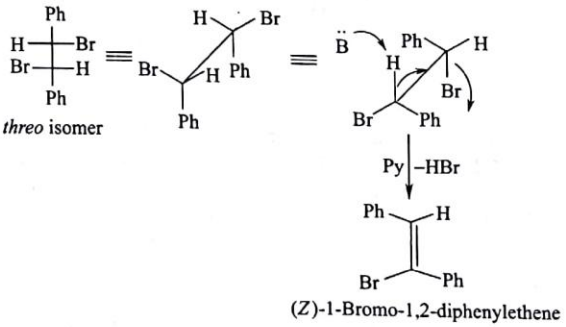


In these examples, esterification of benzoylformic acid with (*R*)-2-octanol gives (*R*)-atrolactic acid as the major isomer and esterification with (*S*)-2-octanol gives (*S*)-atrolactic acid as the major isomer. However, when pyruvic acid esters are taken and then reacted with PhMgBr, then ester from (*R*)-2-octanol gives (*S*)-atrolactic acid and vice versa. These can be shown as follows.



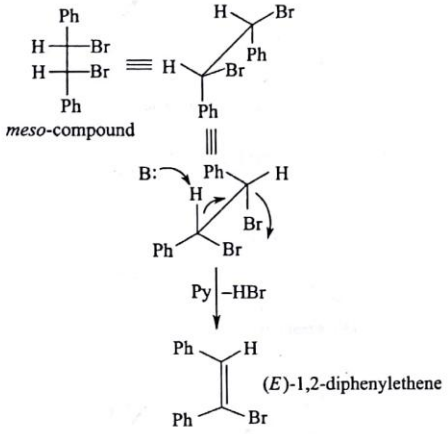
3.82 Pyridine causes dehydrobromination of *threo*-1,2-dibromo-1,2-diphenylethane to give (*Z*)-1-bromo-1,2-diphenylethene. Butiodide ion promoted debromination of *meso*-dibromide loses bromine to yield (*E*)-1,2-dipheylethene. Account for this observations.

Ans

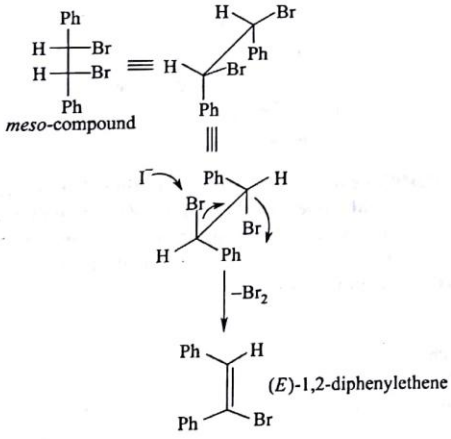


In the case of *threo* isomer (only one enantiomer shown), dehydrobromination (E2) is favoured because it can occur through more stable staggered transition state where Ph groups are *anti* to each other. Dehydrobromination in *meso*-compound

should proceed through less stable transition state having Ph groups is *skew* position.

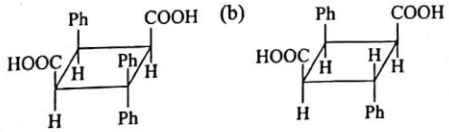


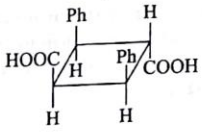
In case of *meso*-compound, debromination (E2) can occur through a more stable transition state where the Ph groups are *anti*. Dehydrobromination should proceed through an unstable transition state where the Ph groups are in *skew* position.

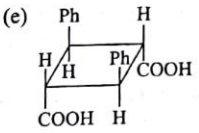


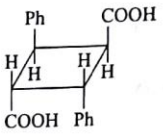
3.83 How many diastereoisomers are possible for the compound 2,4-diphenylcyclobutane-1,3-dicarboxylic acids. Find out their elements of symmetry and hence show their point groups (assume planar cyclobutane).

Ans Five diastereoisomers are possible and all of them are achiral. Their structures are shown here.





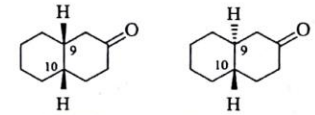




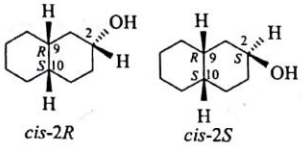
Elements of symmetry	Point group
(a) $C_2 + 2\sigma_v$ planes	C_{2v}
(b) One plane of symmetry	C_s
(c) One plane of symmetry	C_s
(d) Centre of symmetry $i \equiv S_2$	C_i
(e) $C_2 + 2\sigma_v$ plans	C_{2v}

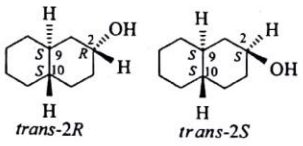
3.84 Draw the diastereoisomers of 2-decalone. Do you expect any change in the number of diastereoisomers when 2-decalone is converted into 2-decalol. How many chiral centres are present in 2-decalone and 2-decalol? (assume planar fused rings).

Ans 2-Decalone has two diastereoisomers. They are shown in planar form.



Each of these two compounds contains two chiral centres, C-9 and C-10, and therefore, can exist as enantiomers. In one of the *cis* isomers, C-9 is *R* and C-10 is *S*. In *trans* isomer shown, both C-9 and C-10 have *S*-configurations. When 2-decalone is converted into 2-decalol, then the number of diastereoisomers is increased to four. They are shown here. All of them are capable of exhibiting enantiomerism.



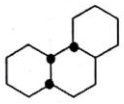
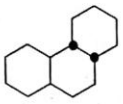
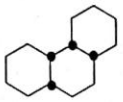


In each of these stereoisomers, there are three chiral centres, C-2, C-9, and C-10. Therefore, eight stereoisomers are

possible. Only four of them are shown. Absolute configurations of these chiral centres have been mentioned for the structures.

3.85 Draw the Linstead structures of the following perhydrophenanthrenes and comment on their optical activity: (a) *cis-syn-trans* form, (b) *cis-anti-cis* from, (c) *cis-syn-cis* form.

Ans The defined structures are as follows:

(a)  (b)  (c) 

Compounds (a) and (b) are chiral and, therefore, can exist as enantiomers. Compound (c) is a *meso* compound having a plane of symmetry.

3.86 Draw the structures of the following compounds.

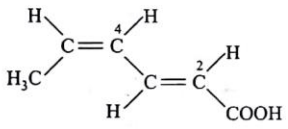
(a) (2*E*,4*Z*)-2,4-Hexadienoic acid

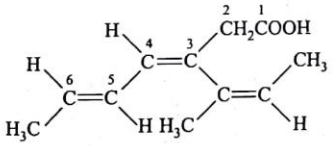
(b) 3-[*E*-1-methoxypropenyl]-(3*Z*,5*Z*)-3,5-heptadienoic acid

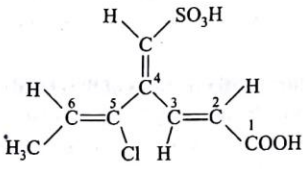
(c) (2*E*,5*Z*)-5-chloro-4-[(*E*)-hydroxysulphonylmethylene]-2,5-heptadienoic acid.

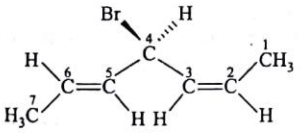
(d) (2*Z*,4r,5*E*)-heptadiene

Ans

(a) 

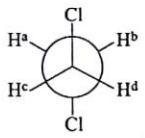
(b) 

(c) 

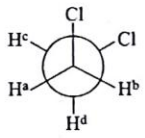
(d) 

3.87 Draw the anti, *gauche*, and eclipsed conformations of 1,2-dichloroethane and find out the topicity of hydrogen atoms of each conformation. Find out the elements of symmetry in each case and give their point-group designation.

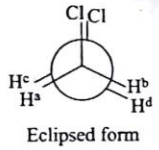
Ans The conformations are shown in the following Newman projections.



anti–form



P–*gauche* form



Eclipsed form

H^a/H^b - Enantiotopic	H^a/H^b - Diastereotopic	H^a/H^b - Enantiotopic
H^c/H^d - Enantiotopic	H^c/H^d - Diastereotopic	H^c/H^d - Enantiotopic
H^a/H^c - Homotopic	H^b/H^c - Homotopic	H^a/H^c - Enantiotopic
H^b/H^d - Homotopic	H^a/H^d - Homotopic	H^b/H^d - Enantiotropy
H^a/H^d - Enantiotopic	H^a/H^c - Diastereotopic	H^a/H^d - Homotopic
H^b/H^c - Enantiotopic	H^b/H^d - Homotopic	H^b/H^c - Homotopic

anti form: $C_2 + C_i$ Point group: C_i

gauche form: C_1 Point group: C_1

eclipsed form: $C_2 + 2\sigma_v$ Point group: C_{2v}

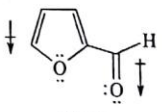
3.88 The rotational energy barriers in CH_3CH_2X (X = F, Cl, Br, I) are remarkably similar in magnitude (around 14–15 kJ mol^{-1}) despite considerable difference in the size of the halogens. How can you explain the fact?

Ans The energy barrier in these cases are believed to be steric in origin. As the size of the halogen increases, the C—X bond length also increases proportionately. Therefore, effect of increase in the size of the halogen atom is nullified by the increase in the bond length of the C—X bond.

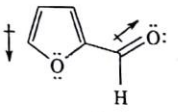
	F	Cl	Br	I
Covalent radius (nm):	0.064	0.099	0.114	0.133
C—X bond length (nm):	0.1353	0.1701	0.1860	0.2100

3.89 Draw the *s-cis*- and *s-trans*- conformations of furfural. How is conformational equilibrium affected in polar solvents and also in gaseous state? Can you differentiate these by dipole moment values?

Ans The *s-cis* and *s-trans* conformations of furfural are shown here.



s-trans

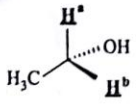


s-cis

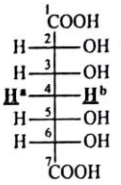
Conformationally, *s-trans* is found to be more stable in polar solvent which reduces the dipole–dipole repulsion due to ring oxygen and the aldehydic oxygen. In the gaseous state, *s-cis* conformation is found to be more contributing due to the dominating polar repulsive interaction between the two oxygen atoms in *s-trans* form. The energy barrier for rotation about C—C bond is around 45.6 kJ mol^{-1}. *s-cis* and *s-trans* conformations differ in their dipole moments. In *s-trans* form ring and carbonyl dipoles are reinforcing each other and that will give a higher value. In *s-cis* form, the aforementioned dipoles are opposed and, therefore, the resultant dipole moment value will be low.

3.90 Identify the *pro-R* and *pro-S* hydrogen atoms (marked) in each of the following molecules.

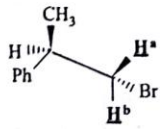
(a)



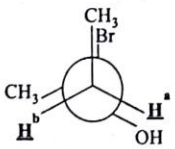
(b)



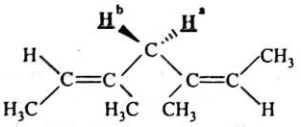
(c)



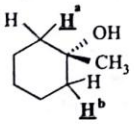
(d)



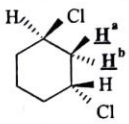
(e)



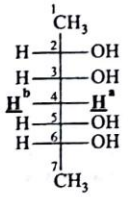
(f)



(g)



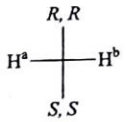
(h)



Ans

(a) In the compound, H^a is *pro-S* and H^b is *pro-R*.

(b) In the compound, C-2 and C-3 have *R*-configurations and C-5 and C-6 have *S*-configuration. Therefore, the compound can be represented by the Fischer projection,

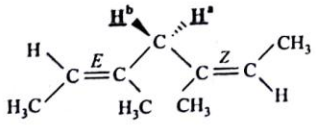


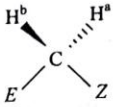
According to CIP rules, (*R,R*) gets priority over (*s,s*). Therefore, H^a in the compound is *pro-S* and H^b is *pro-R*.

(c) In this compound, H^a is *pro-S* and H^b is *pro-R*.

(d) In this molecule, H^b is *pro-R* and H^a is *Pro-S*.

(e) In this case, diastereoisomeric *E* and *Z* groups are attached to the carbon centre bearing H^a and H^b. The molecule can be represented as

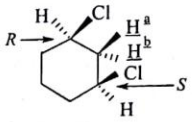




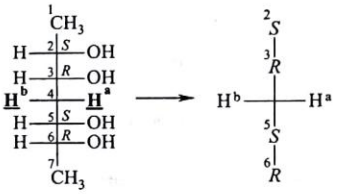
According to CIP rules, *Z*-gets preference over *E*. Therefore H^a is *pro-S* and H^b is *pro-R*.

(f) In this cyclohexane derivative, H^a is *pro-R* and H^b is *pro-S*.

(g) In this molecule, the carbon atoms bearing —Ch(Cl)- groups are enantiomorphic having *R* and *S* configurations. According to CIP rules, the enantiomorphic group with *R*-configuration gets priority over the enantiomorphic group having *S*-configuration. Therefore, in this compound H^a is *pro-S* and H^b is *pro-R*.



(g) In this structure, C-2 and C-3 have *S* and *R* configuration respectively. Again, C-5 and C-6 have *S* and *R* configuration respectively. Therefore, the compound can be represented as



According to CIP rules, like configuration (*R, R*) or (*S, S*) gets preference over either (*R,S*) or (*S, R*). However, in this case, standard sub rules (5) may be used where *R* precedes over *S*. According to this rule, H^a in (h) represents *pro-r* hydrogen and H^b represents *pro-s* hydrogen. C-4 is a *pro*-pseudoasymmetric centre.

3.91 Find out the absolute configurations of the chiral centres of compounds formed from the following reactions.

(a) Br_2 is added to *Re-Re* and *Si-Si* faces of fumaric acid.

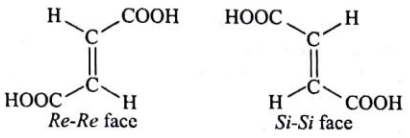
(b) Acetaldehyde is treated with PhMgBr where nucleophilic attack occurs on the *Si*-face.

(c) *R*-3-hydroxybutanal is treated with CH_3MgBr where nucleophilic attack on the aldehydic carbonyl takes place from the *Re*-face.

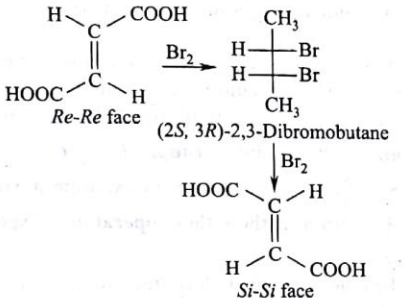
(d) *Z*-isomer of 2,3-dibromobut-2-ene is catalytically hydrogenated where hydrogenation takes place from the *Re-Si* face looking from the top.

Ans

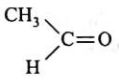
(a) Fumaric acid is *trans*-butenedioic acid. It can be represented as follows, one having *Re-Re* face and the other having *Si-Si* face looking from the top.



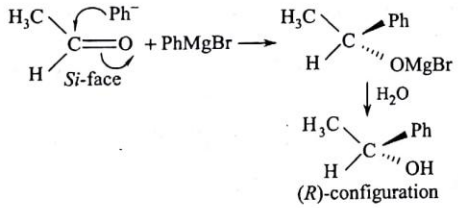
Br_2 addition is electrophilic *trans*-addition. One bromine becomes attached from the top and the other from the bottom. In case of *trans*-addition to a symmetrical *trans*-alkene, *meso*-compound is always formed. Therefore, both *Re-Re* and *Si-Si* faces give the some *meso*-2,3-dibromobutanedioic acid. That is *Re-Re* and *Si-Si* faces are homotopic in this particular case.



(b) The *Si*-face of acetaldehyde, as observed from the top, is

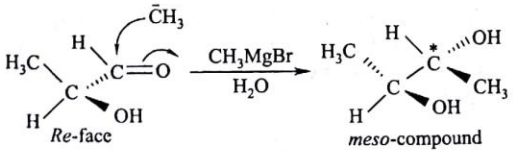


The nucleophilic addition to the *Si*-face of acetaldehyde with PhMgBr is given here.



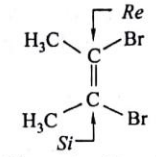
The secondary alcohol formed has *R* configuration.

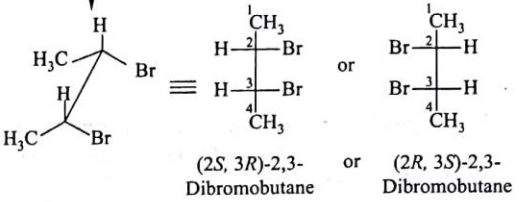
(c) *R*-3-Hydroxypropanal in flying wedge projection is shown and that reacts with CH_3MgBr from the *Re*-face.



The carbonyl face of the compound represents a diastereotopic face. The absolute configuration of the newly formed chiral centre (asterisked) is *R*.

(d) The compound on catalytic hydrogenation gives *meso*-2,3-dibromobutane. Catalytic hydrogenation is a *cis*-addition reaction.





3.92 Give an example in each case satisfying each of the following statements:

(a) A molecule having a pair of homomorphic ligands with *S*-configurations but one *pro-R* and the other *pro*-S

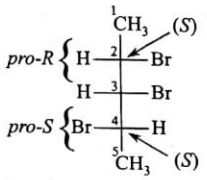
(b) A molecule with enantiomorphic groups along with *pro*-r and *pro*-s H atoms on a pro-pseudoasymmetric centre

(c) Enantiotopic ligands in a biphenyl molecule having prochiral axis

(d) Enantiotopic ligands in an allene having prochiral axis

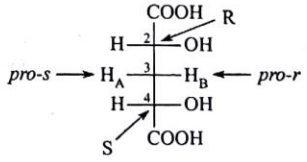
Ans

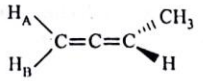
(a)



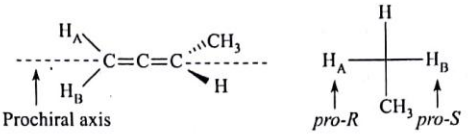
In the molecule, C-2 and C-4 centres ($-CHBrCH_3$) are homomorphic ligands having *S* configuration. Therefore, C-3 represents a prochiral centre. The top $-CH(Br)CH_3$ group is *pro-R* and the bottom $-CH(Br)CH_3$ is *pro-S*.

(b) The molecule shown by Fischer projection has enantiomorphic groups. C-2 and C-4 are chiral centres with *R* and *S*-configurations respectively. C-3 centre is pro-pseudoasymmetric. H_A is *pro-s* and H_B is *pro-s*.

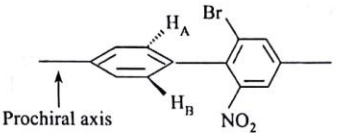


(c) 

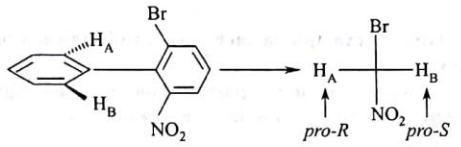
It has a prochiral axis. H_A is *pro-r* and H_B is *pro-S*. This can be easily understood from the so-called Fischer projection of the molecule, shown here.



(c)

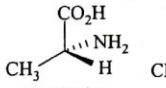


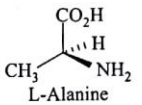
It has prochiral axis. In this case H_A is *pro-R* and H_B is *pro-S*. This is evident from the Fischer projection of the compound, shown here.



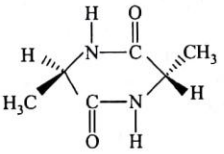
3.93 What products are obtained when two alanine molecules undergo dimerization to form diketopiperazine derivative?

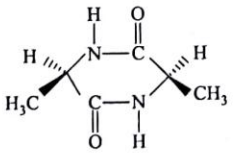
Ans Alanine is $CH_3C^*H(NH_2)COOH$ having one chiral centre. It can exit as enantiomers, that is, D-alanine and L-alanine. If two molecules of the same enantiomer (homochiral) dimerize then a chiral *cis*-diketopiperazine is obtained having C_2 point group. If two molecules having opposite chirality (heterochiral) dimerize then achiral *trans*-diketopiperazine is obtained. Its point group is C_i.


D-Alanine


L-Alanine

trans-Diketopiperazine
(Combination of two heterochiral molecules)
Point group: *Ci*


(Achiral)


(Chiral)

cis-Diketopiperazine
(Combination of two homochiral molecules)
Point group: C_2

3.94 Justify the statement that AB_3 type molecule cannot have an inversion centre but a molecule AB_4 might possibly have one.

Ans An inversion centre may be in space in the centre of a molecule or at a single atom in the centre of a molecule. If it is in space all types of atoms in a molecule must be present in even numbers, spaced either side of the so called centre of inversion. If it is at an atom, then only that type of atom must be present in an odd number. Since in AB_3 type molecules, neither of these conditions are satisfied, these types of molecules have no centre of inversion. In AB_4, A is present in odd number and B is present in even number, therefore a centre of inversion is possible through A.

3.95 Answer the following:

(a) Three students individually concluded that CH_4 has point group T_d, D_{4h} and D_{2h}. What types of structures did they assume?

(b) A student reported that H_2O molecule belongs to the point group $D_{\infty h}$. What mistake did the student make?

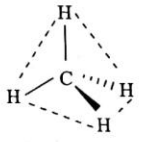
(c) A point group consists of the following operations. Identify the point group. $E, C_3, C_3^2, C_2, C_2', C_2'', \sigma_h, S_3, S_3^5, \sigma_v, \sigma_v', \sigma_v''$. Give an example having those point group and show these operations diagrammatically.

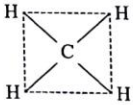
(d) A dicarboxylic acid has the molecular formula $C_4H_4O_4$. It satisfies the symmetry operations: E, C_2, σ_h, i. Draw the structure of the compound.

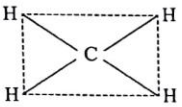
(e) What is meant by the point group C_{1h}? What are its equivalent operations?

Ans

(a) The student who assigned T_d point group for CH_4 was correct because the structure of CH_4 is found to have a regular tetrahedral geometry. The student who assigned D_{4h} point group for CH_4 assumed the structure as square planar. The third student assumed the structure of CH_4 as rectangular planar and assigned the point group D_{2h}.

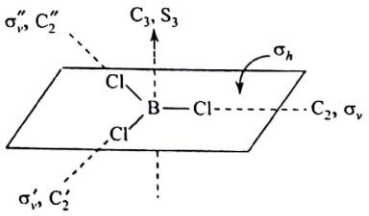

T_d point group


D_{4h} point group

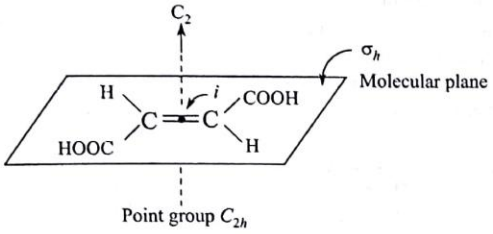

D_{2h} point group

(b) The student made the mistake that H_2O molecule is linear having the structure H—O—H .

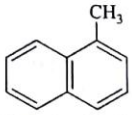
(c) These operators show that the molecule belongs to the point group D_{3h}. An example having D_{3h} point group is BCl_3. The symmetry operations are shown in the following diagram.



(d) The structure of the compound is *trans*-Butenedioic acid (Fumaric acid). The symmetry operations are shown diagrammatically.



(e) The point group C_{1h} indicates that the molecule has trivial axis C_1 along with a horizontal plane of symmetry. C_{1h} is equivalent to C_s and S_1 point groups. An example of a molecule belonging to C_{1h} is given.



1-Methylnaphthalene

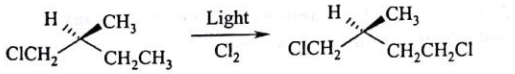
3.96 (*S*)-1-Chloro-2-methylbutane has been shown to have (+)-rotation. Among the products of light-initiated chlorination are (–)-1,4-dichloro-2-methylbutane and (±)-1,2-dichloro-2-methylbutane.

(a) Write out the absolute configuration of the (–)-1, 4-dichloro-2-methylbutane produced by the reaction. What relationship does this example show between sign of rotation and configuration?

(b) What does the fact that 1,2-dichloro-2-methylbutane is totally racemic indicate? Propose the reaction mechanism and the nature of the intermediate.

Ans

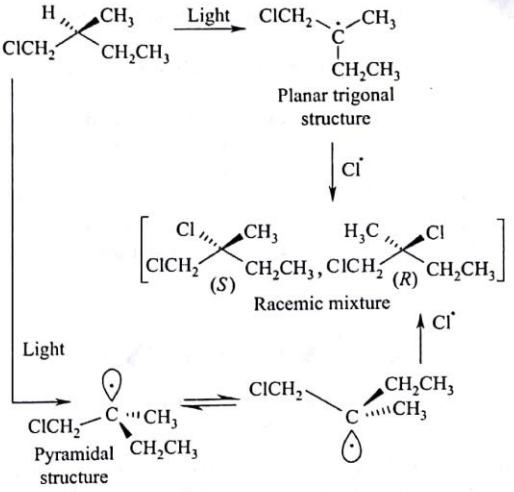
(a) The formation of (–)-1,4-dichloro-2-methylbutane does not change the configuration of the original chiral centre, although the sign of specific rotation has changed. This demonstrates that there is no prior relationship between sign of rotation [(+) or (–)] and configuration (*R* or *S*).



(*S*)-1-Chloro-2-methylbutane (+)- rotation

(*S*)-1,4-Dichloro-2-methylbutane (–)-rotation

(b) The light induced formation of (±)-1,2-dichloro-2-methylbutane suggest that reaction proceeds through the generation of a tertiary free radical. This radical can have a planar structure or rapidly interconverting pyramidal structure. Rate of interconversion of pyramidal structures is faster than the rate of the reaction with the chlorine radical. Whatever may be the case, the final outcome is the formation of (±)-1,2-dichloro-2-methylbutane.



3.97 Consider the chlorination of (*S*)-2-flurobutane. The monochlorination fraction of the reaction products contains 1-chloro-2-fluorobutane, 2-chloro-2-flurobutane, 1-chloro-3-fluorobutane, and 2-chloro-3-fluorobutane.

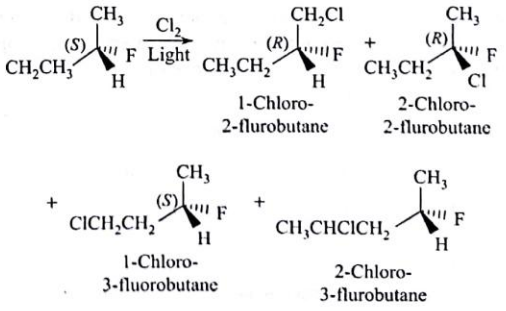
(a) The 1-chloro-2-fluorobutane constitutes 1% of the monochloro products. What is the absolute configuration of the compound?

(b) The 1-chloro-3-fluorobutane constitutes 26% of the monochloro products. What is its absolute configuration?

(c) The 2-chloro-2-flurobutane fraction amounts to 31%. This material is found to be racemic. How do you explain this result?

(d) Careful examination of the 2-chloro-3-fluorobutane product reveals that it is actually a mixture consisting of 2*S*,3*S* diastereoisomer, and 24% of the 2*R*,3*S* diastereoisomers. Can you offer an explanation for the fact that these two isomers are not produced in equal amounts?

Ans Possible products from radical-substitution reactions are given here. Different percentage of the products depends on the different stabilities of the intermediate radicals.

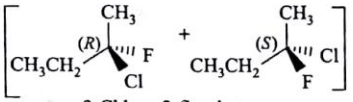


(a) The absolute configuration of 1-chloro-2-fluorobutane is (*R*).

(b) The absolute configuration of 1-chloro-2-fluorobutane is (*S*).

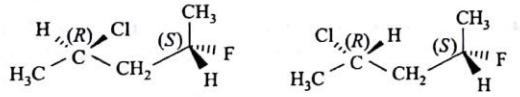
The absolute configuration of these two products remain unaffected because the reaction does not involve any bond attached to the chiral centre.

(c) 2-Chloro-2-fluorobutane can be formed as a pair of enanantiomes in the 1:1 ratio. That is why we get a racemic mixture. They are formed through a planar radical having enantiotopic face.



2-Chloro-2-flurobutane
(racemic)

(d) 2-Chloro-3-fluorobutane has two chiral centres. The configuration of the carbon centre bearing the F atom remains unaffected and its stereochemical descriptor is (*S*). The new chiral centre formed by the substitution of Cl may have the configuration (*R*) and (*S*). Therefore, we get a mixture of two diastereoisomers.

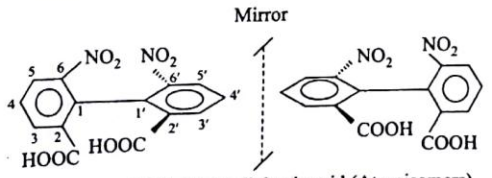


(2*R*,3*S*)-2-Chloro-3-flurobutane (2*R*,3*S*)-2-Chloro-3-flurobutane
(A pair of diastereoisomers)

In the process of formation of diastereoisomers, the transitions states have different free energies of formation. Since the two competing reactions start at the same place and pass through transition states of different energies, the two activation energies are different. Therefore, one diastereoisomer will be formed in greater amount than the other.

3.98 Give examples of the following terms:
(a) Conformational chirality (b) R_a and S_a descriptors (c) Buttressing effect (d) Spiro compounds with central chirality (e) Molecular chirality due to chiral planes

Ans (a) The term 'conformational chirality' is used to refer to chirality in molecules which arises because of restricted rotation of a part of a molecule about carbon–carbon single bond due to steric interactions. This is also known as atropisomerism. An example is the existence of optically active 6, 6′-dinitrodimenic acid.

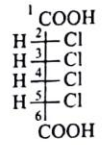


Enantiomers of 6,6′-Dinitrodiphenic acid (Atropisomers)

3.99 Draw Fischer's structures of all the active and *meso*-compounds of the compound of 2,3,4,5,-tetrachlorohexanedioic acid. Give the stereochemical names of each compound.

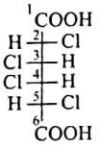
Ans Fischer's projection of all the stereoisomers of 2,3,4, 5,-tetrachlorohexanedioic acid have been given. There are two *meso*-compounds and two pairs of active isomers (enantiomers)

(a)



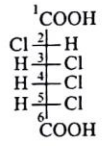
(1*S*,2*S*,3*R*,4*R*)-1,2,3,4-
Tetrachlorohexanedioic acid
meso-compound

(d)



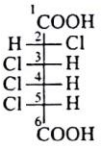
(1*S*,2*R*,3*S*,4*S*)-1,2,3,4-
Tetrachlorohexanedioic acid
meso-compound

(b)



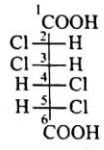
(1*R*,2*S*,3*S*,4*S*)-1,2,3,4-
Tetrachlorohexanedioic acid
active isomer

(e)



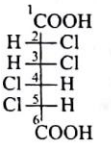
(1*S*,2*R*,3*R*,4*R*)-1,2,3,4-
Tetrachlorohexanedioic acid
active isomer

(c)



(1*R*,2*R*,3*R*,4*R*)-1,2,3,4-
Tetrachlorohexanedioic acid
active isomer

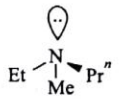
(f)



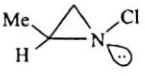
(1*S*,2*S*,3*S*,4*S*)-1,2,3,4-
Tetrachlorohexanedioic acid
active isomer

3.100 Which of the following compounds cannot exit as isolable enantiomers. Give reason.

(a)

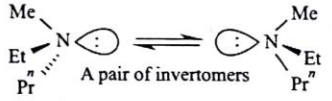


(b)

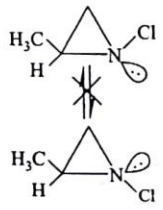


Ans The compound (a) contains a chiral nitrogen atom where the lone pair of electrons on the nitrogen atom is equivalent to a substituent. However, the compound is not resolvable because of rapid interconversion between the enantiomers by inversion at the nitrogen atom. The frequency of inversion

is found to be about 10^9 times per second. These types of non-resolvable enantiomers formed by the inversion process are called invertomers.

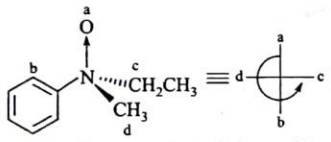


However, the second compound, *N*-chloroaziridine (b) can exits as a resolvable compound. The energy barrier for inversion is quite high (75 kJ $mole^{-1}$), because of highly strained state involving sp^3 nitrogen atom

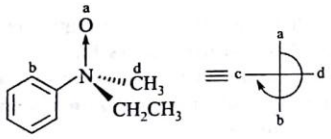


3.101 Give perspective formulae of (*R*)-*N*-Benzyl-*N*-methyl-*N*-(prop-2-en-1-yl)anilinium iodide and (*S*)-*N*-Ethyl-*N*-methylanilinium oxide.

Ans The structures are given here.

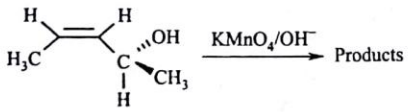


(*R*)-*N*-Ethyl-*N*-methylanilinium oxide



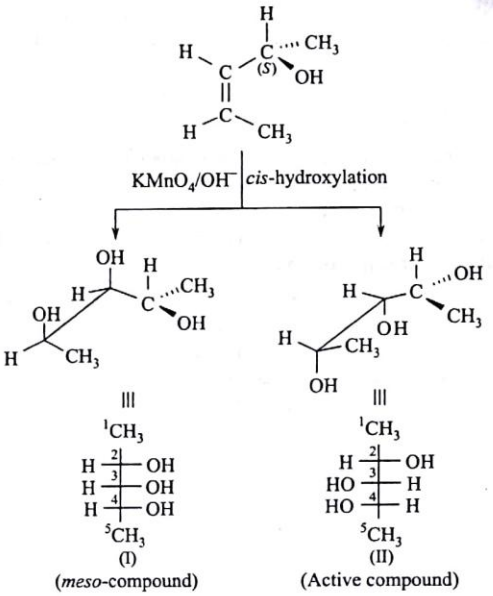
(*R*)-*N*-Ethyl-*N*-methylanilinium oxide

3.102 Draw the Fischer's projection of the compounds formed from the following reaction. Identify the chirotopic-nonstereogenic and achirotopic-stereogenic centres (if any) in the products.



Will you get the same result when the dihydroxylation is carried out with $PhCO_3H/H_2O$?

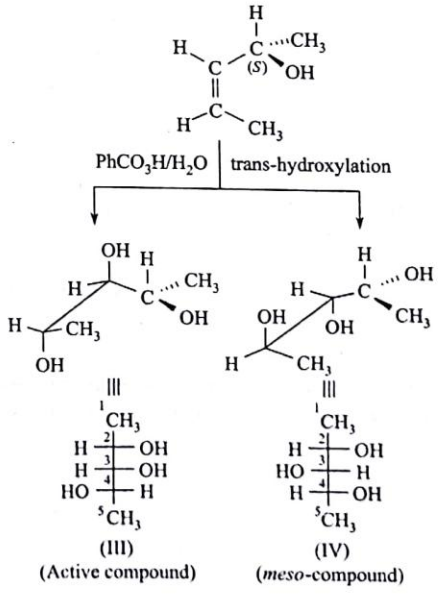
Ans It is a reaction giving *cis*-hydroxylation of the double bond. The substrate molecule is a (*Z*)-isomer. This (*Z*)/*cis*-combination would give one *meso* comound and an optically active isomer. This is shown. The existing chiral centre in the parent compound has (*S*)-configuration.



(I) (*meso*-compound) (II) (Active compound)

In the meso compound (I), C-2 and C-4 are chirotopic as well as stereogenic. C-3 centre is achirotopic and stereogenic. In active isomer (II), C-2, C-3, and C-4 centres are chirotopic. C-2 and C-3 are also stereogenic but C-3 is non-stereogenic, because interchange of position of H and OH does not produce any new stereoisomer. So also is the case of interchange of positions of chiral centres at C-2 and C-4.

When dihydroxylation of the olefinic double bond is carried out with $PhCO_3H$ then *trans*-hydroxylation occurs and two stereoisomers are obtained. One of them is a *meso*-compound and the other is active.

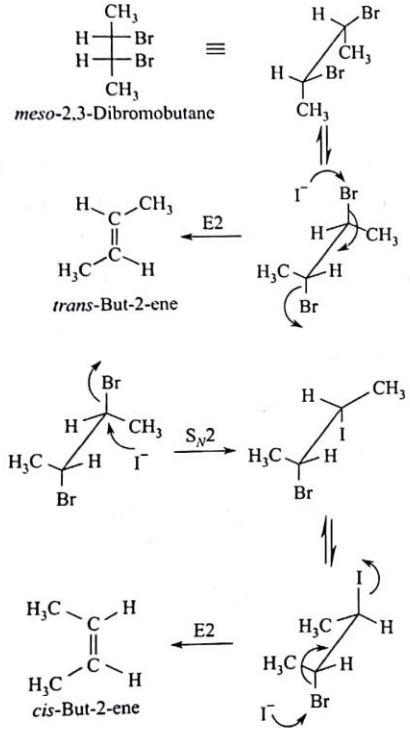


(III) (Active compound) (IV) (*meso*-compound)

In active compound, (III) C-2, C-3, and C-4 centres are chirotopic. In (III), C-2 and C-4 are stereogenic but C-3 is non-stereogenic. In case of *meso*-compound (IV), C-2 and C-4 are chirotopic but C-3 is achirotopic. However, C-3 is non-stereogenic.

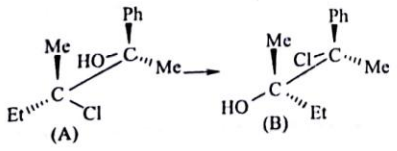
3.103 Iodide ion-catalysed debromination of *meso*- or active form of 2,3-dibromobutane is found to give a mixture of both *cis*- and *trans*-but-2-ene. Account for this observation. Analyse the reaction in terms of stereoselectivity or stereospecificity.

Ans It is a case of merged substitution–elimination. Iodide ion is a good nucleophile and can also act as a catalyst for debromination. Iodide ion-catalysed E2 elimination is stereoelectronically *trans*-elimination.

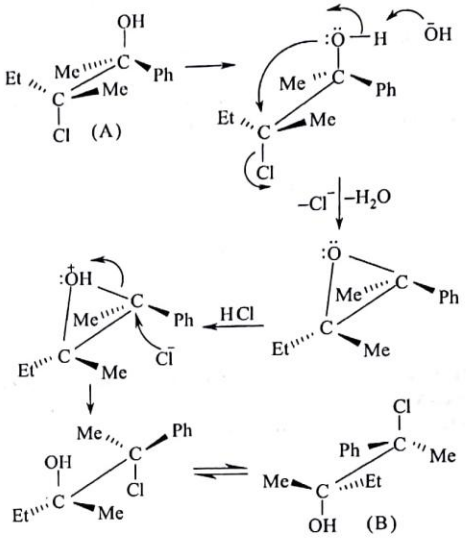


Similarly, active isomer also gives *trans*- and *cis*-But-2-ene by direct elimination and through merged substitution–elimination.

3.104 How can you carry out the following conversions? Comment on the stereochemical outcome of the reaction.



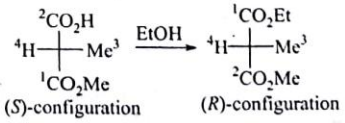
Ans The necessary transformation can be carried out by epoxidation of the parent chlorohydrin by the action of NaOH and this is followed by ring opening of the epoxide by HCl. During ring opening, the nucleophilic attack by Cl^- takes place on that carbon atom which can initiate the formation of a more stable carbocation. The necessary reactions are shown.

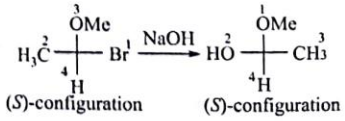


In these reactions, the positions of –OH and –Cl have been mutually interchanged. Both the chiral centres of the parent chlorohydrin have undergone inversion of configuration during the transformation.

3.105 Show that inversion of configuration may not change stereochemical descriptors like *R,S* and also the changes of stereochemical descriptors from *R* to *S* and vice versa do not necessarily indicate that inversion of configuration has taken place.

Ans Change of configuration at a chiral centre is a chemical change involving bonds attached to the chiral centre. However, assignment of stereochemical descriptors to a chiral centre is based on certain rules suggested and accepted by chemists. Therefore, change of configurations has no relation with the stereochemical descripors to indicate the configurations of chiral centres in molecules. Examples are given here.

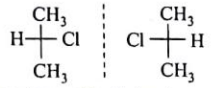




In the first example, there is no change in the configuration but stereochemical descriptor (*S*) has changed to (*R*), because no bond attached to the chiral centre has cleaved. In the second example, there is a change of configuration, because it is a case of S_N2 substitution, but there is no change in the stereochemical descriptors.

3.106 Explain this statement: Chirality of a molecule is a dimension-dependent property.

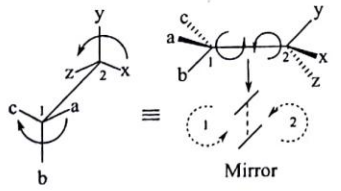
Ans When we call a molecule asymmetric (loosely called chiral), we should consider that it is not superimposable on its mirror image in three-dimensional framework. A so-called planar two-dimensinal structre can also be a chiral, if it is not allowed to be manipulated in a three-dimensional framework. For example, 2-chloropropane is not superimposable on its mirror image in a two-dimensional framework. Therefore, chirality or asymmetry of a molecule is a dimension-dependent property.



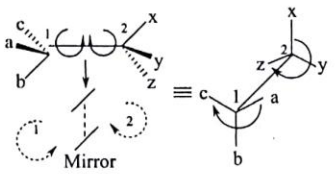
Non-superimposable if structures are not allowed to use three-dimensional movement. Therefore, structures are two-dimentionally chiral, but three-dimensionally achiral.

3.107 What do the terms *perf* and *pref* mean? Where are these terms used in case of stereochemical naming of compounds?

Ans Let one of the two adjacent chiral centres contain the groups a, b, c and the other x, y, z and the orders of decreasing sequence-rule priority at the two centres are a > b > c and x > y > z. Then when the substituents at one centre (C-1 in the following diagram) trace a path a → b → c, (observed from C-2 side) which is the reflection of the path from x → y → z (observed from C-1 side) at the other centre (C-2 in the diagram), the relative configuration at the two chiral centres is *priority reflective* (*pref*). When the path traced by a → b → c is not a reflection of the path traced from x → y → z, observing the path in the same manner, the relative configuration at the two chiral centres is said to be *priority antireflective* (*parf*). In other words, if looking down from any one side, the path a → b → c and the path x → y → z are both clockwise or anticlockwise then that represents *pref* and when one path is clockwise and the other is anticlockwise then the relative configuration is *parf*. This is more convenient to understand.



a → b → c is clockwise and x → y → z is anticlockwise looking from one side—priority antireflective (*perf*)

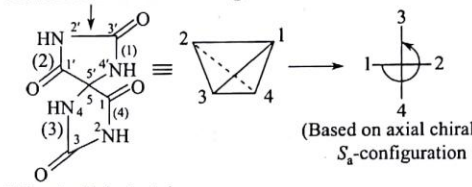


a → b → c and x → y → z are both anticlockwise or clockwise looking from one side—priority reflective (*pref*)

3.108 Assign stereochemical name to 5,5′-*spiro*-bishydantoin on the basis of axial chirality as well as on the basis of central chirality.

Ans The absolute configuration of 5,5′-*spiro*-bishydantoin on the basis of axial as well as central chirality are given here. The numbers within parentheses in the following diagram indicate the priority of groups based on axial chirality.

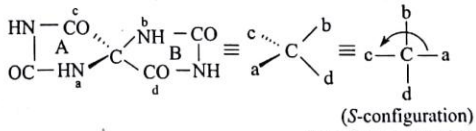
Viewed from this side Configuration based on axial chirality:



(Based on axial chirality)
S_a-configuration

5,5′-*spiro*-bishydantoin

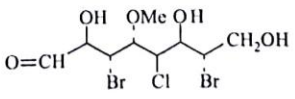
Since the heterocyclic rings are in perpendicular planes, it can be given a configurational descriptor on the basis of chiral centre using CIP rules. In this case we can start from any one of the two equivalent ring systems. If in one ring (say A) we assign arbitrarily priority 'a' to NH (sequence rules), priority 'b' is then given to the NH of the other (ring B). Priority 'c' is given to CO of ring A because if we explore outward, starting from that CO, we get $CONHCH_2NH$ (a) and from the other CO of (ring B) similar exploration gives $CONHCH_2NH$(b)). Since NH (a) has higher priority over NH (b), CO of ring A gets priority of CO of ring B. The CO of ring B should get the lowest priority 'd'. The configuration of the chiral centre is, therefore, *S*.



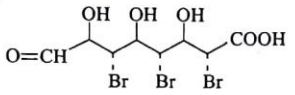
(*S*-configuration)
based on central chirality

3.109 Convert the following *zig-zag* structures to the corresponding Fischer's projection and give their stereochemical names based on IUPAC rules.

(a)

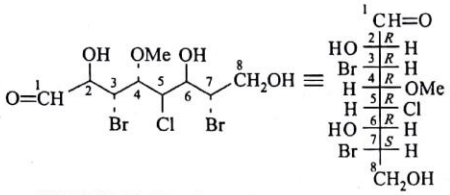


(b)



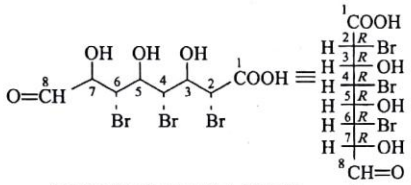
Ans Fischer projection formulae and stereochemical names are given here.

(a)



(2*R*,3*R*,4*R*,5*R*,6*R*,7*S*)-3,7-Dibromo-5-chloro-2,6, 8-trihydroxy-4-methoxyoctanal

(b)

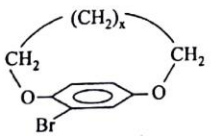


(2*R*,3*R*,4*R*,5*R*,6*R*,7*R*)-3,5.7-Tribromo-2, 5.7-trihydroxy-8-oxooctanoic acid

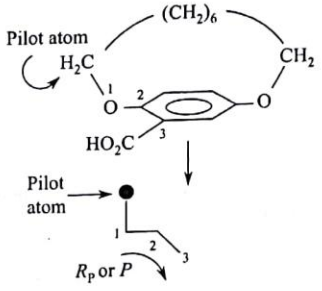
3.110 Describe with an example the CIP method of assigning stereochemical descriptors to a molecule having chirality plane. On the basis of this rule, draw the structure of the (R_p)- and (S_p)- isomers of *trans*-cyclooctene

Ans Asymmetry (chirality) in molecules due to the presence of chiral plane has been observed in certain *ansa* compounds and large cyclenes. An example is given to explain how CIP method is used to assign *R,S* descriptors to such compounds.

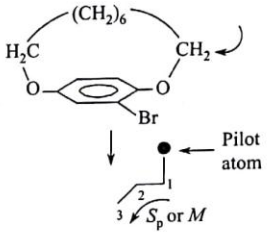
In assigning *R,S* configuration for such a compound, preferred site of the planar aromatic ring attached to the polymethylene chains is to be selected first based on substituents and then the nearest CH_2 group of the polymethylene chain is taken as the reference centre (*pilot group*) and counting is started from the first in-plane atom on that side (here 'O'). This is continued along the atoms in the plane following the direction leading to the more preferred atom (diagram (I)) 1 → 2 → 3 or (diagram (ii)) a → b → c. Now observation is done from the reference (pilot group) CH_2 group. If 1 → 2 → 3 is clockwise then the descriptor should be R_p and when anticlockwise, the descriptor is S_p. In example (a) the compound has R_p configuration. In (b) it is S_p, subscript '*P*' stands for chirality plane. Instead of 'R_p' and 'S_p', helicity descriptors '*P*' and '*M*' are also used respectively.



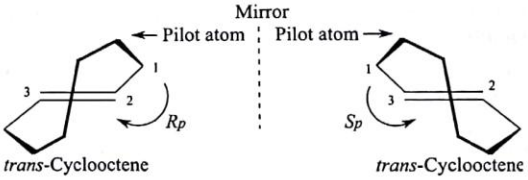
Optically active *ansa* compound



(b)



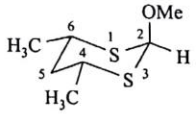
The R_p and S_p isomers of *trans*-cyclooctene are given. The configuration has been assigned on the basis of the rule discussed now.



3.111 Draw the structures of the following compounds:
(a) *r*-2-Methoxy-4*t*,6*t*-dimethyl-1,3-dithiacyclohexane
(b) (3*R*)-3*r*, 5*t*, 7*c*-Trimethoxycyclooctan-2-one
(c) (R_a)-Penta-2,3-dienedioic acid (Glutinic acid)
(d) (S_a)-1,1′-Binapthyl

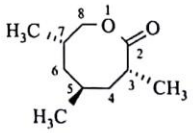
Ans The structures of the mentioned compounds are shown.

(a)



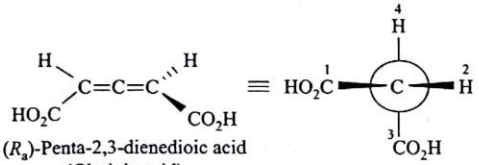
r-2-Methoxy-4*t*,6*t*-dimethyl-1, 3-dithiacyclohexane

(b)



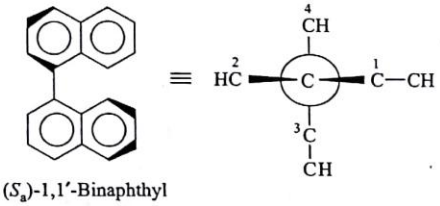
(3*R*)-3*r*,5*t*,7*c*- Trimethyloxacyclooctan-2-one

(c)



(R_a)-Penta-2,3-dienedioic acid
(Glutinic acid)

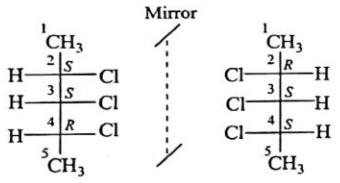
(d)



(S_a)-1,1′-Binaphthyl

3.110 Show by an example that chirality descriptor of a pseudoasymmetric centre is invariant to reflection operation carried out on the molecule.

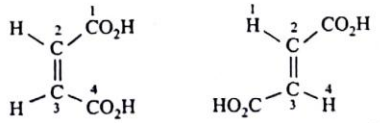
Ans The stereochemical descriptor of a pseudoasymmetric centre is reflection invariant. This can be shown by the following example.



In this example C-3 centre is pseudoasymmetric and its configuration is '*s*' in both the Fischer projections although one is the mirror reflection of the other. The stereochemical descriptors of C-2 and C-4 have changed by the reflection.

3.111 A student carried out bromination on a diastereoisomer of butenedioic acid and obtained racemic 2,3-dibromobutanedioic acid. Another student carried out dihydroxylation on the same diastereoisomer with alkaline $KMnO_4$ but got *meso*-2,3-dihydroxybutanedioic acid. Explain the reaction on the basis of *Re/Si* faces of butenedioic acid.

Ans The structures of two diastereoisomeric butenedioic acid are given here.

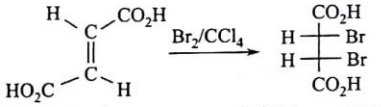


cis-Butenedioic acid
C-2 *Re*/C-3 *Si*

trans-Butenedioic acid
C-2 *Re*/C-3 *Re*

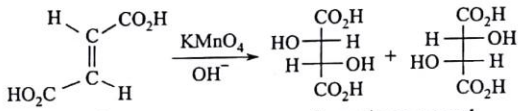
In these structures, *cis* isomer represents *Re-Si* face when looking from the top. Similarly, *trans* isomer represents *Re/Re* face.

From the reactions mentioned, bromination of an olefinic double bond is a *trans*-addition and a symmetrical *trans*-olefin gives a *meso*-2,3-dibromo compound. Therefore, *Re/Re* face of butenedioic acid gives *meso*-dibromo compound.



Re/Re face

meso-2,3-Dibromobutanedioic acid



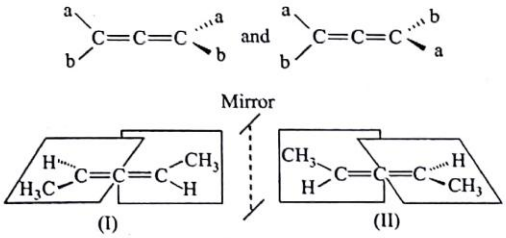
Re/Re face

Racemic compound

On the other hand, dihydroxylation of a symmetrical *trans*-olefin with alkaline $KMnO_4$ is a *cis*-addition reaction. A *trans*-olefin undergoes *cis*-addition to give a pair of enantiomers in equal amounts. Finally a racemic compound is formed. Therefore, both the students carried out a reaction on *trans*-butenedioic acid. Here the reactions are shown on *Re/Re* face, but *Si/Si* face gives the same result.

3.112 Explain with an example that cumulenes with an odd number of double bond cannot be a chiral molecule irrespective of the nature of substituents on the terminal carbon atoms but cumulenes with an even number of double bonds never exhibit diastereoisomerim but exhibit enantiomerism.

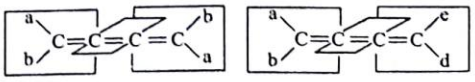
Ans Cumulenes with an even number of double bonds cannot exhibit *cis–trans* isomerism diastereoisomerism, because interchange of groups on any terminal sp^2 carbon does not produce a diastereoisomer with different relative positions and dihedral angles among the substituents. For example, the following allenes are not *cis–trans* diastereoisomers but enantiomers.



(I) (II)

These compounds are enantiomers.

Cumulenes with odd number of double bonds never exhibit enantiomorphism irrespective of the nature of substituents on the terminal carbons. This is because of the fact that in cumulenes with odd number of double bonds, the terminal carbon atoms along with their substituents lie in the same plane and such cumulenes always have σ plane irrespective of the nature of substituents.



3.113 Comment on the symmetry-element present in a molecule with 'homotopic', 'enantiotopic' and 'diatereotopic' ligands and faces respectively. Give examples.

Ans Homomorphic atoms or groups in a molecule may be classified according to their symmetry relationship as follows.

Criterion of substitution or addition	Criterion of symmetry	Nature of the ligands or π-faces
Identical products are formed	Ligands exchange via C_n axes Faces exchange via C_2	Homotopic
Enantiomeric products	Ligands or faces interconvert through S_n, σ, i	Enantiotopic
Diastereomeric products	No symmetry element exchanges the ligands or faces	Diastereotopic

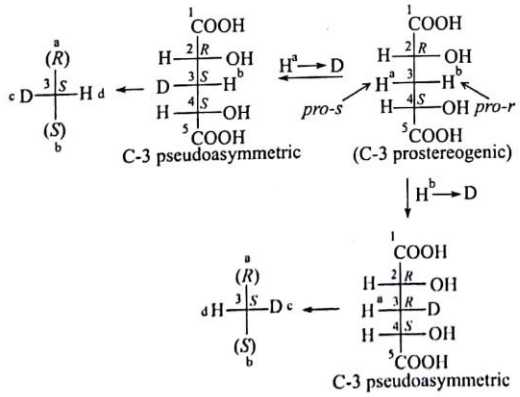
3.114 Answer these questions:

(a) 'During assignments of *pro-R* and *pro-S* descriptors to a pair of identical atoms or groups, one cannot change the priority sequence of the other two ligands on the prostereogenic carbon.' Is this statement correct? Justify with suitable examples.

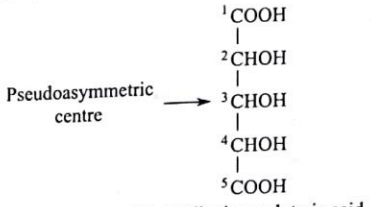
(b) What is the basic structural requirement for the presence of a pdeudoasymmetric centre in an acyclic compound?

Ans The answers are as follows:

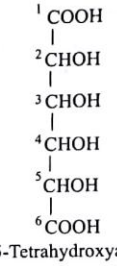
(a) In the following molecule, the carbon atom bearing H^a or H^b is a prostereogenic centre. To assign *pro-R* or *pro-S* descriptors to these two hydrogens, replacement experiment (hypothetically) can be carried out but such replacement manipulation should not disturb the priority sequence of the other two groups by CIP rules. That is you cannot carry out replacement of any of the hydrogen atoms on the prostereogenic centre by a group or atom which has higher priority over *R* and *S* chiral centres attached to the same prostereogenic centre (C-3). Thus, H^a or H^b cannot be replaced by an atom like Br or a group like –OH.



(b) In general an acyclic molecule can have one pseudoasymmetric centre only when the number of constitutionally alike chiral centres is $(n - 1)$ and the value of n is even and the minimum value is four. For example, 2,3,4-trihydroxyglutaric acids can have a pseudoasymmetric centre but 2,3,4,5-tetrahydroxyadipic acid has no possibility of having a pseudoasymmetric centre.



2,3,4-Trihydroxyglutaric acid



2,3,4,5-Tetrahydroxyadipic acid
(Pseudoasymmetric centre is not possible)

3.115 Define the terms 'optical purity' and 'optical yield'.

Ans *Optical purity* of a enantiomeric mixture means the excess of one enantiomer over the *d, l* pair in a *d, l*-mixture. Optical purity is expressed as fraction or percentage optical purity. For example, if one enantiomeric mixture is 30% optically pure with respect to *d*-form, then the remaining 70% is a racemic modification. That is, % composition of this mixture is *d*-isomer, (30 + 35) = 65% and *l*-isomer, 35%. Optical purity is also called *enantiomeric excess* (*ee*).

% Optical purity is related to optical activity of enantiomers by the following expression.

$$\%\ \text{Optical purity} = \frac{\text{Specific rotation of enantiomeric mixture}}{\text{Specific rotation of pure enantiomer}} \times 100 = \frac{[\alpha]_{obs}}{[\alpha]_{max}} \times 100$$

On the other hand, on occasion the starting mateial employed in asymmetric syntheses is not 100% optically pure. In these cases it is useful to use the term *optical yield* rather than optical purity of the product. Optical yield is expressed by the following equation.

$$\%\ \text{Optical yield} \times \left[\frac{\text{OP of product}}{\text{OP of reactant}}\right] \times 100$$

3.116 Calculate the *anti/gauche* ratio of *n*-butane when rotated about C-2/C-3 sigma bond.

Ans *Calculation of % of anti and gauche forms of n-Butane at 298°K*:

The populations of the various conformers are related to their energy differences by the following equation.

$$\Delta G^\circ = -RT \ln K \qquad 3.1$$

where ΔG°, the conformational free energy, is equal to the excess of standard free energy of one conformer over that of the minimum energy conformer.

In the case of *n*-butane, the equilibrium *anti* ↔ *gauche* has $\Delta H^\circ = -0.8$ kcal/mole (3.36 kJ mol^{-1}). In this case there is a statistical factor of 2 which favours the *gauche* form (since there are two enantiomorphic *gauche* conformers) leading to entropy advantage of $R\ln 2$ for the latter.

Thus, $$\Delta S^\circ = -R\ln 2 \qquad 3.2$$

Now from the relation, $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$

At 298°K, $\Delta G^\circ = -0.8$ kcal/mol $- (-RT\ln 2)$

$= -0.8$ kcal/mol $+ 0.41$ kcal/mol

$= -0.39$ kcal/mol ($\equiv 1.64$ kJ mol^{-1})

Putting this value of ΔG° in the equation $\Delta G^\circ = -RT \ln K$,

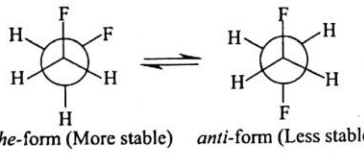
$$\text{we get } K = \frac{(anti)}{(gauche)} = 1.9$$

That is, at (25°C) the distribution of conformations in *n*-butane is 66% *anti* and 34% *gauche*.

It must be noted that *gauche* conformers of *n*-butane represent chiral molecule but not resolvable for rapid change in conformations.

3.117 Contrary to $ClCH_2$-CH_2Cl, in FCH_2-CH_2F gauche conformer is the more stable conformer. Explain this fact.

Ans The situation in FCH_2CH_2F is found to be quite different from either $ClCH_2CH_2Cl$ or $BrCH_2CH_2Br$ in the fact that *gauche* conformer is found to more stable than the *anti* conformer, even in gaseous state. Different explanations have been offered for this unusual stability of *gauche* conformer over the *anti* form.

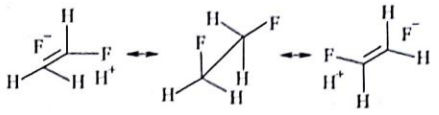


gauche-form (More stable) *anti*-form (Less stable)

Allinger et al. (1977) has explained the stability of *gauche* form on the basis of hyperconjugative interaction of the type, which is initiated by the high electronegativity of fluorine atom.

$$F{-}CH_2{-}CH_2{-}F \longleftrightarrow \bar{F}CH{=}CH{-}F\dot{H} \longleftrightarrow \dot{H}F{-}CH{=}CH_2\bar{F}$$

In order to involve both fluorine atoms simultaneously in this interaction, the two C-F bonds must be orthogonal.



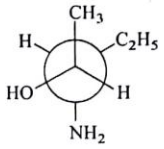
Small size of fluorine atom minimizes the van der Waals repulsive interaction in *gauche* conformer.

Another explanation for preferred *gauche* conformation in the case of FCH_2CH_2F is the so called *gauche* effect. According to *gauche* effect, a chain segment A-B-C-D will prefer *gauche* conformation when A and D are highly electronegative relative to B and C or A and D are themselves unshared electron pairs. In this case A and D are fluorine atom of high electronegativity.

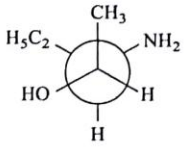
3.118 Draw the staggered conformations of *erythro* and *threo* isomers of 3-aminopentan-2-ol and identify the preferred conformer with reasons.

Ans One enantiomer of *threo* form is shown in the following diagram.

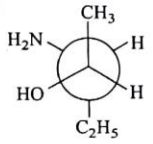
(I)



(III)

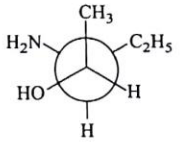


(II)

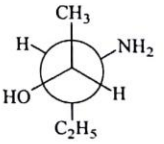


Of these conformations, (II) is most favourable because in this case CH_3/C_2H_5 produces no steric interaction. Moreover $-NH_2$ and $-OH$ can form intramolecular hydrogen bond. Intramolecular hydrogen bond is also possible in (I), but in this case the CH_3/C_2H_5 interaction is considerably high. (III) is the most unfavourable conformation. Again, one enantiomer of *erythro* form is shown.

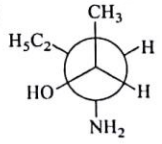
(IV)



(V)



(VI)



In this case, conformations (IV) and (V) are equally probable because they can form intramolecular hydrogen bond between $-NH_2$ and $-OH$ groups, although steric repulsion between

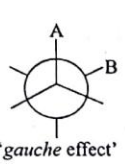
$-CH_3$ and $-C_2H_5$ is strong. Conformation (VI) is unfavourable because intramolecular hydrogen bond formation is not possible although steric strain is released.

3.119 (a) What is 'gauche effect'? Give examples.

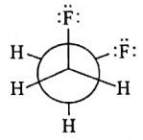
(b) Draw the eclipsed and bisecting conformations of propylene (propene). What are their point groups?

Ans

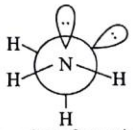
(a) In a conformational array, where A and B are second-row electronegative atoms such as N, O, or F, or unshared electron pairs, the often observed preference for the gauche conformation (skew position) of A and B is called the 'gauche effect'. A few examples are given here.



'*gauche* effect'

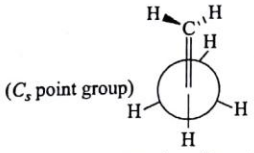


Preferred conformation of FCH_2CH_2F due to *gauche* effect



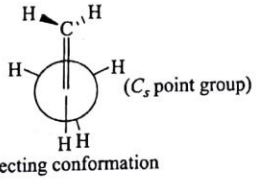
Preferred conformation of H_2NNH_2due to *gauche* effect

(b) The eclipsed and bisecting forms of propylene (propene) have been shown below. Both of them have only one plane of symmetry. Therefore, they belong to the point group C_s.



(C_s point group)

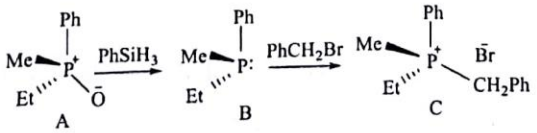
Eclipsed conformation



(C_s point group)

Bisecting conformation

3.120 Each reaction in the sequence shown is reported to proceed with retention of configuration. Yet the starting material has the *R* configuration and the product has the *S*-configuration. Reconcile this apparent contradiction.



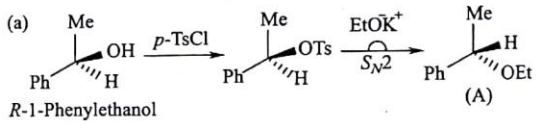
Ans In the compound A, phosphonium salt is chiral with a chiral centre and the ligands have the priorities O> Ph> Et> Me by CIP rules. Its configurational descriptor is *R*. Compound B is also chiral where lone pair of electrons (..) serves as one of the ligands and retention of configuration occurs because O atom is lost without disturbing the other bonds. The configuration of (C) is *S* but here no inversion has occurred because it is an S_N2 displacement where (B) acts as a nucleophile on the achiral substrate $PhCH_2Br$. The *S* descriptor of the product is due to the fact that the priority of ligands attached to P^+ is now -Ph > $-CH_2Ph$ > -Et > -Me.

3.121 Answer these questions.

(a) Optically pure (*R*)-enantiomer of 1-phenylethanol is separately treated with (i) *p*-TsCl followed by EtO^-K^+ and (ii) K followed by Et-OTs. Identify the products.

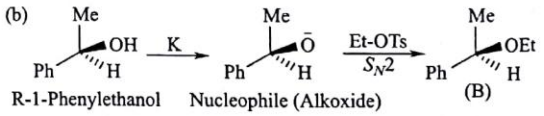
(b) If we take 50% optically pure (*R*)-enantiomer of 1-phenylethanol and carry out both the reactions as stated separately then what should be the product composition in each case. Comment on the optical purity of product in each case.

Ans



R-1-Phenylethanol

There is no change in the configuration in (A) during tosylation because none of the bonds attached to the chiral centre is involved in the reaction. Change in configuration occurs in the second step where S_N2 displacement is the reaction.



R-1-Phenylethanol Nucleophile (Alkoxide)

In this reaction no change in the relative configuration of the chiral centre has taken place during the sequence of reactions shown.

Therefore, compound (A) obtained in (i) and compound (B) obtained in (ii) are enantiomeric.

(ii) 50% optically pure (*R*)-enantiomer means the mixture composition is 75% (*R*)-isomer and 25% (*S*)-enantiomer.

According to sequence (i):

$$\underset{75\%}{R\text{-Alcohol}} \xrightarrow[EtŌK^+]{p\text{-TsCl}} \underset{75\%}{S\text{-ether}}\ (A)$$

$$\underset{25\%}{S\text{-Alcohol}} \xrightarrow[EtŌK^+]{p\text{-TsCl}} \underset{25\%}{R\text{-ether}}\ (B)$$

The optical purity of the resultant enantiomeric mixture is 50% with respect to (*S*)- ether (A).

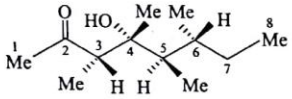
According to sequence (ii):

$$\underset{75\%}{\textit{R}\text{-Alcohol}} \xrightarrow[\text{Et-OTs}]{\text{K}} \underset{75\%}{\textit{R}\text{-ether (B)}}$$

$$\underset{25\%}{\textit{S}\text{-Alcohol}} \xrightarrow[\text{Et-OTs}]{\text{K}} \underset{25\%}{\textit{S}\text{-ether (A)}}$$

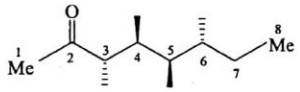
The optical purity of the resulting enantiomeric mixture is 50% with respect to (*R*)- ether (B).

3.122 Give the stereochemical nomenclatures of the following compound based on CIP rule, Prelog (like-unlike) rule, Brewster method, and Masamune method. What would be the change in the naming in each case when its mirror image is taken?



Ans According to CIP rule, the configurational descriptors of chiral centres are 3*S*, 4*R*, 5*R*, 6*R*. According to Prelog rule, the compound is *ull*, meaning C-4 has unlike (*u*) configuration with respect to C-3, C-5 has like (*l*) configuration with respect to C-4 and C-6 has like (*l*) configuration with respect to C-5.

On the basis of Brewster method, the nomenclature is *S* (3*l*, 4*u*, 5*u*, 6*u*). According to Masamune, the given compound can be written as follows and its stereochemical nomenclature is 3,4-*anti*-4, 5-*syn*-5, 6-*anti*.



When the enantiomer of the given compound is considered then the stereochemical nomenclature would be as follows.

C I P: 3*R*, 4*S*, 5*S*, 6*S*; Prelog: *ull*; Brewster: *R* (3*l*,4*u*,5*u*,6*u*); Masamune: 3,4-*anti*, 4,5-*syn*, 5,6-*anti*. It should be noted that the last three names indicate the relative configuration.

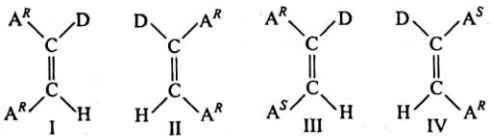
3.123 How many stereoisomers are possible for each of the following compound? Mention the number of active isomers and *meso*-forms (when applicable).

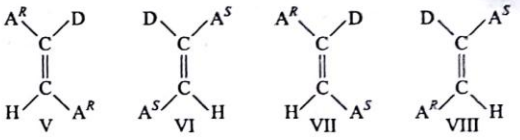
(a) CH_3–CHBr–CD=CH–CHBr–CH_3

(b) CH_3–$(CHBr)_6$–CH_3

Ans

(a) The compound has four pairs of enantiomers. The molecule contains two unlike chiral centres. The two sp^2 carbons contain identical ligands, which may be enantiomorphic. If we represent the chiral centre by A and the CIP configurations by *R* and *S*, the stereoisomers can be represented as follows.

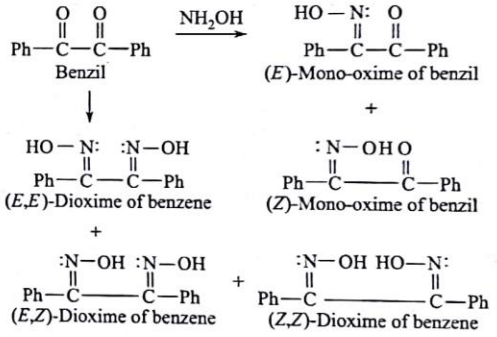




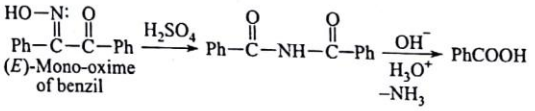
(b) In this molecule there are even numbers (six) of chiral centre and the molecule can be constitutionally divided into two mirror-image halves. Therefore, it can have $[2^{(n-1)}] = 2^5 = 32$, that is, active stereoisomers and $[2^{(n-2/2)}] = 2^2 = 4$ *meso* compounds.

3.124 What are the products when benzil is converted into mono-oxime and di-oxime? Give their (*E*)/(*Z*) nomenclature based on CIP rules. One of the mono-oximes gives benzoic acid as the only isolable product after Beckman rearrangement followed by hydrolysis. Identify that mono-oxime and explain.

Ans The structures of diastereoisomeric mono-oximes and dioximes of benzyl are given here.



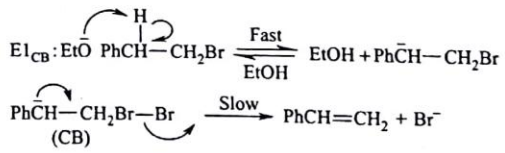
When (*E*)-mono-oxime is subjected to Beckmann rearrangement then the following amide is obtaind by *trans*-migration.



It is evident that (*E*)-mono-oxime of benzil gives the amide which on alkaline hydrolysis gives salt of benzoic acid and ammonia. On acidification of the hydrolysed product, we get benzoic acid.

3.125 Show that the formation of $PhCH{=}CH_2$ from $PhCH_2CH_2Br$ in the presence of OEt^-/EtOH can be interpreted kinetically as El_{CB} or E2.

Ans Plausible $E1_{CB}$ and E2 mechanisms are given here.



Since the reaction is carried out in EtOH medium, the concentration of the ethanol formed in the first step of the reaction may be neglected. Hence equilibrium constant 'k' is,

$$k=[Ph\bar{C}HCH_2Br]/[PhCH_2CH_2Br][Et\bar{O}]$$

The rate-determining step of the reaction is the loss of Br^- from the carbanion (conjugate base)

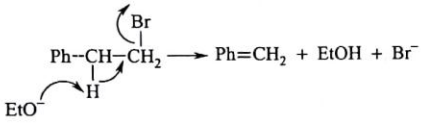
$$\text{Therefore, rate} = K\,[Ph\bar{C}HCH_2Br] = kK\,[PhCH_2CH_2Br][EtO]$$

Since k and K are both constants, their product is also constant (say K).

$$\therefore \text{ Rate} = K'\,[PhCH_2CH_2Br][Et\bar{O}]$$

Thus kinetically, the $E1_{cb}$ can be interpreted as a second order reaction.

E2: It is a one step process and occur through the participation of both $PhCH_2CH_2Br$ and Eto^-.

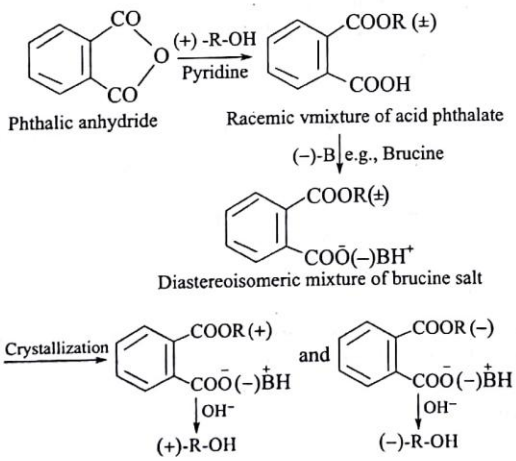


Rate = $k[PhCH_2CH_2Br][Eto^-]$, that is, second order.

Therefore, $E1_{cb}$ and E2 mechanisms cannot be kinetically distinguished in this particular reaction.

3.126 Describe a method for the resolution of racemic alcohols.

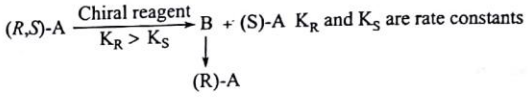
Ans *Resolution of active alcohols*: (±)-Alcohols are usually resolved by converting them into their half-esters using phthalic or succinic anhydride. These half-esters are then resolved as typical active acids.



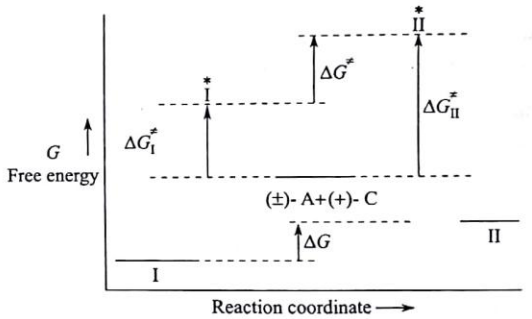
Hydrolysis may be carried out with hot aqueous sodium hydroxide, or, if there is possibility of racemization by base, the alcohols may be recovered from half-esters by reducing with lithium aluminium hydride.

3.127 What is meant by kinetic resolution? Describe the method with suitable energy diagram.

Ans A *kinetic resolution* is an enantioselective chemical reaction of a racemate with a chiral reagent in which one of the enantiomers forms a product at a faster rate than the other. The difference in rates of the reaction arises from a difference in activation energy (E_a) required to reach the respective transition state for reaction from each enantiomer. Recovery of one of the unreacted enantiomers, (*S*)-A, in a non-racemic form constitutes a resolution.



The unreacted enantiomer is (+)-A (say) and B is the product. The other enantiomer (−)-A can be isolated by reversing the original enantioselective reaction in a non-selective manner. The energy diagram of kinetic method of resolution can be shown as follows.



I is equivalent to the product B and II is the product from the other enantiomer (−)-A, which is formed very slowly. (±)-A is racemate and (+)-C is the chiral reagent. (a) is formed at a faster rate having less activation energy. ΔG is the free energy difference of the products in ground state and $\Delta\Delta G^{\ddagger}$ is the difference in activation energy leading to transition states.

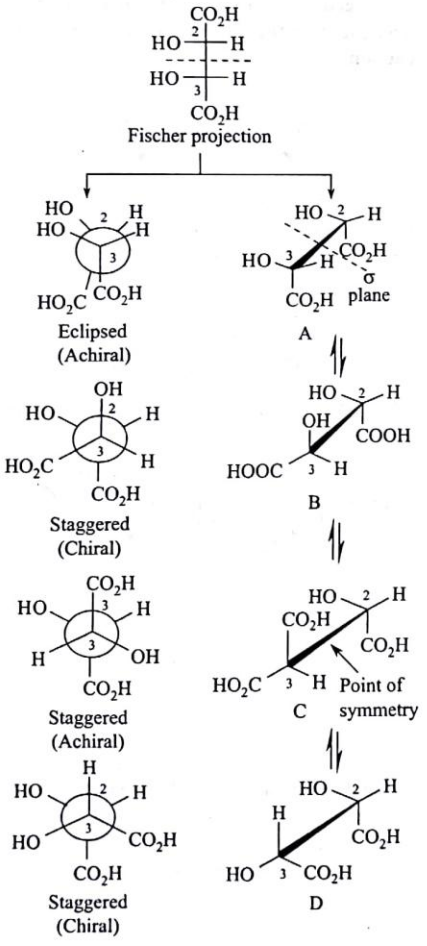
If the resolution is carried out in such a way that equilibrium is not allowed to be attained then the product composition depends on $\Delta\Delta G^{\ddagger}$ and the reaction is said to be kinetically controlled. For kinetic resolution, therefore, the reaction should be done in such a manner that the reaction remains kinetically controlled. If the reaction is allowed to reach the equilibrium, then the product ratio will depend on ΔG and the reaction will be thermodynamically controlled. Under this equilibrium condition, no resolution can be effected, that is, both the diastreoisomers will be formed.

3.128 Discuss the conformational enantiomerism taking *meso*-tartaric acid as an example.

Ans When achiral molecules with or without chiral centres shows free rotation about C—C bond/bonds, then certain conformations are found to be chiral and they exist in

equimolecular amounts of enantiomeric forms. Thus apparently achiral molecules can be considered as racemic mixture of enantiomers. This phenomenon is called 'conformational enantiomerism'. This has been illustrated by *meso*-tartaric containing chiral centres.

The Fischer projection formula of *meso*-tartaric acid has a plane of symmetry bisecting the C-2–C-3 bond, as shown in the diagram, so this structure is clearly achiral. The eclipsed orientation of bonds that is assumed in the Fischer drawing is, however, an unstable conformation, and the staggered conformers that undoubtedly make up most of the sample molecules. Fischer conformation (A) and three staggered conformers all displayed in both sawhorse and Newman projections. The second and fourth conformations (B and D) are dissymmetric, and are in fact enantiomeric structures. The third conformer (C) has a centre of symmetry and is achiral.

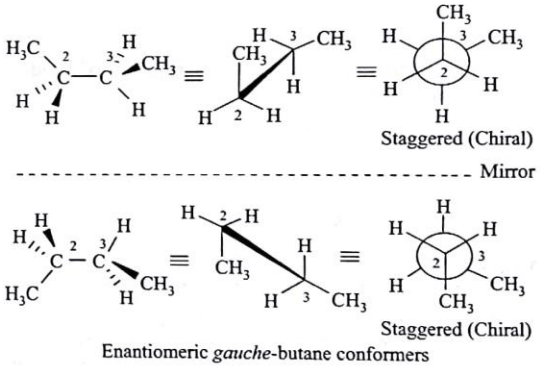


Conformations of *meso*-Tartaric Acid

Since a significant proportion of the *meso*-tartaric acid molecules in a sample will have chiral conformations, the achiral properties of the sample (e.g., optical inactivity) should not be attributed to the symmetry of the Fischer formula. Equilibria among the various conformations are rapidly established, and the proportion of each conformer present at equilibrium depends on its relative potential energy (the most stable conformers predominate). Since enantiomers have equal potential energies, they will be present in equal concentration, thus cancelling their macroscopic optical activity and other chiral behavior. Simply put, any chiral species that is present is racemic.

3.129 Draw the enantiomeric *gauche*-butane conformers of *n*-butane and comment on their chirality.

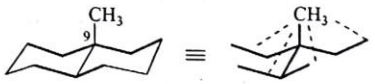
Ans It is interesting to note that chiral conformations are present in most conformationally mobile compounds, even in the absence of any chiral centres. The *gauche* conformers of *n*-butane, for example, are chiral and are present in equal concentration in any sample of this hydrocarbon. The following illustration shows the enantiomeric relationship of these conformers, which are an example of a chiral axis rather than a chiral centre.



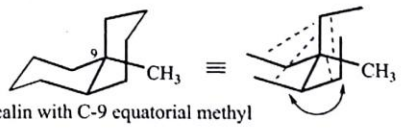
Enantiomeric *gauche*-butane conformers

3.130 Draw the chair forms of *trans*-9-methyldecalin and *cis*-9-methyldecalin. Which one is more stable and why?

Ans In *trans* isomer with axial methyl, there are four *butane-gauche* interactions involving the axial methyl groups but in *cis* isomer with equatorial methyl group there are five *butane-gauche* interactions. These are shown by bold bonds.



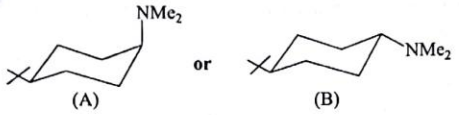
trans-Decalin with C-9 axial methyl



cis-Decalin with C-9 equatorial methyl

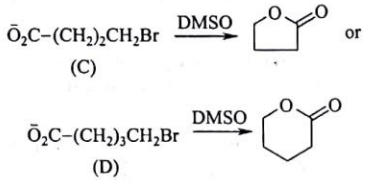
3.131 For the following pairs of reactions, indicate which one would you expect to be more favourable. Explain the basis of your prediction.

(a) Which isomer will be converted to a quaternary salt more rapidly?



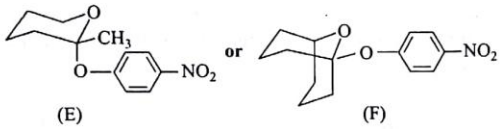
(A) (B)

(b) Which lactone will be formed more rapidly?



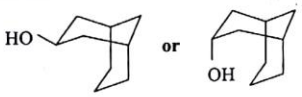
(C) (D)

(c) Which compound will undergo hydrolysis rapidly?



(E) (F)

(d) Which compound will be more rapidly oxidized by chromic acid?



(G) (H)

Ans These are the answers:

(a) B is more reactive because quaternary salt formation from A will increase *syn*-diaxial interaction

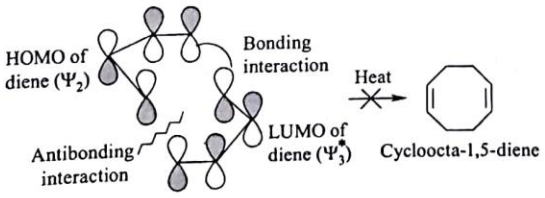
(b) C will lactonize more easily to give γ-lactone because the formation of a lower-membered ring is thermodynamically more favourable.

(c) E will undergo hydrolysis more rapidly because of favourable stereoelectronic arrangement.

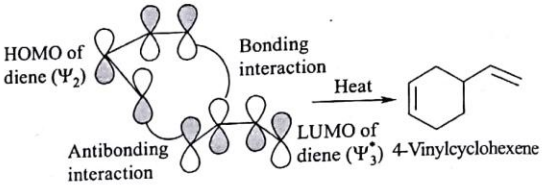
(d) H will under oxidation at a faster rate because of steric assistance.

3.132 Explain by FMO theory why buta-1,3-diene fails to dimerize to give cyclooctadiene by thermal cycloaddition reaction? However, cyclohexene derivative is formed by normal Diels–Alder reaction.

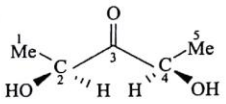
Ans In cycloaddition reaction between two molecules of buta-1,3-diene, HOMO of one should interact with LUMO of the other. However, that interaction, according to FMO approach, is symmetry disallowed. Consequently, cycloocta-1,5-diene is not formed thermally.



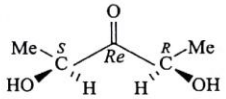
However, thermal Diels–Alder reaction, according to FMO theory, is symmetry allowed and the product is a cyclohexene derivative.



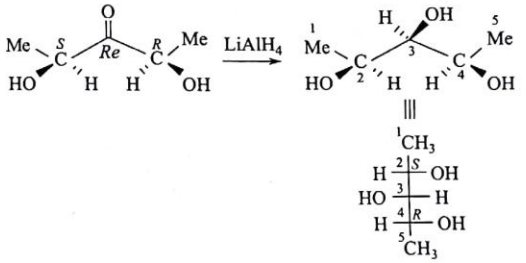
3.133 Find out the absolute configurations of the chiral centres of the following compound and determine the nature of streoface (*Re* or *Si*) of the compound looking from the top of the paper. What happens when the compound is reduced with $LiAlH_4$? Comment on the topicity and stereogenicity of the new chiral centre formed by the above reaction.



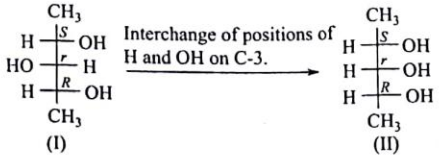
Ans Absolute configurations of the chiral centres C-2 and C-4 are (*S*) and (*R*) respectively. Therefore, looking from the top, the topicity of the carbonyl-face is *Re*.



When the compound is reduced with $LiAlH_4$, we get the following compound.



The new chiral centre is 'achirotopic' because its site symmetry is achiral having a σ-plane. However C-3 centre is stereogenic, because the interchange of positions of –H and –OH on this carbon gives a new stereoisomer. The stereogenic C-3 has '*r*' configuration (I) and '*s*' configuration in (II).



(I) (II)

3.134 Give examples in each case, which conform to each of the following facts.

(a) A cyclic molecule having achirotopic-stereogenic centre

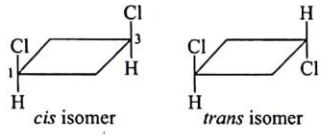
(b) A cyclic molecule having a chirotopic-nonstereogenic centre

(c) A cumulene with an odd number of double bonds having a stereogenic axis

(d) A cumulene with an even number of double bonds having a stereogenic centre

Ans

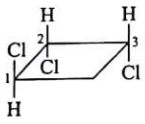
(a) 1,3-disubstituted cyclobutanes having identical substituents contain achirotopic-stereogenic centres.

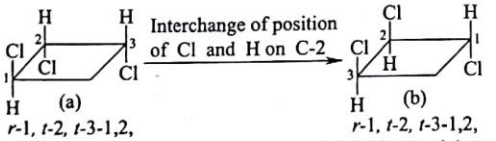


cis isomer *trans* isomer

These structures are diastereoisomers and they are interconvertible when the positions of Cl and H on C-1 or C-3 are interchanged. Both these are achiral due to the presence of a plane of symmetry passing through C-1 and C-2 (The structure on the right also has $i \equiv S_2$). Therefore, C-1 and C-3 are achirotopic centres judged on local symmetry.

(b) In the following 1,2,3-trisubstrituted cyclobutane, C-2 centre is chirotopic but non-stereogenic. The molecule is chiral and, therefore, C-2 is chirotopic. Interchange of positions of Cl and H on C-2 produces the parent compound. Therefore, C-2 is nonstereogenic.

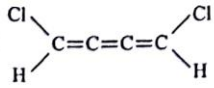


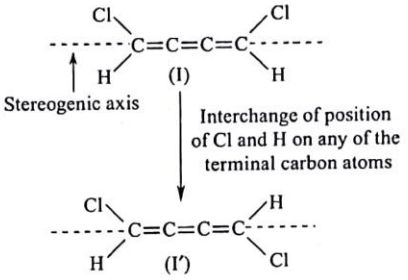


r-1, *t*-2, *t*-3-1,2, 3-Trichlorocyclobutane

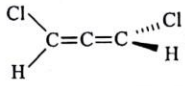
r-1, *t*-2, *t*-3-1,2, 3-Trichlorocyclobutane

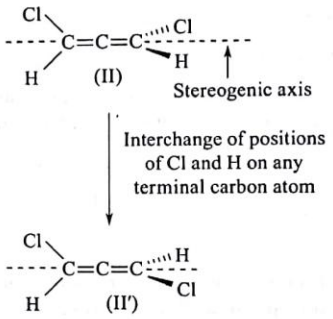
These are identical compounds, that is, the stereochemical relations of three chlorine atom is *cis–trans*.

(c)  represents a cumulene having a stereogenic axis passing through the line joining the carbon atoms.



(I) and (I′) are *cis–trans* isomers (diastereoisomers). In this case the stereogenic axis does not represent the chiral axis.

(d)  represents a cumulene with an even number of double bonds having a stereogenic axis.

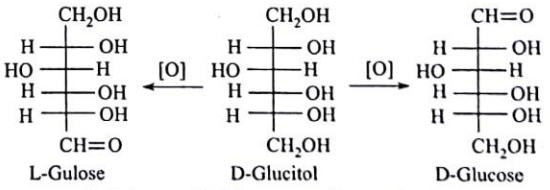


(II) and (II′) are enantiomers. Therefore, it has a stereogenic axis. In this case, stereogenic axis also represents a chiral axis.

3.135 Dermine the topicity of the hydroxymethylene groups (—CH_2OH) of (a) D-Glucitol, (b) D-Mannitol, and (c) D-Galactitol.

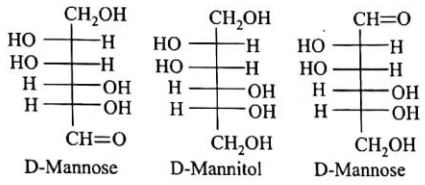
Ans

(a) In case of D-Glucitol, the terminal —CH_2OH groups are diastereotopic, because no symmetry operations interconvert these groups. Selective oxidation of —CH_2OH to —CHO gives a pair of diastereoisomers.

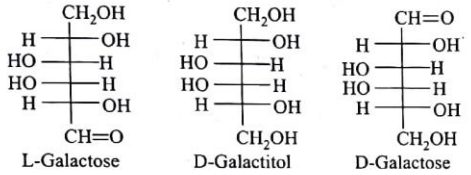


L-Gulose and D-Glucose are diastereoisomers

(b) In case of D-Mannitol, the terminal —CH_2OH groups are homotopic, because C_2 symmetry operation interconverts these groups. Selective oxidation of —CH_2OH to —CHO gives homomeric compounds.

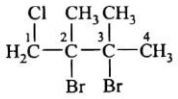


(c) In case of D-Galactitol, the terminal $-CH_2OH$ groups are enantiotopic, because σsymmetry operation interconverts these groups. Selective oxidation of $-CH_2OH$ to $-CHO$ gives enantiomeric compounds.



D-Galactose and L-Galactose are enantiomeric compounds.

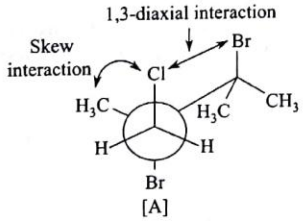
3.136 (a) Give the most stable conformation of the following compound about C-1/C-2 bond and explain.

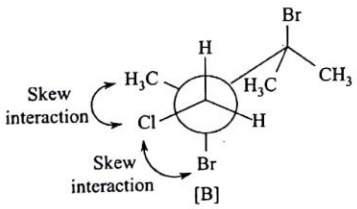


(b) Draw the most stable conformation of *meso*-form of phenylisopropylpinacol with reasons.

Ans

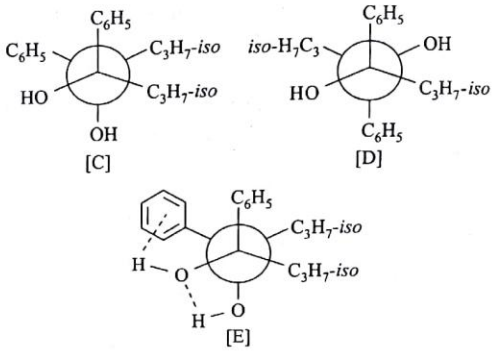
(a) Two of the many possible conformations of the compound are given here.





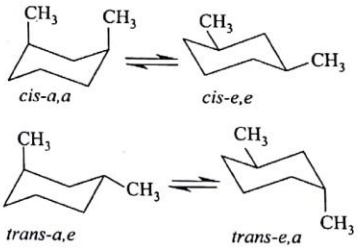
Of the staggered conformations, conformation [A] is less stable because of strong 1,3-diaxial-type interaction between the two halogen atoms, although the conformation [B] has an additional skew conformation between the two halogen atoms.

(b) Two possible conformations of *meso*-form of phenylisopropylpinacol are given here. The conformation [C] is more stable than the conformation [D]. This is because of strong intramolecular hydrogen bonding between the –OH groups along with an interesting intramolecular hydrogen bond involving the benzene nucleus, as shown in [E]. This type of intramolecular hydrogen bonds has been confirmed by IR spectra.



3.137 Draw all the possible conformations of *cis*- and *trans*-1,3-dimethylcyclohexane. Comment on their relative stability based on steric interactions. Are the compounds resolvable? Discuss the result of ring inversion in each case.

Ans *cis*- and *trans*-1,3-dimethylcyclohexane have chair conformations as shown here.



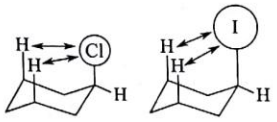
cis isomer has (*a*,*a*) and (*e*,*e*) diastereoisomeric conformations. The (*a*, *a*) form has two butane-*gauche* and one CH_3 /CH_3 *syn-diaxial* interactions and, therefore, very unstable (enthalpy increases by an amount of $2 \times 0.9 + 3.6 = 5.4$ kcal mol^{-1}(22.68 kJ mol^{-1}). The (*e*,*e*) form has no interaction and, therefore, most stable. The *trans*-form has only one conformation, that is, (*a*,*e*) or (*e*,*a*). They are topomeric. The *trans*- form has two butane-*gauche* interactions and, therefore, energy increases by an amount of 1.8 kcal mol^{-1} (7.56 kJ mol^{-1}).

The *cis*-forms are achiral (*meso*) having a plane of symmetry, that is, it belongs to C_s point group. The *trans*-form is chiral and, therefore, can exist as enantiomorphic forms, that is, resolvable.

Ring inversion of *cis*-forms give conformational diastereoisomers but ring inversion of *trans* forms give topomers (same configuration and superimposable).

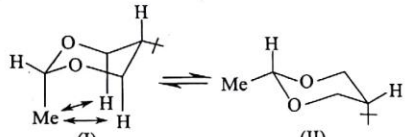
3.138 Conformational free energy values of Cl, Br, and I atoms are almost identical although the size of halogen atoms increases as Cl < Br < I. Offer an explanation.

Ans Conformational free energy (A-values) of Cl = 2.68 kJ mol^{-1}, Br = 2.80 kJ mol^{-1}, and I = 2.55 kJ mol^{-1}. These values indicate that conformational free energy is not solely a function of substituent size. As the sizes of the halogens get larger (their van der Waals radius increases), the C-X (X=halogen) bond becomes longer and thus X becomes more away from the *syn-axial* hydrogen atoms at C-3 and C-5. Thus the increase in size of halogen is proportionately compensated by the simultaneous increases in distance between the *syn-axial* hydrogen atoms and X atom. Polarizability of halogen atoms, which increases with the size of the halogen atom, has also some role for the lowering of the conformational free energy with the increase of the size of the halogen atoms.



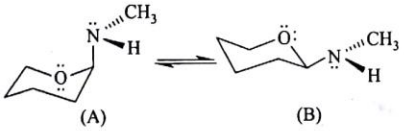
3.139 *cis*-2-Methyl-5-*t*-butyl-1,3-dioxane prefers that conformation where the bulky *tert*-butyl group occupies the axial position. Give an explanation.

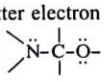
Ans Two conformations of this *cis*-compound are shown here.



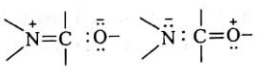
In case of conformation (I), there are *syn-axial* interactions between CH_3 and $H^'s$ at C-4 and C-6. This interaction destabilizes the conformer. Conformation (II) is obtained by ring inversion where bulky *t*-butyl group assumes axial position but is free from *syn-axial* interaction because 1,3-*syn-axial* positions are occupied by oxygen atoms having lone pair of electrons. Since lone pair offers no steric interaction, this conformation is relatively more stable.

3.140 Between the following two conformations find out the preferred conformations with explanation.

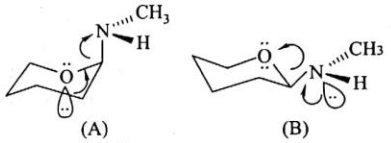


Ans Compounds containing the 'N' atom are better electron donors and 'O' atom is a better electron acceptor.  moiety can cause *endo* and *exo*-anomeric effects.

On the basis of valence bond picture, orbital overlap can be shown as given here but the former is more preferred.

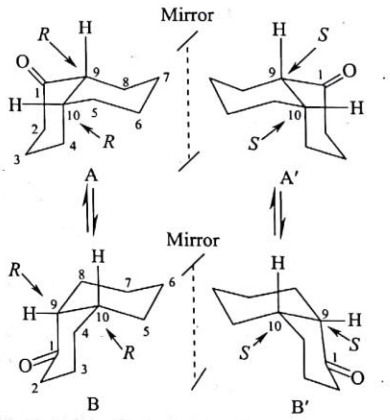


In the present case, conformation (A) can have anomeric effect because the lone pair of electrons on the oxygen atom lie antiperiplanar to C-N σ^*-orbital but reverse overlap is not possible. In case of conformation (B), *exo*-anomeric effect is possible because N contains a lone pair of electrons that is antiperiplanar to C-O σ^* orbital. Since the N atom is a better donor, *exo*-anomeric effect will predominate and consequently conformation B will be more preferred.



3.141 Draw the steroid and non-steroid conformations of *cis*-1-decalone. Is it resolvable? Identify the chiral centre and give their CIP configurational descriptors.

Ans The steroid and non-steroid conformations of *cis*-1-decalone are shown. These are interconvertible by ring inversion.

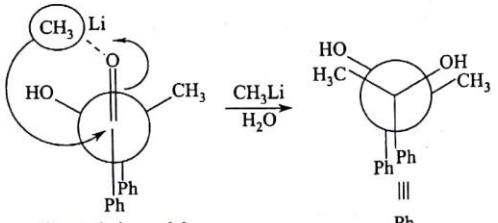


A and A′ are steroid conformations of *cis*-1-decalone. These two are enantiomorphic. Ring inversion of A gives B and A′ gives B′. B and B′ are non-steroid conformations and are also enantiomeric to each other. Thus, *cis*-1-decalone has two configurational stereoisomers, that is, C-9(*R*)-C-10(*R*) and C-9(*S*)-C-10(*S*). Each of these configurational stereoisomers can exist in two conformational stereoisomer having a diastereoisomeric relationship.

3.142 What would be the stereochemical outcome if open-chain and rigid-models of Cram are used to reduce

(*R*)-isomer of PhCOC*(CH_3)PhOH with CH_3Li? What is the experimental product and what does it support?

Ans Cram's open-chain model of (*R*)-PhCOC*(CH_3)PhOH can be written as follows in Newman projection and the reaction with CH_3Li is shown.

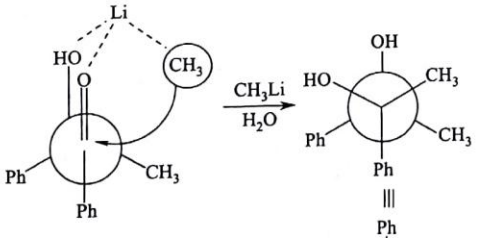


Open-chain model

threo isomer (Major)

The other product is *meso*-, which should be the minor product according to open-chain model.

The rigid model involving five-membered cyclic system where the metallic part of the reagent (Li) is doubly coordinated is shown now along with the possible product.

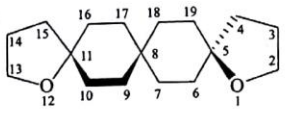


meso-compound

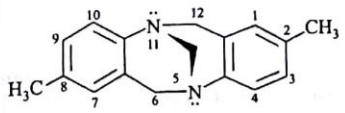
In practice, as high as 92% of the *meso*-compound is obtained. This confirms that in this case Cram's rigid model is the preferred transition state.

3.143 Give the stereochemical nomenclatures of the following two compounds.

(a)

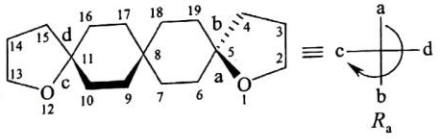


(b)



Ans

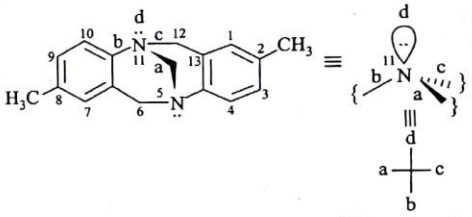
(a) It is trispiro compound with axial chirality. When-projected as Fischer projection, the axial chirality is found to be R_a.



R_a

The compound can be named as [5(11)R_a]-1,12-Dioxotrispiro[4.2.2.4^{11}.2^8 .2^5]nonadecane.

(b) The compound is trivially called Troger's base. It is a heterocyclic compound and bears two chiral nitrogen atoms. The configurations of both N-5 and N-11 are '*S*'. Since it is a rigid molecule with bridgehead nitrogen atoms, pyramidal inversion is prevented. The determination of the configuration of N-11 can be shown as follows. Similarly the configuration of N-5 is also found to be '*S*'. The stereochemical name of Troger's base is '(5*S*,11*S*)-2,8-Dimethyl-11-methanodibenzo[*b*, *f*][1,5]diazocine'.

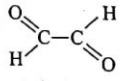


'*S*' configuration

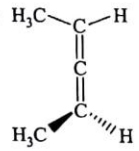
3.144 Identify the point groups of each of the following compounds and find the element/elements of symmetry in each case.

(a)

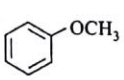
(b)



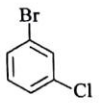
(c)



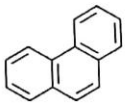
(d)



(e)

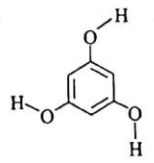


(f)



(g)

(h)



(i) 

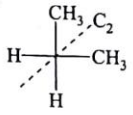
(j) $\overset{+}{C}H_3$

Ans

(a) C_{2v}: It has a C_2 axis and two σ_v planes.

(b) C_{2h}: It has a C_2 axis and a σ_h plane (molecular plane)

(c) C_2: It has only one C_2 axis. It can be shown in the corresponding Fischer projection.

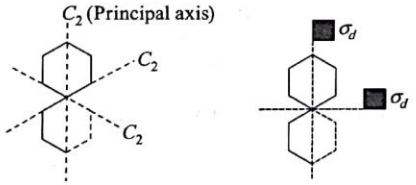


(d) C_{2v}: It has a C_2 axis and two σ_v planes. If we assume $-OCH_3$ (achiral group) as a sphere then one σ_v is vertical and the other one is the molecular plane. C_2 axis is passing through the $-OCH_3$ group and the opposite *para*-carbon.

(e) C_s: It has only one plane of symmetry, i.e., molecular plane.

(f) C_{2v}: It has a C_2 axis and two σ_v planes.

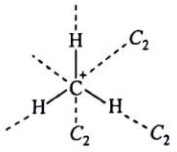
(g) D_{2d}: It has a C_2 principal proper axis, two additional C_2 axes perpendicular to the principal axis, and two σ_d planes intersecting the principal axis. These are shown as follows. A model will be helpful for understanding.

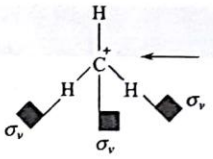


(h) C_{3h}: It has a vertical C_3 proper axis, along with a σ_h plane. Molecular plane (plane of the paper) represents the σ_h plane.

(i) Cyclopentadienyl anion is planar and consequently it belongs to the point group D_{5h}. It has a principal C_5 proper axis, $5C_2$ axes, 5 σ_v planes, and a σ_h plane.

(j) D_{3h} : $^+CH_3$ is a trigonal planar ion; therefore, it has a C_3 proper axis, three additional c_2 axes, three σ_v planes intersecting the C_3 axis, and a σ_h plane bisecting the C_3 axis.



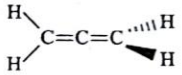


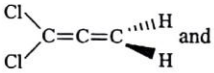
C_3 principal axis is perpendicular to the plane of the paper and passing through the central carbon

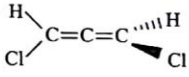
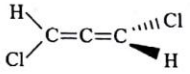
3.145 Allene is converted sequentially into substituted allenes according to the following scheme. Find out the change in the point group in each case. How many of them are chiral?

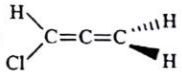
$$\underset{\text{(A)}}{H_2C{=}C{=}CH_2} \longrightarrow \underset{\text{(B)}}{Cl_2C{=}C{=}CH_2} \longrightarrow \underset{\text{(C)}}{ClCH{=}C{=}CHCl}$$

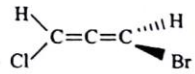
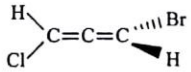
$$\longrightarrow \underset{\text{(D)}}{CHCl{=}C{=}CH_2} \longrightarrow \underset{\text{(E)}}{CHCl{=}C{=}CHBr}$$

Ans Allene (A) has the structure, 

The elements of symmetry of allene are three C_2 axes, two σ_v planes, and an S_4 axis. It belongs to the point group D_{2d} (dihedral symmetry). It is an achiral molecule. When allene is converted into $Cl_2C{=}C{=}CH_2$ (B) the desymmetrization takes place to C_{2v} point group. (B) has the structure,  and has C_2 proper axis along with two σ_v planes intersecting the C_2 axis. It is an achiral molecule.

In the compound (C),  or  the only element of symmetry is C_2 proper axis. It belongs to the point group C_n ($n = 2$). The molecule is chiral. It is a dissymmetric molecule.

The compound (D) with the structure  has only a plane of symmetry passing through H and Cl. Its point group is C_s. It is an achiral molecule.

The molecule (E)  or  has no element of symmetry except the trivial axis (C_1). Therefore, the molecule belongs to the point group C_1. It is chiral and is an asymmetric system.

EXERCISES

3.1 Which of the following have an inversion centre? NH_3, CH_4, C_2H_2, C_2H_4, $SOCl_2$, SO_2Cl_2?

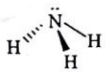
3.2 Draw neat diagrams of a tetrahedron and an octahedron and label the characteristic elements of symmetry in each case.

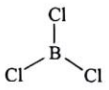
3.3 Define the term 'symmetry operation'. Show diagrammatically that (a) $S_2^6 = C_3$ (b) $S_6^3 = i$, $i^2 = E$, $\sigma^2 = E$, where the symbols have their conventional meanings.

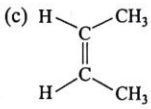
3.4 Show with a diagram that $S_n^n = E$ (when n = even) and $S_n^{2n} = E$ (when n = odd).

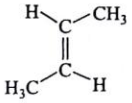
3.5 What are the elements of symmetry present in an equilateral triangle?

3.6 List the symmetry elements in the following molecules.

(a) 

(b) 

(c) 

(d) 

(e) $CH_2{=}C{=}CH_2$

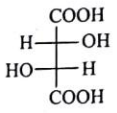
3.7 Classify the molecules as dissymmetric and non-dissymmetric in terms of point groups. Give suitable examples.

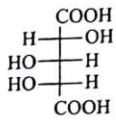
3.8 Define symmetry number. What are the symmetry number of molecules possessing (a) C_3, (b) C_i, (c) C_{nh}, and (d) D_{nh} point group?

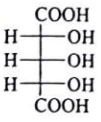
3.9 Write True or False against each of the following statements:

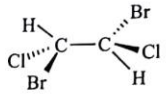
(a) A sphere has all possible elements of symmetry.
(b) An octahedron has a centre of inversion but a tetrahedron has none.
(c) Molecules having dihedral symmetry are always optically inactive.
(d) AB_3-type molecule cannot have an inversion centre.
(e) A non-dissymmetric conformation with C_n must also have a σ plane.
(f) A non-dissymmetric conformation with a σ must also have a C_n.
(g) Absence of σ is a necessary but not a sufficient condition for dissymmetry.
(h) Presence of a σ is a sufficient but not a necessary condition for reflection symmetry.
(i) D_n, D_{nh}, and D_{nd}—all these point groups have nC_2 axes.
(j) Molecules possessing D_n and D_{nd} point groups are optically active.

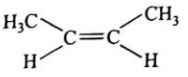
3.9 The following molecules have centres, which are (a) stereogenic but achirotopic, (b) chirotopic but non-stereogenic, or (c) chirotopic and stereogenic. Label such centres in each case.

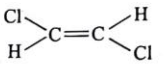
(a) 

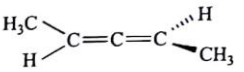
(b) 

(c) 

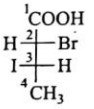
(d) 

(e) 

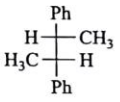
(f) 

(g) 

3.10 Convert the following Fischer projections into sawhorse and Newman projections having the characteristic written here within parentheses, in each case.

(a) 

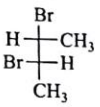
(Dihedral angle between CO_2H and CH_3group is 60°)

(b) 

(Dihedral angle between the two H atoms is 180°)

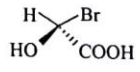
(c) 

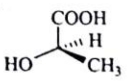
(Sawhorse projection having a centre of symmetry)

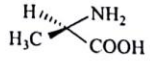
(d) 

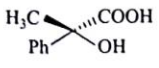
(Sawhorse projection having a plane of symmetry)

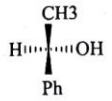
3.11 Convert the following flying wedge projections into Fischer projections.

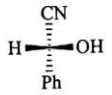
(a) 

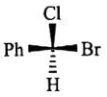
(c) 

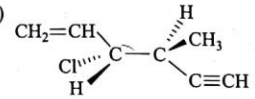
(b) 

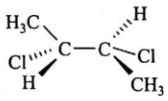
(d) 

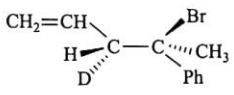
(e) 

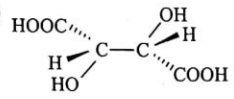
(f) 

(g) 

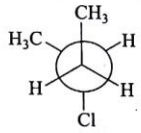
(h) 

(i) 

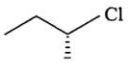
(j) 

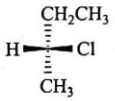
(k) 

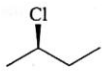
3.12 Give the Fischer projection of this structure.

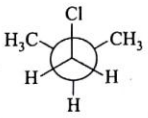


Determine whether each of the following compounds is equivalent to this Newman projection or to its enantiomer.

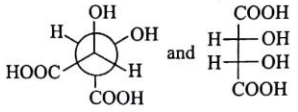
(a) 

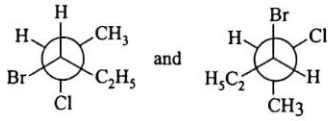
(b) 

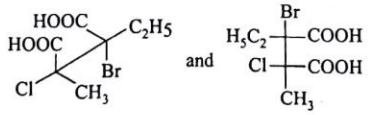
(c) 

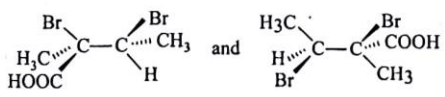
(d) 

3.13 Identify whether the following pairs of compounds represents enantiomers, diastereoisomers, or homomers.

(a) 

(b) 

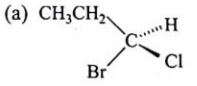
(c) 

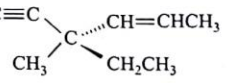
(d) 

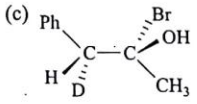
3.14 Write True or False against each of the following statements:

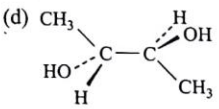
(a) When a molecule has only one chiral centre, then that chiral centre is both stereogenic and chirotopic.
(b) Stereogenicity and chirotopicity of a centre are separable properties.
(c) The configurational isomers and conformational isomers differ only in the energy barrier of their interconversions at ordinary conditions.
(d) All geometrical isomers are diastereoisomers.
(e) Both asymmetric and dissymmetric molecules can exhibit enantiomerism.
(f) Diastereoisomers are chemically different towards the same achiral reagent.
(g) *meso*-tartaric acid can have C_1, C_i, and C_s point groups in its different conformational isomers.
(h) Enantiomeric groups should always remain attached to a prochiral centre.
(i) All aldehydes except formaldehyde have prochiral face.
(j) Two faces of *cis*-But-2-ene are enantiotopic depending on the nature of the addition reaction.
(k) Homotopic groups in a molecule can be interconverted by rotation about an axis of symmetry (C_n).
(l) A diastereotopic centre must remain attached to a chiral centre.
(m) All molecules having the general formula $CabX_2$ have enantiotopic atoms.

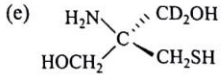
3.15 Find the absolute configuration of each stereocentre of the following compounds.

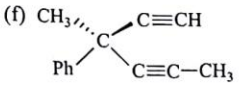
(a) 

(b) 

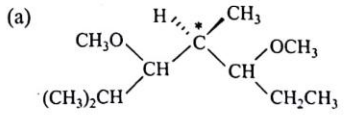
(c) 

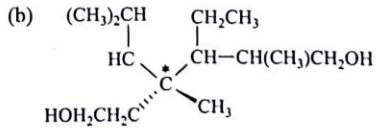
(d) 

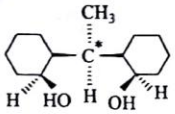
(e) 

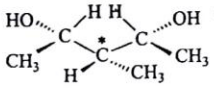
(f) 

3.16 Find out the absolute configuration of the asterisked (*) centre in (a), (b), (c), and (d).

(a) 

(b) 

(c) 

(d) 

3.17 Write down the wedge formula of the chiral centre of each of the following compounds having the noted stereochemistry and ligands attached to the chiral centre.

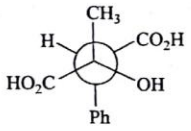
(a) $-Ph$, $CH\equiv C-$, $CH\equiv \overset{14}{C}-$, $-H$ having *R* configuration

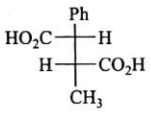
(b) $-NH_2$, $-C\equiv N$, $-CH=NH$, $-N_3$ having *S* configuration

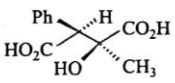
(c) $-OH$, $-OD$, $-\overset{17}{O}H$, $-\overset{18}{O}D$ with *S* configuration

(d) $-CH_2NH_2$, $-CH_2\overset{15}{C}H_2$, CH_2NH_3, $-\overset{18}{C}H_2CH_2$ with *R* configuration

3.18 Determine the absolute configuration of each chiral centre of the following structures and comment on their stereochemical relationship.

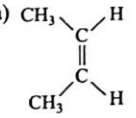
(a) 

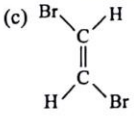
(b) 

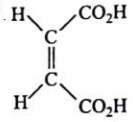
(c) 

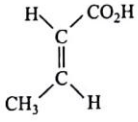
3.19 What do you mean be *pro-R* and *pro-S* enantiotopic atoms/groups and *Re* and *Si* enantiotopic faces? Give suitable examples in favour of your answer.

3.20 Identify the (*Re-Re*), (*Re-Si*), or (*Si-Si*) faces of the following compounds, when viewed from the top.

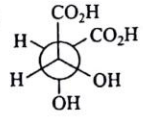
(a) 

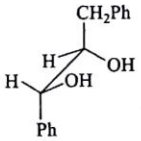
(c) 

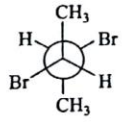
(b) 

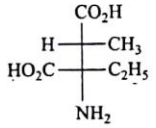
(d) 

3.21 Designate each of the following structures with *erythro* or *threo* prefix.

(a) 

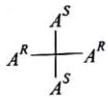
(c) 

(b) 

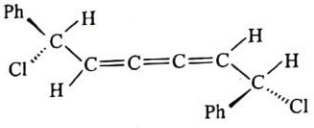
(d) 

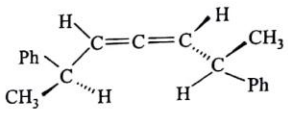
3.22 Which of the following molecules are chiral?

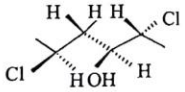
(a) 

(b) 

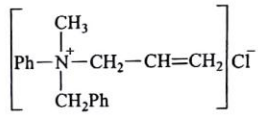
A^* = Chiral centre
R,S = Absolute configuration of the chiral centres

(c) 

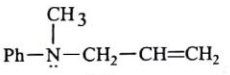
(d) 

(e) 

3.23 Explain why compound (A) is resolvable but compound (B) is not.



(A)



(B)

3.24 Write True or False against each of the following statements.

(a) Change of configuration at a chiral centre does not necessarily mean that *R,S* designation of the chiral centre should also undergo a change.

(b) Between $-CD_2NH_2$ and $-CH_2OH$ group, $-CH_2OH$ will get preference in sequence rule for the determination of priorities.

(c) Lone pair (..) on a chiral centre has the lowest priority.

(d) In determining the priority of cyclic unsaturated systems exhibiting resonance, atomic number of certain atoms of systems may be given a fractional value.

(e) *Erythro* and *threo* descriptors have ambiguity.

(f) $CH_3CH(OH)CD_3$ is a resolvable molecule.

(g) Cumulenes with an even number of double bonds can never exist as pairs of geometrical isomers.

(h) Atropisomerism is a function of temperature.

(i) Spiro compounds exhibit enantiomerism due to the presence of a 'chiral axis'.

(j) Molecules having C_1-symmetry must have a chiral centre.

(k) $:NR^1R^2R^2$ (tertiary amine) and $:CR^1R^2R^2$ are not resolvable although they represent molecules with chiral atoms.

(l) A carbon centre in a molecule is always chirotopic if it is stereogenic.

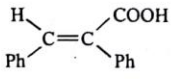
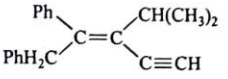
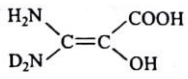
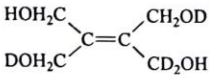
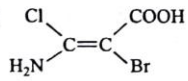
(m) Optical activity of a molecule does not depend on a pseudoasymmetric centre.

(n) *erythro*- and *threo*-terms do not always coincide with *parf* and *pref* terms.

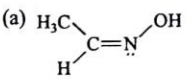
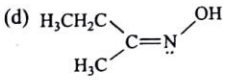
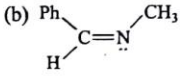
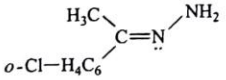
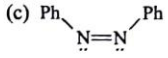
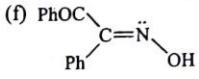
(o) Molecules having a C_n and D_n point group must exhibit enantiomerism.
(p) Enantiotopic atoms or groups should always remain attached to a prochiral centre.
(q) Diastereoisomers must differ in their point group.
(r) A pair of enantiomers must have the same symmetry point group and should always be optically active.
(s) When a compound exists as enantiomers as well as diastereoisomers, then it must have chiral centres.

3.25 C_8H_{12} represents a conjugated polyene with odd number of double bonds. It can form six geometric isomers. Write down the probable structure of the molecule.

3.26 Allocate the symbol *seq-cis* and *seq-trans* to each of the followings structures.

(a) 
(d) 
(b) 
(e) 
(c) 

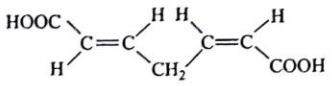
3.27 Designate the following structures with *E,Z* descriptors, and give the IUPAC name for each compound.

(a) 
(d) 
(b) 
(e) 
(c) 
(f) 

3.28 Write down the structures of the following IUPAC names.

(a) (2*E*,4*Z*) Hexa-2,4-dienoic acid
(b) (2*E*,4*Z*)-5-Chlorohexa-2,4-dienoic acid
(c) (*Z*) and (*E*)-2-Pentenal semicarbazide
(d) (1*Z*, 3*Z*)-1-Chloro-3-[2-chloro(*E*)-vinyl]penta-1,3-diene
(e) 3-(*E*)-1-Chlorophenyl-3*Z*,5*E*) hepta-3,5-dienoic acid
(f) (*E*)-(3-Bromo-3-chloroallyl)-benzene
(g) (*E*)-1,4-Dichloro-3(2-chloroethyl)-2-methylpent-2-ene

3.29 The following compound can be named as (2*Z*, 5*E*)-hepta-2,5-dienedioic acid or (2*E*,5*Z*)-hepta-2,5-dienoic acid. Which one is the correct name according to IUPAC rules?



3.30 (a) How many diastereoisomers are possible for the compound 2-decalol? Write down their hexagonal planar structures and comment on their optical activity.

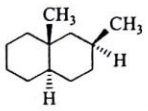
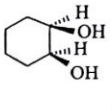
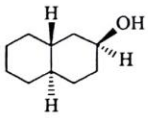
(b) How many stereoisomers are possible for the compound $C\dot{A}\dot{A}$= Cab ($\dot{A}$= identical chiral group)?

3.31 Write down the hexagonal ring structures (Linstead) of the following stereoisomeric perhydrophenanthrenes and classify them as *meso* or active isomers.

(a) *trans-anti-trans* (b) *cis-syn-trans*
(c) *cis-syn-cis* (d) *trans-syn-trans*

3.32 How many diastereoisomers are possible for perhydroanthracene? Write down their planar structures according to Linstead convention. Identify the *meso* compounds.

3.33 Find out the absolute configuration of each stereocentre of the following compounds.

(a) 
(b) 
(c) 

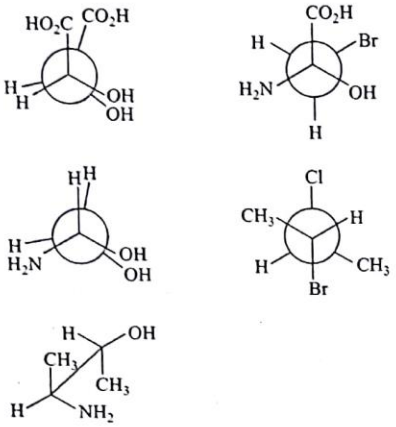
3.34 Write True or False against the following statements.

(a) Presence of a double bond is necessary but not a sufficient condition for alkenes to exhibit diastereoisomerism.
(b) Diastereoisomers can also exhibit enantiomerism.
(c) 1,2-Dimethylcyclopropane can have diastereoisomers.
(d) *trans*-1,2-Dimethylcyclopropane is optically inactive due to the presence of centre of inversion.
(e) 1,3-disubstituted cyclobutanes cannot be optically active, whatever may be the nature of substituents.
(f) (2*E*,4*Z*)-Hexa-2,4-diene is not a correct IUPAC name.
(g) C-2 and C-3 atoms of But-2-ene are stereogenic but not chirotopic.
(h) Geometric isomers have different chemical properties because they are diastereoisomers.
(i) Perhydrophenanthrene and Perhydroanthracene have equal number of diastereoisomers.
(j) 1,2,3-Trimethylcyclopropane and 1,2,3-Trimethylcyclopentane have an equal number of diastereoisomers.

3.35 Write down the Newman projections of the following compounds having the specified conformation noted against each compound.

(a) $CH_3CH_2CH_2OH$ (+ *sp*, considering rotation about C-1—C-2 bond)
(b) $CHClBrCH(NH_2)OH$ (+ *sc*)
(c) CH_3CH_3 (+ *sc*)
(d) $CH_3CHClCH(NO_2)_2$ (− *sp*)
(e) $(CH_3)_2NH_2$ (+ *ac*)

3.36 Designate the following Newman and sawhorse formulas as *sp*, *sc*, *ac*, or *ap* with proper sign.



3.37 What is the *P*, *M* system of nomenclature of substituted ethanes and compounds containing axial chirality? Give appropriate examples.

3.38 Write True or False against each of the following statements.

(a) Dihedral angle and torsion angle carry the same meaning.
(b) Torsional curves of ethane and propane (rotation about C-1 and C-2 bond) are almost same in nature.
(c) Intramolecular H-bonding can control the conformational preference of acyclic molecules.
(d) *P-gauche* conformation of $CH_3CH_2CH_2Cl$ is more stable them ± *ap* conformation.
(e) Mesityl oxide has no configurational isomers but has conformational isomers about C-2—C-3 sigma bond.
(f) Butane-*gauche* interaction is steric in origin.
(g) ± *ap* conformation of 1-chloropropane is more stable than either +*sc* or −*sc* conformation.
(h) *meso*-Tartaric acid can have both chiral and achiral conformations.
(i) It is the quantum of energy barrier that differentiates between conformational and configurational isomers.
(j) Stereochemistry of a compound is its absolute character but stereodescriptos used to differentiate it from others are purely conventional.

3.39 Write down the chair and boat conformations of cyclohexane and discuss their relative stability.

3.40 What are the elements of symmetry in chair and boat forms of cyclohexane? Draw the Newman projection formulae of chair and boat forms of cyclohexane.

3.41 What do you mean by inversion of chair form of cyclohexane? What do you mean by C_2 pathway of inversion of cyclohexane chair form? Draw the energy diagram of this inversion path.

3.42 Compare among the planar, chair, boat, and twist boat conformations of cyclohexane with reference to (a) elements of symmetry, (b) stability based on angle and torsional strains, and (c) chirality.

3.43 Chair form of cyclohexane-1,4-dicarboxylic acid can have three stereoisomers. What are they? Relate them as conformational isomers or configurational isomers?

3.44 Write down the chair conformation of each of the following compounds and discuss its stability relative to cyclohexane itself.

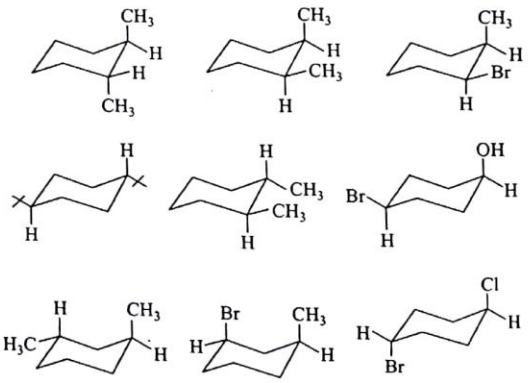
(a) (a,a) *trans*-1,2-Dimethylcyclohexane
(b) *cis*-1,3-Dimethylcyclohexane
(c) (a,e)-*trans*-1,2-Dimethylcyclohexane
(d) (a,e)-*trans*-1,4-Dimethylcyclohexane

3.45 What is meant by inversion of chair conformation of cyclohexane? What are the two pathways through which such an inversion is possible?

3.46 pk_a values of *cis*- and *trans*-4-*t*-butylcyclohexanecarboxylic acids in 66% aqueous dimethylformamide are found to be 8.23 and 7.79 respectively. Explain this difference in acid strengths.

3.47 Discuss the conformation of 3-alkylated cyclohexanone and cyclohexane. What are $A^{1,3}$ and $A^{1,2}$ -strains?

3.48 Are the following cyclohexanes resolvable? Find out the *R*,*S* nomenclature of different chiral centres of each of the compound.



3.49 *cis*-1,2-Dibromocyclohexane represents a chiral molecule but it cannot be resolved. How can you explain this fact?

3.50 Write True or False against each of the following statements.

(a) Point groups of planar and chair forms of cyclohexane are different.
(b) Inversion of ring in methylcyclohexane does not give topomers.
(c) 1,4-cyclohexanediol is more stable in its boat conformation.

(d) *cis*-1,2-Dibromocyclohexane is chiral but not resolvable.
(e) Both *cis* and *trans* isomers of 1-bromo-2-chlorocyclohexane are chiral and resolvable.
(f) (*a*,*a*) and (*e*,*e*) isomers of 1,2-dimethylcyclohexanes are configurational as well as conformational isomers.
(g) *cis*-1,3-Dimethylcyclohexane is very unstable in its (*a*,*a*) form but 1,3-diaxial form of 1,3- cyclohexanediol is stable.
(h) Ring inversion of *trans*-1,2-dimethylcyclohexane gives the superimposable structure.
(i) Thiatane and oxetane are planar molecules.
(j) Half-chair conformation of cyclopentane is a chiral molecule.

3.51 What do you mean by 'stereospecific' and 'stereoselective' reactions? Give suitable examples. Justify the statement that 'all stereospecific reactions are stereoselective but all stereoselective reactions are not necessarily stereospecific'.

3.52 Give the mechanism of reactions of (*E*)-but-2-ene with triplet methylene. Is the reaction stereospecific or stereoselective? Give reason.

3.53 Iodide ion-catalysed debromination of 2,3-dibromobutane is stereospecific. Justify this statement showing the mechanism of debromination.

3.54 Draw the energy profile diagram of the following hypothetical reactions and offer an explanation in favour of your answer.

$$C \underset{K_3}{\overset{K_2}{\rightleftharpoons}} A \underset{K_4}{\overset{K_1}{\rightleftharpoons}} B,\ K_1 > K_2,\ K_4 > K_3$$

where A = reactant; B, C = stable products; K_1, K_2, K_3, K_4 = rates of reactions. Which product is formed at low temperature? Which is the thermodynamically more stable product?

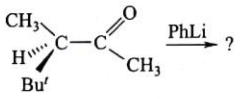
3.55 When the compound $CH_3CH(D)=CHBrCHCH_3$ is treated with sodium ethoxide in ethanol, the products are (*E*)-but-2-ene, (*Z*)-but-2-ene-2-*d* and but-1-ene-3-*d*. (*Z*)-but-2-ene and (*E*)-but-2-ene-2-*d* are not obtained. How can you explain this result?

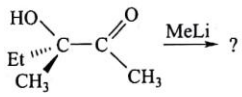
3.56 Show with suitable examples that change of descriptors from *R* to *S* in a chemical reaction does not necessarily mean that inversion of configuration has taken place.

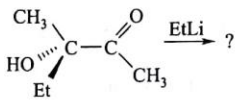
3.57 Show that the descriptor (*R* or *S*) may remain unchanged even when absolute configuration of a chiral centre has undergone inversion.

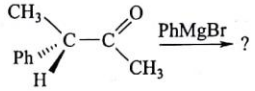
3.58 Define the term 'asymmetric induction'. Explain Cram's rule with suitable example. Is Cram's rule applicable to a thermodynamically controlled reaction? Give reasons.

3.59 Use Cram's rule or Prelog's rule to predict the major product in the following reactions.

(a) 

(b) 

(c) 

(d) 

(e) $PhCOCO{-}O{-}CH(Et)CPh_3$ (*S*-isomer) + EtMgBr →?

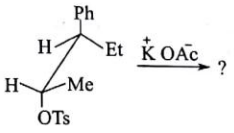
3.60 Account for the following observations.

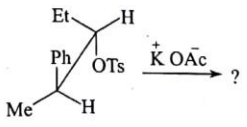
(a) When an optically active enantiomer of 2-iodooctane is treated with radioactive iodide ion in solution, the initial rate of racemization is twice the initial rate of displacement of normal iodine atom by radioactive iodine atom.
(b) (*R*)-2-Bromopropanoic acid gives (*S*)-lactic acid with very concentrated potassium hydroxide solution, but (*R*)-Lactic acid with dilute potassium hydroxide solution.

3.61 Pyridine causes dehydrobromination of *threo*-1,2-dibromo-1,2-dimethylethane to give (*Z*)-1-bromo-1,2-diphenylethene but *erythro*-dibromide loses bromine to yield (*E*)-1,2-diphenylethene. Propose the mechanisms of the reactions.

3.62 (*Re-Si*)-face of But-2-ene is separately treated with (a) I_2, $AgOCOCH_3$ in PhH and (b) I_2, $AgOCOCH_3$, H_2O. Identify the product in each case and propose the mechanism of the reaction.

3.63 Identify the product/products from each of the following reactions.

(a) 

(b) 

3.64 Write True or False against the following statements.

(a) 100% stereoselective reactions are called stereospecific.
(b) All irreversible reactions leading to stable products are both kinetically and thermodynamically controlled reactions.
(c) E2 elimination is more stereoselective than E1 elimination.
(d) *meso*-2,3-Dibromobutane gives 100% (*E*)-but-2-ene when subjected to iodine-catalysed debromination and

100% (*E*)-2-bromobut-2-ene when subjected to dehydrobromination.

(e) When the configuration of a chiral centre changes from *R* to *S* then inversion of configuration must have taken place.

(f) In retention of configuration of a chiral centre, *R* will remain *R* or *S* will remain *S*.

(g) A reaction leading to the formation of equimolecular amounts of enantiomers cannot be called an asymmetric synthesis.

(h) Addition of Br_2 to R—CH=CH—R type molecule is always stereospecific.

(i) S_N2 reactions may lead to racemization under certain conditions.

(j) E2 and $E1_{CB}$ reactions cannot be differentiated by kinetic studies alone.

(k) Pyrolytic elimination reactions are stereospecific reactions.

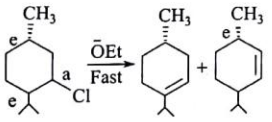
(l) Curtin–Hammett principle is applicable only in those cases where a reactant can react in different conformations and energy barrier for conformational interconversion is very low.

3.65 Account for the following facts:

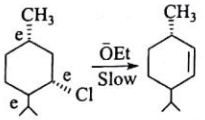
(a) *cis*-4-Hydroxcycyclohexane carboxylic acid readily forms a lactone but *trans* isomer cannot.

(b) *trans*-1,2-Dibromocyclohexane and *cis*-1,2-dibromocyclohexane can be differentiated from their dipole moment measurement.

(c)

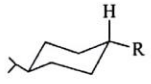


However,

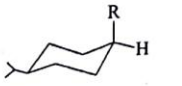


(d) Relative rates of saponification of the following compounds are found to be different. (Assume $B_{AC}2$ mechanism of saponification.)

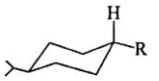
R = —$OCOC_6H_4NO_2$-*p*



K_{trans}/K_{cis} = 2.5



R = —$CO_2C_6H_5$



K_{trans}/K_{cis} = 20

3.66 *Trans*-4-*t*-butylcyclohexanol is oxidized four times more slowly than *cis* isomer, when treated with CrO_3 at 25°C. Give an explanation with the mechanism of oxidation.

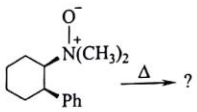
3.67 *trans*-4-*t*-Butylcyclohexyl tosylate does not undergo base-catalysed E2 elimination. Explain.

3.68 Predict the major product in each of the following reactions.

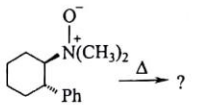
(a) *cis*-Stilbene $\xrightarrow[Ac_2O]{LiAlD_4}$?

(b) *trans*-Stilbene $\xrightarrow[Ac_2O]{LiAlD_4}$?

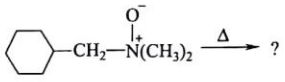
(c)



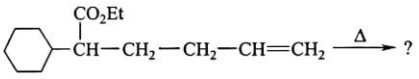
(d)



(e)



(f)



3.69 What is the point group of *cis*-9-methyldecalin? Is it chiral and resolvable?

3.70 1-acetyl-2-hydroxynaphthalene-3-carboxylic acid forms (*E*) and (*Z*)-oximes. The (*Z*)-diastereoisomer is resolvable. On the basis of that, write down the structures of oximes and account for the observed fact. What are the Beckmann rearrangement products of (*E*) and (*Z*)-diastereoisomers?

3.71 Spiro[4,4]nonane-1,6-dione has axial chirality. Write down its *R* and *S* forms. How many diastereoisomeric diols are formed where the *spiro* compound is reduced? Find out the absolute configuration of each stereocentre of these diols.

3.72 Fruit sugar, fructose has $[\alpha]_D^{20} = -92°$ (in water). Calculate the rotation that would be observed for a solution of 1 g of fructose in 100 ml of water and measured in a tube 5 cm long at 20°C using a sodium lamp.

3.73 Citronellol is a fragrant component of many plant oils like rose oil. A synthetic sample of (–)-citronellol with an enantiomeric excess of 88% has $[\alpha]_D^{20} = -92°$. Find out the optical rotation of the pure enantiomer? (–)-Citronellol has the (*S*)-configuration and has the following structural formula. Draw the correct flying-wedge formula for (±)- citronellol.

$(CH_3)_2C{=}CHCH_2CH_2CH(CH_3)CH_2CH_2OH$

(–)-Citronellol

3.74 Predict the predominant products in the following reactions and name them as *threo* or *erythro* and also designate them as *pref-parf* isomers.

(a) (*R*)-$CH_3C(Et)PhCOCH_3 + CH_3CH_2Li \longrightarrow$

(b) (*R*)-$CH_3C(Et)PhCOCH_2CH_3 + CH_3Li \longrightarrow$

3.75 Complete the following reaction sequence indicating the predominant product, if any.

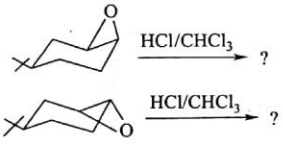
$$(S)\text{-}CH_3CH(Et)PhCOCH_3 \xrightarrow[+]{CH_3MgI} (A) + (B)$$

$$(S)\text{-}CH_3CH(Et)PhCOCH_3 \xrightarrow[H_3O^+]{KOH/H_2O} (C) + (D) + (E)$$

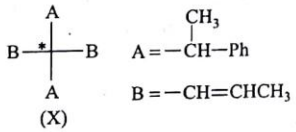
3.76 How can you show that maleic acid and fumaric acid have the same constitutional structure but different configurations?

3.77 Predict the products in the following reactions and indicate the predominant product. Explain by application of Cram's rule. (*R*)-*n*-BuCOCHCl(Et) + $NaBH_4 \longrightarrow$?

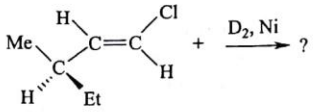
3.78 Write the products of the following reactions. Discuss the mechanism involved in each case.



3.79 Find out the number of stereoisomers possible for the following compound (X). Comment on the chirotopicity and stereogenicity of the asterisked carbon. Identify the optically active and inactive isomers.



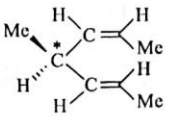
3.80 Identify the products and discuss the stereochemical aspects of the following reaction. Give the IUPAC name of the compound.



3.81 The compound $CH_3COCH(CH_3)COCH_3$ is treated with a 2 molar proportion of HCN in the presence of a basic catalyst. Identify the products and give their Fischer projections. Discuss their behaviour towards plane polarized light.

3.82 Discuss the chirotopicity and stereogenicity of the asterisked carbon atom of each of the following molecules. Is the term pseudoasymmetry applicable in these cases? Explain.

(a)



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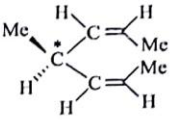
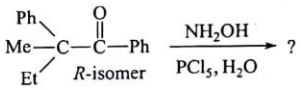


3.83 Oxime from cyclohexen-2-one in acetic anhydride does not give Beckmann rearrangement but *N*-acetylaniline is obtained. Explain.

3.84 Write down the structures of *E*,*Z*-isomers of oximes of 1-acetyl-2-hydroxynaphthalene-3-carboxylic acid. One of them is resolvable and the other is not. Explain the fact.

3.85 Give the products of the following reactions showing the stereochemical aspects in three-dimensional structures.

(a)



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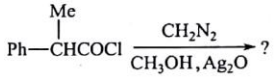

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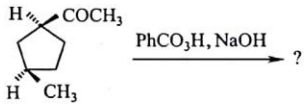

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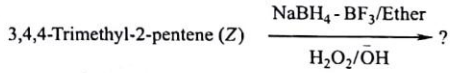
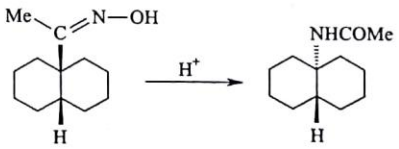


3.86 Identify the products when *pref* and *perf* isomers of 3-phenyl-2-pentyl tosylate and 2-phenyl-3-pentyl tosylate are subjected to acetolysis.

3.87 Cyclohexene is subjected to Pre´vost and Woodward hydroxylation separately. Identify the products. Are the compounds optically active? Are they resolvable? Comment on their reactivity with lead tetraacetate.

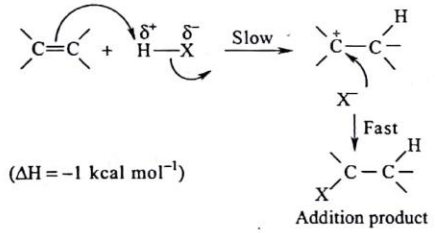
3.88 How can you explain this inversion of configuration in the following Beckmann rearrangement?



4 Aliphatic and Alicyclic Hydrocarbons and their Halides

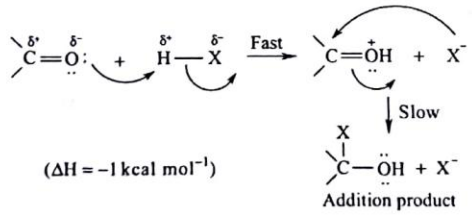
4.1 Why do halogen acids that are easily added to alkenes fail to give addition products with ketones?

Ans >C=C< is a nonpolar functional group having a pair of π-electrons. These π-electrons can attract an electrophile but repel a nucleophile. When H—X ionizes to H^+ and X^-, H^+ is attracted by the π-electrons but X^- is repelled. Consequently, the initial attack is an electrophilic (H^+) attack to generate a carbocation. This is followed by the X^- attack on the carbocation leading to the formation of the addition product.



Enthalpy calculation based on bond energies show that the ΔH of the reaction is −13 kcal mol^{-1}. Therefore, the reaction leads to a stable product.

$\overset{\delta^+}{C}=\overset{\delta^-}{O}$ is a polar group having an electron-deficient carbon centre and an electron-rich oxygen centre. When HX is added to a compound with >C=O group, we can expect an addition product by the following mechanism.



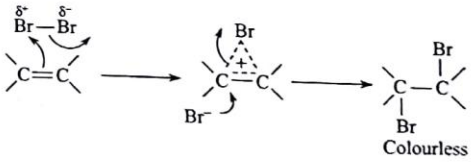
However, the ΔH calculation of this reaction gives a value of −1 kcal/mol. Therefore, the reaction is thermodynamically not favourable. That is why >C=O group fails to give a stable addition product with HX.

4.2 Explain why HCN fails to add to olefinic double bond.

Ans HCN is a highly covalent molecule and an extremely weak acid (pk_a = 9.22). Reaction of HCN with the >C=O group is carried out in presence of NaOH that acts as a catalyst to generate CN^- as a nucleophilic reagent. This CN^- ion then reacts with the electron-deficient carbon atom of the polar $\overset{\delta^+}{C}=\overset{\delta^-}{O}$ group to give cyanohydrin. Since >C=C< is not a polar group but electron-rich, it will repel CN^-, which is also an electron-rich reagent. Consequently, addition of CN^- to >C=C< will require high activation energy and the reaction will be extremely slow. That is why olefins like $CH_2=CH_2$ fail to react with HCN.

4.3 Bromination of olefins is always carried out in CCl_4 but not in CH_3OH. Explain.

Ans When Br_2 is added to an olefin in CCl_4 medium, bromination takes place and the brown colour of bromine fades out. This is the test for the presence of olefinic unsaturation in a molecule.



If CH_3OH or CH_3CH_2OH is used as solvent then Br_2 can oxidize them into aldehydes with the formation of HBr. In this case also the yellow colour of the bromine is discharged and that will give a false indication regarding the presence of an olefinic double bond.

$$CH_3CH_2OH \xrightarrow[[O]]{Br_2} CH_3CHO$$

4.4 The hydrogen atoms of acetylene are more acidic than those of ethylene. Explain.

Ans In the case of H—C≡C—H, the carbon atom of the ≡C—H group is *sp* hybridized and in $H_2C=CH_2$, the carbon atom of

$=CH_2$ bond is sp^2 hybridized. Electronegativity of *sp* carbon is greater than that of sp^2 carbon and consequently C—H bond in HC≡C—H is more polar having an electron deficiency on the 'H' atom. Therefore, it has a greater tendency to come out as H^+. Secondly, dissociation of $HC^-\equiv C-H$ gives $HC\equiv C^-$ and dissociation of $H_2C=CH_2$ gives $H_2C=C-H^-$. Since in $HC\equiv C^-$, the negative charge resides on the more electronegative carbon, consequently it is more stable than $H_2C=CH^-$ where the negative charge resides on the less electronegative carbon.

4.5 Explain why the halogen atom of vinyl chloride is less reactive than that of ethyl chloride towards substitution reactions.

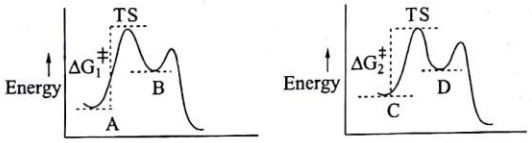
Ans In $CH_2=CH-Cl$ (vinyl chloride), the 'Cl' atom is bonded to an sp^2 hybridized carbon atom and consequently polarizability of the C—Cl bond is less than that in the case of the C—Cl bond in ethyl chloride (CH_3CH_2-Cl) where the sand carbon atom is sp^3 hybridized. Secondly, in $CH_2=CH-Cl$, resonance like,

$$CH_2=CH_2-\ddot{Cl}: \longleftrightarrow \bar{C}H_2-CH_2=\overset{+}{Cl}:$$

is possible and this makes the C—Cl bond more strong. Consequently the removal of Cl^- from $CH_2=CH-Cl$ will require a very large amount of activation energy. That is why $CH_2=CH-Cl$ is very unreactive compared to CH_3CH_2Cl in the case of substitution reactions.

4.6 Buta-1, 3-diene reacts slower with free radicals than but-2-ene.

Ans Buta-1, 3-diene ($CH_2=CH-CH=CH_2$) is a conjugated diene and consequently it has less internal energy than that of but-2-ene ($CH_3-CH=CH-CH_3$). Therefore, for reaction with a radical, $CH_2=CH-CH=CH_2$ will require more activation energy and consequently the rate of the reaction will be slower. This can be shown graphically.

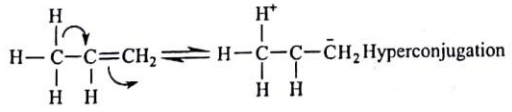


A → $CH_2=CH-CH=CH_2+R^{\cdot}$ C → $CH_3-CH=CH-CH_3+R^{\cdot}$

B → $CH_2=CH-\dot{C}H-CH_2R$ D → $CH_2-\dot{C}H-CHR-CH_3$

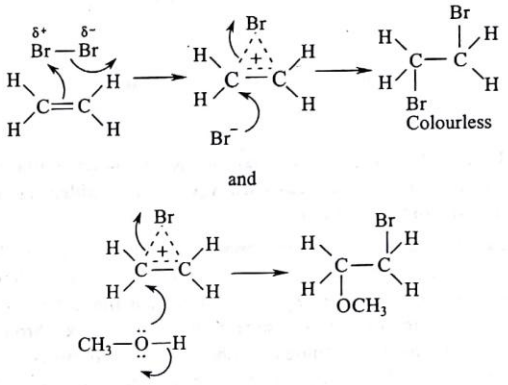
4.7 Propylene is more reactive towards addition of H_2SO_4 than ethylene. Explain.

Ans In $CH_3-CH=CH_2$, the π-bond is more activated by the hyperconjugation involving the methyl group, but in ethylene this is not possible. That is why $CH_3-CH=CH_2$ is more reactive towards electrophilic addition.



4.8 State the possible products when ethylene is treated with bromine in methanolic solution.

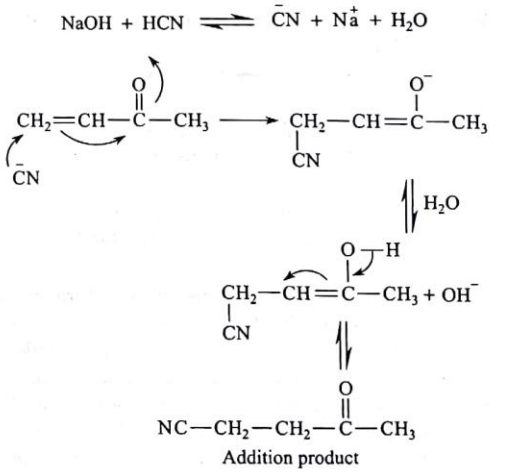
Ans When $CH_2=CH_2$ is treated with Br_2 in the presence of CH_3-OH (solvent), the following addition products are formed. In this case both Br^- and CH_3-O-H can act as nucleophilic reagents.



4.9 Why does HCN fail to add to olefinic bond? How can the bond be activated so that the overall addition of HCN to it may be possible?

Ans For the first part of the answer, see 4.2.

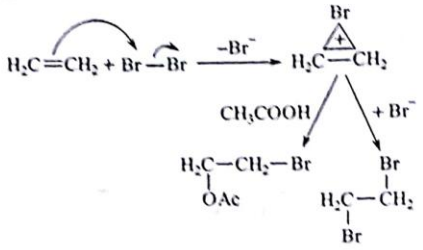
When an electron withdrawing group is found to be attached to the olefinic double bond, >C=C< gets activated towards nucleophile addition and in that case HCN can be added to >C=C<. For example HCN can be added to $CH_2=CH-CO-CH_3$ (methylvinyl ketone). The mechanism of the reaction can be shown as follows:



The net result is the addition of HCN to olefinic double bond. NaOH is used as catalyst to generate CN^-. It is in fact an example of Michael type conjugate addition.

4.10 What will be the products when ethylene is passed through bromine in acetic acid solution?

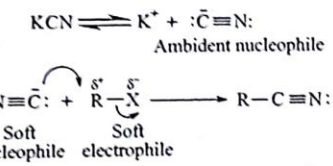
Ans The product are 1, 2-dibromoethane and 2-bromoethyl acetate.



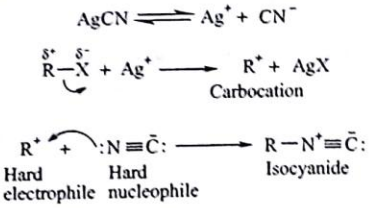
4.11 Alkyl halides with ethanolic KCN solution mainly produce cyanides whereas with AgCN, isocyanides are the main products. Explain.

Ans CN^- is an ambident nucleophile. It can take part in nucleophilic reactions through the carbon end as well as through the nitrogen end. Since a lone pair of electrons on the carbon atom is more polarizable, in S_N2 substitution, CN^- attacks through its carbon-end and cyanides are obtained as major products.

When AgCN is used, the reaction proceeds according to S_N1 mechanism. When the reaction takes place according to S_N1 pathway, then more basic nitrogen-end takes part in the reaction and isocyanides are formed as major products. The mechanisms are given here.



When AgCN is used, the reaction proceeds according to S_N1 mechanism:

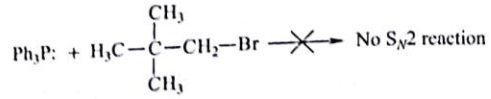


This can also be explained on the basis of hard and soft nucleophiles reacting with hard and soft electrophiles. A hard nucleophile always reacts with a hard electrophile and a soft nucleophile reacts with a soft electrophile centre. A more polarizable electron pair represents a soft nucleophile, whereas, a centre with a less polarizable electron pair represents a hard nucleophile. Similarly a centre having partial electron deficiency (δ^+) represents a soft electrophile and a centre with a positive centre represents a hard electrophile. In $:C^-\equiv N:$ the carbon-end is a soft nucleophile and the nitrogen-end is a hard nucleophile.

4.12 $(CH_3)_3C-CH=CH_2$ cannot be prepared from $(CH_3)_3CH_2Br$ and HCHO by Wittig reaction. Explain.

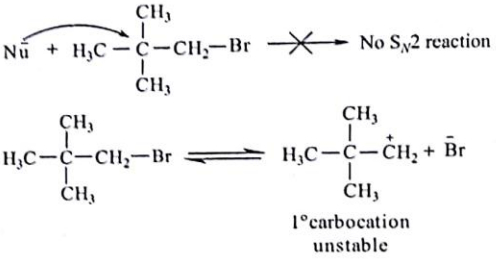
Ans For Wittig reaction to occur, the initial reaction is an S_N2 type substitution between $Ph_3P:$ and alkyl halides.

In the present case, the halide is neopentyl bromide which does undergo S_N2 substitution due to steric hindrance. That is why it cannot participate in Wittig reaction and consequently $(CH_3)_3C-CH=CH_2$ cannot be prepared from $(CH_3)_3C-CH=CH_2$ and HCHO.



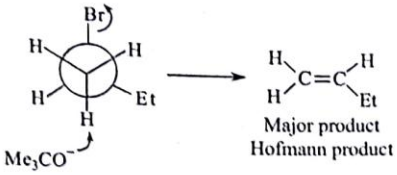
4.13 Neopentyl halides cannot be made to undergo substitution reaction. Explain.

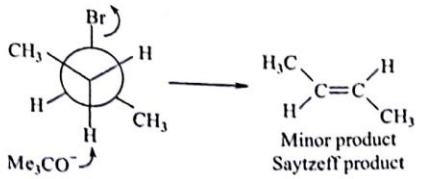
Ans Neopentyl halides cannot undergo S_N2 substitution reaction because a nucleophile cannot approach from the rear side due to steric hindrance. S_N1 substitution reaction is also not possible because 1° carbocation is very unstable.



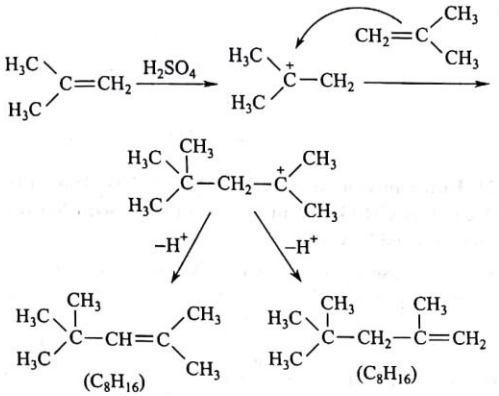
4.14 $CH_2=CH-CH_2-CH_3$ is formed as a major product from $CH_3-CHBr-CH_2-CH_3$ when $(CH_3)_3CO^-K^+$ is used as base for dehydrobromination. Explain this fact.

Ans $CH_3CHBrCH_2CH_3$ can undergo E2 elimination reaction involving hydrogen atoms from both the carbon atoms adjacent to Br atom. When a bulky base like $(CH_3)_3CO^-$ is used, then the reaction takes place from the less hindered side and the product is a less substituted alkene (Hofmann product). The reaction can be shown by the following Newman projection formulae.





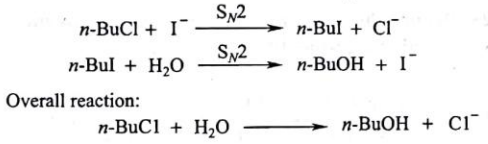
4.15 Isobutene in the presence of H_2SO_4 forms a mixture of two isomeric alkenes C_8H_{16}. Formulate the reaction. How can you distinguish between the isomers chemically?



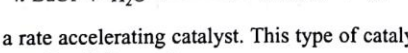
These two isomers can be distinguished by ozonolysis and identifying the oxidized products.

4.16 The hydrolysis of *n*-BuCl in aqueous ethanol is accelerated in the presence of NaI. Explain the reaction.

Ans When NaI is added, I^- acts as nucleophile to displace Cl^- and since I^- is a stronger nucleophile, the reaction rate is accelerated compared to the reaction with H_2O which is a weaker nucleophile. Again, I^- is a better leaving group and consequently the second nucleophilic substitution will also be faster even with a weak nucleophile like H_2O.



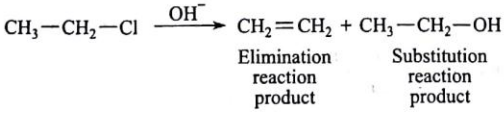
Overall reaction:



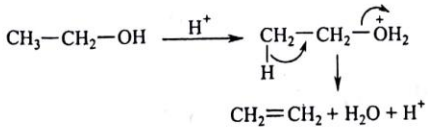
I^- acts as a rate accelerating catalyst. This type of catalyst is known as a *nucleophilic catalyst.*

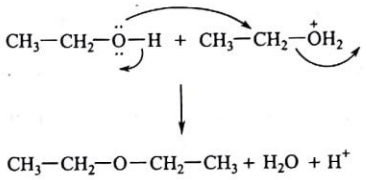
4.17 What are the disadvantages in the preparation of alkenes by (a) R–X + Base and (b) R–OH + Acid?

Ans During base catalysed elimination from R–X for the preparation of alkene, substitution reaction can also occur to give the substituted product.



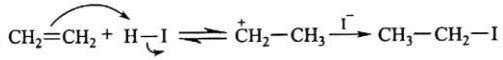
During acid catalysed dehydration of alcohols, for the preparation of alkenes, some intermolecular dehydration can occur to give ether.



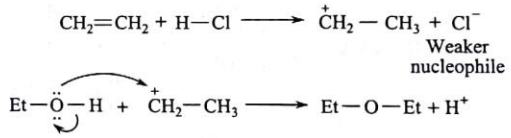


4.18 The reaction between HI and C_2H_4 in C_2H_5OH gives predominantly C_2H_5I whereas the reaction with HCl under the same condition gives predominantly $C_2H_5OC_2H_5$. Explain.

Ans C_2H_4 and HI in EtOH mainly produce EtI because I^- is a strong nucleophilic reagent and reacts readily with the intermediate carbocation.

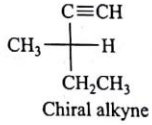


When the reaction is carried with in HCl, then EtOH acts as a better nucleophile compared to Cl^-, because the nucleophilicities of Cl^- and EtOH are comparable and remain in larger concentration (mass effect). Here Et_2O is obtained as a major product.



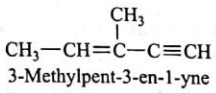
4.19 Draw the structure of (a) A chiral alkyne of six carbon atoms (b) An alkyne of six-carbon atoms that gives the same single product by hydroboration-oxidation or Hg^{2+} catalysed hydration (c) Two six-carbon alkynes that are constitutional isomers and each of them can exist as diastereoisomers.

Ans The compounds are given here.

(a) 
Chiral alkyne

(b) $CH_3-CH_2-C\equiv C-CH_2-CH_3$

(c) $CH_3-CH=CH-C\equiv C-CH_3$ and
Hex-2-en-4-yne


3-Methylpent-3-en-1-yne

4.20 Using but-1-yne as the only source of carbon in the products, propose synthesis of each of the following compounds.

(a) $CH_3CH_2C\equiv CD$
(b) $CH_3CH_2CD_2CD_3$
(c) $CH_3CH_2CD_2CD{=}O$
(d) *cis*-Oct-3-ene
(e) $CH_3CD_2COCD_3$
(f) $CH_3CD_2COCOCD_2CH_3$

Ans The conversions can be shown as follows.

(a) $CH_3-CH_2-C\equiv CH \xrightarrow{RMgBr} CH_3-CH_2-C\equiv CMgBr + CH_4$

$CH_3-CH_2-C\equiv CMgBr \xrightarrow{D_2O} CH_3-CH_2-C\equiv CD$

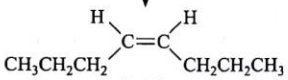
(b) $CH_3-CH_2-C\equiv CD \xrightarrow{D_2/Ni} CH_3-CH_2-CD_2-CD_3$

(c) $CH_3-CH_2-C\equiv CD \xrightarrow[D_2O_2/OD^-]{B_2D_6}$ (Hydroboration -oxidation) $CH_3-CH_2-CD=CD-O-D$ $\rightleftharpoons$ (Tautomerization) $CH_3-CH_2-CD_2-CD=O$

(d) $CH_3-CH_2-C\equiv CH \xrightarrow{RMgBr} CH_3-CH_2-C\equiv CMgBr$

$\xrightarrow{CH_3CH_2CH_2CH_2Cl} CH_3-CH_2-C\equiv C-CH_2-CH_2-CH_2-CH_3$

$\xrightarrow{H_2/Ni}$ *cis*-Oct-3-ene



(e) $CH_3-CH_2-C\equiv CH \xrightarrow[NaBH_4/OH^-]{Hg(OAc)_2/THF/H_2O} CH_3-CH_2-\overset{OH}{\overset{|}{C}}=CH_2$ $\rightleftharpoons$ (Tautomerization) $CH_3-CH_2-\overset{O}{\overset{\|}{C}}-CH_3 \xrightarrow{D_2O/D_2SO_4} CH_3-CD_2-\overset{O}{\overset{\|}{C}}-CD_3$

(f) $CH_3-CH_2-C\equiv CH \xrightarrow{RMgBr} CH_3-CH_2-C\equiv CMgBr$

$\xrightarrow{CH_3CH_2Cl} CH_3-CH_2-C\equiv C-CH_2-CH_3$

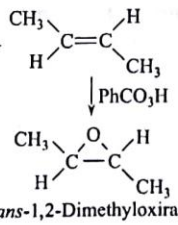
$\xrightarrow[Zn/H^+]{O_3} CH_3-CH_2-\overset{O}{\overset{\|}{C}}-\overset{O}{\overset{\|}{C}}-CH_2-CH_3$

$\xrightarrow{D_2O\,|\,D_2SO_4} CH_3-CD_2-\overset{O}{\overset{\|}{C}}-\overset{O}{\overset{\|}{C}}-CD_2-CH_3$

4.21 How would you convert but-2-yne into (a) *trans*-1, 3-Dimethyloxirane and (b) *cis*-1, 3-Dimethyloxirane.

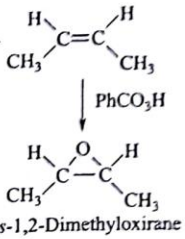
Ans The necessary conversion can be carried out in two steps, as shown here.

(a) $CH_3-C\equiv C-CH_3 \xrightarrow{Na/liq\ NH_3}$



trans-1,2-Dimethyloxirane

(b) $CH_3-C\equiv C-CH_3 \xrightarrow{H_2/Ni}$

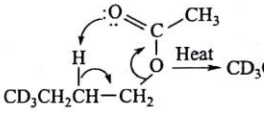


cis-1,2-Dimethyloxirane

4.22 How can you obtain $CD_3CH_2CH=CH_2$(100%) from $CD_3CH_2CH_2CH_2OH$? Could dehydration with hot dilute H_2SO_4 be used? Explain.

Ans It is a case of regioselective dehydration. This can be done by acetylation followed by the pyrolysis of the acetate.

$CD_3CH_2CH_2CH_2OH \xrightarrow{Ac_2O/H_2SO_4} CD_3CH_2CH_2CH_2O-\overset{O}{\overset{\|}{C}}-CH_3$ (Acetate)

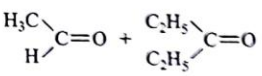


$\xrightarrow{Heat} CD_3CH_2CH_2=CH_2 + CH_3COOH$

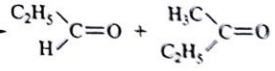
Acid catalysed dehydration would lead to isomerisation of the intermediate carbocation and consequently a mixture of alkenes will be obtained. Regioselective dehydration will not occur.

4.23 Deduce the structural formulae for the alkenes that give the following ozonolysis products.

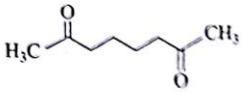
(a) $C_7H_{14} \xrightarrow[Zn\ dust]{O_3\ in\ CHCl_3}$



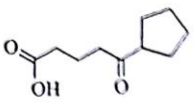
(b) C_7H_{14} (Two isomers) $\xrightarrow[H_2O_2]{O_3\ in\ CHCl_3}$



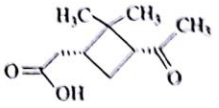
(c) $C_8H_{14} \xrightarrow[H_2O_2\ or\ Zn\ dust]{O_3\ in\ CHCl_3}$



(d) $C_{10}H_{16} \xrightarrow[Zn\ dust]{O_3\ in\ CHCl_3}$

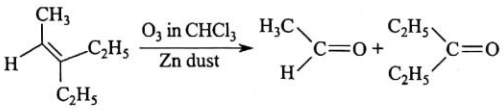


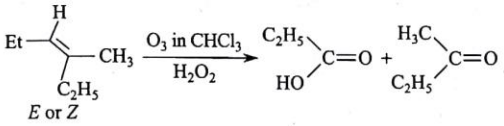
(e) $C_{10}H_{16} \xrightarrow[Zn\ dust]{O_3\ in\ CHCl_3}$

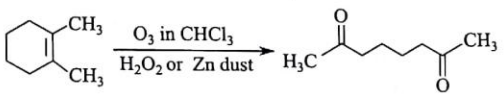


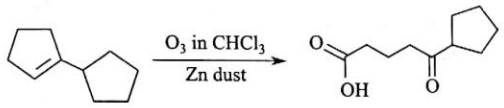
(f) $C_8H_{12} \xrightarrow[H_2O_2\ or\ Zn\ dust]{O_3\ in\ CHCl_3}$

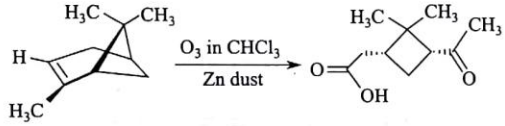
Ans The necessary structural formulae for the alkenes that give these ozonolysis products are given here.

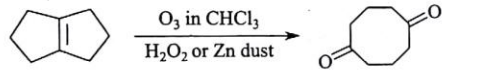
(a)


(b)


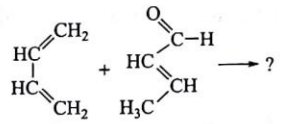
(c)


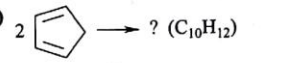
(d)


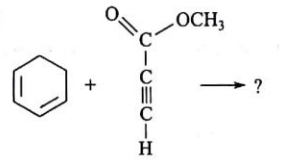
(e)


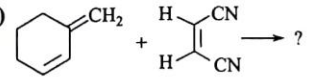
(f)


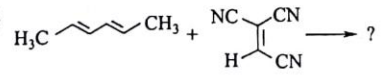
4.24 Give the Diels–Alder addition products of the following reactions. One of these compounds does not give the Diels–Alder product. Identify it and give reasons.

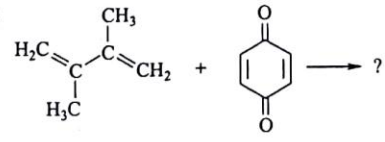
(a)


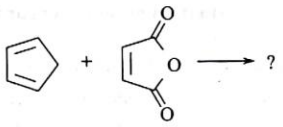
(b)


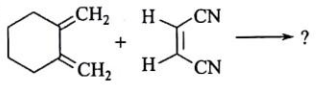
(c)


(d)


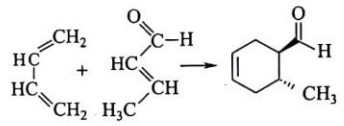
(e)


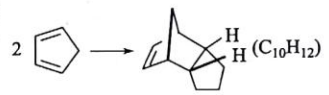
(f)


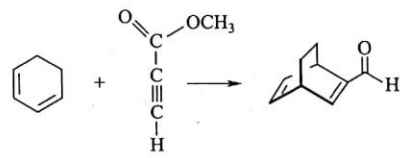
(g)


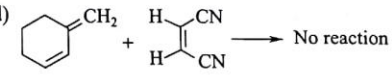
(h)


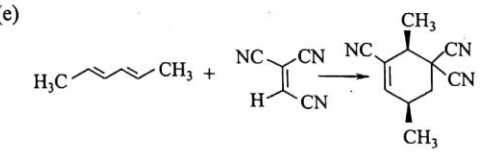
Ans The structures of the Diels–Alder adducts are shown here. In case of the example (d), there will be no reaction because the diene part in this reaction is a rigid *s-trans* compound. Only those dienes that can assume *s-cis*-conformation during the transition state of the reaction can undergo Diels–Alder cyclization.

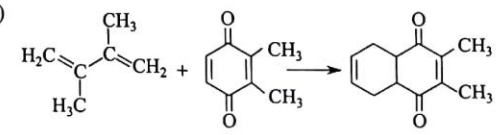
(a)


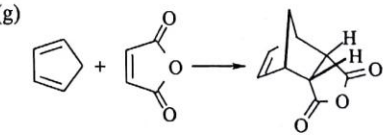
(b)


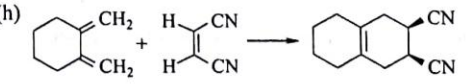
(c)


(d)


(e)


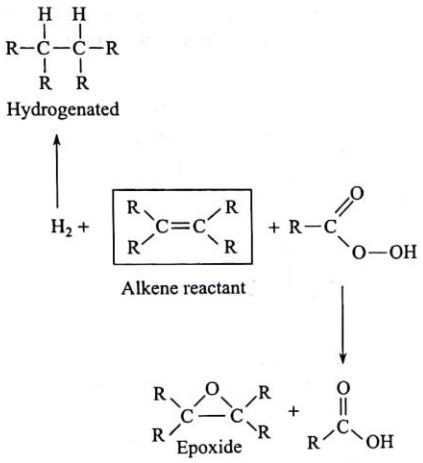
(f)


(g)


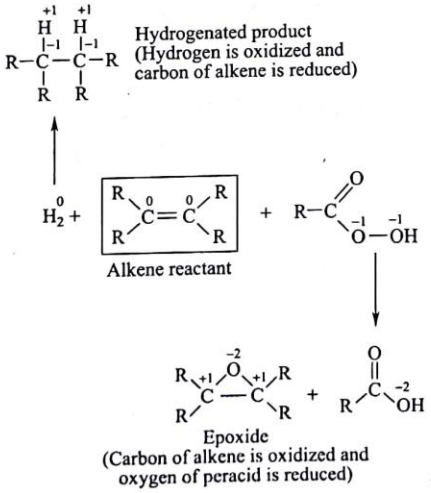
(h)


4.25 Show by the changes in oxidation numbers of carbon how the addition of H_2 to and epoxidation of an alkene by a peracid are cases of oxidation–reduction reactions.

Ans It is important to remember that whenever an atom or group is reduced, some other atom or group is oxidized, and a balanced equation must balance the electron gain in the reduced species with the electron loss in the oxidized moiety, as well as numbers and kinds of atoms. Starting from an alkene (drawn in the box), the following diagram shows a hydrogenation reaction (the catalyst is not shown) and an epoxidation reaction.

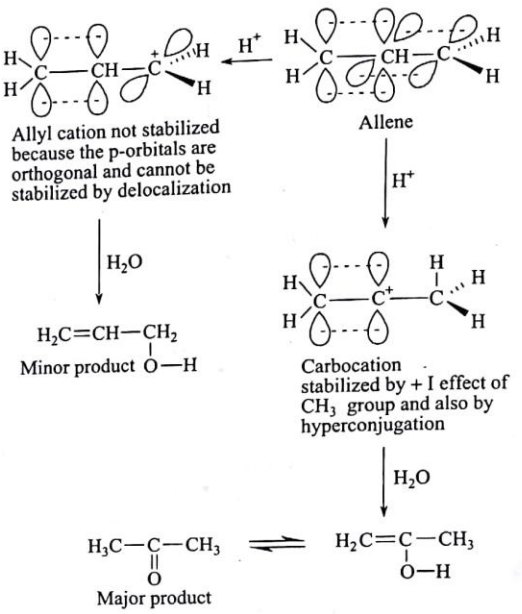


Changes in the oxidation numbers of carbon atoms are shown in the following figure.



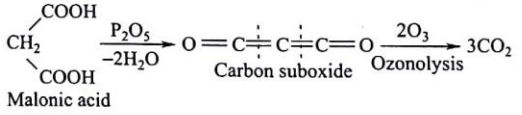
4.26 What is the major product when allene is subjected to acid catalysed hydration?

Ans When allene is subjected to acid catalysed hydration, acetone is the major product and not the allyl alcohol. The course of the reaction can be shown as follows.



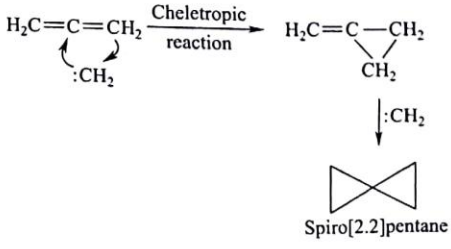
4.27 What happens when malonic acid (propanedioic acid) is dehydrated with P_2O_5 and the resultant compound is subjected to ozonolysis?

Ans The product is carbon suboxide. The product of ozonolysis is only carbon dioxide.



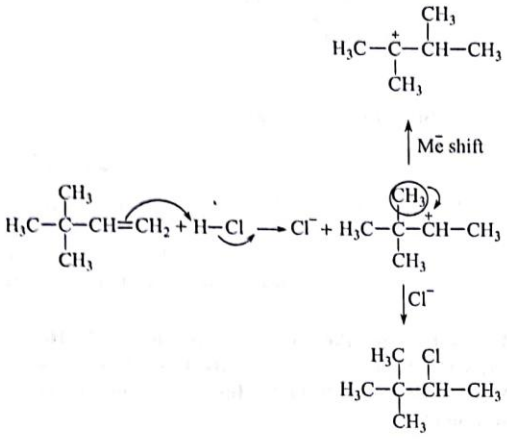
4.28 Give the product obtained by the reaction between allene and :CH_2 (mythelene).

Ans When allene reacts with mythelene, a cyclopropane derivative as well as a bicylopropane, a *spiro* compound is formed. This is an example of a cheletropic reaction which belongs to the class of pericyclic reactions.

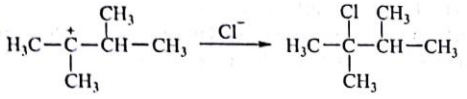


4.29 Treatment of $Me_3C{-}CH{=}CH_2$ and $Me_3C{-}CH(OH)Me$ with concentrated HCl gives the same two isomeric alkyl chlorides. What are these two products?

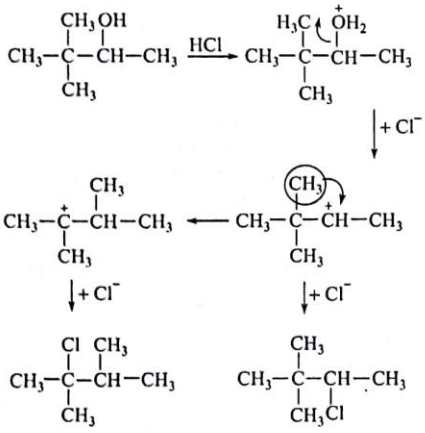
(a)



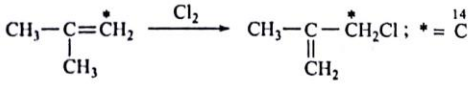
(b)



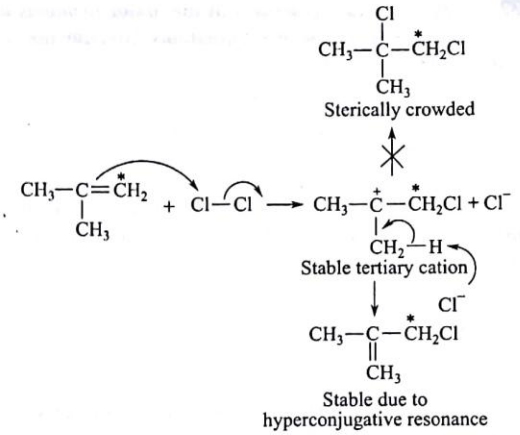
A and B are isomeric alkyl chlorides.



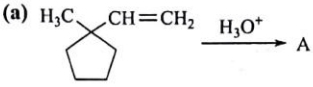
4.30 Account for the following structural change.

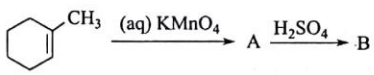


Ans Isobutylene undergoes electrophilic attack by Cl_2 to produce a tertiary carbocation. This is followed by loss of a proton to give the product shown. Nucleophilic attack is hindered because that will create an sp^3 carbon with much steric compression.



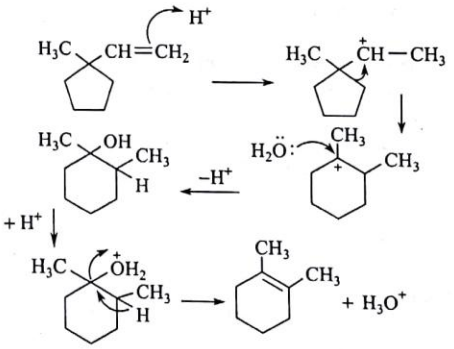
4.31 Complete the reactions shown here and propose a plausible mechanism in each case.

(a) 

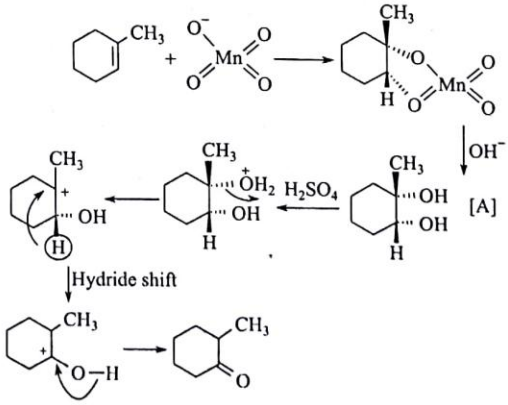
(b) 

Ans The courses of the reactions are shown here.

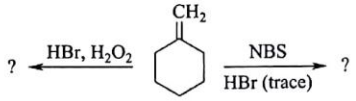
(a)



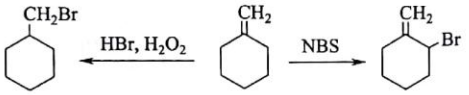
(b)



4.32 Write down the structures of the major products in the following reactions with explanations. Give the plausible mechanism in each case.



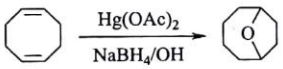
Ans Bromination with NBS/HBr gives allylic bromination. However, with HBr/H_2O_2, anti-Markownikov hydrobromination takes place. The products are shown here.



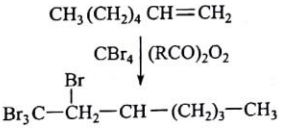
Mechanisms of both the reactions have been discussed in earlier problems.

4.33 Give a plausible mechanism for the following transformation.

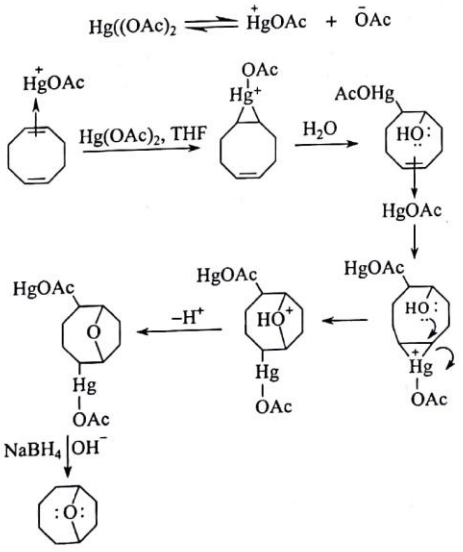
(a)



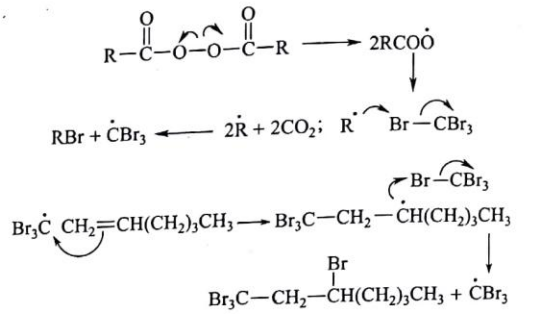
(b)



Ans (a) Here, one of the double bonds undergo normal oxymercuration. During oxymercuration of the second double bond, the —OH group introduced in the first oxymercuration, rather than water, acts as an internal nucleophile and that finally gives the product shown. The mechanism is shown here.

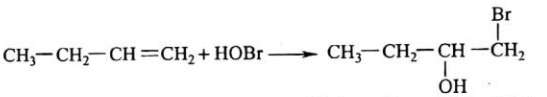


(b) The condition of the reaction suggests that the reaction proceeds through free radical mechanism. The course of the reaction is shown here.



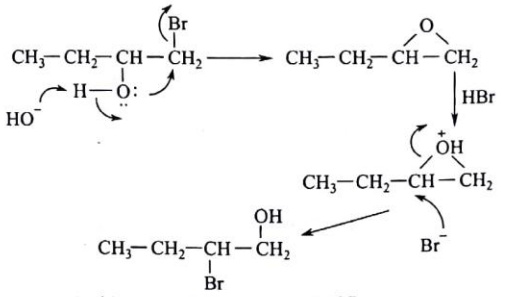
4.34 What is the addition product of HOBr to $CH_3CH_2CH{=}CH_2$? Is it a Markownikov or an anti-Markownikov addition? How can you reverse the addition?

Ans In the case of normal addition of HOBr to $CH_3CH_2CH{=}CH_2$, Markownikov addition takes place where the OH^- group (anionic part of HOBr) goes to the carbon bearing the least number of hydrogen atoms.



Markownikov addition HOBr

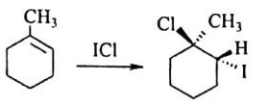
When this bromohydrine is treated with NaOH, then an epoxide is formed. In the epoxide, on treatment with HBr, the ring opens through an apparent more stable carbocation. This results in the formation of another isomeric bromohydrin in which the position of —OH and —Br have changed compared to the initial halohydrin. The net result is an anti-Markownikov addition of HOBr. The reaction is shown here.

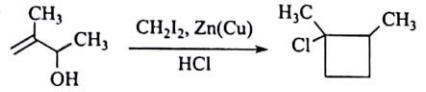


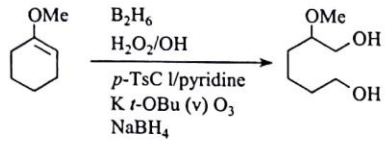
Anti-Markownikov addition of HOBr

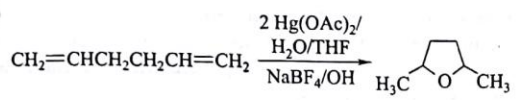
4.35 Give the steps of the following transformations.

(a)

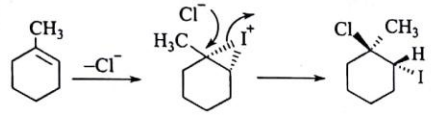


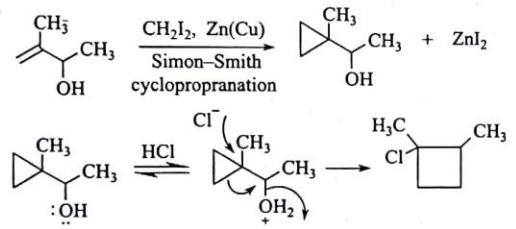
(b) 

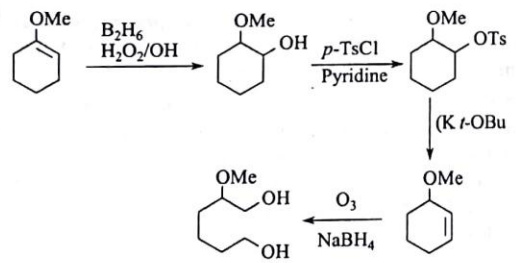
(c) 

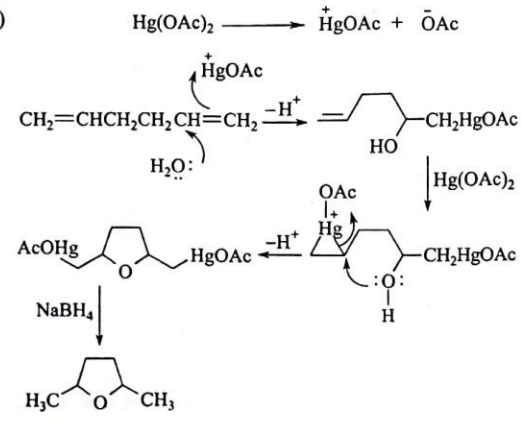
(d) 

Ans The course of the reaction can be shown as follows.

(a) 

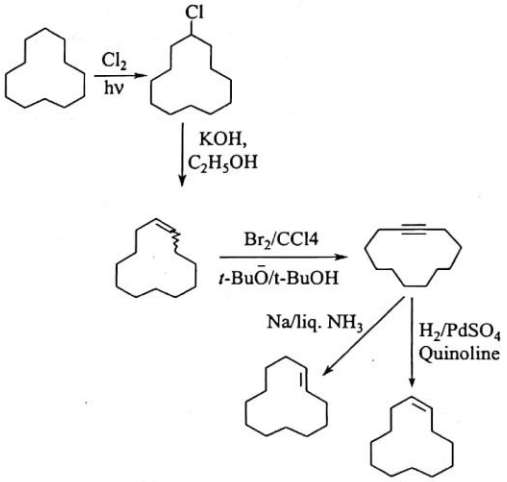
(b) 

(c) 

(d) 

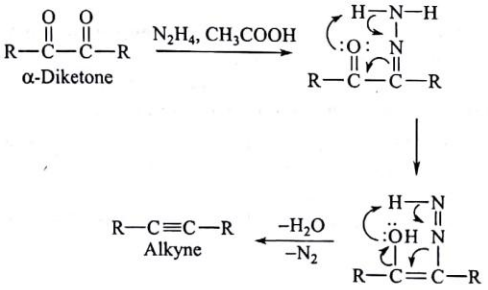
4.36 How can you carry out the following transformations? Give the necessary explanation in favour of your answer.

Ans A triple bond can be introduced in place of a double bond by bromination followed by dehydrobromination. The ring, because of its large size, is not much strained due to the inclusion of the triple bond. Catalytic hydrogenation gives *cis*-addition of hydrogen but reduction with Na/ liq.NH_3 gives *trans*-hydrogenation. That is why isomeric cycloalkenes, differing in the position of the double bond, are obtained.



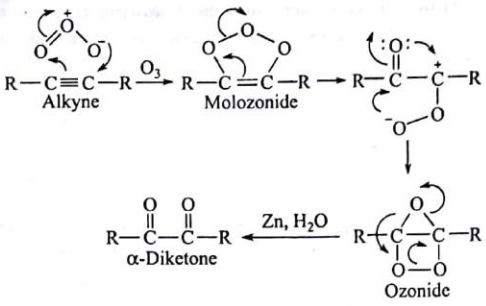
4.37 Give the methods of conversion of an alkyne to an α-diketone and vice versa.

Ans These conversions can be shown as follows.



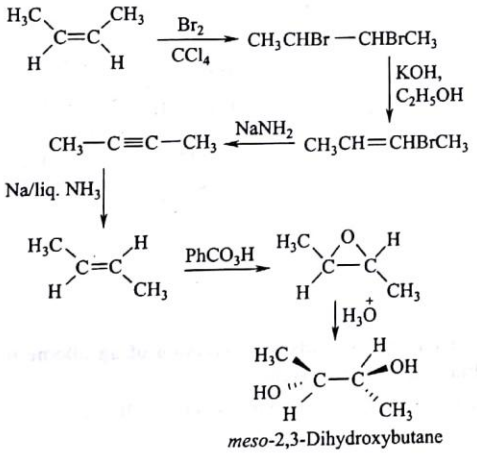
A mono-hydrazone is formed first which loses N2 and H2O through the aforementioned cyclic mechanism.

An alkyne can be converted into an α-diketone by ozonolysis.



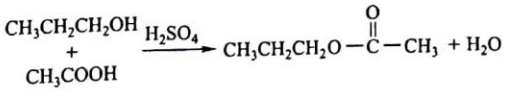
4.38 You have *cis*-but-2-ene at your disposal along with other inorganic reagents but no OsO_4 or $KMnO_4$. How can you proceed to get *meso*-2, 3-dihydroxybutane?

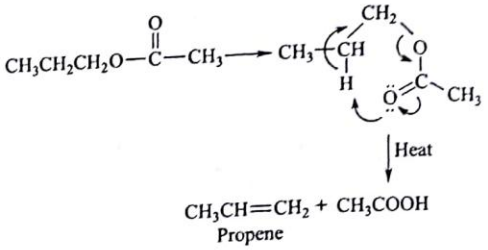
Ans Since OsO_4 and $KMnO_4$ are not available, we cannot carry out *cis*-hydroxylation. Therefore, we will have to follow a longer method. We need to convert *cis*-but-2-ene to *trans*-but-2-ene and then carry out *trans*-hydroxylation to get the *meso*-compound as mentioned in the problem. The course of the reaction is shown here.



4.39 You have acetic acid and 1-bromopropane in your laboratory. You need to prepare propene by a *cis*-elimination. You have only NaOH and H_2SO_4 as inorganic reagents. Explain the method you would use.

Ans From the list of the available chemicals given in the problem, it is evident that propene can be obtained by pyrolysis of an ester of the type $CH_3CH_2CH_2OCOCH_3$. To get that ester we need $CH_3CH_2CH_2OH$ and CH_3COOH. This can be achieved as follows.

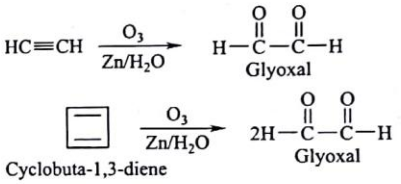




$CH_3CH{=}CH_2 + CH_3COOH$
Propene

4.40 C_2H_2 and another compound $(CH)_n$ give glyoxal as the only product of ozonolysis. What would be the value on '*n*' in the compound $(CH)_n$? Identify the compound and give its IUPAC name.

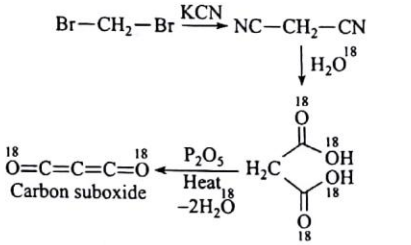
Ans Ozonolysis of C_2H_2 gives glyoxal as the only carbonyl compound. No other alkyne can give glyoxal through ozonolysis. Therefore, $(CH)_n$ cannot be an alkyne. However, a cyclic diene can afford glyoxal by ozonolysis. If we take the value of '*n*' in $(CH)_n$ as 4, then we get the compound C_4H_4 and that can represent a cyclodiene, that is, cyclobuta-1,3-diene (IUPAC). This compound also produces glyoxal as the only compound by ozonolysis.

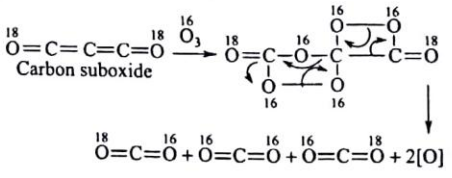


4.41 How can you use ozonolysis to prepare CO_2 as the only product with one of the oxygen atoms of the two molecules of CO_2 labelled with ^{18}O?

Ans It has been observed that C_3O_2 (carbon suboxide) on ozonolysis produces CO_2 as the only product. Carbon suboxide can be obtained by the treatment of P_2O_5 on malonic acid.

If we need CO_2 molecule with one of the oxygen atoms labelled with ^{18}O, then we need to carry out the reaction as follows.

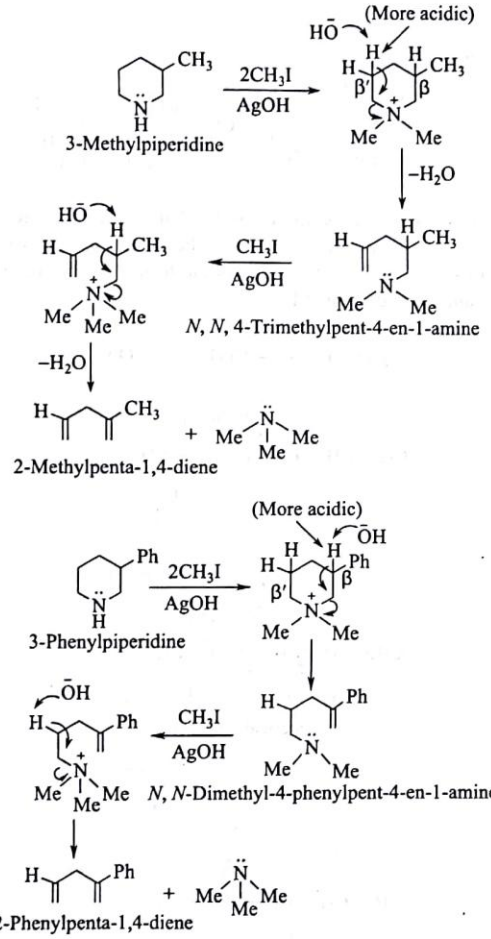




As shown here, two of the three CO_2 molecules have one of the oxygen atoms labelled. Another molecule is an ordinary CO_2 with unlabelled oxygen atoms.

4.42 What products are formed when 3-methylpiperidine and 3-phenylpiperidine are separately subjected to Hofmann exhaustive methylation in a repetitive way?

Ans Hofmann exhaustive methylation, when carried out on 3-methylpiperidine and 3-phenylpiperidine, give the isolated dienes. The reactions are shown here.

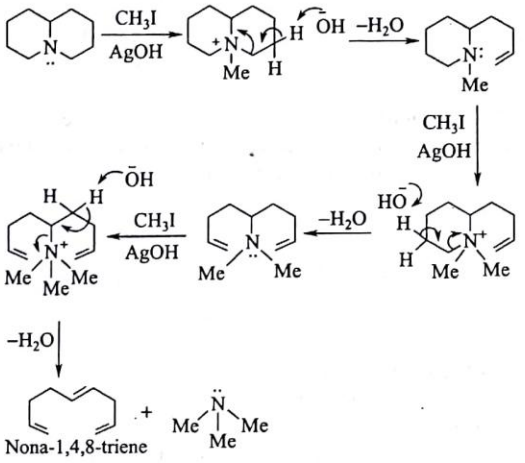


In the first case, the hydrogen atoms attached to the β-methylene group is more acidic compared to the β-hydrogen on the carbon atom bearing the CH_3 group. Therefore, elimination starts from that side.

In the case of the second compound, the hydrogen atom on the β-carbon bearing the Ph group is more acidic and the first elimination involves that hydrogen atom.

4.43 Nona-1, 4, 8-triene is formed by repetitive Hofmann exhaustive methylation method. Identify the compound and show the reactions involved.

Ans The compound called octahydro-1-*H*-quinolizine (IUPAC) gives nona-1,4,8-triene by Hofmann exhaustive methylation method. The course of the reaction is given here.



It is to be noted that the sequence of elimination reactions shown here may be different, but the end-result is the same.

4.44 Give the product and mechanism of the following reactions.

(a) $HOCH_2CH_2CH_2CH{=}CH_2 + I_2 \longrightarrow ?$

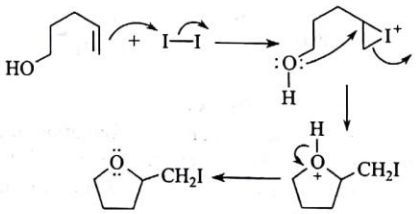
(b) $CH_3CH_2C(CH_3){=}CH_2 + I{-}N{=}C{=}O \longrightarrow ?$

(c) $CH_2{=}CHCD_2Cl + PhCO_3H \longrightarrow A$

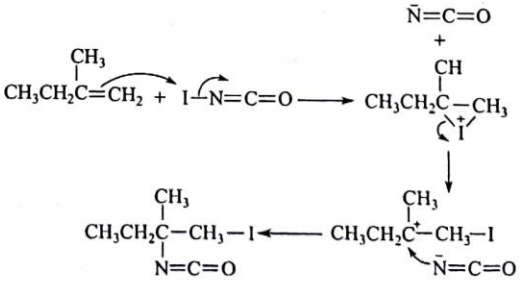
$A + CH_3ONa/CH_3OH \longrightarrow B$

$A + CH_3ONa/CH_3OH \longrightarrow B$

Ans (a) In this case the product is a tetrahydrofuran derivative. The course of the reaction is given here.

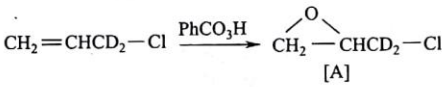


(b) In this case an iodo-isocyanate is formed. The reaction takes place as follows.

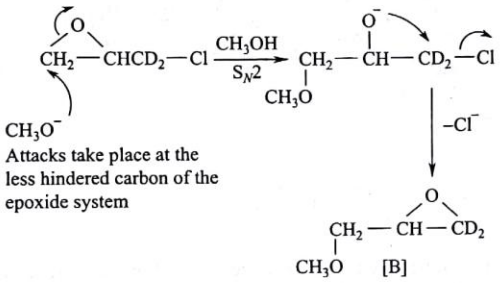


(c) The first step of the reaction is epoxidation and this is

followed by a rearrangement. The reaction is shown as follows.

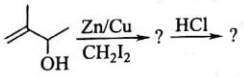


The mechanism of epoxidation by peracid has already been discussed in other problems before. The epoxide formed then rearranges as follows to generate a new epoxide.

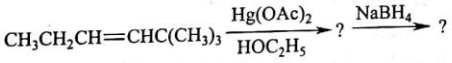


4.45 Predict the major products from each of the following reactions. Show the reactions involved.

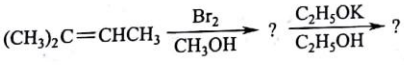
(a)



(b)

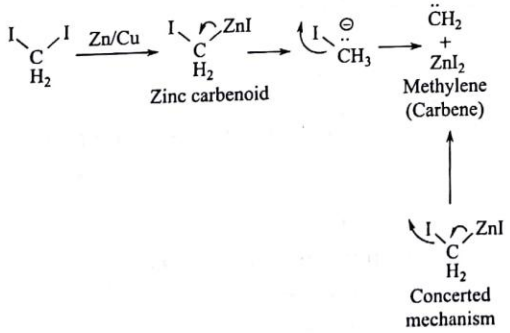


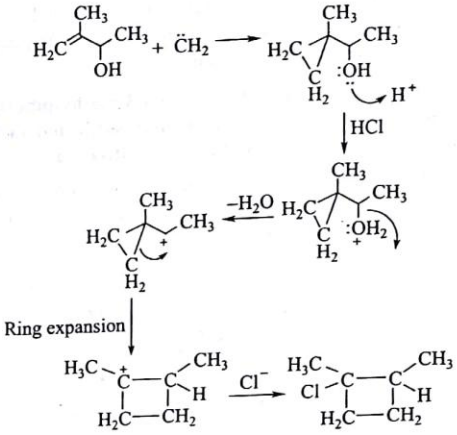
(c)



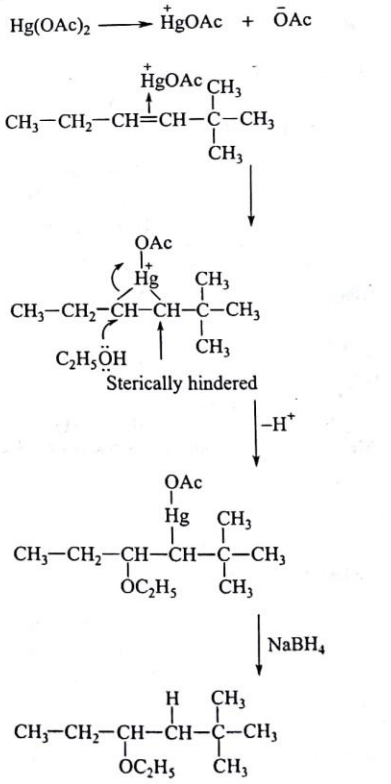
Ans The products are as follows:

(a) The first step of the reaction is the formation of a cyclopropane ring by carbenoid reaction. This is followed by an acid catalysed rearrangement. The course of the reaction is shown here.



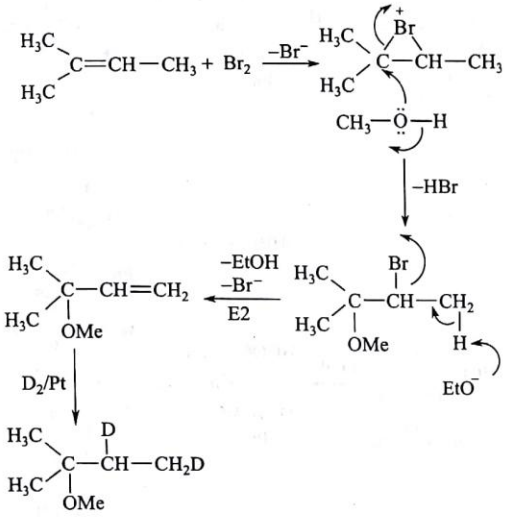


(b) It is a case of oxymercuration–demurcuration reaction. The course of the reaction can be shown as follows. In this case steric factor controls the formation of predominantly one compound.

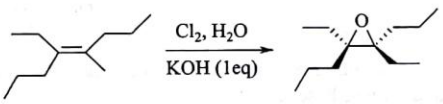


(c) The reaction takes place in three steps. Bromination in the presence of CH_3OH (nuclephilic solvent) gives a bromo-methoxy compound. This is followed by base

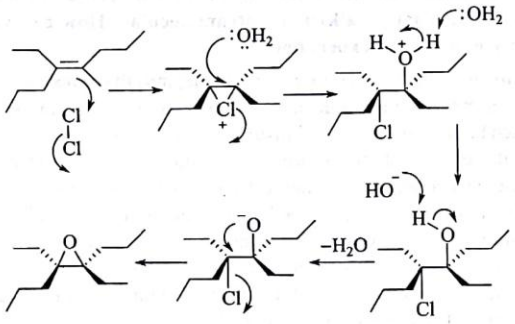
catalysed dehydrobromination (E2) and finally addition of deuterium gives the final product. Reactions are given here.



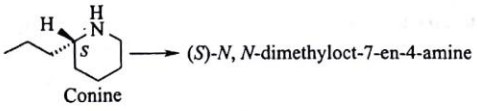
4.46 Propose a plausible mechanism for the following transformation.



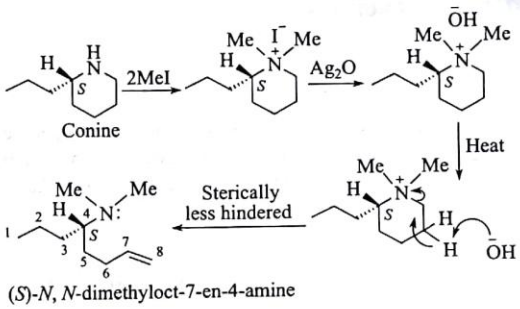
Ans The transformation can be carried out as follows.



4.47 How can you carry out the following transformation?



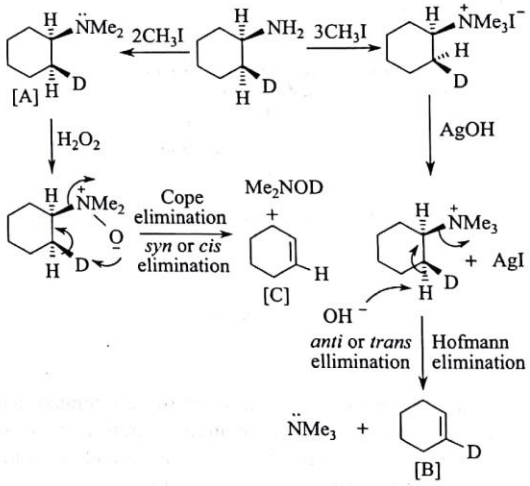
Ans This transformation can be accomplished by using Hofmann exhaustive methylation method. The reactions are as follows.



Conine contains one chiral centre with (*S*)-configuration. During this transformation, any bond attached to the chiral centre is not involved and, therefore, there is no change in its configuration and based on the CIP priority rule, the configuration of the centre remains as (*S*).

4.48 Give an example to show that Cope elimination is an intramolecular *cis*-elimination but Hofmann elimination is an intramolecular *trans*-elimination.

Ans This can be demonstrated by the following reaction.



In this case, when the reaction is carried out according to the conditions of the Hoffmann elimination reaction then cyclohexene is obtained having a deuterium substituted on a carbon [B]. This is accountable if *trans*-elimination occurs. On the other hand, when the reaction condition is according to Cope elimination, then again cyclohexene [C] is formed without any deuterium attached to any carbon. This is possible if the elimination is a case of *cis*-elimination.

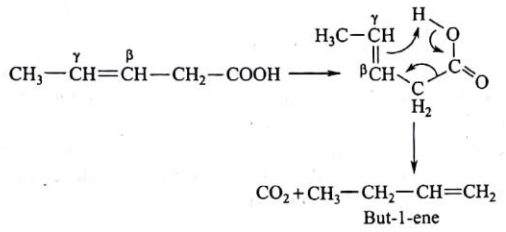
4.49 The following compounds give alkenes through pyrolytic decarboxylation reactions. Give the mechanisms of the reactions and the corresponding products. Why does the compound (c) fail to undergo similar decarboxylation?

(a) $CH_3CH{=}CHCH_2COOH$

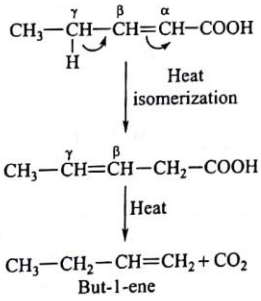
(b) $CH_3CH_2CH{=}CHCOOH$

(c) $(CH_3)_3CH{=}CHCOOH$

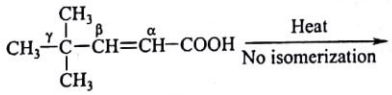
Ans The compound (a) is a βγ-unsaturated carboxylic acid. It undergoes easy decarboxylation on heating. The reaction occurs through a six-membered cyclic transition state, as shown here.



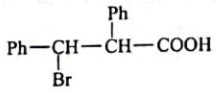
The second compound (b) is an αβ-unsaturated acid with hydrogen atoms on the γ-carbon. During pyrolysis of this compound, it isomerizes to βγ-unsaturated acid and then undergoes decarboxylation following the cyclic mechanism as shown for (a).



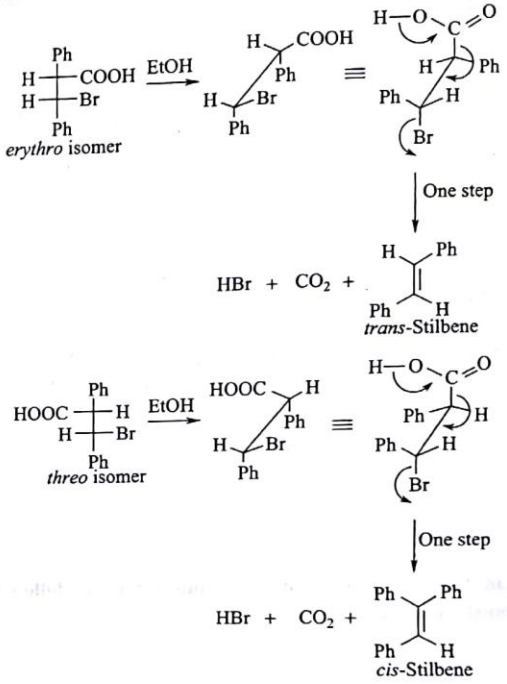
The third compound (c) is also an αβ-unsaturated acid but the γ-carbon has no hydrogen atom. Therefore, it cannot isomerize to a βγ-unsaturated acid and consequently does not undergo pyrolytic decarboxylation on heating.



4.50 (*E*) and (*Z*)-stilbenes are formed by decarboxylative debromination of the following compound which can exist as *erythro* and *threo* isomers. Show the reactions in saw-horse formula.



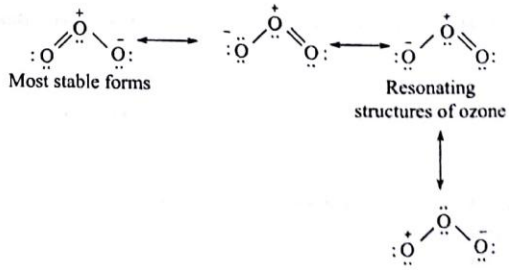
Ans The mechanisms of decarboxylative decarboxylation can be shown as follows.

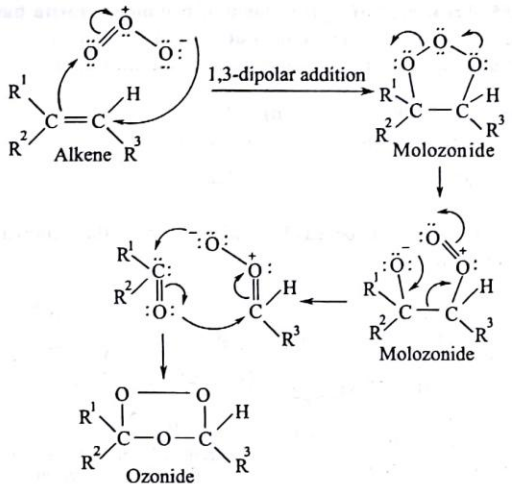


These reactions are stereopecific when carried out in less polar and weaker bases like EtOH.

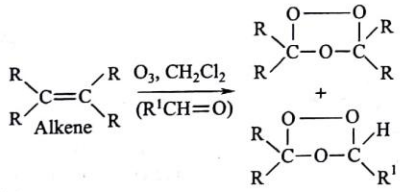
4.51 During ozonolysis of an alkene, ozonide formation from molozoide is completely an intermolecular process but that from an alkyne is intramolecular. How can you prove this by an experiment?

Ans In the case of ozonolysis of alkene, initially a molozonide is formed by intermolecular 1,3-cycloaddition. Molozonide then breaks up into a 1,3-dipolar ion and a carbonyl compound and they recombine to form a more stable ozonide. Ozonide can be decomposed under different reaction conditions to give oxidized products or reduced products. The formation of ozonide from molozonide by intermolecular process is supported by the fact that when an other carbonyl compound is present in the reaction medium, then a mixture of ozonides are formed. The mechanism is shown here.

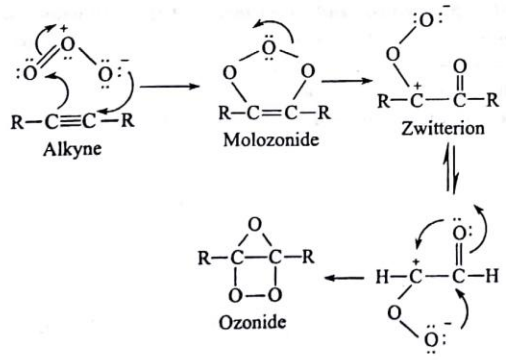




When ozonolysis of an alkene is carried out in the presence of an added aldehyde, then a mixture of ozonides has been isolated. This is possible if the parent alkene forms a carbonyl compound and a zwitterion through molozonide intermediate. Therefore, ozonolysis of an alkene is an intermolecular reaction.

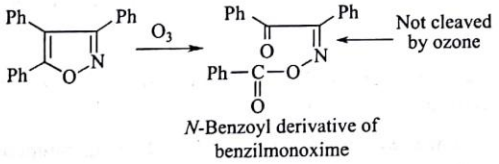


In the case of ozonolysis of an alkyne, initial 1, 3-cycloaddition of ozone to form a molozonide is intermolecular but the subsequent transformation of molozonide to an ozonide is intramolecular and the presence of another carbonyl compound does not give a mixture of ozonides. Formation of ozonide from alkyne is shown here.



4.52 Show by an example that ozone cannot oxidize multiple bonds other than C=C and C≡C.

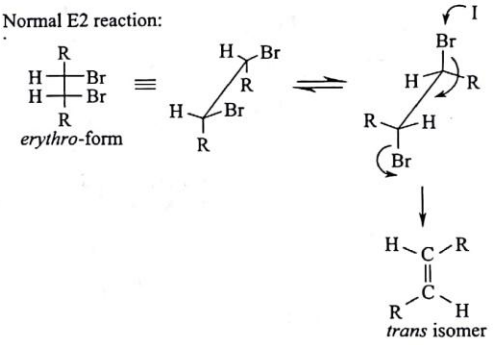
Ans When triphenylisoxazole is subjected to ozonolysis then *N*-benzoyl derivative of benzilmonoxime is obtained. C=N bond of the isoxazole derivative is not oxidized.



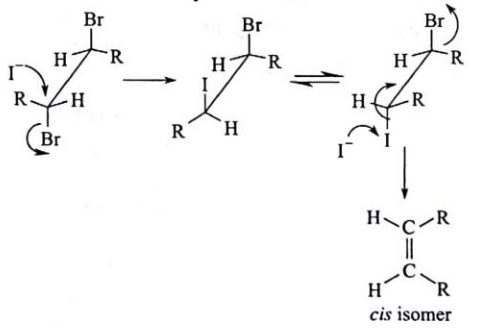
4.53 Iodide ion catalysed debromination of *threo* or *erythro* form of RCHBr–CHRBr may be also a case of merged substitution-elimination reaction. Give the mechanism of the reaction.

Ans Here *erythro*- or *threo*-forms give a mixture of *trans* and *cis* isomers. This is explainable if we consider the reaction partly as direct iodide ion catalysed normal E2 elimination and partly substitution of iodine in place of bromine followed by another E2 reaction. The course of the reaction is given here.

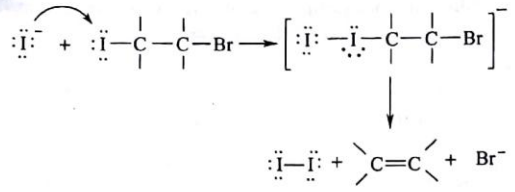
Normal E2 reaction:



Substitution followed by elimination:

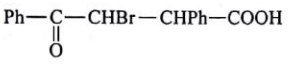


In the second E2 reaction, the iodine atom in bromoiodide is more susceptible to a nucleophilic attack than a bromine atom, for iodine readily 'expands its valence shell', allowing the formation of a new I–I bond before I–C bond breaks.

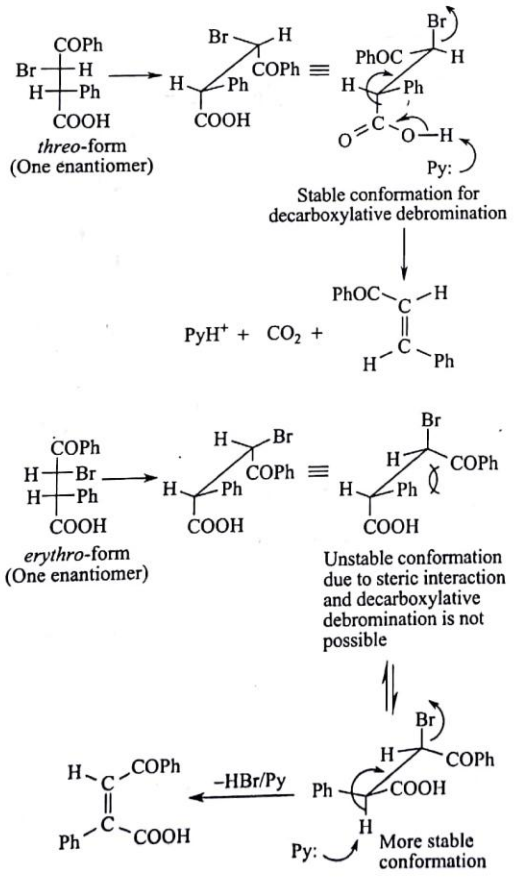


The same course is followed in the case of a *threo* isomer to produce the same mixture of *trans*- and *cis*-alkene.

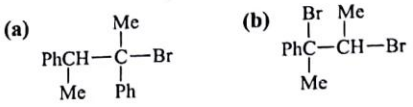
4.54 When the *threo* isomer of the following compound is treated with pyridine, it undergoes 'decarboxylative debromination', but when its *eyrtho*-form is treated in the same way, it undergoes simple dehydrobromination. Explain.



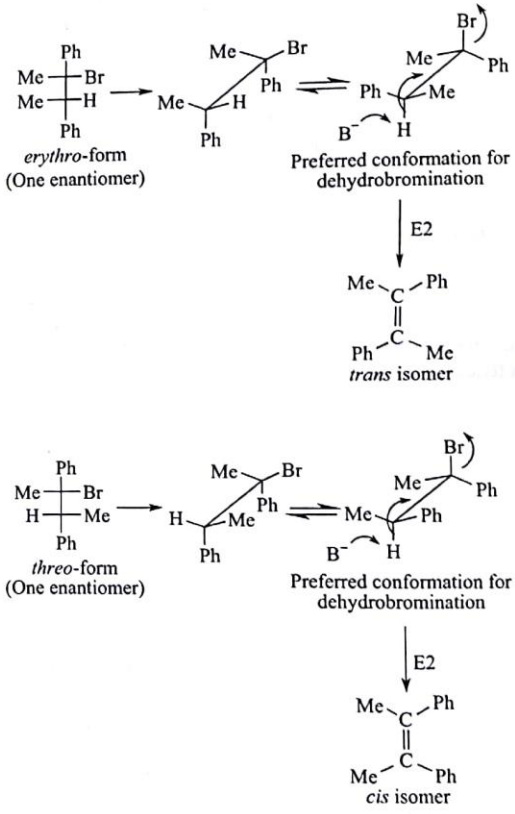
Ans The courses of the reactions are shown here. For E2 elimination to occur, the leaving groups must be anti-periplanar to each other.



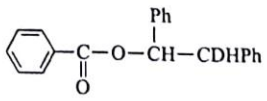
4.55 Treatment of *erythro*-form of bromide (a) with base mainly gives a *trans*-olefin, but similar treatment of the *erythro*-form of (b) mainly gives a *cis*-olefin. Explain.



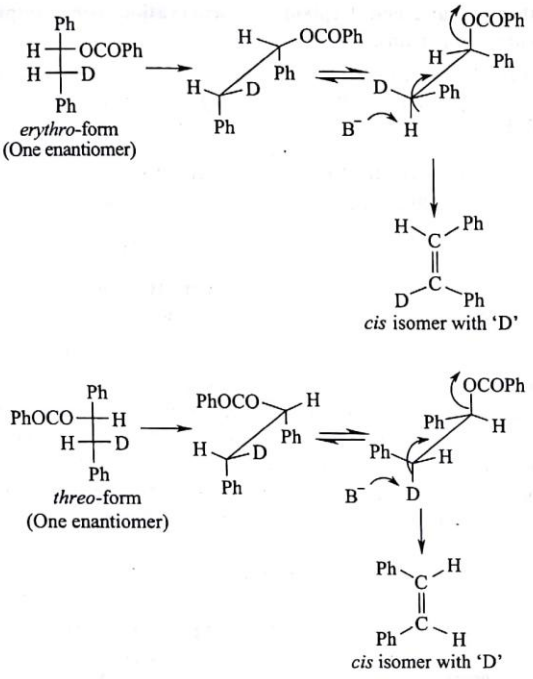
Ans Reasons can be easily explained from the following mechanisms.



4.56 The *erythro*- and *threo*-forms of the following compound is treated separately with a base. In one case, a *cis*-compound is formed without deuterium and in the other case a *cis*-compound is formed with deuterium. Identify the products and offer suitable explanations.

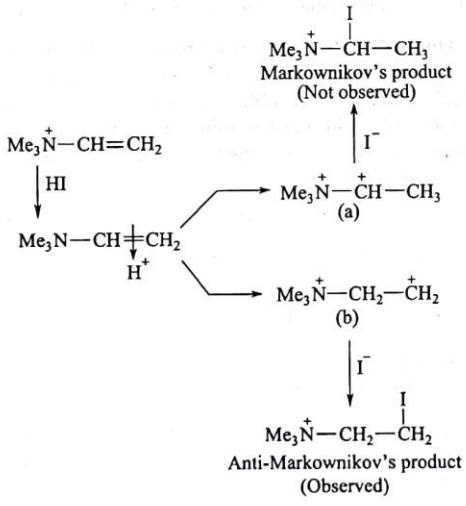


Ans The products are formed by E2 elimination reactions. The courses of the reactions are shown here. Mechanisms explain the observed fact.

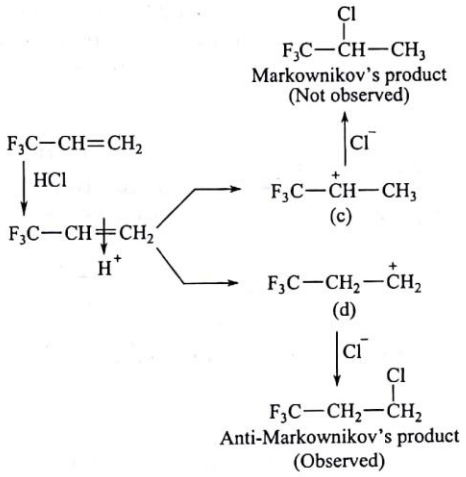


4.57 Give two examples where ionic addition reactions to substituted alkenes lead to the formation of anti-Markownikov products.

Ans In the following two examples we find that anti-Markownikov addition has taken place.



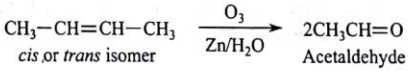
In this example, the dipositive ion (a) is very unstable because of proximity of two positive charges. The dipositive ion (b) is comparatively more stable because the positive charges are not on the adjacent centres.



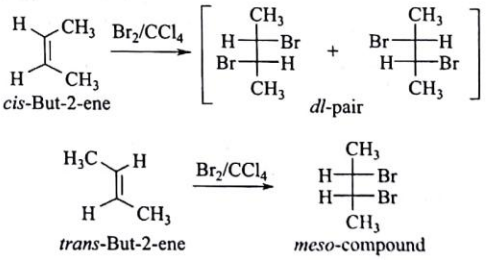
In this example, the carbocation (c) is not stable. Its instability is due to strong –I effect of the $-CF_3$ group which enhances the electron deficiency of the cationic carbon. The carbocation (d) is more stable and gives the corresponding anti-Markownikov product.

4.58 How can you prove that *cis*- and *trans*-but-2-ene are constitutionally identical but stereochemically different?

Ans When *cis*- and *trans*-but-2-ene are separately subjected to ozonolysis, then each of them gives two moles of acetaldehyde. This proves that they are constitutionally identical.



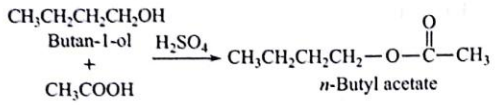
However, when they are subjected to bromination (with a chiral reagent Br_2), which is stereospecifically *trans*-addition, *cis* isomer gives *threo-dl*-pair of 2, 3-dibromobutane. However, *trans* isomer gives *meso*-compound. This accounts for the different stereochemical natures of *cis*- and *trans*-but-2-ene.

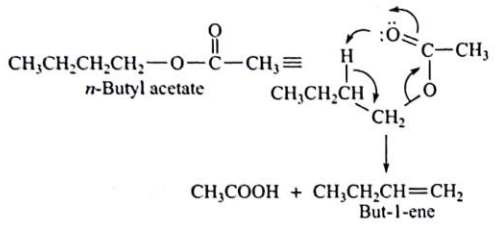


4.59 How can you convert $CH_3CH_2CH_2CH_2OH$ into almost 100% $CH_3CH_2CH{=}CH_2$?

Ans Alcohols are readily dehydrated to alkenes by acid catalysis but in that case the position of the double bond is not regioselective. There is a possibility of getting isomeric alkenes through rearrangements. In this particular case, regioselective

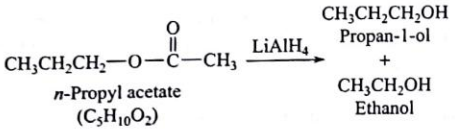
formation of the double bond is possible if is converted into the corresponding acetate by reacting with CH_3COOH in the presence of H_2SO_4. The acetate on pyrolysis gives the desired alkene through a cyclic mechanism, as shown here.

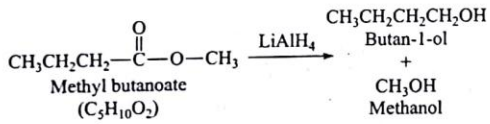




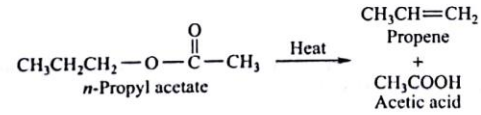
4.60 Two isomeric compounds (A and B)) are represented by the molecular formula $C_5H_{10}O_2$. (A) on reduction with $LiAlH_4$ gives propan-1-ol and ethanol but (B) gives butan-1-ol and methanol on similar reduction. Identify the compounds (A) and (B) and rationalize the reactions. What are the effects of heat on these compounds?

Ans Since compounds (A) and (B) give mixtures of two alcohols by the reduction with $LiAlH_4$, it can be concluded that both are esters. The compound (A) gives propan-1-ol and ethanol and, therefore, the corresponding compound should be *n*-propyl acetate. Since the compound (B) gives *n*-butanol and methanol, the compound is methyl butanoate. The reactions are shown here.



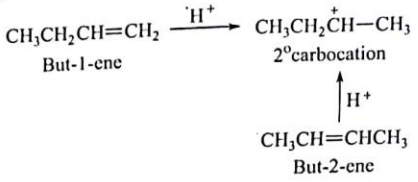


n-Propyl acetate gives propylene and acetic acid on heating. Methyl butanoate does not give such a type of reaction on heating.

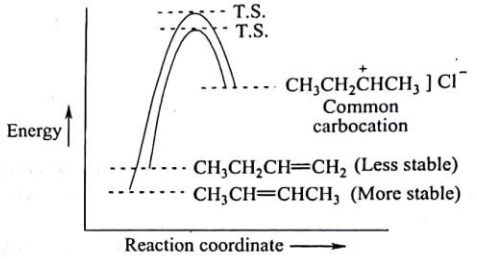


4.61 Reaction of either but-1-ene or but-2-ene with HCl gives the same product 2-chlorobutane through the same carbocation, but the reaction of but-1-ene is faster than that of but-2-ene. Explain this observation using simple energy diagrams.

Ans The same carbocation formed from but-1-ene and but-2-ene by reacting with H^+ (electrophile) can be shown as follows.



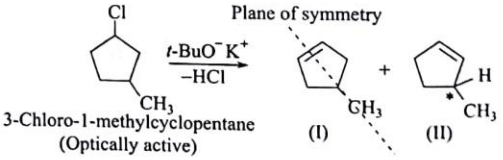
Now, but-1-ene is thermodynamically less stable than but-2-ene. Consequently but-1-ene will require less activation energy to reach the transition state to generate the carbocation compared to that from but-2-ene. Since in electrophilic addition, the formation of the carbocation is the rate determining step, the rate of the reaction of but-1-ene is faster than that of but-2-ene. This is graphically shown here.



From this diagram, it is obvious that but-1-ene will react at a faster rate to form the carbocation through a transition state.

4.62 Optically active 1-chloro-3-methylcyclopentane was treated with potassium *t*-butoxide in *t*-butyl alcohol. Two isomeric alkenes were obtained. The major product is not resolvable, whereas the minor product is resolvable. What are the structures of the major and minor products? Explain the reactions.

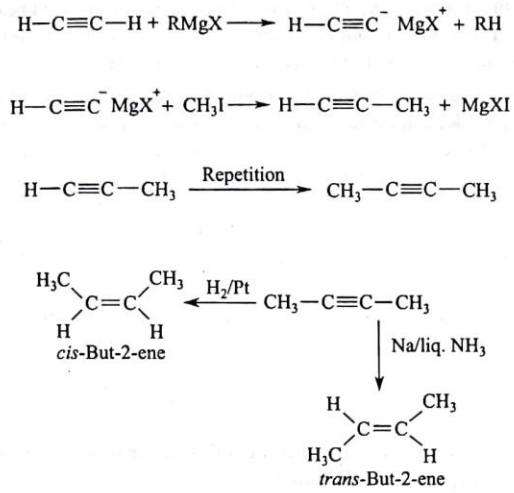
Ans The reaction is shown here.



Here the major product is (I) which is not resolvable because of the presence of a plane of symmetry. The compound (II) is the minor product and is resolvable, it has a chiral centre.

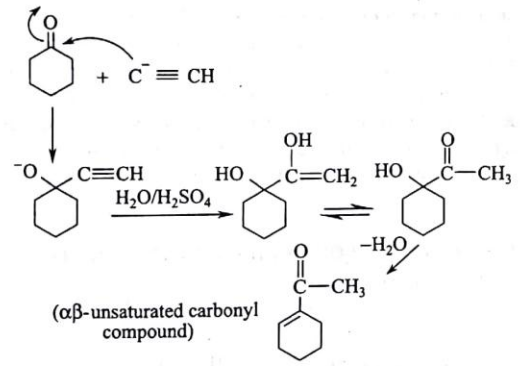
4.63 Using the acidic character of the acetylenic hydrogen atoms, synthesise *cis*- and *trans*-but-2-ene from acetylene.

Ans The said transformation can be done as follows.



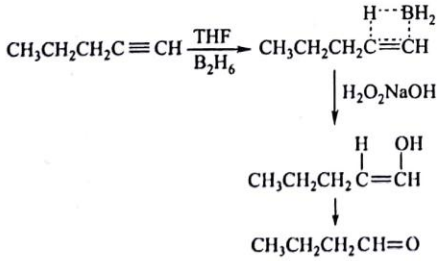
4.64 Show how $HC{\equiv}C^-$ can be used to prepare an αβ-unsaturated carbonyl compound with a $-COCH_3$ group.

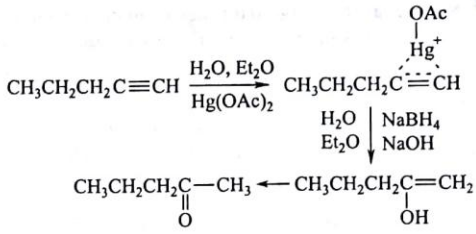
Ans The method is shown by synthesizing an αβ-unsaturated carbonyl compound starting from cyclohexanone.



4.65 How will you go about converting the compound $CH_3CH_2CH_2C{\equiv}CH$ to $CH_3CH_2CH_2{-}CO{-}CH_3$ and the isomeric $CH_3CH_2CH_2CH_2CH{=}O$ by changing the nature of the reaction?

Ans The reactions to carry out the above transformations are shown here.

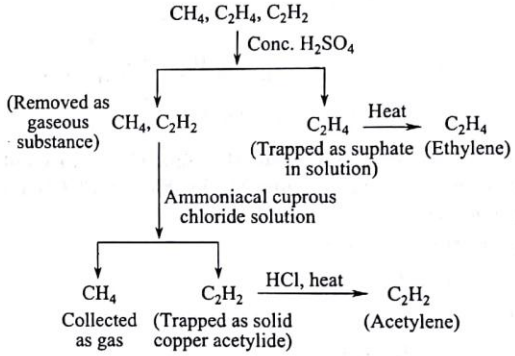




The first case is hydroboration–oxidation and the second reaction is oxymercuration–demercuration. Both the reactions are regioselective hydration. Hydroboration-oxidation amounts to anti–Markownikov hydration of water to an alkene and oxymercuration–demercuration is Markownikov way of hydration of an alkene.

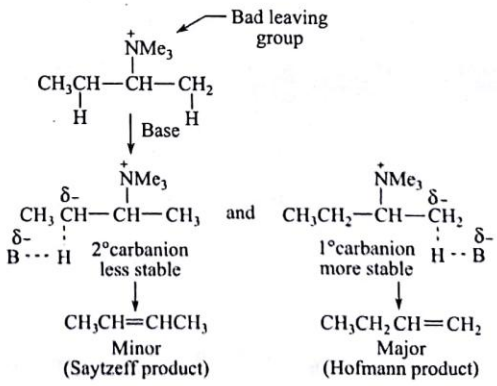
4.66 How can you separate a gaseous mixture of methane, ethylene, and acetylene?

Ans The schematic diagram of the separation method is given here.



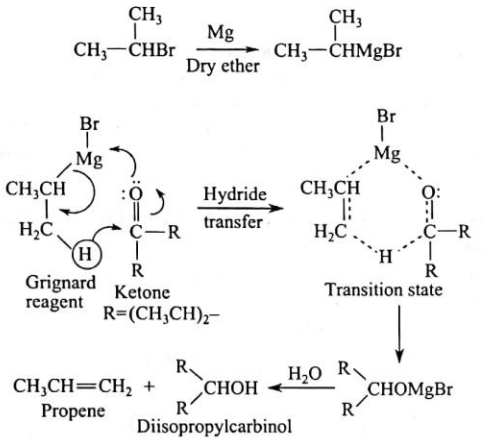
4.67 Explain why a bad leaving group leads to Hofmann elimination even when the size of the base used is not bulky.

Ans In E2 elimination to prepare an alkene, when the leaving group is bad then the transition state is found to be carbanion-like and when there is a choice, 1° carbanion is preferentially formed because it is most stable amongst the three classes of carbanions. An example is given here.



4.68 Show that the Grignard reagent formed from a suitable alkyl halide sometimes function as a reducing agent.

Ans Grignard reagent prepared from isopropyl bromide can reduce a hindered ketone to the corresponding alcohol by hydride transfer reaction. Normal reaction of Grignard reagent is prevented due to steric interaction. The course of the reaction is shown here.



4.69 What happens when the following dibromides are treated separately with Mg in dry ether? Offer an explanation.

(a) $BrCH_2CH_2CH_2CH_2Br$

(b) $BrCH_2CH_2CH_2Br$

(c) $CH_3CH_2\underset{\displaystyle Br}{\underset{|}{C}}H-CH_2Br$

Ans The compound (a) gives di-Grignard but the compound (b) gives cyclopropane by a intramolecular Wurtz like reaction.

(a) $BrCH_2CH_2CH_2CH_2Br \xrightarrow[\text{Dry ether}]{Mg/} BrMgCH_2CH_2CH_2CH_2MgBr$ (Di-Grignard)

(b) $BrCH_2CH_2CH_2Br \xrightarrow{Mg/\text{Dry ether}}$ Cyclopropane

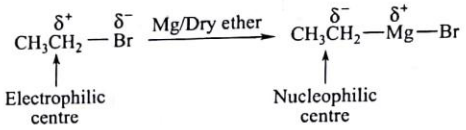
Entropy factor is probably responsible for this different behaviour of these dibromides. If the chain is long then entropy change to form a cyclic compound will be more negative compared to the smaller chain leading to the formation of a cyclic compound.

In the case of the third compound (c), a simple elimination reaction (debromination) takes place to give an alkene.

(c) $CH_3CH_2\underset{\displaystyle Br}{\underset{|}{C}}H-CH_2Br \xrightarrow{Mg/\text{Dry ether}} CH_3CH_2CH=CH_2$

4.70 When an alkyl halide is converted to a Grignard reagent then the carbon atom linked to halogen atom changes its polarity. Justify this statement with an example.

Ans In an alkyl halide, the carbon atom attached to the halogen is electron deficient and functions as a electrophilic centre. However, when it is converted into a Grignard reagent then the said carbon becomes an electron-rich centre and functions as a nucleophilic centre. Thus in the conversion of an alkyl halide to the corresponding Grignard reagent, change of polarity of the reactive carbon centre occurs (umpolung).

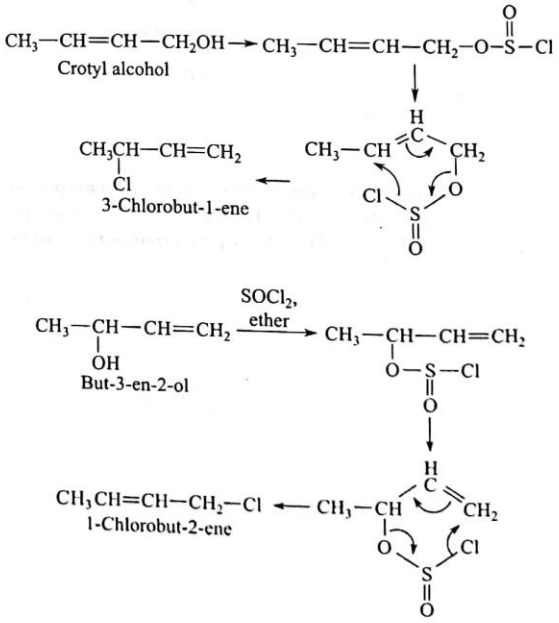


4.71 What are products in the following reactions? What is the expected mechanism?

(a) $CH_3-CH=CH-CH_2OH \xrightarrow{SOCl_2,\ \text{ether}} ?$

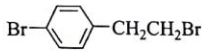
(b) $CH_3-\underset{\displaystyle OH}{\underset{|}{C}}H-CH=CH_2 \xrightarrow{SOCl_2,\ \text{ether}} ?$

Ans In both the cases, initially the corresponding chlorosulphite is formed along with HCl. Since the medium is weakly polar ether, HCl does not sufficiently ionize to produce chloride ion. For this reasons crotyl alcohol (a) is converted into 3-chlorobut-1-ene and (b) is converted into γ-substituted chloride. The reaction occurs in a cyclic manner with concomitant migration of the olefinic double bond. The reaction is in fact S_Ni'. The courses of the reactions are shown here.

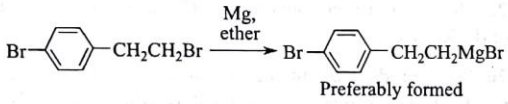


This mechanism is supported by the fact that when isotopic chloride ion is present in the reaction medium, no incorporation of that occur in the product-molecules.

4.72 What type of Grignard reagent is formed when the following compound is treated with one mole of Mg in dry ether? Offer an explanation.

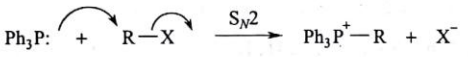


Ans The compound is simultaneously an aryl halide and an aryl substituted alkyl halide. Grignard reagent is possible from both the positions, but when one mole of Mg metal is used in dry ether then the Grignard reagent is preferentially formed from the alkyl side chain. The bromine atom attached to the benzene nucleus is more strongly bonded to the ring carbon because Ar—Br bond is shorter due to —I effect of the aryl ring along with delocalization involving lone pair of electrons on the bromine atom.



4.73 Explain why the reactivity of alkyl halides towards Wittig reaction is 1° > 2° > 3° and also the fact that the reactivity order of alkyl halides is R—I > R—Br > R—Cl.

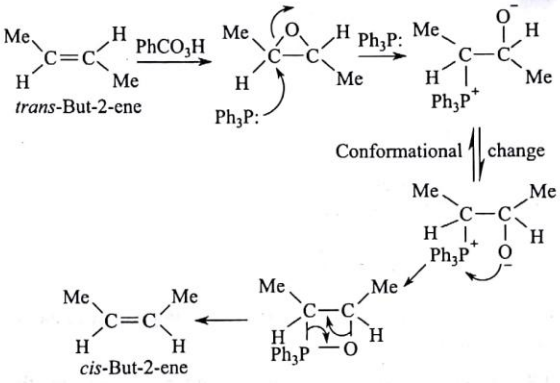
Ans In the Wittig reaction, the first step is an S_N2 substitution where Ph_3P: is the nucleophile and alkyl halide is the substrate molecule. The rates of S_N2 substitution is 1° > 2° > 3° halides due to steric factor.



Secondly, in S_N2 reaction, the rate of loss of halide ion as leaving group is I^- > Br^- > Cl^-

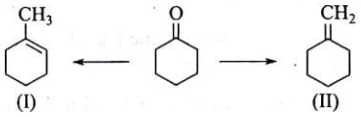
4.74 Show how Ph_3P: can be used to carry out stereomutation of *trans*-but-2-ene to *cis*-but-2-ene and vice-versa.

Ans This transformation can be carried out as follows.



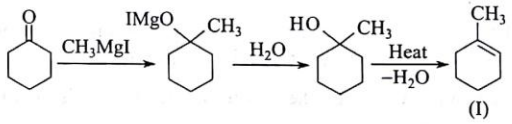
Similar sequential reactions can convert *cis*-but-2-ene to *trans*-but-2-ene

4.75 Carry out the following transformations.

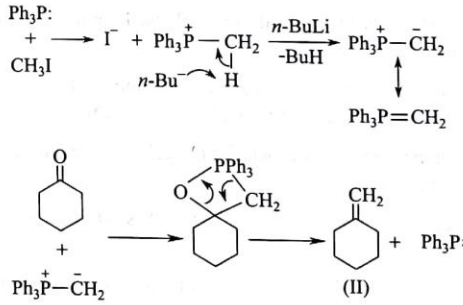


Ans These transformations can be done as follows.

(a)



(b)



EXERCISES

4.1 A compound with a molecular formula C_6H_{14} has two 3° hydrogen atoms. Give the structure and IUPAC name of the compound.

4.2 Which is the lowest alkane that can be transformed into a chiral molecule by substituting two of its hydrogen by D and T isotopes?

4.3 You have only malonic acid, $CH_2(COOH)_2$ with you. Can you get methane from it?

4.4 A student carried out Wurtz reaction with two alkyl halides R^1—Cl and R^2—Cl and gets a mixture of *n*-butane, ethane and propane. What are R^1—Cl and R^2—Cl?

4.5 Give the structures of isomeric saturated hydrocarbons such that (a) one with twelve primary hydrogen only (b) one with nine primary hydrogen and (c) one with six primary hydrogen atoms.

4.6 Complete the following equations.

(a) $2CH_3CH_2Br + 2Na \xrightarrow{\text{Dry ether}} ?$

(b) $CH_3I + Mg \longrightarrow ? \xrightarrow{H_2O} ?$

(c) $CH_3COONa \xrightarrow[\text{Heat}]{\text{NaOH, CaO}} ?$

(d) $CH_3COOK \xrightarrow[\text{Electrolysed}]{\text{Water solutin}} ?$

(e) $CH_3CH_2CH_2CH_3 \xrightarrow[\text{Heat}]{AlCl_3} ?$

4.7. Which alkyl halide is to be used to prepare *n*-hexane by Wurtz reaction?

4.8. Name the compounds that would be formed by the action of metallic sodium on the following alkyl halides.

(a) *n*-propyl iodide
(b) Isopropyl iodide
(c) 2-bromobutane

4.9. Why do we fail to prepare methane by Wurtz or Kolbe method of synthesis of alkanes?

4.10. Reaction between methane and iodine does not produce methyl iodide. Explain why. How can you get methyl iodide from this reaction?

4.11 What is the product of reaction between tertiary butyl chloride and zinc–copper couple in ethanol?

4.12 What would be the products when butane is thermally decomposed?

4.13 How can you conclude that all the four hydrogens of methane are equivalent?

4.14 Ethane produces only one type of monosubstituted compound. What would be your conclusion from this fact?

4.15 Octane number of a petroleum fuel is 50. What do you mean by this statement?

4.16 Cetane number of a petroleum fuel is 80. What does it mean?

4.17. Explain the difference in melting points or boiling points, as indicated, for each of the following sets of compounds.

(a) CH4 (b.p.–146°C), CH_3CH_3 (b.p.–89°C)
(b) CH_3CH_3 (m.p.–183°C), $CH_3(CH_2)_{18}CH_3$ (m.p.–37°C)
(c) $CH_3CH_2CH_2CH_2CH_2CH_3$ (b.p.–69°C),

$$CH_3-\underset{\displaystyle CH_3}{\underset{|}{CH}}-\underset{\displaystyle CH_3}{\underset{|}{CH}}-CH_3 \text{ (b.p. 58° C)}$$

4.18 Bromination of olefins is always carried out in CCl_4 but not in CH_3CH_2OH. Give reasons.

4.19 $CH_3CH{=}CH_2$ is more reactive towards electrophilic addition than ethylene. Explain.

4.20 Reaction between HI and $CH_2{=}CH_2$ in ethanol gives predominantly EtI, whereas the reaction with HCl, under the same conditions, gives predominantly Et_2O. Explain.

4.21 Addition of HBr to $CH_3CH{=}CH_2$ in the absence and in the presence of $PhCO_3H$ gives different products but under the same conditions, addition of HCl gives only one product. Explain.

4.22 When CH_3^-, $(CH_3)_2CH^-$, and $(CH_3)_3C^-$ are separately attached to $-CH{=}CH_2$ group, which one will activate the double bond most?

4.23 Isobutene, in the presence of H_2SO_4, forms a mixture of two isomeric compounds with the molecular formula C_8H_{16}. Identify them and give their IUPAC names. How would you distinguish them chemically?

4.24 What alkenes would you expect from the following compounds? Give the experimental conditions in each case: (a) Me_3CCl (b) Me_2CHCH_2OAc (c) $MeCH(OH)CMe_3$.

4.25 How would you convert $RC{\equiv}CH$ to (a) $R{-}CO{-}CH_3$ and (b) $RCH_2CH{=}O$?

4.26 What product is obtained as the major product when $CH_2{=}C{=}CH_2$ is subjected to acid catalysed hydration? Give explanation.

4.27 Convert acetylene to (±)–$CH_3CH(OH)COOH$ using intramolecular Cannizzaro as one of the steps.

4.28 Compare giving reasons the ease of hydration of but-1-in, (*Z*)-but-2-ene and (*E*)-but-2-ene.

4.29 Addition HBr to penta-1, 3-diene can occur through 1, 2-addition and 1, 4-addition to give the same product. Give a method to distinguish between the two processes.

4.30 When $RCH_2CH{=}CHCH_2$ is treated with *N*-bromosuccinimide (NBS) then two isomeric monobromo compounds are formed. Identify the products with explanation.

4.31 Arrange the following compounds in order of decreasing rate of hydrolysis with explanation.

$$PhCH_2Cl,\ Ph\underset{\displaystyle Cl}{\underset{|}{C}}HCH_3,\ Ph_2CHCl,\ Ph_3CCl$$

4.32 What happens when $CH_3CH{=}CH_2$ is treated with Br_2 in the presence of NaCl solution?

4.33 How can you convert a chiral secondary alcohol to the corresponding chiral choride with 100% retention of configuration and with 100% inversion of configuration? Give examples with mechanisms.

4.34 An alkyl halide reacts with OH^- to produce an alcohol but the reverse reaction does not occur. Offer an explanation. Under what condition can an alcohol be transformed into an alkyl halide?

4.35 Under what conditions can RCl be converted into RI and vice versa. Give an explanation.

4.36 1-Bromo-6-methoxy hexane can be converted to the corresponding Grignard reagent, whereas the corresponding alcohol cannot. Explain.

4.37 Each of the following hydrocarbons contains no double or triple bonds and reacts with chlorine to give a single monochloride. Deduce the structure of each hydrocarbon and the corresponding chloride.

(a) C_8H_{18}
(b) C_8H_{16}
(c) C_8H_8

4.38 The reaction of the unusual hydrocarbon spiropentane with chlorine and light is one of the best ways of preparing chlorospiropentane. (a) Explain why chlorination is such a useful preparative method in this case. (b) Write the reaction mechanism.

4.39 Consider the reaction of isopropyl iodide with various nucleophiles. For each of the following pairs, predict which will give the larger substitution/elimination reaction.

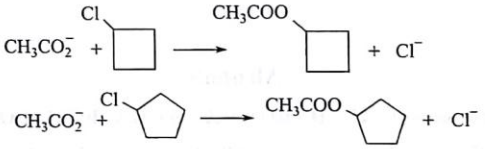
(a) SCN^- or OCN^-
(b) I^- or C^-
(c) $N(CH_3)_3$ or $P(CH_3)_3$
(d) CH_3S^- or CH_3O^-

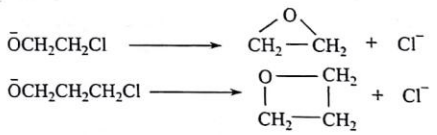
4.40 2-Bromo, 2-chloro, and 2-iodo-2-methylbutanes react at different rates with pure methanol and produce the same mixture of 2-methoxy-2-methylbutane and alkenes as products. Explain these results in terms of the reaction mechanism.

4.41 For each of the following pairs, predict which one is faster and explain why.

(a) $N_3^- + (CH_3)_2CHCH_2Br \xrightarrow{C_2H_5OH} (CH_3)_2CHCH_2N_3 + Br^-$

$C_6H_5S^- + (CH_3)_2CHCH_2Br \xrightarrow{C_2H_5OH} (CH_3)_2CHCH_2SC_6H_5 + Br^-$

(b) 

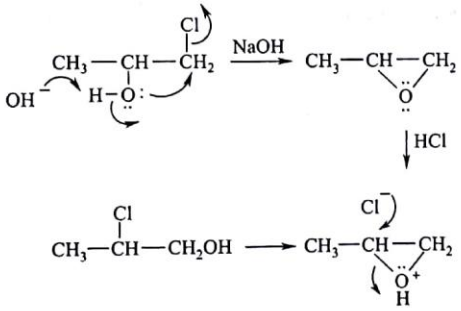
(c) 

5 Alcohols and Ethers

Alcohols

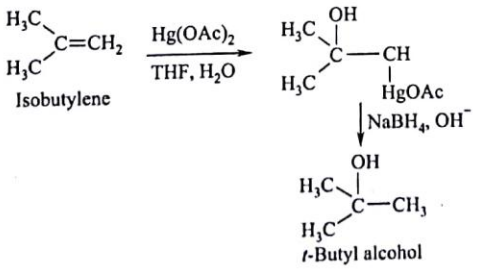
5.1 Convert $CH_3CH(OH)\,CH_2Cl$ to $CH_3CH(Cl)CH_2OH$.

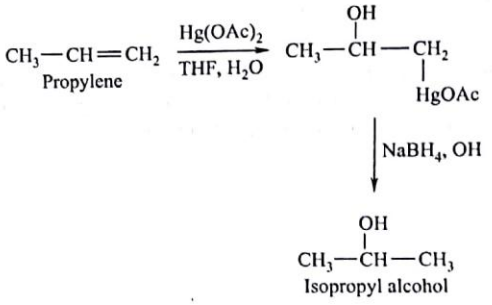
Ans The conversion can be done as follows. First step is the conversion the chlorohydrin to an epoxide by base and then ring opening by acid (HCl). Ring opening takes place through the incipient formation of more stable carbocation.



5.2 Starting from an appropriate alkene, show all the steps in the synthesis of *t*-Butyl alcohol and isopropyl alcohol by oxymercuration–demercuration.

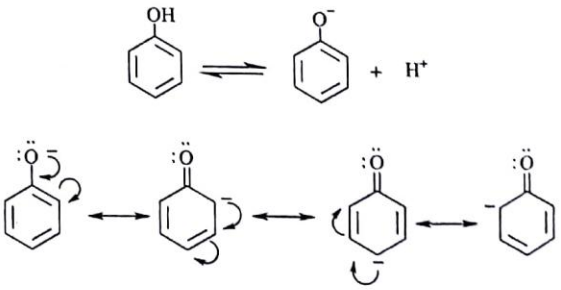
Ans Oxymercuration and demercuration reaction leads to Markowanikov way of hydration of alkenes. Therefore, isobutylene gives *t*-butyl alcohol and propene gives isopropyl alcohol respectively, when subjected to oxymercuration–demercuration reactions.





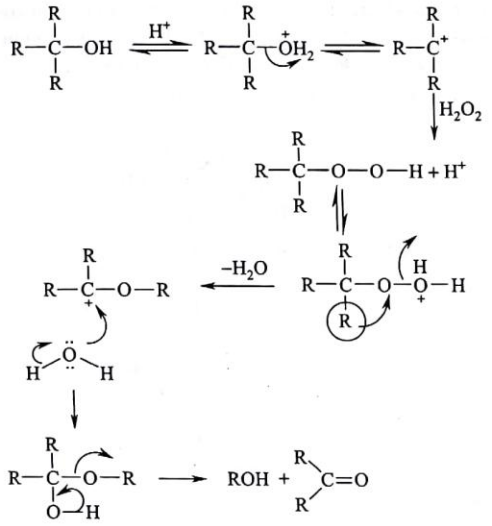
5.3 Alcohols are weaker acids than phenols but are stronger nucleophiles. Explain.

Ans Phenol is a stronger acid because after losing H^+ ion, the resultant phenoxide ion becomes stabilized by delocalization as shown here. As a result of which, the polarizability and hence nucleophilicity of the lone pair of electrons on the oxygen atom decreases. No such ionization and delocalization of the alkoxide ion is possible in case of alcohol. Alcohols have higher electron density on the oxygen atom and consequently greater polarizability.



5.4 What will be the product or products if $R_3C{-}OH$ is treated with H_2O_2 and H^+. Give the mechanism.

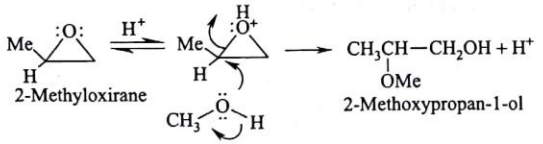
Ans The products are $R_2C{=}O$ and ROH. The reaction is known as hydroperoxide rearrangement and the mechanism can be shown as follows.



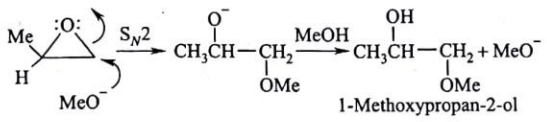
5.5 Show how does 2-methyloxirane undergo ring opening in presence of (a) acid and CH_3OH and (b) CH_3OH and CH_3O^-?

Ans 2-Methyloxirane is cyclic ether. Oxiranes undergo easy ring opening due to the release of the strong angle strain that is present in the three-membered ring. However in acid and basic conditions, the mode of ring opening is different. In case of acid catalysed ring opening, the ring opening takes place through the formation of the more stable carbocation. However, in case base catalysed ring opening, the reaction is like S_N2 type displacement and attacks take place on the less hindered carbon centre. For this reason, we get isomeric compounds. Mechanisms are shown here.

Acid catalysed ring opening:



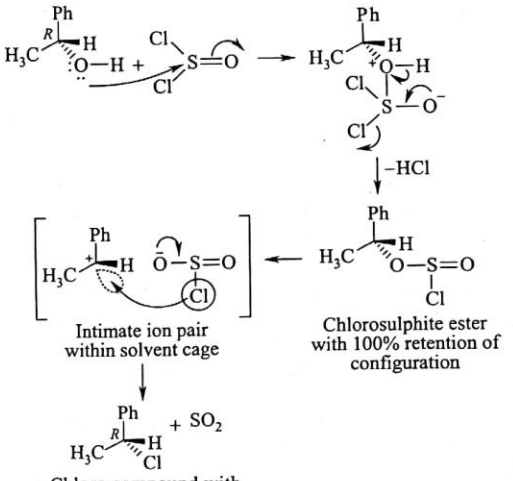
Base catalysed ring opening:



5.6 What happens when (*R*)-PhCH(OH)CH_3 is separately treated with (a) $SOCl_2$ in ether and (b) $SOCl_2$ in pyridine. Give the mechanism of the reaction using sawhorse structures.

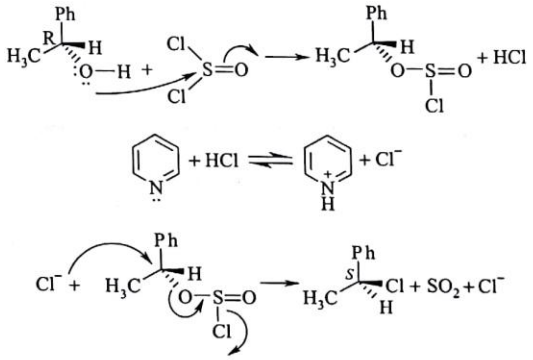
Ans The mechanism is as follows:

(a) When the reaction between (*R*)-PhCH(OH)CH_3 and SOC_2 is carried out in ether medium then we get the corresponding chloro compound with 100% retention of configuration. Reaction occurs through intimate ion-pair in solvent cage. The whole process can be shown as follows.



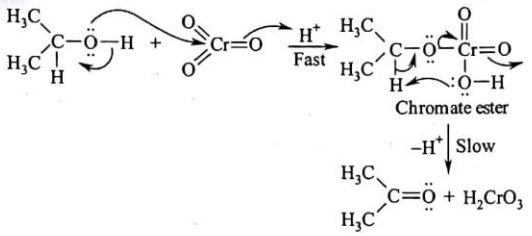
The formation of the intimate ion-pair is supported by the fact that the solution of the chlorosulphite ester is conducting and when isotopically labelled chloride ion is present in the reaction medium, no incorporation of the isotopically labelled chlorine takes place. The carbocation in ion-pair gets no chance to collapse into its planar form.

(b) When the solvent is changed to a basic solvent like pyridine, the HCl produced initially during the formation of chlosulphite ester, reacts with the basic solvent to produce a large concentration of chloride ion. This enhanced concentration of the Cl^- initiates S_N2 type displacement reaction and finally a chloro compound is formed with 100% inversion of configuration. The reaction is shown here.

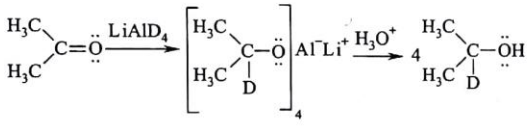


5.7 Me_2CDOH and Me_2CHOH can be used to predict the rate limiting step of oxidation by CrO_3 in CH_3COOH. Illustrate this statement. How will you obtain Me_2CDOH?

Ans The mechanism of the oxidation of an alcohol by CrO_3 and acid can be shown as follows.

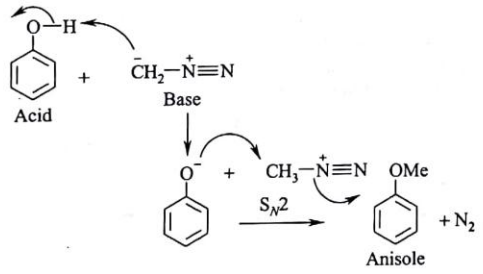


In the aforementioned reaction, if Me_2CDOH is taken instead of Me_2CHOH, the rate of the reaction is found to be much slower, that is, $K_H/K_D > 4$. This confirms that the reaction shows primary kinetic isotope effect. Consequently, it can be concluded that the rate determining step of the reaction is the cleavage of the C—H bond of the chromate ester as shown above. Formation of the chromate ester step is fast. Me_2CDOH can be prepared as follows.

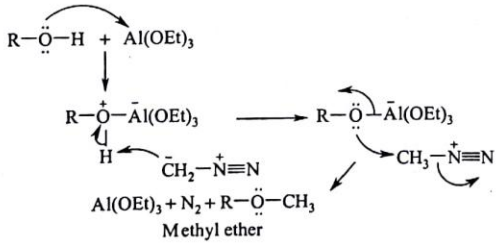


5.8 Alcohols, unlike phenols, require suitable catalyst for methylation by diazomethane. Explain.

Ans *O*-Methylation of phenol can be done with diazomethane (CH_2N_2) easily in ether medium because H atom of the OH group is sufficiently acidic to be taken up by the diazomethane as base. The total reaction can be shown as follows.

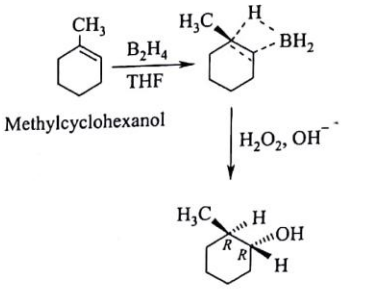


Hydrogen atom of OH group of alcohols are not to acidic to react with weak base like diazomethane. Therefore, the acidity of alcohols is to be enhanced to carry out *O*-methylation to get methyl ether. This is done by using Lewis acid like $Al(OEt)_3$. The course of the reaction is shown here.

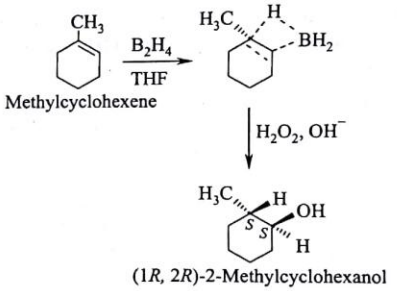


5.9 Demonstrate by an example that hydroboration–oxidation method of preparation of an alcohol from an alkene is stereoselective as well as regioselective.

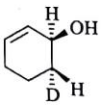
Ans Following is the necessary example.



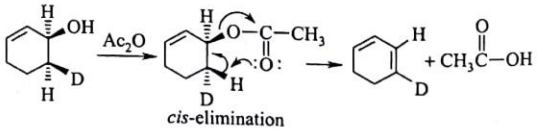
Or



5.10 The following alcohol gives a conjugated cycloalkadiene in which 100% deuterium is retained. Give the necessary reaction with explanation.

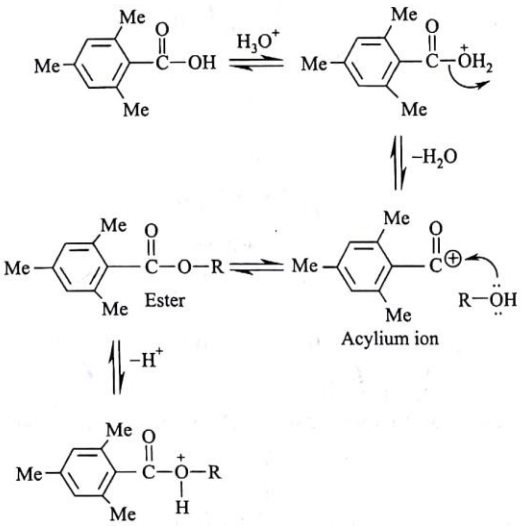


Ans Conjugated cycloalkadiene with 100% retention of deuterium is possible if we can carryout *cis*-elimination. The method involves the conversion of the alcohol to its corresponding acetate and then subject the acetate to pyrolysis.



5.11 Acid catalysed esterification of 2,4,6-trimethylbenzoic acid and trimethylacetic acid follow the same mechanism. Give the mechanism with explanation.

Ans The mechanism is known as $A_{AC}1$.



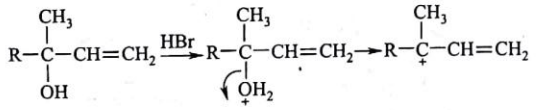
The same type of mechanism is observed in the case of $(CH_3)_3C{-}COOH$ (trimethylacetic acid).

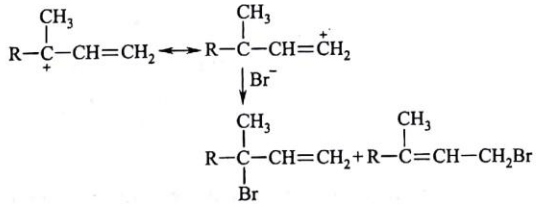
5.12 The following two alcohols give the same bromo compound when treated with HBr. Explain.

(a) $R{-}C(CH_3)(OH){-}CH{=}CH_2$ **(b)** $R{-}C(CH_3){=}CH{-}CH_2OH$

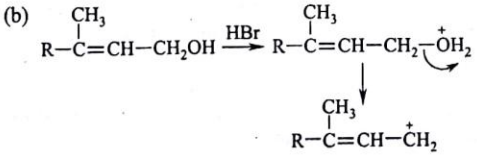
Ans The reaction in each case proceeds according to S_N1' mechanism. The course of the reaction is shown here.

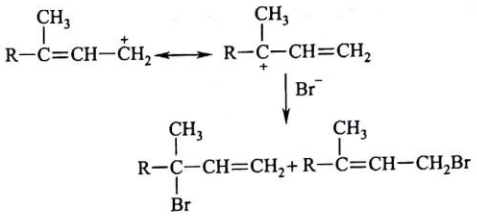
(a)





(b)





5.13 What reagents could you use for the following conversions?

(a) $MeCO(CH_2)_2CO_2Et \longrightarrow MeCO(CH_2)_2CH_2OH + EtOH$

(b) $MeCO(CH_2)_2CO_2Et \longrightarrow MeCHOH(CH_2)_2CO_2Et$

(c) $HO_2C(CH_2)_4COCl \longrightarrow HO_2C(CH_2)_4CH_2OH$

(d) $O_2N(CH_2)_3CH{=}O \longrightarrow O_2N(CH_2)_3CH_2OH$

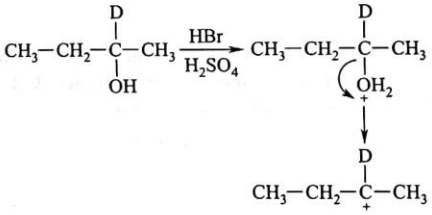
Ans The necessary reagent in each case is given here.

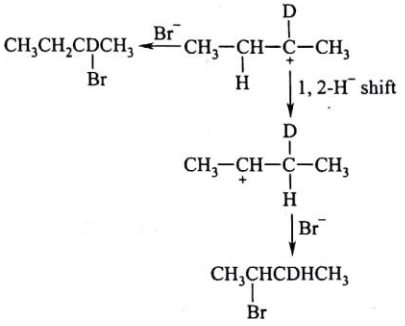
(a) Protection of C=O group and $LiAlH_4$ (c) $NaBH_4$

(b) $NaBH_4$ (d) $LiAlH_4$/pyridine

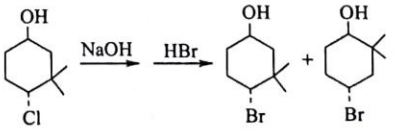
5.14 A student attempted to prepare $CH_3CH_2CDBrCH_3$ by treating $CH_3CH_2CDOHCH_3$ by HBr and H_2SO_4 but analysis of the reaction products showed that actually, a mixture of $CH_3CHDCHBrCH_3$ and $CH_3CH_2CDBrCH_3$ was obtained. Provide an explanation.

Ans The following rearrangement leads to a mixture of compounds.

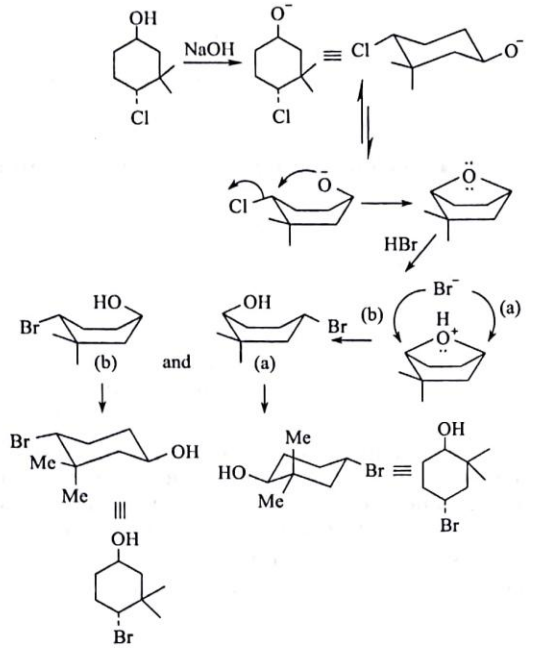




5.15 Provide a mechanistic rationalization for the following reaction course.

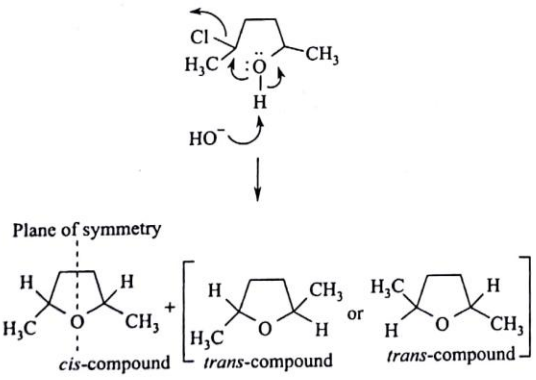


Ans This transformation can be accounted for if we consider the following mechanism.

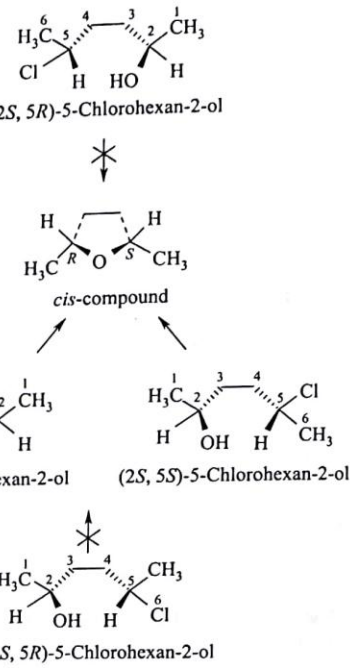


5.16 Optically active 5-chloro-hexan-2-ol is allowed to react with KOH in methanol. The product, $C_6H_{12}O$ is found to be inactive. Explain the reaction.

Ans The reaction can be shown as follows.

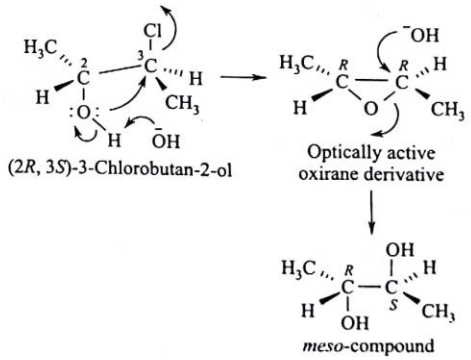


The starting compound was optically active. It was not racemic. So, if the *trans* isomer had been formed, it would not have been racemic. However, the product obtained is inactive and is sure to be *meso* isomer. Therefore, the product is *cis* isomer. This means that the starting material was either (2*R*, 5*R*)-5-Chlorohexan-2-ol or (2*S*, 5*S*)-5-Chlorohexan-2-ol, and not the (2*R*, 5*S*) or (2*S*, 5*R*)-isomers.



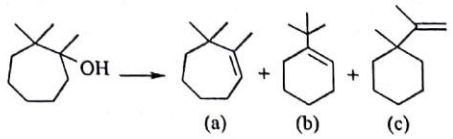
5.17 Optically active (2*R*,3*S*)-3-chlorobutan-2-ol is allowed to react with NaOH in ethanol when an optically active oxirane is formed. Reaction of the oxirane with KOH in water medium gives butane-2,3-diol. What is the stereo-structure of the diol? Comment on the optical activity of the diol.

Ans The course of the reaction can be shown as follows.

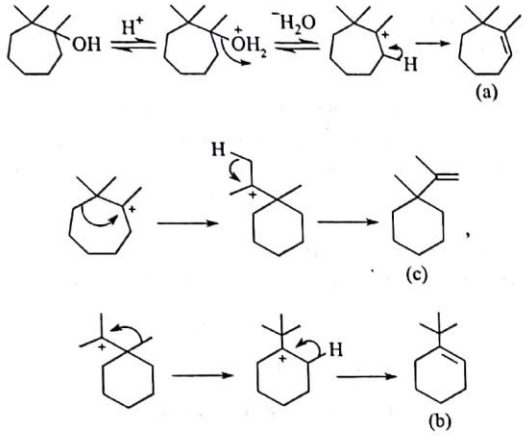


During the formation of the oxirane derivative, inversion of configuration has taken place at the centre bearing the chlorine atom. During hydrolysis of the oxirane, another inversion of configuration has taken place at the same centre. Consequently, the final product is optically inactive *meso*-compound. It is to be noted that we get the same result if during the hydrolysis of the oxirane, the attack by hydroxide ion takes place on the other carbon.

5.18 Write a mechanism of the following transformation.

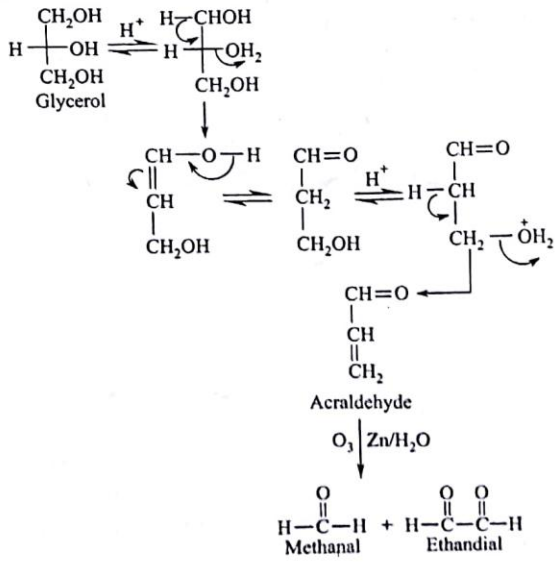


Ans Mechanism of the given transformation can be shown as follows.



5.19 Glycerol, on treatment with H_2SO_4 gives a compound C_3H_4O which on ozonolysis gives ethanedial and methanal. Explain the reaction and give the necessary mechanism.

Ans Acid catalysed dehydration of glycerol forms acraldehyde (propenal). This on ozonolysis produces ethanedial and methanal. The mechanism of dehydration of glycerol can be shown as follows.



5.20 What is Lucas reagent? How is it used to distinguish between 1°, 2°, and 3° alcohols?

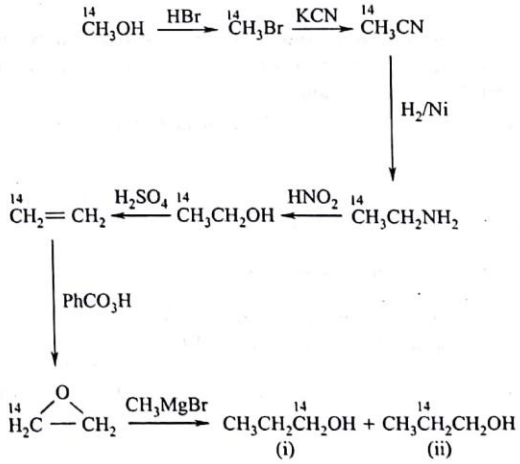
Ans Mixture of anhydrous $ZnCl_2$ and concentrated HCl or (gaseous HCl) is known as Lucas reagent. In the laboratory, the reagent is used to distinguish between saturated liquid 1°, 2°, and 3° alcohols.

A saturated alcohol reacts with HCl in presence of anhydrous $ZnCl_2$ to form the corresponding alkyl chloride which is immiscible with the parent alcohol. Therefore, the mixture appears cloudy. The reactivity of the three classes of alcohols towards the formation of the corresponding alkyl halides with HCl is 3° > 2° > 1°. Thus, when HCl (gas) is passed into a tertiary alcohol in presence of anhydrous $ZnCl_2$, the liquid immediately becomes cloudy, in case of secondary alcohol cloudiness appears after about five minutes. In case of primary alcohol, the reaction is extremely slow and takes a very long time to show the cloudiness.

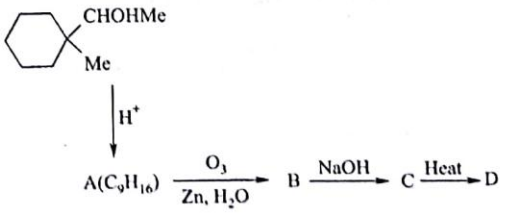
$$ROH + HCl \xrightarrow{ZnCl_2} RCl + H_2O$$

5.21 How can you transform $^{14}CH_3OH$ to (a) $CH_3CH_2{}^{14}CH_2OH$ and (b) $CH_3{}^{14}CH_2CH_2OH$. You can use reagents of your choice.

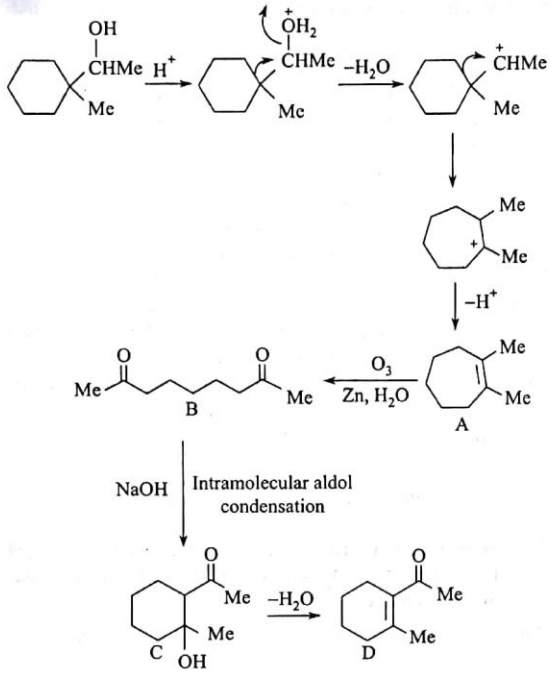
Ans A plausible method can be outlined as shown here.



5.22 Identify the compound (A), (B), (C), and (D) in the following reaction.

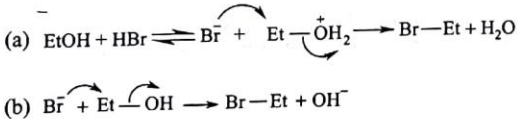


Ans The reactions are shown here.



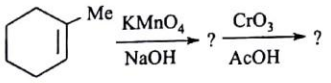
5.23 A concentrated aqueous solution of HBr reacts with EtOH to give EtBr, but a concentrated aqueous solution of NaBr does not. Explain.

Ans We can assume an S_N2 mechanism for the reactions, shown here.

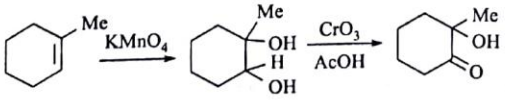


In case of (a), a strong nucleophile, Br^-, displaces a weak nucleophile and good leaving group H_2O. Therefore, the reaction is very facile with low activation energy and takes place readily. In case of (b), the leaving group is $-OH^-$. Now, $-OH^-$ is a strong nucleophile and a poor leaving group. A weaker base normally cannot displace a stronger base and the activation energy would be very high. This is why the reaction between EtOH and NaBr fails to give EtBr.

5.24 Complete the following equation and comment.



Ans The course of the reaction is shown here.



Alkaline permanganate converts a double bond to a *cis*-diol. In the present case, this dihydroxylation produces a secondary and tertiary alcoholic group. Now, CrO_3/AcOH is a comparatively weaker oxidizing group and can oxidize the secondary alcoholic group but cannot oxidize the tertiary alcoholic group. This is why the final product is a α-hydroxy carbonyl compound like acyloin.

5.25 Show that three moles of an alcohol are oxidized to three moles of carbonyl compound by two moles of chromium (VI) reagent.

Ans The reaction of oxidation of an alcohol can be shown as follows.

$$RCH_2OH{=}RCH{=}O + 2H^+ + 2e^-$$

Thus, the oxidation of an alcohol by Cr^{6+} is a two electron process. The equation showing the change in the oxidation state of the oxidizing agent can be shown as follows.

$$Cr^{6+} + 3e = Cr^{3+}$$

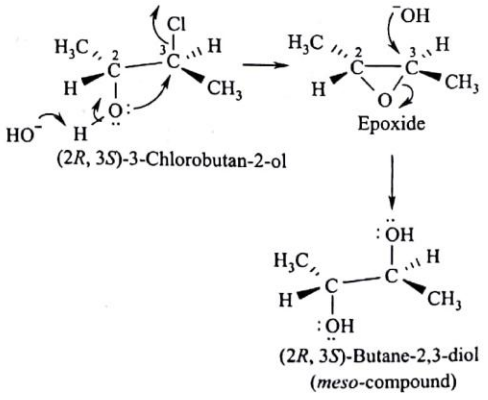
Now adding the two half-reactions together and multiplying these with appropriate factors to cancel the electrons, we get:

$$3 \times [RCH_2OH{=}RCH{=}O + 2H^+ + + 2\bar{e}]$$
$$2 \times [3\bar{e} + Cr^{6+} = Cr^{3+}]$$
$$\overline{3\,RCH_2OH + 2Cr^{6+} = 3\,RCH{=}O + 6H^+ + 2Cr^{3+}}$$

As shown, three moles of alcohol are oxidized by two moles of Cr^{6+} reagent.

5.26 Optically active (2*R*,3*S*)-3-chlorobutan-2-ol is allowed to react with NaOH in ethanol to give an optically active oxirane, which is treated with potassium hydroxide in water to obtain butane-2,3-diol. What is the stereo-structure of the diol? What can you say about its optical rotation?

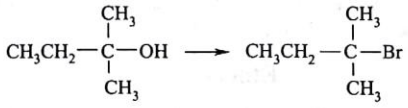
Ans (2*R*,3*S*)-3-chlorobutan-2-ol is a halohydrin and reacts with NaOH to form an epoxide. Epoxide then reacts with KOH to form butane-2,3-diol. The final product is a *meso*-compound. The course of the reaction is shown here.



The same result is obtained when OH— reacts with C-2 position of the epoxide.

5.27 Give the best conditions for carrying out the following transformation.

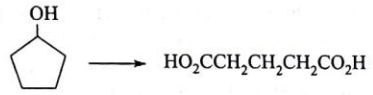
(a)



(b) $CH_3CH_2CH{=}CH_2 \longrightarrow CH_3CH_2CH(OH){-}CH_2OH$

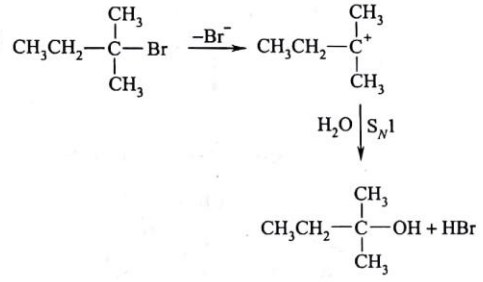
(c)

(d)

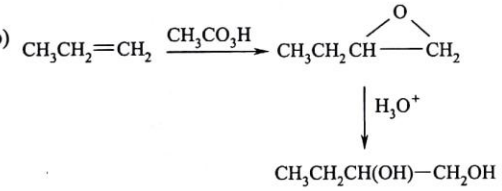


Ans The necessary reactions are given here.

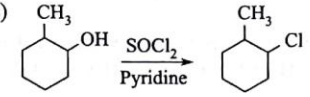
(a)



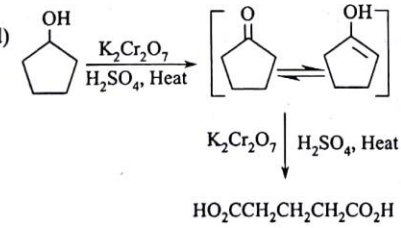
(b)



(c)

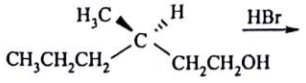


(d)

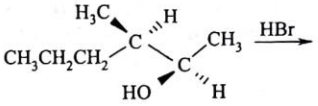


5.28 Which of the following reactions give(s) resolvable products? Justify your answer.

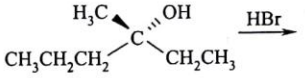
(a)



(b)

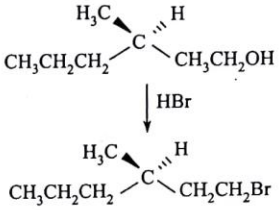


(c)



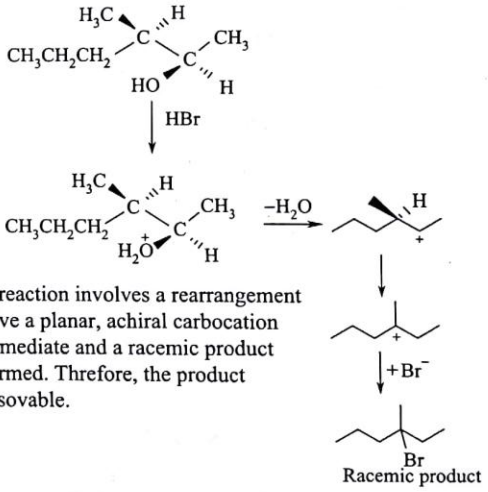
Ans

(a)



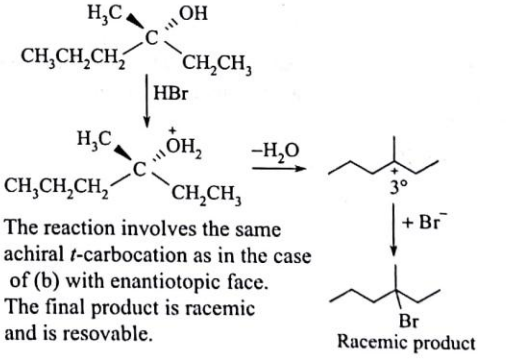
The stereocentre is not involved in the reaction. The configuration is retained and the product is optically active.

(b)



The reaction involves a rearrangement to give a planar, achiral carbocation intermediate and a racemic product is formed. Threfore, the product is resovable.

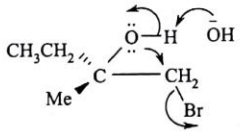
(c)



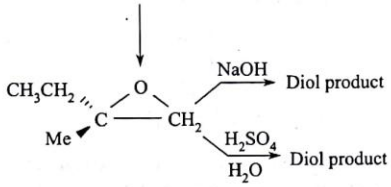
The reaction involves the same achiral *t*-carbocation as in the case of (b) with enantiotopic face. The final product is racemic and is resovable.

5.29 (*S*)- 1-Bromo-2-methylbutan-2-ol is converted to an optically active epoxide with dilute NaOH, as depicted here. The epoxide ring can be cleaved either in strong

base or in acid to give diol products. What is difference (if any) between the products formed by the acidic and basic hydrolysis conditions? Write a step by step mechanism to explain any differences you expect to observe.

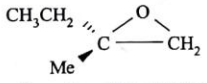


(*S*)-1-Bromo-2-methylbutan--2-ol

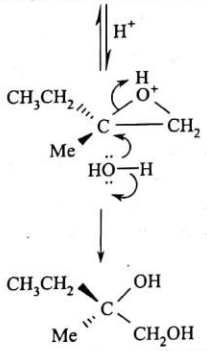


Ans The courses of the reactions are shown here.

Acidic hydrolysis:



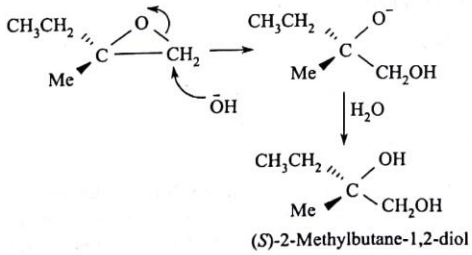
(*S*)-configuration of the chiral centre.



(*R*)-2-Methylbutane-1,2-diol

The acid-catalysed cleavage process favours cleavage via a stable carbocation-like intermediate and the inversion occurs at the tertiary centre.

Basic hydrolysis:



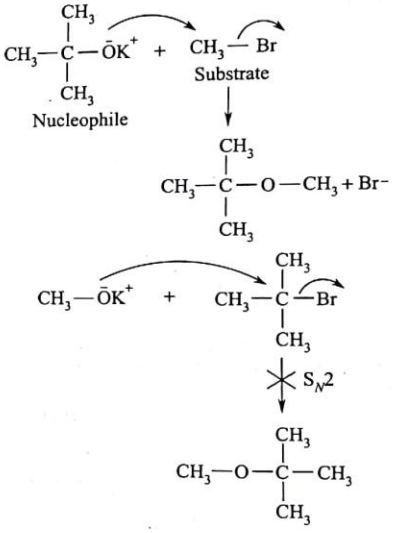
(*S*)-2-Methylbutane-1,2-diol

The mechanism of the basic hydrolysis is like the S_N2 mechanism and the nucleophilic attack by OH^- takes place at the less hindered carbon centre. This leads to the enantiomer of the product obtained by acid hydrolysis.

Ethers

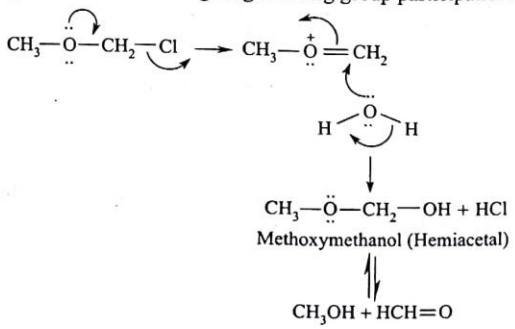
5.1 Shown here is the synthesis of $(CH_3)_3C{-}O{-}CH_3$ by Williamsons' method. Use either the reaction of (a) methyl bromide and K-*t*-butoxide or (b) *t*-butyl bromide and K-methoxide. Indicate a route of your choice with reasoning.

Ans The reaction involving an alkyl halide and an alkoxide to form ether is a S_N2 substitution. In S_N2 substitution, tertiary halides fail to undergo substitution because a nucleophile can not approach from the rear side due to steric interaction. It should be noted that rate is not dependent on the bulk of the nucleophile. For this reason, the first procedure is a better choice for the production of methyl-*t*-butyl ether (MTBE).

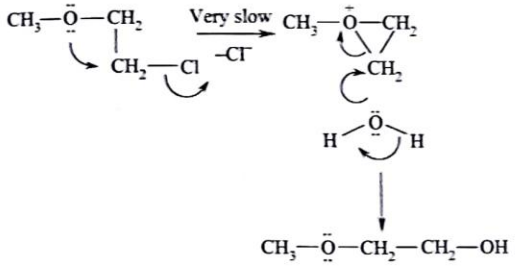


5.2 Methyl chloromethyl ether is readily hydrolysed by water to HCH=O and CH_3OH but $CH_3OCH_2CH_2Cl$ does not. Explain.

Ans Methyl chloromethyl ether is hydrolysed by the following mechanism involving neighbouring group participation.

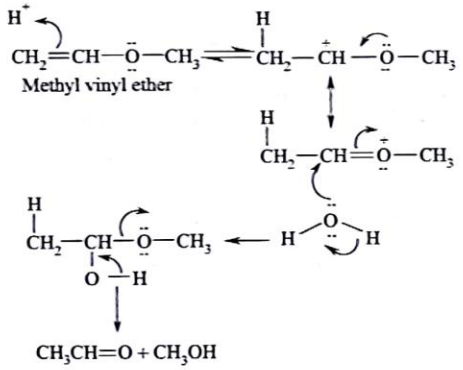


In case of $CH_3OCH_2CH_2Cl$, similar neighbouring group participation requires an intermediate strained three membered ring system. Obviously, the activation energy of formation of this strained intermediate would be very high and the reaction rate is extreme slow.



5.3 CH_2=CHOCH$_3$ can be readily cleaved by dilute acids to a mixture of a carbonyl compound and an alcohol but $CH_3CH_2OCH_3$ does not. Explain and give the mechanism.

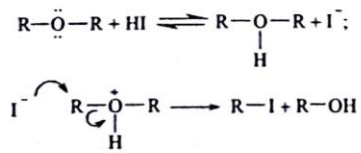
Ans Vinylic ethers undergo ready hydrolysis through C-protonation. *C*-protonated form is further stabilized by delocalization involving lone pair of electrons on the oxygen atom. The mechanism can be shown as follows.



$CH_3CH_2OCH_3$ type of ethers cannot be hydrolysed by dilute acid because no *C*-protonation is possible and *O*-protonated form is rapid and reversible.

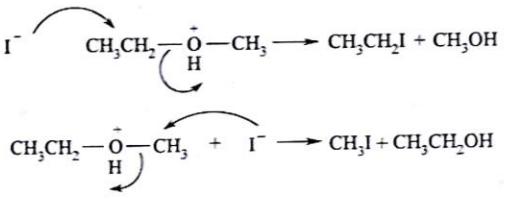
5.4 Ethers like ROR can be cleaved by concentrated HI but not by HCl. Explain.

Ans The cleavage of ether by a halogen hydracid is eventually a S_N2 type displacement where halide ion acts as a nucleophile. Since I^- is a very strong nucleophile compared to Cl^-, reaction easily occurs when HI is used and not by HCl. The course of the reaction is shown here.



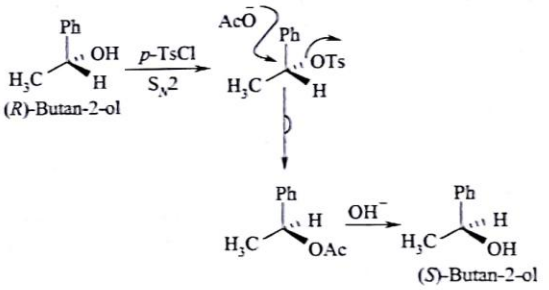
5.5 When $CH_3CH_2OCH_3$ is treated with concentrated HI, four products are obtained. What are they? Explain.

Ans Since the ether is an unsymmetrical one, cleavage through nucleophilic attack by I^- takes in two different ways leading to the formation of four products. The course of the reaction is shown here.



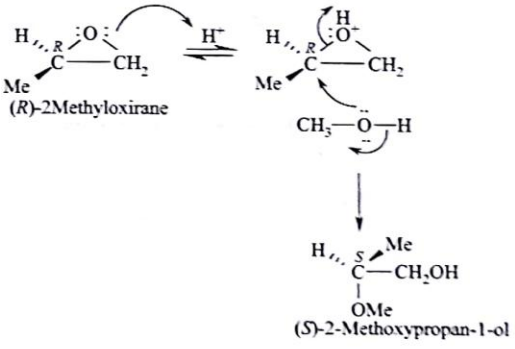
5.6 Convert (*R*)-Butan-2-ol to (*S*)-butan–2-ol.

Ans It is a case of stereomutation and the conversion can be made by the following method.

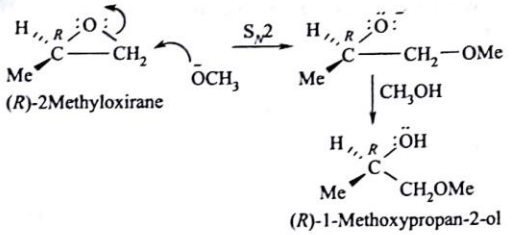


5.7 (*R*)-2-Methyloxyrane gives isomeric methoxy alcohols when separately treated with NaOEt/CH3OH and CH_3OH/H^+. Give the products with mechanism. Discuss the stereochemistry of the products.

Ans The acid catalysed reaction is shown here.



The nucleophilic attack by CH_3OH on the protonated intermediate occurs on the more stable incipient secondary carbon atom. Since the attack takes place from the opposite face of the oxide ring, inversion of configuration takes place as the chiral centre of the parent oxirane derivative and the product is (*S*)-2-Methoxypropan-1ol. The base catalysed reaction is given as follows.



In this case, a direct S_N2 reaction takes place and the attack by CH_3O^- occurs on the less hindered carbon of the epoxide. The product is (*R*)-1-methoxypropan-1-ol. In this case, no change in the absolute configuration of the chiral centre of the parent oxirane derivative because no bond attached to the chiralcentre has been cleaved during the reaction.

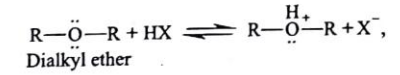
5.8 Epoxides are cleaved by dilute hydrochloric acid but dialkyl ethers do not. Account for these observations.

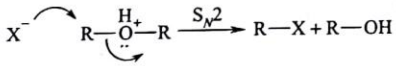
Ans Epoxides are cyclic ethers and because of its cyclopropane like structure, the ring is highly strained and its ground state energy is high and requires less activation energy to reach its transition state. Therefore, it undergoes reaction under milder condition to release its strain, even under the mild condition of dilute acid.

In case of dialkyl ethers, the compounds are very stable and its ground state energy level is low. Consequently, it requires larger amount of activation energy to react. This is why, it does not react under mild condition of dilute acid.

5.9 Dialkyl ethers are most easily cleaved by concentrated HI and less easily by HBr or HCl. Offer an explanation.

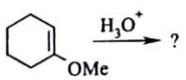
Ans Halogen hydracid catalysed cleavage of dialkyl ethers occur according to the mechanism shown here.



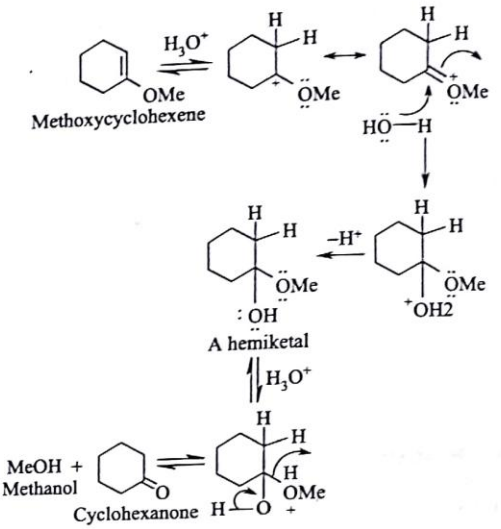


In the second step of the reaction, S_N2 type displacement reaction occurs where halide ion is the necessary nucleophile. Now, among the halide ions, the increasing order of nucleophilicity is $I^- > Br^- > Cl^- > F^-$. Since the source of these halide ions in this case is the corresponding halogen hydracids, the reactivity order is HI > HBr > HCl.

5.10 Give the products and mechanism of the following reaction.

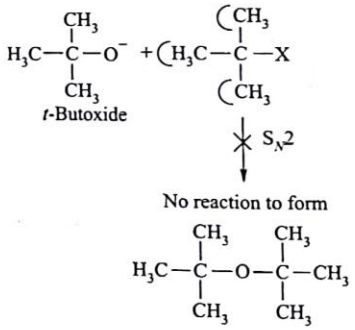


Ans The course of the reaction is shown here.

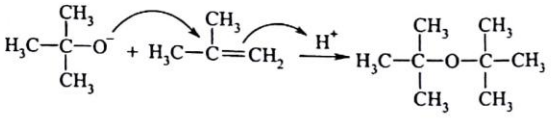


5.11 Can you synthesize $(CH_3)_3C{-}O{-}C(CH_3)_3$ by using Williamson's method. If not, how would you proceed to synthesize $(CH_3)_3C{-}O{-}C(CH_3)_3$?

Ans Williumson's synthesis is a reaction between an alkoxide and alkyl halide in a S_N2 type reaction. In the present case, to get $(CH_3)_3C{-}O{-}C(CH_3)_3$ we need a tertiary butyl alkoxide to react with a tertiary halide. However, tertiary halides do not participate in S_N2 type substitution because of steric factor. Therefore, $(CH_3)_3C{-}O{-}C(CH_3)_3$ cannot be prepared by the Williamson's synthesis.



However, $(CH_3)_3C{-}O{-}C(CH_3)_3$ can be synthesized by slowly adding *t*-butyl alkoxide to a solution isobutylene in acidic medium. The course of the reaction is shown here.



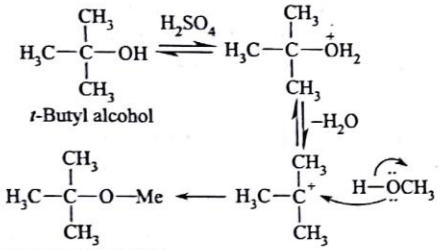
5.12 Why are unsymmetrical dialkyl ethers generally not prepared by heating two different alcohols with sulphuric acid. However, when *t*-butyl alcohol is heated in methyl alcohol containing sulphuric acid, a good yield of *t*-butyl

methyl ether results. Explain this result by means of the reaction mechanism.

Ans When two different alcohols are used to prepare unsymmetrical ether, then a mixture of ethers may be formed.

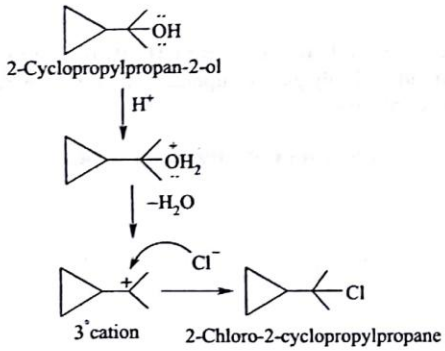
$$R{-}OH + R'{-}OH \xrightarrow[-H_2O]{H_2SO_4} R{-}O{-}R + R'{-}O{-}R' + R{-}O{-}R'$$

However, when a mixture of *t*-butyl alcohol and methyl alcohol is treated in presence of H_2SO_4, *t*-butyl alcohol readily forms the corresponding *t*-butyl cation by dehydration and that carbocation then reacts with methyl alcohol to give the corresponding unsymmetrical ether. The course of the reaction is given here.



5.13 Explain why 2-cyclopropylpropan-2-ol reacts with HCl to give 2-chloro-2-cyclopropylpropane instead of 1-chloro-2,2-dimethylcyclobutane.

Ans Formation of 2-chloro-2-cyclopropylpropane from 2-cyclopropylpropan-2-ol can be shown as follows.

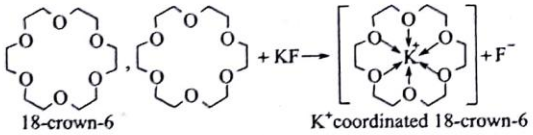


The rearrangement leading to the formation of cyclobutane derivative is not observed in this case because that will lead to the formation of a 2° carbocation which is less stable than the 3° cation, although there is a slight decrease in angle strain.

5.14 (a) 18-Crown-6 is a useful catalyst for the reaction between KF with 1-bromooctane to give 1-fluorooctane. Explain this fact. Do you expect a similar reaction with NaF? (b) What is purple benzene?

Ans

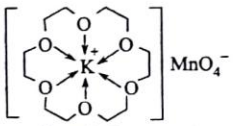
(a) The structure of 18-crown is given here.



$$CH_3(CH_2)_6CH_2Br + F^- \longrightarrow CH_3(CH_2)_6CH_2F$$

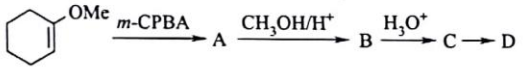
The cavity inside 18-crown-6 is just the right in size for coordination with the K^+ effectively. The diameter of K^+ ion is 2.66 Å. The Na^+ is smaller (diameter = 1.96 Å) and it is not coordinated so tightly. Therefore, 18-crown-6 solubilises potassium salts much more effectively than sodium salt. Thus, reaction between KF and 18-crown-6 produces large concentration of fluoride ions in non polar solvent (substrate itself) which acts as a good nucleophile to displace bromine from 1-bromooctane. Reaction is shown in the aforementioned diagram.

(b) When 18-crown-6 is dissolved in benzene and then small amount of $KMnO_4$ is added then $KMnO_4$ dissolves in benzene to give it a purple colour. This is called 'purple benzene'. The structure of the coordinated compound is given here.

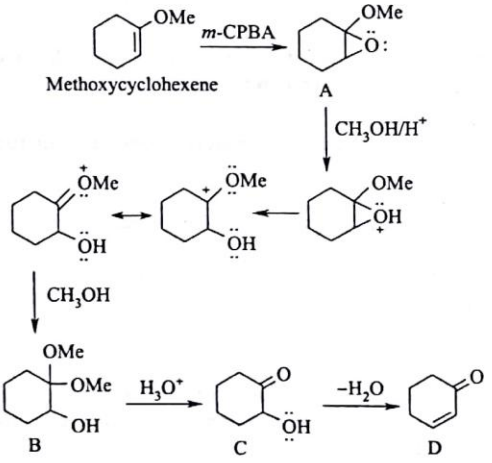


K^+ coordinated 18-crown-6
(In benzene solution)

5.15 Identify the products in the following sequence of reactions.

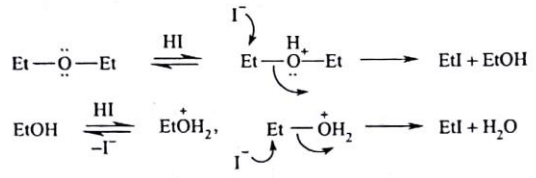


The course of the reaction and products are shown here.



5.16 Prolonged reaction of diethyl ether with excess of HI gives ethyl iodide. Write out the reaction mechanism.

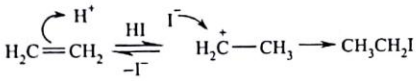
Ans The mechanism is given here.



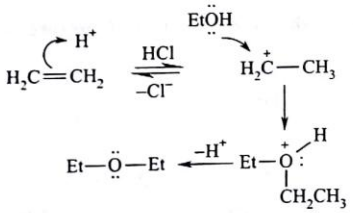
Thus, the final products are ethyl iodide and water.

5.17 The reaction between HI and C_2H_4 in EtOH gives predominantly EtI, whereas the reaction with HCl under the same conditions give predominantly Et_2O, Explain.

Ans The reaction between HI and C_2H_4 gives predominantly EtI and water, In this case, I^- is much more strong nucleophile compared to EtOH, and consequently, formation of Et_2O does not take place. The reaction is shown here.



When HCl is used in EtOH medium, an ethyl cation is formed and the medium contains Cl^- and EtOH as nucleophiles. Now, nucleophilicity of EtOH is comparable to Cl^- and its concentration is greater. Therefore, EtOH reacts preferentially to give EtO_2 as the major product.



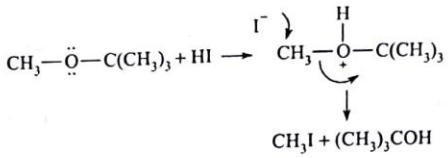
5.18 Give six types of ethers that cannot be synthesized by the typical Williamson ether synthesis.

Ans These are as follows:

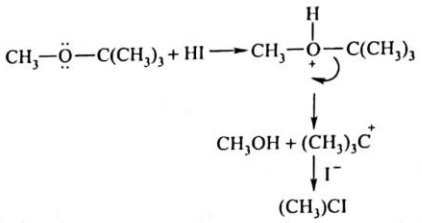
(a) $HR_2C-O-CR_2H$, both the alkyl groups are secondary.
(b) $HR_2C-O-CR_3$, one group is secondary and the other is tertiary.
(c) $R_3C-O-CR_3$, both the groups are tertiary.
(d) Ar–O–Ar
(e) RCH=CH–O–CH=CHR′, vinyl halides do not undergo nucleophilic displacement reaction(S_N2).
(f) $R_3CCH_2-O-CH_2CR'_3$, neopentyl type halides are inert to S_N2 reactions.

5.19 $(CH_3)_3C-O-CH_3$ reacts with HI in anhydrous condition and in aqueous condition to give different sets of products. Explain.

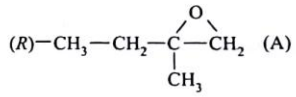
Ans In anhydrous condition, the reaction proceeds according to S_N2 pathway where nucleophilic I^- attacks the least hindered carbon centre. The products are *tertiary*-butyl alcohol and methyl iodide.



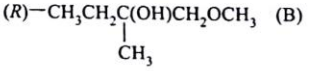
When the reaction is carried out with concentrated HI having some water in the reaction medium), the reaction proceeds according to S_N1 reaction because H_2O is more polar solvent. The reaction produces a very stable carbocation by initial ionic cleavage along with methanol. The *t*-carbocation reacts with I^- to give *t*-butyl iodide.

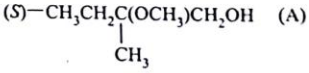


5.20 Explain the following observations.



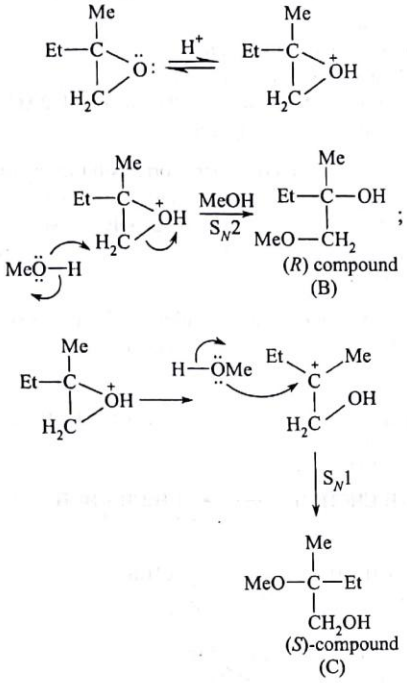
The compound (a) reacts with CH_3OH in acid to give a mixture of optically pure compounds (b) and (c) with very little racemization.



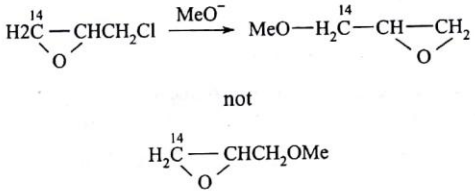


Ans The compound (B) is formed by S_N2 reaction on the less substituted carbon of the epoxide. Since no bond attached to the chiral centre is involved in the reaction, there is no change in the configuration of the chiral centre and the product has (*R*)-configuration. The compound (C) arises from an S_N1 ring opening to give a stable 3° carbocation which undergoes bonding almost exclusively from the back side. This occurs because OH group has not moved out of the way and blocks approach from the front side. Probably, a weak hydrogen-bond is present in the transition state and compelled backside attack by the nucleophile. Finally, we get inversion of

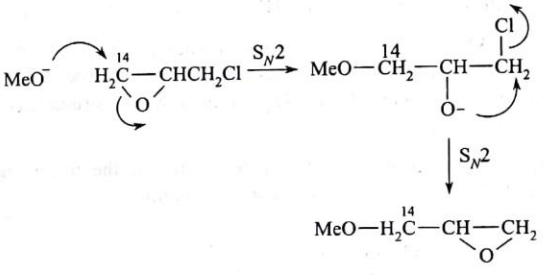
configuration at the chiral centre in the product and the abosolute configuration of the product is (*S*). The course of the reaction is shown here.



5.21 Account for the following observation.



Ans This not a direct Williamson synthesis of an ether. The reaction is initiated by a ring opening through a nucleophilic attack by MeO^- and this is followed by another intramolecular nucleophilic substitution resulting into another epoxide. The sequence of reactions is shown here.



EXERCISES

5.1 Draw the structures and IUPAC names of the isomeric 2° heptanols containing one methyl side chain.

5.2 What is Lucas reagent? How is it used to distinguish three classes of alcohols?

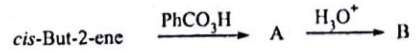
5.3 Alcohols are neutral towards alkali but readily forms alkoxides with alkali metals such as Na and K. Offer an explanation.

5.4 Potassium *t*-butoxide is a widely used base in organic reactions but the corresponding sodium compound is unknown. Give reason.

5.5 The dehydration of *n*-BuOH with acid gives two isomeric alkenes. What are they? Which one would be the major compound?

5.6 What are three isomeric alcohols having the molecular formula $C_4H_{10}O$? Which of them will react first when a mixture of them is treated with one equivalent of acetic acid?

5.7 Identify the compounds A and B in the following reactions. Comment on the stereochemical aspects where necessary.



5.8 How can you use CH_3CH_2OH to get CH_3CH_2OD and CH_3CH_2D?

5.9 How can you convert $(CH_3)_3CCH{=}O$ to neopentyl alcohol using HCH=O as reducing agent?

5.10 What are the compounds formed when vapour of each of the following compounds is passed through the hot copper tube? (a) Butan-1-ol, (b) Butan-2-ol (c) 2-Methylbutan-2-ol.

5.11 Describe the action of an oxidizing agent on primary, secondary, and tertiary alcohols.

5.12 Write down the action of the following reagents on ethyl and isopropyl alcohol.

(a) Na
(b) $POCl_3$
(c) Hot H_2SO_4
(d) CH_3COOH in presence of a few drops of H_2SO_4
(e) CH_3COCl

5.13 How can you distinguish between (a) methanol and ethanol (b) propan-1-ol and propan-2-ol.

5.14 Outline the synthesis of each of the following compounds:

(a) Methanol from carbon monoxide
(b) Ethanol from ethylene

(c) *sec*-Butyl alcohol from but-2-ene
(d) *t*-Butyl alcohol from isobutene
(e) Ethanol from acetylene
(f) *n*-Butanol from acetylene.

5.15 What are the oxidation products of ethylene glycol, when oxidation is carried out with (a) HNO_3 (b) HIO_4?

5.16 How would you establish the structure of ethylene glycol?

5.17 How is glycerol isolated from oils and fats? How can you establish that glycerol is a trihydric alcohol? Describe the preparation of nitroglycerin and allyl alcohol from glycerol.

5.18 Write the reactions involved in the industrial preparation of glycerol. Mention the necessary reaction conditions.

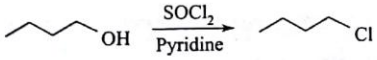
5.19 Write down with equations of the reactions of glycerol with the reagents. (a) HCl (b) HI (c) PCl_5 (d) $KHSO_4$ (e) HIO_4.

5.20 What are the products formed when glycerol is treated separately with dilute nitric acid and hydrogen peroxide-ferrous sulphate solution ($H_2O_2/FeSO_4$). Write down the structures of the products.

5.21 Write equations showing how each of the following alcohols can be prepared from an alkyl halide.

(a) (*R*)-Butan-1-ol-*1*-^2H
(b) 4-Methylpentan-1-ol
(c) 1-Methylcyclohexanol

5.22 Give the mechanism of the following reaction showing the role of pyridine.



5.23 What product is expected when each of the following alcohols is converted into the corresponding alkyl bromide by the sulphonate displacement method?

(a) (*S*)-Pentan-2-ol (b) *cis*-4-Methylcyclohexanol

5.24 Explain why acid-catalysed dehydration of an alcohol is not a suitable method for the preparation of but-1-ene from butan-1-ol. How can you convert butan-1-ol exclusively to but-1-ene?

5.25 Methyl neopentyl ether can be prepared readily from sodium neopentoxide and methyl benzenesulphonate, but not from sodium methoxide and benzenesulphonate. Write equations for these two reactions and explain why one combination works and the other does not.

5.26 Show how the following ethers may be prepared.

(a) 1-Methoxy-1-methylcyclohexane (b) Di-*n*-butyl ether.

5.27 When methyl neopentyl ether is treated with anhydrous hydrogen bromide, an alcohol and an alkyl bromide are produced. What are they? Give the reactions with explanation.

5.28 Write the equation for the reaction of *trans*-2,3-dimethyloxirane with sulphuric acid in methanol. What is the stereostructure of the product?

5.29 Write the structure of 15-crown-5 and 18-crown-6, explaining the method of naming crown ethers.

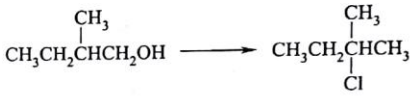
5.30 Explain why each of the following is not a correct name.

(a) 4-Hexanol
(b) 2-Hydroxt-3-methylhexane
(c) 3-(Hydroxymethyl)-1-hexanol
(d) 2-Isopropyl-1-butanol. Give the correct IUPAC name of each of the above compounds.

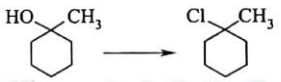
5.31 How many isomeric ethers correspond to the molecular formula $C_5H_{12}O$? Give common and IUPAC names for each structure. Which of these ethers is capable of optical activity? Draw the structures of the two mirror images and show that they are not superimposable.

5.32 Give the reagents and conditions for the best conversions of alcohol to alkyl halide as shown here.

(a) 

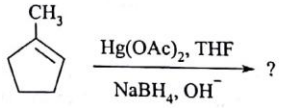
(b) 

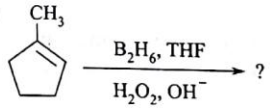
(c) 

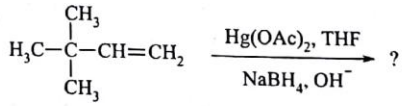
(d) 

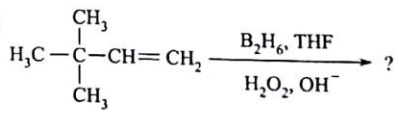
5.33 Explain why 2-cyclopropylpropan-2-ol reacts with HCl to give 2-chloro-2-cyclopropylpropane instead of 1-chloro-2,2-dimethylcyclobutane.

5.34 Give the major product in each of the following reactions.

(a) 

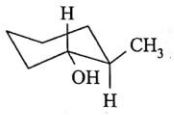
(b) 

(c) 

(d) 

5.35 Show how you might employ hydroboration-oxidation reactions to carryout the following synthesis.

(a) 2-Methylbut-2-ene ⟶ $CH_3CH(OH)CH(CH_3)_2$

(b) 1-Methylcyclohexene ⟶ 

(c) 2-Bromo-2-methylpentane ⟶ $CH_3CH(OH)CH_2CH_2CH_2CH_3$

5.36 Two syntheses of 2-ethoxy-1-phenylpropane shown here give a pair of enantiomers A and B. Explain this result.

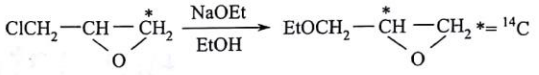
$PhCH_2\overset{*}{C}HCH_3$ (OH) $\xrightarrow[C_2H_5Br]{K}$ $PhCH_2\overset{*}{C}HCH_3$ (OC_2H_5) (A)

$PhCH_2\overset{*}{C}HCH_3$ (OH) $\xrightarrow[C_2H_5OH/K_2CO_3]{TsCl/base}$ $PhCH_2\overset{*}{C}HCH_3$ (OC_2H_5) (B)

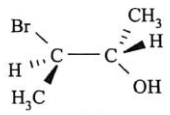
5.37 What is silylation of an alcohol? How this method can be used to carry out the following conversion?

$HOCH_2CH_2CH_2Br \longrightarrow HOCH_2CH_2CH_2CH_3$

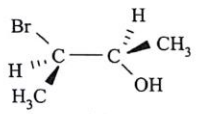
5.38 Explain the following observation.



5.39 When the 3-bromobutan-2-ol with stereochemical structure A is treated with concentrated HBr it yields *meso*-2,3-dibromobutane. A similar reaction of the 3-bromobutan-2-ol with stereochemical structure B gives (±)–2,3-dibromobutane. Propose mechanisms that will account for the stereochemistry of these reactions.



(A)



(B)

5.40 Give stereochemical formulae for H–L in the following reactions.

(a) (*R*)-Butan-2-ol $\xrightarrow{NaH}$ C_4H_9ONa (H) $\xrightarrow{CH_3I}$ $C_5H_{12}O$ (J)

(b) (*R*)-Butan-2-ol $\xrightarrow{MsCl}$ $C_5H_{12}SO_3$ (K) $\xrightarrow{C_2H_5ONa}$ $C_5H_{12}O$ (L)

6 Aliphatic Carbonyl Compounds

6.1 Justify the following statements regarding a carbonyl group with suitable examples.

(a) The group has planar geometry.

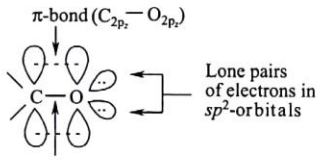
(b) It is a polar group and can function as an acid as well as a base.

(c) Depending on the nature of the carbonyl compound, it can behave as an enantiotopic face or a diastereotopic face.

(d) Carbonyl compounds with α-hydrogen atoms exhibit kinetic acidity to generate a stable carbanion in the presence of strong base.

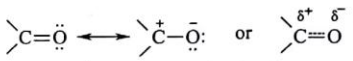
Ans The following are the examples:

(a) One of the bonds of the double bond between carbon and oxygen in the >C=Ö: group is a stable sigma-bond (σ-bond), formed by the overlapping between the sp^2 hybridized orbital of carbon and the sp^2 hybridized orbital of oxygen. The other bond is a weak pi-bond (π-bond), formed by the overlapping of $2p$ orbitals on carbon and oxygen. Since both the carbon and oxygen atom of the >C=O group are sp^2-hybridized, the structure of >C=O group is planar.



Structure of carbonyl group

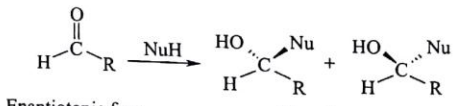
(b) Oxygen is more electronegative than carbon and that is why bonded electron pairs are always near the oxygen atom. This makes the >C=O group to assume some polar character This is why dipole moment of >C=O group is found to be high (2.3–2.8D). The actual structure of carbonyl group is considered to be a resonance hybrid.



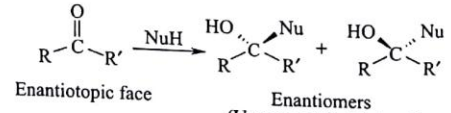
Resonating structures of >C=O group

It is to be noted that in >C=O group, the carbon atom is always the electron deficient centre and therefore, undergoes ready nucleophilic attack. In these reactions carbonyl carbon of $>C^{\delta+}=O^{\delta-}$ accepts a pair of electrons from the nucleophile to form a new covalent bond. In this respect, the >C=O group behaves as an acid (electron acceptor). On the other hand, lone pair of electrons on oxygen atom of >C=O group can accept a cation like H^+ from acidic medium. In this case carbonyl group functions as a base (electron donor).

(c) The carbonyl group in aldehydes and unsymmetrical ketones are enantiotopic and undergo nucleophilic addition reaction to form equimolecular amounts of enantiomers. Carbonyl group of symmetrical ketone is not enantiotopic.

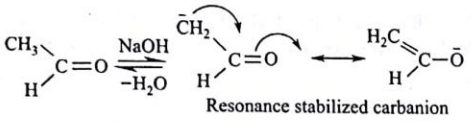


Enantiotopic face (Aldehyde) — Enantiomers



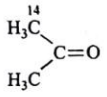
Enantiotopic face — Enantiomers (Unsymmetrical ketone)

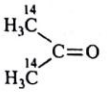
(d) α-hydrogen atom of any carbonyl compound exhibits acidic character although it is attached to an sp^3 carbon. This is because of the fact that the resultant carbanion obtained by the loss of H^+ is stabilized by resonance. This acidic character is exhibited only in the presence of a strong base. This acidity is, therefore, dependent on the bond strength of the C—H bond, that is, a kinetic property.

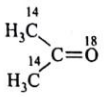


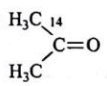
Resonance stabilized carbanion

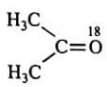
6.2 How can you synthesize the following carbonyl compounds with ^{14}C labelled carbon? You have the freedom of choosing your substrate and reagents and ^{14}C labelled compounds, not more than one carbon.

(a) 

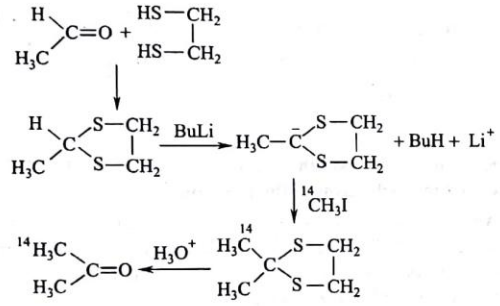
(c) 

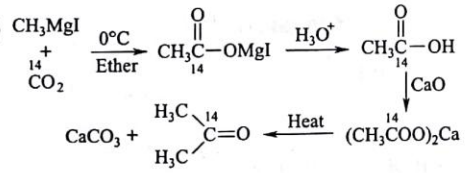
(e) 

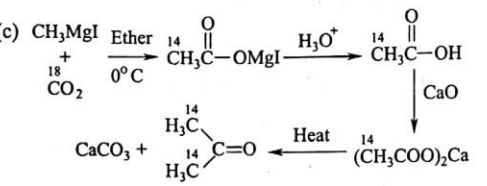
(b) 

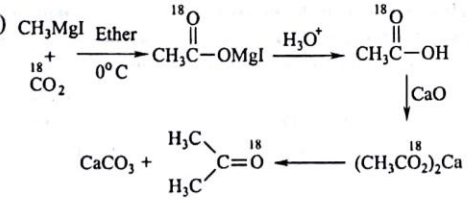
(d) 

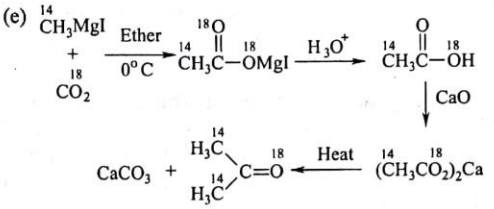
Ans The synthesis of the desired compounds are given here.

(a) 

(b) 

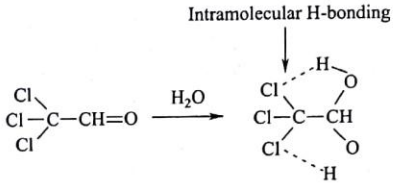
(c) 

(d) 

(e) 

6.3 Why does chloral normally exist as chloral hydrate?

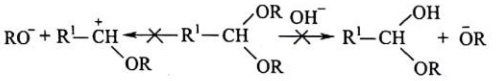
Ans Chloral is trichloroacetaldehyde. It readily forms a stable hydrate because the hydrate can become stabilized by intramolecular hydrogen bonding.



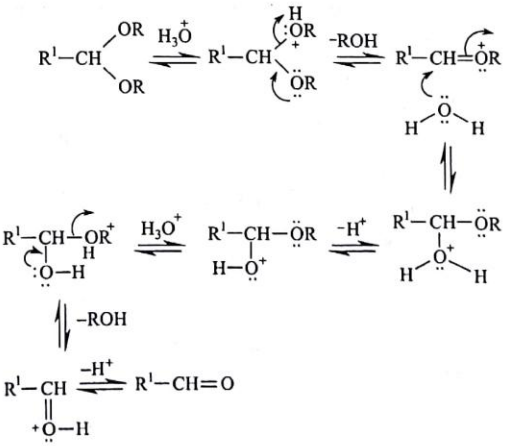
Repulsive forces among the *gem*-chlorine atoms are also minimized through this intramolecular hydrogen bonding.

6.4 Acetals and ketals are stable in alkali but susceptible to acid hydrolysis. Explain.

Ans Acetals are stable in alkali because OH^-, being a comparatively poor nucleophile, cannot displace an alkoxide ion, which is a stronger nucleophile. Moreover, OR^- from an acetal or ketal cannot be lost by itself to generate a carbocation to initiate S_N1-type displacement.



However, in acidic condition acetals and ketals undergo easy hydrolysis to give back the parent carbonyl compound and alcohol. In this case the reaction occurs according to the following mechanism.

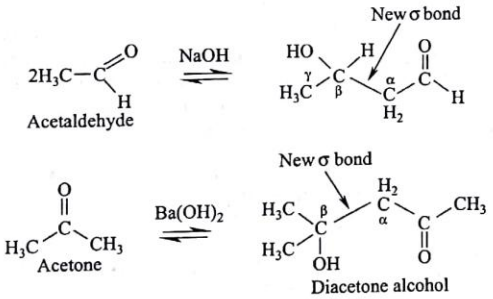


In this case RO^- is first protonated and is transformed into a good leaving group (ROH). The raction is an all-step reversible process.

6.5 When acetaldehyde is treated with a base, aldol is obtained in a fairly good yield but when acetone is treated in the same way, the yield of diacetone alcohol is extremely low. Explain why. How would you improve the yield of diacetone alcohol?

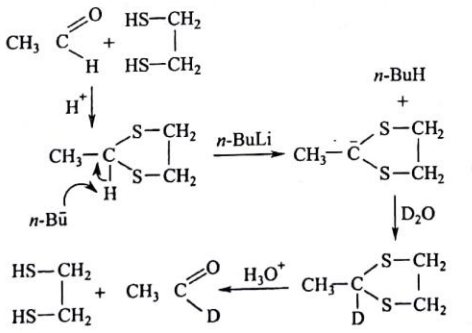
Ans In the presence of acid or base catalysts, the aldol reaction is reversible, and the beta-hydroxy carbonyl products may revert to the initial aldehyde or ketone reactants.

In the absence of such catalysts these aldol products are perfectly stable and isolable compounds. Because of this reversibility, the yield of aldol products is related to their relative thermodynamic stability. In the case of aldehyde reactants (as in the case of acetaldehyde), the aldol reaction is modestly exothermic and the yields are good. However, aldol reactions of ketones (such as in case of acetone) are less favorable and the equilibrium product concentration is small. A unique way of overcoming this disadvantage has been found. A comparatively insoluble base, $Ba(OH)_2$, is used to catalyse the aldol reaction of acetone, and the product is removed from contact with this base by siphoning and recirculation of the low boiling acetone (b.p. 56°C) using a special extractor called Soxhlet.



6.6 How will you get $CH_3CD{=}O$ from $CH_3CH{=}O$?

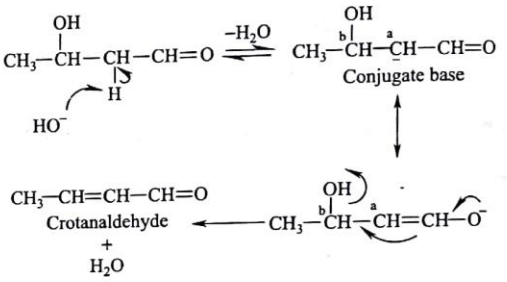
Ans This can be done by carrying out the following umpolung reaction using thioglycol.



6.7 Unlike alcohols, $CH_3CH(OH)CH_2CH{=}O$ can be dehydrated even in the presence of a base. Explain.

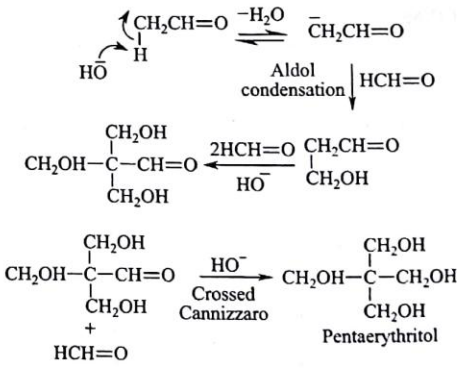
Ans Simple alcohols undergo intramolecular dehydration only in the presence of acid. The alcoholic —OH group gets protonated first and then E2 elimination takes place to give alkene/alkenes.

However, the aldol $CH_3CH(OH)CH_2CH{=}O$ undergoes base-catalysed dehydration through $E1_{CB}$ mechanism. This is possible due to the acidic nature of the α-hydrogen atom along with the presence of a bad leaving group (—OH group) at the β–position. The mechanism of the reaction can be shown as follows.



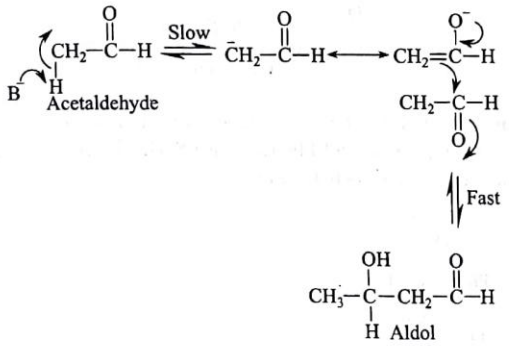
6.8 How can you synthesize $(CH_2OH)_4C$ from $CH_3CH{=}O$? Give the mechanism of the reaction.

Ans This can be done by carrying out a reaction between one mole of $CH_3CH{=}O$ and four moles of $HCH{=}O$ in the presence of a base. The conversion involves both mixed aldol condensation and Cannizzaro reaction.



6.9 How would you demonstrate that the rate determining step of aldol condensation is the formation of a carbanion from the concerned carbonyl compound?

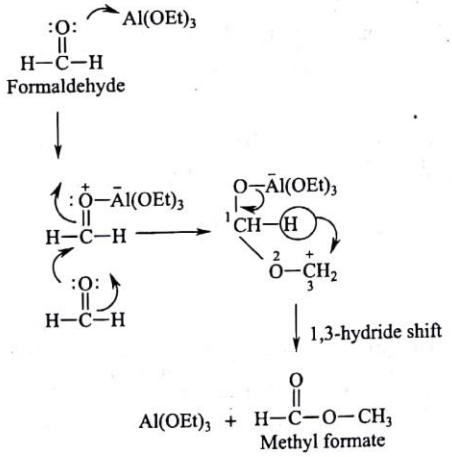
Ans Aldol condensation occurs through the formation of an intermediate carbanion. The mechanism of the reaction can be shown as follows taking acetaldehyde as an example.



In this mechanism, the step pertaining to the formation of the carbanion is the slow step. This is supported by the fact that when $CD_3CH{=}O$ is taken in place of $CH_3CH{=}O$, the reaction shows primary kinetic isotope effect.

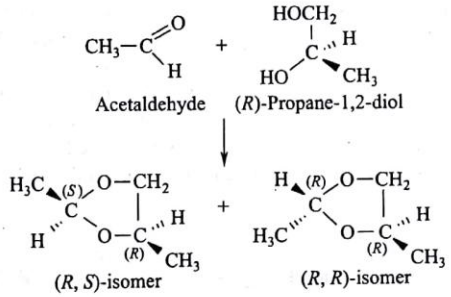
6.10 How can you convert HCH=O to methyl formate in a one-step reaction? Give the mechanism.

Ans The reaction that converts HCH=O to methyl formate in one step is called Tischenko reaction. This is carried out by reacting HCH=O with $Al(OEt)_3$. It could be considered as a variation of Cannizzaro reaction. The course of the reaction can be shown as follows.



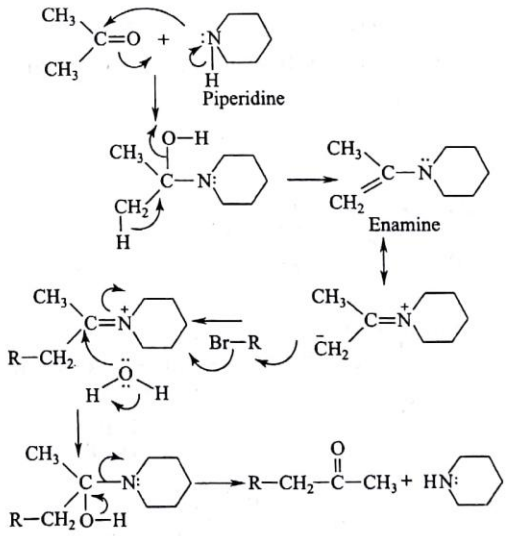
6.11 Acetaldehyde reacts with (*R*)-propane-1,2-diol to give two stereoisomeric products. What are they? Give an explanation.

Ans Acetaldehyde has an enantiotopic *Re*-face as well as *Si*-face to react with a nucleophilic reagent. This reaction is a case of acetal formation and in this case a new chiral centre is created involving the carbonyl carbon of the acetaldehyde. Therefore, the stereoisomers is (*R*,*R*)-isomer and (*R*,*S*)-isomer as shown. They are diastereoisomers.



6.12 Enamine formation of a ketone is a case of simultaneous method of protection of carbonyl group along with the generation of a nucleophilic centre. Explain with an example.

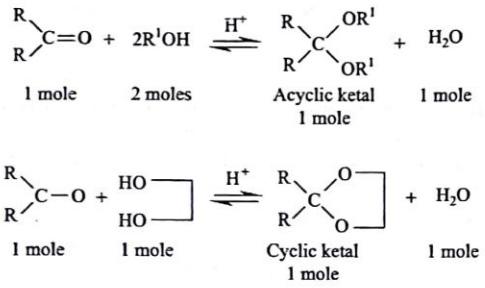
Ans Secondary amines, particularly cyclic ones, react with ketones to form stable enamines. These enamines can react as good nucleophile towards an electrophilic reactant to produce a substituted compound. The carbonyl group of the parent ketone can be regenerated by hydrolysis with dilute acid. Thus enamine formation can lead to substitution on the a-carbon of the ketone as well as a method of protection of the carbonyl group during the course of the reaction. An example is given here.



6.13 Ketones readily form cyclic ketals with $CH_2OH{-}CH_2OH$ but acyclic ketals are difficult to prepare. Explain.

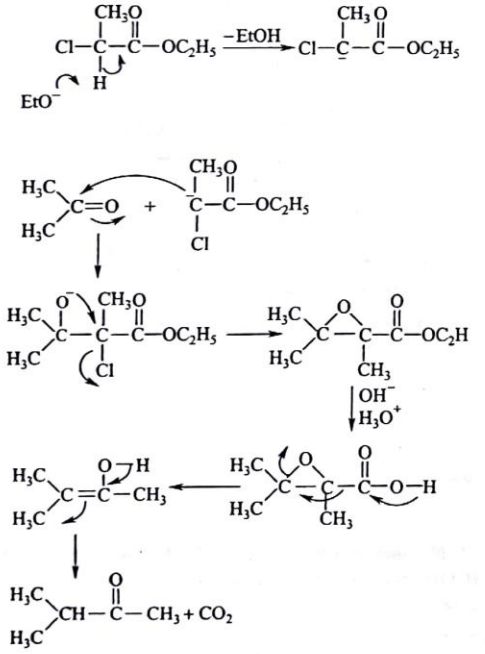
Ans Formations of acyclic and cyclic ketals involve the cleavage and formation of the same number of covalent bonds. Therefore, the enthalpy change has the same value

in both the cases. However in case of cyclic ketal formation, 2 moles of reactants give 2 moles of products but in case of acyclic ketal formation, three moles of reactants give two moles of products, that is, entropy change is negative. Therefore, from the standpoint of entropy factor, cyclic ketal formation is thermodynamically more favoured. This is why we find the difference in the rate of cyclic and acyclic ketal formations.

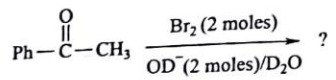


6.14 Convert $(CH_3)_2C{=}O$ to $(CH_3)_2CHCOCH_3$ by a suitable base-catalysed condensation. Give the mechanism.

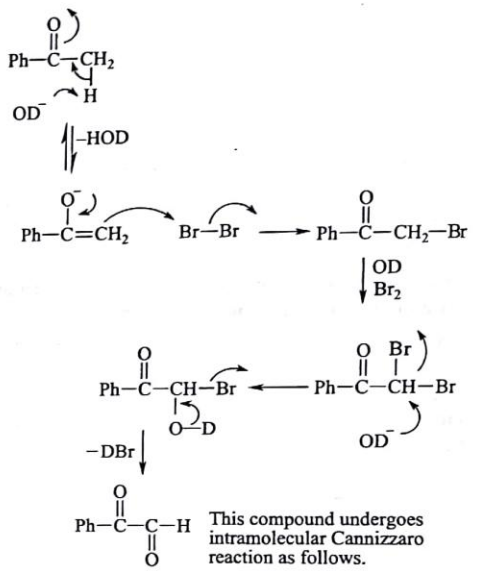
Ans This conversion can be achieved by Darzen's glycidic ester condensation. The course of the reaction is shown here.

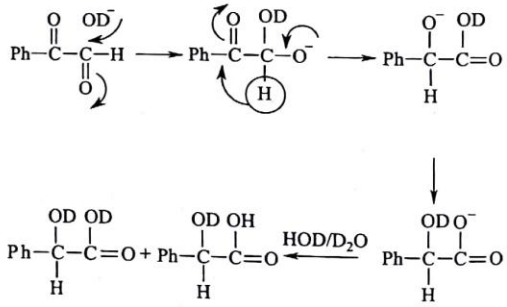


6.15 Write the products and propose the mechanism of the following sequence of reactions.



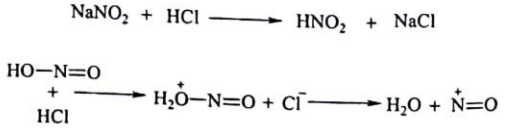
Ans The final product of the whole reaction is a mixture of PhCH(OD)COOD and PhCH(OD)COOH. The course of the reaction can be shown as follows.

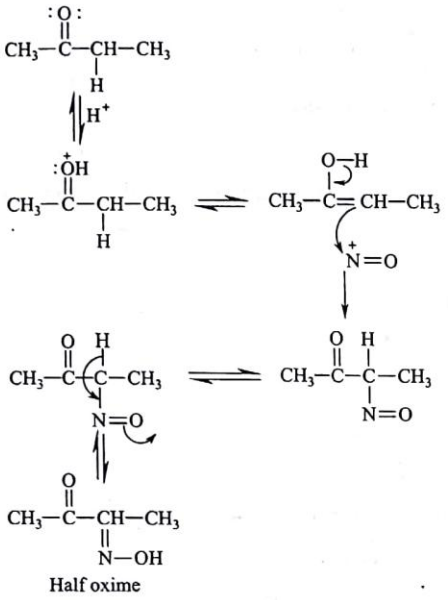




6.16 How can you convert $CH_3CH_2COCH_3$ to its half oxime of the diketone, $CH_3COCOCH_3$.

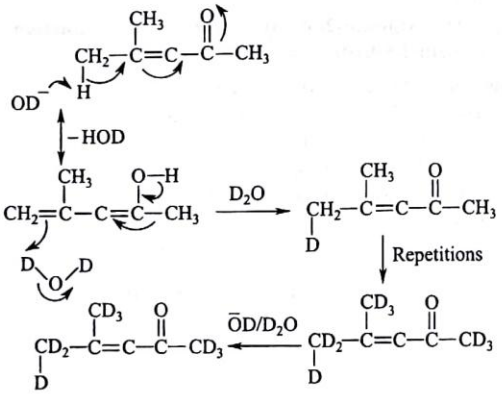
Ans This can be done by reacting the ketone with nitrous acid. The mechanism of the reaction can be shown as follows.



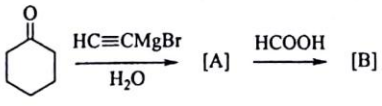


6.17 What happens when mesityl oxide is treated with NaOD in D_2O?

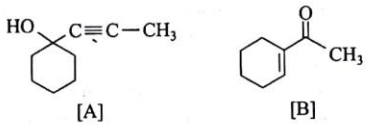
Ans Mesityl oxide has the structure $(CH_3)_2C{=}CHCOCH_3$. When mesityl oxide is treated with $NaOD/D_2O$, all the hydrogen atoms of the CH_3 groups will be replaced by deuterium. Here hydrogen atoms of $(CH_3)_2C{=}$ group are subsituted by deuterium due to vinylogous effect. The course of the reaction can be shown as follows.



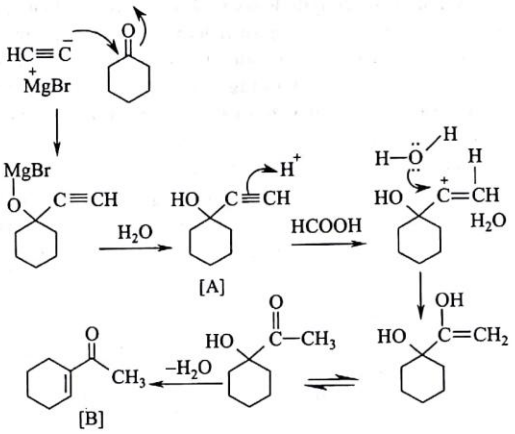
6.18 Identify [A] and [B] in the following transformation and give the mechanism of formation of [A] from [B].



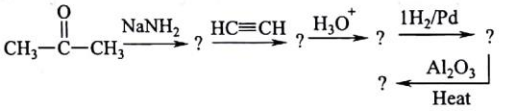
Ans The products [A] and [B] in these reactions are



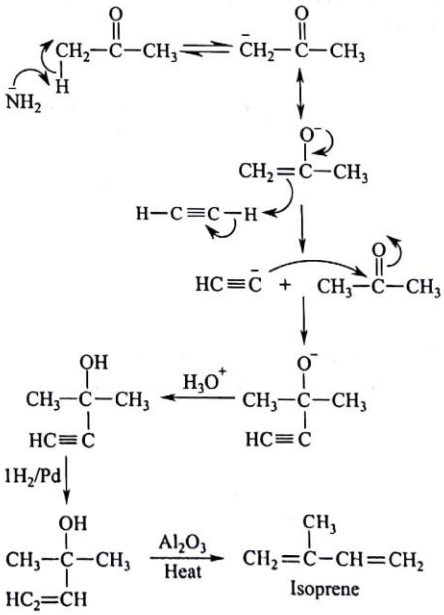
The mechanism of the reaction can be shown as follows.



6.19 Complete the following reactions with reasoning.



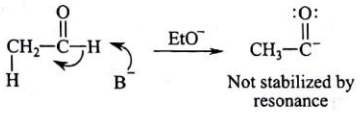
Ans This sequence of reactions is a method for the synthesis of 2-methylbuta-1,3-diene, trivially known as 'isoprene'. The course of the reaction can be shown as follows.



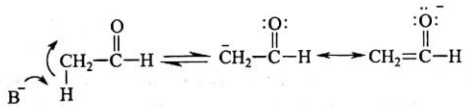
Since a-hydrogen of acetone is more acidic than acetylenic hydrogen, the initial carbanion is formed from acetone. This carbanion is stabilized by enolate ion formation. This enolate then abstracts an acidic hydrogen from acetylene to form acetylenic carbanion and acetone molecule is regenerated. Subsequent reactions give isoprene.

6.20 When acetaldehyde is treated with a base, then carbanion is formed by losing an α-hydrogen atom from an sp^3 hybridized carbon, but aldehydic hydrogen is never lost to form the corresponding carbanion, although it is attached to an sp^2 hybridized carbon. Explain this fact.

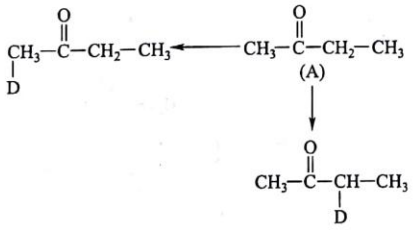
Ans The aldehydic hydrogen in acetaldehyde is supposed to be more acidic because it is attached to an sp^2 hybridized carbon but the corresponding carbanion obtained by the loss of this hydrogen as proton does not produce a resonance stable carbanion. This is why this aldehydic hydrogen is not affected by base.



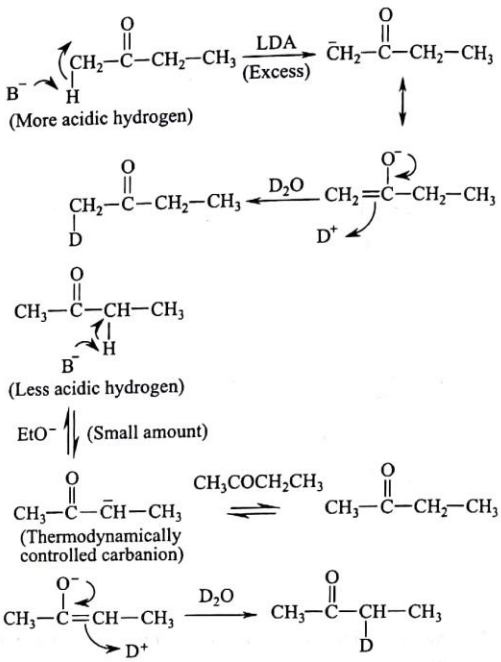
On the other hand, when a carbanion is formed by the loss of α-hydrogen atom then it is stabilized by resonance. This is shown here.



6.21 How can you carry out regioselective deuteriation as shown here?



Ans The compound (A) is an unsymmetrical ketone having two types of α-hydrogen atoms. When the reaction with excess strong base like LDA is used then more acidic α-hydrogen is lost as proton to give a kinetically controlled carbanion. It reacts with D_2O to give the corresponding deuterium substituted compound. However, when a less amount of base is used then an equilibrium is set in to give thermodynamically controlled carbanion and an isomeric deuterium substituted compound is formed. The courses of the reactions are given.

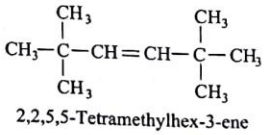


6.22 Explain why each of the following synthesis cannot be accomplished in the specified manner.

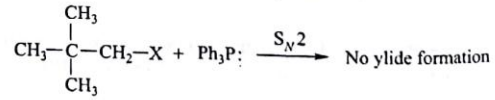
(a) 2,2,5,5-Tetramethylhex-3-ene by Wittig reaction
(b) 2,2-Dimethyl-3-hydroxycyclobutanone by an intramolecular aldol condensation
(c) 2-Ethyl-3-hydroxybutanal by a mixed aldol condensation
(d) 3-Methylhexan-2-ol by Clemmensen reduction of 4-methyl-5-hydroxyhexan-3-one

Ans The explanations are as follows:

(a) To get 2,2,5,5-Tetramethylhex-3-ene by Wittig reaction, we need to have a phosphorus ylide by reacting a neopentyl halide with triphenylphosphine using an S_N2 substitution. However, neopentyl halide cannot under go S_N2 reaction.



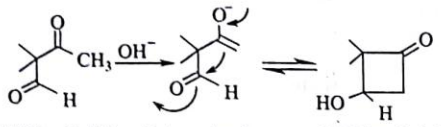
2,2,5,5-Tetramethylhex-3-ene



Neopentyl halide

(b) To get 2,2-Dimethyl-3-hydroxycyclobutanone by an intramolecular aldol condensation, we need to carry out the following reaction but the four-membered ring is too

strained to be formed in this reversible intramolecular aldol condensation.



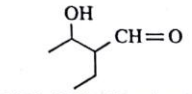
2,2-Dimethyl-3-oxobutanal — Intramolecular aldol — 2,2-Dimethyl-3-hydroxycyclobutanone (Highly strained molecular)

(c) To get 2-Ethyl-3-hydroxybutanal by a mixed aldol condensation, we need to carry out the reaction between the following two compounds, carbonyl compounds.

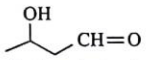
$CH_3CH{=}O$ and $CH_3CH_2CH_2CH{=}O$

Ethanal — Butanal

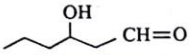
Since both these compounds contain α-hydrogen atoms, the desired product is formed along with other intermolecular aldol condensation products. Therefore, we will get a mixture of compounds. Possible products are shown.



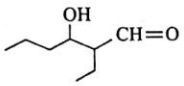
2-Ethyl-3-hydroxybutanal



3-Hydroxybutanal

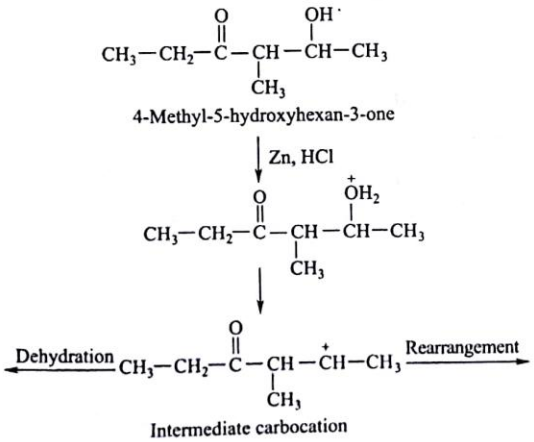


3-Hydroxyhexanal



2-Ethyl-3-hydroxyhexanal

(d) Clemmensen reduction is carried out in acidic condition. Therefore, the compound 4-methyl-5-hydroxyhexan-3-one can lose —OH group to generate an intermediate carbocation. This may lead to dehydration and intramolecular rearrangement.



4-Methyl-5-hydroxyhexan-3-one

Zn, HCl

Dehydration ← Rearrangement →

Intermediate carbocation

6.23 Compound A, C_7H_{16}, reacts with $Na_2Cr_2O_7$ in aqueous H_2SO_4 to give B, $C_7H_{14}O$. When B is treated with NaOD at 25°C for several hours, analysis shows that it has incorporated two deuterium atoms. Compound B is not oxidized by Ag_2O. What are A and B? Explain the reactions.

Ans

$$A\ (C_7H_{16}O) \xrightarrow[H_2SO_4]{Na_2Cr_2O_7} B\ (C_7H_{14}O) \xrightarrow{NaOD} C_7H_{12}D_2O$$

$$B \xrightarrow{Ag_2O} \text{No reaction}$$

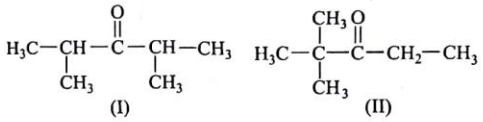
(a) A, $C_7H_{16}O$: Its DBE is zero. Therefore, it has no rings or no unsaturation.

(b) $A \xrightarrow{Cr^{6+}} B$: A is an alcohol, B is an aldehyde or ketone

(c) $B \xrightarrow{Ag_2O}$ No reaction: B is not an aldehyde

(d) $B \xrightarrow{NaOD} C_7H_{12}D_2O$: Only two hydrogen atoms are exchangeable (a to the carbonyl group of B).

On the basis of these facts, the possible structures of the compound 'A' could be (I) or (II)

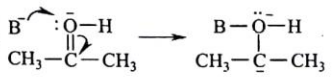


(I) (II)

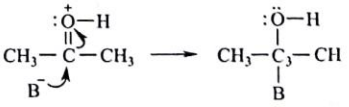
To distinguish between these two possibilities, more information is needed.

6.24 In a reaction of protonated acetone, why does reaction with a base always occur at carbon rather than at the positive oxygen?

Ans Consider the reaction of a base at the possible two sites.

Reaction on oxygen: 

Since the oxygen atom of the protonated molecule already has eight electrons, one pair of electrons of the double bond must be displaced onto the carbon as the new bond is formed using the electron pair from the base. The resultant intermediate would be a high-energy charge-separated species.

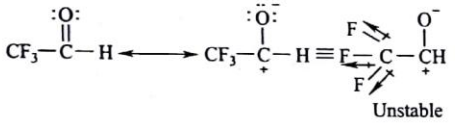
Reaction on carbon: 

In this reaction, the carbon atom already has eight electrons, so one pair in the double bond must be displaced onto the oxygen. However, in this case, the resultant molecule is neutral, and is quite stable having much lower energy.

6.25 Is the equilibrium constant for the following equilibrium greater than, less than, or equal to unity? Explain.

$$CF_3CH{=}O + CH_3CH(OCH_3)_2 \rightleftharpoons CH_3CH{=}O + CF_3CH(OCH_3)_2$$

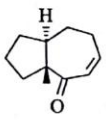
Ans The equilibrium constant is greater than unity. The fluorinated carbonyl group is destabilized because the dipolar resonance structure is less stable.

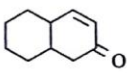


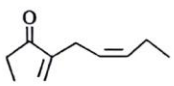
The fluorinated compound is destabilized by electrostatic repulsion between C—F dipole and C^+.

6.26 Each of following compounds may be obtained by an intramolecular aldol condensation. Show the precursor in each case.

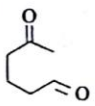
(a) 

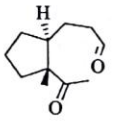
(c) 

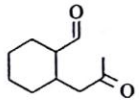
(b) 

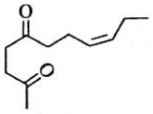
(d) 

Ans The structures of required precursors are given here.

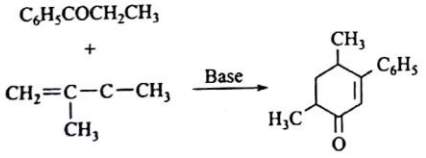
(a) 

(c) 

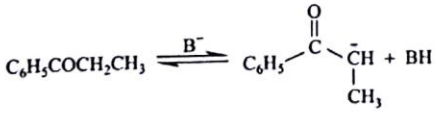
(b) 

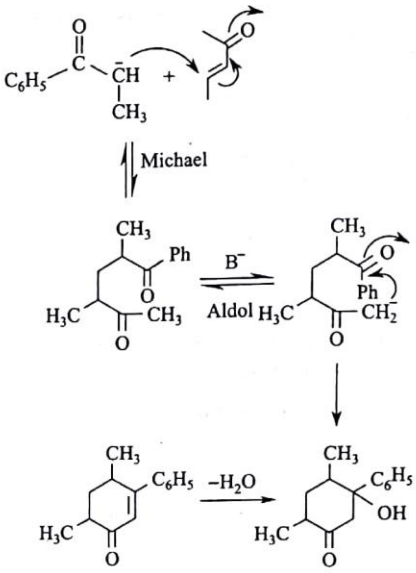
(d) 

6.27 The following reaction illustrates the Robinson annelation reaction. Give the mechanisms for the steps that occur.



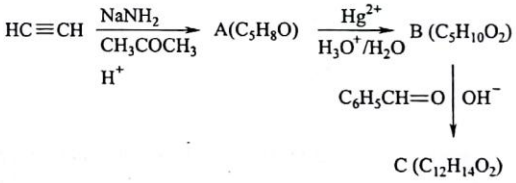
Ans



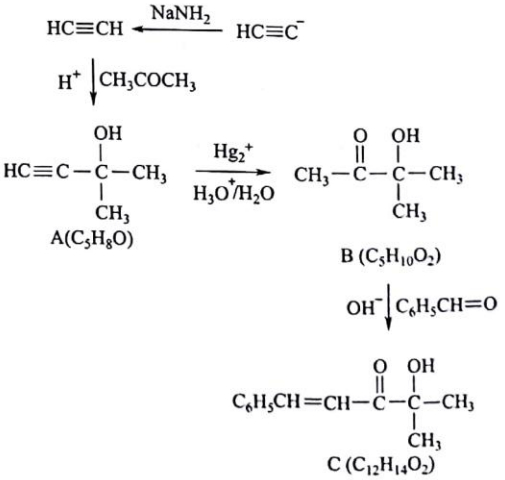


Michael followed by aldol condensation leading to the formation of a carbocyclic ring system is called Robinson's annelation.

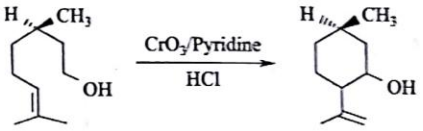
6.28 Write the structural formulae for A, B, and C.

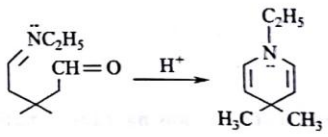


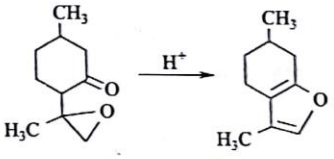
Ans The necessary reactions and products are shown.



6.29 Give the mechanism of each of the following transformations.

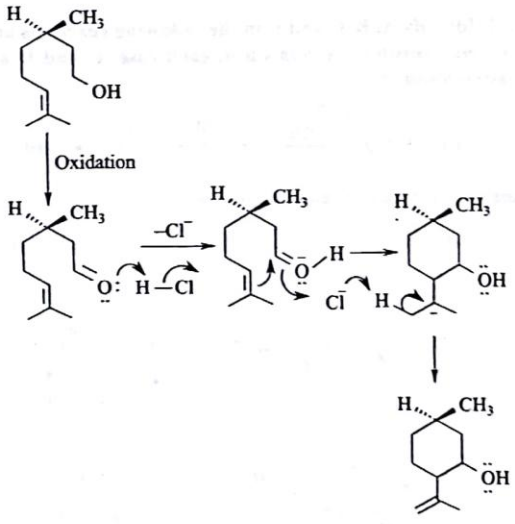
(a) 

(b) 

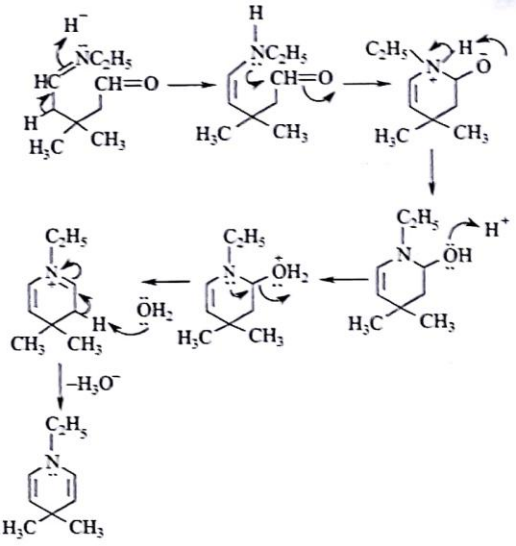
(c) 

Ans The mechanism of each of the reactions is given.

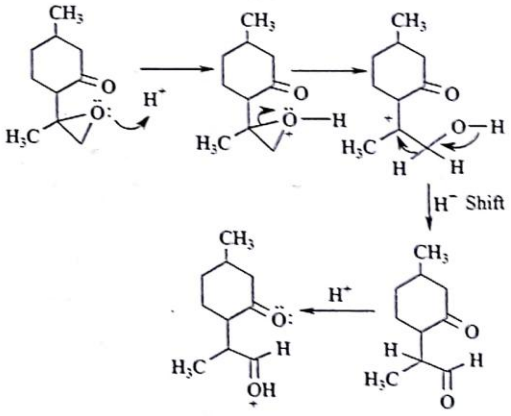
(a) The alcohol is oxidized to an aldehyde. Under the acidic conditions, the aldehyde is protonated; the carbonyl carbon, which has carbocation character, adds to the double bond to give another carbocation. Loss of a proton yields the final product. The reactions are shown.



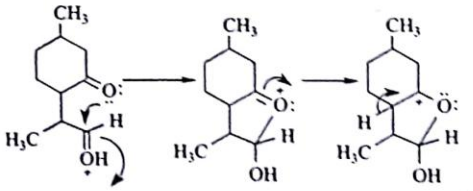
(b) Enamine formation with one aldehyde group is followed by enamine formation with the second. Undoubtedly, an imine is formed with the first aldehyde, but that remains in equilibrium with an enamine. The plausible mechanism of the formation of the product is given here.



(c) The epoxide, after protonation, opens to a carbocation, which is an intermediate in the pinacol rearrangement. Completion of the pinacol rearrangement results in the protonated aldehyde.



The oxygen of the second carbonyl group attacks the carbon of the protonated carbonyl group. This is followed by protons and water gives the furan ring system. The follow-up reactions are shown here in the formation of the final product.



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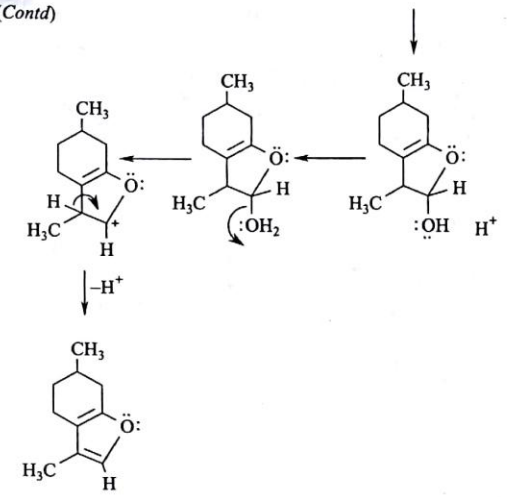
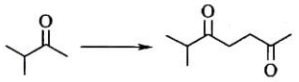
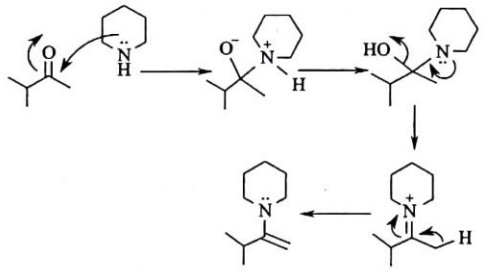
(Contd)



6.30 Carry out the following transformation through an enamine intermediate and using bromoacetone as a reactant.

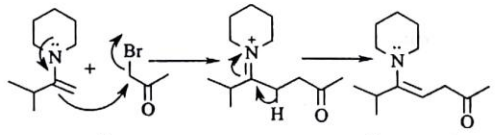


Ans The course of the reactions is given here.



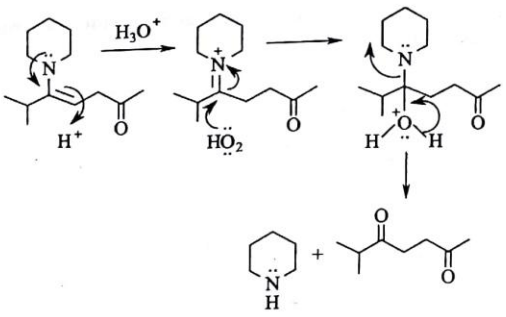
Enamine

This intermediate enamine reacts with bromoacetone as expected by S_N2 mode of reaction and a new enamine is formed.

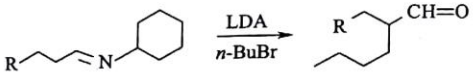


Bromoacetone New enamine

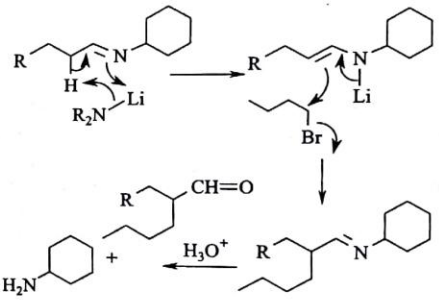
The newly formed enamine is then subjected to acid catalysed hydolysis and the desired compound is formed.



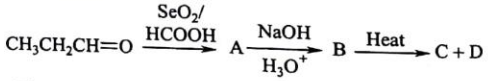
6.31 Give the mechanism of the following transformation.



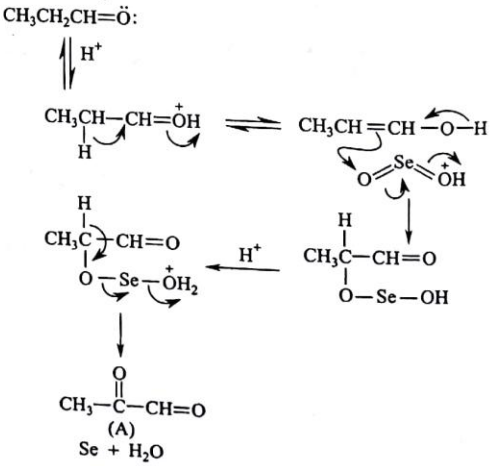
Ans The reactions are shown here.



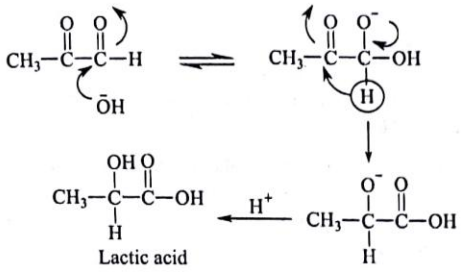
6.32 Identify A, B, C and D in the following reactions and give the plausible mechanism in each case. C and D are diastereoisomers.



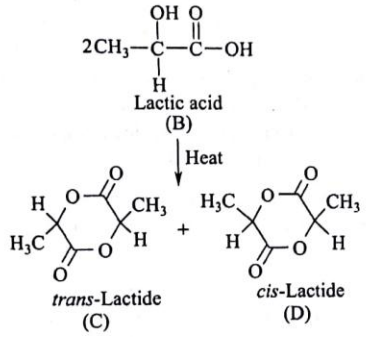
Ans The sequence of reactions is shown.



The second part of the reaction is intramolecular Cannizzaro reaction.



Lactic acid is an α-hydroxy acid. On heating, α-hydroxy acid undergoes dimerization to form diastereoisomeric lactides. *trans*-Lactide (say C) is optically inactive due to the presence of centre of symmetry but *cis* isomer (say D) is active and can exist as a pair of enantiomers.

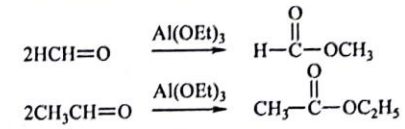


6.33 Answer these questions.

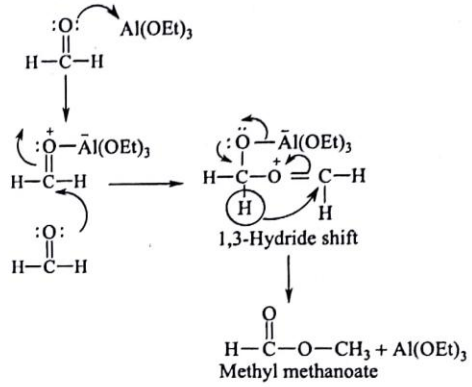
(a) What is Tischenko reaction? Give its mechanism.

(b) What are the products when a mixture of $CH_3CH{=}O$ and $HCH{=}O$ is treated with $Al(OEt)_3$?

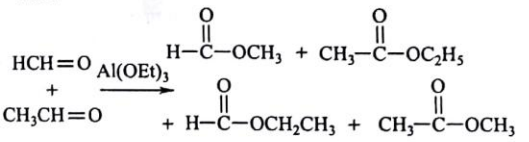
Ans (a) The Tischenko reaction is a disproportionation reaction that allows the preparation of esters from two equivalents of an aldehyde, with or without α-H atom/atoms using magnesium or aluminium alkoxide.



The mechanism of the reaction can be shown as follows. The aluminium alkoxide acts as a Lewis acid to coordinate with one molecule of the aldehyde, and to facilitate the addition of a second equivalent of aldehyde generating a hemiacetal intermediate. The total mechanism is shown here.



(b) A mixture of products is formed. The structures are given here.



EXERCISES

6.1 Carry out the following transformations.

(a) $CH_3CH{=}O \longrightarrow CH_3CH_2CH_2OH$

(b) $CH_3CH{=}O \longrightarrow PhCH_2CH{=}O$

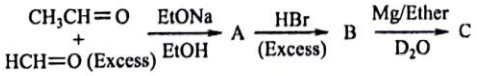
(c) $CH_3CH{=}O \longrightarrow CH_3COCH_3$

(d) $CH_3CH{=}O \longrightarrow CH_3CH_2NH_2$

(e) $CH_3CH{=}O \longrightarrow CH_3CHOHCO_2H$

(f) $CH_3CH{=}O \longrightarrow CH_3CHBrCHBrCO_2H$

6.2 Complete the following reactions:



6.3 The bromination of acetone is catalysed by acids, and the rate law is zero order with respect to bromine. Explain this fact with a energy diagram.

6.4 What are the products of the following Cannizzaro and crossed Cannizzaro reactions?

(a) $Me_3CH{=}O \xrightarrow{OH^-} ?$

(b) $Me_3CH{=}O + HCH{=}O \xrightarrow{OH^-} ?$

(c) $p\text{-}NO_2C_6H_4CH{=}O + HCH{=}O \xrightarrow{OH^-} ?$

(d) $PhCH{=}O + HCH{=}O \longrightarrow ?$

6.5 How can you prove by chemical experiment that in the Cannizzaro reaction, a hydride is *directly* transformed form one aldehyde molecule to another?

6.6 How can you convert $CH_3CH{=}O$ to $PhCH_2CH_2OH{=}O$?

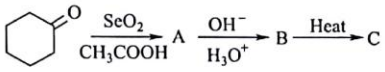
6.6 Alcohols do not undergo base catalysed dehydration but aldols do. Account for this fact with an explanation and the mechanism.

6.7 Give the products of the following sequence of reactions and give a plausible mechanism for each step.

$$PhCH_2CH{=}O \xrightarrow[CH_3COOH]{Se_2O} A \xrightarrow{OH^-} B \xrightarrow{Heat} C + D$$

6.8 A hydrocarbon 'X' on ozonolysis followed by intramolecular aldol condensation and dehydration gives cyclohex-2-enone. Identify the compound 'X' and explain the reactions.

6.9 Give the products of the following reactions and give a plausible mechanism for each step.



6.10 Write the equations for the following reactions.

(a) Formaldehyde + Ammonia
(b) Acetone + 2,4-dinitrophenylhydrazine
(c) Acetone + Ammonia
(d) Pinacol + dil. H_2SO_4
(e) Acetone + Mg/Hg + HCl
(f) Ethanol + Chlorine (excess)
(g) $CH_3CHO + SeO_2$

6.11 Answer the following.

(a) How is acetone converted into (i) mesityl oxide, and (ii) glycerol?
(b) Describe one method or preparation of formaldehyde. What is formalin? How does formaldehyde react with the following reagents? (i) ammonia, (ii) caustic soda solution, (iii) calcium hydroxide solution, and (iv) ammoniacal silver nitrate.

6.12 Give one example and mechanism of reaction of each. (a) Rosenmund reaction, (b) Stephen reduction, (c) Baeyer–Vililger oxidation, (d) Wolf–Kishner reaction, (e) Tischenko reaction, (f) Pinacol–Pinacolone transformation, and (g) Meerwein–Poundorf–Verley reduction.

6.13 A compound with molecular formula, $C_5H_{10}O$ forms an oxime, reduces Tollens' reagent, and shows Cannizzaro reaction. Name the compound with its structural formula. What are the products of Cannizzaro reaction?

6.14 An aldehyde undergoes Cannizzaro reaction to form an acid (A) and an alcohol (B). Acid A reduces Tollens' reagent. Alcohol B on oxidation forms acid A. What is the aldehyde?

6.15 A compound of carbon, hydrogen, and oxygen contains 69.77% carbon and 11.64% hydrogen. The molecular weight of the compound is 86. The compound does not reduce Fehling's solution but forms bisulphite compound and shows iodoform reaction. What is the probable structure of the compound?

6.16 The compound A formed by the hydrolysis of the compound $C_4H_8Cl_2$ decolourizes Schiff reagent. On oxidation of A, it forms the compound B which, when heated with sodalime, gives propane. What are the two probable structures of the two compounds?

6.17 A compound with molecular formula $C_4H_8Cl_2$ gives a compound on hydrolysis which forms an oxime but does not reduce Fehling's solution. What is the name and structure of the compound?

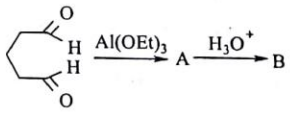
6.18 A compound forms phenylhydrazone and reduces Tollens' reagent. The phenylhydrazone of the compound contains 20.9% of nitrogen. Write down the structure and name of the compound.

6.19 A compound of molecular formula $C_5H_{10}O$ forms an oxime but does not reduce Tollens' reagent. The compound shows haloform reaction. When reduced by Clemensen's method the compound forms normal pentane. What is the compound?

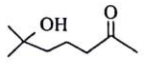
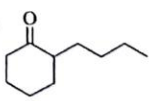
6.20 Compound $C_5H_{12}O$ (A) on oxidation gives the compound $C_6H_{10}O$ (B). Compound B forms phenylhydrazone and shows haloform reaction. When compound A is dehydrated with concentrated H_2SO_4, an alkene C is formed whose molecular formula is C_5H_{10}. Alkene C forms acetone and acetaldehyde on ozonolysis. Write down the names and structures of the compounds A, B, and C.

6.21 What are the fundamental differences between Cannizzaro reaction and Tischenko reaction? Explain with suitable examples.

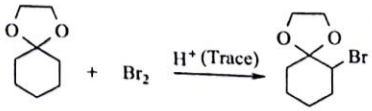
6.22 Complete the following sequence of reactions. Give the mechanism of the conversion of the parent dialdehyde to the compound A (the structure identified by you).



6.23 Which method is preferable for deoxygenation of each of the following aldehydes and ketones? If neither the Wolff–Kishner nor the Clemmensen method is expected to be suitable, indicate which one will.

(a) 
(c) 
(b) 
(d) 

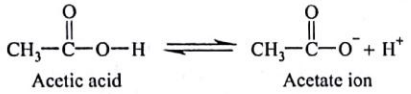
6.24 Propose a plausible mechanism for the following reaction.

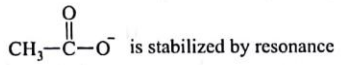


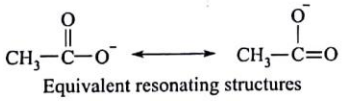
7 Aliphatic Acids and their Derivatives

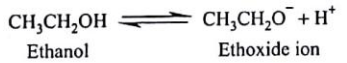
7.1 Why is acetic acid more acidic than ethyl alcohol?

Ans Acetic acid on dissociation produces a stable carboxylate anion but ethyl alcohol does not give a stable anion.



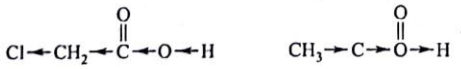






7.2 Why is chloroacetic acid stronger than acetic acid?

Ans In the case of $Cl-CH_2COOH$, the –I effect of chlorine atom withdraws electron density from the $-O-H$ part of the $-C(=O)-O-H$ group and makes the $-O-H$ bond more polarized. Consequently, heterolytic cleavage of $-O-H$ bond to give H^+ ion becomes easier. In the case of CH_3-COOH, +I effect pushes bonded electrons towards the $-O-H$ group of the $-COOH$ group. As a result of this, the $-O-H$ bond becomes stronger and heterolytic cleavage to produce H^+ becomes difficult.



7.3 Why is $Cl-CH_2COOH$ more acidic than $Cl-CH_2-CH_2-COOH$?

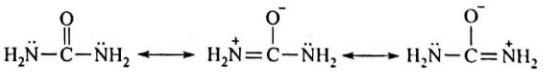
Ans When a strong electron-withdrawing group remains attached to the carbon atom bearing $-COOH$, then acidity is increased due to –I effect. Inductive effect rapidly decreases as the distance between the electron-withdrawing group and $-COOH$ decreases. In case of $Cl-CH_2-COOH$, the Cl-atom is nearer to the $-COOH$ group, but in $Cl-CH_2-CH_2-COOH$, it is away from the $-COOH$ group. Therefore, in $Cl-CH_2-CH_2-COOH$, –I effect on $-COOH$ is much less and consequently it is much weaker than $Cl-CH_2-CH_2-COOH$.

7.4 Between acrylic acid and propionic acid, which one is more acidic and why?

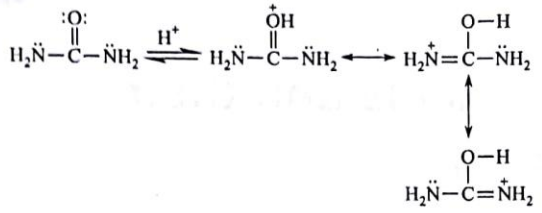
Ans Acrylic acid is $CH_2=CH-\overset{\overset{O}{\|}}{C}-OH$ and propionic acid is $CH_3CH_2-\overset{\overset{O}{\|}}{C}-OH$ H. In the case of acrylic acid, the $-COOH$ group is directly attached to an sp^2 hybridized carbon and in propionic acid the $-COOH$ group is attached to an sp^3 hybridized carbon. Since electronegativity of sp^2-carbon is greater than that of sp^3-carbon, $CH_2=CH-$ group in acrylic acid acts as an electron-withdrawing group (–I effect). On the other hand, CH_3-CH_2 group has strong +I effect and consequently, it decreases the acidic character. That is why acrylic acid is a stronger acid than propionic acid.

7.5 Explain why urea is a weak monoacidic base.

Ans Urea can be represented by the following resonating structures.



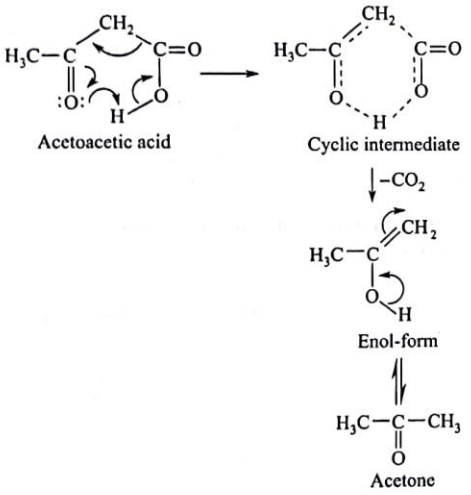
In these resonating forms, electron density increases on the oxygen atom. Therefore, protonation of urea is likely to occur on the oxygen atom. Basicity also depends on the stability of the protonated form. In the case of urea, protonation occurs at the oxygen atom and that protonated form also becomes stabilized by the following resonating forms.



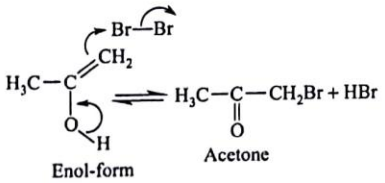
That is why urea behaves as a monoacidic base and protonation occurs at the oxygen atom.

7.6 β–Ketoacids are readily decarboxylated on heating. Give mechanism of the reaction with supporting evidence.

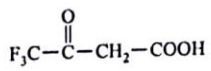
Ans β–Ketoacids like acetoacetic acid undergo easy thermal decarboxylation. The mechanism is as shown here.



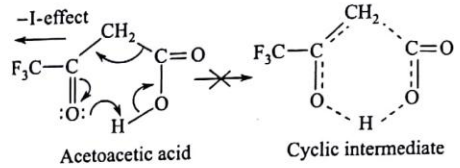
When the same reaction is carried out in the presence of Br_2 then along with acetone some amount of bromoacetone is also formed. This is possible if there is formation of an intermediate enol. This evidence supports the aforementioned proposed mechanism.



7.7 The following acid does not undergo decarboxylation although it a β-keto acid. Give an explanation.



Ans β-Keto acids undergo decarboxylation through a cyclic transition state. If this transition state is not formed by any cause then decarboxylation is inhibited. In case of the given fluoro compound, formation of the cyclic transition state is prevented by strong I effect of the $-CF_3$ group. Hence decarboxylation does not occur.

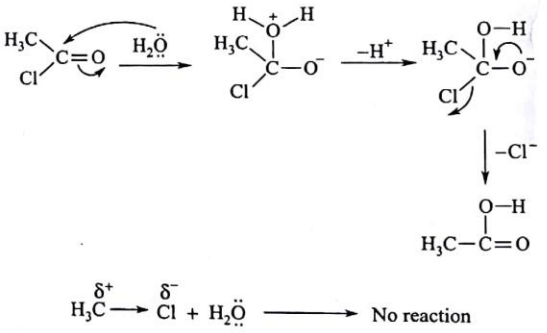


7.8 Acetyl chloride reacts with water more readily than methyl chloride. Explain.

Ans Acetyl chloride is CH_3COCl and methyl chloride is CH_3Cl.

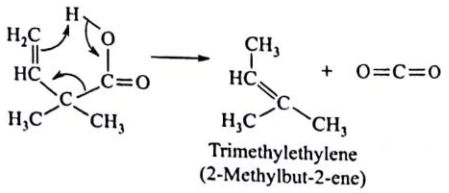
In the case of acetyl chloride –I effect of the Cl atom and polarizablity of the >C=O group make the carbonyl-carbon more electrophilic to be readily attacked by a weak nucleophile like H_2O.

In the case of methyl chloride, only the –I effect of the Cl atom makes the carbon electrophilic and, therefore, it is less reactive towards a weak nucleophile like H_2O.



7.9 2,2-Dimethylbut-3-enoic acid, on warming, gives trimethylethylene. Suggest a plausible mechanism.

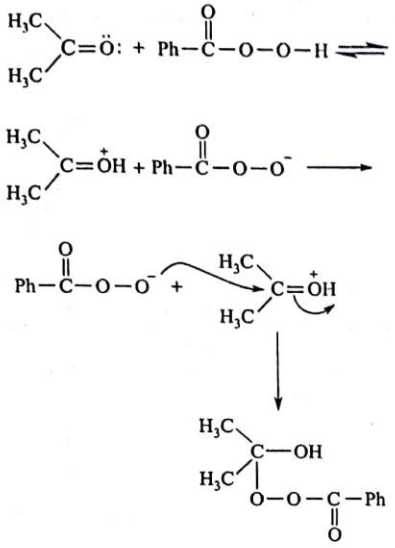
Ans The structure of 2,2-dimethybut-3-enoic acid is $CH_2=CH-\underset{\displaystyle CH_3}{\overset{\displaystyle CH_3}{\overset{|}{\underset{|}{C}}}}-COOH$. The compound is a βγ-unsaturated acid. On heating it undergoes ready decarboxylation. The mechanism can be shown as follows. Cyclic intermediate has not been shown.



7.10 How can you use (a) $PhCO_3H$ and (b) CH_2N_2 to prepare CH_3COOCH_3? Give the mechanism in each use.

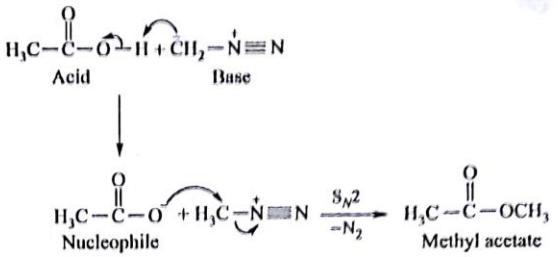
Ans

(a) CH_3COCH_3 can be converted into CH_3COOCH_3 by treating with perbenzoic acid, $PhCO_3H$. The reaction is called Baeyer–Villiger oxidation. The reaction mechanism can be shown as follows:



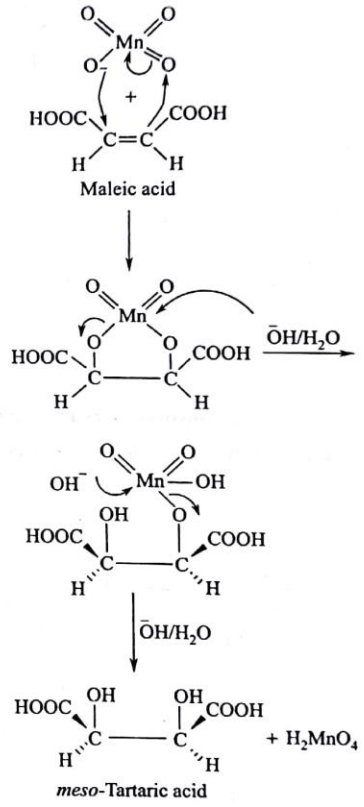
Methyl acetate

(b) $H_3C-\overset{O}{\overset{\|}{C}}-OH$ can be converted into $H_3C-\overset{O}{\overset{\|}{C}}-OCH_3$ using CH_2N_2 in dry ether. The mechanism can be shown as follows:



7.11 What product is obtained when maleic acid is treated with alkaline $KMnO_4$ solution? Give the mechanism of this reaction.

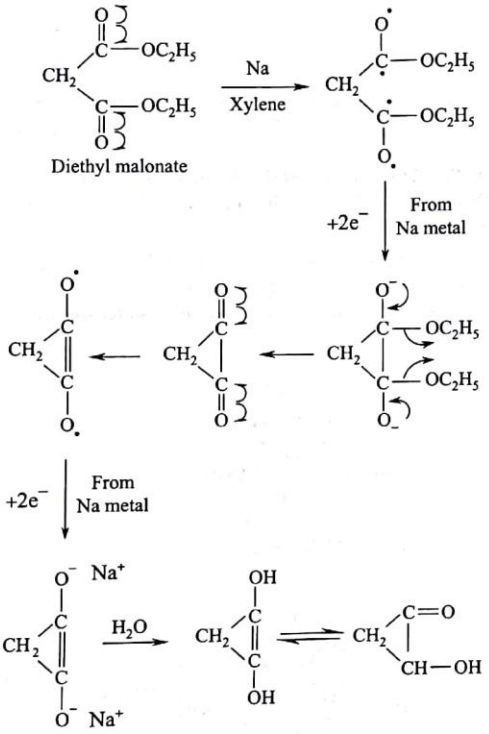
Ans Maleic acid is *cis*-butenedioic acid. When it reacts with alkaline $KMnO_4$ solution then *cis*-hydroxylation occurs to give *meso*-tartaric acid. This reaction is stereospecific. The mechanism can be shown as follows:



Since the hydroxylation process takes place simultaneously, conformational change does not occur and *cis*-hydroxylation takes place.

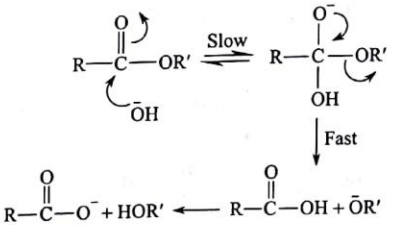
7.12 What product is obtained when diethyl malonate is treated with Na metal in xylene? Give the mechanism of the reaction.

Ans It is a case of acyloin condensation of diethyl malonate, the product is a three-membered cyclic acyloin, α-hydroxyketone. The mechanism can be shown as follows:

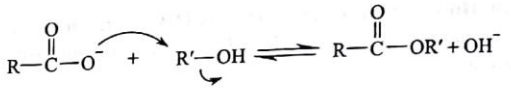


7.13 Give the $B_{AC}2$ mechanism of ester hydrolysis.

Ans $B_{AC}2$ mechanism of ester hydrolysis can be shown as follows:

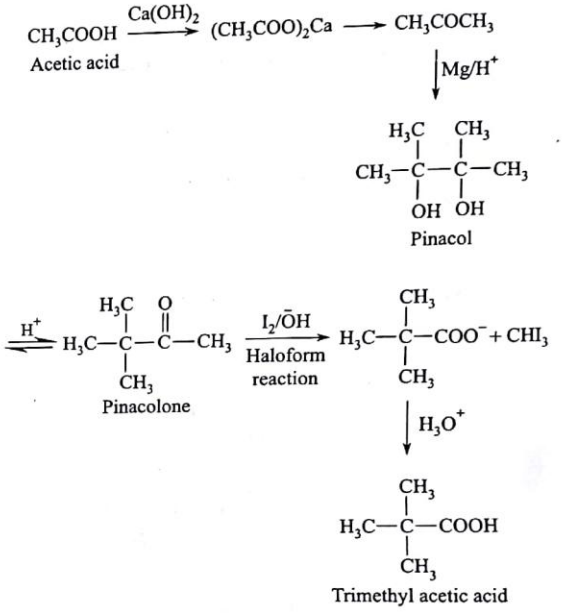


$B_{AC}2$ stands for 'base catalysed acyl oxygen fission bimolecular (2)'. The $B_{AC}2$ hydrolysis is irreversible because the carboxylate ion $R-COO^-$ is resonance stabilized and consequently is a poor nucleophile. It cannot displace OH^- from $R'-OH$ by S_N2 type displacement.



7.14 Prepare trimethylacetic acid from acetic acid.

Ans Trimethylacetic acid can be prepared from acetic acid by the following sequence of reactions.

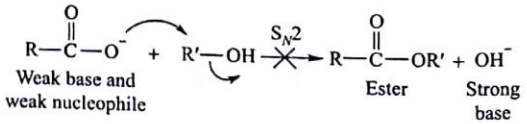


7.15 Esterification reaction is always catalysed by acids but de-esterification is catalysed by both acid and alkali and the latter is preferred. Explain with suitable examples.

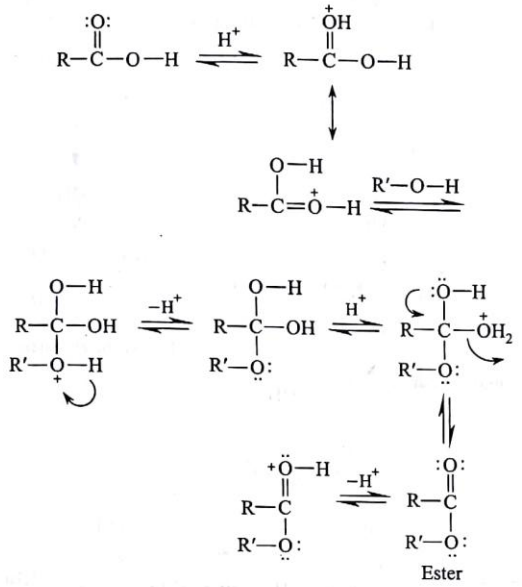
Ans Esterification is always acid catalysed because when base is used, it reacts with carboxylic acid (RCOOH) to form an acid anion having poor nucleophilicity and therefore, cannot react with an alcohol (R'OH) in an S_N2 type displacement reaction to form ester by the removal of more strong nucleophilic reagent O—H. De-esterification, however, is possible by both acid and alkali according to mechanisms shown here:

In case of base catalysed esterification:

This part of the reaction cannot occur:



Acid catalysed esterification ($A_{AC}2$):



Acid catalysed de-esterification also occurs by the same mechanism. In this case H_2O takes the place of R′—OH. The only difference is that during esterification, concentrated acid (H_2SO_4) is used but in the case of de-esterification dilute acid (H_3O^+) is used.

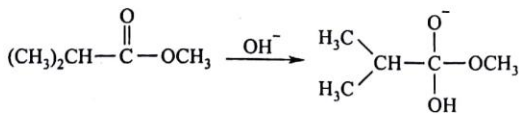
For base catalysed esterification, see 7.14.

7.16 Which one of the following would most readily be hydrolysed with NaOH?

(a) $CH_3COOC_4H_9$
(b) $(CH_3)_2CHCOOCH_3$
(c) CH_3COOCH_3.

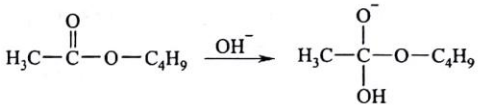
Ans CH_3COOCH_3 will be most readily hydrolysed by NaOH. If we assume that the mechanism is $B_{AC}2$, both steric and +I effects of the alkyl group can decrease the rate of the reaction.

In the case of $(CH_3)_2CH—CO—OCH_3$, +I of the $(CH_3)_2CH—$ group can decrease the electrophilic character of the carbonyl carbon and nucleophilic attack by OH^- requires more activation energy. Moreover, formation of the tetrahedral intermediate in the rate determining step becomes difficult due to the steric crowding.



Tetrahedral intermediate unstable due to steric crowding

In the case of $CH_3—CO—O—C_4H_9$, steric factor is the major hindrance for slowing down the rate of the reaction. Inductive effect is insignificant here.

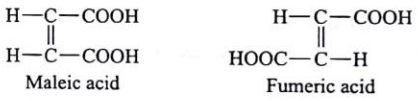


Tetrahedral intermediate unstable due to steric compression

Therefore, the order of rate of hydrolysis is (c) > (a) > (b).

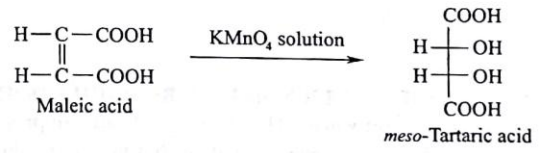
7.17 Two dicarboxylic acids have the general formula HOOC—CH=CH—COOH. On treatment with cold dilute $KMnO_4$ solution, they yield two diastereomeric tartaric acids. Show how this information allows one to write the stereochemical formulae for the two acids.

Ans HOOC—CH=CH—COOH is butenedioic acid. It can have two diastereoisomers known as maleic acid (*cis*-butenedioic acid) and fumeric acid (*trans*-butenedioic acid).

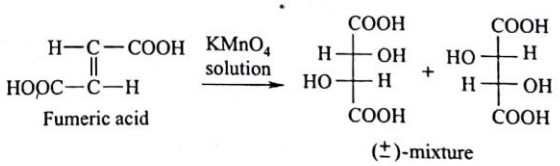


Maleic acid — Fumeric acid

When these diastereoisomers are treated separately with cold alkaline $KMnO_4$, then stereospecific *cis*-hydroxylation occurs. When a symmetrical *cis*-olefin of the type $C_{ab}=C_{ab}$ undergoes *cis*-addition with X_2 (X = Cl, Br, —OH, etc.), then a *meso*-compound is formed. However, when *trans* isomer of $C_{ab}=C_{ab}$ undergoes *cis*-addition then racemic mixture of enantiomers is obtained. Therefore, from the nature of the addition products by carrying out identical addition reactions, it is possible to know the configurations of the *cis*- and *trans*-diastereoisomers.



Maleic acid — *meso*-Tartaric acid

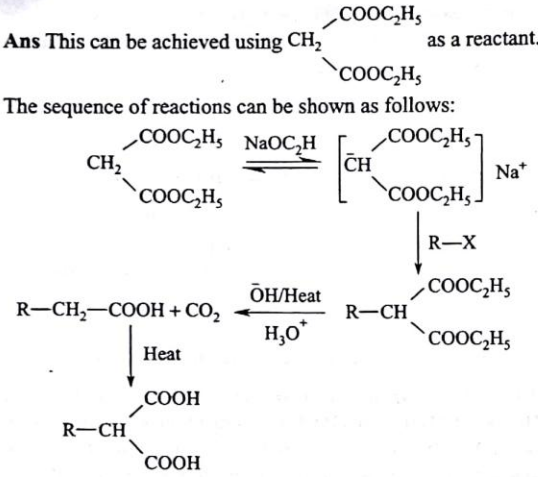


Fumeric acid — (±)-mixture

7.18 Convert R—X to RCH_2COOH using decarboxylation as one of the steps.

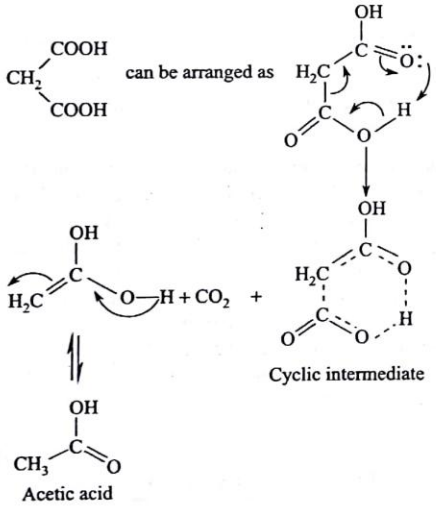
Ans This can be achieved using $CH_2(COOC_2H_5)_2$ as a reactant.

The sequence of reactions can be shown as follows:



7.19 $CH_2(COOH)_2$ on heating produces CH_3COOH. Give the mechanism.

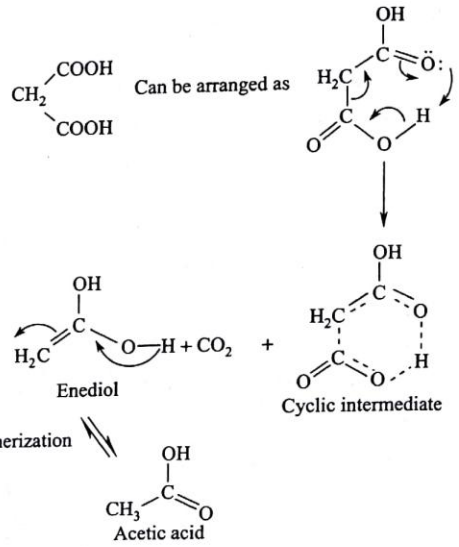
Ans Gem-dicarboxylic acids undergo thermal decarboxylation through a cyclic intermediate as shown here.

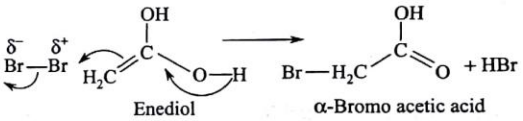


7.20 When CH_3COOH is heated with Br_2, $BrCH_2COOH$ is not obtained, but when $CH_2(COOH)_2$ is heated in presence of Br_2 then bromoacetic acid is obtained. Give the mechanism of the reaction.

Ans CH_3COOH does not undergo α-bromination when heated with elemental bromine. However, when malonic acid is strongly heated in the presence of elemental bromine then α-bromoacetic acid is obtained along with acetic acid itself.

Malonic acid undergoes thermal decarboxylation through an intermediate *enediol*. When this enediol tautomerizes to a carboxylic acid, then π-electron can pick up H^+ as well as Br^+ to give CH_3COOH along with $BrCH_2COOH$. The mechanism can be shown as follows:

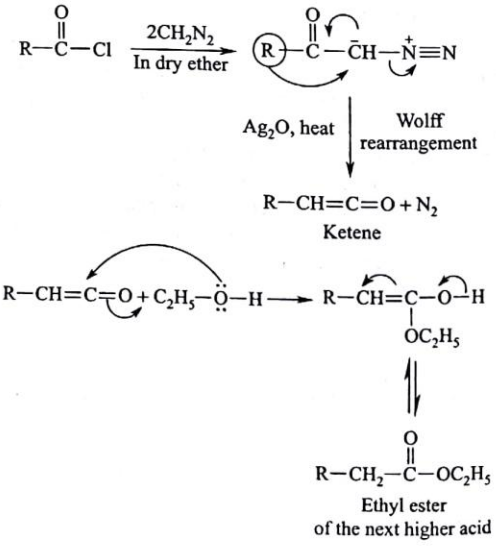




It should be noted that isolation of $Br-CH_2COOH$ in this reaction serves as evidence of the cyclic mechanism of thermal decarboxylation of gem-dicarboxylic acid.

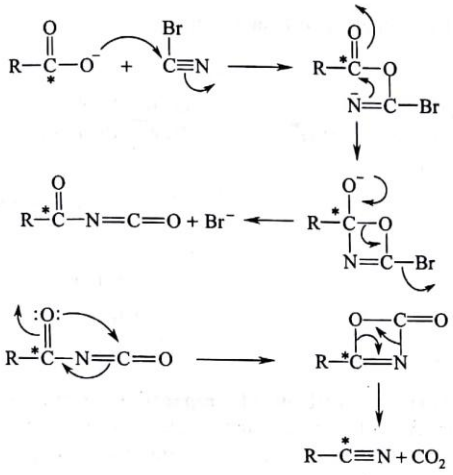
7.21 What happens when an acid chloride is treated with excess of diazomethane and the product reacts with ethanol in the presence of Ag_2O catalyst?

Ans This is a case of formation of an ester through the formation of ketene. The sequence of reaction can be shown as follows. The reaction is called Arndt–Eistert reaction.



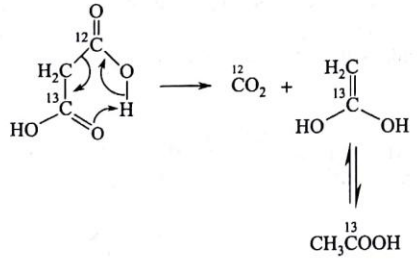
7.22 When $R-\overset{*}{C}(=O)-O^-$ ion is treated with BrCN, the products obtained are $RC^{*}\equiv N$, CO_2 and Br. Can you account for this fact?

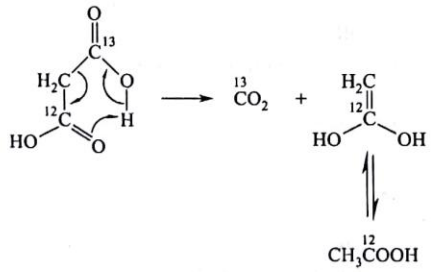
Ans The formation of these products from the given reactants can be accounted for by the following mechanism.



7.23 What is the composition of the products when $HO_2\overset{12}{C}-CH_2-\overset{13}{C}O_2H$ is subjected to pyrolysis? Give the plausible mechanism.

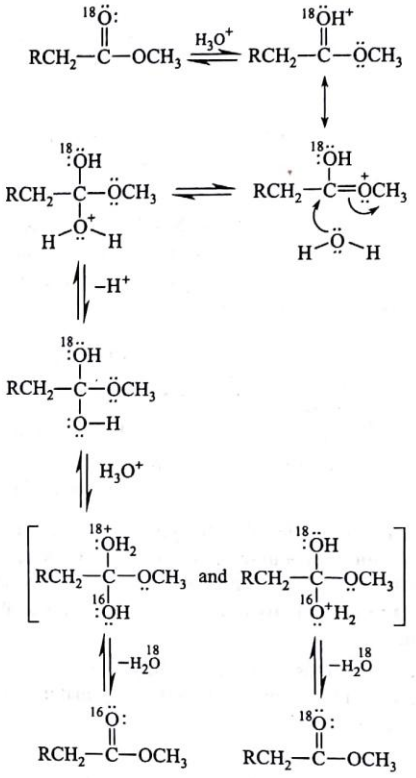
Ans The products are $CH_3\overset{12}{C}OOH$, $\overset{13}{C}O_2$, $CH_3\overset{13}{C}OOH$, and $\overset{12}{C}O_2$. Gem-dicarboxylic acid undergoes decarboxylation through a six-membered cyclic intermediate. The reactions can be shown as follows.





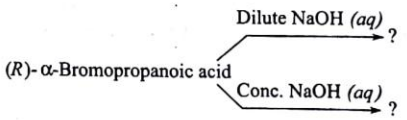
7.24 Account for the gradual loss of ^{18}O content in the unreacted ester during acid catalysed hydrolysis of $RCH_2\overset{18}{C}OOCH_3$.

Ans The mechanism of acid catalysed hydrolysis of an ester is as follows.

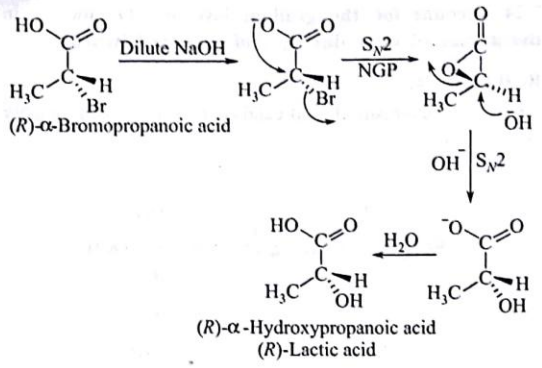


Loss of H_2O from the intermediate dihydroxy compound and simultaneous loss of H^+ can occur both from $^{18}OH_2$ and $^{16}OH_2$. Therefore, the recovered ester gradually losses ^{18}O during acid catalysed hydrolysis.

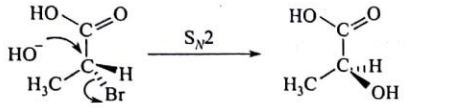
7.25 Write the products of the following reactions and explain their formation.



Ans When dilute aqueous NaOH solution is used, substitution involves neighboring group participation (NGP) and that leads to retention of configuration at the chiral centre and the product is (*R*)-lactic acid. The reaction is as follows.

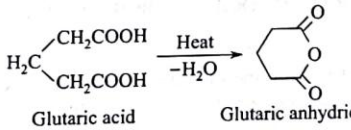


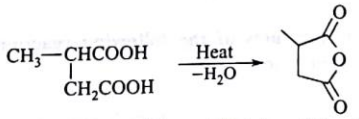
When concentrated aqueous NaOH solution is used, the initial S_N2 (NGP) does not occur. Direct S_N2 substitution occurs with inversion of configuration at the chiral centre. The product is (*S*)-lactic acid.

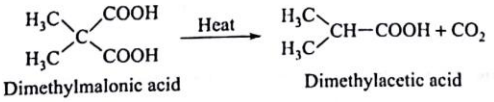


7.26 Three isomeric dicarboxylic acids, A, B, and C have the same molecular formula, $C_5H_8O_4$. A and B give anhydrides on heating but C gives a monocarboxylic acid along with CO_2. Identify the compounds and explain the reaction.

Ans The compounds A and B may be glutaric acid or methylsuccinic acid. The compound C is dimethylmalonic acid. The reactions are given here.



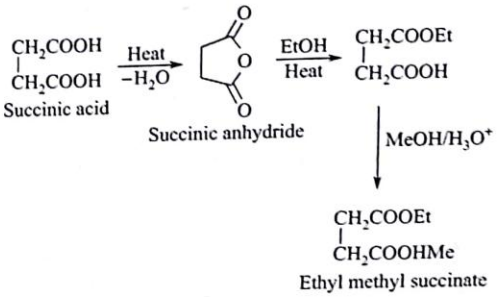




Glutaric acid and methylsuccinic acid undergo intramolecular dehydration involving two –COOH groups. In these cases decarboxylation does not occur because the –COOH groups are on different carbon atoms. In the case of dimethylsuccinic acid, both the –COOH groups are on the same carbon atom, the gem-dicarboxylic acid. This class of dicarboxylic acids undergo easy decarboxylation through a cyclic transition state.

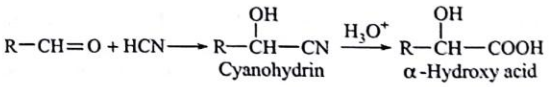
7.27 How can you convert succinic acid to its ethyl methyl ester?

Ans This can be carried out as follows:

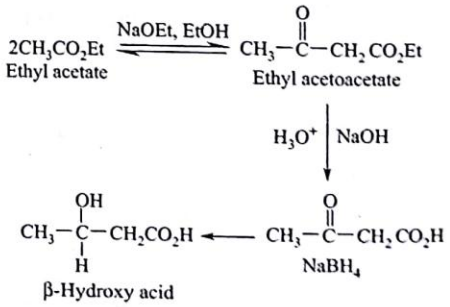


7.28 Give the methods of preparation of α-, β-, and γ-hydroxy acids (one in each case). How can you distinguish among these hydroxy-acids just by the application of heat?

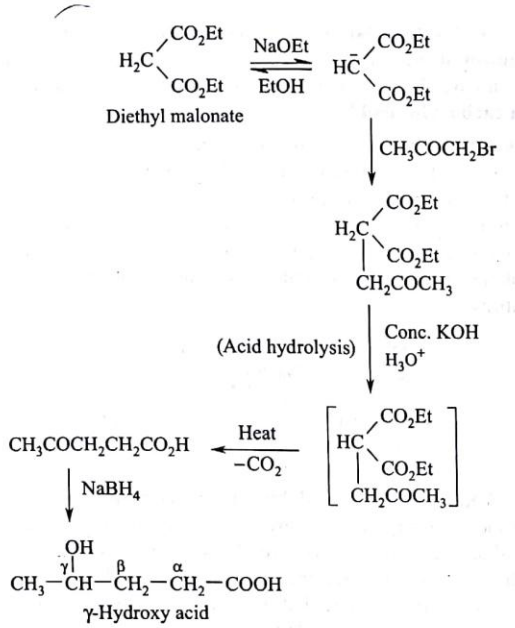
Ans There are many reactions by which α-hydroxy acids can be synthesized, but the most common one is to convert an aldehyde to the corresponding cyanohydrin by reacting with HCN followed by hydrolysis of the cyanohydrin.



β-Hydroxy acids can be obtained by the reduction of β-keto acids with $NaBH_4$. β-Keto acids can be obtained by Claisen ester condensation. An example is given here.

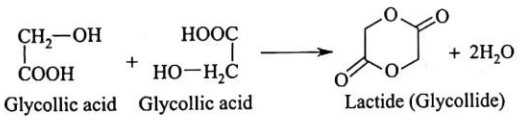


γ-Hydroxy acids can be obtained by $NaBH_4$ reduction of the γ-keto acids. γ-Keto acids can be obtained from active methylene compounds such as acetoacetic esters or diethyl malonate. An example is given here.

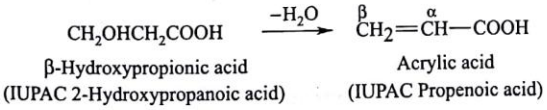


α-, β- and γ-hydroxy acids can be distinguished from the respective product that is formed by the application of heat. The reactions are shown here.

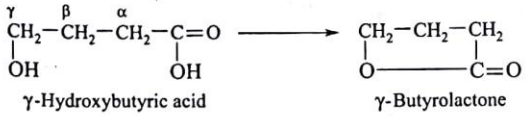
α-Hydroxy acid on heating forms a dimeric anhydride called lactide (name derived from lactic acid). An example is given here.



β-Hydroxy acid undergoes intramolecular dehydration to form an αβ-unsaturated acid.

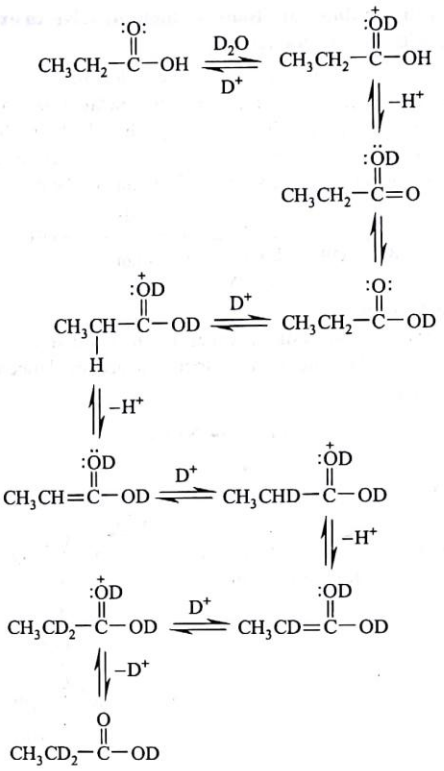


γ-Hydroxy acid, when heated, gives a five membered internal cyclic ester called γ-lactone.



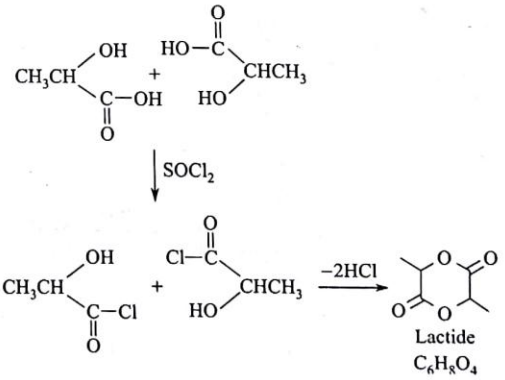
7.29 On refluxing with D_2O containing a strong acid, propanoic acid is slowly converted to CH_3CD_2COOD. Write a plausible mechanism for this reaction.

Ans A plausible mechanism is given here.



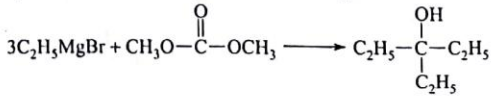
7.30 Treatment of 2-hydroxypropanoic acid (lactic acid) with thionyl chloride gives a product having $C_6H_8O_4$. Propose a structure for this compound.

Ans The product is a lactide.



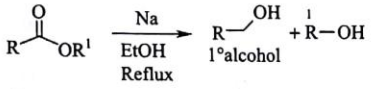
7.31 What happens when a carbonate ester reacts with excess of CH_3CH_2MgBr?

Ans Carbonate esters yield tertiary alcohols by reacting with Grignard reagents in which all three of the carbinol alkyl groups come from the organometallic reagent.



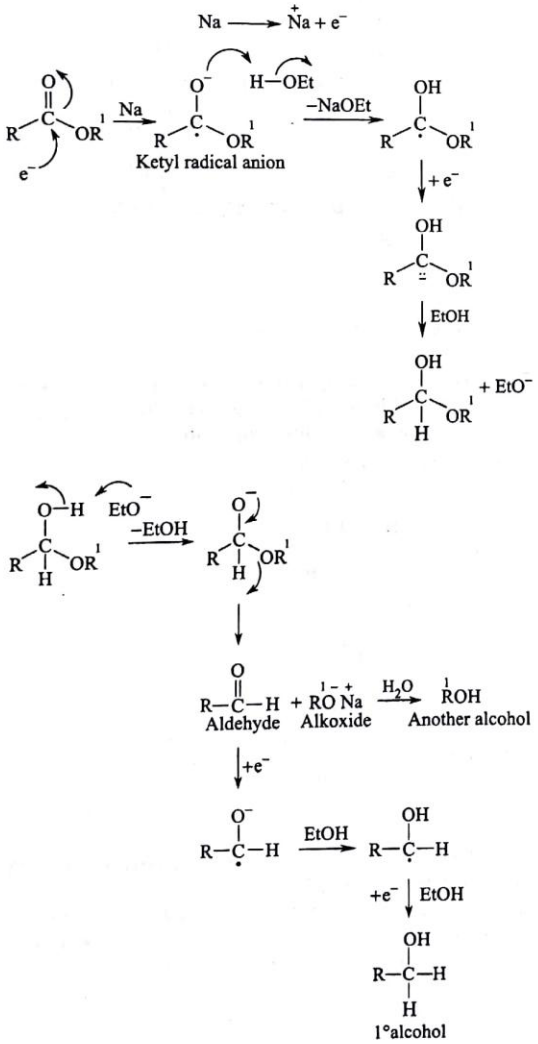
7.32 What is Bouvealt–Blanc reduction? Give an example along with the mechanism.

Ans Bouvealt–Blanc reduction is the reduction of carboxylic acid-esters to a mixture of alcohols using metallic sodium in the presence of an alcohol which is usually ethanol. One of the alcohols in the product-mixture is always a primary alcohol and the nature of the other one depends on the nature of the parent ester.



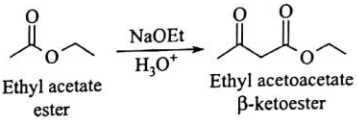
Mechanism:

In this reaction, sodium serves as single electron reducing agent and EtOH is the proton donor. The accepted mechanism is shown here.

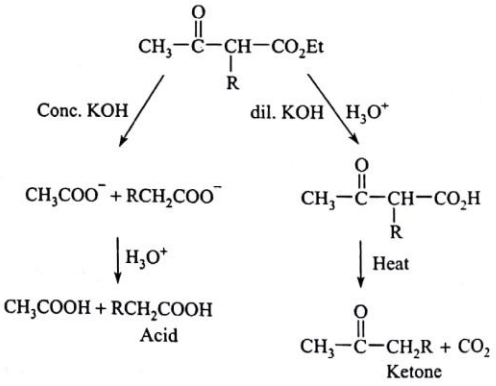


7.33 What is Claisen ester condensation? Give the mechanism of the reaction. Give examples where Claisen ester condensation can be used to synthesize a ketone as well as a carboxylic acid?

Ans Self condensation of two molecules of an ester containing α-hydrogen, promoted by a base such as sodium ethoxide, is known as Claisen condensation. The condensation product is a β-ketoester. If two different esters are used, an essentially statistical mixture of all four products is generally obtained, and the preparation does not have high synthetic utility.

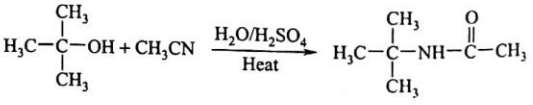


β-Keto esters formed by Claisen condensation can be made to undergo alkaline hydrolysis by two different ways. If dilute KOH solution is used, the major product is a ketone. However, when concentrated KOH is used, then the major product is an acid. The first one is called 'ketone hydrolysis' and the second one is called 'acid hydrolysis'. Examples are given here.



7.34 Answer the following:

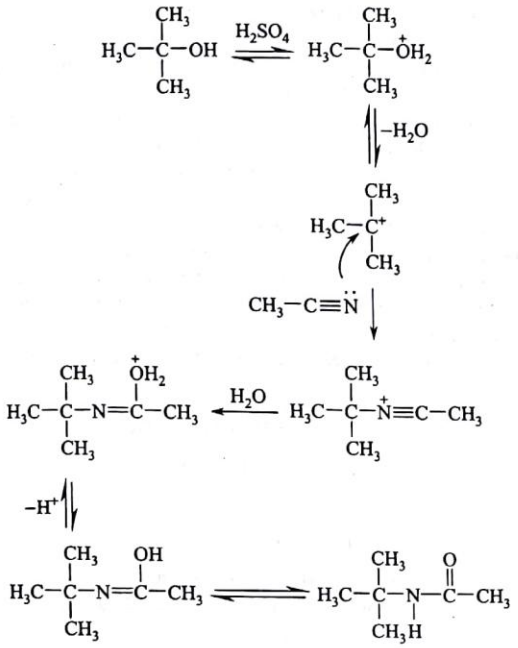
(a) Write a mechanism that explains the following reaction. What is the name of the reaction?



(b) What product is expected when 2-methylpentane-2, 4-diol is treated with acetonitrile and aqueous sulphuric acid?

Ans

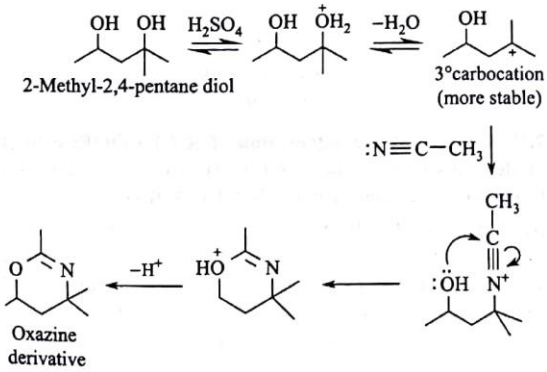
(a) The necessary reactions are shown here.



This reaction is called 'Ritter reaction'.

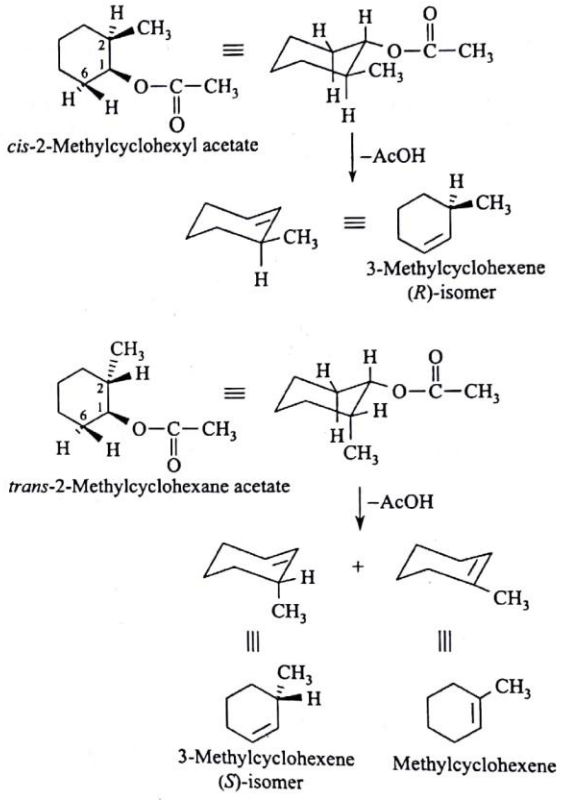
This reaction is called 'Ritter reaction'.

When 2-methylpentane-2,4-diol is treated with acetonitrile and aqueous sulphuric acid then an oxazine derivative is formed. The necessary reactions are shown here.

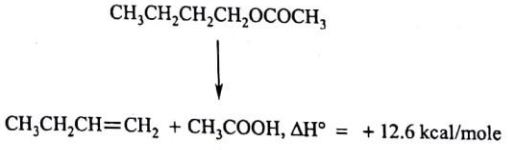


7.35 Explain why the pyrolysis of *cis*-2-methylcyclohexyl acetate gives only 3-methylcyclohexene, whereas *trans*-2-methylcyclohexyl acetate gives a mixture of 1-methylcyclohexene and 3-methylcyclohexene.

Ans Pyrolysis of acetate to an unsaturated compound takes place through a cyclic transition state and stereochemically *cis*-elimination. In case of *cis*-2-methylcyclohexyl acetate, elimination can involve only one *cis*-hydrogen atom and that leads to the formation of only one product. However, in the case of *trans*-2-methylcyclohexyl acetate, there are two such hydrogen atoms and leads to the formation of two isomeric cyclohexenes. The necessary reactions are given here in chair conformation of the reactants.



7.36 The elimination of a carboxylic acid from an ester is generally an endothermic process, for example,

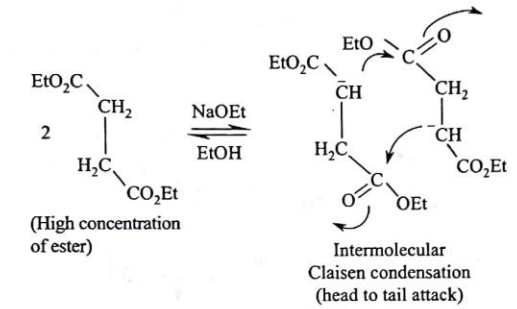


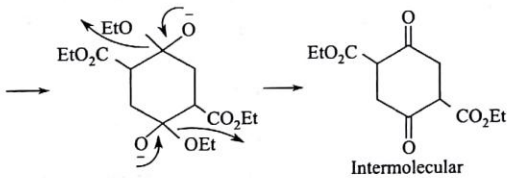
yet the pyrolytic elimination is a useful preparative reaction. How can you reconcile these two observations? Why is pyrolytic elimination carried out at high temperature (300–500°C)?

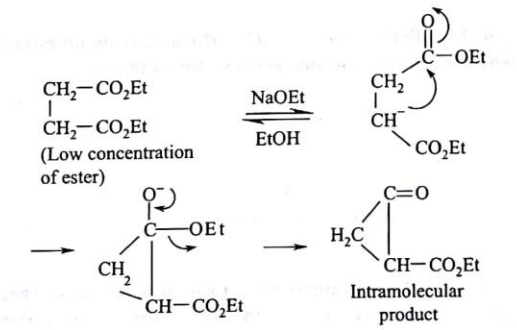
Ans In this reaction, one mole of reacant gives two moles of products. Therefore, the reaction has a favourable entropy (positive S°). According to the thermodynamic equation, $\Delta G = \Delta H - T\Delta S$, to make the reaction thermodynamically viable, that is, ΔG must be negative. In this case, T (temperature) must be high because the enthalpy change, that is, ΔH is positive (endothermic). For this reason, pyrolytic *syn*-elimination is carried out at high temperature.

7.37 What is the high dilution technique that is used in Claisen condensation? How does it affect the nature of product?

Ans Concentration of the reacting ester can control the nature of the final product in Claisen condensation. For example, when the concentration of diethyl succinate is high then base catalysed intermolecular Claisen condensation reaction takes place as the intermolecular reaction sites are closer. However when the concentration of the ester is low, intramolecar Claisen condensation (Dieckman reaction) occurs to give a cyclic compound.



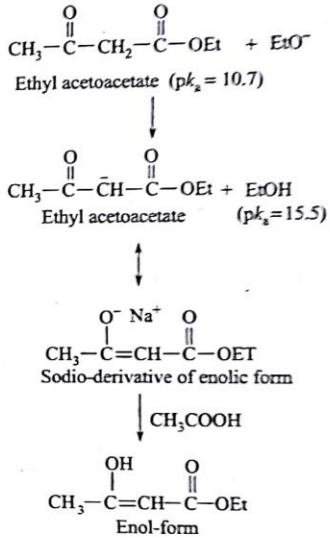




7.38 Explain why Claisen ester condensation to form a β-ketoester requires one equivalent amount of NaOEt and not catalytic amount?

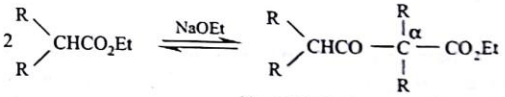
Ans Claisen ester condensation is a reversible reaction and that is why the final product (ketonic form of β–keto ester) is stabilized as a sodio-derivative of the enolic form using excess of sodium ethoxide. If this is not done, the first step will produce a very small concentration of carbanion, since the first step favours the starting materials. The reason is stated here.

EtOH is a conjugate acid of EtO^- and stronger than CH_3CO_2Et. Again $\bar{C}H_2CO_2Et$ is a conjugate base of a weaker acid CH_3CO_2Et and consequently stronger than EtO^-. Therefore, the equilibrium of the reversible reaction always favours the reactant side. For this reason, the Claisen condensation has been driven to completion by converting ketonic form of β-keto ester to sodio-derivative of the conjugate base (enolic form) using excess (1 mole) of sodium ethoxide. Acidic hydrogen of keto-form of β-keto ester is taken up by ethoxide ion to form quantitatively the conjugate base of the product. β-keto ester is a stronger acid than ethyl alcohol and the reaction becomes almost irreversible. The isolated sodium salt is then acidified with acetic acid to get back the enolic form, which readily tautomerizes to the more stable ketonic form.



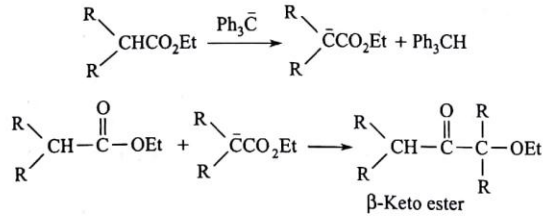
7.39 Claisen ester condensation of $R_2CHCOOEt$ cannot be done with a base like NaOEt? How can you carry out Claisen ester condensation of $R_2CHCOOEt$?

Ans Esters like R_2CHCO_2Et, containing only one α-hydrogen atom, cannot be made to undergo Claisen condensation using sodium ethoxide as a base because the condensation product (β-keto ester) cannot be isolated as a sodium salt of an enolic form due to the lack of acidic hydrogen on the α-carbon.



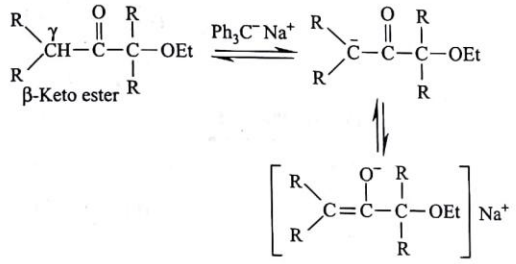
No acidic hydrogen on the α-carbon

In this example, the formation of β-keto ester is negligible. However, esters of the type R_2CHCO_2Et can be made to undergo condensation using a very strong base like sodium triphenylmethide, $Ph_3C^-\ Na^+$. In this case, the first step becomes almost irreversible because the conjugate acid Ph_3CH of the strong base Ph_3C^- is very weak (pKa = 31.5) and $R_2\bar{C}—CO_2Et$ is a weaker base than Ph_3C^-.



β-Keto ester

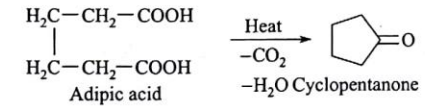
Very strong base Ph_3C^- can convert β-keto ester to its conjugate base by accepting a weak γ-hydrogen atom.



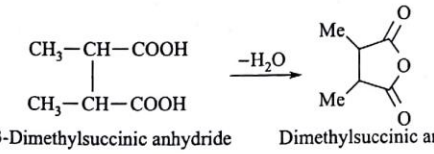
β-Keto ester

7.40 Adipic acid and 2,3-dimethybutanedioic acid are constitutional isomers. How can you distinguish these two? What is Blanc's rule?

Ans These two isomeric compounds can be distinguished by the heat. If adipic acid is heated, it forms cyclopentanone by losing a molecule of CO_2. When 2,3-dimethylbutanedioic acid is heated, it gives the corresponding anhydride by losing a molecule of water.



Adipic acid — Cyclopentanone

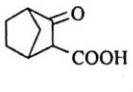


2,3-Dimethylsuccinic anhydride — Dimethylsuccinic anhydride

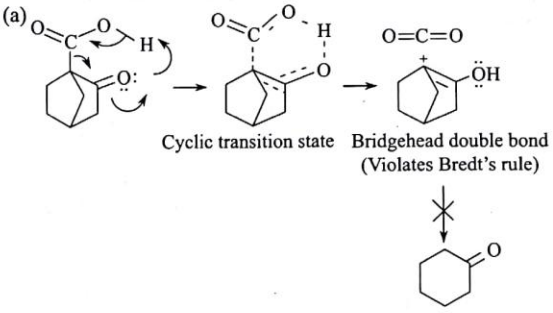
Blanc's rule: Blanc's rule states that when an aliphatic dicarboxylic acid contains six and more carbon atoms, then on heating it alone or in the presence of CaO, a cyclic ketone is obtained having one carbon less than that of the parent acid. On the other hand, when the dicarboxylic acid contains five or lesser number of carbon atoms, then on similar heating, it gives the corresponding anhydride with the same number of carbon atoms.

7.41 Which of the following two isomeric cyclic β-keto-acids will undergo easy decarboxylation on heating? Give reasons.

(a) 

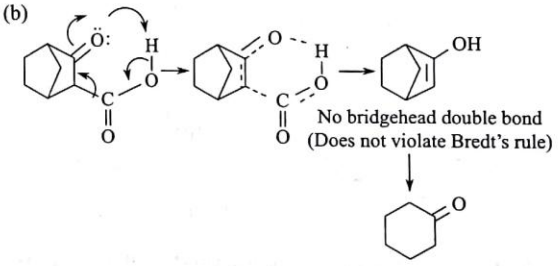
(b) 

Ans β-Keto acids undergo easy thermal decarboxylation through a cyclic transition state. However, the reaction may fail if any factor prevents the formation of this cyclic transition state. In case of the compound (a), such transition state formation is prevented by the violation of the so called Bredt's rule, which states that a double bond cannot be placed in a bridged-bicyclic molecule at the bridgehead carbon atoms. This is shown here.

(a) 

Cyclic transition state — Bridgehead double bond (Violates Bredt's rule)

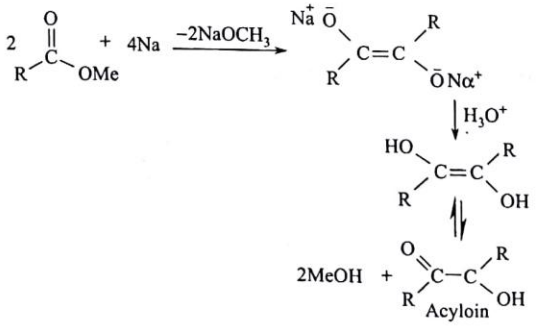
The compound (b) undergoes easy decarboxylation because its transition state formation does not violate Bredt's rule.

(b) 

No bridgehead double bond (Does not violate Bredt's rule)

7.42 What is the name of the reaction which is the bimolecular reductive coupling of aliphatic esters by reaction with molten and highly dispersed metallic sodium in an inert solvent like xylene? Give an example of the reaction along with its mechanism.

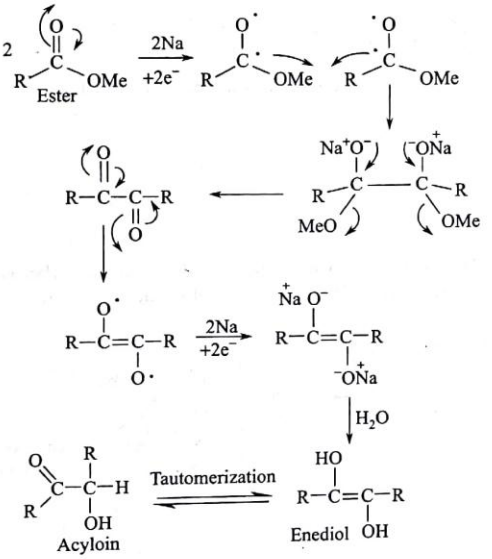
Ans The bimolecular reductive coupling of aliphatic carboxylic esters by reaction with molten and highly dispersed metallic sodium in an inert solvent like xylene under reflux condition gives α-hydroxy ketones, commonly known as acyloins. The reaction is called 'acyloin condensation'.



Acyloin

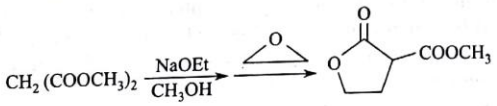
The accepted mechanism of the reaction is given here.

In this proposed mechanism, the metal reacts with the ester in a single electron transfer (SET) process to give a radical anion species which can dimerize to a dialkoxy dianion. Subsequent loss of two alkoxide anions gives a diketone. Further reduction involving electron transfer from the sodium metal to the diketone leads to a new dianion, which upon acidic work-up yields an enediol that tautomerizes to an acyloin.

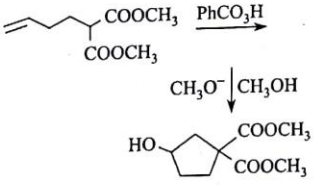


7.43 Propose a mechanism for each of the following transformations.

(a)

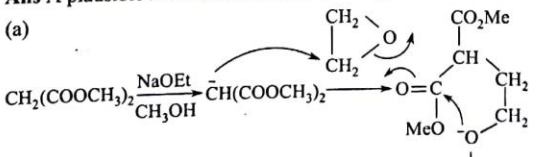


(b)



Ans A plausible mechanism in each case is given here.

(a)



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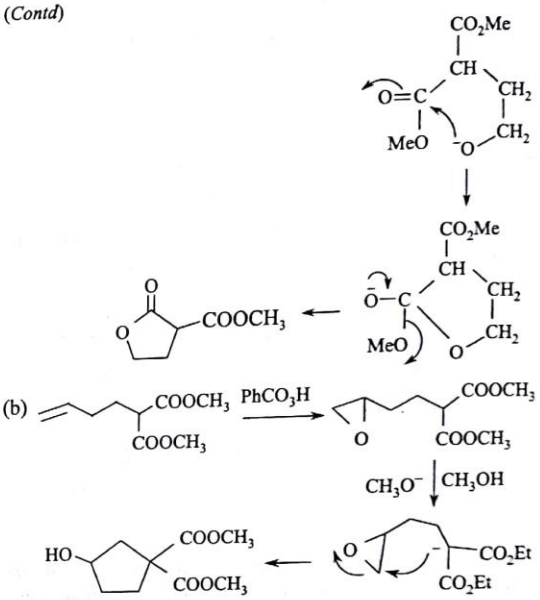
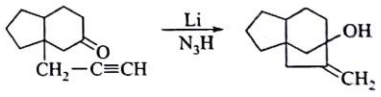
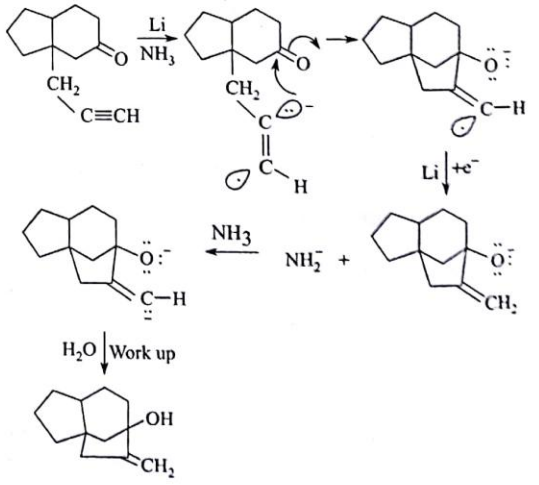


7.44 The following reaction is similar to acyloin condensation. Propose a mechanism for the reaction.

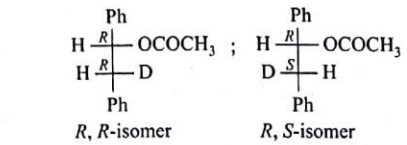


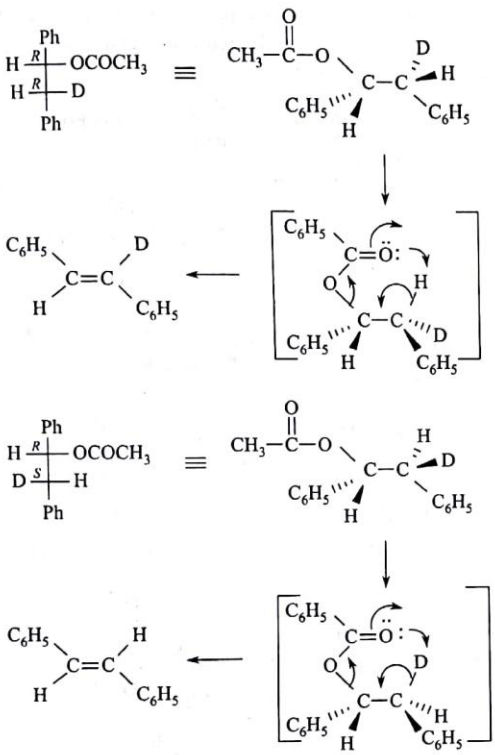
Ans A suggestive mechanism is given below.



7.45 Draw the Fischer projection formulae of (*R*, *R*) and (*R*, *S*) isomers of PhCH(OCOCH$_3$)CH(D)Ph. What products are obtained when they are pyrolysed?

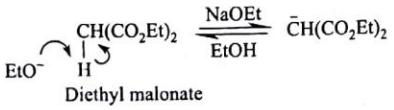
Ans

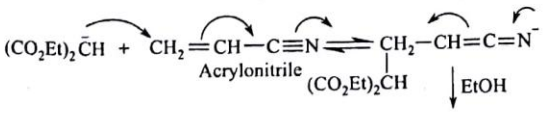




7.46 What is cyanoethylation? How can you synthesize pentanedioic acid (glutaric acid) using this method?

Ans Conjugate addition of an anion derived from active methylene compounds such as diethyl malonate and ethyl acetoacetate to acylonitrile is commonly called cyanoethylation because through this reaction we can introduce $-CH_2CH_2CN$ group in a reactant. The reaction can be used to prepare long-chain dicarboxylic acid. For example glutaric acid can be prepared as follows.





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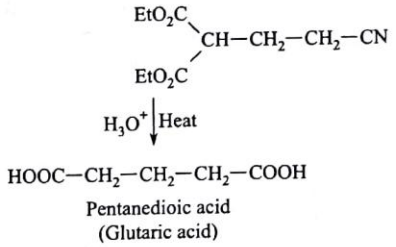
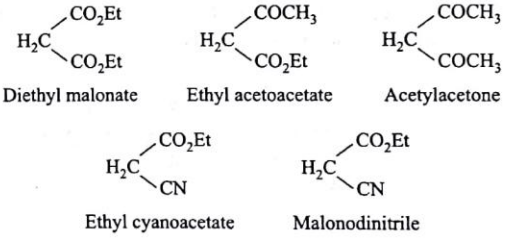


7.47 What is Knoevenagel reaction? Show how diethyl malonate participates in Knoevenagel reaction to give an α,β-unsaturated carboxylic acid? Give the mechanism of the reaction.

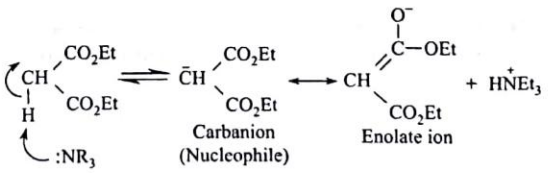
Ans The reaction of carbonyl compounds with active methylene compounds in the presence of a weak base to afford α, β-unsaturated dicarbonyl or related compounds is known as Knoevenagel condensation. The reaction was first introduced by E. Knoevenagel in 1894. Active methylene compounds may be diethyl malonate (DEM), ethyl acetoacetate (EAA), acetylacetone, cyanoacetic ester, etc. In these compounds, a methylene group ($-CH_2-$) is flanked by two strong electron withdrawing groups. The following compounds are considered as potential active methylene compounds.

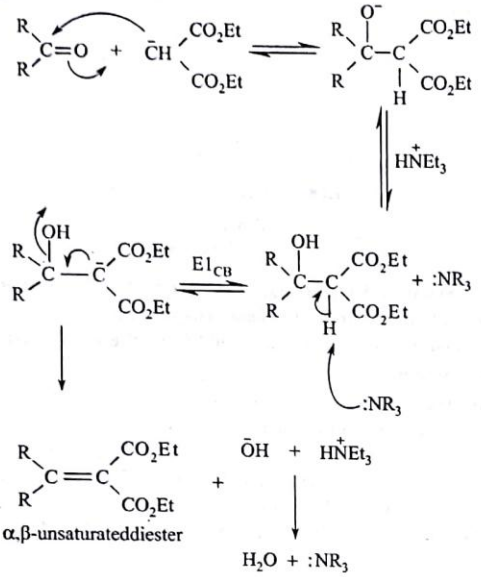


Both aliphatic and aromatic carbonyl compounds can take part in Knoevenagel reaction. A few examples are given here. Mild basic catalysts such as Et_3N, Et_2NH, pyridine (C_5H_5N), and piperidine ($C_5H_{11}N$) are used in the reaction.

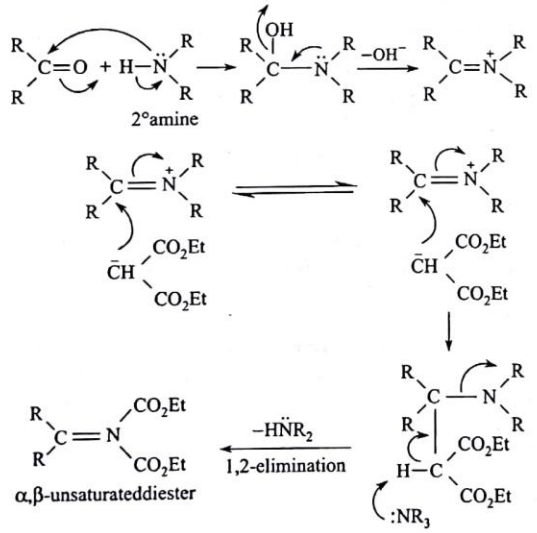
Mechanism:

The Koevenagel condensation is a base-catalysed aldol-type reaction, and the exact mechanism depends on the reacting substances and the nature of the catalyst used. When a tertiary amine is used as a catalyst, the formation of a β-hydroxydicarbonyl intermediate is expected, which undergoes base catalysed dehydration ($E1_{CB}$) to give the final product. The course of the reaction can be shown as follows.

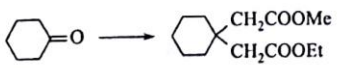




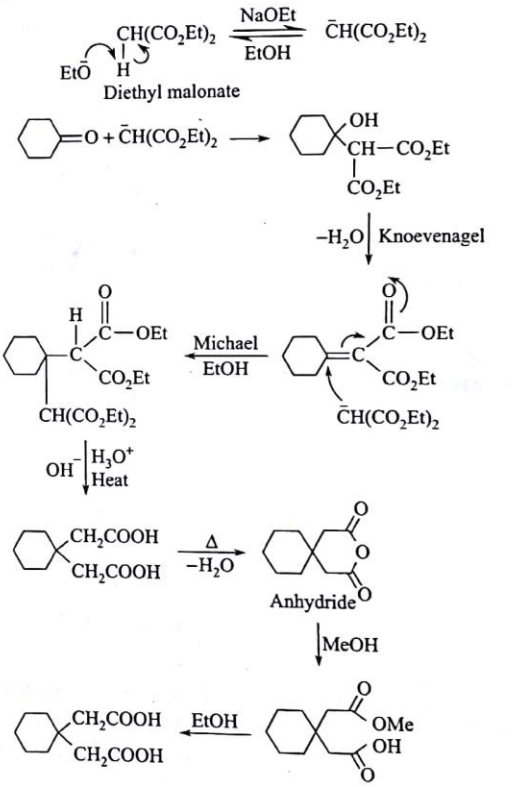
However, when secondary or primary amines are used as catalysts, the carbonyl compound and the amine form an iminium salt and that reacts with the enolate form (or carbanion) and the active methylene group, to form an intermediate which undergoes α-elimination to give the final compound. The course of the reaction is given here.



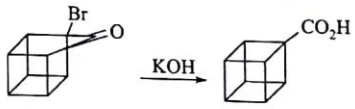
7.48 Show how Knoevenagel reaction followed by Michael reaction can be used to carry out the following transformation.



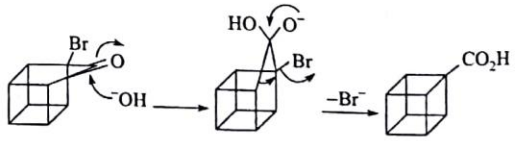
Ans This transformation can be done as follows, Cyclohexanone is made to react with diethyl malonate in the presence of sodium ethoxide in ethanol, when Knoevenagel condensation reaction occurs to give αβ-unsaturated ester. This ester then undergoes Michael condensation with carbanion derived from diethyl malonate. The product is hydrolysed and heated to produce a succinic acid derivative. It is then converted into the corresponding anhydride and then subsequently converted into the desired compound. The necessary reactions are shown here.



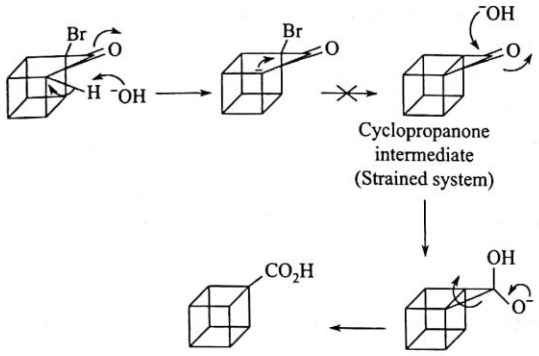
7.49 Give the mechanism of the following transformation.



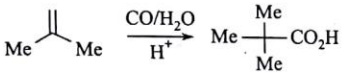
Ans The mechanism is given here.



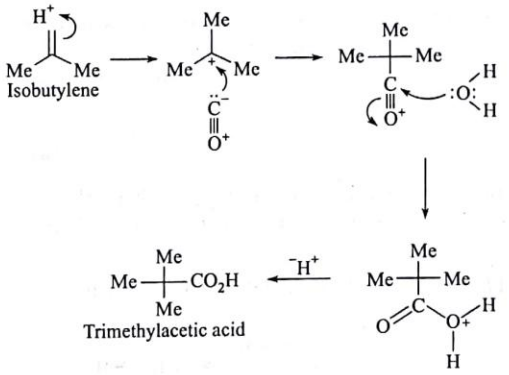
The alternative mechanism could be a Favorskii rearrangement but the intermediate cyclopropanone derivative would be too strained to be formed.



7.50 Give the mechanism of the following conversion.



Ans A plausible mechanism of this conversion is given here.



EXERCISES

7.1 Show how the following conversions may be accomplished.

(a) Cyclohexanone ⟶ 1-Methylcyclohexane carboxylic acid
(b) 2-Methylbutane ⟶ 2,2-Dimethylbutanoic acid
(c) 2-Methylpropan-1-ol ⟶ 3-Methylbutanoic acid

7.2 Write the structure of the product of the reaction of (R)-1-deuterio-1-iodobutane with sodium propionate.

7.3 Show how hex-2-enoic acid can be synthesized starting with 1-Chloropentane.

7.4 How can you prove that in case of $A_{Al}2$ mechanism of esterification, both the oxygen atom of the acid are not retained in the ester?

7.5 Give the name of the reaction of the following transformation and give its mechanism.

$$RCOOAg \xrightarrow{Br_2} RBr + AgBr$$

7.6 Give the mechanism of the reduction of an ester like RCO_2R' by $LiAlH_4$.

7.7 Esterification of trimethylacetic acid with methanol in the presence of conc. H_2SO_4 should be carried out under different reaction conditions and not as in the case of $A_{AC}2$ reaction. Explain this and give the mechanism of esterification with conditions.

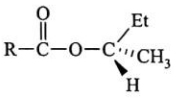
7.8 An esterification reaction cannot occur in the presence of a base. Offer an explanation.

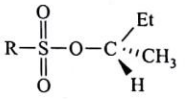
7.9 Explain why RCOOH-type compounds easily lose a H^+ to exhibit acidic character.

7.10 Show how you would prepare each of the following carboxylic acids through Grignard synthesis.

(a) Phenyl acetic acid
(b) But-3-enoic acid
(c) Hexanoic acid
(d) 2,2-Dimethylpentanoic acid.

7.11 Give the mechanisms of base catalysed hydrolysis of the following compound, and discuss the respective stereochemical outcomes.

(a) 

(b) 

7.12 Write the stereochemical formulae for compounds A to F.

(a) *cis*-3-Methylcyclopentanol + $C_6H_5SO_2Cl$ ⟶ B + $C_6H_5SO_3^-$ $\xleftarrow[\text{Heat}]{OH^-}$ A

(b) *cis*-3-Methylcyclopentanol + C_6H_5COCl ⟶ D + $C_6H_5CO_2^-$ $\xleftarrow[\text{Heat}]{OH^-}$ C

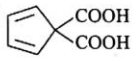
(c) (*R*)-2-Bromooctane + $CH_3CO_2^-Na^+$ ⟶ E + NaBr; E $\xrightarrow{OH^-/H_2O}$ F

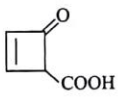
7.13 It is difficult to hydrolyse trimethylacetamide to the corresponding acid by a base. Explain.

7.14 Identify the compounds A , B , C, and D in the following sequence of reactions. C is resolvable but not D.

$$CH_3COOH \xrightarrow[P]{Br_2} A \xrightarrow{OH^-} B \xrightarrow{Heat} C + D$$

7.15 The following acids are found to be reluctant to undergo decarboxylation. Offer an explanation.

(a) 

(b) 

7.16 When optically pure alcohol $PhCHOHCH_3$ is heated with HCO_2H, racemic formate ester is obtained. Explain this observation.

7.17 Give the mechanism of the following reaction:

$$R-\overset{O}{\overset{\|}{C}}-NH_2 \xrightarrow{LiAlH_4} R-CH_2-NH_2$$

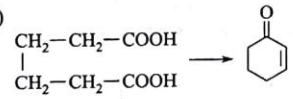
7.18 Answer these questions:

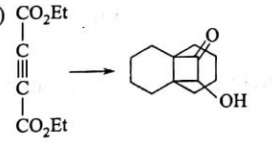
(a) Give the mechanism of methyl ester formation of a carboxylic acid with diazomethane.

(b) Give the mechanism of formation of methyl ester from a carboxylic acid using Gilmann's reagent.

(c) Give the mechanism of esterification of trimethylacetic acid with CH_3OH and H_2SO_4.

7.19 How would you carry out the following conversions?

(a) 

(b) 

7.20 What is Arndt–Eistert reaction? Give the mechanism of the reaction. Why should one use excess (2 molar proportions) of diazomethane in this reaction?

7.21 Which of the following will smoothly undergo decarboxylation on pyrolysis? Give reasons in favour of your answer.

(a) $CH_3-\overset{O}{\overset{\|}{C}}-CH_2-COOH$

(b) $CF_3-\overset{O}{\overset{\|}{C}}-CH_2-COOH$

(c) $CH_3-CH=CH-CH_2-COOH$

(d) $CH_3-CH_2-CH=CH-COOH$

(e) $(CH_3)_3C-CH=CH-COOH$

7.22 How can you separate acetic acid and phenol from their mixture in water? Give appropriate reasons.

7.23 Convert n-$C_5H_{11}CO_2H$ into n-$C_4H_9CO_2H$ by three different methods.

7.24 Using $\overset{*}{M}eI$, NaCN, $Na\overset{*}{C}N$ ($\overset{*}{C}={}^{14}C$) and any other chemicals, suggest a synthesis for each of the following.

(a) $\overset{*}{C}H_3CO_2H$

(b) $CH_3\overset{*}{C}O_2H$

(c) $\overset{*}{C}H_3CO\overset{*}{C}H_3$

(d) $\overset{*}{C}H_3\overset{*}{C}H=O$

7.25 Complete the following reactions with mechanisms.

(a) $Me_3CCH_2OAc + OH^- \xrightarrow{B_{Ac}2} ?$

(c) $Me_3CCH_2OAc + OH^- \xrightarrow{B_{AL}1} ?$

7.26 Draw the energy profile diagram of $A_{Ac}2$ esterification mechanism and comment.

7.27 What are hydroxamic acids? Give the mechanism of formation of hydroxamic from an ester? What is the use of this reaction in the laboratory?

7.28 Complete the following reactions:

(a) $(CH_3CO)_2O + CH_3CH=O \longrightarrow ?$

(b) $CH_3COCl + HCO_2Na \longrightarrow ?$

(c) $(CH_3CO)_2O + N_2O_5 \longrightarrow ?$

(d) $CH_2=C=O + CH_3CO_2H \longrightarrow ?$

7.29 Give the mechanism of the following reaction with explanation.

$$Ph-\overset{O}{\overset{\|}{C}}-OMe + MeONa \longrightarrow Me_2O + PhCO_2^-$$

7.30 Write down the resonating structures of carboxylic acid and carboxylate ion.

7.31 Why is carboxylate ion more stable than carboxylic acid molecule?

7.32 Show the molecular association of acetic acid and formic acid through hydrogen-bonding.

7.33 CH_3COOH is acidic but CH_3CH_2OH is neutral. Why?

7.34 How is the acidity of carboxylic acid explained?

7.35 An organic liquid which is soluble in water liberates carbon dioxide from $NaHCO_3$ and reduces both $KMnO_4$ solution and Tollens' reagent. Identify the liquid.

7.36 Trimethylacetic acid does not undergo H.V.Z. reaction. Why?

7.37 Arrange the following in order of increasing acidity.

(a) Ka's (i) 5.9×10^{-2} (ii) 3×10^{-5} (iii) 6.9×10^{-5} (iv) 1.5×10^{-3} (v) $9. \times 10^{-4}$

(b) (i) F_3CCOOH (ii) Br_3CCOOH (iii) I_3CCOOH (iv) Cl_3CCOOH

(c) (i) Cl_2CHCH_2COOH (ii) CH_3CCl_2COOH (iii) $ClCH_2CHClCOOH$ (iv) $ClCH_2CH_2COOH$

7.38 Which acid chloride of the type RCOCl contains 38.2% of chlorine?

7.39 Which acid chloride of the type RCOCl forms an amide containing 23.3% of nitrogen?

7.40 A neutral liquid having the molecular formula $C_4H_{10}O_2$ gives an alcohol (A) and an acid (B) on hydrolysis. Equivalent weight of the acid is 74. The alcohol responds to haloform reaction. Give the name and formula of the neutral liquid.

7.41 Name and give the structural formulae of the aliphatic acids and esters which have empirical formula $C_2H_4O_2$. Outline the chemical tests that you would apply to distinguish between each isomer.

7.42 For each of the following pairs of substances describe one simple chemical test which would serve to distinguish between them.

(a) Ethanoyl chloride and ethanoic anhydride
(b) Methyl ethanoate and Ethyl methanoate
(c) Ethanamide and Dimethyl methnamide
(d) 2-Methylpropanamide and *N*-Methylpropanmide

7.43 On analysis, a compound X of molecular weight 59 was found to contain 40.67% carbon, 8.5% hydrogen, 23.72% nitrogen, the reminder being oxygen. Derive the formula of X, write a structural formula and name the compound. How does the compound X react with (a) phosphorus pentoxide, (b) sodium hydroxide, (c) nitrous acid, and (d) bromine and potassium hydroxide?

7.44 What happens when malonic acid is (a) heated alone and (b) heated with P_2O_5? How does malonic acid react with bromine and nitrous acid? Give the mechanism of decarboxylation of malonic acid under the action of heat.

7.45 State what happens when succinic anhydride is (a) reduced with sodium/alcohol, (b) heated in a current of dry ammonia, and (c) boiled with water. Give equations.

7.46 Describe the synthesis of succinic acid from ethylene. Mention two other methods for its preparation. What product is formed when succinic acid is heated with acetic anhydride?

7.47 Which acid chloride of the type RCOCl contains 38.2% of chlorine?

7.48 Which acid chloride of the type RCOCl forms an amide containing 23.3% of nitrogen?

7.49 A neutral liquid having the molecular formula $C_4H_{10}O_2$ gives an alcohol (A) and an acid (B) on hydrolysis. Equivalent weight of the acid is 74; the alcohol responds to haloform reaction. Give the name and formula of the neutral liquid.

7.50 Name and give the structural formulae of the aliphatic acids and esters which have empirical formula $C_2H_4O_2$. Outline the chemical tests that you would apply to distinguish between each isomer.

7.51 For each of the following pairs of substances describe one simple chemical test which would serve to distinguish between them.

(a) Ethanoyl chloride and ethanoic anhydride
(b) Methyl ethanoate and ethyl methanoate
(c) Ethanamide and dimethyl methnamide
(d) 2-Methylpropanamide and *N*-methylpropanmide

7.52 On analysis, a compound X of molecular weight 59 was found to contain 40.67% carbon, 8.5% hydrogen, 72% nitrogen, the reminder being oxygen. Derive the formula of X, write a structural formula, and name the compound. How does the compound X react with (a) phosphorus pentoxide, (b) sodium hydroxide, (c) nitrous acid, and (d) bromine and potassium hydroxide.

7.54 Name and give (formulae of the products (A, B, C, D) in the following sequence of reactions.

(a) $CH_3CHO \xrightarrow{[O]} A \xrightarrow{SOCl_2} B \xrightarrow{CH_3COONa} C$

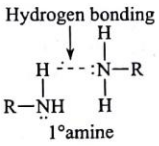
(b) $CH_3COOC_2H_5 \xrightarrow{NH_3} A \xrightarrow{P_2O_5} B \xrightarrow{HCl} C$

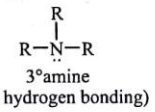
(c) $CH_3COOC_2H_5 \xrightarrow{PCl_5} A \xrightarrow{(NH_4)_2CO_3} B \xrightarrow{\text{Distilled}} C \xrightarrow{Br_2/KOH} D$

8 Aliphatic and Alicyclic Amines, Nitriles, Isocyanides, Ylides, Diazocompounds, and Organometallic Compounds

8.1 In case of isomeric aliphatic amines, tertiary amine has the lowest boiling point. Account for this fact.

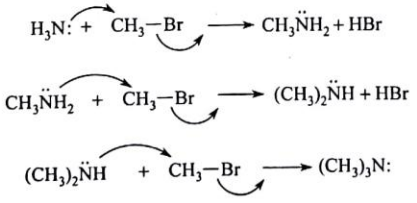
Ans Primary and secondary amines can form intermolecular hydrogen bonding, although weak, and that raises the boiling point of primary and secondary amines. Since tertiary amines have no hydrogen atom attached to nitrogen and intermolecular hydrogen bodings are not possible. This is why tertiary amine has a lower boiling point.





8.2 Account for the fact that pure primary amine cannot be prepared by the reaction between an alkyl halide and concentrated ammonia solution.

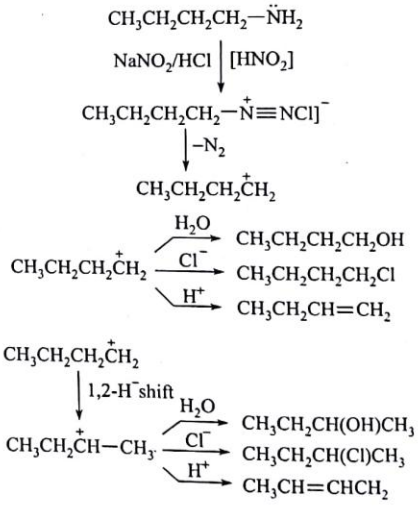
Ans When an alkyl halide is treated with :NH_3 then nucleophilic substitution takes place. After the formation of monoalkylated amine, it is more nucleophilic compared to ammonia and reaction becomes more easy and this trend is continued and we get a mixture of amines.



Nucleophilicity: $(CH_3)_2\ddot{N}H > CH_3\ddot{N}H_2 > H_3N$:

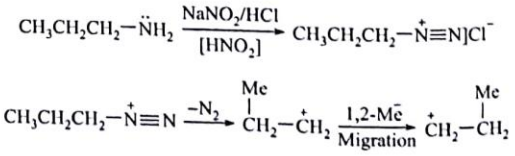
8.3 Treatment of $CH_3CH_2CH_2CH_2NH_2$ with $NaNO_2$/HCl gives two alcohols, two alkenes, and two alkyl chlorides. Identify the compounds and offer an explanation.

Ans Since pairs of isomers are formed, some type of rearrangement takes place in the reactions. The probable mechanisms of the formation of products are given here.

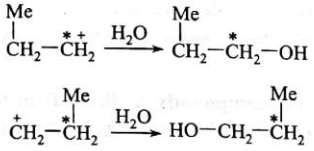


8.4 Devise an experimental method to show whether the Me group in $CH_3CH_2CH_3NH_2$ undergoes migration during deamination with HNO_2.

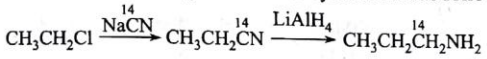
Ans Deamination of primary amine by reacting with HNO_2 forms an unstable diazonium cation which readily looses a molecule of N to form a carbocation. This cation can undergo rearrangement through the migration of a Me group. This is shown here.



The aforementioned 1,2-shift can be monitored if we make the carbon atom attached to $-NH_2$ of the parent compound labelled with ^{14}C. In that case reaction of the carbocations with H_2O can give apparently two compounds differing in the position of the labelled carbon.

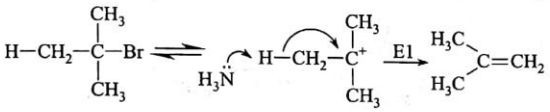


The ^{14}C labelled compound can be synthesized as follows.

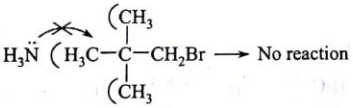


8.5 A student failed to get $(CH_3)_3CNH_2$ and $(CH_3)_3CH_2NH_2$ by the action of NH_3 on the corresponding bromides. Provide reasons. How can you prepare these compounds?

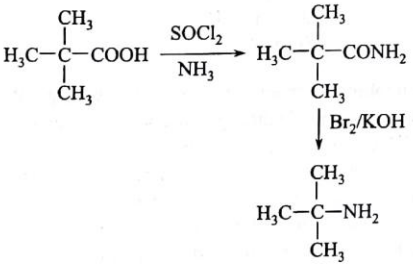
Ans In case of the formation of $(CH_3)_3NH_2$ from $(CH_3)_3Br$ by the action of NH_3, E1 elimination occurs to form an alkene.



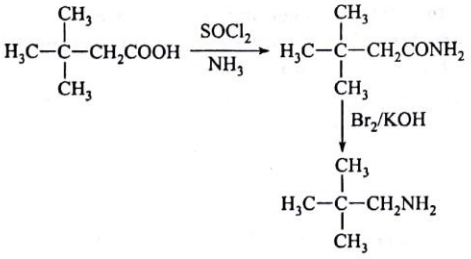
In case of neopentyl bromide, NH_3 fails to react to form the corresponding amine by S_N2 mechanism because of steric interaction.



The aforementioned amines can be prepared by Hofmann degradation from the corresponding carboxylic acid. Reactions are shown here.



The second compound can be synthesized as follows.



8.6 Complete the following equations.

(a) $Ph(CN)CH(CN)CO_2Et \xrightarrow[\text{Heat}]{\text{aq. HCl}} ?$

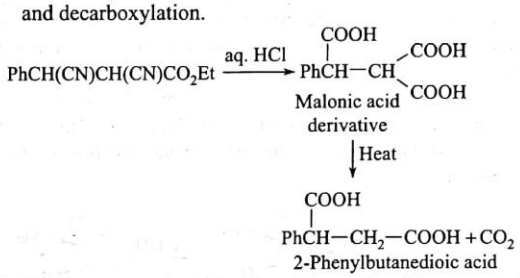
(b) $Me_2CHNO_2 + HCH{=}O + EtNH_2 \longrightarrow ?$

(c) $H_2NCONH_2 + CH_3CH_2CH_2CH_2OH \xrightarrow{\text{Heat}} ?$

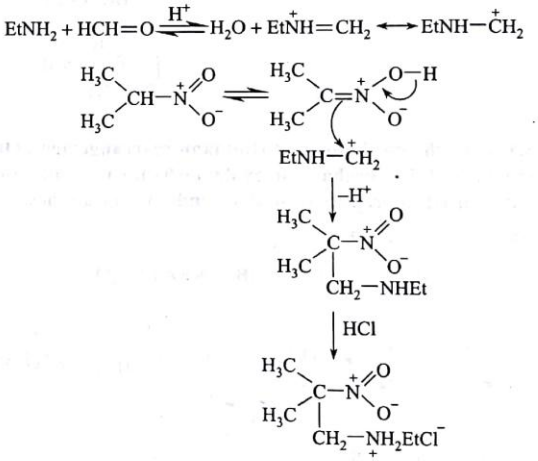
(d) $Me_2C(CN)NHNHC(CN)Me_2 \xrightarrow{HOCl} ?$

Ans

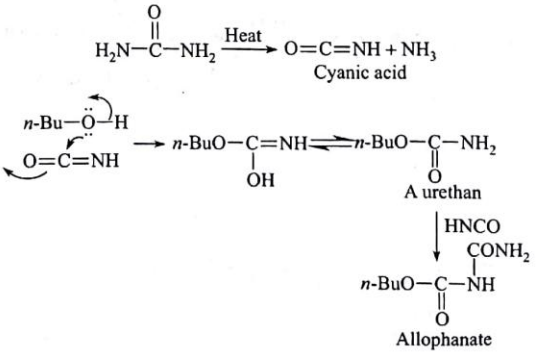
(a) A succinic acid derivative is formed through hydrolysis and decarboxylation.



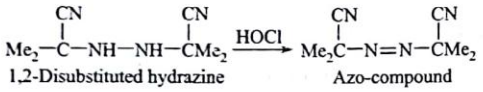
(b) This is an example of the Mannich reaction. The course of the reaction is given here.



(c) Urea forms cyanic acid (HNCO) on heating. This reacts with the alcohol to form a urethane. With excess of cyanic acid, the final product is an allophanate.

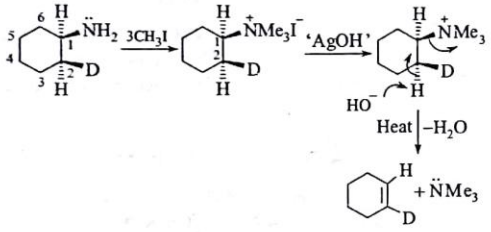


(d) HOCl can oxidize a 1,2-disubstituted hydrazine. In this case also oxidation occurs to give an azo-compound.



8.7 How can you demonstrate that Hofmann elimination is stereospecific *trans*-elimination reaction?

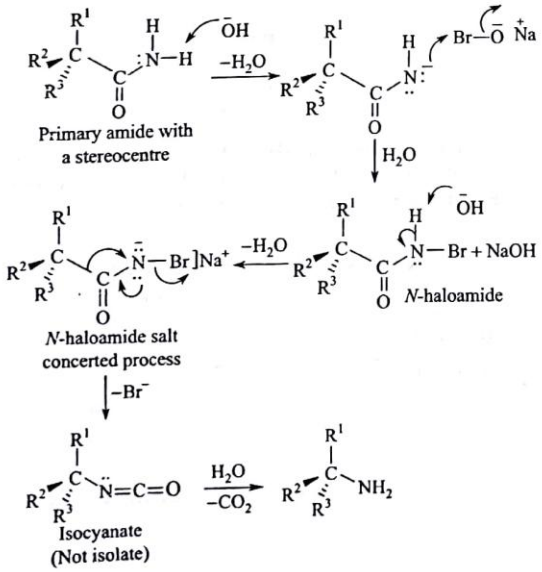
Ans If the following compound is subjected to Hofmann elimination, after being converted to a quaternary ammonium hydroxide, then the cycloalkene formed contains deuterium. This supports the fact that the Hofmann elimination is stereospecifically *trans*, because H at C-2 and $-N + Me_3$ are anti to each other. Another product is possible if the *trans*-hydrogen atom of the other *ortho*-position (C-6) is involved.



8.8 Give the mechanism of Hofmann rearrangement. On the basis of this mechanism, explain why the reaction cannot be used to prepare secondary and tertiary amines.

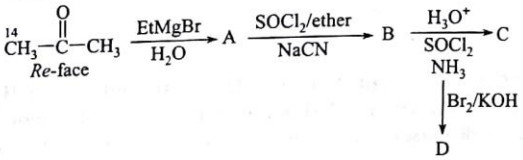
Ans The mechanism is given here.

$$Br_2 + 2NaOH \longrightarrow NaBr + NaOBr + H_2O$$

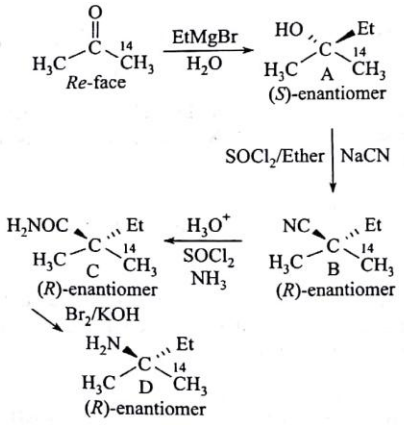


From the aforegiven mechanism, it is evident that for the formation of the intermediate *N*-haloamide salt, we need two hydrogen atoms on the nitrogen atom of the amide group, that is, only primary carboxamide can undergo Hofmann degradation. Therefore, *N*-substituted carboxamide cannot give Hofmann degradation reaction and that is why secondary and tertiary amines cannot be prepared by this method.

8.9 Identify the compounds A, B, C, D in the following reactions. Explain the reactions including stereochemical aspects.



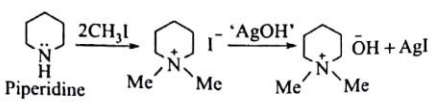
Ans The reactions are shown here.

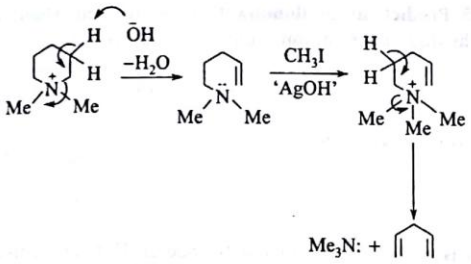


The alcohol (A) undergoes inversion of configuration when converted into a nitrile through the corresponding chloro compound. When (A) is converted into its chloro compound with $SOCl_2$, then the retention of configuration occurs. Subsequent reactions from (A) to (D) do not involve any change in the configurations of the chiral centre because the reactions do not need to cleave any bond directly attached to the chiral centre.

8.10 How Hofmann degradation can be used to determine the structure of cyclic secondary amine like piperidine. Show the reactions with explanation.

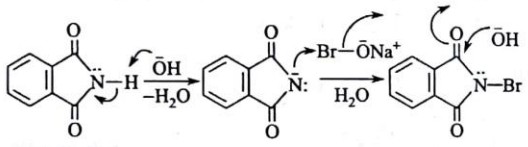
Ans This can be done by carrying out repeated Hofmann degradation reactions as shown here.

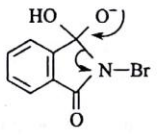


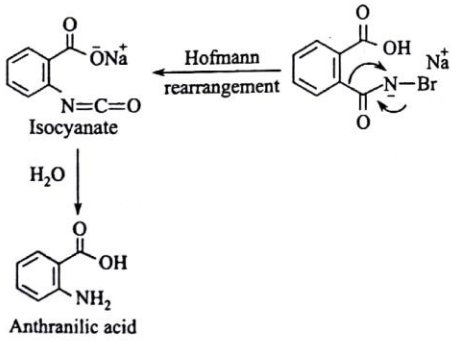


8.11 Give an example where a secondary amide undergoes Hofmann degradation.

Ans Normally primary amides like $RCONH_2$ undergo Hofmann degradation to produce a primary amine but cyclic imides like succinimide and phthalimide can undergo Hofmann degradation. Reaction is shown with phthalimide which finally gives anthranilic acid when treated with Br2 and alkali. The reactions are shown here.

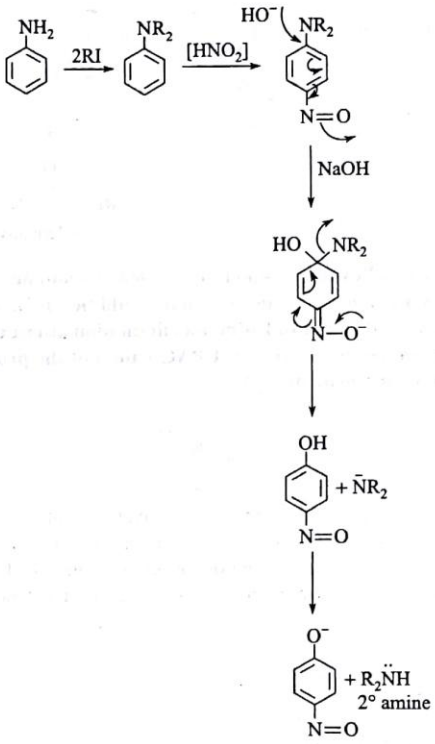






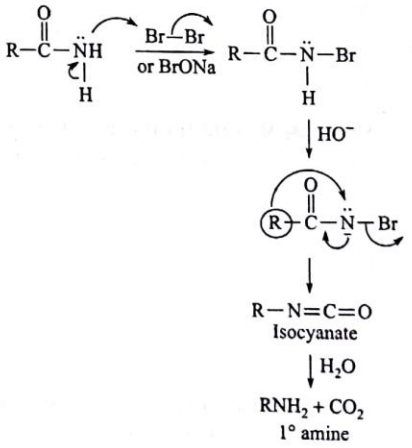
8.12 Give a method by which pure aliphatic secondary amines can be prepared in good yield.

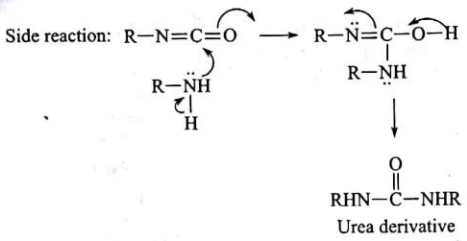
Ans This is done taking the help of the aromatic compound aniline. The course of the reactions is shown here.



8.13 When Hofmann degradation is carried out on $RCONH_2$ then some amount of RNHCONHR is also formed. Account for this observations.

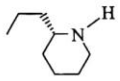
Ans In Hofmann degradation, the intermediate compound is an isocyanate. This isocyanate can react with some of the primary amine, already formed in the reaction and consequently some *N*-alkylated urea is formed. The reaction is shown here.



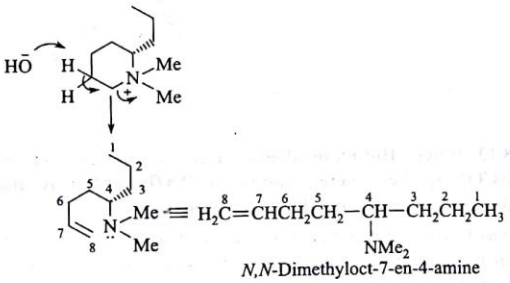
Side reaction: 

Urea derivative

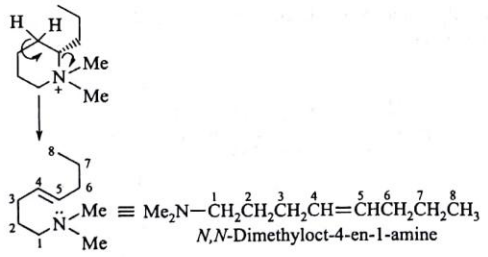
8.14 The following compound is called (+)-coniine, a poisonous alkaloid of hemlock. What would be the products when it is subjected to Hofmann elimination after exhaustive methylation? Give the IUPAC names of the products (without stereochemistry).



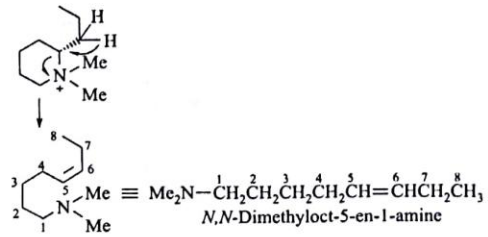
Ans The compound is a piperidine derivative. Hofmann elimination can occur involving three different β-hydrogen atoms shown here. Thus three compounds are possible. The IUPAC names are given here without mentioning the stereochemical aspects.



N,N-Dimethyloct-7-en-4-amine

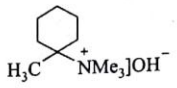


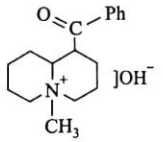
N,N-Dimethyloct-4-en-1-amine



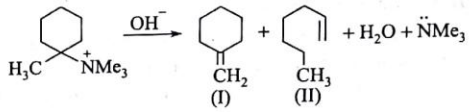
N,N-Dimethyloct-5-en-1-amine

8.15 Predict the predominant alkene formed when each of the quaternary ammonium hydroxide is heated.

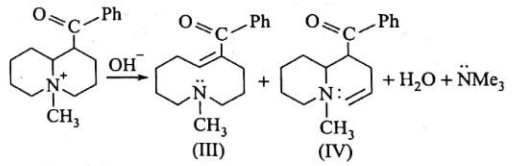
(a) 

(b) 

Ans Both the given compounds undergo Hofmann elimination to give mixture of alkenes but one of them predominates. Reactions are shown here.

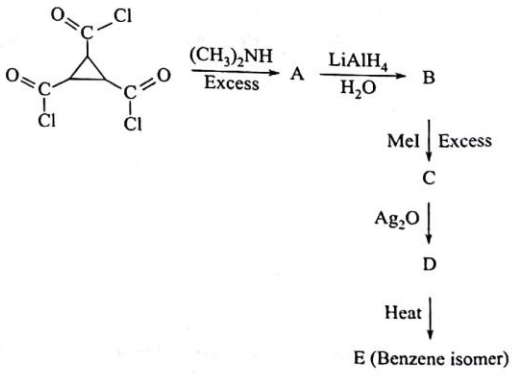
(a) 

In this case, the compound (I) is the major product because loss of β-hydrogen from the $-CH_3$ group is sterically more favourable as it is more exposed for the approach of hydroxide base.

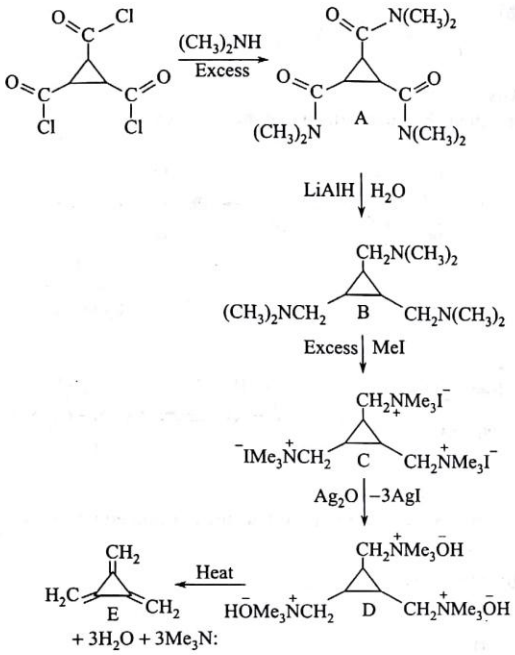
(b) 

In this case, the compound (III) would be the major compound, because the β-hydrogen attached to the ring carbon bearing the benzoyl group is more acidic compared to the other β-hydrogen atom.

8.16 Identify the compounds in the following sequence of reactions.



Ans Reactions mentioned in the question are shown here. 'E' is an isomer of benzene.



8.17 What are the common features in the preparation of amines by Hofmann, Curtius, Lossen, and Schmidt rearrangements?

Ans The common features of Hofmann, Curtius, Lossen, and Schmidt rearrangements are given here.

(a) All are selective methods for the synthesis of pure primary amines.

(b) All are intramolecular rearrangements in which an alkyl (some cases aryl groups) migrates on an electron deficient nitrogen atom.

(c) In all these cases an isocyanate (R=N=C=O) is an intermediate, which on acid or base catalysed hydolysis gives a primary amine.

(d) When the migrating group (R*) is a chiral centre then 100% retention of configuration occurs in the migrating group in the amine formed.

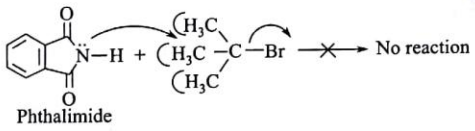
8.18 Answer these questions.

(a) Could *tert*-butylamine be prepared by the Gabriel phthalimide synthesis? If so, write out the synthesis. If not, explain why.

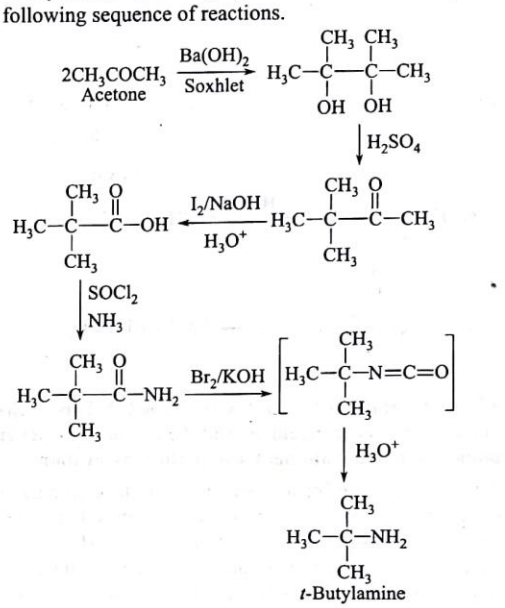
(b) How can you proceed to synthesize *tert*-butylamine from acetone?

Ans The answers are as follows:

(a) It is to be noted that *tert*-amine cannot be prepared by Gabriel phthalimide synthesis. This is because of the fact the *N*-alkylation of pthalimide is a S_N2 substitution and *tert*-halides do not take part in S_N2 substitution because of steric factor.

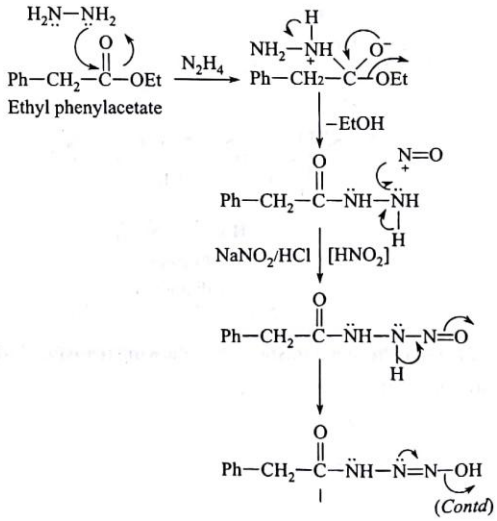


(b) *t*-Butylamine can be prepared from acetone by the following sequence of reactions.



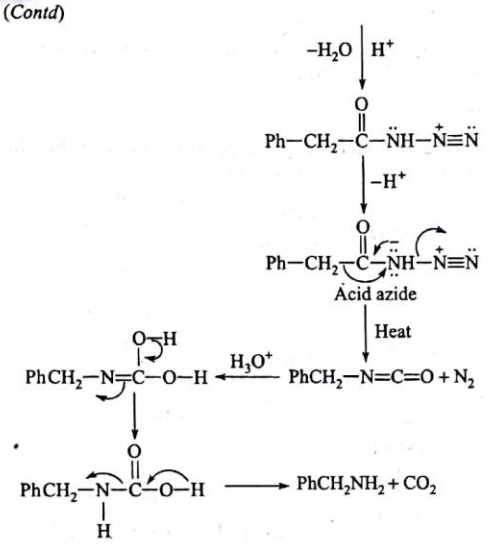
8.19 Using suitable ester and hydrazine as primary reactants, proceed to synthesize $PhCH_2NH_2$. Give the mechanisms of the steps and the name of the reaction (if any).

Ans The method of synthesis may be shown as follows. The rearrangement that occurs from acid azide to the corresponding isocyanate is called 'Curtius rearrangement'



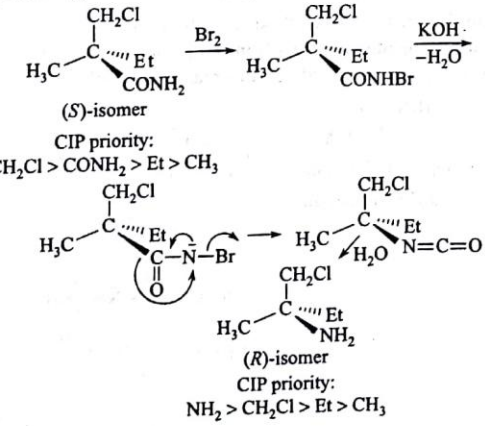
(*Contd*)

(*Contd*)



8.20 (*S*)-isomer of $ClCH_2C(CH_3)(Et)CONH_2$ is subjected to Hofmann rearrangement and the product is a (*R*)-enantiomer of a chiral amine. Explain this observation.

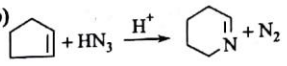
Ans In case of Hofmann rearrangement, the configuration of the migrating group bearing the chiral centre is retained. In this case also when (*S*)-isomer of $Me_2NC(CH_3)(Et)CONH_2$ underwent Hofmann rearrangement, the configuration is retained but after the reaction the product has stereochemical descriptor (*R*), because of the change in the priority order of ligands attached to the chiral centre according to CIP rules. The rearrangement is shown here.



8.21 Give the mechanism of the following transformations.

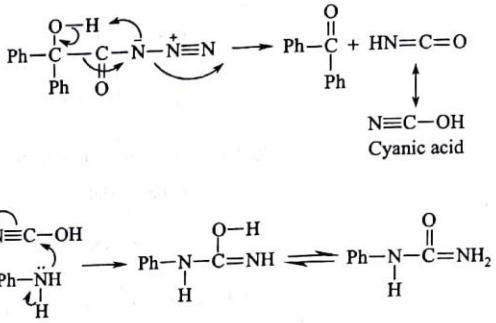
(a) $Ph_2C(OH)-C(=O)-N_3 + PhNH_2 \rightarrow Ph_2C=O + PhNH-C(=O)-NH_2$

(b)



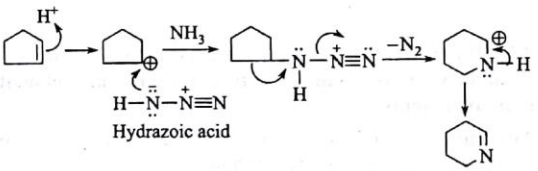
Ans

(a) Plausible mechanism may be as follows.



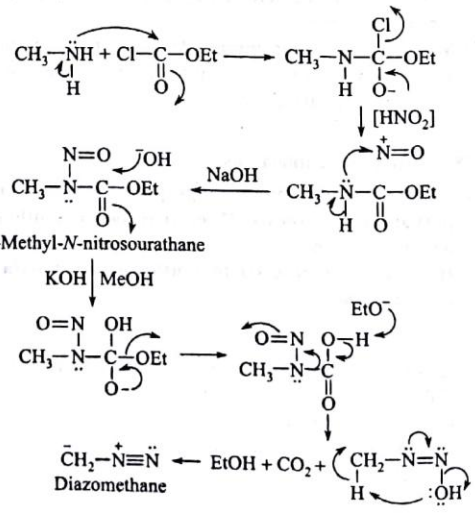
In this case, the normal Curtius rearrangement does not occur.

(b) Mechanism may be as follows.



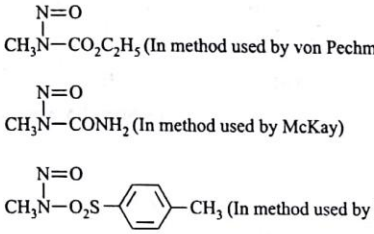
8.22 Von Pechmann prepared diazomethane from CH_3NH_2 and $ClCO_2C_2H_5$. Give the method with mechanism.

Ans The plausible mechanism is given here.



8.23 What are the common structural features present in different starting materials which on treatment with alkali produce diazomethane? Give the mechanism of any of these the reaction.

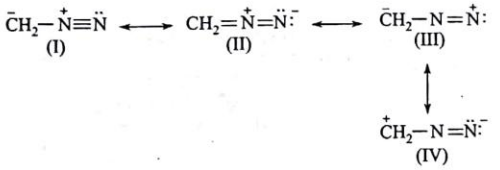
Ans The common structural feature of compounds that leads to the generation of diazomethane is that the compounds must contain MeN-NO moiety. For example, the following compounds give diazomethane when treated with alkali.



For the mechanism of von Pechmann reaction for the preparation of diazomethane, see 8.22.

8.24 Although diazomethane is a polar structure, its dipole moment value is quite low. Offer an explanation.

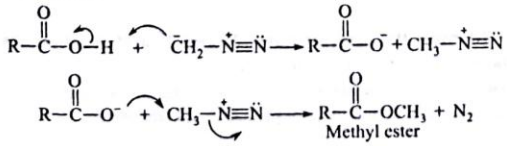
Ans Although diazomethane is an aliphatic diazonium compound having a +ve charge and a –Ve centre, its dipole moment value is low (less than 1.0D). This is due to the fact that diazomethane is a resonance hybrid and in this resonance reversal of polarity occurs. This why we get an average value of the dipole moment which is obviously low. Resonating structures of diazomethane is given here.

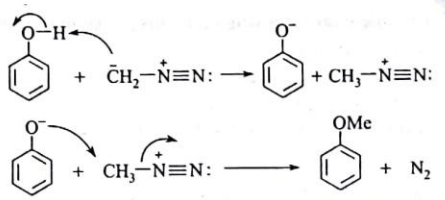


In structures (II) and (IV), we find that centres of +ve and –ve charges have changed their positions. Since nitrogen is more electronegative than carbon, the derection of dipole is towards the nitrogen atom.

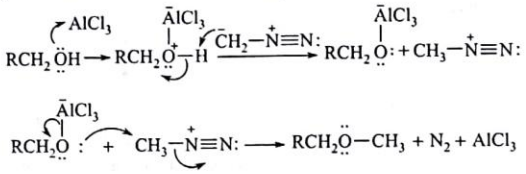
8.25 Explain why diazomethane is a versatile reagent to convert carboxylic acids to its methyl ester and phenol to anisole. Can alcohols be converted to the corresponding methyl ether by same method?

Ans Diazomethane can function as a base in its resonating forms and can abstract an acidic proton to form $CH_3-\overset{+}{N}\equiv N:$, which then reacts with acid anion or phenoxide ion to give the corresponding methyl ester or methyl ether. Reactions are shown here.



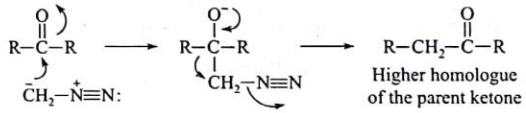


Alcohols cannot be converted in to their methyl ethers by reaction with diazomethane, because hydrogen atom of the –OH group is not sufficiently acidic to be abstracted by diazomethane. However conversion can be accomplished in presence of Lewis acid like $AlCl_3$, as shown here.

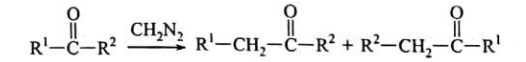


8.26 Show examples of the use of diazomethane to get the higher homologues of both acylic and cyclic ketones. Show possibilities of formation of any other compound.

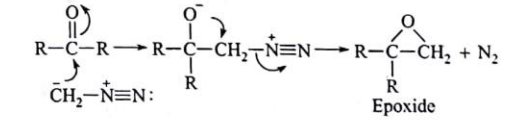
Ans Necessary examples are given here.



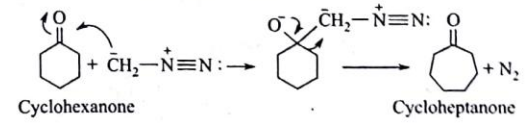
If a mixed ketone is taken then two isomeric higher homologues are obtained.

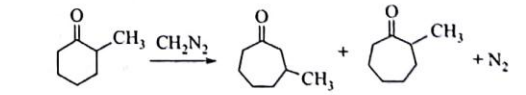


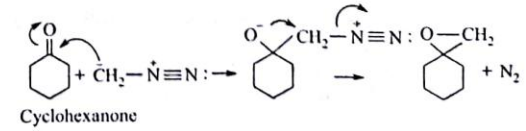
Along with the higher homologue of the ketone, some amount of epoxide is also formed.



In case of cyclic ketones similar reactions take place.







8.27 Complete the following reactions giving mechanisms.

(a) $C_6H_6 + N_2CHCO_2Et \longrightarrow ?$

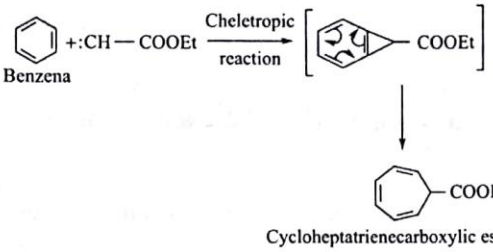
(b) $EtCH{=}O + CH_2N_2 \longrightarrow ?$

(c) $MeCOCH_2Cl + CH_2N_2 \longrightarrow ?$

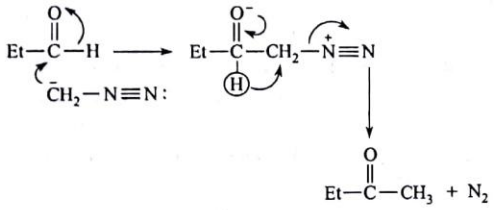
(d) $MeNHCONH_2 + HNO_2 \longrightarrow A + KOH \longrightarrow ?$

Ans The following are the mechanisms:

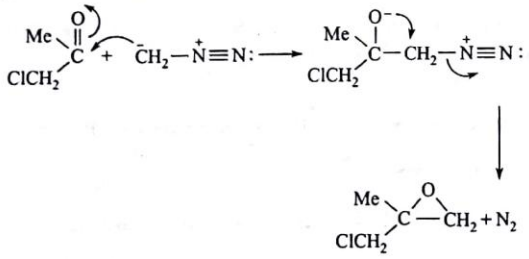
(a) Diazoacetic ester gives a carbine with reaction with a p-bond of benzene and finally a cycloheptatriene derivative is formed.



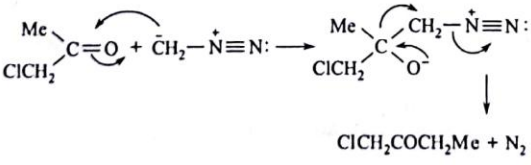
(b) An aldehyde reacts with diazomethane to form a ketone where one of the alkyl groups is methyl group. The mechanism is shown here.



(c) Two products are formed. These are shown here.

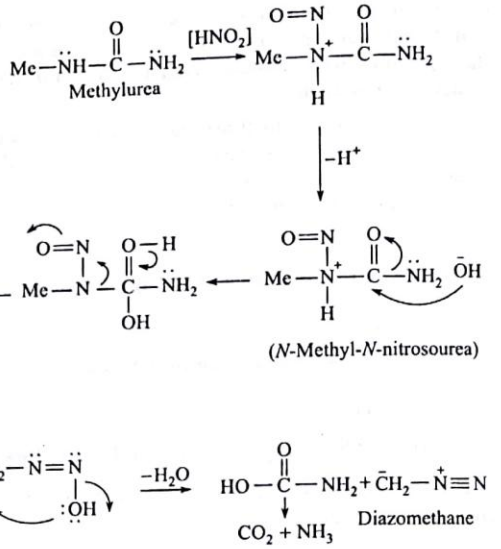


Another compound is a ketone.

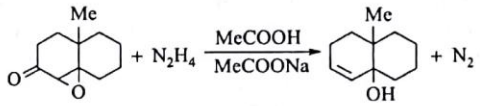


Since Me group is more electron rich, it will migrate preferentially.

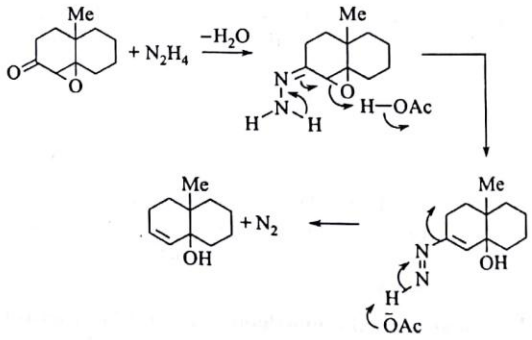
(d) This is another reaction by which diazomethane is prepared in the laboratory. The mechanism is shown here.



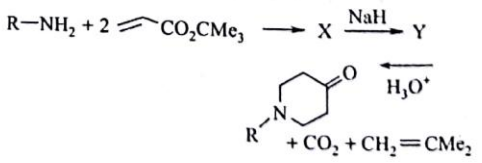
8.28 Give the plausible mechanism of the following conversions.



Ans Plausible mechanism can be shown as follows.

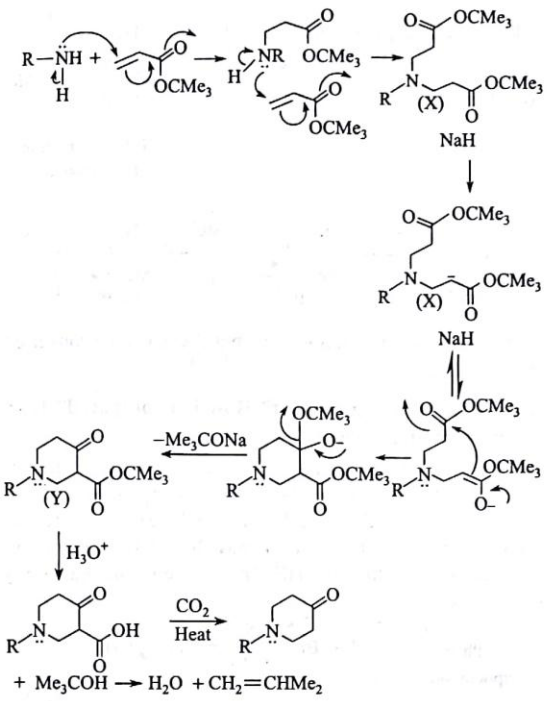


8.29 Give the mechanism of the reaction given here.



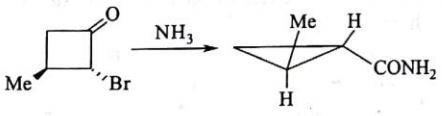
Identify the intermediates X and Y and mention the names of the reactions involved.

Ans Plausible mechanism of the aforementioned reaction is given here. (X) and (Y) are probable intermediates.

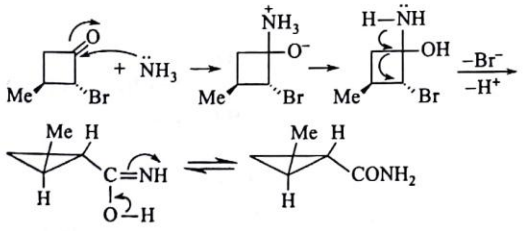


The initial reactions between αβ-unsaturated ester with the RNH_2 is a Michael type conjugate additions. These reactions give a diester (X), which undergoes base (NaH) catalysed Dickmann cyclization leading to the formation of a cyclic b-keto ester. Subsequent hydrolysis followed by decarboxylation results in the final compound.

8.30 Give plausible mechanism of the following conversions and comment on the stereochemistry of the reaction.

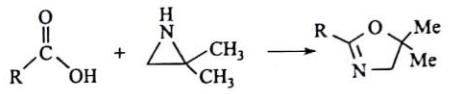


Ans The following is the probable mechanism of this transformation.



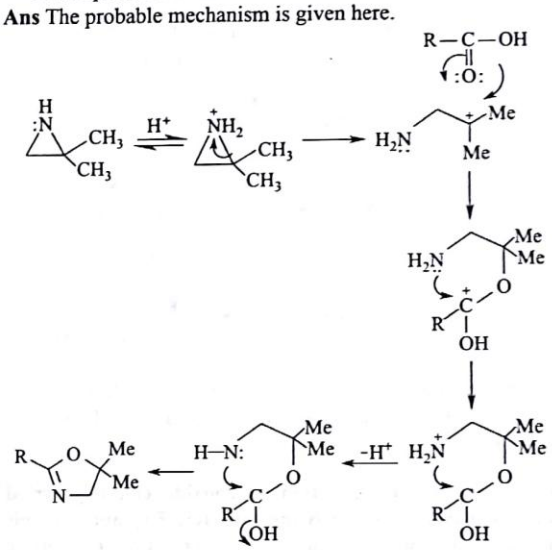
In the parent ketone, the carbon atoms bearing Me and Br groups are chiral centres. During the reaction, the chiral centre bearing the bromine atom undergoes inversion in configuration during bond migration. The configuration of the chiral centre bearing Me group is not disturbed.

8.31 When a carboxylic acid is treated with 2, 2-dimethylaziridine, an oxazoline is formed.



Give a plausible mechanism.

Ans The probable mechanism is given here.



8.32 Which of the following reactions is faster and why?

(a) $R\bar{S}\,\overset{+}{Na} + RX \longrightarrow R_2S + NaX$

(b) $R\bar{O}\,\overset{+}{Na} + RX \longrightarrow R_2O + NaX$

Ans Since the alkyl sulphide is more nucleophilic than the alkoxide, the reaction (a) proceeds further than the reaction (b).

$$RS^- + R{-}X \xrightarrow[\text{Faster}]{S_N2} R{-}S{-}R + X^-;$$

$$RO^- + R{-}X \xrightarrow[\text{Slower}]{S_N2} R{-}O{-}R + X^-$$

8.33 Complete the following eqations and give a plausible mechanism in each case.

(a) $CH_2{=}CH{-}C{=}CH_2 + SO_2 \longrightarrow ?$

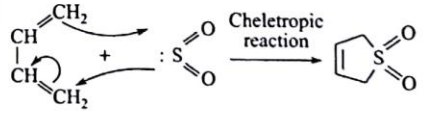
(b) $MeCONH_2 + P_2S_5 \xrightarrow{C_6H_6} ?$

(c) $CH_2{=}CHCN + HOCH_2CH_2SH \longrightarrow ?$

(d) $CH_2{=}CH_2 + (SCN)_2 \longrightarrow ?$

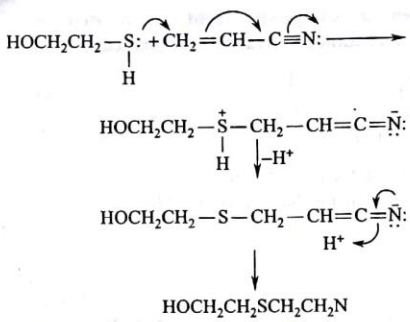
Ans The necessary reactions are shown here.

(a)

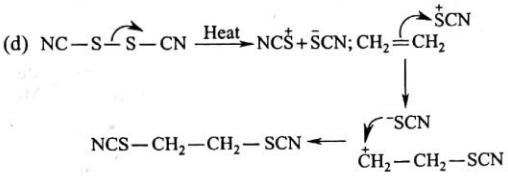


(b) $MeCONH_2 + P_2S_5 \xrightarrow{C_6H_6} Me{-}\overset{S}{\overset{\|}{C}}{-}NH_2$

(c)



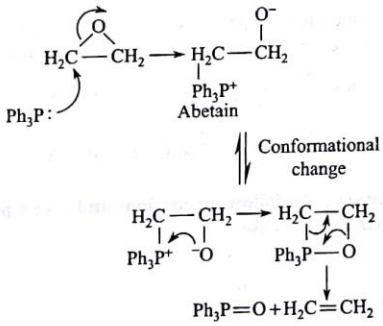
(d)



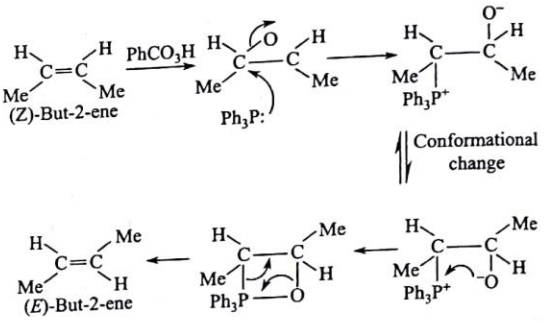
The reaction can also proceed by free radical mechanism because S—S bond is relatively weak (bond energy = 225.9 kJ/mole)

8.34 How is deoxygenation of epoxide can be carried out using Ph_3P:? What is the product? Explain how this method can be used to interconvert diastereisomeric alkenes.

Ans Deoxygenation of an epoxide using nucleophilic reagent Ph_3P: can be shown as follows.



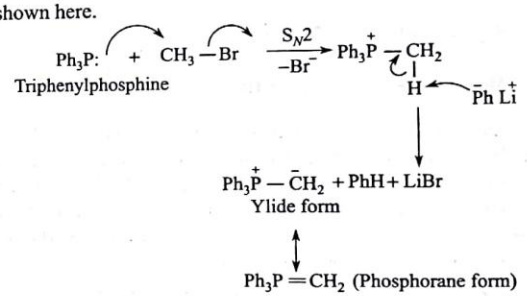
In the aforegiven deoxygenation reaction, the intermediate betain can undergo conformational change and the reaction between positively charged phosphorus and negatively charged oxygen gives a four-membered cyclic intermediate, which readily decomposes to an alkene and $Ph_3P{=}O$. This change of conformation and the formation of four-membered cyclic intermediate has been used to carry out interconversions of diastereoisomeric alkenes. The process is called 'stereomutation'. An example is given here.



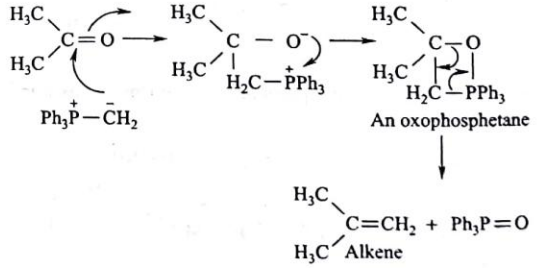
By similar set of reactions, (*E*)-but-2-ene can be converted into (*Z*)-but-2-ene.

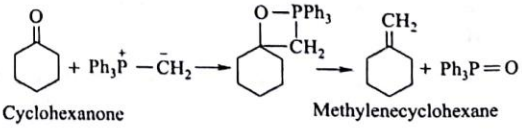
8.35 What is Wittig reagent? How is it prepared? Give the use of Wittig reagent.

Ans Triphenyl phosphonium ylide is called Wittig reagent. It is prepared by the reaction between triphenylphosphine and a primary or secondary alkyl halide and treating the resultant phosphonium salt with strong base like PhLi or *n*-BuLi in solvents like dry ether or THF. The course of the reaction is shown here.

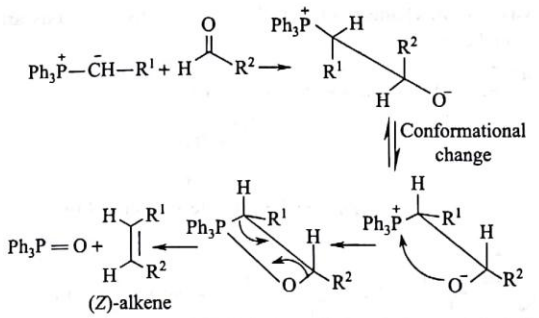


Wittig reagents are used to generate an olefinic double bond (C=C) regioselectively in place of C=O. An illustration is given here.



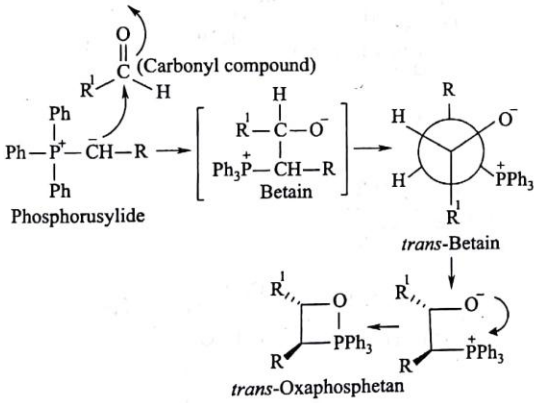


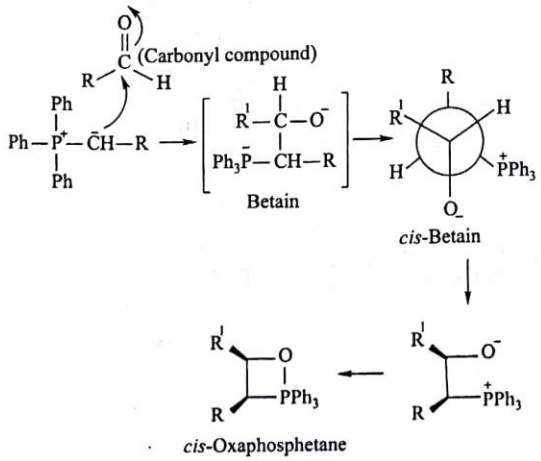
Alkenes can be synthesized using Wittig reagent. Examples are given here.



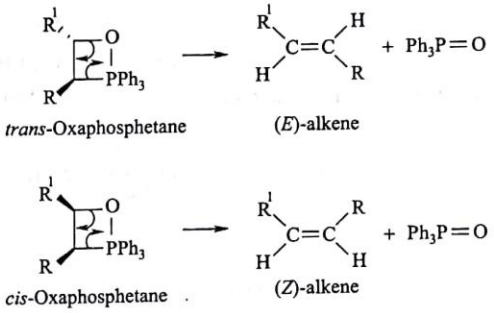
8.36 Discuss the stereochemistry of reaction between $Ph_3\overset{+}{P}-\bar{C}HR$ and $^1RCH{=}O$ to explain the formations of *E* and *Z* isomers of $R^1CH{=}CHR$.

Ans The ylide reacts with the carbonyl compound to form a four-membered intermediate called oxaphosphetane, through a betain. The formation of *cis*- and *trans*-oxaphosphetane can be explained on the basis of conformations of the betain.





Decomposition of the oxaphosphetane to alkene and triphenylphosphonium oxide is shown here. The driving force for the rapid decomposition of the oxaphosphetanes to alkenes is the formation of very stable phosphine oxide.



8.37 Complete the following equations.

(a) $\bigcirc{=}O + Ph_3P{=}CHPh \longrightarrow ?$

(b) $Ph_3P + ClCH_2COMe \rightarrow ? \xrightarrow{Na_2CO_3} ? \xrightarrow{PhCH=O} ?$

(c) $PhCO(CH_2)_4Br \xrightarrow{Ph_3P} ? \xrightarrow[EtOH]{EtONa} PhCO(CH_2)_3CH{=}PPh_3 \rightarrow ?$

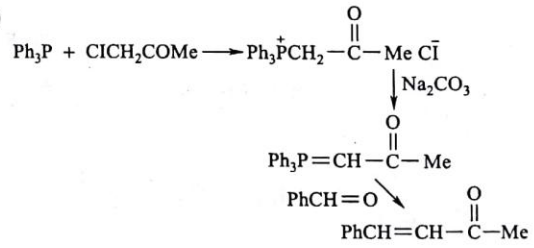
(d) $Ph_3P{=}CH_2 + MeCH{=}CHCOMe \longrightarrow ?$

(e) $Ph_2C{=}O + Ph_3P{=}CH-OCH_3 \longrightarrow ? \xrightarrow{H_3O^+} ?$

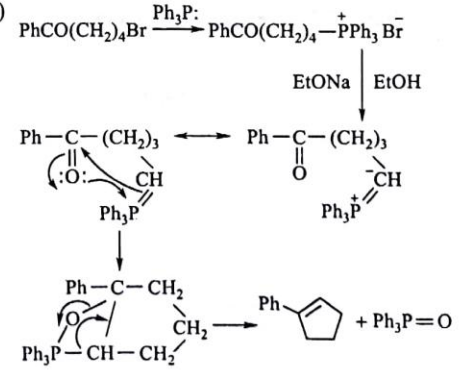
Ans The products are shown here.

(a) $\bigcirc{=}O + Ph_3P{=}CHPh \longrightarrow \bigcirc{=}CHPh$

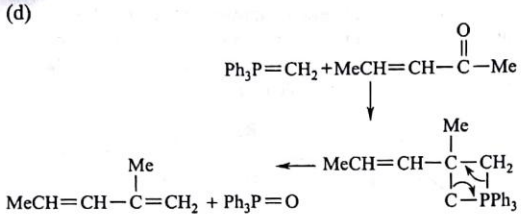
(b)



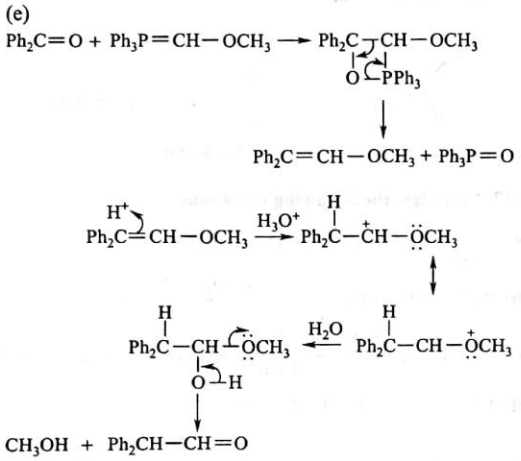
(c)



(d)



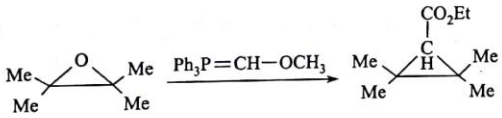
(e)



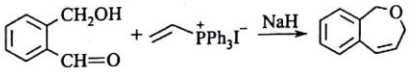
8.38 Give the mechanism of the following transformations.

(a) $BrCH_2COOMe \xrightarrow[BuLi,\ PhCH=O]{Ph_3P} PhCH=CH-CO_2Me$

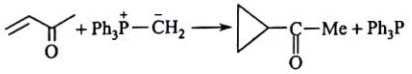
(b)



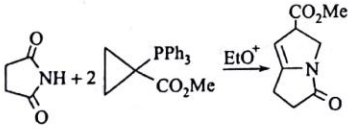
(c)



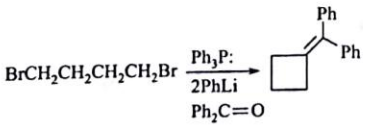
(d)



(e)

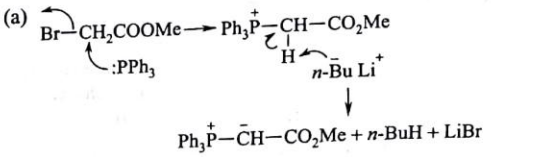


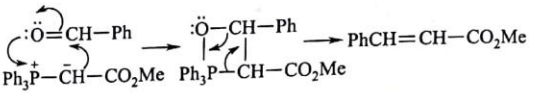
(f)



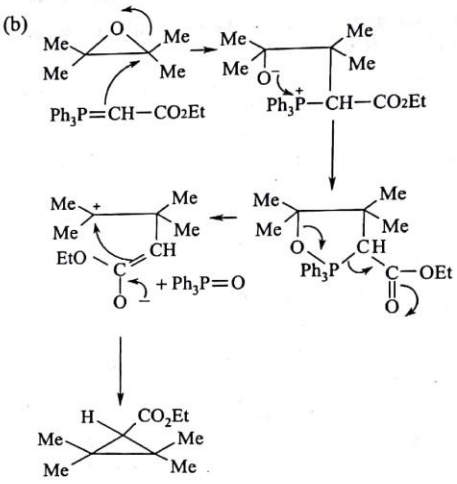
Ans The mechanism of the aforegiven transformations are given here.

(a)

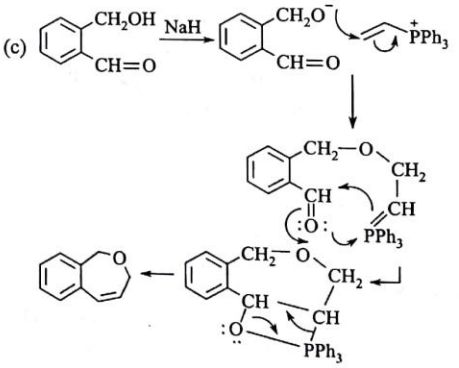




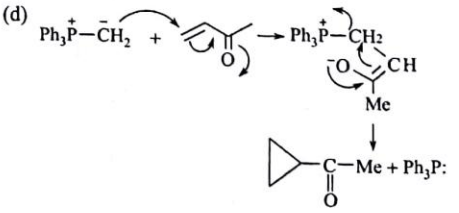
(b)



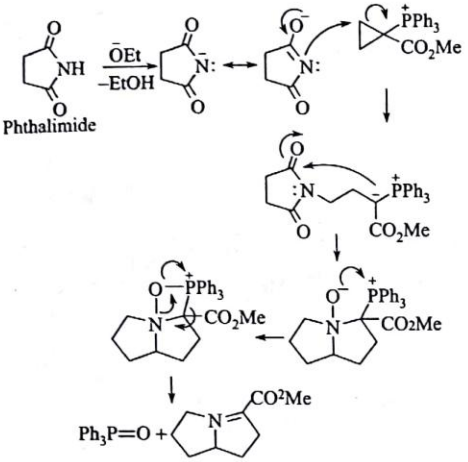
(c)



(d)



(e)



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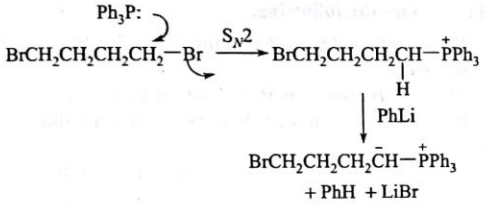
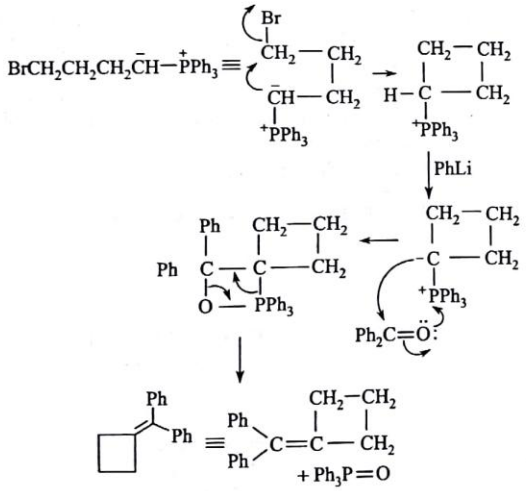


(g)



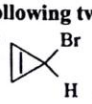
8.39 Explain the following.

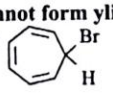
(a) The phosphorus ylide from 5-bromocyclopenta-1, 3-diene is very unreactive.

(b) $Ph_2P{-}CH_2Ph$ cannot be used for the preparation of phosphorus ylides.

(c) $Ph_3\overset{+}{P}{-}\overset{-}{C}Ph_2$ does not react with carbonyl compounds.

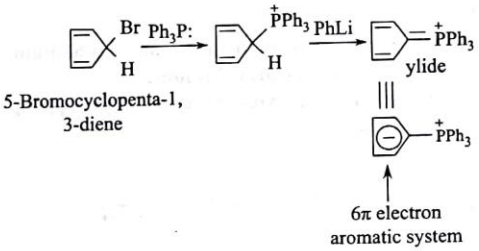
(d) Following two cyclic bromides cannot form ylides.

(i) 

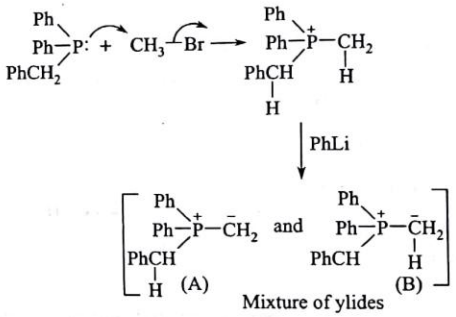
(ii) 

Ans

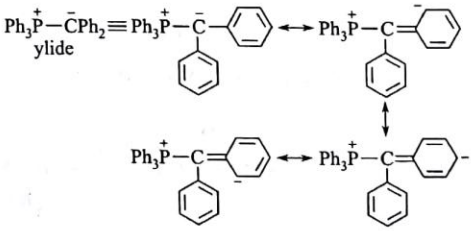
(a) When phosphorus ylide is prepared from 5-bromocyclopenta-1, 3-diene, the resultant ylide is very much stable because of the formation of aromatic cyclopenta-1, 3-dienide ion. This ylide fails to react with carbonyl compounds.



(b) If we try to prepare a phosphorus ylide using $Ph_2P{-}CH_2Ph$, then two α-hydrogen atoms will be present in the intermediate compound and that will complicate the formation of the desired ylide and subsequent reactions with carbonyl compounds. The possible reaction is shown here.

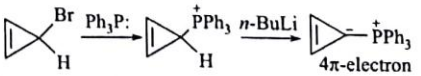


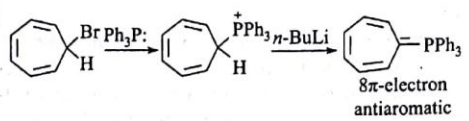
(c) The ylide $Ph_3\overset{+}{P}{-}\overset{-}{C}Ph_2$ cannot react with carbonyl compounds because the negative charge on the $\overset{-}{C}Ph_2$ group becomes extensibly delocalized involving benzene nuclei and turned out to be very poor nucleophilic centre.



(d) When the two compounds, shown in the question, react with Ph_3P: and then with *n*-BuLi, then the rings with a carbanionic centre become antiaromatic. Since antiaromatic system is very unstable, ylides formations are resisted.

(i)

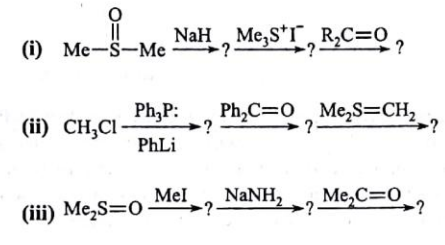


(ii) 

8.40 Answer the following.

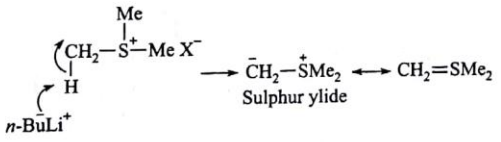
(a) How is sulphur ylides formed from sulphonium salts and strong base like alkyl lithium?

(b) Complete the following reaction with appropriate mechanism.

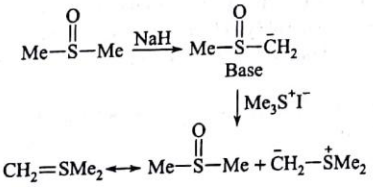


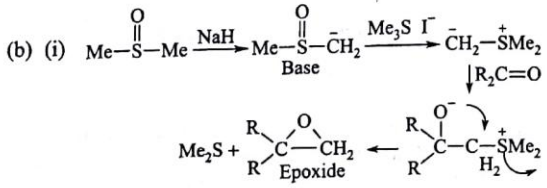
Ans

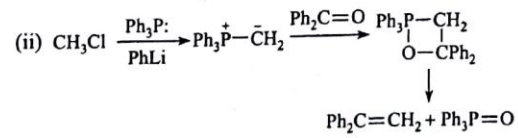
(a) Sulphur ylides are formed by the action of base on sulphonium salts having a-hydrogen atom. Alkyl lithiums are normally used as base.

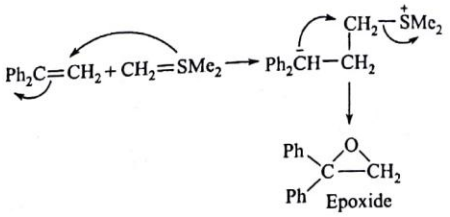


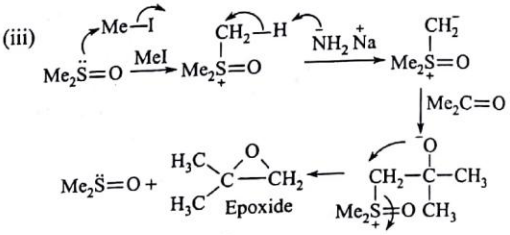
Another useful base is methylsulphinyl carbanion obtained from dimethyl sulphoxide.



(b) (i) 

(ii) 



(iii) 

8.41 Explain the following.

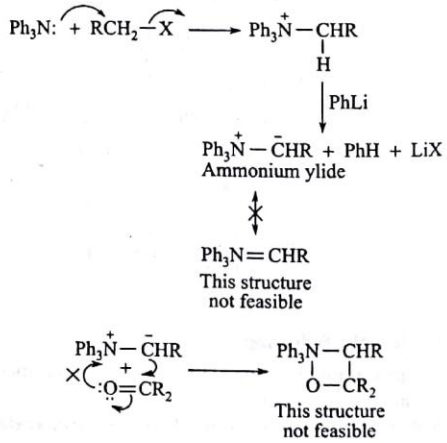
(a) Ph_3N: cannot be used as a substitute for Ph_3P: in Wittig reaction.

(b) $Me_2S{=}CH_2$ reacts with $R_2C{=}O$ to give an epoxide but $Ph_3P{=}CH_2$ reacts with $R_2C{=}O$ to give an alkene.

Ans

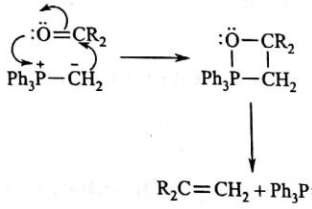
(a) Ph_3N: is less nucleophilic compared to Ph_3P:, because lone pair of electrons on the phosphorus atom is more polarizable compared to that on the nitrogen atom of Ph_3N:. This is because of the fact that 'P' is bigger in size and less electronegative than 'N'.

More over, nitrogen ylide, if formed is not stabilized by delocalization of electrons due to the absence of '*d*' orbital on the nitrogen atom. For the same reason, ylide fails to react with carbonyl compound.

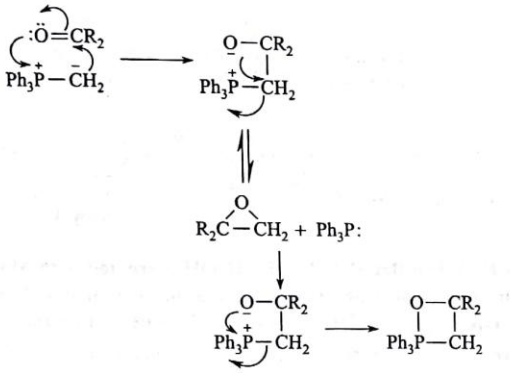


(b) Sulphur ylides reacts with a ketone to form an epoxide. In contrast to the phosphorus ylides and related reagents, reactions of sulfur ylides with carbonyl compounds do not usually lead to four-membered ring species analogous to oxaphosphatanes. The exact reason for this difference in the respective reaction product may be the

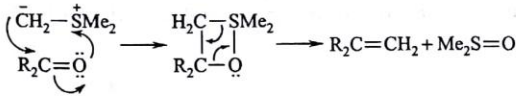
stability of the final products. In case of phosphorus ylide, a four-membered ring species analogous to oxaphosphatane is formed (probably through reversible formation of a betain) and it readily decomposes to form very stable products alkene and triphenylphosphine oxide.



Alternatively, epoxide formation can be shown as follows but the final products are not as stable as the previous one.

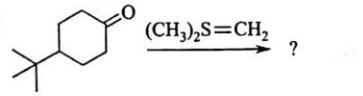


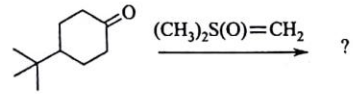
In case of sulphur ylide, formation of four-membered intermediate is unlikely because, sulphur ylide behaves as a nucleophilic carbanionic reagent rather than as ylide, and the following reaction does not occur.



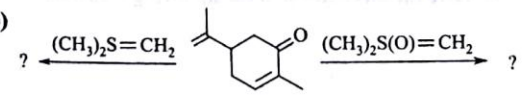
8.42 Give the products of the following reactions.

(a)



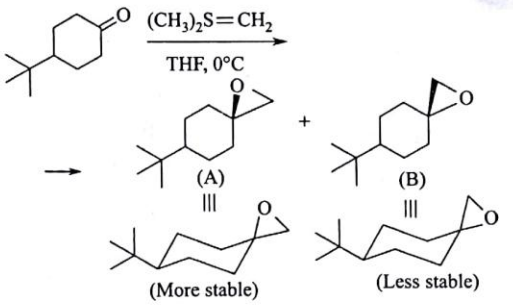


(b)



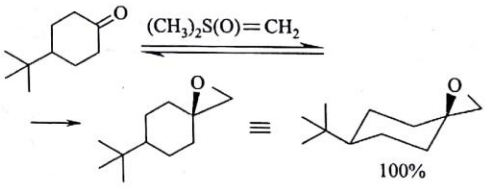
Ans The product in the case of $[(CH_3)_2S{=}CH_2)]$ are two diastereoisomeric spiro-compounds with one epoxy-ring. The structures are shown here.

(a)

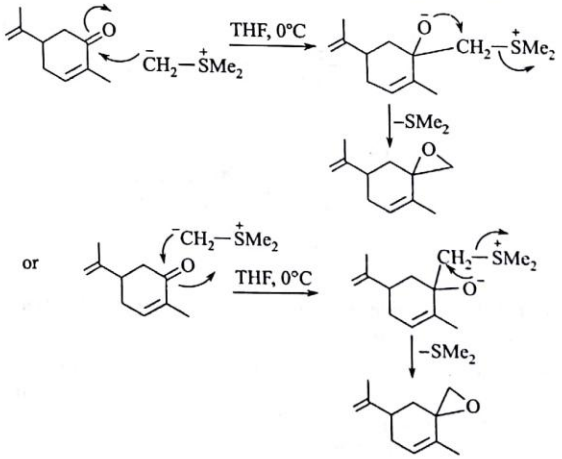


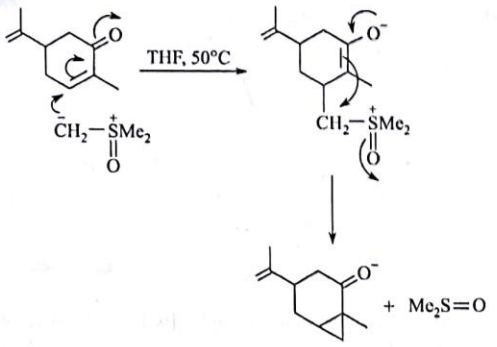
Dimethylsulphonium methylid $[(CH_3)_2S{=}CH_2)]$ generally adds irreversibly to ketones and aldehydes. In the aforementioned problem, (A) is the major product and because of less diaxial interaction, that is, the size of the oxygen atom is smaller than the carbon atom. The reaction is considered to be kinetic process. This can also be explained on the basis of steric approach-controlled reaction. Equatorial approach of sulphur ylide is stereically more favoured leading to the formation of product (A).

On the other hand, dimethylsulphoxonium methylide $[(CH_3)_2S(O){=}CH_2)]$ adds reversibly to a carbonyl compound. This gives almost exclusively the product (A) with equatorial C—C bond. Therefore, this product is essentially thermodynamically controlled.



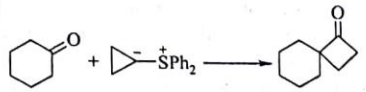
(b) In this case, when less stable ylide $[(CH_3)_2S{=}CH_2)]$ is used then 1, 2- addition occurs to give an epoxy compound but when more stable ylide $[(CH_3)_2S(O){=}CH_2)]$, then conjugate addition (1, 4-addition) is the preferred reaction. Products and their formations, in each case, are shown here.



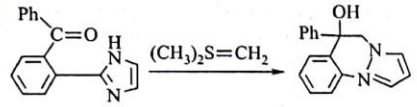


8.43 Give the mechanism of the following transformations.

(a)

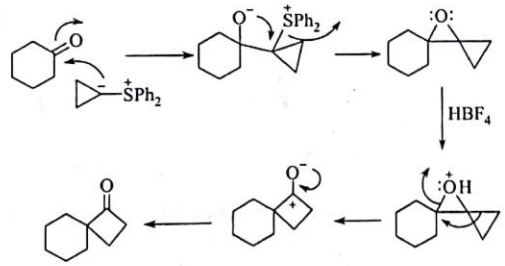


(b)

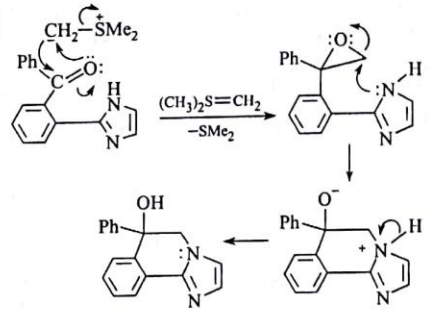


Ans The mechanism of the aforegiven transformations are given here.

(a)



(b)



8.44 What is Gilmann reagent? How is it prepared? Mention two uses of this reagent in organic chemistry.

Ans Lithium dialkylcuprates having the general formula R_2CuLi are called Gilman's reagents. Henri Gilman prepared lithium dimethylcuprate by adding cuprous iodide to methyllithium in tetrahydrofuran at –78°C.

$$CH_3I + 2Li \longrightarrow CH_3Li + LiI;$$
$$2CH_3Li + CuI \longrightarrow \underset{\text{Gilman reagent}}{(CH_3)_2CuLi} + LiI$$

Gilmann reagent is used to synthesize long-chain hydrocarbons and carbonyl compounds. Illustrations are given here.

$$(CH_3)_2CuLi + CH_2CH_2CH_2CH_2CH_2I \xrightarrow{Et_2O} \underset{n\text{-Hexane}}{CH_3{-}CH_2CH_2CH_2CH_2CH_3} + CH_3Cu + LiI$$

Ketones are synthesized by the following reaction.

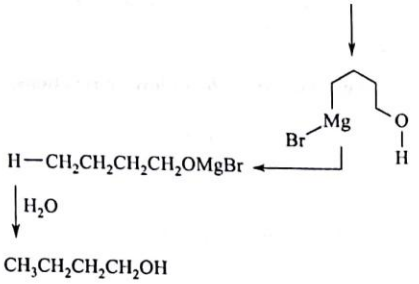
$$\underset{\text{Gilman reagent}}{R_2CuLi} + \underset{\text{Acyl halide}}{R^1{-}C(=O){-}Cl} \longrightarrow \underset{\text{Ketone}}{R{-}C(=O){-}R^1}$$

$$\underset{\text{Acetylcycyclohexane}}{\text{C(=O)–Cl}} + \underset{\text{Gilman reagent}}{(CH_3)_2CuLi} \xrightarrow{-78°C} \underset{\substack{\text{Cyclohexyl}\\ \text{methyl ketone}}}{\text{C(=O)–CH}_3}$$

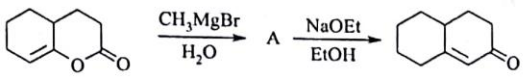
8.45 When $BrCH_2CH_2CH_2CH_2OH$ is treated with Mg in dry ether and when resultant solution is hydrolysed then $CH_3CH_2CH_2CH_2OH$ is obtained. Provide an explanation.

Ans The aforementioned compound contains an OH group with a hydrogen reactive to Grignard reagent. Therefore, after the formation of the Grignard reagent from the bromine-side, it reacts immediately to give the given alcohol. The course of the reaction is shown here.

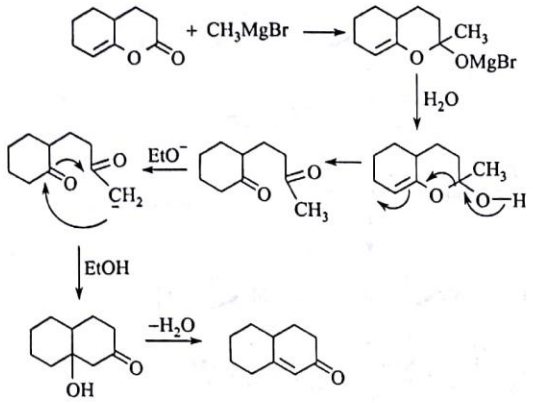
$$Br{-}CH_2CH_2CH_2CH_2OH \xrightarrow[\text{Ether}]{Mg} BrMgCH_2CH_2CH_2CH_2OH$$



8.46 Give the mechanism of the following transformation.

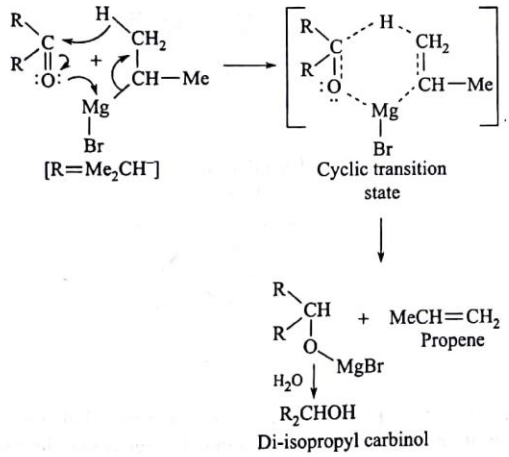


Ans The mechanism of the aforementioned change is given here.



8.47 Give an example where a Grignard reagent react as a reducing agent rather than as a source of nucleophilic reagent.

Ans When isopropylmagnesium bromide is added to di-isopropyl ketone, the expected tertiary alcohol is not formed. In this case, di-isopropyl carbinol and propene are formed. Here the Grignard reagent serves as a reducing agent to provide a hydride. The accepted mechanism involving a cyclic transition state is given here.



8.48 Complete the following equations.

(a) $C_6H_{11}MgBr + BrCH_2CBr{=}CH_2 \xrightarrow{Et_2O} ?$

(b) $n\text{-}PrMgbr + MeC(OMe)_3 \xrightarrow[H^+]{C_6H_6} ?$

(c) $CH_2{=}C{=}O + EtMgBr \xrightarrow[H^+]{C_6H_6} ?$

(d) $3EtMgBr + (EtO)_2CO \xrightarrow[H^+]{Et_2O} ?$

Ans The respective reactiona are shown here.

(a) $C_6H_{11}MgBr + BrCH_2CBr{=}CH_2 \xrightarrow{Et_2O} C_6H_{11}CH_2\underset{Br}{C}{=}CH_2 + MgBr_2$

In this case, only the allylic bromine is sufficiently reactive to undergo double decomposition.

(b) $n\text{-}PrMgBr + MeC(OMe)_3 \xrightarrow[-MgBr(OMe)]{C_6H_6} n\text{-}Pr\text{-}C(OMe)_2\text{-}Me$ (Ketal)

ortho-ester

$\xrightarrow{H^+}$ $n\text{-}Pr\text{-}\underset{Me}{C}{=}O$

(c) $CH_2{=}C{=}O + EtMgBr \xrightarrow{C_6H_5} CH_2{=}\underset{Et}{C}\text{-}OMgBr$

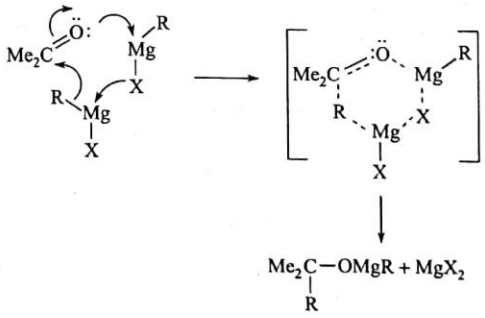
Ketene

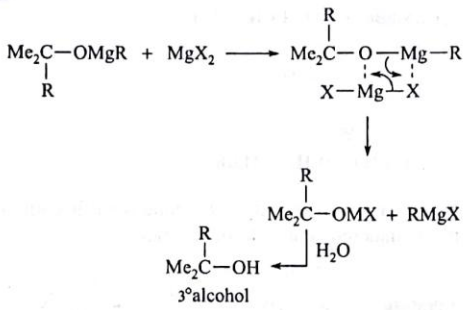
$\xrightarrow{H^+} CH_2{=}\underset{Et}{C}\text{-}OH \rightleftharpoons CH_3\text{-}\underset{Et}{C}{=}O$

(d) $3EtMgBr + (EtO)_2CO \xrightarrow{Ether} Et_3C\text{-}OMgBr \xrightarrow{H_3O^+} Et_3COH$

8.49 When dimethylketone reacts with a Grignard reagent, use of excess amount of Grignard reagent facilitates the reaction. Offer a mechanistic explanation of this fact.

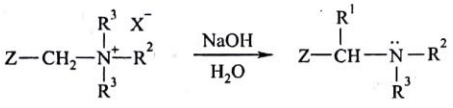
Ans The carbonyl carbon of a ketone is a weak electrophilic centre because of the +I effect of the methyl groups. When excess amount of Grignard reagent is used then a part of the Grignard reagent acts as a Lewis acid to enhance the electrophilic reactivity of the carbonyl carbon. The reaction is found to a cylic one, as shown here.

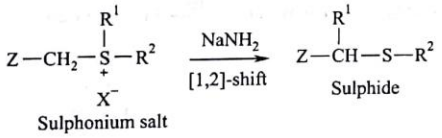




8.50 What is Stevens reaction? Give illustrations.

Ans The base promoted conversion of sulphonium or quaternary ammonium salts to the corresponding sulphides or tertiary amines involving the [1, 2]-shift of one of the groups on the nitrogen or the sulphur atom is called Stevens rearrangement. T.S Stevens reported this reaction in 1928.



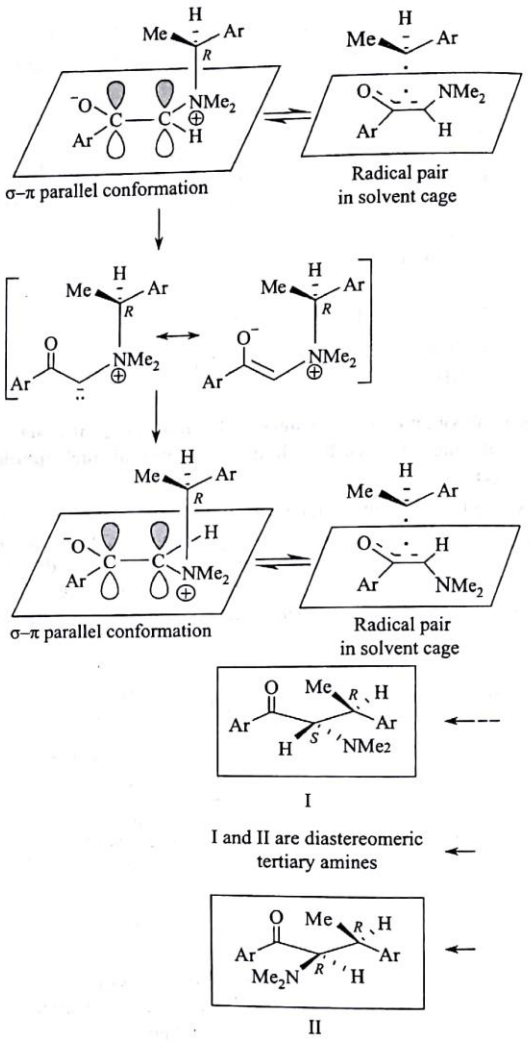


The 'Z' in the aforegiven examples is an electron withdrawing group which may be aryl, heteroaryl, RCO—, —COOR, —CN, etc. The migrating group may be CH_3, alkyl, benzyl, allyl, etc. The base used may be NaOH, NaH, KH, RLi, RONa, etc.

8.51 Discuss the mechanism of Stevens rearrangement involving a quaternary ammonium salt.

Ans The mechanism of the Stevens reaction involving a quaternary ammonium salt is given here.

Stevens rearrangement is not a concerted 1, 2-shift of a group. If the Stevens reaction is considered to be a concerted one then it would be asymmetry-forbidden process based on Woodward–Hofmann rules. Experiments have confirmed that mechanism of Stevens rearrangement is an intramolecular homolytic cleavage-radical pair recombination process, which explains the non-formation of cross-over products and the observed retention of configuration at the migrating terminus. The radicals are held in solvent-cage in which there is a lack of rotation, and they recombine very rapidly. The course of the reaction is shown here.

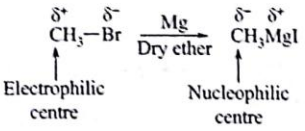


8.52 What is upolung? Justify the statement that conversion of an alkyl halide to a Grignard reagent may be considered as a case of umpolung.

Ans Umpolung or polarity inversion in organic chemistry is the chemical modification of a functional group with the aim of the reversal of polarity of that group. This modification allows secondary reactions of this functional group that would otherwise not be possible. The concept was introduced by D. Seebach (hence the German word *umpolung* for reversed polarity) and E.J. Corey.

In case of an alkyl halide the, the carbon of the alkyl group directly attached to the halogen atom is electron deficient and normally serves as an electrophilic centre. When the same alkyl halide is converted into a Grignard reagent then the same carbon centre becomes electron rich and serves as

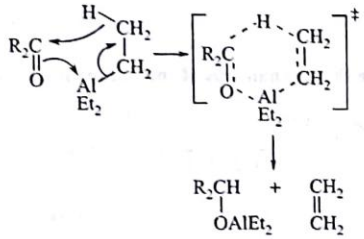
a nucleophilic reagent. Therefore, conversion of an alkyl halide to a Grignard reagent amounts to reversal of polarity (Umpolung).



8.53 Suggest a mechanism for the reaction.

$$R_2C{=}O + Et_3Al \longrightarrow R_2CHOAlO_2 + C_2H_4$$

Ans The reaction can be interpreted as one step reaction involving a cyclic transition state as shown here.

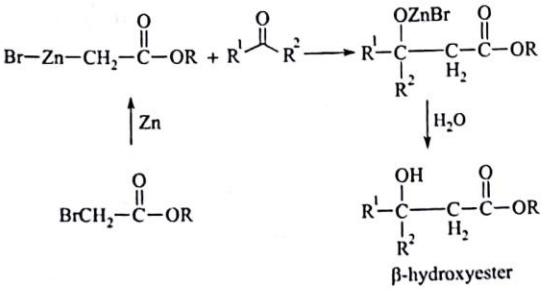


8.54 Give the use of an organozinc compound in organic chemistry. What is the advantage of using an organozinc compound over organomagnesium compound?

Ans A good use of organozinc compound is found in Reformatsky reaction.

The addition reactions of ester-stabilized organozinc reagents to carbonyl compounds leading to the formation of β-hydroxy esters is called Reformatsky reaction.

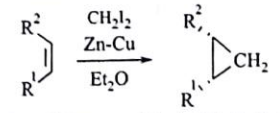
Organozinc compounds are formed from α-halogenoesters in the same manner as Grignard Reagents. This reaction is possible due to the stability of esters against organozincs. Due to the very low basicity of zinc enolates, there is hardly any competition from proton transfer, and the scope of carbonyl addition partners is quite broad. In presence of ketones or aldehydes, the organozinc compounds react as the nucleophilic partner in an addition to give β-hydroxy esters.

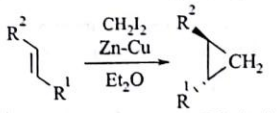


In the aforegiven example, if R^1 and R^2 are different groups then enantiomeric mixture of β-hydroxy esters is obtained. Some amounts of β-hydroxy carboxylic acid as well as α, β-unsaturated acid are formed during hydrolysis.

8.55 What is Simmons–Smith reaction? Give the mechanism of the reaction.

Ans The reaction is a general method of creating a cyclopropane system from alkenes by reacting with methylene iodide (CH_2I_2) and zinc-copper couple, commonly referred to as *Simmons–Smith* reagent. The active species is iodomethylzinc iodide (ICH_2ZnI). The reaction is stereospecific with respect to the parent alkene.

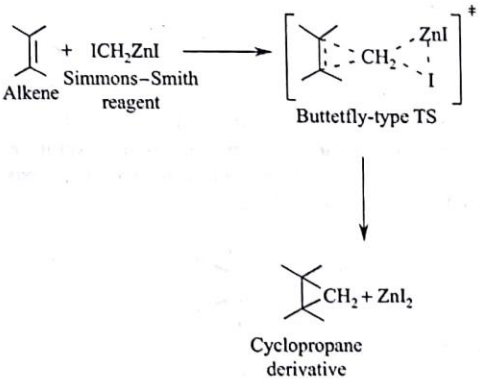




Accepted mechanism of the Simmons–Smith reaction is given here.

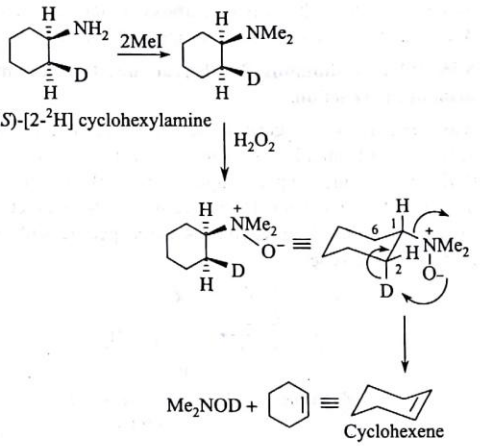
The Simmons–Smith cyclopropanation is a concerted process, and proceeds through a three-centred 'butterfly-type' transition state. This suggestion is in agreement with theoretical studies as well as with the stereochemical outcomes of large number of reactions. The accepted mechanism is shown here.

$$CH_2I_2 + Zn(Cu) \longrightarrow ICH_2ZnI$$

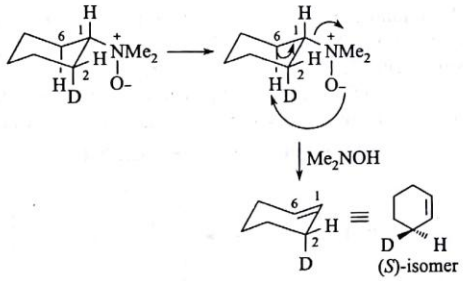


8.56 Draw the structure of (1*R*, 2S)-[2-^{2}H] cyclohexylamine and carry out Cope elimination after the necessary modification of the compound. What would be the product when diastereoisomeric (1*R*, 2*S*)-isomer is subjected to similar reactions.

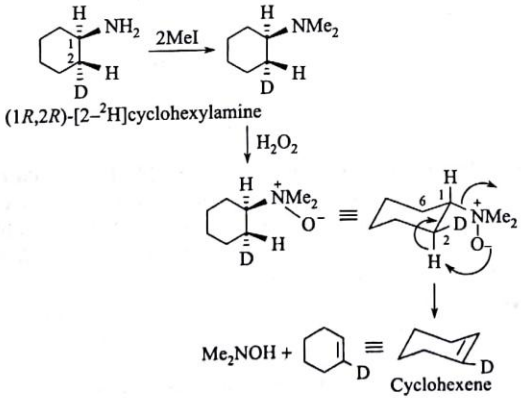
Ans The structure of (1*R*, 2*S*)-[2-^{2}H] cyclohexylamine is given here. To carry out Cope elimination, we need to convert it into the corresponding secondary amine and then to its *N*-oxide. The course of the reaction is shown here.



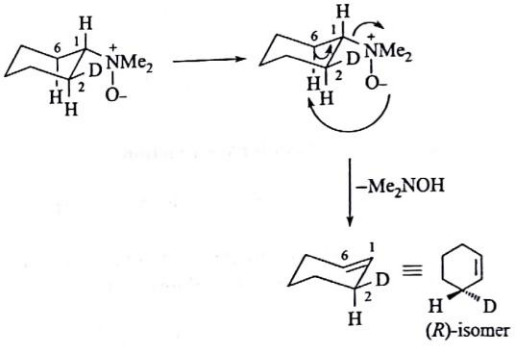
It is to be noted that Cope elimination is stereospecific *cis*-elimination and occurs following E2 mechanism. In the aforegiven example, axial 'D' and equatorial $\overset{+}{N}Me_2O^-$ are *cis* to each other and cyclohexene is formed without 'D'. A deuterium subsitituted compound is formed when *cis*-elimination occurs involving C-6 α-axial hydrogen atom. In this case, a chiral cyclohexene derivative is formed having (*S*)-configuration.



When diastereoisomeric (1*R*, 2*R*)–[2–²H] cyclohexylamine is subjected to similar cope elimination after converting it into the corresponding *N*-oxide, then also two compounds are formed. These are shown here.

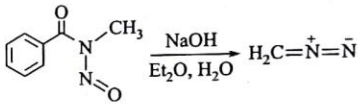


Another deuterium substituted cyclohexene is formed when reaction involves α-H atom at C-6 position. The reaction is shown here.

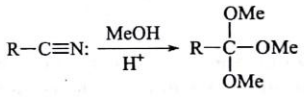


8.57 Give the mechanisms of the following conversions.

(a)

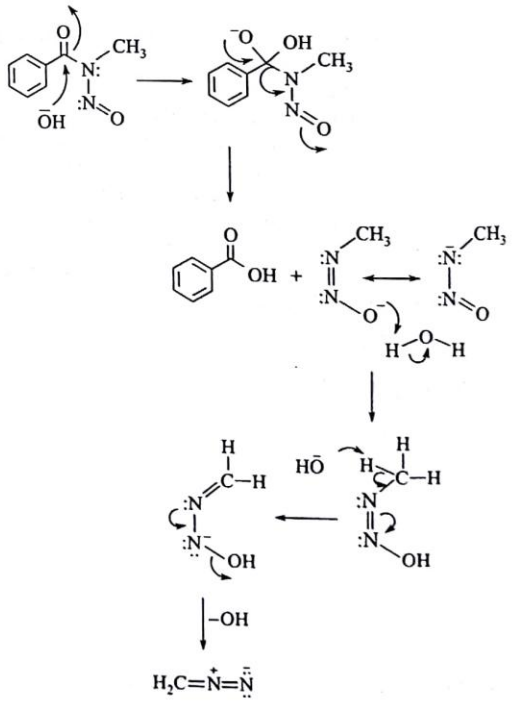


(b)



Ans The respective mechanisms are given here.

(a)



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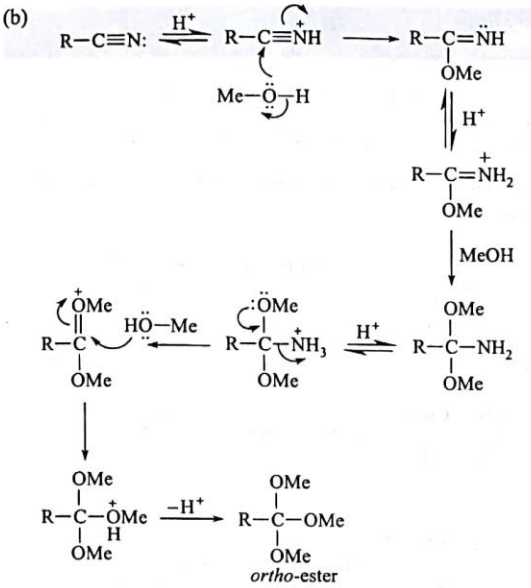


ortho-ester

8.58 Give two uses of dialkylcadmium in organic synthesis.

Ans When a Grignard reagent reacts with cadmium chloride, dialkylcadmium compounds are formed.

$$2RMgX + CdCl_2 \longrightarrow R_2Cd + 2MgClX$$

Dialkylcadmium compounds are used to prepare ketones from acid chloride. Mixed ketones can be prepared with good yield.

$$2R^1COCl + R^2_2Cd \longrightarrow 2R^1{-}\overset{O}{\overset{\|}{C}}{-}R^2 + CdCl_2$$

This method of ketone synthesis may be further used to prepare long-chain monocarboxylic acid. An example is given here.

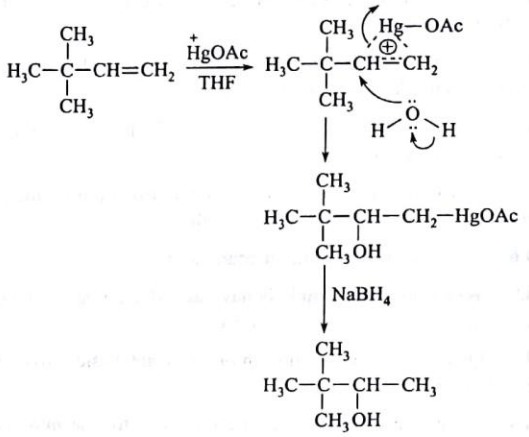
$$CH_3(CH_2)_5OH \xrightarrow[Mg]{HBr} CH_3(CH_2)_5MgBr \xrightarrow{CdCl_2} [CH_3(CH_2)_5]_2Cd \xrightarrow{EtCO_2(CH_2)_4COCl} CH_3(CH_2)_5{-}\overset{O}{\overset{\|}{C}}{-}(CH_2)_4CO_2Et + CdCl_2 \xrightarrow[Zn/Hg]{HCl} CH_3(CH_2)_5{-}CH_2{-}(CH_2)_4CO_2H$$

Dodecanoic acid

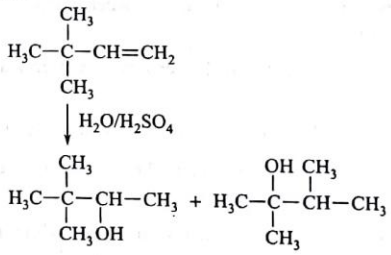
8.59 Mercuric acetate may be used to convert an alkene to an alcohol without any rearrangement when acid-catalysed hydration gives a mixture of compounds. Give an example to justify the statement.

Ans The following compound can be hydrated to an alcohol following Markownikov's rule using $Hg(OAc)_2$ in THF followed by demercuration with alkaline $NaNH_2$. In this case, rearrangement does not occur. Reactions are shown here.

$$Hg(OAc)_2 \longrightarrow \overset{+}{H}gOAc + \bar{O}Ac$$

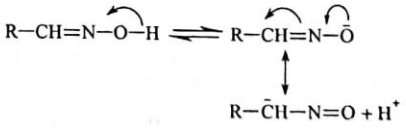


In the aforementioned reaction, usually called 'oxymercuration–demercuration', there is no rearrangement to give mixture of alcohols. Acid catalysed hydration gives mixture of alcohols.



8.60 Oximes are more acidic than hydroxylamines. Explain.

Ans In case of oximes having the general formula R–CH=N–O–H, loss of H^+ gives a resonance stabilized anion. Therefore, it has the potentiality to loose a proton and consequently acidic.



However, in the case of hydroxyl amine, loss of H^+ from either –OH or $-NH_2$ does not produce any resonance stabilized anion because both N and O have no d-orbital to accommodate an extra pair of electron.

$$H_2N{-}OH \rightleftharpoons \underset{\text{Unstable}}{H_2N{-}\bar{O}} + H^+ \quad \text{OR} \quad \underset{\text{Unstable}}{H\bar{N}{-}OH} + H^+$$

EXERCISES

8.1 Give a test to distinguish between methyl nitrite and nitromethane.

8.2 How can you distinguish between methyl cyanide and methyl isocyanide?

8.3 Methyl cyanide is soluble in water while methyl isocyanide is insoluble. Offer an explanation.

8.4 Nitromethane is soluble in sodium hydroxide solution. Give an explanation.

8.5 Nitromethane is acidic in nature but trimethylnitromethane is not. How can you account for this?

8.6 Why are amines basic in character?

8.7 Whey does isocyanide behave as reducing agent? Give an example of its reducing property.

8.8 Quaternary ammonium chloride is not basic. Give an explanation.

8.9 What types of valencies are observed for the nitrogen atom of a quaternary ammonium salt?

8.10 Write down the structure of a quaternary ammonium hydroxide. Is it a weak base or a strong base?

8.11 How would you distinguish between methylamine and dimethylamine?

8.12 How can you distinguish a tertiary amine from a secondary amine?

8.13 What is carbylamine reaction? Give an example.

8.14 How would you get methylamine from acetamide? What is the name of the reaction?

8.15 What is reaction product from dimethylmethylamine and nitrous acid? What happens when the resultant compound is treated with phenol and concentrated sulphuric acid and then sodium hydroxide solution is added to the reaction product?

8.16 $C_3H_7NO_2$ is a nitroalkane. It reacts with nitrous acid to form a colourless compound which turns red when sodium hydroxide solution is added. What is the possible structure of the parent compound?

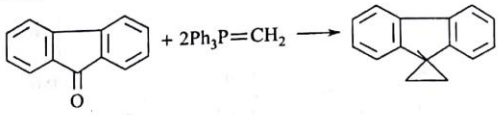
An aliphatic monoamine reacts with nitrous acid to form ethanol. What is the possible structure of the amine?

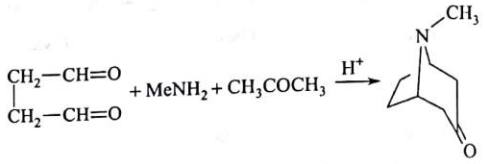
8.17 An organic nitrogenous compound may be an amine or an amide or a nitrile. How can you ascertain the correct nature of the compound?

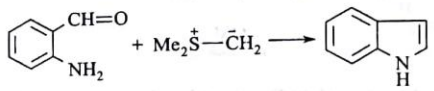
8.18 Distinguish between the following pairs of compounds by chemical reactions.
(a) Methyl cyanide and Methyl isocyanide
(b) Ethyl nitrate and nitroethane
(c) Nitromethane and 2-Nitropropane.

8.19 A saturated monoamine contains hydrogen, carbon, and nitrogen. Percentage of nitrogen is 31.3% in the compound. Find out the probable structures of the compound.

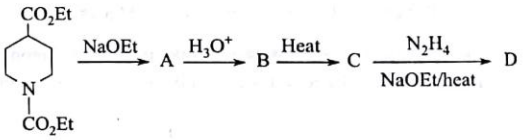
8.20 Give a plausible mechanism for the following transformations.

(a) 

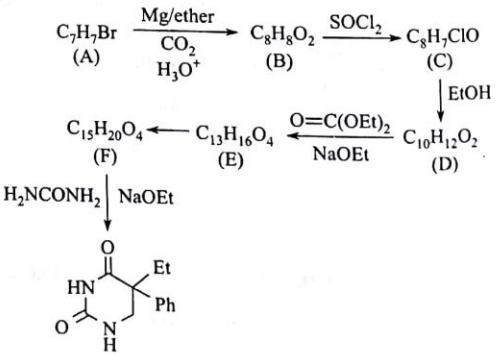
(b) 

(c) 

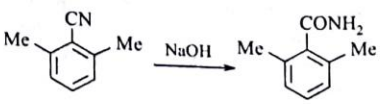
8.21 Identify the products A, B, C, and D in the following sequence of reactions.



8.22 Identify the compounds A–F in the following reaction sequence:



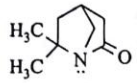
8.23 The following reaction is stopped in the amide stage. Explain.

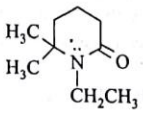


8.24 Answer the following.

(a) Phosphorus and sulphur ylides are more stable compared to their nitrogen analogues. Explain.

(b) The bicyclic lactam A is much more readily hydrolysed than the monocyclic lactam B. Give reasons.

(i) 

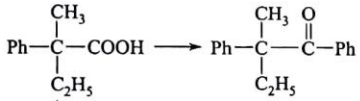
(ii) 

8.25 Write the structures of [A] to [D] in the following reactions sequence. Explain the formation of [D] from [C].

$$MeO-CH_2Cl \xrightarrow{Ph_3P} [A] \xrightarrow{PhLi} [B] \xrightarrow{PhCH=O}$$

$$\longrightarrow [C] + Ph_3P=O \xrightarrow{HCl/H_2O} [D] + MeOH$$

8.26 Carry out the following transformations.

(a) 

(b) $BrCH_2-CH-CH_2 \longrightarrow H_2C-CH=CH_2-CH_2-CH=CH_2$

8.27 Complete the following reaction sequence with mechanisms.

$$TsO-(CH_2)_4-OTs \xrightarrow{Ph_3P\ (excess)} [A] \xrightarrow[(2\ eq.)]{PhLi} [B]$$

$$PhCH=O\ (2\ eq.) \downarrow$$

$$[C]$$

8.28 Explain the following reaction scheme.

$$PhMgBr \xrightarrow[H_3O^+]{\text{O}} [D] \xrightarrow[Pyridine]{CrO_3} [E] \xrightarrow[H_3O^+]{DEM/Et_3N} [F] \xrightarrow{\Delta} [G] \xrightarrow[Me_2S]{O_3} [H]$$

8.29 Predict the product of the following reaction and give plausible mechanism.

$$Et-C\equiv N: \xrightarrow{H_2O_2/aq.\ NaOH} ?$$

8.30 Give efficient method of for the preparation of R_3C-NH_2 and R_3C-CN.

8.31 Suggest mechanisms for the following transformations.

(a) $R-C\equiv N + R'COOH \xrightarrow{300°C} RCOOH + R'-C\equiv N$

(b) $Et_2NH \xrightarrow{HCH=O/HCOOH} Et_2NCH_3$

8.32 Explain whether a Grignard reagent acts as a neucleophile or electrophile.

8.33 Explain the mechanism of formation of addition compounds of carbonyl group with Grignard reagents.

8.34 Why does a Grignard reagent fail to form addition compound with C=C bond or C≡C bond?

8.35 What is an active hydrogen atom? Name three compounds containing active hydrogen atom.

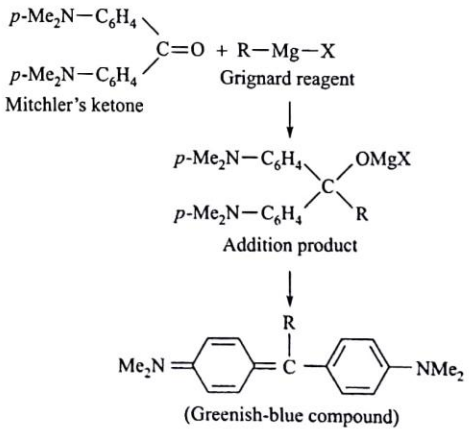
8.36 How does a Grignard reagent used for determining the active hydrogen atom in a compound. Give examples. What is the name of the method?

8.37 Discuss very briefly the structures of Grignard reagents. How would you detect the presence of Grignard reagent in a solution?

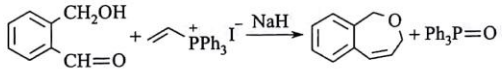
8.38 0.1 g of an aliphatic saturated alcohol reacts with methylmagnesium iodide to evolve 37.3 ml methane at N.T.P. The alcohol responds to iodoform test. Identify the alcohol.

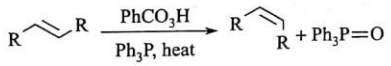
8.39 How can you test the formation of a Grignard reagent?

Hint: Formation of a Grignard reagent can be detected by the following test. 0.5 ml of the solution containing Grignard reagent is removed from the reaction vessel to a dry test tube and to this 0.5 ml of a 1% solution of Michler's ketone (4, 4′-tetramethyldiaminobeazophenone) in benzene is added followed by 1 ml of water and 3–4 drops of 0.01 M iodine in glacial acetic. On shaking the mixture, a greenish-blue colour results if a Grignard reagent is present. Colour fades in the absence of iodine.

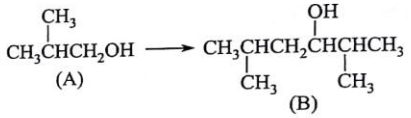


8.40 Give the mechanism of each of the following transformations.

(a) 

(b) 

8.41 Starting from the alcohol (A), synthesize the compound (B) through a Grignard reaction.



8.42 What happens when the following compound is successively treated with one mole, two moles, and three moles of CH_3MgBr. Give reasons in favour of your answer?