

# UNIT : 3 STRUCTURE OF ATOM

## Important Points

### Composition of atom

#### Electron ( ${}_{-1}e^0$ )

- (1) It was discovered by **J.J. Thomson** (1897) and is *negatively charged particle*.
- (2) Electron is a component particle of cathode rays.
- (3) Cathode rays were discovered by **William Crooke's & J.J. Thomson** (1880).

### Properties of Cathode rays

- (i) Cathode rays travel in straight line.
- (ii) Cathode rays produce mechanical effect, as they can rotate the wheel placed in their path.
- (iii) Cathode rays consist of negatively charged particles known as *electron*.
- (iv) When cathode rays fall on solids such as *Cu*, X-rays are produced.
- (v) The nature of these rays does not depend upon the nature of gas or the cathode material used in discharge tube.
- (vi) The  $e/m$  (charge to mass ratio) for cathode rays was found to be the same as that for an  $e^-$  ( $-1.76 \times 10^8$  coulomb per gm). Thus, *the cathode rays are a stream of electrons*.

#### Proton ( $H^+$ , $p$ )

- (1) Proton was discovered by **Goldstein**
- (2) It is a component particle of anode rays.

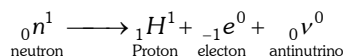
**Goldstein (1886)** used perforated cathode in the discharge tube and repeated Thomson's experiment and observed the formation of anode rays. These rays also termed as *positive* or *canal rays*.

### Properties of anode rays

- (i) Anode rays travel in straight line.
- (ii) Anode rays are material particles.
- (iii) Anode rays are positively charged.
- (iv) Anode rays may get deflected by external magnetic field.
- (v) Anode rays also affect the photographic plate.
- (vi) The  $e/m$  ratio of these rays is smaller than that of electrons.
- (vii) Unlike cathode rays, their  $e/m$  value is dependent upon the nature of the gas taken in the tube. It is maximum when gas present in the tube is hydrogen.

#### Neutron ( ${}_0n^1$ , $n$ )

- (1) Neutron was discovered by **James Chadwick** (1932) according to the following nuclear reaction,  ${}_4\text{Be}^9 + {}_2\text{He}^4 \rightarrow {}_6\text{C}^{12} + {}_0n^1$  OR  ${}_5\text{B}^{11} + {}_2\text{He}^4 \rightarrow {}_7\text{N}^{14} + {}_0n^1$
- (2) Neutron is an unstable particle. It decays as follows,



Name of constant	Unit	Electron(e <sup>-</sup> )	Proton(p <sup>+</sup> )	Neutron(n)
Mass (m)	Amu	0.000546	1.00728	1.00899
	Kg	$9.109 \times 10^{-31}$	$1.673 \times 10^{-27}$	$1.675 \times 10^{-27}$
	Relative	1/1837	1	1
Charge(e)	Coulomb (C)	$-1.602 \times 10^{-19}$	$+1.602 \times 10^{-19}$	Zero
	Esu	$-4.8 \times 10^{-10}$	$+4.8 \times 10^{-10}$	Zero
	Relative	-1	+1	Zero
Specific charge (e/m)	C/g	$1.76 \times 10^8$	$9.58 \times 10^4$	Zero
Density	Gram / cc	$2.17 \times 10^{-17}$	$1.114 \times 10^{-14}$	$1.5 \times 10^{-14}$

• The atomic mass unit (amu) is 1/12 of the mass of an individual atom of  ${}_6\text{C}^{12}$ , i.e.  $1.660 \times 10^{-27}$  kg .

### Other non fundamental particles

Particle	Symbol	Nature	Charge esu $\times 10^{-10}$	Mass (amu)	Discovered by
Positron	$e^+, 1e^0, \beta^+$	+	+ 4.8029	0.0005486	Anderson (1932)
Neutrino	$\nu$	0	0	< 0.00002	Pauli (1933) and Fermi (1934)
Anti-proton	$p^-$	-	- 4.8029	1.00787	Chamberlain Sugri (1956) and Weighland (1955)
Positive mu meson	$\mu^+$	+	+ 4.8029	0.1152	Yukawa (1935)
Negative mu meson	$\mu^-$	-	- 4.8029	0.1152	Anderson (1937)
Positive pi meson	$\pi^+$	+	+ 4.8029	0.1514	} Powell (1947)
Negative pi meson	$\pi^-$	-	- 4.8029	0.1514	
Neutral pi meson	$\pi^0$	0	0	0.1454	

### Atomic number, Mass number and Atomic species

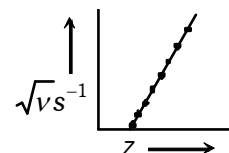
#### (1) Atomic number or Nuclear charge

(i) The number of protons present in the nucleus of the atom is called *atomic number* (Z).

(ii) It was determined by **Moseley** as,  $\sqrt{\nu} = a(Z-b)$  or  $aZ - ab$

Where,  $\nu = X$  - ray's frequency

Z= atomic number of the metal  $a$  &  $b$  are constant.



#### (2) Mass number

Mass number (A) = Z + n

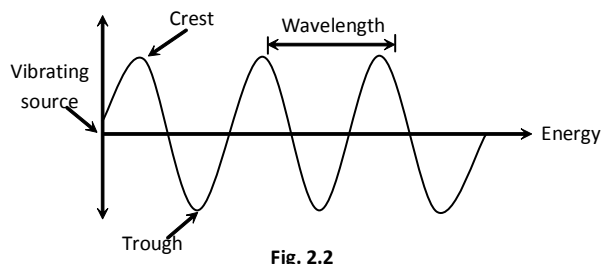
### Different types of atomic species

Atomic species	Similarities	Differences	Examples
Isotopes (Soddy)	(i) Atomic No. (Z) (ii) No. of protons (iii) No. of electrons (iv) Electronic configuration (v) Chemical properties (vi) Position in the periodic table	(i) Mass No. (A) (ii) No. of neutrons (iii) Physical properties	(i) ${}^1_1H, {}^2_1H, {}^3_1H$ (ii) ${}^{16}_8O, {}^{17}_8O, {}^{18}_8O$ (iii) ${}^{35}_{17}Cl, {}^{37}_{17}Cl$
Isobars	(i) Mass No. (A) (ii) No. of nucleons	(i) Atomic No. (Z) (ii) No. of protons, electrons and neutrons (iii) Electronic configuration (iv) Chemical properties (v) Position in the periodic table.	(i) ${}^{40}_{18}Ar, {}^{40}_{19}K, {}^{40}_{20}Ca$ (ii) ${}^{130}_{52}Te, {}^{130}_{54}Xe, {}^{130}_{56}Ba$
Isotones	No. of neutrons	(i) Atomic No. (ii) Mass No., protons and electrons. (iii) Electronic configuration (iv) Physical and chemical properties (v) Position in the periodic table.	(i) ${}^{30}_{14}Si, {}^{31}_{15}P, {}^{32}_{16}S$ (ii) ${}^{39}_{19}K, {}^{40}_{20}Ca$ (iii) ${}^3_1H, {}^4_2He$ (iv) ${}^{13}_6C, {}^{14}_7N$
Isoelectronic species	(i) No. of electrons (ii) Electronic configuration	At. No., mass No.	(i) $N_2O, CO_2, CNO^- (22e^-)$ (ii) $CO, CN^-, N_2 (14e^-)$ (iii) $H^-, He, Li^+, Be^{2+} (2e^-)$ (iv) $P^{3-}, S^{2-}, Cl^-, Ar, K^+ \text{ and } Ca^{2+} (18e^-)$

### Electromagnetic radiations

- (1) Light and other forms of radiant energy propagate without any medium in the space in the form of waves are known as *electromagnetic radiations*. These waves can be produced by a charged body moving in a magnetic field or a magnet in a electric field. e.g.  $\alpha$  – rays,  $\gamma$  – rays, cosmic rays, ordinary light rays etc.
- (2) **Characteristics**
  - (i) All electromagnetic radiations travel with the velocity of light.
  - (ii) These consist of electric and magnetic fields components that oscillate in directions perpendicular to each other and perpendicular to the direction in which the wave is travelling.

(3) A wave is always characterized by the following five characteristics,



(i) **Wavelength** : The distance between two nearest crests or nearest troughs is called the wavelength. It is denoted by  $\lambda$  (lambda) and is measured in terms of centimeter(cm), angstrom( $\text{\AA}$ ), micron( $\mu$ ) or nanometre (nm).

$$1\text{\AA} = 10^{-8} \text{ cm} = 10^{-10} \text{ m} ; 1\mu = 10^{-4} \text{ cm} = 10^{-6} \text{ m} ;$$

$$1\text{nm} = 10^{-7} \text{ cm} = 10^{-9} \text{ m} ; 1\text{cm} = 10^8 \text{\AA} = 10^4 \mu = 10^7 \text{ nm}$$

(ii) **Frequency** : It is defined as the number of waves which pass through a point in one second. It is denoted by the symbol  $\nu$  (nu)

$$\lambda \nu = \text{distance travelled in one second} = \text{velocity} = c \quad \nu = \frac{c}{\lambda}$$

(iii) **Velocity** : It is defined as the distance covered in one second by the wave. It is denoted by the letter 'c'. All electromagnetic waves travel with the same velocity, i.e.,  $3 \times 10^{10} \text{ cm/sec}$ .

$$c = \lambda \nu = 3 \times 10^{10} \text{ cm/sec}$$

(iv) **Wave number** : This is the reciprocal of wavelength, i.e., the number of wavelengths per centimetre. It is denoted by the symbol  $\bar{\nu}$  (nu bar). It is expressed in  $\text{cm}^{-1}$  or  $\text{m}^{-1}$ .

$$\bar{\nu} = \frac{1}{\lambda}$$

(v) **Amplitude** : It is defined as the height of the crest or depth of the trough of a wave. It is denoted by the letter 'A'. It determines the intensity of the radiation.

The arrangement of various types of electromagnetic radiations in the order of their increasing or decreasing wavelengths or frequencies is known as **electromagnetic spectrum**.

## Atomic spectrum - Hydrogen spectrum

### Atomic spectrum

Spectrum is the impression produced on a photographic film when the radiation of particular wavelength is (are) analysed through a prism or diffraction grating.

### Types of spectrum

(1) **Emission spectrum**: Spectrum produced by the emitted radiation is known as emission spectrum. This spectrum corresponds to the radiation emitted (energy evolved) when an excited electron returns back to the ground state.

(i) **Continuous spectrum**: When sunlight is passed through a prism, it gets dispersed into continuous bands of different colours. If the light of an incandescent object resolved through prism or spectroscope, it also gives continuous spectrum of colours.

- (ii) **Line spectrum:** If the radiation's obtained by the excitation of a substance are analysed with help of a spectroscope a series of thin bright lines of specific colours are obtained. There is dark space in between two consecutive lines. This type of spectrum is called line spectrum or atomic spectrum..

- (2) **Absorption spectrum :** Spectrum produced by the absorbed radiations is called absorption spectrum.

### **Hydrogen spectrum**

- (1) All these lines of H-spectrum have Lyman, Balmer, Paschen, Barckett, Pfund and Humphrey series. These spectral series were named by the name of scientist discovered them.
- (2) To evaluate wavelength of various H-lines Ritz introduced the following expression,

$$\bar{\nu} = \frac{1}{\lambda} = \frac{\nu}{c} = R \left[ \frac{1}{n_1^2} - \frac{1}{n_2^2} \right] z^2$$

Where  $R$  is universal constant known as Rydberg's constant its value is  $109,678 \text{ cm}^{-1}$ .

### **Plum pudding model of Thomson**

- (1) He suggested that atom is a positively charged sphere having electrons embedded uniformly giving an overall picture of plum pudding.
- (2) This model failed to explain the line spectrum of an element and the scattering experiment of Rutherford.

### **Rutherford's nuclear model**

From the observations of  $\alpha$  ray scattering experiments he concluded that, an atom consists of

- (i) **Nucleus** which is small in size but carries the entire mass i.e. contains all the neutrons and protons.
- (ii) **Extra nuclear part** which contains electrons. This model was similar to the solar system.
- (3) **Properties of the nucleus**
- (i) Nucleus is a small, heavy, positively charged portion of the atom and located at the centre of the atom.
- (ii) All the positive charge of atom (i.e. protons) are present in nucleus.
- (iii) Nucleus contains neutrons and protons, and hence these particles collectively are also referred to as **nucleons**.
- (iv) The **size** of nucleus is measured in **Fermi** ( $1 \text{ Fermi} = 10^{-13} \text{ cm}$ ).
- (v) The **radius** of nucleus is of the order of  $1.5 \times 10^{-13} \text{ cm}$ . to  $6.5 \times 10^{-13} \text{ cm}$ . i.e. 1.5 to 6.5 Fermi. Generally the radius of the nucleus ( $r_n$ ) is given by the following relation,

$$r_n = r_o (= 1.4 \times 10^{-13} \text{ cm}) \times A^{1/3}$$

This exhibited that nucleus is  $10^{-5}$  times small in size as compared to the total size of atom.

- (vi) The **Volume** of the nucleus is about  $10^{-39} \text{ cm}^3$  and that of atom is  $10^{-24} \text{ cm}^3$ , i.e., volume of the nucleus is  $10^{-15}$  times that of an atom.
- (vii) The **density** of the nucleus is of the order of  $10^{15} \text{ g cm}^{-3}$  or  $10^8 \text{ tonnes cm}^{-3}$  or  $10^{12} \text{ kg/cc}$ . If nucleus is spherical than,

$$\text{Density} = \frac{\text{mass of the nucleus}}{\text{volume of the nucleus}} = \frac{\text{mass number}}{6.023 \times 10^{23} \times \frac{4}{3} \pi r^3}$$

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## Planck's quantum theory

To explain black body irradiation, Max Planck put forward a theory known as Planck's quantum theory.

- (i) The radiant energy which is emitted or absorbed by the black body is not continuous but discontinuous in the form of small discrete packets of energy, each such packet of energy is called a '**quantum**'. In case of light, the quantum of energy is called a '**photon**'.
- (ii) The energy of each quantum is directly proportional to the frequency ( $\nu$ ) of the radiation, i.e.

$$E \propto \nu \text{ OR } E = h\nu = \frac{hc}{\lambda} \text{ Where, } h = \text{Planck's constant} = 6.62 \times 10^{-27} \text{ erg. sec. or } 6.62 \times 10^{-34} \text{ Joules sec.}$$

- (iii) The total amount of energy emitted or absorbed by a body will be some whole number quanta. Hence  $E = nh\nu$ , where  $n$  is an integer.

## Photoelectric effect

- (1) When radiations with certain minimum frequency ( $\nu_0$ ) strike the surface of a metal, the electrons are ejected from the surface of the metal. This phenomenon is called *photoelectric effect* and the electrons emitted are called *photo-electrons*. The current constituted by photoelectrons is known as photoelectric current. This minimum frequency is known as threshold frequency.
- (2) The electrons are ejected only if the radiation striking the surface of the metal has at least a minimum frequency called *Threshold frequency*. The minimum potential at which the plate photoelectric current becomes zero is called *stopping potential*.
- (3) The velocity or kinetic energy of the electron ejected depend upon the frequency of the incident radiation and is independent of its intensity.
- (4) The number of photoelectrons ejected is proportional to the intensity of incident radiation.
- (5) **Einstein's photoelectric effect equation**

According to Einstein,

Maximum kinetic energy of the ejected electron = absorbed energy – threshold energy

$$\frac{1}{2}mv_{\max}^2 = h\nu - h\nu_0 = hc \left[ \frac{1}{\lambda} - \frac{1}{\lambda_0} \right]$$

Where,  $\nu_0$  and  $\lambda_0$  are threshold frequency and threshold wavelength.

## Advantages of Bohr's theory

- (i) **Calculation of radius of Bohr's orbit** : According to Bohr, radius of  $n^{\text{th}}$  orbit in which electron

$$\text{moves is } r_n = \left[ \frac{h^2}{4\pi^2 m e^2 k} \right] \cdot \frac{n^2}{Z}$$

Where, Orbit number, Mass number Charge on the electron Atomic number of element,  $k$  = Coulombic constant

Where,  $n$  = Orbit number,  $m$  = Mass number  $[9.1 \times 10^{-31} \text{ kg}]$ ,  $e$  = Charge on the electron  $[1.6 \times 10^{-19}]$

$Z$  = Atomic number of element,  $k$  = Coulombic constant  $[9 \times 10^9 \text{ Nm}^2\text{c}^{-2}]$

After putting the values of  $m, e, k, h$ , we get  $r_n = \frac{n^2}{Z} \times 0.529 \text{ \AA}$

(iii) **Calculation of velocity of electron**

$$V_n = \frac{2\pi e^2 ZK}{nh}, V_n = \left[ \frac{Ze^2}{mr} \right]^{1/2}; V_n = \frac{2.188 \times 10^8 Z}{n} \text{ cm. sec}^{-1}$$

(iv) **Calculation of energy of electron in Bohr's orbit**

$$\text{Total energy of electron} = \text{K.E.} + \text{P.E. of electron} = \frac{kZe^2}{2r} - \frac{kZe^2}{r} = -\frac{kZe^2}{2r}$$

$$\text{Substituting of } r, \text{ gives us } E = \frac{-2\pi^2 mZ^2 e^4 k^2}{n^2 h^2} \text{ Where, } n=1, 2, 3, \dots$$

Putting the value of m, e, k, h,  $\pi$  we get

$$E = -21.8 \times 10^{-12} \times \frac{Z^2}{n^2} \text{ erg per atom}$$

$$= -21.8 \times 10^{-19} \times \frac{Z^2}{n^2} \text{ J per atom (1 J} = 10^7 \text{ erg)} \quad E = -13.6 \times \frac{Z^2}{n^2} \text{ eV per atom (1 eV} = 1.6 \times 10^{-19} \text{ J)}$$

$$= -13.6 \times \frac{Z^2}{n^2} \text{ kcal/mole (1 cal} = 4.18 \text{ J)} \quad \text{or} \quad \frac{-1312}{n^2} Z^2 \text{ kJmol}^{-1}$$

When an electron jumps from an outer orbit (higher energy) to an inner orbit (lower energy) then the energy emitted in form of radiation is given by

$$\Delta E = E_{n_2} - E_{n_1} = \frac{2\pi^2 k^2 m e^4 Z^2}{h^2} \left( \frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$

$$\Rightarrow \Delta E = 13.6 Z^2 \left( \frac{1}{n_1^2} - \frac{1}{n_2^2} \right) \text{ eV/atom}$$

$$\text{As we know that } E = h\bar{\nu}, c = v\lambda \text{ and } \bar{\nu} = \frac{1}{\lambda} = \frac{\Delta E}{hc} = \frac{2\pi^2 k^2 m e^4 Z^2}{ch^3} \left( \frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$

$$\text{This can be represented as } \frac{1}{\lambda} = \bar{\nu} = RZ^2 \left( \frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$

Where,  $R = \frac{2\pi^2 k^2 m e^4}{ch^3}$ ; R is known as Rydberg constant. Its value to be used is  $109678 \text{ cm}^{-1}$ .

(6) **Spectral evidence for quantisation** (Explanation for hydrogen spectrum on the basis of bohr atomic model)

(i) The optical spectrum of hydrogen consists of several series of lines called **Lyman, Balmer, Paschen, Brackett, Pfund** and **Humphrey**.

(ii) To evaluate wavelength of various H-lines Ritz introduced the following expression,

$$\bar{\nu} = \frac{1}{\lambda} = \frac{v}{c} = R \left[ \frac{1}{n_1^2} - \frac{1}{n_2^2} \right] \text{ Where, } R \text{ is } = \frac{2\pi^2 m e^4}{ch^3} = \text{Rydberg's constant}$$

It's theoretical value =  $109,737 \text{ cm}^{-1}$  and It's experimental value =  $109,677.581 \text{ cm}^{-1}$

This remarkable agreement between the theoretical and experimental value was great achievement of the Bohr model.

(iii) Comparative study of important spectral series of Hydrogen is shown in following table.

S.No.	Spectral series	Lies in the region	Transition $n_2 > n_1$	$\lambda_{\max} = \frac{n_1^2 n_2^2}{(n_2^2 - n_1^2)R}$	$\lambda_{\min} = \frac{n_1^2}{R}$	$\frac{\lambda_{\max}}{\lambda_{\min}} = \frac{n_2^2}{n_2^2 - n_1^2}$
(1)	Lyman series	Ultraviolet region	$n_1 = 1$ $n_2 = 2, 3, 4, \dots, \infty$	$n_1 = 1$ and $n_2 = 2$ $\lambda_{\max} = \frac{4}{3R}$	$n_1 = 1$ and $n_2 = \infty$ $\lambda_{\min} = \frac{1}{R}$	$\frac{4}{3}$
(2)	Balmer series	Visible region	$n_1 = 2$ $n_2 = 3, 4, 5, \dots, \infty$	$n_1 = 2$ and $n_2 = 3$ $\lambda_{\max} = \frac{36}{5R}$	$n_1 = 2$ and $n_2 = \infty$ $\lambda_{\min} = \frac{4}{R}$	$\frac{9}{5}$
(3)	Paschen series	Infra red region	$n_1 = 3$ $n_2 = 4, 5, 6, \dots, \infty$	$n_1 = 3$ and $n_2 = 4$ $\lambda_{\max} = \frac{144}{7R}$	$n_1 = 3$ and $n_2 = \infty$ $\lambda_{\min} = \frac{9}{R}$	$\frac{16}{7}$
(4)	Brackett series	Infra red region	$n_1 = 4$ $n_2 = 5, 6, 7, \dots, \infty$	$n_1 = 4$ and $n_2 = 5$ $\lambda_{\max} = \frac{16 \times 25}{9R}$	$n_1 = 4$ and $n_2 = \infty$ $\lambda_{\min} = \frac{16}{R}$	$\frac{25}{9}$
(5)	Pfund series	Infra red region	$n_1 = 5$ $n_2 = 6, 7, 8, \dots, \infty$	$n_1 = 5$ and $n_2 = 6$ $\lambda_{\max} = \frac{25 \times 36}{11R}$	$n_1 = 5$ and $n_2 = \infty$ $\lambda_{\min} = \frac{25}{R}$	$\frac{36}{11}$
(6)	Humphrey series	Far infrared region	$n_1 = 6$ $n_2 = 7, 8, \dots, \infty$	$n_1 = 6$ and $n_2 = 7$ $\lambda_{\max} = \frac{36 \times 49}{13R}$	$n_1 = 6$ and $n_2 = \infty$ $\lambda_{\min} = \frac{36}{R}$	$\frac{49}{13}$

(iv) If an electron from  $n^{\text{th}}$  excited state comes to various energy states, the maximum spectral lines obtained will be  $= \frac{n(n-1)}{2}$ .  $n$  = principal quantum number.

$$\text{As } n = 6 \text{ then total number of spectral lines} = \frac{6(6-1)}{2} = \frac{30}{2} = 15.$$

### **Bohr-Sommerfeld's model**

It is an extension of Bohr's model. The electrons in an atom revolve around the nuclei in elliptical orbit. The circular path is a special case of ellipse. Association of elliptical orbits with circular orbit explains the fine line spectrum of atoms.

### **Dual nature of electron**

- (1) In 1924, the French physicist, **Louis de Broglie** suggested that if light has both particle and wave like nature, the similar duality must be true for matter. Thus an electron, behaves both as a material particle and as a wave.
- (2) According to de-broglie, the wavelength associated with a particle of mass  $m$ , moving with velocity  $v$  is given by the relation  $\lambda = \frac{h}{mv}$ , where  $h$  = Planck's constant.



- (3) This was experimentally verified by **Davisson and Germer** by observing diffraction effects with an electron beam. Let the electron is accelerated with a potential of  $V$  than the Kinetic energy is

$$\frac{1}{2}mv^2 = eV ; m^2v^2 = 2eVm \quad mv = \sqrt{2eVm} = P ; \lambda = \frac{h}{\sqrt{2eVm}} \quad \lambda = \frac{h}{\sqrt{2k.E m}}$$

- (4) If Bohr's theory is associated with de-Broglie's equation then wave length of an electron can be determined in bohr's orbit and relate it with circumference and multiply with a whole number

$$2\pi r = n\lambda \text{ or } \lambda = \frac{2\pi r}{n} \text{ From de-Broglie equation, } \lambda = \frac{h}{mv}.$$

$$\text{Thus } \frac{h}{mv} = \frac{2\pi r}{n} \text{ or } mvr = \frac{nh}{2\pi}$$

- (5) The de-Broglie equation is applicable to all material objects but it has significance only in case of microscopic particles.

### Heisenberg's uncertainty principle

This principle states "It is impossible to specify at any given moment both the position and momentum (velocity) of an electron".

Mathematically it is represented as,  $\Delta x \cdot \Delta p \geq \frac{h}{4\pi}$

Where  $\Delta x$  = uncertainty is position of the particle,  $\Delta p$  = uncertainty in the momentum of the particle

Now since  $\Delta p = m \Delta v$

So equation becomes,  $\Delta x \cdot m\Delta v \geq \frac{h}{4\pi}$  OR  $\Delta x \times \Delta v \geq \frac{h}{4\pi m}$

In terms of uncertainty in energy,  $\Delta E$  and uncertainty in time  $\Delta t$ , this principle is written as,

$$\Delta E \cdot \Delta t \geq \frac{h}{4\pi}$$

### Schrödinger wave equation

- (1) Schrodinger wave equation is given by **Erwin Schrödinger** in 1926 and based on dual nature of electron.

The Schrodinger wave equation is,  $\frac{\partial^2 \Psi}{\partial x^2} + \frac{\partial^2 \Psi}{\partial y^2} + \frac{\partial^2 \Psi}{\partial z^2} + \frac{8\pi^2 m}{h^2} (E - V) \Psi = 0$

Where  $x, y$  and  $z$  are the 3 space co-ordinates,  $m$  = mass of electron,  $h$  = Planck's constant,  $E$  = Total energy,  $V$  = potential energy of electron,  $\Psi$  = amplitude of wave also called as wave function,

$\frac{\partial^2}{\partial x^2}$  is mathematical operation to be performed on  $\Psi$

- (2) The Schrodinger wave equation can also be written as,

$\nabla^2 \Psi + \frac{8\pi^2 m}{h^2} (E - V) \Psi = 0$  Where  $\nabla$  = laplacian operator.

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### (3) Physical significance of $\Psi$ and $\Psi^2$

- (i) The wave function  $\Psi$  represents the amplitude of the electron wave. The amplitude  $\Psi$  is thus a function of space co-ordinates and time i.e.  $\Psi = \Psi(x, y, z, \dots, \text{times})$
- (ii) For a single particle, the square of the wave function  $\Psi^2$  at any point is proportional to the probability of finding the particle at that point.
- (iii) If  $\Psi^2$  is maximum then probability of finding  $e^-$  is maximum around nucleus and the place where probability of finding  $e^-$  is maximum is called *electron density*, electron cloud or an atomic orbital. It is different from the Bohr's orbit.
- (iv) The solution of this equation provides a set of number called *quantum numbers* which describe specific or definite energy state of the electron in atom and information about the shapes and orientations of the most probable distribution of electrons around the nucleus.

It was Erwin Schrodinger who developed a new model of atom in 1920. He incorporated the idea of quantisation, and the conclusions of de-Broglie's principle and Heisenberg's principle in his model.

In this model, the behaviour of the electron in an atom is described by the mathematical equation

known as Schrodinger Wave Equation. ) 
$$\frac{\delta^2\Psi}{\delta x^2} + \frac{\delta^2\Psi}{\delta y^2} + \frac{\delta^2\Psi}{\delta z^2} + \frac{8\pi^2m}{h^2}(E - V)\Psi = 0$$

(Here x, y and z are three space coordinates, m = mass of electron, h = Planck's constant, E = Total energy, V = Potential energy and  $\Psi$  = Wave function of electron wave)

The above expression can also be expressed as 
$$\nabla^2\Psi + \frac{8\pi^2m}{h^2}(E - V)\Psi = 0$$

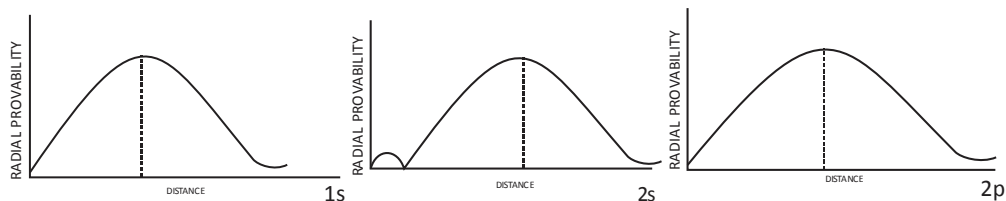
The permitted solutions of Schrodinger equation are known as *wave functions* which correspond to a definite energy state called orbital. Thus, the discrete Bohr orbits are replaced by orbital's i.e., three dimensional geometrical volumes where there is maximum probability of locating the electrons.

In simple words, the equation may be interpreted by stating that a body/particle of mass  $m$ , potential energy  $E$ , velocity  $v$ , has *wave like characteristics associated with it, with amplitude given by wave function*.

### Probability Distribution

In wave mechanics a moving electron is represented by wave function,  $\Psi$ . It has on physical significance and refers to the amplitude of electron wave. However,  $\Psi^2$  is a significant term and give intensity of electrons. An atomic orbital is a region around the nucleus where there is more probability of intensity of electrons. An orbital is considered as a diffused electron cloud having more density close to the nucleus. The probability of finding an electron in a given volume is understood best in the form of radial probability distribution curves. The probability curves for some orbital's are given in the figure. The distance of maximum radial probability is radius of an atom. There are two humps for 2p-orbital which means that the 2s electron penetrates a little closer to nucleus. The point at which radial probability becomes zero is known as nodal point.

The radial probability plots for some orbitals are shown in the given figure.



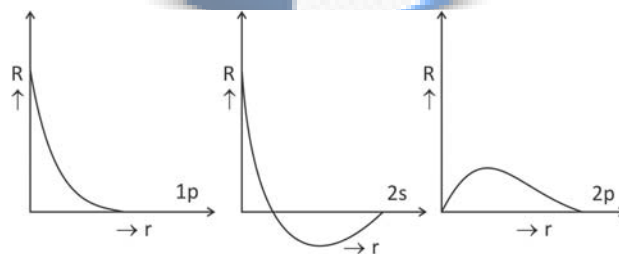
## ORBITAL WAVE FUNCTIONS AND SHAPES OF ORBITALS

According to wave mechanics, atomic orbitals are described by wave functions known as orbital wave functions. These orbital wave functions can be represented by the product of two wave functions, (i) *radial wave function* and (ii) *angular wave function*.

The radial wave function depends upon distance 'r' from the nucleus. On the other hand, angular wave function depends upon the direction given by the angles with respect to different co-ordinate axis. It is found that the wave function for s-orbital is independent of angles and, therefore, s-orbitals do not have angular dependence. Thus, all s-orbitals are spherically symmetrical. However, all other types of orbitals (*p*, *d* or *f*) have angular dependence and, therefore, have directional dependence.

### Radial Probability Distribution Curves

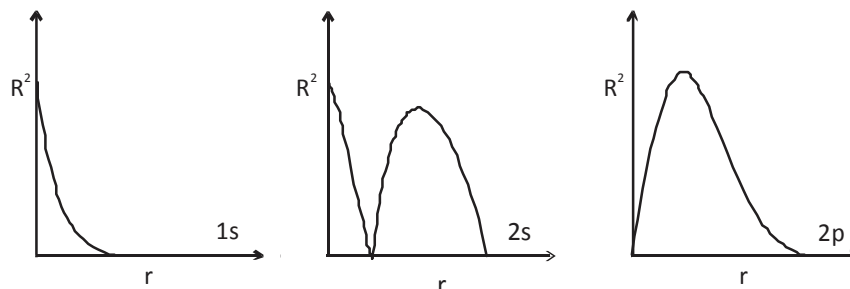
If we draw a graph between radial wave function,  $R$  (radial part of wave function) and  $r$  (distance from nucleus), we obtain graphs as shown below. These graphs are for 1s, 2s and 2p-orbitals of hydrogen atom. This type of dependence is known as *radial dependence*. These plots show radial dependence on only one side of the nucleus. These plots do not have any direct physical significance, but are useful in molecular structure because atomic wave functions are needed to build molecular wave functions. It is clear from the graph, that in 1s radial wave function,  $j$ , is positive everywhere, but for other s orbitals *i.e.*, for 2s or 3s-orbitals it is positive in some regions and negative in others. It may be noted that +ve and -ve signs have only relative significance. During superposition (in the formation of molecular orbitals) relative signs play a very important part.



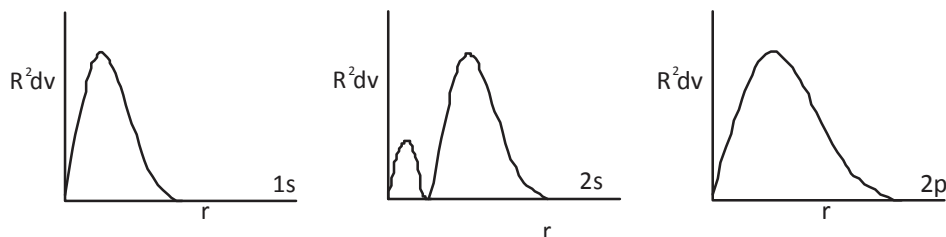
Graphs between radial wave function,  $R$  and  $r$  (distance from nucleus)

We know that square of the wave function\*,  $R^2$ , represents the probability of finding the electron in a unit volume *i.e.*, probability density. The graphs between square of the radial wave function  $R^2$  and  $r$  (distance from nucleus) are known as radial probability density graphs. These graphs differ slightly from the earlier graphs as  $R^2$  is positive throughout.

(“In case  $R$  is not real,  $IRI^2$  can be taken in place of  $R^2$ . In such cases  $IRI^2 = R$ . .)



Graph between  $R^2$  (radial probability density) and  $r$



Graph between radial probability function  $R^2 dV$  (or  $4\pi r^2 R$  and  $r^2$ )

As  $R^2$  represents the probability density, *i.e.*, probability of finding the electron in a unit volume,  $R^2 dV$  gives the probability of finding the given electron in a volume  $dV$ . The product  $R^2 dV$  is also known as radial probability distribution function. The graph of  $R^2 dV$  versus  $r$  (distance from nucleus) is known as radial probability distribution function graphs.

If we observe the radial probability distributive graph of  $1s$ , we find it is quite different from the radial probability density graph. The radial probability density is maximum close to the nucleus, but the radial probability is least. This is due to the fact that volume of the spherical shell ( $dV$ ) near the nucleus is very small resulting in a small value of radial probability  $R^2 dV$ . At the nucleus (*i.e.*,  $r = 0$ ),  $dV$  is zero, hence  $R^2 dV$  as also zero, although  $R^2$  is very large at this point. As the distance from nucleus ( $r$ ) increases, the volume of the shell  $dV$  ( $4\pi r^2 dr$ ) increases while  $R^2$  decreases. As a result, the radial probability keeps on increasing gradually and reaches a maximum value and then decreases gradually. The maximum in the curve indicates the most probable value and the corresponding distance from the nucleus is called distance of maximum probability ( $r_0$ ). For hydrogen atom in ground state, this has a value of 53 pm.

It is important to note that Bohr predicted that the electron will always be at a distance of 53 pm from the nucleus for hydrogen atom in ground state. However, according to wave mechanical model the electron is most likely to be found at this distance and there is probability of finding the electron at distances both shorter and longer than this.

The radial probability distribution curve for  $2s$ -orbital ( $n = 2, l = 0$ ) shows two maxima, a smaller one nearer the nucleus and a bigger one at a larger distance. Comparing the location of the maxima in the  $2s$  orbital, we conclude that an electron in the  $2s$ -orbital has greater probability to stay further away than an electron in the  $1s$  orbital.

The radial probability distribution curves of three  $2p$ -orbitals ( $n = 2, l = 1$ ) are identical. It shows only one maximum. The distance of maximum probability for a  $2p$ -orbital is slightly less than that for a  $2s$ -orbital. However, in contrast to the curve for  $2p$ -orbital, there is a small additional maximum in the curve for  $2s$ -orbital. In other words,  $2s$ -orbital penetrates closer to the nucleus, than a  $2p$ -orbital. Thus, an electron in  $2s$ -orbital has a lower energy than an electron in a  $2p$ -orbital.

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### Some Note worth points

1. The radius of maximum probability of 1s electron is  $0.529\text{\AA}$ .
2. The number of regions of maximum probability for 1s, 2p, 3d and 4f is one. For 2s, 3p, 4d and 5f these are two and so on.
3. The small humps indicate that the electron has a tendency to penetrate closer to the nucleus.
4. In between the regions of zero electron density called node. More is the number nodes more is the energy of an orbital.
5. In these curves, the first orbital of each type (1s, 2p, 3d, 4f) has one region of maximum probability and no node. Whereas the first orbital of each type (2s, 3p, 4d, 5f) has two regions of maximum probability and one node so on.

### Quantum numbers

Each orbital in an atom is specified by a set of three quantum numbers ( $n, l, m$ ) and each electron is designated by a set of four quantum numbers ( $n, l, m$  and  $s$ ).

(1) **Principle quantum number ( $n$ )**

- (i) The maximum number of an electron in an orbit represented by this quantum number as  $2n^2$ .
- (ii) It gives the information of orbit  $K, L, M, N$  —————.
- (iii) Angular momentum can also be calculated using principle quantum number

(2) **Azimuthal quantum number ( $l$ )**

- (i) Azimuthal quantum number is also known as angular quantum number. Proposed by *Sommerfeld* and denoted by ' $l$ '.
- (ii) It determines the number of sub shells or sublevels to which the electron belongs.

Value of $l$	0	1	2	3
Name of subshell	s	p	d	f
Shape of subshell	Spherical	Dumbbell	Double dumbbell	Complex

- (iii) It tells about the shape of subshells.
- (iv) It also expresses the energies of subshells  $s < p < d < f$  (increasing energy).
- (v) The value of  $l = (n - 1)$  always.
- (vii) It represents the orbital angular momentum. Which is equal to  $\frac{h}{2\pi} \sqrt{l(l+1)}$
- (viii) The maximum number of electrons in subshell =  $2(2l + 1)$

(3) **Magnetic quantum number ( $m$ )**

- (i) It was proposed by *Zeeman* and denoted by ' $m$ '.
- (ii) It gives the number of permitted orientation of subshells.
- (iii) The value of  $m$  varies from  $-l$  to  $+l$  through zero.
- (iv) It tells about the splitting of spectral lines in the magnetic field i.e. this quantum number proves the Zeeman effect.
- (v) For a given value of ' $n$ ' the total value of ' $m$ ' is equal to  $n^2$ .

- (vi) For a given value of 'l' the total value of 'm' is equal to (2l + 1).
- (vii) *Degenerate orbitals* : Orbitals having the same energy are known as degenerate orbitals.  
e.g. for p subshell  $p_x$   $p_y$   $p_z$

**(4) Spin quantum numbers (s)**

- (i) It was proposed by *Goldshmidt & Ulen Back* and denoted by the symbol of 's'.
- (ii) The value of 's' is +1/2 and -1/2, which signifies the spin or rotation or direction of electron on it's axis during movement.
- (iii) The spin may be clockwise or anticlockwise.
- (iv) It represents the value of spin angular momentum is equal to  $\frac{h}{2\pi} \sqrt{s(s+1)}$ .
- (v) Maximum spin of an atom (spin multiplicity) =  $\frac{1}{2} \times \text{number of unpaired electrons}$
- (vi) This quantum number is not the result of solution of Schrodinger equation as solved for H-atom.

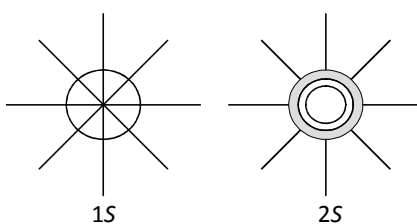
**Distribution of electrons among the quantum levels**

n	l	m	Designation of orbitals	Number of Orbitals in the subshell
1	0	0	1s	1
2	0	0	2s	1
2	1	-1, 0, +1	2p	3
3	0	0	3s	1
3	1	-1, 0, +1	3p	3
3	2	-2, -1, 0, +1, +2	3d	5
4	0	0	4s	1
4	1	-1, 0, +1	4p	3
4	2	-2, -1, 0, +1, +2	4d	5
4	3	-3, -2, -1, 0, +1, +2, +3	4f	7

**Shape of orbitals**

**(1) Shape of 's' orbital**

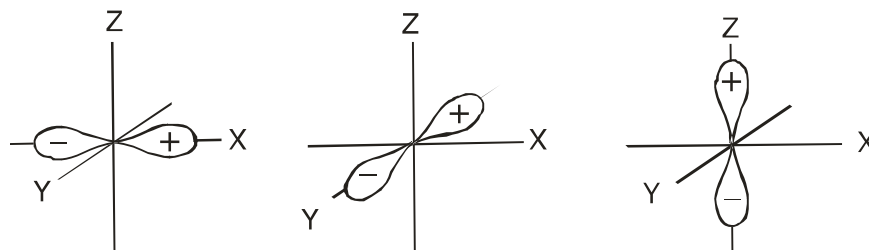
- (i) For 's' orbital  $l=0$  &  $m=0$  so 's' orbital have only one unidirectional orientation i.e. the probability of finding the electrons is same in all directions.
- (ii) The size and energy of 's' orbital with increasing 'n' will be  $1s < 2s < 3s < 4s$ .



- (iii) s-orbitals known as radial node or nodal surface. But there is no radial node for 1s orbital since it is starting from the nucleus.

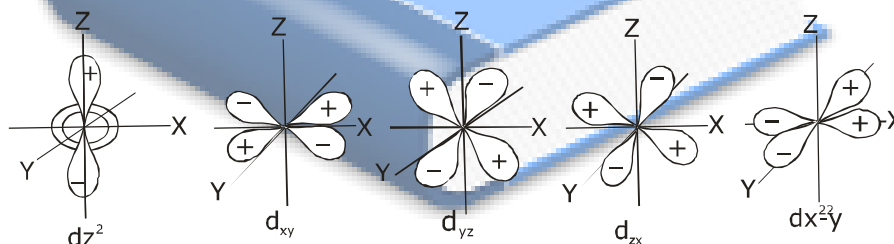
## (2) Shape of 'p' orbitals

- For 'p' orbital  $l=1$ , &  $m=+1,0,-1$  means there are three 'p' orbitals, which is symbolised as  $p_x, p_y, p_z$ .
- Shape of 'p' orbital is dumb bell in which the two lobes on opposite side separated by the nodal plane.
- p-orbital has directional properties.



## (3) Shape of 'd' orbital

- For the 'd' orbital  $l=2$  then the values of 'm' are  $-2, -1, 0, +1, +2$ . It shows that the 'd' orbitals has five orbitals as  $d_{xy}, d_{yz}, d_{zx}, d_{x^2-y^2}, d_{z^2}$ .
- Each 'd' orbital identical in shape, size and energy.
- The shape of d orbital is double dumb bell.
- It has directional properties



## (4) Shape of 'f' orbital

- For the 'f' orbital  $l=3$  then the values of 'm' are  $-3, -2, -1, 0, +1, +2, +3$ . It shows that the 'f' orbitals have seven orientation as  $f_{x(x^2-y^2)}, f_{y(x^2-y^2)}, f_{z(x^2-y^2)}, f_{xyz}, f_{z^3}, f_{yz^2}$  and  $f_{xz^2}$ .
- The 'f' orbital is complicated in shape.

## Rules for filling of electrons in various orbitals

The atom is built up by filling electrons in various orbitals according to the following rules,

### (1) Aufbau's principle

This principle states that the electrons are added one by one to the various orbitals in order of their increasing energy starting with the orbital of lowest energy. The increasing order of energy of various orbitals is  $1s < 2s < 2p < 3s < 3p < 4s < 3d < 4p < 5s < 4d < 5p < 6s < 4f < 5d < 6p < 7s < 5f < 6d < 7p$ .....

## (2) $(n+l)$ Rule

In neutral isolated atom, the lower the value of  $(n + l)$  for an orbital, lower is its energy. However, if the two different types of orbitals have the same value of  $(n + l)$ , the orbitals with lower value of  $n$  has lower energy.

## (3) Pauli's exclusion principle

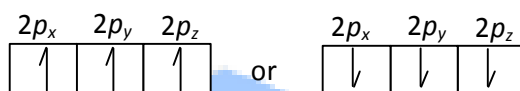
According to this principle "no two electrons in an atom will have same value of all the four quantum numbers".

## (4) Hund's Rule of maximum multiplicity

"Electron pairing in orbitals cannot occur until each orbitals of a given subshell contains one electron each or is singly occupied".

As we now know the Hund's rule, let us see how the three electrons are arranged in orbitals.

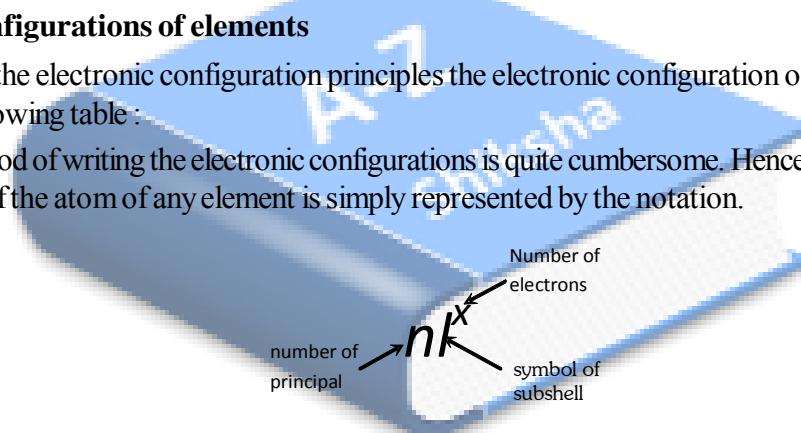
The important point to be remembered is that all the singly occupied orbitals should have electrons with parallel spins i.e in the same direction either-clockwise or anticlockwise .



## Electronic configurations of elements

On the basis of the electronic configuration principles the electronic configuration of various elements are given in the following table :

The above method of writing the electronic configurations is quite cumbersome. Hence, usually the electronic configuration of the atom of any element is simply represented by the notation.



## Some Unexpected Electronic Configuration

Some of the exceptions are important though, because they occur with common elements, notably chromium and copper.

$\text{Cu}$  has 29 electrons. Its expected electronic configuration is  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^9$  but in reality the configuration is  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^{10}$  as this configuration is more stable. Similarly  $\text{Cr}$  has the configuration of  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^5$  instead of  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^4$  .

Factors responsible for the extra stability of half-filled and completely filled subshells,

- (i) *Symmetrical distribution* : It is well known fact that symmetry leads to stability. Thus the electronic configuration in which all the orbitals of the same subshell are either completely filled or are exactly half filled are more stable because of symmetrical distribution of electrons.
- (ii) *Exchange energy* : The electrons with parallel spins present in the degenerate orbitals tend to exchange their position. The energy released during this exchange is called exchange energy. The number of exchanges that can take place is maximum when the degenerate orbitals (orbitals of same subshell having equal energy) are exactly half-filled or completely. As a result, the exchange energy is maximum and so is the stability.

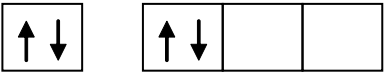
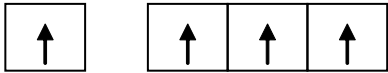
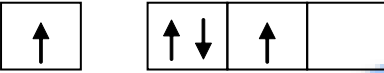
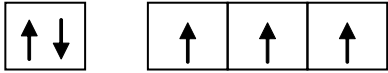


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### M.C.Q.

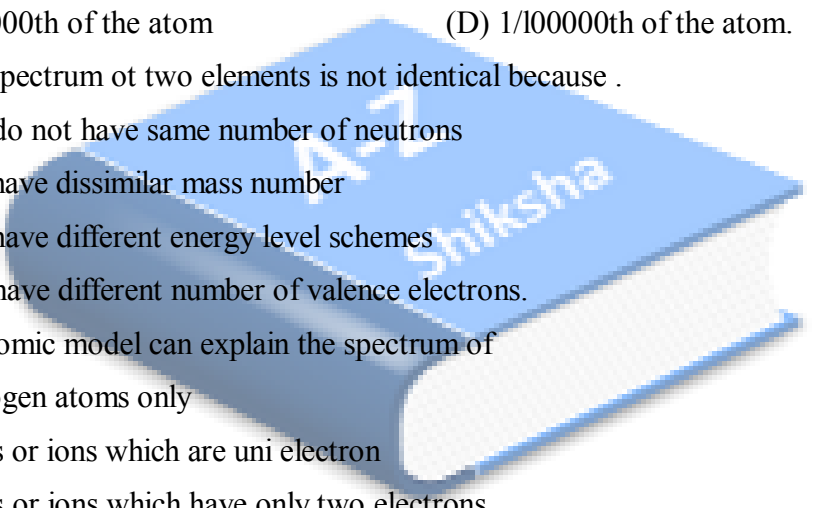
- What is wrong about anode rays?  
(A) Their  $e/m$  ratio is constant  
(B) They are deflected by electrical and magnetic field  
(C) They are produced by ionisation of molecules of the residual gas  
(D) Their  $elm$  ratio depends on nature of residual gas.
- When atoms of the gold sheet are bombarded by a beam of  $\alpha$  -particles, only a few  $\alpha$ -particles get deflected whereas most of them go straight undeflected. This is because  
(A) The force of attraction on  $\alpha$ -particles by the oppositely charged electron is not sufficient  
(B) The nucleus occupies much smaller volume as compared to the volume of atom  
(C) The force of repulsion on fast moving  $\alpha$ -particles is very small  
(D) The neutrons in the nucleus do not have any effect on  $\alpha$  -particles.
- Which of the following is not a characteristic of Planck's quantum theory of radiations?  
(A) Radiations are associated with energy  
(B) Magnitude of energy associated with a quantum is equal to  $h\nu$   
(C) Radiation energy is neither emitted nor absorbed continuously  
(D) A body can emit less or more than a quantum of energy.
- Which of the following statements is wrong? The probability of finding the electron in  $p_x$  orbital is  
(A) Maximum on two opposite sides of the nucleus along  $x$ -axis  
(B) zero at the nucleus  
(C) same on all the sides around the nucleus  
(D) zero on the  $z$ -axis
- In uni electron system, the wave number of any spectral line is directly proportional to  
(A) the number particles present in the system  
(B) the velocity of electron undergoing transition  
(C)  $\frac{1}{n_1^2} - \frac{1}{n_2^2}$  (D) the charge on the nucleus and the  $\epsilon$  of light used.
- The conclusion that every additional electron enters the orbital with lowest possible energy has been drawn from  
(A) Pauli's exclusion principle (B) Hund's rule  
(C) Aufbau principle (D) de-Broglie's equation.
- Bohr's model of atom is not in agreement with  
(A) Line spectra of hydrogen atom (B) Pauli's principle  
(C) Planck's theory (D) Heisenberg's principle.

8. Which of the following statements is correct?
- (A) All electromagnetic radiations do not possess the same velocity  
 (B) Matter waves are associated with electrical and magnetic fields  
 (C) Matter waves and electromagnetic radiations are alike  
 (D) The velocity of matter wave is generally less than that of light
9. Which experimental observation correctly account for the phenomenon?
- | Experimental observation          | Phenomenon                 |
|-----------------------------------|----------------------------|
| (A) X-rays spectra                | Charge on nucleus          |
| (B) $\alpha$ -particle scattering | Quantized electron orbit . |
| (C) Photoelectric effect          | The nuclear atom           |
| (D) Emission spectra              | Quantization of energy. .  |
10. In the Schrodinger's wave equation  $\psi$  represents
- (A) orbit                      (B) wave function                      (C) wave                      (D) radial probability
11. Which of the following gave the idea of a nucleus of the atom?
- (A) Oil drop experiment                      (B) Davisson and Germer's experiment  
 (C)  $\alpha$ -ray scattering experiment                      (D) Austen's mass spectrogram experiment.
12. Cathode rays have same charge to mass ratio as
- (A)  $\alpha$ -particles                      (B)  $\beta$ -rays                      (C) Anode rays                      (D) Protons
13. Which of the following statements is/are correct?
- (A) Isotopes have same number of nucleons  
 (B) Isobars have same number of protons  
 (C) Isotones have same number of neutrons  
 (D) Isobars are atoms of different elements with same isotopic number
14. According to Bohr's Model of hydrogen atom
- (A) Total energy of the electron is quantized  
 (B) Angular momentum of the electron is quantized and given as  $\sqrt{l(l+1)} \frac{h}{2\pi}$   
 (C) Both (A) and (B)  
 (D) None of the above.
15. Rutherford's experiment established that
- (A) inside the atom there are positive centres immersed in sea of electrons  
 (B) nucleus contains protons, neutrons and mesons  
 (C) most of the space in an atom is empty  
 (D) all A, B and C.

16. Mathematically, Heisenberg's uncertainty principle can best be explained by  
 (A)  $\Delta x \times \Delta p \geq \frac{h}{\pi}$     (B)  $\Delta p \geq \frac{\pi h}{\Delta x}$     (C)  $\Delta x \times \Delta p \geq \frac{h}{4\pi}$     (D)  $\Delta x \geq \frac{\Delta p \times h}{4\pi}$
17. The correct Schrodinger's wave equation for an electron with E as total energy and V as potential energy is  
 (A)  $\frac{\delta^2 \varphi}{\delta x^2} + \frac{\delta^2 \varphi}{\delta y^2} + \frac{\delta^2 \varphi}{\delta z^2} + \frac{8\pi^2}{mh^2} (E - V)\varphi = 0$     (B)  $\frac{\delta^2 \varphi}{\delta x^2} + \frac{\delta^2 \varphi}{\delta y^2} + \frac{\delta^2 \varphi}{\delta z^2} + \frac{8\pi m}{h^2} (E - V)\varphi = 0$   
 (C)  $\frac{\delta^2 \varphi}{\delta x^2} + \frac{\delta^2 \varphi}{\delta y^2} + \frac{\delta^2 \varphi}{\delta z^2} + \frac{8\pi^2 m}{h^2} (E - V)\varphi = 0$     (D)  $\frac{\delta^2 \varphi}{\delta x^2} + \frac{\delta^2 \varphi}{\delta y^2} + \frac{\delta^2 \varphi}{\delta z^2} + \frac{8\pi m^2}{h} (E - V)\varphi = 0$
18. In which of the following electron distributions in ground state, only the Hund's rule is violated?  
 (A)     (B)   
 (C)     (D) 
19. Which of the following expressions imposes the condition of quantization of energy of an electron in an atom?  
 (A)  $E = mc^2$     (B)  $E = h \nu$     (C)  $\lambda = \frac{h}{mv}$     (D)  $mvr = \frac{n h}{2\pi}$
20. The total number of electrons in a subshell designated by azimuthal quantum number,  $l$  is given as  
 (A)  $2l + 1$     (B)  $l^2$     (C)  $4l + 2$     (D)  $2l + 2$ .
21. According to Bohr's model of the atom, an electron can revolve around the atomic nucleus in a suitable orbit without emitting energy if its orbit  
 (A) is a perfect circle    (B) is a circle with a large radius  
 (C) houses a whole number of de-Broglie waves  
 (D) houses odd number of de-Broglie waves.
22. Which of the following concerning Bohr's model is false?  
 (A) Predicts that probability of electron near nucleus is more  
 (B) Angular momentum of electron in H atom  
 (C) Introduces the idea of stationary states  
 (D) Explains line spectrum of hydrogen.
23. The kinetic energy of the electron in the  $n$ th orbit of an atom is given by the relation (A) (B) (C) (D) none of these
24. According to Sommerfeld's model, only circular orbit is possible for the electron in  
 (A) K shell    (B) L shell    (C) M shell    (D) N shell.

25. According to Bohr's atomic model  
 (A) electron on H atom can have only certain values of angular momentum  
 (B) electrons have a particle as well as wave character  
 (C) atomic spectrum of atom should contain only five lines  
 (D) all the above statements are correct. .
26. The transition of electrons in H atom that will emit maximum energy is  
 (A)  $n_3 \longrightarrow n_2$  (B)  $n_4 \longrightarrow n_3$  (C)  $n_5 \longrightarrow n_4$  (D)  $n_6 \longrightarrow n_5$
27. The limiting line in Balmer series will have a frequency of  
 (A)  $3.29 \times 10^{15} \text{s}^{-1}$  (B)  $3.65 \times 10^{14} \text{s}^{-1}$  (C)  $8.22 \times 10^{14} \text{s}^{-1}$  (D)  $9.22 \times 10^{14} \text{s}^{-1}$
28. The wavelength of a spectral line for electron transition is inversely related to  
 (A) Z (nuclear charge) (B) velocity of electron  
 (C) number of electrons undergoing transition  
 (D) the energy difference between the energy levels involving transition.
29. The phenomenon of splitting of spectral lines under the influence of the electric field is known as  
 (A) Photoelectric effect (B) Stark effect  
 (C) Zeeman effect (D) Electromagnetic effect.
30. If the energy of electron in H atom is given by expression,  $-\frac{1312}{n^2} \text{kJ mol}^{-1}$ , then the energy required to excite the electron from ground state to second orbit is  
 (A) 328 kJ (B) 656 kJ (C) 984 kJ (D) 1312 kJ.
31. In the atomic spectrum of hydrogen, the spectral lines pertaining to electronic transition of  $n=4$  to  $n=2$  refers to  
 (A) Lyman lines (B) Balmer lines (C) Paschen lines (D) Brackett lines.
32. When electronic transition occurs from higher energy state to a lower energy state with energy difference equal to  $\Delta E$  electron volts, the wavelength of line emitted is approximately equal to  
 (A)  $\frac{12397}{\Delta E} \times 10^{-10} \text{m}$  (B)  $\frac{12397}{\Delta E} \times 10^{10} \text{m}$  (C)  $\frac{12397}{\Delta E} \times 10^{-10} \text{cm}$  (D)  $\frac{12397}{\Delta E} \times 10^{10} \text{cm}$
33. If ionising energy of H atom is 13.6 eV, then the second ionising energy of He should be  
 (A) 13.6eV (B) 27.2eV  
 (C) 54.4 eV (D) Cannot be predicted.
34. The first line in the Balmer series in the H atom will have the frequency  
 (A)  $4.57 \times 10^{14} \text{S}^{-1}$  (B)  $3.29 \times 10^{15} \text{s}^{-1}$  (C)  $8.22 \times 10^{15} \text{S}^{-1}$  (D)  $8.05 \times 10^{13} \text{S}^{-1}$ .
35. The orbital configuration of  ${}_{24}\text{Cr}$  is  $3d^5 4s^1$ . The number of unpaired electrons in is  
 (A) 3 (B) 2 (C) 1 (D) 4.

36. How many electrons in  ${}_{19}\text{K}$  have  $n=3$ ;  $l=0$  ?  
 (A) 1 (B) 2 (C) 4 (D) 3.
37. The maximum number of electrons in s, p and d-subshells are  
 (A) 2 in each (B) 2, 4 and 6 (C) 2, 6 and 10 (D) 2, 6 and 12.
38. In an atom which has 2K, 8L, 8M and 2N electrons in the ground state, the total number of electrons having  $l=1$  are  
 (A) 20 (B) 8 (C) 12 (D) 10.
39. The number of electrons that can be accommodated in  $d_{xy}$  orbital is  
 (A) 10 (B) 4 (C) 1 (D) 2.
40. The electronic configuration of Mn can be written as  
 (A)  $[\text{Ar}] 4s^2$  (B)  $[\text{Ar}] 3d^6, 4s^2$  (C)  $[\text{Ar}] 3d^5, 4s^1$  (D)  $[\text{Ar}] 3d^5, 4s^2$ .
41. Which of the following sets of quantum numbers is not possible for 23rd electron of Cr (At. no. 24) ?  
 (A) 3, 2, +2,  $-\frac{1}{2}$  (B) 3, 2, -2,  $+\frac{1}{2}$  (C) 3, 2, +1,  $+\frac{1}{2}$  (D) 3, 1, +1,  $+\frac{1}{2}$ .
42. Which d-orbital does not have four lobes?  
 (A)  $dx^2-y^2$  (B)  $dxy$  (C)  $dyz$  (D)
43. The total number of electrons present in any main energy level can be calculated from  
 (A)  $(2l+1)$  (B)  $2n^2$  (C)  $(2n+1)$  (D)  $n^2$ .
44. Which shape is associated with the orbital designated by  $n=2$ ;  $l=1$  ?  
 (A) spherical (B) tetrahedral (C) dumb-bell (D) pyramidal.
45. Which of the following statements about quantum numbers is wrong?  
 (A) If the value of  $l=0$ , the electron distribution is spherical  
 (B) The shape of the orbital is given by subsidiary quantum number  
 (C) The Zeeman's effect is explained by magnetic quantum number  
 (D) The spin quantum number gives the orientations of electron cloud.
46. The two electrons have the following sets of quantum numbers . X: 3, 2, -2,  $+\frac{1}{2}$   
 Y : 3, 0, 0,  $+\frac{1}{2}$ . What is true of the following?  
 (A) X and Y have same energy (B) X and Y have unequal energy  
 (C) X and Y represent same electron (D) None of the statements is correct.
47. If the value of azimuthal quantum number of an electron is 2, then which of the following values of magnetic quantum numbers is not permissible,  
 (A) 3 (B) 2 (C) 0 (D) 1.
48. An isotone of  ${}_{32}\text{Ge}^{76}$  is (i)  ${}_{32}\text{Ge}^{77}$  (ii)  ${}_{33}\text{As}^{77}$  (iii)  ${}_{34}\text{Se}^{77}$  (iv)  ${}_{34}\text{Se}^{78}$ .  
 (A) only (i) & (ii) (B) only (ii) & (iii) (C) only (ii) & (iv) (D) (ii), (iii) & (iv)

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49. The fundamental particles which are responsible for keeping nucleons together is  
(A) Meson (B) Antiproton (C) Positron (D) Electron. .
50. The positron is as heavy as  
(A) electron (B) neutron (C) alpha particle (D) proton.
51. Atoms may be regarded as comprising of protons, electrons and neutrons. If the mass attributed to the neutrons were halved and that attributed to electrons were doubled then atomic mass of would  
(A) remain approximately the same (B) be doubled  
(C) Approximately be halved (D) be reduced by approximately 25%.
52. How many electrons in an atom with atomic number 105 can have  $(n + l) = 8$  ?  
(A) 30 (B) 17 (C) 15 (D) Unpredictable.
53. The size of the nucleus is approximately  
(A) 1/100th of the atom (B) 1/1000 th of the atom  
(C) 1/10000th of the atom (D) 1/100000th of the atom.
54. The line spectrum of two elements is not identical because .  
(A) they do not have same number of neutrons  
(B) they have dissimilar mass number  
(C) they have different energy level schemes  
(D) they have different number of valence electrons.
55. Bohr's atomic model can explain the spectrum of  
(A) hydrogen atoms only  
(B) atoms or ions which are uni electron  
(C) atoms or ions which have only two electrons  
(D) hydrogen molecule.
56. The electronic configuration of a dipositive ion  $M^{+2}$  is 2, 8, 14 and its mass number is 56. The number of neutrons present is  
(A) 32 (B) 42 (C) 30 (D) 34.
57. An electron of mass  $m$  and charge  $-e$  moves in circular orbit of radius  $r$  around the nucleus of charge  $+Ze$  in uni electron system. In C.G.S. system the potential energy of electron is  
(A) (B) (C) (D)
58. An atom has 2 K, 8 L, 11 M, 2 N electrons, the total number of s-electrons will be  
(A) 6 (B) 8 (C) 10 (D) 4.
59. In an atom with 2K, 8L, 11M and 2N electrons the number of electrons with  $m = 0$  ;  $s = + \frac{1}{2}$  are  
(A) 2 (B) 7 (C) 8 (D) 16.
- 

60. For a sub-shell with azimuthal quantum number  $l$ , the total values of magnetic quantum number  $m$  can be related to  $l$  as
- (A)  $m = (+2)$       (B)  $m = (2^2 + 2)$       (C)  $l = \frac{(m-1)}{2}$       (D)  $=2m+1$ .
61. An orbital with  $l=0$  is
- (A) symmetrical about X-axis only      (B) symmetrical about Y-axis only  
(C) spherically symmetrical      (D) unsymmetrical.
62. The units for equation are
- (A)  $\frac{kg\ m^2s^{-1}}{kgms^{-1}}$       (B)  $\frac{kg\ ms^2}{ms^{-1}}$       (C)  $\frac{kg\ m^2s^{-2}}{kgm^2s^{-1}}$       (D)  $\frac{kg\ ms^{-3}}{kg\ m}$
63. The momentum of a photon of frequency  $50 \times 10^{17}S^{-1}$  is nearly
- (A)  $1.1 \times 10^{-23}\ kg\ ms^{-1}$       (B)  $3.33 \times 10^{-43}\ kg\ ms^{-1}$   
(C)  $2.27 \times 10^{-40}\ kg\ ms^{-1}$       (D) none
64. A near U.V. photon of 300 nm is absorbed by a gas and then remitted as two photons. One photon is red with wavelength 760 nm. Hence wavelength of the second photon is
- (A) 460 nm      (B) 1060nm      (C) 496nm      (D) 300nm
65. The transition in  $He^+$  ion that would have the same wave number as the first Lyman line in hydrogen spectrum is
- (A)  $2 \longrightarrow 1$       (B)  $5 \longrightarrow 3$       (C)  $4 \longrightarrow 2$       (D)  $6 \longrightarrow 4$
66. The work function of a metal is 4.2 eV. If radiations of  $2000\ \text{Å}$  fall on the metal then the kinetic energy of the fastest photo electron is
- (A)  $1.6 \times 10^{-19}J$       (B)  $16 \times 10^{10}J$       (C)  $3.2 \times 10^{-19}J$       (D)  $6.6 \times 10^{-10}J$
67. A certain metal when irradiated to light ( $\nu = 3.2 \times 10^{16}\ Hz$ ) emits photoelectrons with twice kinetic energy as did photo electrons when the same metal is irradiated by light ( $\nu = 2.0 \times 10^{16}Hz$ ). The  $\phi$  of metal
- (A)  $1.2 \times 10^{14}\ H_z$       (B)  $8 \times 10^{15}\ H_z$       (C)  $1.2 \times 10^{16}\ H_z$       (D)  $4 \times 10^{12}\ H_z$
68. The ratio of the radii of the first three Bohr orbit in H atom is
- (A)  $1: \frac{1}{2} : \frac{1}{3}$       (B) 1:2:3      (C) 1:4:9      (D) 1:8:27
- Hint :  $r_n = n^2 a_0$  i.e.  $r_1 : r_2 : r_3 = 1^2 : 2^2 : 3^2 = 1 : 4 : 9$
69. An electron of a velocity  $v$  is found to have a certain value of de-Broglie wavelength. The velocity to be possessed by the neutron to have the same de-Broglie wavelength is
- (A)  $v$       (B)  $\frac{v}{1840}$       (C)  $1840\ v$       (D)  $\frac{1840}{v}$
70. The momentum of a particle associated with de-Broglie's wave length of  $6\ \text{Å}$  is
- (A)  $1.1 \times 10^{-24}kgms^{-1}$       (B)  $1.1 \times 10^{34}kgms^{-1}$   
(C)  $39.6 \times 10^{-34}kgms^{-1}$       (D)  $39.6 \times 10^{-24}kgms^{-1}$

71. Frequency of matter wave is equal to  $\nu = \text{frequency}$ ,  $v = \text{velocity of particle}$   
 (A) (K.E.)/ $2h$       (B)  $2 \cdot (\text{K.E.})/h$       (C) (K.E./ $h$ )      (D)  $\lambda$
- $$\lambda = \frac{h}{m v} \quad \nu = \lambda v \quad \therefore \lambda = \frac{v}{\nu} \quad \therefore \frac{v}{\nu} = \frac{h}{m v} \quad \therefore v = \frac{m v^2}{h} = \frac{2 \cdot \text{K.E.}}{h} \quad (\text{K.E.} = \frac{1}{2} m v^2)$$
72. If threshold wavelength for ejection of electron from metal is 300nm, then work function for photoelectric emission is  
 (A)  $1.2 \times 10^{-18}$  J      (B)  $1.2 \times 10^{-20}$  J      (C)  $6 \times 10^{-19}$  J      (D)  $6 \times 10^{-12}$  J
- Work function is  $h\nu_0 = \frac{hc}{\lambda_0} = 6 \times 10^{-19}$  J
73. The mass of one mole of electron is  
 (A)  $9.1 \times 10^{-28}$ g      (B) 0.55mg      (C)  $9.1 \times 10^{-24}$ g      (D) 1.008mg
74. In two H atoms A and B the electrons move around the nucleus in circular orbits of radius  $r$  and  $4r$  respectively. The ratio of the times taken by them to complete one revolution is  
 (A) 1: 4      (B) 1: 2      (C) 1: 8      (D) 2: 1
75. For the electronic transition from  $n=2$  to  $n=1$  which one of the following will produce shortest wave length?  
 (A) H atom      (B) D atom      (C)  $\text{He}^+$  ion      (D)  $\text{Li}^{+2}$  ion
76. The energy required to dislodge electron from excited isolated H atom ( $\text{IE}_1 = 13.6\text{eV}$ ) is  
 (A)  $=13.6\text{eV}$       (B)  $>13.6\text{eV}$       (C)  $<13.6\text{eV}$  and  $>3.4\text{eV}$       (D)  $3.4\text{eV}$
77. Velocity of electron in the first orbit of H-atom is compared to that of velocity of light is approximately  
 (A)  $\frac{1}{1000} th$       (B)  $\frac{1}{137} th$       (C)  $\frac{1}{10} th$       (D) same
78. How many electrons in Cu atom have  $(n + l) = 4$   
 (A) 6      (B) 7      (C) 8      (D) 4
79. In any subshell the maximum number of electrons having same value of spin quantum number is  
 (A)  $\sqrt{l(l+1)}$       (B)  $l+2$       (C)  $2l+1$       (D)  $4l+2$
80. For a certain particle, it is found that uncertainty in velocity is reciprocal of uncertainty in position This implies that  
 (A) Mass of the particle is  $> \text{unity}$       (B) Mass of the particle is unity  
 (C) Mass of the particle  $\leq h$       (D) Mass of the particle  $\geq h/4\pi$
81. How many electrons in K ( $Z=19$ ) have  $n = 4$  and ?  
 (A) 1      (B) 2      (C) 3      (D) 4
82. Suggest two transitions in hydrogen spectrum for which wave number ratio is 108:7  
 (A)  $2 \rightarrow 1, 3 \rightarrow 1$       (B)  $2 \rightarrow 1, 4 \rightarrow 3$       (C)  $2 \rightarrow 1, 5 \rightarrow 4$       (D)  $2 \rightarrow 1, 4 \rightarrow 1$



83. The ratio of K.E. to P.E. of an electron in Bohr orbit of H like species is  
 (A) 1 : 2                      (B)– 1 : 2                      (C) 1 : 1                      (D)– 1 : 1
84. For particles having same KE., the de-broglie wavelength is  
 (A) Directly proportional to its velocity,                      (B) Inversely proportional to its velocity ,  
 (C) Independent of its mass and velocity                      (D) Unpredictable.
85. In one joule of energy, the number of photon with wave number equal to  $x$  is  
 (A)  $(hcx)^{-1}$                       (B)  $x(hc)^{-1}$                       (C)  $(hcx)$                       (D)  $hc(x)^{-1}$
86. Which of the expression given below gives IE of H atoms in terms of Rydberg's constant ( $R_H$ )?  
 (A)  $R_H hc$                       (B)  $R_H \cdot N_A \cdot hc$                       (C)  $R_H (2hc)$                       (D)  $R_H \cdot c$
87. One unpaired electron causes magnetic moment of 1.1 B.M. The magnetic moment of  $Fe^{+2}$  ion is  
 (A) 4.4                      (B) 5.5                      (C) 2.2                      (D) 0
88. If numerical value of mass and velocity are equal then de-Broglie wave length in terms of K.E. is  
 (A)  $\frac{mh}{2K.E.}$                       (B)  $\frac{v h}{2K.E.}$                       (C) both correct                      (D) none
89. If uncertainty in position and velocity are equal then uncertainty in momentum will be  
 (A)  $\frac{1}{2} \sqrt{\frac{mh}{\pi}}$                       (B)  $\frac{1}{2} \sqrt{\frac{h}{\pi m}}$                       (C)  $\frac{h}{4\pi m}$                       (D)  $\frac{mh}{4\pi}$
90. Number of waves made by a Bohr electron in one complete revolution in its fourth orbit is  
 (A) 2                      (B) 3                      (C) 4                      (D) infinite
91. Which of the following electronic transitions require that the greatest amount of energy be absorbed by a hydrogen atom?  
 (A)  $n=1$  to  $n=2$                       (B)  $n=2$  to  $n=4$                       (C)  $n=3$  to  $n=6$                       (D)  $n=\infty$  to  $n=1$
92. How fast an electron is moving if it has a wavelength equal to the distance it travel in one second?  
 (A)  $\sqrt{h/m}$                       (B)  $\sqrt{m/h}$                       (C)  $\sqrt{h/p}$                       (D)  $\sqrt{h/2(K.E)}$
93. If uncertainties in the measurement of position and momentum are equal, the uncertainty in the measurement of velocity is  
 (A)  $\frac{1}{2} \sqrt{\frac{mh}{\pi}}$                       (B)  $\frac{1}{2\pi} \sqrt{\frac{h}{m}}$                       (C)  $\frac{1}{2m} \sqrt{\frac{h}{\pi}}$                       (D) none of these
94. Energy equivalent of  $10.00 \text{ cm}^{-1}$  is  
 (A)  $19.9 \times 10^{-23}$  J per photon                      (B)  $28.6 \times 10^{-3}$  kcal  $\text{mol}^{-1}$  photon  
 (C)  $12.0 \times 10^{-3}$  kJ  $\text{mol}^{-1}$  photon                      (D) all are correct

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95. The ratio of energy of the electron in ground state of hydrogen to the electron in first excited state of  $\text{Be}^{+3}$  is  
(A) 1: 4                      (B) 1: 8                      (C) 1: 16                      (D) 16: 1
96. The shortest wavelength of H-atom in Lyman series is  $x$ , then longest wavelength in Balmer series of  $\text{He}^+$  is  
(A)  $\frac{9x}{5}$                       (B)  $\frac{36x}{5}$                       (C)  $\frac{x}{4}$                       (D)  $\frac{5x}{9}$
97. The radius of first Bohr orbit is  $x$ , then de-Broglie wavelength of electron in 3rd orbit is nearly  
(A)  $2\pi x$                       (B)  $6\pi x$                       (C)  $9x$                       (D)  $x/3$
98. With increasing principle quantum number, the energy difference between adjacent energy levels in H atom  
(A) decreases                      (B) increases                      (C) remains constant  
(D) decreases for low value of  $Z$  and increases for higher value of  $Z$ ,
99. The electrons present in K-shell of the atom will differ in  
(A) principal quantum number                      (B) azimuthal quantum number  
(C) magnetic quantum number                      (D) spin quantum number.
100. The ratio of the ionisation energy of H and  $\text{Be}^{3+}$  is..... (Pb. C.E.T. 1996)  
(A) 1: 1                      (B) 1: 3                      (C) 1 : 9                      (D) 1: 16.
101. The maximum number of electrons in a subshell for which  $l = 3$  is (Andhra B. Tech 1982)  
(A) 14                      (B) 10                      (C) 8                      (D) 4.
102. The number of electrons in the M shell of the element with atomic number 24 is (Andhra B. Tech. 1982)  
(A) 24                      (B) 12                      (C) 13                      (D) 8.
103. Sodium chloride imparts a yellow colour to the Bunsen flame. This can be interpreted due to the  
(A) low ionization energy of sodium  
(B) sublimation of metallic sodium to give yellow vapour  
(C) emission of excess energy absorbed as a radiation in the visible region  
(D) photosensitivity of sodium.
104. The exact path of electron 2p-orbital cannot be determined.” The above statement is based upon (Delhi P.M. T. 1981)  
(A) Hund’s Rule                      (B) Bohr’s Rule                      (C) Uncertainty principle                      (D) Aufbau principle.
105. The maximum number of electrons in a subshell is given by the expression (C.B.S.E. 1989)  
(A)  $4l - 2$                       (B)  $4l + 2$                       (C)  $2l + 1$                       (D)  $2n^2$ .

106. If  $r$  is the radius of first orbit, the radius of  $n$ th orbit of the H atom will be (C.B.S.E. 1989)
- (A)  $r n^2$                       (B)  $r n$                       (C)  $r/n$                       (D)  $r^2 n^2$
107. The energy of hydrogen atom in its ground state is  $-13.6$  eV. The energy of the level corresponding to the quantum number  $n = 5$  is (C.B.S.E. 1990, M.P.C.E.T. 1999)
- (A)  $-0.54$  eV                      (B)  $-5.40$  eV                      (C)  $-0.85$  eV                      (D)  $-2.72$  eV.
108. At  $200^\circ\text{C}$  hydrogen molecules have velocity  $10^5$  cm sec $^{-1}$ . The de-Broglie wavelength in this case is approximately (C.B.S.E. 1991)
- (A)  $2 \text{ \AA}$                       (B)  $1000 \text{ \AA}$                       (C)  $100 \text{ \AA}$                       (D)  $10 \text{ \AA}$ .
109. The number of electrons in 3d shell for element with atomic number 26 is (C.E.E. T. Sample Paper 1992)
- (A) 4                      (B) 6                      (C) 8                      (D) 10.
110. In a set of degenerate orbitals the electrons distribute themselves to retain similar spins as far as possible. This statement is attributed to (Pb. C.E. T. 1989)
- (A) Pauli's exclusion principle                      (B) Aufbau principle  
(C) Hund's Rule                      (D) Slater rules.
111. The ground state configuration of  $\text{Fe}^{3+}$  ion in gaseous state is: (At. No. of Fe = 26) (Karnataka C.E.E.T. 1992)
- (A)  $[\text{Ar}]^{18} 3d^3 4s^2$                       (B)  $[\text{Ar}]^{18} 3d^6 4s^2$                       (C)  $[\text{Ar}]^{18} 3d^5$                       (D)  $[\text{Ar}]^{18} 3d^6$ .
112. If uncertainty in the position of electron is zero, the uncertainty in its momentum would be (B.H.U.1992)
- (A) zero                      (B)  $\geq \frac{h}{4\pi}$                       (C)  $<$                       (D) infinite.
113. The radius of second Bohr's orbit is (B.H. U. 1989)
- (A)  $0.053$  nm                      (B)  $0.053/4$  nm                      (C)  $0.053 \times 4$  nm                      (D)  $0.053 \times 20$  nm.
114. For which of the following sets of quantum -numbers an electron will have the highest energy ? (C.B.S.E. 1994)
- (A)  $3, 2, 1, 1/2$                       (B)  $4, 2, -1, 1/2$                       (C)  $4, 1, 0, -1/2$                       (D)  $5, 0, 0, 1/2$ .
115. The uncertainty in the position of an electron (mass  $9.1 \times 10^{-28}$  g) moving with a velocity of  $3.0 \times 10^4$  cms $^{-1}$  accurate up to 0.011% will be (C.B.S.E. 1995)
- (A)  $1.92$  cm                      (B)  $7.68$  cm                      (C)  $0.175$  cm                      (D)  $3.84$  cm.

116. The radius of hydrogen atom in the ground state is  $0.53 \text{ \AA}$ , the radius of  ${}_3\text{Li}^{2+}$  in the similar state is  
 (A)  $1.06 \text{ \AA}$  (B)  $0.265 \text{ \AA}$  (C)  $0.17 \text{ \AA}$  (D)  $0.53 \text{ \AA}$ .  
 (C.B.S.E. 1995)
117. Splitting of spectral lines under the influence of magnetic field is called  
 (A) Stark effect (B) Zeeman effect (C) Photoelectric effect (D) None of these.  
 (A.F.M.C. 1995)
118. The total number of orbitals in a shell with principal quantum number 'n' is  
 (A)  $2n$  (B)  $2n^2$  (C)  $n^2$  (D)  $n + 1$ .  
 (A.I.I.M.S. 1997)
119. Which of the following expressions gives the de-Broglie relationship ?  
 (A)  $\frac{h}{mv} = p$  (B)  $\lambda = \frac{h}{mv}$  (C)  $\lambda = \frac{h}{mp}$  (D)  $\lambda m = \frac{v}{p}$  (M.P.P.M.T. 1998)
120. The uncertainty in the momentum of an electron is  $1.0 \times 10^{-5} \text{ kg ms}^{-1}$ . The uncertainty in its position will be ( $h = 6.62 \times 10^{-34} \text{ kg m}^2\text{s}^{-1}$ )  
 (A)  $1.05 \times 10^{-28} \text{ m}$  (B)  $1.05 \times 10^{-26} \text{ m}$  (C)  $5.27 \times 10^{-30} \text{ m}$  (D)  $5.25 \times 10^{-28} \text{ m}$ .  
 (Pune A.F.M.C. 1998)
121. If the radius of first Bohr orbit be  $a_0$ , then the radius of third Bohr orbit would be  
 (A)  $3 \times a_0$  (B)  $6 \times a_0$  (C)  $9 \times a_0$  (D)  $1/9 \times a_0$ .  
 (M.P.C.E.T. 1998)
122. The first emission line in the atomic spectrum of hydrogen in the Balmer series appears at  
 (A)  $\frac{9R}{400} \text{ cm}^{-1}$  (B)  $\frac{7R}{144} \text{ cm}^{-1}$  (C)  $\frac{3R}{4} \text{ cm}^{-1}$  (D)  $\frac{5R}{36} \text{ cm}^{-1}$   
 (E.A.M.C.E.T. 1998)
123. The ratio of specific charge of a proton and an  $\alpha$ -particle is  
 (A)  $2 : 1$  (B)  $1 : 2$  (C)  $1 : 4$  (D)  $1 : 1$   
 (M.P.C.E.T. 1999)
124. The de-Broglie wavelength of a particle with mass  $1 \text{ g}$  and velocity  $100 \text{ m/s}$  is  
 (A)  $6.63 \times 10^{-33} \text{ m}$  (B)  $6.63 \times 10^{-34} \text{ m}$  (C)  $6.63 \times 10^{-35} \text{ m}$  (D)  $6.65 \times 10^{-35} \text{ m}$ .  
 (C.B.S.E. 1999)
125. Which of the following sets of quantum numbers belongs to highest energy ?  
 (A)  $n = 4, l = 0, m = 0, s = +\frac{1}{2}$  (B)  $n = 3, l = 0, m = 0, s = +\frac{1}{2}$   
 (C)  $n = 3, l = 1, m = 1, s = +\frac{1}{2}$  (D)  $n = 3, l = 2, m = 1, s = +\frac{1}{2}$   
 (C.P.M.T. 1999)

126. If wavelength of photon is  $2.2 \times 10^{-11}$  m,  $h = 6.6 \times 10^{-34}$  Js, then momentum of photon is  
 (A)  $3 \times 10^{-23}$  kg ms<sup>-1</sup> (B)  $3.33 \times 10^{22}$  kg ms<sup>-1</sup>  
 (C)  $1.452 \times 10^{-44}$  kgms<sup>-1</sup> (D)  $6.89 \times 10^{43}$  kg ms<sup>-1</sup>.  
 (M.P.C.E.T. 1999)
127. According to Bohr's theory, the energy required for the transition of H atom from  $n = 6$  to  $n = 8$  state is  
 (A) equal to energy required for the transitions from  $n = 5$  to  $n = 7$  state  
 (B) larger than in (A)  
 (C) less than in (A)  
 (D) equal to energy for the transition from  $n = 7$  to  $n = 9$  state (Kerala M.E.E. 2000)
128. An electron has kinetic energy of  $2.14 \times 10^{-22}$ J. Its de-Broglie wavelength will be nearly ( $m_e = 9.1 \times 10^{-31}$  kg)  
 (A)  $9.28 \times 10^{-4}$  (B)  $9.28 \times 10^{-7}$ m (C)  $9.28 \times 10^{-8}$ m (D)  $9.28 \times 10^{-10}$ m.  
 (M.P.C.E.T. 2000)
129. What will be de-Broglie wavelength of an electron moving with a velocity of  $1.20 \times 10^5$ ms<sup>-1</sup> ?  
 (A)  $6.068 \times 10^{-9}$  (B)  $3.133 \times 10^{-37}$  (C)  $6.626 \times 10^{-9}$  (D)  $6.018 \times 10^{-7}$   
 (M.P.C.E.T. 2000)
130. The de-Broglie wavelength associated with ball of mass 200 g and moving at a speed of 5 m hour<sup>-1</sup> is of the order of ( $h = 6.625 \times 10^{-34}$  Js)  
 (A)  $10^{-15}$ m (B)  $10^{-20}$ m (C)  $10^{-30}$ m (D)  $10^{-25}$ m  
 (Kerala P.M.T. 2001)
131. The third line of the Balmer series. in the emission spectrum of the hydrogen atom, is due to the transition from the  
 (A) fourth Bohr orbit to the first Bohr orbit (B) fifth Bohr orbit to the second Bohr orbit  
 (C) sixth Bohr orbit to the third Bohr orbit (D) seventh Bohr orbit to the third Bohr orbit  
 (Kerala P.M.T. 2001)
132. The highest number of unpaired electrons are w present in (D.C.E. 2001)  
 (A) Fe<sup>o</sup> (B) Fe<sup>4+</sup> (C) Fe<sup>2+</sup> (D) Fe<sup>3+</sup>.
133. Rutherford's atomic model suggests the existence  
 (A) Atom (B) Nucleus (C)  $\alpha$ -particle (D) Mesons  
 (A.E.M.C. 2001)
134. Which is not true with respect to cathode rays?  
 (A) A stream of electrons (B) Charged particles  
 (C) Move with speed as that of light (D) Can be deflected by magnetic fields  
 (Kerala C.E.T. 2001)

135. A element M has an atomic mass 19 and atomic number 9. Its ion is represented by  
 (A)  $M^+$  (B)  $M^{2+}$  (C)  $M^-$  (D)  $M^{2-}$ .  
 (Manipal P.M.T. 2001)
136. Which of the following ions has the maximum magnetic moment ?  
 (A)  $Mn^{2+}$  (B)  $Fe^{2+}$  (C)  $Ti^{2+}$  (D)  $Cr^{2+}$ .  
 (A.I.E.E.E. 2002)
137. The value of the energy for the first excited state of hydrogen will be  
 (A)  $-13.6eV$  (B)  $-3.40eV$  (C)  $-1.51eV$  (D)  $-0.85eV$ .  
 (M.P.C.E.T. 2002)
138. In hydrogen atom, energy of first excited state is  $-3.4 eV$ . Find out the K.E. of the same orbit of hydrogen atom  
 (A)  $+3.4eV$  (B)  $+6.8eV$  (C)  $-13.6eV$  (D)  $+13.6eV$   
 (C.B.S.E. P.M.T. 2002)
139. The energy of the first electron in helium will be  
 (A)  $-13.6eV$  (B)  $-54.4eV$  (C)  $-5.44eV$  (D) zero.  
 (Bihar C.EE. 2002)
140. In a hydrogen atom, if the energy of an electron in the ground state is  $13.6 eV$ , then that in the 2nd excited state is  
 (A)  $1.51eV$  (B)  $3.4eV$  (C)  $6.04eV$  (D)  $13.6eV$ .  
 (A.I.E.E.E. 2002)
141. In the Bohr's orbit, what is the ratio of total kinetic energy and total energy of the electron  
 (A)  $-1$  (B)  $-2$  (C)  $1$  (D)  $+2$ .  
 (Rajashan P.M.T. 2002)
142. The ratio between kinetic energy and the total energy of the electrons of hydrogen atom according to Bohr's model is  
 (A)  $2 : 1$  (B)  $1 : 1$  (C)  $1 : (-1)$  (D)  $1 : 2$ .  
 (Pb. P.M.T. 2002)
143. In Bohr series of lines of hydrogen spectrum, the third line from the red end corresponds to which one of the following inter-orbit jumps of the electron for Bohr orbits in an atom of hydrogen ?  
 (A)  $3 \longrightarrow 2$  (B)  $5 \longrightarrow 2$  (C)  $4 \longrightarrow 1$  (D)  $2 \longrightarrow 5$ .  
 (A.I.E.E.E. 2003)
144. The orbital angular momentum for an electron revolving in an orbit is given by  $\sqrt{l(l+1)} \cdot \frac{h}{2\pi}$   
 This momentum for an s-electron will be given by

- (A)  $+\frac{1}{2} \cdot \frac{h}{2\pi}$       (B) zero      (C)  $\frac{h}{2\pi}$       (D)  $\sqrt{2} \frac{h}{2\pi}$   
(A.I.E.E.E. 2003)
145. The atomic number of an element is 35. What is the total number of electrons present in all the p-orbitals of the ground state atom of that element ?  
(A) 6      (B) 11      (C) 17      (D) 23.  
(E.A.M.C.E.T. 2003)
146. The emission spectrum of hydrogen is found to satisfy the expression for the energy change "E (in Joules) such that "E =  $2 \cdot 18 \times 10^{-18}$  J where  $n_1 = 1, 2, 3, \dots$  and  $n_2 = 2, 3, 4, \dots$ . The spectral lines correspond to Paschen series it  
(A)  $n_1 = 1$  and  $n_2 = 2, 3, 4$       (B)  $n_1 = 3$  and  $n_2 = 4, 5, 6$   
(C)  $n_1 = 1$  and  $n_2 = 3, 4, 5$       (D)  $n_1 = 2$  and  $n_2 = 3, 4, 5$   
(Kerala Engg. 2003)
147. Among the following series of transition metal ions, the one where all metal ions have same 3d electronic configuration is  
(A)  $Ti^{2+}, V^{3+}, Cr^{4+}, Mn^{5+}$       (B)  $Ti^{3+}, V^{2+}, Cr^{3+}, Mn^{4+}$   
(C)  $Ti^+, V^{4+}, Cr^{6+}, Mn^{7+}$       (D)  $Ti^{4+}, V^{3+}, Cr^{2+}, Mn^{3+}$   
(C.B.S.E. P.M.T. 2004)
148. For d-electron, the orbital angular momentum is  
(A)  $\sqrt{6} h / 2\pi$       (B)  $\sqrt{2} h / 2\pi$       (C)  $h / 2\pi$       (D)  $2h/\pi$ .  
(J & K Med.2004)
149. Time taken for an electron to complete one revolution in the Bohr orbit of hydrogen atom is  
(A)  $\frac{4\pi^2 m r^2}{nh}$       (B)  $\frac{nh}{4\pi^2 m r}$       (C)  $\frac{2\pi m r}{n^2 h^2}$       (D)  $\frac{h}{2\pi m r}$   
(Kerala P.M.T. 2004)
150. Which of the following sets of quantum numbers is correct for an electron in  $4f$ -orbital ?  
(A)  $n = 4, l = 3, m = +4, s = +\frac{1}{2}$       (B)  $n = 3, l = 2, m = -2, s = +\frac{1}{2}$   
(C)  $n = 4, l = 3, m = +1, s = +\frac{1}{2}$       (D)  $n = 4, l = 4, m = -4, s = -\frac{1}{2}$   
(A.I.E.E.E. 2004)
151. The wavelength of radiation emitted when in a hydrogen atom electron falls from infinity to stationary state 1, would be (Rydberg constant =  $1.09 \times 10^7 m^{-1}$ )  
(A) 91nm      (B)  $9.1 \times 10^{-8} nm$       (C) 406 nm      (D) 192 nm  
(A.I.E.E.E. 2004)
152. The relationship between energy E, of the radiation with a wavelength 8000 Å and the energy of the radiation with a wavelength 16000 Å is  
(A)  $E_1 = 6E_2$ ,      (B)  $E_1 = 2E_2$       (C)  $E_1 = 4E_2$       (D)  $E_1 = 1/2E_2$   
(Kerala Engg. 2005)

153. The energy of second Bohr orbit of the hydrogen atom is  $-328 \text{ kJ mol}^{-1}$ , hence the energy of fourth Bohr orbit would be

- (A)  $-41 \text{ kJ mol}^{-1}$       (B)  $-1312 \text{ kJ mol}^{-1}$       (C)  $-164 \text{ kJ mol}^{-1}$       (D)  $-82 \text{ kJ mol}^{-1}$

(C.B.S.E. P.M.T. 2005)

154. Which of the following statements in relation to the hydrogen atom is correct?

- (A) 3s-orbital is lower in energy than 3p-orbital  
 (B) 3p-orbital is lower in energy than 3d-orbital  
 (C) 3s and 3p orbitals are of lower energy than 3d orbital  
 (D) 3s, 3p and 3d orbitals all have the same energy.      (A.I.E.E.E. 2005)

155. The correct order of number of unpaired electrons in the ions  $\text{Cu}^{2+}$ ,  $\text{Ni}^{2+}$ ,  $\text{Fe}^{3+}$  and  $\text{Cr}^{3+}$  is

- (A)  $\text{Cu}^{2+} > \text{Ni}^{2+} > \text{Cr}^{3+} > \text{Fe}^{3+}$       (B)  $\text{Cr}^{3+} > \text{Fe}^{2+} > \text{Ni}^{2+} > \text{Cu}^{2+}$   
 (C)  $\text{Fe}^{3+} > \text{Cr}^{3+} > \text{Cu}^{2+} > \text{Ni}^{2+}$       (D)  $\text{Fe}^{3+} > \text{Cr}^{3+} > \text{Ni}^{2+} > \text{Cu}^{2+}$ .

(Kerala P.M.T. 2005)

156. The most probable radius (in pm) for finding the electron in  $\text{He}^+$  is

- (A) 0.0      (B) 52.9      (C) 26.5      (D) 105.8

(A.I.I.M.S. 2005)

157. Ground state electronic configuration of nitrogen atom can be represented by

- (A)  $\uparrow\downarrow$   $\uparrow\downarrow$   $\uparrow$   $\uparrow$   $\uparrow$       (B)  $\uparrow\downarrow$   $\uparrow\downarrow$   $\uparrow$   $\downarrow$   $\uparrow$   
 (C)  $\uparrow\downarrow$   $\uparrow\downarrow$   $\uparrow$   $\downarrow$   $\downarrow$       (D)  $\uparrow\downarrow$   $\uparrow\downarrow$   $\downarrow$   $\downarrow$   $\downarrow$

(I.I.T. 1999)

158. Which one of the following sets of quantum number represent an impossible arrangement?

- |     | n | l | $m_l$ | $m_s$         |     | n | l | $m_l$ | $m_s$          |
|-----|---|---|-------|---------------|-----|---|---|-------|----------------|
| (A) | 3 | 2 | -2    | $\frac{1}{2}$ | (B) | 4 | 0 | 0     | $\frac{1}{2}$  |
| (C) | 3 | 2 | -3    | $\frac{1}{2}$ | (D) | 5 | 3 | 0     | $-\frac{1}{2}$ |

(I.I.T. 1986)

159. The orbital diagram in which Aufbau principle is violated is

- (A)  $\uparrow\downarrow$   $\uparrow\downarrow$   $\uparrow$   $\square$       (B)  $\downarrow$   $\uparrow\downarrow$   $\uparrow$   $\uparrow$   
 (C)  $\uparrow\downarrow$   $\uparrow$   $\uparrow$   $\uparrow$       (D)  $\uparrow\downarrow$   $\uparrow\downarrow$   $\uparrow\downarrow$   $\uparrow$



160. If the speed of electron in Bohr first orbit of hydrogen atom be  $x$ , then speed of the electron in 3rd orbit is

- (A)  $x/9$  (B)  $x/3$  (C)  $3x$  (D)  $9x$  (I.I.T.1990)

161. If wavelength of photon is  $2.2 \times 10^{-11} \text{m}$ ,  $h = 6.6 \times 10^{-34} \text{Js}$ , then momentum of photon is

- (A)  $3 \times 10^{-23} \text{kg/s}$  (B)  $1.452 \times 10^{-44} \text{kg/s}$  (C)  $3.33 \times 10^{22} \text{kg/s}$  (D)  $6.89 \times 10^{43} \text{kg/s}$ .

(Roorkee 1990)

162. The wave number of first line of Balmer series of hydrogen is  $15200 \text{cm}^{-1}$ . The wave number of the first Balmer line of  $\text{Li}^{1+}$  ion is

- (A)  $15200 \text{cm}^{-1}$  (B)  $60800 \text{cm}^{-1}$  (C)  $76000 \text{cm}^{-1}$  (D)  $136,800 \text{cm}^{-1}$ .

(I.I.T. Screening 1992)

163. Which of the following is violation of Pauli's exclusion principle ?

- (A) (B) (C) (D)

(I.I.T. Screening 1993)

164. The electrons, identified by quantum number  $n$  and  $l$ , (i)  $n = 4, l = 1$  (ii)  $n = 4, l = 0$  (iii)  $n = 3, l = 2$  (iv)  $n = 3, l = 1$  can be placed in order of increasing energy, from the lowest to highest, as

- (A) (iv) < (ii) < (iii) < (i) (B) (ii) < (iv) < (i) < (iii)  
(C) (i) < (iii) < (ii) < (iv) (D) (iii) < (i) < (iv) < (ii) (I.I.T. 1999)

165. The wave length associated with a golf ball weighing 200 g and moving at a speed of 5 m/h is of the order

- (A)  $10^{-10} \text{m}$  (B)  $10^{-20} \text{m}$  (C)  $10^{-30} \text{m}$  (D)  $10^{-40} \text{m}$ .

(I.I.T. Screening2001)

166. If the nitrogen atom had electronic configuration  $1s^7$ , it would have energy lower than that of the normal ground state configuration  $1s^2 2s^2 2p^3$  because the electrons would be closer to the nucleus. Yet,  $1s^7$  is not observed because it violates.

- (A) Heisenberg uncertainty principle (B) Hund's rule  
(C) Pauli's exclusion principle (D) Bohr postulates of stationary orbits.

(I.I.T. Screening2002)

167. The radius of which of the following orbits is same as that of the first Bohr's orbit of hydrogen atom ?

- (A)  $\text{He}^+ (n = 2)$  (B)  $\text{Li}^{2+} (n = 2)$  (C)  $\text{Li}^{2+} (n = 3)$  (D)  $\text{Be}^{3+} (n = 2)$

(I.I.T. Screening2004)

168. Radial nodes present in 3s and 2p -orbitals are respectively  
 (A) 0, 2                      (B) 2, 0                      (C) 2, 1                      (D) 1,2.  
 (I.I.T. Screening2005)
169. Rutherford's experiment, which established the nuclear model of the atom, used a beam of  
 (A)  $\beta$  - particles, which impinged on a metal foil and got absorbed  
 (B)  $\gamma$  - rays, which impinged on a metal foil and ejected electrons  
 (C) helium atoms, which impinged on a metal foil and got scattered  
 (D) helium nuclei, which impinged on a metal foil and got scattered      (I.I.T. Screening2002)

### ANSWER KEY

1	a	2	b	3	d	4	c	5	c	6	c	7	d
8	d	9	d	10	b	11	c	12	b	13	c	14	c
15	c	16	c	17	d	18	a	19	d	20	c	21	c
22	a	23	c	24	a	25	a	26	a	27	c	28	d
29	b	30	c	31	b	32	a	33	c	34	a	35	a
36	b	37	c	38	c	39	d	40	d	41	a	42	d
43	b	44	c	45	d	46	b	47	a	48	c	49	a
50	a	51	d	52	b	53	d	54	c	55	b	56	b
57	b	58	b	59	b	60	c	61	c	62	a	63	a
64	c	65	c	66	c	67	b	68	c	69	d	70	a
71	d	72	c	73	b	74	c	75	d	76	d	77	b
78	b	79	c	80	d	81	a	82	b	83	b	84	a
85	a	86	a	87	a	88	c	89	a	90	c	91	a
92	a	93	c	94	d	95	a	96	a	97	b	98	a
99	b	100	d	101	a	102	c	103	c	104	c	105	b
106	a	107	a	108	a	109	b	110	c	111	c	112	d
113	c	114	b	115	c	116	c	117	b	118	c	119	b
120	c	121	c	122	d	123	b	124	a	125	d	126	a
127	c	128	c	129	a	130	c	131	b	132	d	133	b
134	c	135	a	136	c	137	c	138	a	139	b	140	a
141	a	142	c	143	b	144	b	145	c	146	b	147	a
148	a	149	a	150	c	151	a	152	b	153	d	154	d
155	c	156	c	157	c	157	d	158	c	159	b	160	b
161	a	162	a	163	d	164	a	165	c	166	c	167	d
168	b												

## HINTS

62. Unit of  $h = \text{J s}$ ,  $\text{J} = \text{kgm}^2\text{s}^{-2}$ ,  $m = \text{kg}$ ,  $v = \text{ms}^{-1}$

64.  $E = E_1 + E_2$  now  $E = \frac{hc}{\lambda} \therefore \frac{1}{\lambda} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}$

65.  $\bar{\nu} = R Z^2 \left[ \frac{1}{n_f^2} - \frac{1}{n_i^2} \right] \text{cm}^{-1}$   $\bar{\nu}_H = R \left[ \frac{1}{n_f^2} - \frac{1}{n_i^2} \right] \text{cm}^{-1}$   $\bar{\nu}_{He} = R (2)^2 \left[ \frac{1}{n_f^2} - \frac{1}{n_i^2} \right] \text{cm}^{-1}$

68.  $r_n = n^2 a_0$  i.e.  $r \propto n^2$   $r_1 : r_2 : r_3 = 1^2 : 2^2 : 3^2 = 1 : 4 : 9$

69.  $\lambda_e = \lambda_n \frac{h}{m_e v_e} = \frac{h}{m_n v_n} \therefore v_n = \frac{m_e v_e}{m_n} = \frac{v}{1840}$

71.  $\lambda = \frac{h}{m v}$   $v = \lambda v \therefore \lambda = \frac{v}{v} \therefore \frac{v}{v} = \frac{h}{m v} \therefore v = \frac{m v^2}{h} = \frac{2 \cdot \text{K.E.}}{h}$  (K.E. =  $\frac{1}{2} m v^2$ )

83.  $\text{K.E.} = \frac{Z e^2}{2r}$   $\text{P.E.} = \frac{Z e^2}{r} \therefore \frac{\text{K.E.}}{\text{P.E.}} = \frac{1/2}{-1} = -1 : 2$

85.  $E = h\nu = nh \frac{c}{\lambda} = nhc \bar{\nu} \therefore$  now  $E=1$ ,  $\bar{\nu}=x \therefore n = \frac{1}{hc x} = (hc x)^{-1}$

95.  $E_n = \frac{-13.6 Z^2}{n^2} \text{eV atom}^{-1}$  For hydrogen atom in ground state  $Z=1$  and  $n=1$  for  $\text{Be}^{+3}$  ion in first excited state  $Z=4$  and  $n=2$

100.  $I.E_o = \frac{R_H Z^2}{n^2}$   $I.E_H = \frac{R_H 1^2}{1^2} = R_H$

121. Radius of Bohr orbit =  $\frac{n^2}{Z} \times a_0$

122. for Balmer series  $n_1 = 2$  and  $n_2 = 3$  for first line

138. K.E. of  $e^-$  in  $n$ th orbit =  $-E_n = 3.4 \text{ e.V}$

139.  $E_n = -\frac{13.6}{n^2} Z^2 \text{ e.V}$

141.  $\text{K.E.} = \frac{1}{2} m v^2$   $\text{P.E.} = -\frac{Z e^2}{r}$

Electrostatic force = centrifugal force

$\therefore \frac{Z e^2}{r^2} = \frac{m v^2}{r} \therefore \text{P.E.} = -m v^2$

Total energy = K.E + P.E =  $\frac{1}{2} m v^2 - m v^2 = -\frac{1}{2} m v^2 \therefore \frac{\text{K.E.}}{\text{Total energy}} = -1$