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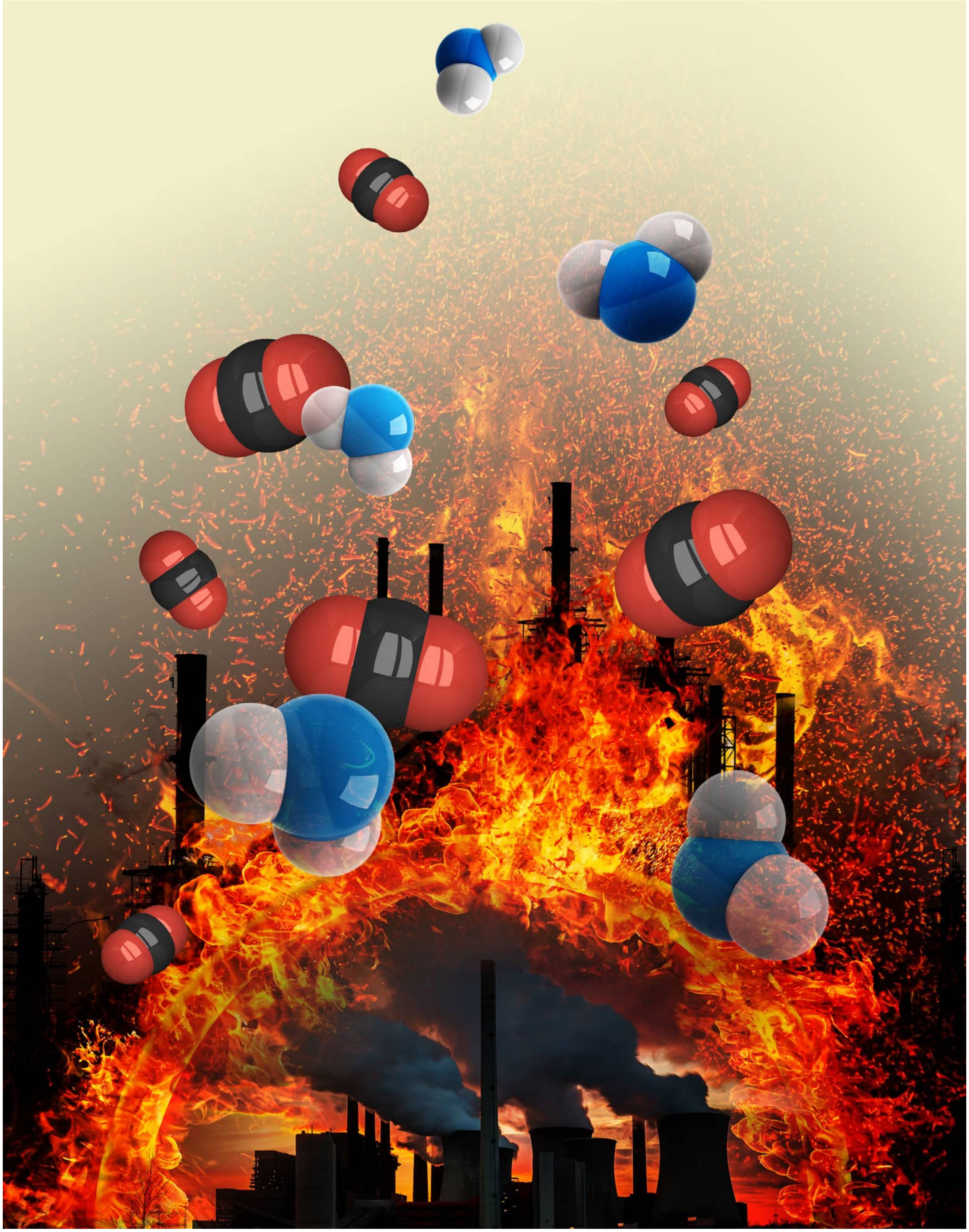
30-SECOND
CHEMISTRY

THE 50 MOST ELEMENTAL CONCEPTS IN CHEMISTRY,
EACH EXPLAINED IN HALF A MINUTE

Editor **Nivaldo Tro**



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THE 50 MOST ELEMENTAL CONCEPTS IN CHEMISTRY, EACH EXPLAINED IN HALF A MINUTE

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IVY PRESS

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Inorganic Chemistry

Organic Chemistry

Biochemistry

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INTRODUCTION

Nivaldo Tro

The core idea of chemistry is that *the whole can be explained by its parts*. The properties of matter can be explained by the bits that compose it. Understand the bits, and you understand the whole. Philosophers call this idea reductionism. Reductionism has not always been popular in the history of thought, nor is it clear that it is universally true. But the stunning and ongoing success of chemistry in explaining the behaviour of matter – even living matter – suggests that, at a minimum, reductionism is a powerful and useful idea.

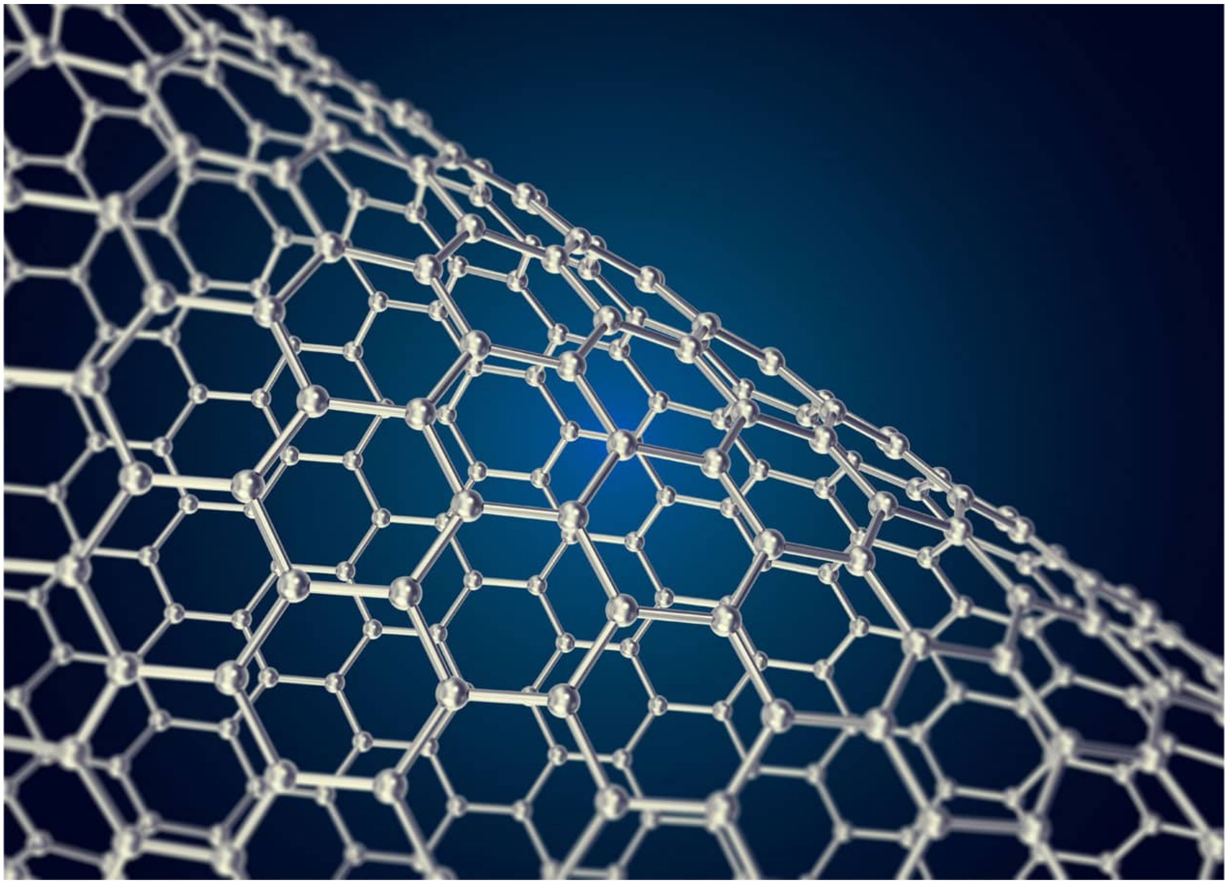
The 'bits' in chemistry are atoms, ions and molecules. Although the idea that matter has fundamental 'bits' is quite old – it was first suggested more than 2,000 years ago – its broad acceptance is quite recent, and occurred only about 200 years ago. Before that time, most thinkers thought that matter was continuous, that it had no smallest bits. The advent of the scientific revolution in the sixteenth century led thinkers to correlate their ideas about nature more carefully with empirical measurements. Since empirical measurements supported the particulate model, the continuous model was discarded.

Chemistry helps us understand that we - and all things around us - are made up of particles.

Once the particulate model was accepted in the 1800s, progress came relatively quickly. Scientists began figuring out the structure of the basic particles that compose matter, and by the early-to-mid twentieth century, chemists had good models that explained how atoms bond together to form molecules, and how the structures of atoms and molecules affect the properties of the substances they compose. In fact, throughout chemistry, the relationship between structure and properties is a key unifying theme.

A second unifying theme of chemistry is the progression from simple to complex. It turns out that, in nature, when you put together simple particles in slightly different ways, you can get vast complexity. Just as the 26 letters of our alphabet can be combined in different ways to compose many words, and just as you can combine those words in many ways to form an even larger number of complex ideas, so the 91 elements that compose matter can be combined to form many compounds, and those compounds can be combined to form an even larger number of complex substances, including all living things.

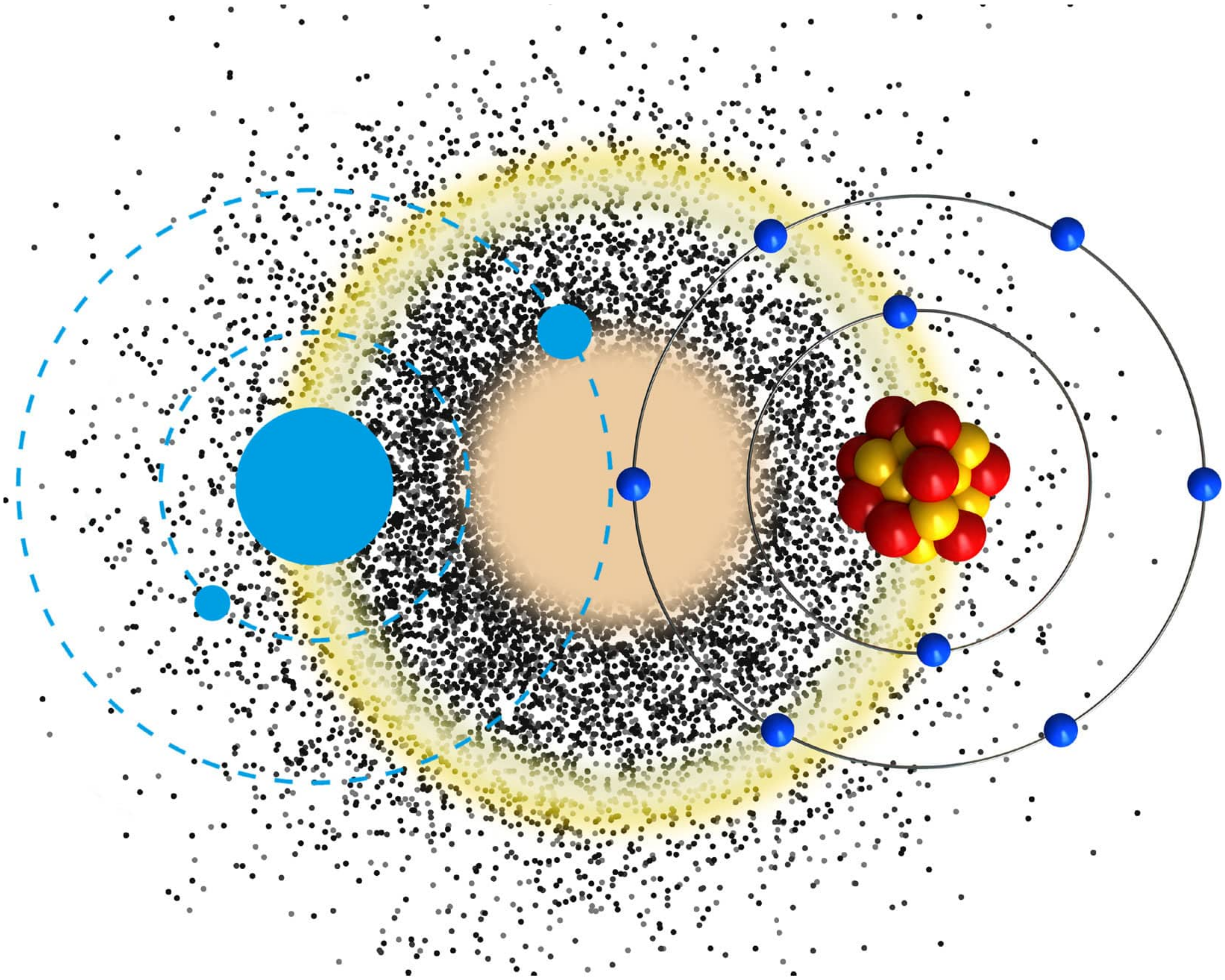
How far can chemistry go in its explanations? We still don't really know. We know that chemistry can explain how a gas behaves, but can it explain how a human brain behaves? The second half of the twentieth century saw the outgrowth of chemistry into biology with tremendous success. We now know details about the structures of the complex molecules at the core of life, and how those structures affect many attributes of living things. We have been able to custom-make molecules to fight disease, and even change the hereditary molecules (DNA) in living organisms to alter the characteristics of those living organisms. The twenty-first century has brought new challenges and new directions. On one frontier, scientists are using the ideas in chemistry to try to explain even more complex phenomena, such as human consciousness, for example. On another frontier, scientists are using chemistry to build ever smaller structures and machines, one atom at a time. Someday we may have molecular submarines, capable of navigating the bloodstream to fight invading cancer cells or viruses. On yet another frontier, scientists have created new materials such as graphene, a two-dimensional substance only one atom thick and stronger than steel. It seems that, at least for the foreseeable future, the power of the particulate model of matter to explain behaviour and produce new technology will continue.



Graphene is a new, carbon-based material that is just one atom thick but is stronger than steel.

A tour of this book

In this book, we present the 50 most important ideas in chemistry. Each entry is broken up into several parts: the 30-second chemistry is the body of the explanation; the 3-second nucleus is the idea expressed in a single sentence; the 3-minute valence describes how the idea fits within a wider context, or can be applied to different circumstances. The book starts with atoms, their structures and their properties. It then goes on to show how atoms bond together to form compounds, and how we can understand bonding and the resulting molecules. From there we move on to the states of matter (gases, liquids and solids) and then on to chemical reactions. We then examine the energetics and describe the laws that govern the flow of energy. Finally, we survey four subfields of chemistry: inorganic chemistry, organic chemistry, biochemistry and nuclear chemistry. Our goal throughout is not to provide exhaustive or detailed accounts of chemistry, but rather to give you a flavour of the field – to show that behind all that happens around you and inside you, particles are doing a complex and beautiful dance that makes it all possible.



The position of electrons within an atom is central to understanding how atoms bond together.

ATOMS, MOLECULES & COMPOUNDS

ATOMS, MOLECULES & COMPOUNDS

GLOSSARY

alkali metals The column of metals (group IA) on the far left of the periodic table that includes lithium, sodium, potassium, rubidium, cesium and francium.

atomic number The unique number assigned to each element that corresponds to the number of protons in the element's nucleus.

atomic theory The idea that all matter is composed of tiny particles called atoms.

classical physics Physics before the advent of quantum mechanics.

covalent bonding The joining of atoms by the sharing of one or more electrons.

electron A subatomic particle with a negative charge and a mass of 0.00055 amu (atomic mass unit).

element A fundamental substance that cannot be divided into simpler substances. There are 91 naturally occurring elements.

Heisenberg's Uncertainty Principle The quantum mechanical principle that certain quantities, such as position and momentum, cannot be simultaneously specified to arbitrary accuracy.

ionic bonding The joining of two atoms by the transfer of an electron from one to the other.

ionic compound A compound, usually composed of a metal and one or more non-metals, that contains atoms joined by ionic bonds.

isotope An atom that has the same number of protons as another atom, but a different number of neutrons.

mass number The sum of the number of protons and neutrons of an atom.

molecular compound A compound, usually composed of two or more non-metals, that contains atoms joined by covalent bonds.

neutron A subatomic particle with no charge and a mass of 1 amu.

noble gases The column of gases (group 8A) on the far right of the periodic table that includes helium, neon, argon, krypton, xenon and radon.

nuclear fusion The joining of two lighter nuclei to form a heavier one.

nuclear model A model for the atom in which most of the mass of the atom is contained in a small dense nucleus composed of protons and neutrons. Most of the volume of the atom is occupied by the electron cloud.

nucleosynthesis The process by which elements form within stars.

proton A subatomic particle with a positive charge and a mass of 1 amu.

quantum mechanics The realm of physics, developed in the early twentieth century, that deals with the very smallest particles that exist.

Schrödinger's Cat thought experiment A thought experiment involving the application of the uncertainty principle to a cat in a box with a radioactive substance that has a 50 per cent chance of decaying. If the atom decays, then the cat dies, so the cat is in a strange state of being both dead and undead, with a 50 per cent probability of each. Schrödinger used this experiment to show that quantum mechanical ideas are not applicable to large scale objects (such as cats).

valence electrons The highest energy electrons (and therefore the most important in bonding) in an atom.

velocity A measure of how fast (and in what direction) an object is moving.

MATTER IS MADE OF PARTICLES

the 30-second chemistry

The Ancient Greek philosophers believed that matter was infinitely divisible – that matter had no fundamental particles. Subsequent thinkers followed suit for more than 2,000 years. It was not until the eighteenth and nineteenth centuries that early chemists used careful measurements – primarily the relative weights of related samples of matter – to determine otherwise. And it wasn't until the early twentieth century that the question was definitely settled: the 1926 Nobel Prize for Physics was awarded to Jean Perrin for settling the matter. The Greeks were wrong – matter is particulate (it is made up of particles), and those particles are called atoms. And that turns out to be among the most important ideas in all of human thought. Why? Because the idea that matter is made of particles has enabled us to understand nature from the bottom up. What we found was remarkable: as far as we can tell, the particles that compose matter – their composition and structure – determine the properties of matter. Matter does what the particles that compose it do. Water boils at 100°C (212°F) because the three atoms that compose a water molecule bond together in a certain order, at a certain angle and at certain distances. Change any of these characteristics and water would be a different substance.

3-SECOND NUCLEUS

Matter is composed of particles. The nature of the particles – especially their structure – determines the properties of matter.

3-MINUTE VALENCE

Humans have wondered about the fundamental composition of matter for 2,500 years. The basic question is this: if you divide a sample of matter into smaller and smaller pieces, could you go on forever or would you eventually get to fundamental particles that are no longer divisible? For most of civilization, humans got the answer to this question wrong.

RELATED TOPICS

See also

THE STRUCTURE OF THE ATOM

INSIDE THE ATOM

WHERE DID ATOMS COME FROM?

3-SECOND BIOGRAPHIES

JOHN DALTON

1766–1844

English chemist who articulated the atomic theory of matter

JEAN PERRIN

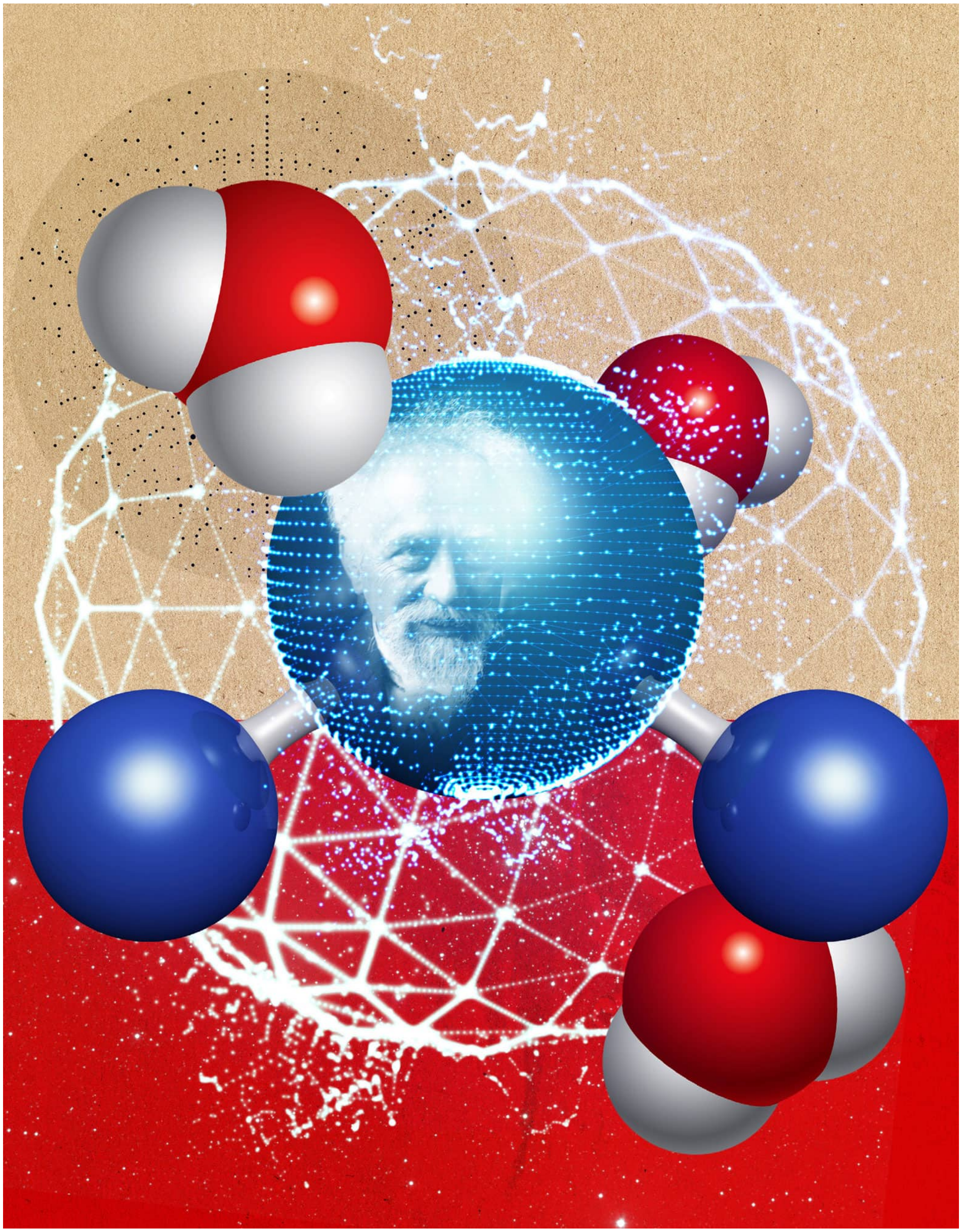
1870–1942

French physicist who studied the motion of tiny particles suspended in liquid to experimentally settle the question of the particulate nature of matter

30-SECOND TEXT

Nivaldo Tro

> ***Jean Perrin won the Nobel Prize essentially for proving the existence of atoms.***



THE STRUCTURE OF THE ATOM

the 30-second chemistry

In 1897, J. J. Thomson discovered a new type of particle – the electron – that was much smaller than the atom itself. Thomson demonstrated that electrons were negatively charged, that they were present in all different kinds of matter and that their mass was 1/2,000th the mass of the lightest atom. Thomson's discovery implied that the atom itself was composed of even smaller particles. Based on his discovery, Thomson developed a model for the atom called the 'plum-pudding model'. In this model, even the lightest atoms were composed of thousands of electrons held in a sphere of positive charge. In 1909, Ernest Rutherford (pictured) set out to confirm Thomson's model, but he proved it wrong instead. Rutherford accelerated particles (8,000 times more massive than electrons) at a thin sheet of gold atoms. Most of these particles were not deflected by the gold atoms, but a few bounced back. Rutherford claimed that his results were 'about as credible as if you fired a 15-inch [38-cm] shell at a piece of tissue paper and it came back and hit you.' Rutherford developed a new model for the atom – the nuclear model – in which the mass of the atom is concentrated in a small space called the nucleus. Most of the volume of the atom is empty space.

3-SECOND NUCLEUS

An atom consists of a tiny nucleus – containing protons and neutrons – with electrons in a diffuse cloud surrounding the nucleus.

3-MINUTE VALENCE

Matter is particulate – it is made of particles. But what are those particles like? What is their structure? The earliest models implied that the distribution of matter within an atom was fairly uniform, but later experiments suggested otherwise. The atom itself is mostly empty space with nearly all of the mass contained in a small space called the nucleus.

RELATED TOPICS

See also

INSIDE THE ATOM

WHERE DID ATOMS COME FROM?

THE DUAL NATURE OF THE ELECTRON

3-SECOND BIOGRAPHIES

J. J. THOMSON

1856–1940

English physicist who discovered the electron

ERNEST RUTHERFORD

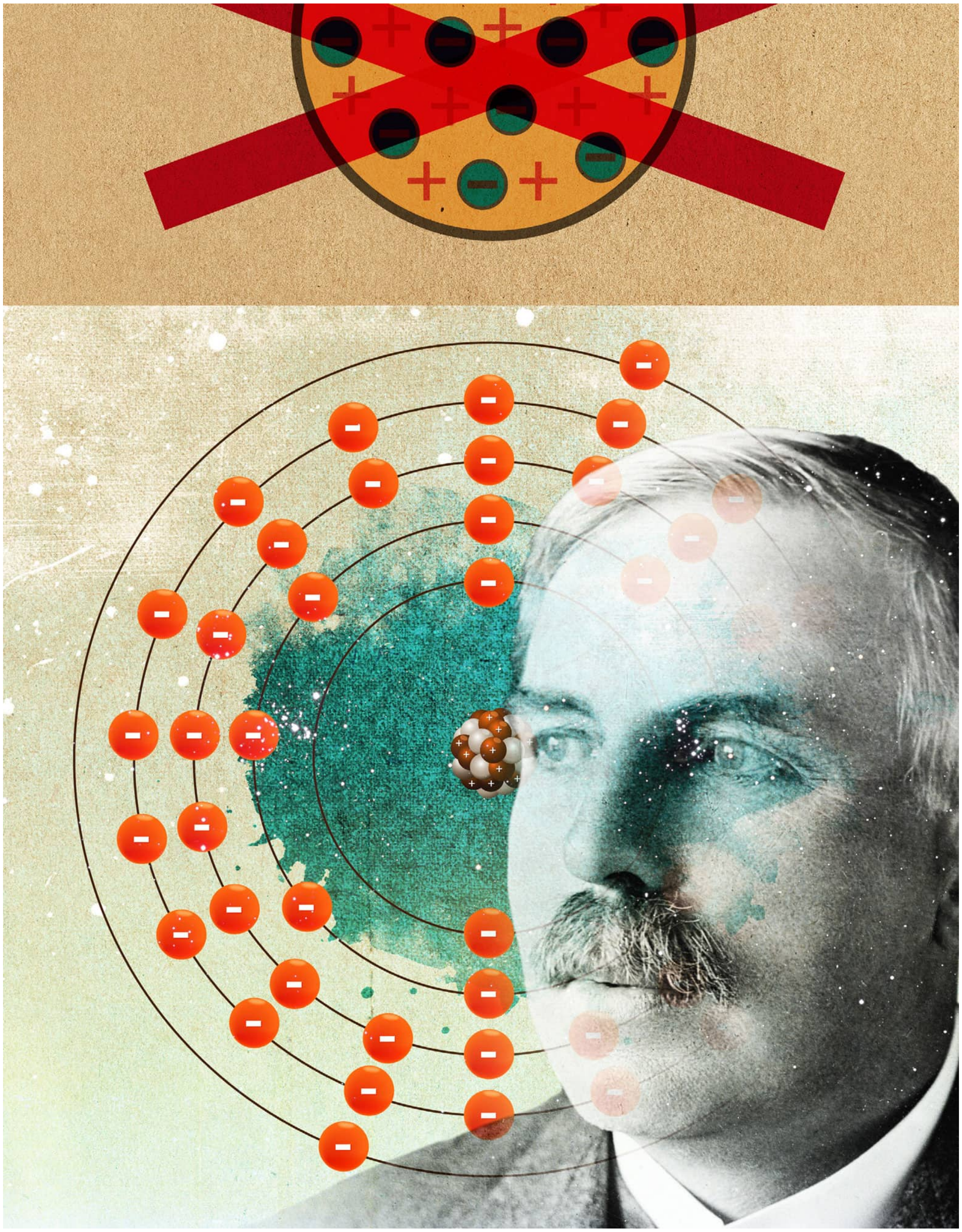
1871–1937

New Zealand physicist whose famous Gold Foil Experiment established the nuclear model for the atom

30-SECOND TEXT

Nivaldo Tro

The nuclear atom, with the nucleus enlarged to be visible. If drawn to scale, the nucleus would be a tiny dot, too small to see.



INSIDE THE ATOM

the 30-second chemistry

The number of protons in the nucleus of an atom is called the atomic number (Z) and it determines the identity of the atom and its corresponding element. For example, helium (Z=2) has two protons in its nucleus and sodium (Z=11) has eleven protons in its nucleus. The number of known elements ranges from Z=1 to Z=118 – as shown in the periodic table on the facing page. Each element has a name, a symbol and a unique atomic number. The number of neutrons in the nucleus of an atom can vary within atoms of the same element. For example, most helium atoms have two neutrons, but some have three. Atoms with the same number of protons but a different number of neutrons are called isotopes. Since most of the mass of an atom is due to its protons and neutrons, the sum of the numbers of these two particles is called the mass number (A). Scientists specify isotopes with the following notation: ${}^{A}_{Z}X$, where X is the chemical symbol, Z is the atomic number and A is the mass number. For example, the helium isotope with 2 neutrons is specified by ${}^{4}_{2}He$.

3-SECOND NUCLEUS

An atom is composed of protons, neutrons and electrons. The number of electrons in a neutral atom always equals the number of protons in its nucleus.

3-MINUTE VALENCE

All atoms are composed of the same three subatomic particles: protons, neutrons and electrons (see table below). So what makes one atom different from another? The numbers of those particles. Incredible as it may seem, both sodium (a reactive metal that explodes in water) and helium (an inert gas that reacts with nothing) are made of the same subatomic particles, just different numbers of them.

RELATED TOPICS

See also

WHERE DID ATOMS COME FROM?

PERIODIC PATTERNS

RADIOACTIVITY

3-SECOND BIOGRAPHY

JAMES CHADWICK

1891–1974

English physicist who discovered the neutron

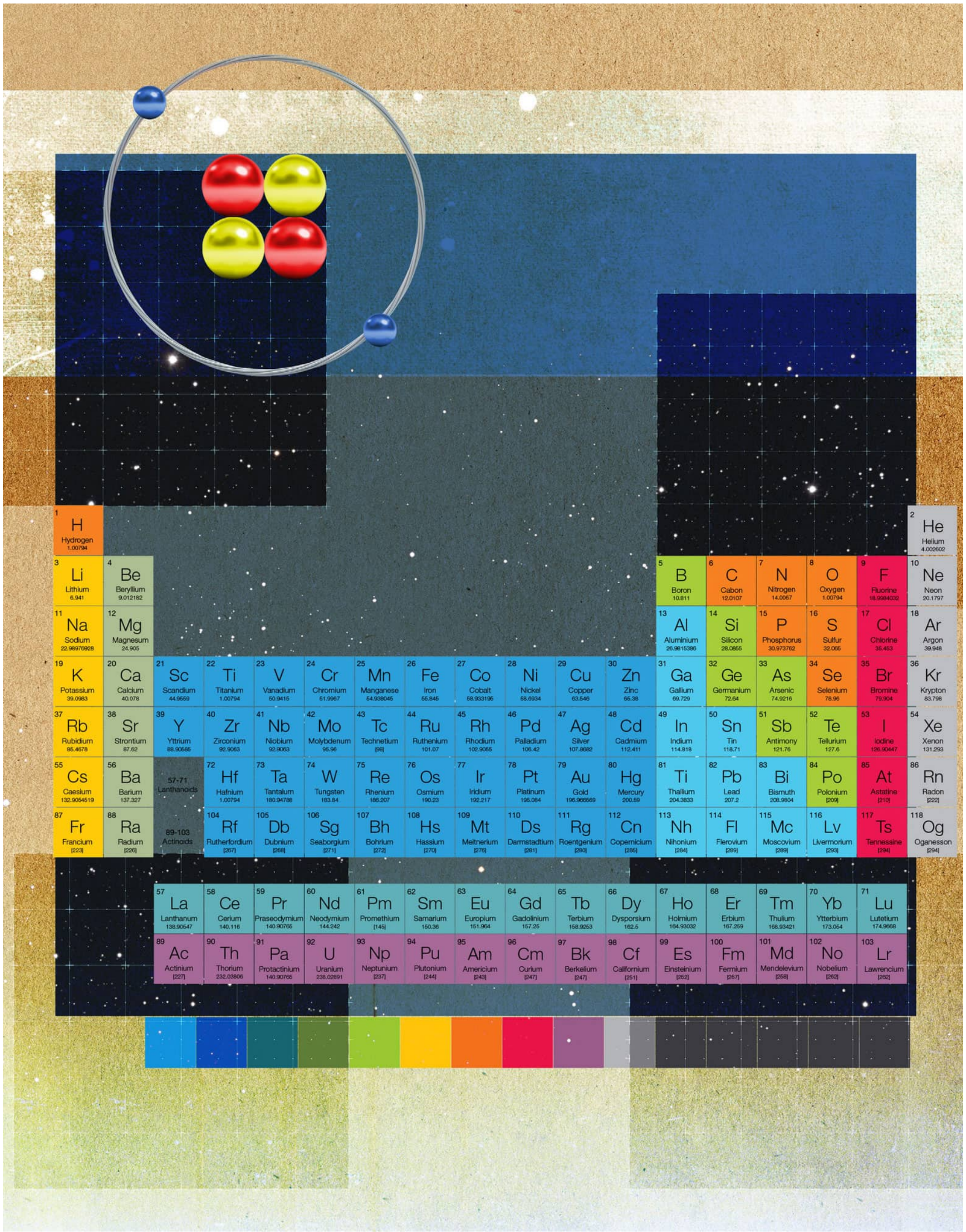
30-SECOND TEXT

Nivaldo Tro

Subatomic Particles

	Mass (amu)	Charge (relative)
Proton	1.0	+1
Neutron	1.0	0
Electron	0.00055	-1

The periodic table lists the 118 known elements (91 naturally occurring and 27 synthetic) according to their atomic number (top left in each element box).


1 H Hydrogen 1.00794
2 He Helium 4.002602
3 Li Lithium 6.941
4 Be Beryllium 9.012182
5 B Boron 10.811
6 C Cabon 12.0107
7 N Nitrogen 14.0067
8 O Oxygen 1.00794
9 F Fluorine 18.9984032
10 Ne Neon 20.1797
11 Na Sodium 22.98976928
12 Mg Magnesum 24.905
13 Al Aluminium 26.9815386
14 Si Silicon 28.0855
15 P Phosphorus 30.973762
16 S Sulfur 32.065
17 Cl Chlorine 35.453
18 Ar Argon 39.948
19 K Potassium 39.0983
20 Ca Calcium 40.078
21 Sc Scandium 44.9559
22 Ti Titanium 1.00794
23 V Vanadium 50.9415
24 Cr Chromium 51.9967
25 Mn Manganese 54.938045
26 Fe Iron 55.845
27 Co Cobalt 58.933196
28 Ni Nickel 58.6934
29 Cu Copper 63.546
30 Zn Zinc 65.38
31 Ga Gallium 69.729
32 Ge Germanium 72.64
33 As Arsenic 74.9216
34 Se Selenium 78.96
35 Br Bromine 79.904
36 Kr Krypton 83.798
37 Rb Rubidium 85.4678
38 Sr Strontium 87.62
39 Y Yttrium 88.90585
40 Zr Zirconium 92.9063
41 Nb Niobium 92.9063
42 Mo Molybdenum 95.96
43 Tc Technetium [98]
44 Ru Ruthenium 101.07
45 Rh Rhodium 102.9055
46 Pd Palladium 106.42
47 Ag Silver 107.8682
48 Cd Cadmium 112.411
49 In Indium 114.818
50 Sn Tin 118.71
51 Sb Antimony 121.76
52 Te Tellurium 127.6
53 I Iodine 126.90447
54 Xe Xenon 131.293
55 Cs Caesium 132.9054519
56 Ba Barium 137.327
57-71 Lanthanoids
72 Hf Hafnium 1.00794
73 Ta Tantalum 180.94788
74 W Tungsten 183.84
75 Re Rhenium 186.207
76 Os Osmium 190.23
77 Ir Iridium 192.217
78 Pt Platinum 195.084
79 Au Gold 196.966569
80 Hg Mercury 200.59
81 Ti Thallium 204.3833
82 Pb Lead 207.2
83 Bi Bismuth 208.9804
84 Po Polonium [209]
85 At Astatine [210]
86 Rn Radon [222]
87 Fr Francium [223]
88 Ra Radium [226]
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104 Rf Rutherfordium [267]
105 Db Dubnium [268]
106 Sg Seaborgium [271]
107 Bh Bohrium [272]
108 Hs Hassium [270]
109 Mt Meitnerium [276]
110 Ds Darmstadtium [281]
111 Rg Roentgenium [280]
112 Cn Copernicium [285]
113 Nh Nihonium [284]
114 Fl Flerovium [289]
115 Mc Moscovium [289]
116 Lv Livermorium [293]
117 Ts Tennessine [294]
118 Og Oganesson [294]
57 La Lanthanum 138.90547
58 Ce Cerium 140.116
59 Pr Praseodymium 140.90765
60 Nd Neodymium 144.242
61 Pm Promethium [145]
62 Sm Samarium 150.36
63 Eu Europium 151.964
64 Gd Gadolinium 157.25
65 Tb Terbium 158.9253
66 Dy Dysporsium 162.5
67 Ho Holmium 164.93032
68 Er Erbium 167.259
69 Tm Thulium 168.93421
70 Yb Ytterbium 173.054
71 Lu Lutetium 174.9668
89 Ac Actinium [227]
90 Th Thorium 232.03806
91 Pa Protactinium 140.90765
92 U Uranium 238.02891
93 Np Neptunium [237]
94 Pu Plutonium [244]
95 Am Americium [243]
96 Cm Curium [247]
97 Bk Berkelium [247]
98 Cf Californium [251]
99 Es Einsteinium [252]
100 Fm Fermium [257]
101 Md Mendelevium [258]
102 No Nobelium [262]
103 Lr Lawrencium [262]

WHERE DID ATOMS COME FROM?

the 30-second chemistry

According to the big bang model, our universe began as a hot, dense collection of matter and energy that rapidly expanded and cooled. During the first 20 minutes of that expansion, hydrogen and helium (the two most abundant elements in the universe) formed from the soup of subatomic particles. Then nucleosynthesis stopped as the universe continued to expand and cool. Eventually, after about 500 million years, the first stars formed. Stars are the nurseries in which all other elements are made. As stars burn – through a process called nuclear fusion – they fuse together the nuclei of smaller atoms to form larger atoms. Young stars fuse hydrogen atoms to form helium. This fusion gives off tremendous amounts of heat and light and can power a star for billions of years. As a star ages, and if it is large enough, fusion can continue to form larger atoms such as carbon and oxygen – all the way up to iron. The formation of elements beyond iron requires the input of energy, and only happens in the supernova stage of a star’s life. A supernova is essentially a large exploding star. The energy emitted by a supernova can power the nucleosynthesis of elements up to uranium, the heaviest naturally occurring element.

3-SECOND NUCLEUS

Atoms form through nucleosynthesis, which began in the first few minutes after the big bang and happens to this day within the core of stars and supernovae.

3-MINUTE VALENCE

Our planet naturally contains about 91 different elements. Where did the atoms that compose these elements come from? How did atoms form? They formed through a process called nucleosynthesis, which began about 13.7 billion years ago at the very birth of our universe.

RELATED TOPICS

See also

RADIOACTIVITY

SPLITTING THE ATOM

NUCLEAR WEIGHT LOSS

3-SECOND BIOGRAPHIES

ARTHUR EDDINGTON

1882–1944

English astronomer and physicist who first suggested that stars are powered by fusion

FRED HOYLE

1915–2001

English astronomer who formulated the theory of nucleosynthesis within stars

30-SECOND TEXT

Nivaldo Tro

> ***In stars, smaller atoms fuse together to form larger atoms. All atoms beyond helium were born in the core of stars and supernovae.***

THE DUAL NATURE OF THE ELECTRON

the 30-second chemistry

An electron travelling through space behaves very differently from a baseball flying towards the outfield. A baseball has a definite trajectory – a deterministic path that it follows. A good outfielder can predict where a baseball will land. This prediction requires the outfielder simultaneously to know two properties of the flying baseball: its position (where it is) and its velocity (how fast it is going). If the outfielder only knew one of these two properties, he or she could not predict the baseball's path. An electron behaves differently because it has a dual nature: a wave nature (associated with its velocity) and a particle nature (associated with its position). The key to understanding electron behaviour is Heisenberg's Uncertainty Principle, which states that 'an electron never exists as both a wave and a particle simultaneously'. It is either one or the other, but not both. Although Heisenberg's principle solved a great paradox (how something can be both a wave and a particle), it implied the death of determinism. If you can't observe the wave nature and particle nature of the electron simultaneously, then you can't simultaneously know its velocity and its position, which means you can't predict its future path.

3-SECOND NUCLEUS

For electrons and other small particles, the trajectories of classical physics are replaced with the probability distributions of quantum mechanics.

3-MINUTE VALENCE

Are the smallest particles that exist, such as electrons, just like those that we can see with our eyes only smaller? Does an electron orbiting an atom behave like a planet orbiting the Sun? No. Electrons behave differently. Electrons, and other small particles, have a wave-particle duality that makes it impossible to predict exact trajectories for them. Instead, we describe their behaviour in terms of probability.

RELATED TOPICS

See also

INSIDE THE ATOM

WHERE ELECTRONS ARE WITHIN AN ATOM

PERIODIC PATTERNS

3-SECOND BIOGRAPHIES

ERWIN SCHRÖDINGER

1887–1961

Austrian physicist central to the development of quantum mechanics and known for the thought experiment ‘Schrödinger’s Cat’

WERNER HEISENBERG

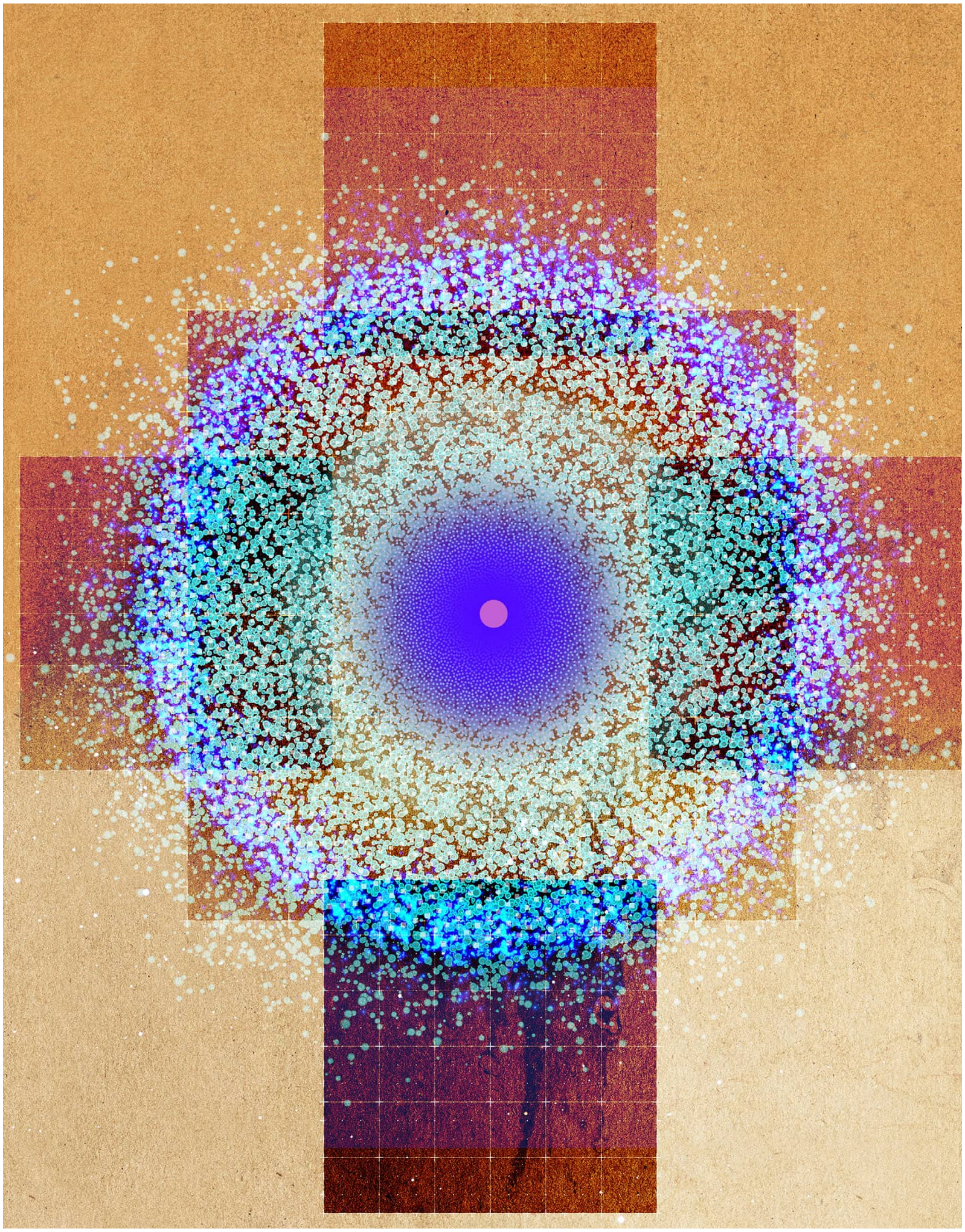
1901–76

German physicist who articulated the ‘Uncertainty Principle’

30-SECOND TEXT

Nivaldo Tro

> ***In an atom, electrons do not orbit the nucleus like planets orbit the Sun. Instead, they exist in clouds of probability.***



WHERE ELECTRONS ARE WITHIN AN ATOM

the 30-second chemistry

The electron orbits of early atomic models were later replaced by quantum mechanical orbitals. Unlike a planetary orbit, an *orbital* is a three-dimensional probability map that shows the probability of finding an electron in a certain volume of space. You can understand an orbital with a simple analogy. Imagine taking a photo every 10 seconds for several minutes of a moth flying around a light bulb, and then superimposing all the photos to make a single image. The result shows the light bulb with dozens of images of the moth. The volume immediately surrounding the light bulb has many moth images, indicating a high probability of finding the moth in that space. Further away from the light bulb there are fewer moth images, meaning that the probability of finding the moth in that space is lower. A quantum mechanical orbital is analogous – the light bulb is the atomic nucleus and the moth is the electron. Just as the early model of the atom had many different orbits at different distances from the nucleus and with different energies, so the quantum mechanical model has many different orbitals, each with different average distances from the nucleus and with different energies. Electrons can be observed in one orbital or another, but never in between.

3-SECOND NUCLEUS

Electrons in atoms exist in quantum mechanical orbitals, three-dimensional probability maps that show the likelihood of finding the electron in a certain volume of space.

3-MINUTE VALENCE

Atoms bond together by sharing or transferring electrons. As a result, the positions of electrons within an atom – where they are – is important because it affects how atoms bond together. In an early model, electrons were thought to orbit the nucleus of the atom much like planets orbit the Sun. However, this model was later proved wrong and was replaced with the quantum mechanical model for the atom.

RELATED TOPICS

See also

THE DUAL NATURE OF THE ELECTRON

BONDING ATOMS TOGETHER

3-SECOND BIOGRAPHIES

NIELS BOHR

1885–1962

Danish physicist central to the development of the quantum mechanical model for atomic structure

ERWIN SCHRÖDINGER

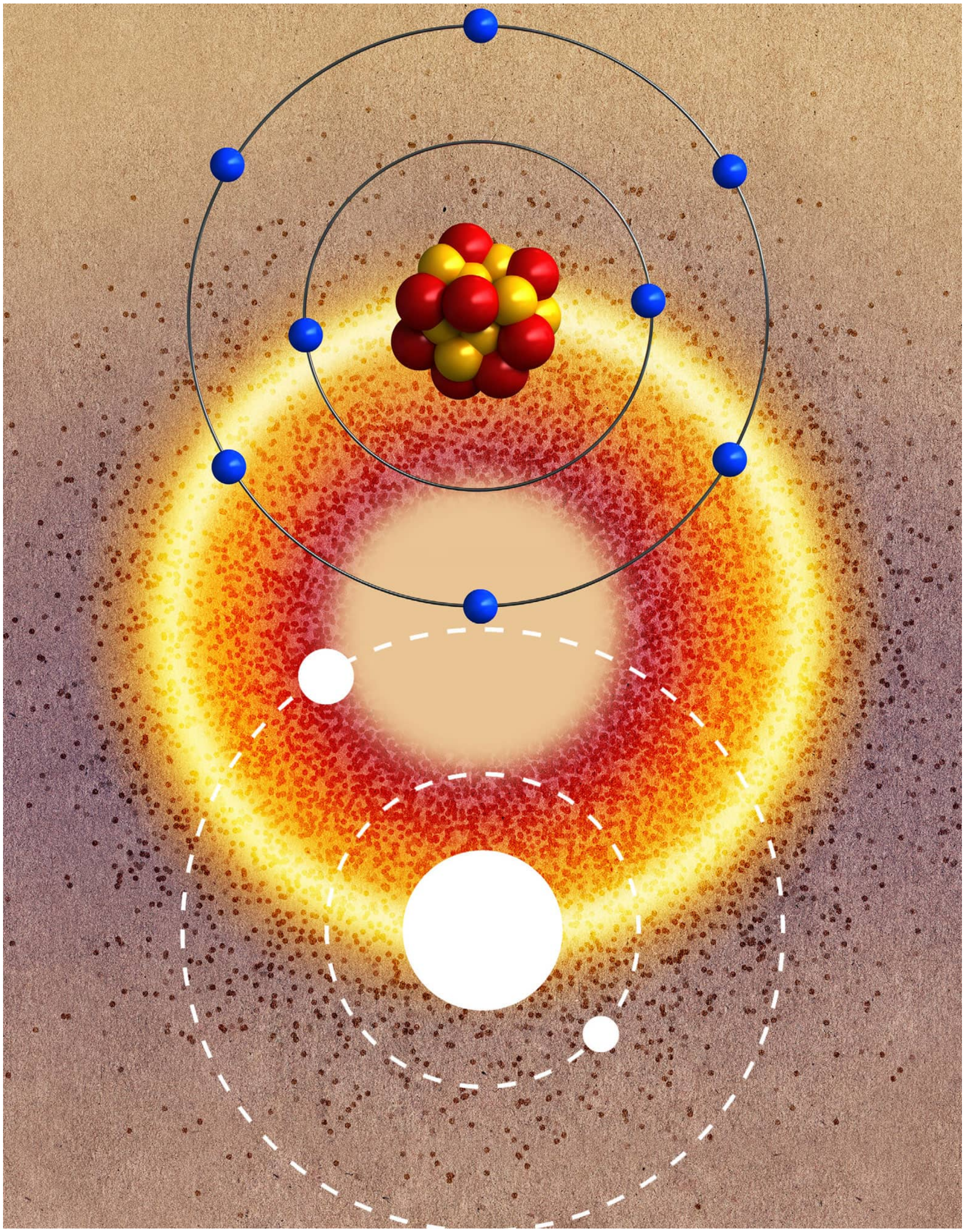
1887–1961

Austrian physicist central to the development of the quantum mechanical model of the atom

30-SECOND TEXT

Nivaldo Tro

> ***Early atomic models had electrons orbiting the nucleus like planets orbit the Sun. These have been replaced by the quantum mechanical model.***



PERIODIC PATTERNS

the 30-second chemistry

The ancient Greeks thought that matter was composed of only four elements: earth, water, fire and air. By the mid-1800s, however, scientists had discovered more than 50 different elements. Dmitri Mendeleev noticed a pattern in the properties of known elements when he listed them in order of increasing atomic number: certain properties recurred periodically. Based on this observation, Mendeleev constructed a table of elements with atomic number increasing from left to right, and elements with similar properties aligning in columns. His table contained some gaps that allowed him to predict the existence and properties of yet undiscovered elements (which were later discovered). Mendeleev's table evolved into the modern periodic table, which lists all known elements to date. The elements on the left and middle of the table are mostly metals, and the elements on the right side of the table are mostly non-metals. Each column represents a family of elements with similar properties. For example, the far left column contains the alkali metals, a family of elements that are all solid metals at room temperature and highly reactive. The far right column, by contrast, contains the noble gases, a family of elements that are all gases at room temperature and display little or no chemical reactivity.

3-SECOND NUCLEUS

When elements are listed in order of increasing atomic number, their properties recur in a regular pattern.

3-MINUTE VALENCE

Our Earth contains about 91 different naturally occurring elements, each one with its own distinctive properties. However, certain groups of elements share similarities. The periodic law and the corresponding periodic table allow us to organize the known elements in ways that help us make sense of their properties.

RELATED TOPICS

See also

INSIDE THE ATOM

BONDING ATOMS TOGETHER

THE UNIQUENESS PRINCIPLE

3-SECOND BIOGRAPHIES

JULIUS LOTHAR MEYER

1830–95

German chemist who made significant contributions to the periodic table

DMITRI MENDELEEV

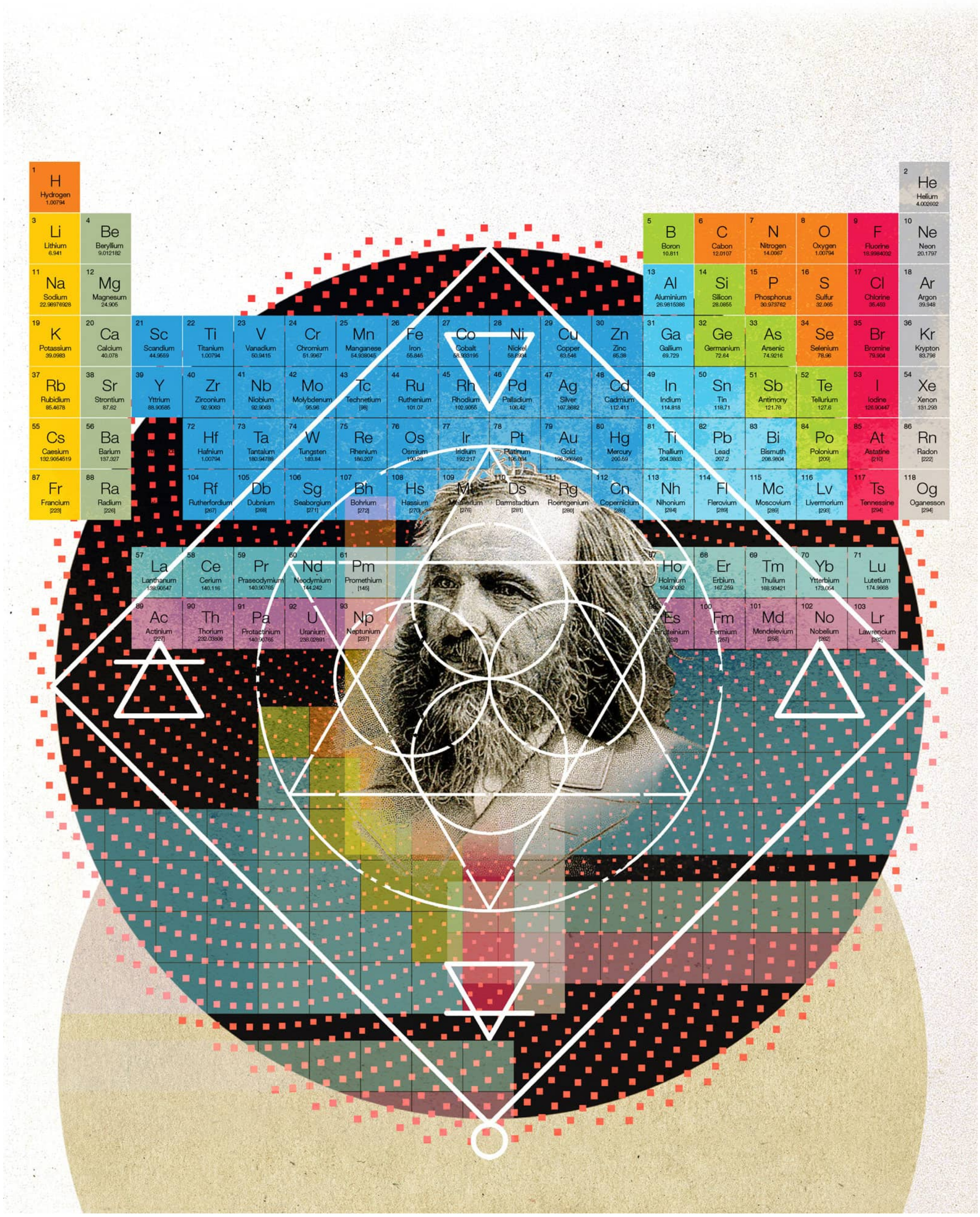
1834–1907

Russian chemistry professor who formulated the periodic law and constructed one of the first periodic tables

30-SECOND TEXT

Nivaldo Tro

> ***Mendeleev formulated one of the first periodic tables, which organizes elements according to atomic number and chemical properties.***


1 H Hydrogen
2 He Helium
3 Li Lithium
4 Be Beryllium
5 B Boron
6 C Cabon
7 N Nitrogen
8 O Oxygen
9 F Fluorine
10 Ne Neon
11 Na Sodium
12 Mg Magnesium
13 Al Aluminium
14 Si Silicon
15 P Phosphorus
16 S Sulfur
17 Cl Chlorine
18 Ar Argon
19 K Potassium
20 Ca Calcium
21 Sc Scandium
22 Ti Titanium
23 V Vanadium
24 Cr Chromium
25 Mn Manganese
26 Fe Iron
27 Co Cobalt
28 Ni Nickel
29 Cu Copper
30 Zn Zinc
31 Ga Gallium
32 Ge Germanium
33 As Arsenic
34 Se Selenium
35 Br Bromine
36 Kr Krypton
37 Rb Rubidium
38 Sr Strontium
39 Y Yttrium
40 Zr Zirconium
41 Nb Niobium
42 Mo Molybdenum
43 Tc Technetium
44 Ru Ruthenium
45 Rh Rhodium
46 Pd Palladium
47 Ag Silver
48 Cd Cadmium
49 In Indium
50 Sn Tin
51 Sb Antimony
52 Te Tellurium
53 I Iodine
54 Xe Xenon
55 Cs Caesium
56 Ba Barium
72 Hf Hafnium
73 Ta Tantalum
74 W Tungsten
75 Re Rhenium
76 Os Osmium
77 Ir Iridium
78 Pt Platinum
79 Au Gold
80 Hg Mercury
81 Tl Thallium
82 Pb Lead
83 Bi Bismuth
84 Po Polonium
85 At Astatine
86 Rn Radon
87 Fr Francium
88 Ra Radium
104 Rf Rutherfordium
105 Db Dubnium
106 Sg Seaborgium
107 Bh Bohrium
108 Hs Hassium
109 Mt Meitnerium
110 Ds Darmstadtium
111 Rg Roentgenium
112 Cn Copernicium
113 Nh Nihonium
114 Fl Flerovium
115 Mc Moscovium
116 Lv Livermorium
117 Ts Tennessine
118 Og Oganesson
57 La Lanthanum
58 Ce Cerium
59 Pr Praseodymium
60 Nd Neodymium
61 Pm Promethium
67 Ho Holmium
68 Er Erbium
69 Tm Thulium
70 Yb Ytterbium
71 Lu Lutetium
89 Ac Actinium
90 Th Thorium
91 Pa Protactinium
92 U Uranium
93 Np Neptunium
Es Einsteinium
100 Fm Fermium
101 Md Mendelevium
102 No Nobelium
103 Lr Lawrencium

BONDING ATOMS TOGETHER

the 30-second chemistry

Atoms bond together by either sharing (covalent bonding) or transferring (ionic bonding) the electrons in their highest-energy orbitals to form compounds. Sharing of electrons typically occurs between two or more non-metals, resulting in a molecular compound, so called because it is composed of distinct molecules (groups of atoms bonded together). Transfer of electrons typically occurs from a metal to a non-metal and results in an ionic compound. Ionic compounds do not contain distinct molecules, but rather exist as an array of ions (charged particles) with alternating positive and negative charge. Water is a good example of a molecular compound. We represent a compound with a chemical formula, which tells us the elements present in the compound and the relative number of atoms of each one. For example, the formula for water is H_2O, which means that a water molecule is composed of two hydrogen atoms and one oxygen atom, and the formula for sucrose (table sugar) is $C_{12}H_{22}O_{11}$. Molecular compounds can contain as few as two atoms in a molecule to as many as thousands. Sodium chloride (table salt) is a good example of an ionic compound. The formula for sodium chloride is NaCl, which indicates sodium and chlorine in a one-to-one atomic ratio.

3-SECOND NUCLEUS

Atoms bond together to form compounds. A compound, unlike a mixture of elements, contains two or more elements in a fixed, definite proportion.

3-MINUTE VALENCE

The universe contains 118 different elements, but would be lifeless if these elements did not bind together to form compounds. When two or more elements combine to form a compound, a completely new substance forms with properties much different from the elements that compose it. In this way, our universe’s 118 different elements can form millions of compounds. And this, among other things, makes life possible.

RELATED TOPICS

See also

WHERE ELECTRONS ARE WITHIN AN ATOM

THE LEWIS MODEL FOR CHEMICAL BONDING

VALENCE BOND & MOLECULAR ORBITAL THEORIES

3-SECOND BIOGRAPHIES

JOSEPH PROUST

1754–1826

French chemist who made observations on the composition of compounds

LINUS PAULING

1901–94

American chemist who made significant contributions to our understanding of chemical bonding

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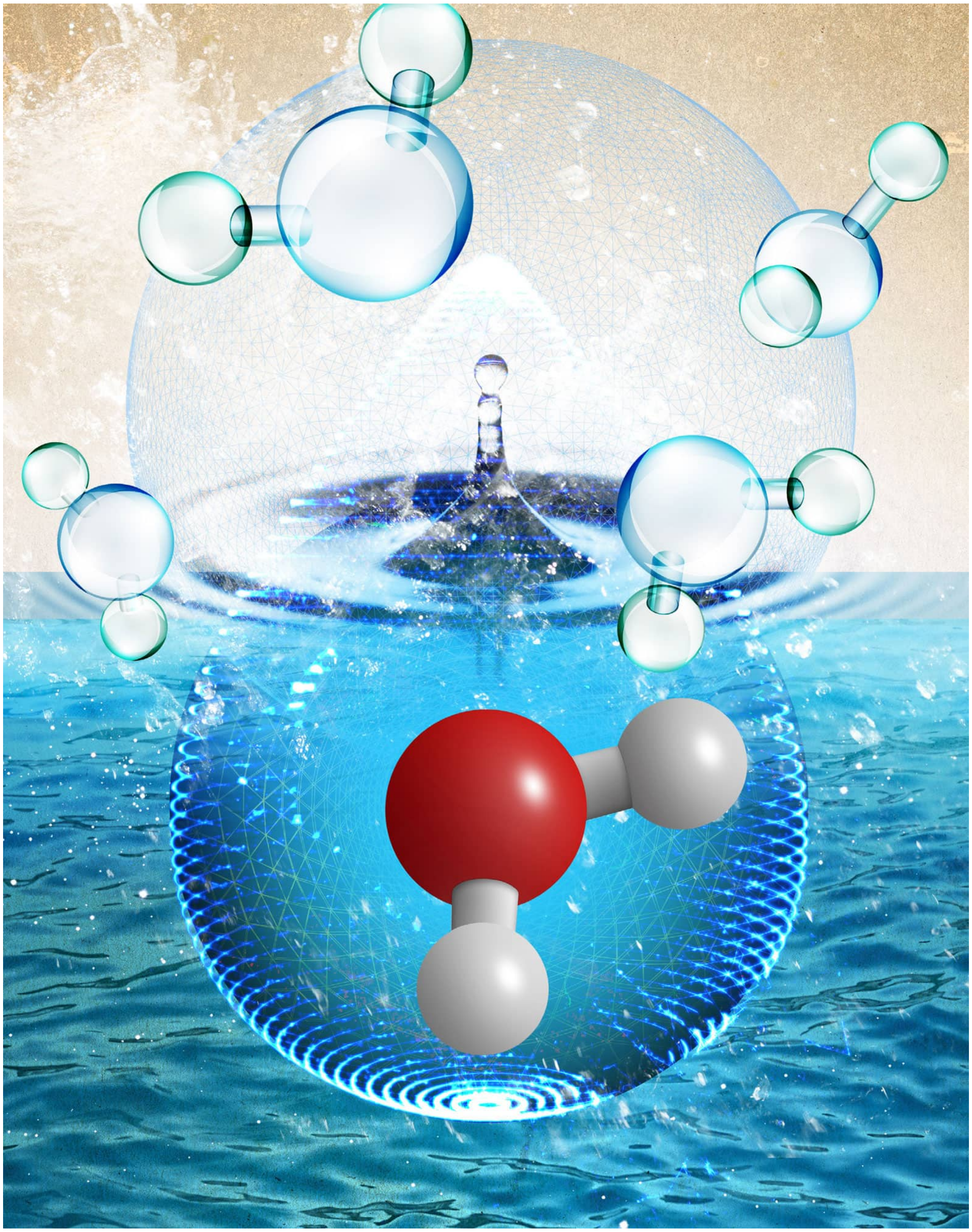
30-SECOND TEXT

Nivaldo Tro

> ***Water is a molecular compound, composed of two hydrogen atoms bonded to one oxygen atom.***



JOHN DALTON

John Dalton was born into a poor, staunchly Quaker family in the town of Eaglesfield in northern England in 1766. At the age of 10 he was sent to a nearby Quaker School and just two years later began teaching there.

Soon afterwards he started to teach and study in Kendal, where he began to carry out and record meteorological observations, many with instruments that he built himself. He did this for 57 years until the day he died, recording more than 200,000 observations. He once wrote that 'my head is too full of triangles, chymical processes and electrical experiments, etc., to think much of marriage.'

Moving to Manchester as a tutor in mathematics and natural philosophy, he joined the Manchester Literary and Philosophical Society. His first communication at the society described a red-green 'colour blindness' – from which he and his brother suffered – that is still referred to as 'daltonism'.

His love of meteorology led him to consider the composition of the air and the nature of its component gases. He concluded that the atmosphere is a mixture of gases and that the total pressure it exerts is the sum of the 'partial pressures' that each individual gas exerts. The overall pressure, he maintained, is due to the particles (what we would call atoms and molecules) of these gases slamming against the walls of the container in which they are held.

Most famously, Dalton devised the first concrete atomic theory that organized a number of the assumptions known at the time, starting with the Greek idea of indivisible atoms. He maintained that the atoms of a given element are unique (particularly in mass) and combine with atoms of another element in whole-number ratios. In chemical reactions, atoms are reshuffled from one configuration to another. He went on to construct one of the first ever tables of atomic weights but this was marred by inaccuracies that could have been easily corrected had he been more open to valuable new ideas from the international scientific community. Despite these difficulties his theory could be tested and its general assumptions held up well.

Given that Dalton had taken a concept that had been imprecisely discussed and largely rejected for 2,000 years and fashioned it into a guiding paradigm that revolutionized all of science, his colleagues were anxious to honour him. However, due to his Quaker beliefs he refused many of these honours, including a doctorate degree from Oxford University that would have required him to wear scarlet robes. Later, told that the robes were in fact green (he was colour-blind, after all), he received the degree. When Dalton died, he could not stop 40,000 people filing past his coffin and 100 coaches following his funeral cortège.

1766
Born in Eaglesfield, England in a white bungalow that still stands

1776
Sent to Pardshaw Hall Quaker School

1781–93
Teaches at the Stramongate School in Kendal

1787
Begins to keep meteorological diaries

1793
Now at the New College in Manchester, publishes a paper on red-green colour blindness now often known as 'daltonism'

1801
Formulates Dalton's Law of Partial Pressures

1803
Delivers a paper in which he first describes his atomic theory

1808
Publishes *A New System of Chemical Philosophy*, in which his atomic theory is presented in full

1810
Nominated for membership of the Royal Society but refuses the offer because Quakers resist public recognition

1822
Renominated and elected to the Royal Society without his knowledge

1826
Receives the Royal Society's first Royal Medal

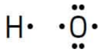
1832
Initially refuses an honorary doctorate degree from Oxford University that would have required him to wear scarlet robes. Persuaded that the robes were a dull green, he accepts the degree

1844
Dies and is accorded a civic funeral with full honours

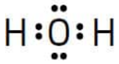
THE LEWIS MODEL FOR CHEMICAL BONDING

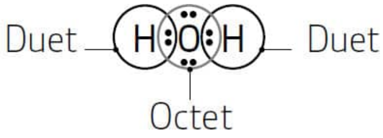
the 30-second chemistry

In the simplest model for chemical bonding, called the Lewis model, atoms share or transfer their highest energy electrons (called valence electrons) to obtain an octet – eight electrons in their highest energy (or outermost) set of orbitals. One important exception is hydrogen, which shares/transfers its one electron to obtain a duet – two electrons in its outermost orbital. When applying the Lewis model, chemists use special symbols to represent atoms and their valence electrons. For example, the Lewis symbols for hydrogen and oxygen are as follows:



The one dot next to H represents hydrogen's one valence electron and the six dots around the O represent oxygen's six valence electrons. The bonding between hydrogen and oxygen to form water involves the sharing of the valence electrons, and we draw the Lewis symbol for water as follows:





The shared electrons (those between two elements) count towards the octet (or duet) of both atoms. So in this Lewis structure, each hydrogen atom has a duet and oxygen an octet.

3-SECOND NUCLEUS

In the Lewis model for chemical bonding, atoms bond to obtain octets – eight electrons in their valence shell.

3-MINUTE VALENCE

The most powerful pieces of scientific knowledge are theories (or models). Theories explain not only what happens in nature but also why it happens. The Lewis model for chemical bonding explains why, for example, water is H_2O and not some other combination of atoms. The Lewis model is simple, however, and other more sophisticated models are even more powerful at predicting and explaining chemical bonding.

RELATED TOPICS

See also

WHERE ELECTRONS ARE WITHIN AN ATOM

BONDING ATOMS TOGETHER

VALENCE BOND & MOLECULAR ORBITAL THEORIES

3-SECOND BIOGRAPHY

GILBERT N. LEWIS

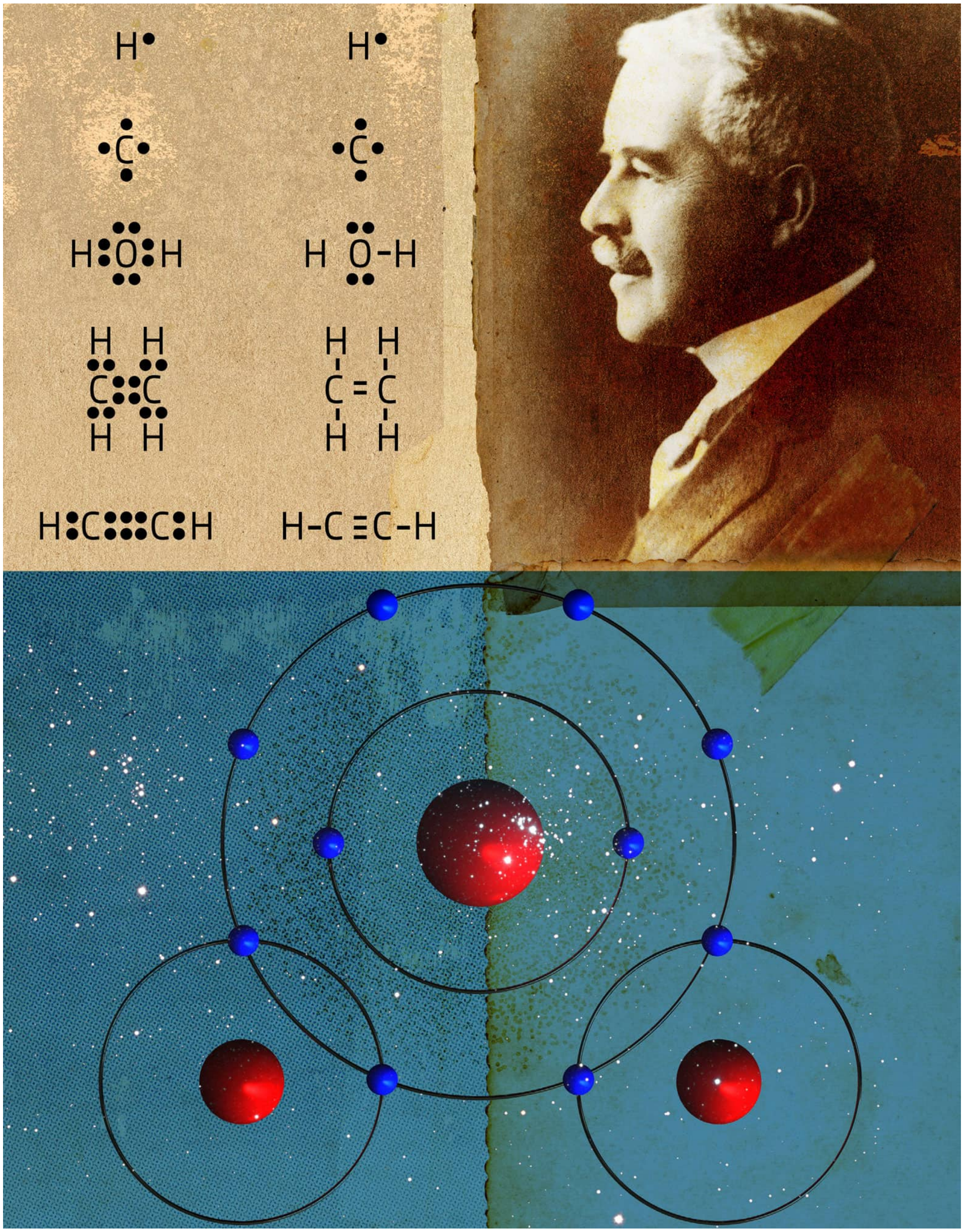
1875–1946

American chemist and University of California, Berkeley chemistry professor who constructed the Lewis model for chemical bonding

30-SECOND TEXT

Nivaldo Tro

The Lewis model shows how atoms share electrons to obtain octets.


H
H
C
C
H:O:H
H O–H
H H
C::C
H H
H H
C=C
H H
H:C:::C:H
H–C≡C–H

VALENCE BOND & MOLECULAR ORBITAL THEORIES

the 30-second chemistry

Chemists use three different models to explain chemical bonding: the Lewis model, valence bond theory and molecular orbital theory, each increasingly complex but also increasingly powerful. The Lewis model requires nothing more than paper and pencil to enable chemists to predict and explain a great deal of chemical behaviour. Valence bond and molecular orbital theory, by contrast, both require more complex calculations, usually on a computer. In valence bond theory, a chemical bond is modelled as the overlap between half-filled atomic orbitals. As the orbitals overlap, the energy of the electrons in those orbitals decreases, stabilizing the molecule relative to its constituent atoms. A molecular orbital is to a molecule what an atomic orbital is to an atom. Each molecule has its own unique set of molecular orbitals that depend on the constituent atoms and their arrangement in space. If the overall energy of the electrons in the molecular orbitals is lower than in the constituent atoms' atomic orbitals, the resulting molecule is stable. Both valence bond theory and molecular orbital theory can accurately predict details about molecular structure including molecular geometries, bond lengths and bond strengths.

3-SECOND NUCLEUS

In the valence bond model, a chemical bond is the overlap between half-filled atomic orbitals. In molecular orbital theory, atomic orbitals are completely replaced by molecular orbitals.

3-MINUTE VALENCE

The Lewis model for chemical bonding is practical and useful; however, it also has limits. We know, for example, that electrons are not stationary dots that sit between atoms. Two more powerful bonding models – valence bond theory and molecular orbital theory – take into account the quantum mechanical nature of electrons and provide even more powerful predictions and explanations of chemical bonding.

RELATED TOPICS

See also

WHERE ELECTRONS ARE WITHIN AN ATOM

BONDING ATOMS TOGETHER

THE LEWIS MODEL FOR CHEMICAL BONDING

3-SECOND BIOGRAPHIES

JOHN EDWARD JONES

1894–1954

English mathematician, physicist and pioneer of computational chemistry

LINUS PAULING

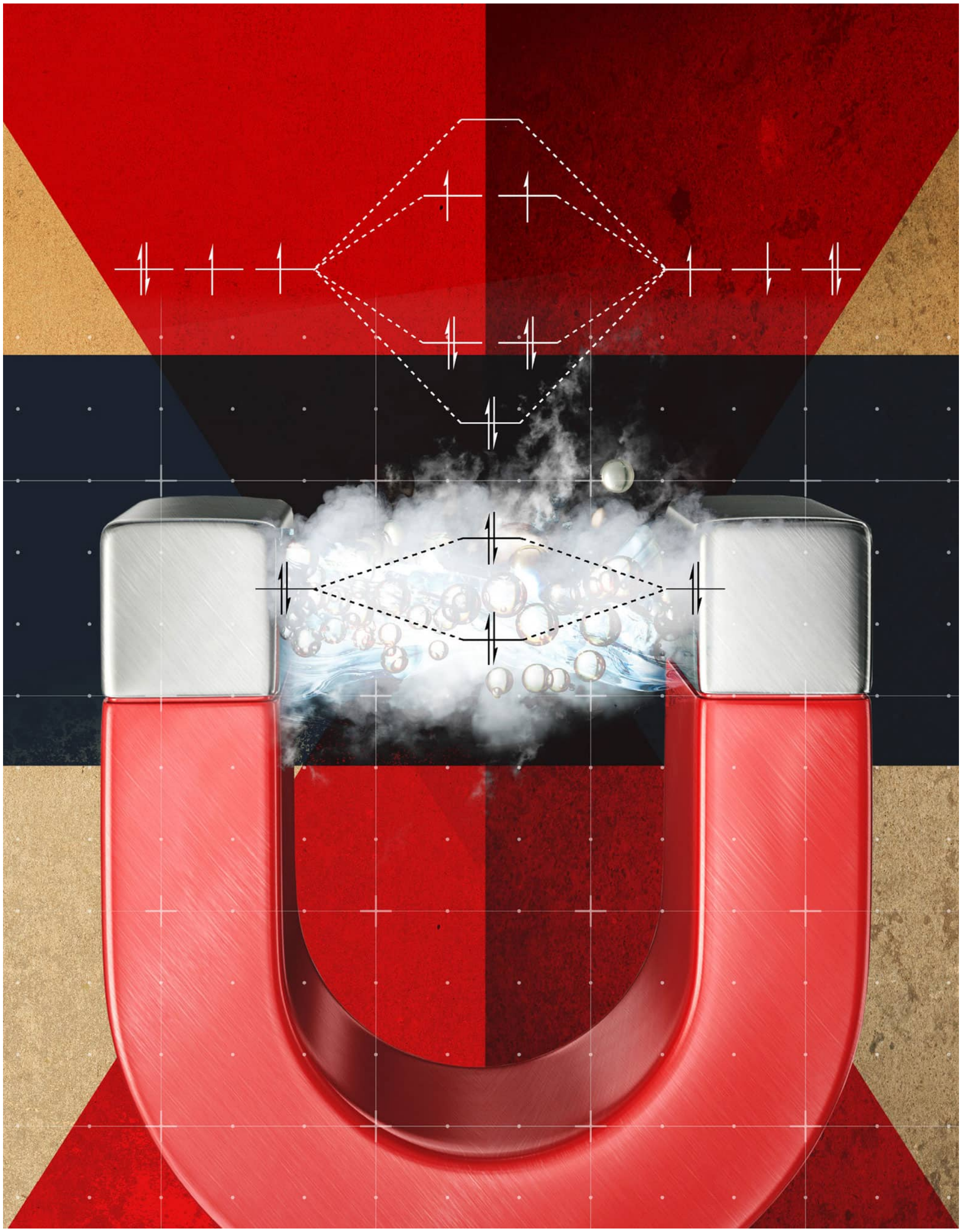
1901–94

American chemist who made significant contributions to valence bond theory

30-SECOND TEXT

Nivaldo Tro

> ***Molecular orbital theory predicts that oxygen should be a magnetic liquid, which it is. The simpler bonding theories fail to predict this property.***



OPPOSITES ATTRACT

the 30-second chemistry

We know from previous entries that atoms can bond together by sharing electrons. But if the bonding atoms are different (two different elements), then the sharing is often not equal – one of the two atoms hogs the electron more than the other. The result is a polar bond, one that has a positive end on one side and a negative end on the other. In a molecule, polar bonds may add together to result in a polar molecule. Polar molecules interact strongly with one another because the positive end of one molecule is attracted to the negative end of its neighbour – just as the north pole of a magnet is attracted to the south pole of another magnet. These attractions affect the properties of the substances that the molecules compose. For example, polar substances tend to have higher melting and boiling points than their nonpolar counterparts because the attraction between neighbouring molecules makes the molecules more difficult to separate. Polar substances also tend not to mix well with nonpolar substances. For example, water and oil do not mix because water is very polar and oil is nonpolar. Water and ethyl alcohol (ethanol), by contrast, mix in all proportions because they are both polar.

3-SECOND NUCLEUS

The often uneven distribution of electrons that can result when two different atoms bond together results in a polar bond, which greatly affects a substance’s properties.

3-MINUTE VALENCE

The existence of liquid water on Earth’s surface can be attributed to polar bonds. Most small molecules are gases at room temperature, but water is among the very few that is a liquid. Why? Because water has highly polar bonds with hydrogen at one end and oxygen on the other. The small size of hydrogen allows the molecules to get very close together and interact strongly. This strong interaction makes it difficult to separate water molecules from one another.

RELATED TOPICS

See also

BONDING ATOMS TOGETHER

THE FORCES THAT HOLD MATTER TOGETHER

THE LIQUID STATE

3-SECOND BIOGRAPHIES

JOHANNES DIDERIK VAN DER WAALS

1837–1923

Dutch physicist who was among the first to postulate forces between molecules

LINUS PAULING

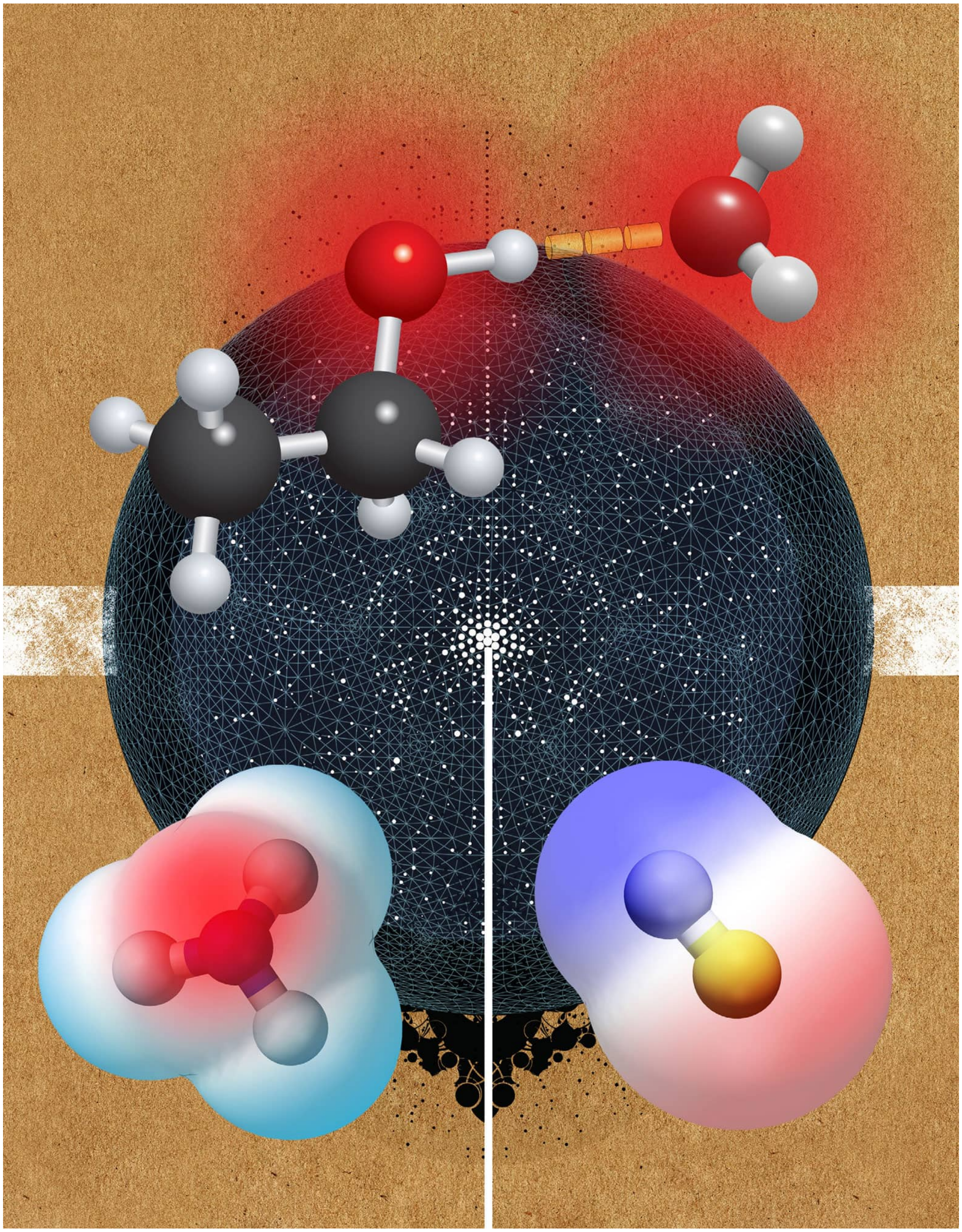
1901–94

American chemist who quantified the polarity of chemical bonds

30-SECOND TEXT

Nivaldo Tro

> ***A polar molecule has an asymmetrical charge distribution that causes an attraction to other polar molecules.***



◐

STATES OF MATTER

STATES OF MATTER

GLOSSARY

amorphous solid A solid whose atoms or molecules are not arranged in an ordered, repeating, three-dimensional array.

covalent bond The joining of atoms by the sharing of one or more electrons.

crystalline solid A solid whose atoms or molecules are arranged in a well-ordered, repeating, three-dimensional array.

dipole force The attractive force that exists between two or more polar molecules due to an asymmetric distribution of charge.

dispersion force The attractive force that exists between atoms and molecules due to temporary dipoles that develop because of charge fluctuations.

homogeneous mixture A mixture containing two or more components that has the same composition throughout.

intermolecular forces Attractive forces that exist between atoms and molecules.

ionic bond The joining of two atoms by the transfer of an electron from one to the other.

'like dissolves like' principle The idea that polar molecules mix well with other polar molecules, but don't mix well with nonpolar molecules. Mostly applicable to aqueous solutions.

macroscopic properties of gases Properties such as temperature, volume, pressure and number of moles of a sample of a gas.

osmotic pressure The pressure required to stop osmotic flow. Osmotic flow is the flow of water through a semipermeable membrane from a more dilute solution to a more concentrated one.

polar bond A chemical bond with asymmetric charge distribution.

polar molecule A molecule containing polar bonds that also has an asymmetric charge distribution over the entire molecule.

polar solute A solute (component of a solution) that has an asymmetric charge distribution. A nonpolar solute has a highly symmetrical charge distribution.

single liquid phase A liquid mixture with uniform composition.

solute The minority component of a solution.

solvent The majority component of a solution.

vapour pressure The pressure of the vapour of a liquid in equilibrium with its liquid.

THE FORCES THAT HOLD MATTER TOGETHER

the 30-second chemistry

Matter exists in three states: solid, liquid and gas. In the gas state, the particles that compose matter are separated by large distances and do not interact with one another very much. In the solid and liquid states, by contrast, the particles interact strongly, held together by attractive forces. Some solids, such as a diamond, are held together by covalent chemical bonds between atoms (which is what makes diamond so strong). Other solids, such as table salt, are held together by ionic bonds between ions. Still other solids, such as ice, and many liquids are held together by attractive forces that exist between molecules. These forces are known as intermolecular forces. Intermolecular forces exist because the electron distribution in a molecule can be either temporarily asymmetrical, resulting in the dispersion force, or permanently asymmetrical, resulting in the dipole force. In either case, the asymmetrical electron distribution causes part of the molecule to be positively charged (either temporarily or permanently) and another part to be negatively charged. The positive and negative ends of neighbouring molecules are then attracted to one another much like opposite poles of a magnet are attracted to one another. These attractions must be overcome for a substance to melt or boil.

3-SECOND NUCLEUS

Solid and liquid matter exist because the particles that compose them have strong attractions to one another.

3-MINUTE VALENCE

Why are some substances solid at room temperature, while others are liquids or gases? Because the particles that compose matter are attracted to one another in varying degrees. Strong attractions between particles are responsible for solids at room temperature, moderately strong attractions result in liquids and weak attractions result in gases. The higher the temperature, the stronger the attractions between particles must be to maintain the liquid and solid state.

RELATED TOPICS

See also

OPPOSITES ATTRACT

THE LIQUID STATE

THE SOLID STATE

3-SECOND BIOGRAPHY

JOHANNES DIDERIK VAN DER WAALS

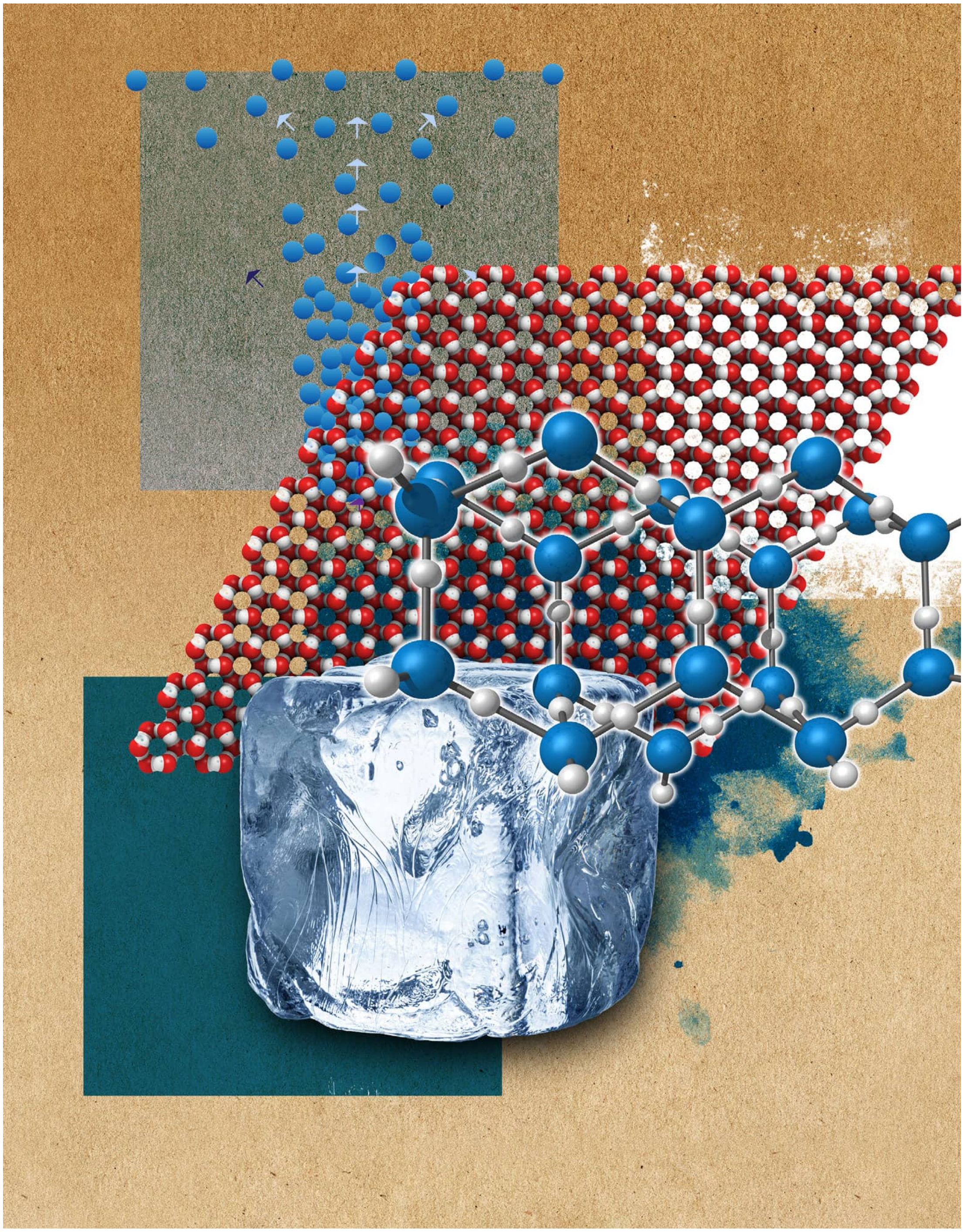
1837–1923

Dutch physicist who was among the first to postulate forces between molecules

30-SECOND TEXT

Nivaldo Tro

> ***The strength of the intermolecular forces between water molecules in ice determines its melting point.***



THE GASEOUS STATE

the 30-second chemistry

Gases have the unique property – unlike solids and liquids – of always completely filling the volume of their container. By the end of the eighteenth century, the relationships between the volume, pressure and amount of gas had been empirically described. Hot-air balloonists Jacques Charles (of Charles' law fame) and Joseph Gay-Lussac not only set new altitude records for ballooning, but also used these adventures to collect data on the temperature-volume relationship of gases, which indicated that the volume occupied by a gas increased with temperature. Robert Boyle demonstrated that the volume occupied by a gas is inversely proportional to its pressure, a relationship that became known as Boyle's law. Amedeo Avogadro hypothesized that equal volumes of gas were occupied by equal numbers of molecules as part of his theory that gases consisted of molecules that in turn were composed of atoms. His theory was largely ignored at the time. Further progress in understanding the origin of these relationships required the acceptance by chemists of the theory of the particle nature of atoms and molecules. The current model to explain these properties is kinetic-molecular theory.

3-SECOND NUCLEUS

Kinetic-molecular theory explains the macroscopic properties of gases based on the behaviour of gas particles.

3-MINUTE VALENCE

Kinetic-molecular theory is based on three postulates. The sizes of the particles that comprise a gas are negligibly small, so that gas particles occupy essentially none of the volume of a gas. Gas particles are in constant motion and have an average kinetic energy proportional to the temperature of the gas. Collisions between gas molecules are perfectly elastic in that energy can be transferred but not lost in the collisions.

RELATED TOPICS

See also

MATTER IS MADE OF PARTICLES

3-SECOND BIOGRAPHY

JAMES CLERK MAXWELL

1831–79

Scottish mathematician who, while best known for his work in electromagnetism, also worked on developing a statistical means of explaining the properties of gases

30-SECOND TEXT

John B. Vincent

> ***The properties of gases make both hot-air ballooning and scuba diving possible.***

THE LIQUID STATE

the 30-second chemistry

The molecules that compose a liquid are like dancers in a crowded night club. The dancers have so much energy that they move around the floor constantly interacting with different people. They are attracted to everyone else in the club and want to dance with everyone. Similarly, molecules in liquids have attractive forces with all the other molecules around them, but they have so much energy that they don’t stay still and are constantly moving past one another. As a whole, the people in the dance club have the same shape as the club. If they all moved from a square club to a circular one, their overall shape would change. Similarly, as a whole, water molecules flow to assume the shape of their container. Not every molecule in a liquid (or person in a dance club) has the same amount of energy. Some have more, some have less. A few have a lot more energy – so much that they can break free of their attraction to the other molecules in the liquid and fly out on their own as a gas molecule (they essentially dance right out of the club). This is how liquids evaporate.

3-SECOND NUCLEUS

Liquids are made up of molecules with enough energy to flow past one another, but generally not enough to overcome their mutual attraction entirely.

3-MINUTE VALENCE

Pour water into a glass – it fills to a certain level, and the shape of the water is the same as the inside of the glass. If you pour the water into a square-shaped glass, it assumes that shape. If you leave the water to stand for a few days, it slowly evaporates away. How do we explain this behaviour from a particulate viewpoint?

RELATED TOPICS

See also

MATTER IS MADE OF PARTICLES

THE FORCES THAT HOLD MATTER TOGETHER

THE GASEOUS STATE

3-SECOND BIOGRAPHIES

ROGER JOSEPH BOSCOVICH

1711–87

Ragusan (now Croatia) physicist who predicted that the states of matter depended on forces between their particles

FRANÇOIS-MARIE RAOULT

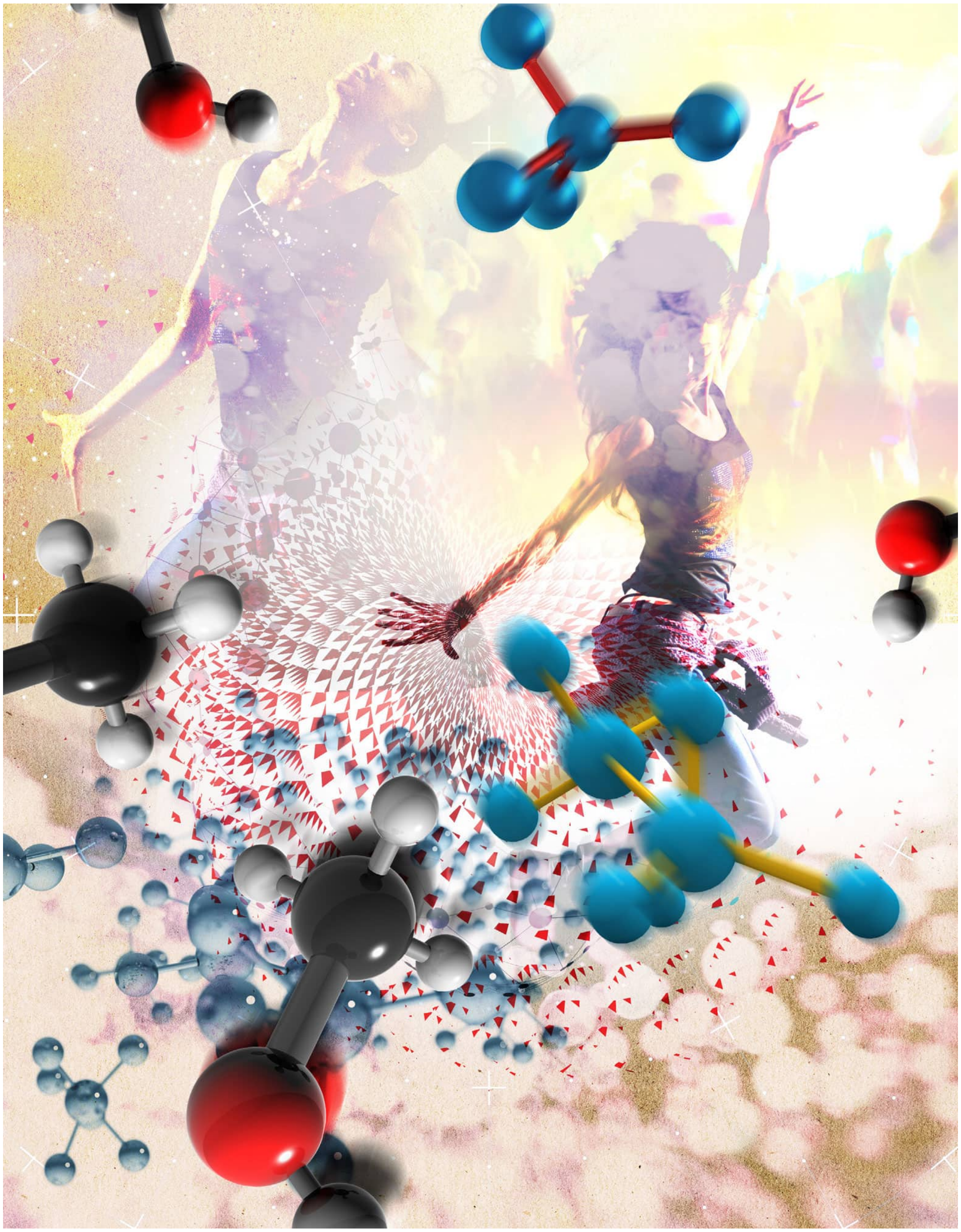
1830–1901

French chemist who explored the properties of solutions

30-SECOND TEXT

Jeff C. Bryan

> ***The molecules that compose the liquid state are in constant motion, not unlike dancers in a crowded night club.***



THE SOLID STATE

the 30-second chemistry

The particles that compose a solid are like the dancers in the nightclub from the previous entry (on liquids), except that they have less energy relative to the strength of their attractions. The dancers are still shaking, but they are not moving around each other because they are strongly attracted to those currently surrounding them. Similarly, the attractions between the particles in a solid are so strong compared to the energy they possess that the particles don’t flow past one another as they do in a liquid. The particles that compose a crystalline solid are not only stuck in one place, but also arranged in an orderly fashion like bricks in a wall. In contrast, the particles that compose an amorphous solid are arranged in a more haphazard way, like a pile of macaroni. Crystalline solids (such as salt or ice) tend to be less flexible than amorphous solids (such as plastic or glass). Although the particles that compose solids do not move past or around one another, they do wiggle and shake. When heated, they get more energy. Eventually, when heated enough, they start moving past one another and the solid melts. The amount of energy (temperature) needed for melting depends on how strongly the molecules are attracted to each other.

3-SECOND NUCLEUS

Solids have a definite size and shape because the particles that compose them are stuck in place.

3-MINUTE VALENCE

Solids behave differently from liquids or gases. They have a fixed shape and size and don’t assume the shape of their container like a liquid, nor are they compressible like a gas.

RELATED TOPICS

See also

MATTER IS MADE OF PARTICLES

THE FORCES THAT HOLD MATTER TOGETHER

THE LIQUID STATE

3-SECOND BIOGRAPHIES

WILLIAM LAWRENCE BRAGG

1890–1971

Australian-born British physicist and winner of the 1915 Nobel Prize in Physics who discovered how to peer in at the structures of solids

LINUS PAULING

1901–94

American winner of the 1954 Nobel Prize in Chemistry, who developed our understanding of how atoms and molecules are attracted to each other

30-SECOND TEXT

Jeff C. Bryan

The molecules in the solid state are like dancers who are stuck in one place on the dance floor.

ROBERT BOYLE

Robert Boyle, born in a castle in Lismore, Ireland in 1627, was the 14th child of Richard Boyle, the Great Earl of Cork and one of the richest men in Britain. Boyle's father sent his 12-year-old son on a Grand Tour of Paris, Geneva and Florence that kept him safe during the Irish Rebellion of 1641. In Geneva, during a fearsome, life-threatening thunderstorm, he pledged to devote his life to promoting God's work on Earth. His ensuing religiosity continued for the rest of his life.

He returned to London to live with his sister Katherine (the 'Lady Ranelagh') in 1644 and together they became early members of the 'Invisible College', so named because it did not have a regular meeting place, which met to discuss science – then still known as 'natural philosophy'. In Stalbridge, Dorsetshire, convinced that observations and experiments were the cornerstones on which scientific investigations had to be built, he set up his first laboratory.

Boyle is properly regarded as a transitional figure between alchemy and chemistry. He was responsible for dropping the 'al-' of alchemy and is best referred to as a 'chymist'. Among many other interests, he was devoted to chrysopoeia, the science of transmutating 'base metals' into gold. Starting in 1654, he and his assistant Robert Hooke set up a laboratory in Lady Ranelagh's house in Oxford. Hooke built a 'pneumatic engine' or vacuum pump that Boyle used to establish what is today known as Boyle's Law, which states the inverse relationship between the volume of a gas and the pressure exerted on it. His experiments lent great support to the idea that air was composed of discrete, rapidly moving 'corpuscles' (what we would call atoms or molecules) that collide with the walls of their container and exert a pressure that Boyle called 'the spring of the air'.

In his book *The Sceptical Chymist* (1661) he defined elements as 'certain primitive and simple, or perfectly unmingled bodies'. He argued that the Aristotelian view that the elements should be confined to earth, air, fire and water was not supported by observations. His primary goal was to transform alchemy to make it more scientific by framing good hypotheses based on sound experimental methods reported with great accuracy and detail. In London, Boyle established another laboratory and, among other endeavours, was active in the isolation and production of the new element: phosphorus. He was also a prolific writer of more than 40 books on a variety of topics including chemistry as well as philosophy, medicine and religion. Boyle died in 1691 one week after his beloved sister.

Glen E. Rodgers

1627
Born in Lismore, Ireland

1639
Sent on a Grand Tour to Paris, Geneva and Florence

1644
Returns to England after his father's death and stays with his sister Katherine, Lady Ranelagh in London, where they are members of the 'Invisible College'

1645
Moves into his father's manor in Stalbridge in Dorsetshire, England, where he sets up his first laboratory

1654
Moves to Oxford where he again lives with his sister. He and his assistant Robert Hooke establish a laboratory. Hooke builds a 'pneumatic engine'

1661
Publishes *The Sceptical Chymist*, in which he strongly expresses his corpuscular or atomic hypothesis and provides a definition of an element

1662
Publishes the second edition of *The Spring of the Air*, in which he establishes Boyle's Law

1668
Moves back to London, where he and Hooke again establish a laboratory. By now the 'Invisible College' has become the 'Royal Society of London for Improving Natural Knowledge'

1691
Dies in London one week after his sister

CERAMICS

the 30-second chemistry

Ceramics are among the most important materials in human civilization. They are solids held together by networks of ionic or covalent bonds extending throughout the material. They differ from metals in that the bonds are to some extent directional and so must be broken in order for planes of atoms to slip past one another. As a result, ceramics cannot be easily deformed, as metals can, but instead tend to be brittle and hard. Ceramics may be made by mixing finely powdered minerals and heating them until their atoms are moving fast enough to move into each other or until the minerals melt into a single liquid phase. When cooled, the atoms in the resulting ceramic are often aligned in the neat rows of a crystal. Glasses may be produced if the cooling is fast enough so that the atoms are frozen in a snapshot of the chaotic liquid from which they were made. Many alumino-silicate mineral ceramics consist of covalently bonded chains or sheets that can absorb water and metal ions in between the layers. These include clays that swell considerably when they take up water, as well as the mineral kaolinite, which is a primary component of fine china or porcelain.

3-SECOND NUCLEUS

The technologically useful properties of ceramic materials depend on the 3D arrangement of their atoms and the nature of the chemical bonds holding them together.

3-MINUTE VALENCE

The first ceramic figurines and pots were made more than 20,000 years ago, long before metal tools. Later artisans used tough ceramics like porcelain, clear ceramics like glass and the cements that dominate cityscapes today. Ceramic scientists continue to produce new technologically useful materials: recent examples include silicon carbide cutting tools, boron-nitride lubricants, silicon computer chips and bioglass-based medical implants made from silica and hydroxyapatite.

RELATED TOPICS

See also

THE LEWIS MODEL FOR CHEMICAL BONDING

3-SECOND BIOGRAPHIES

HERMANN SEGER

1839–93

German chemist who pioneered the scientific study of ceramics using the periodic table

RUSTUM ROY

1924–2010

Indian-born scientist who developed the sol-gel method for preparing ceramics from liquid chemical precursors

W. DAVID KINGERY

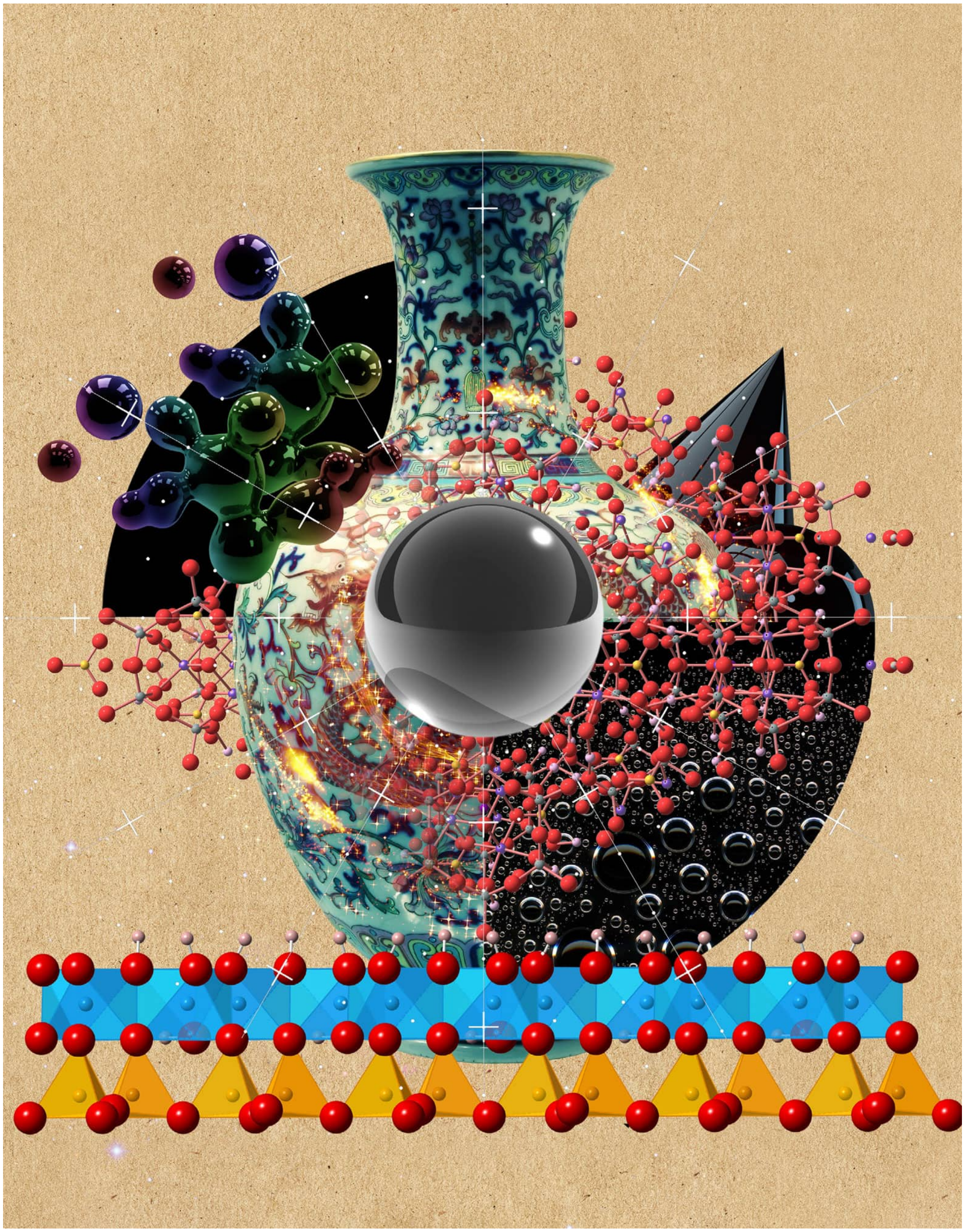
1926–2000

American material scientist who first applied solid state chemistry principles to ceramic synthesis and processing

30-SECOND TEXT

Stephen Contakes

The structure and bonding in ceramic materials determine their many useful properties.



SOLUTIONS

the 30-second chemistry

Solutions are homogeneous mixtures formed when one substance (a solute) dissolves in another substance (a solvent). Ocean water, air and sugar water are common examples of solutions. Aqueous solutions are those in which water is the solvent. Solutions show different properties from the components that compose them. For instance, a salt-water solution has a lower freezing temperature than pure water (which is one reason why freshwater lakes freeze more easily than oceans). Similarly, a salt-water solution has a higher boiling temperature, lower vapour pressure and higher osmotic pressure when compared to pure water. Such solution characteristics are known as ‘colligative properties’. They were first studied experimentally by Richard Watson, a Professor of Chemistry at Cambridge University, who observed the freezing time of a series of 18 aqueous solutions of various salts exposed to an unusually cold (-14°C/6.8°F) February atmosphere in Cambridge. He realized that the primary factor determining the degree of lowering in the freezing point of a solution is the number of solute particles (concentration) and not the type of salt. Calcium chloride ($CaCl_2$) is more effective in treating icy roads than sodium chloride (NaCl) because it provides more solute particles (ions) when mixed with the icy surface.

3-SECOND NUCLEUS

When the particles of one substance are dissolved in a second (the solvent), they interfere with the way the solvent molecules interact, changing the properties of the solution.

3-MINUTE VALENCE

The nature of intermolecular forces in all states of matter partly determines whether one substance dissolves in another. The ‘like dissolves like’ principle is helpful in determining solubility in water: polar solutes tend to be most soluble in water (since water is polar). For example, salt is soluble in water but grease (mostly nonpolar) is not.

RELATED TOPICS

See also

THE GASEOUS STATE

THE LIQUID STATE

3-SECOND BIOGRAPHIES

DAVID BERNOULLI

1700–82

Swiss mathematician whose work *Hydrodynamica* provided the first qualitative discussion of aqueous salt solutions

RICHARD WATSON

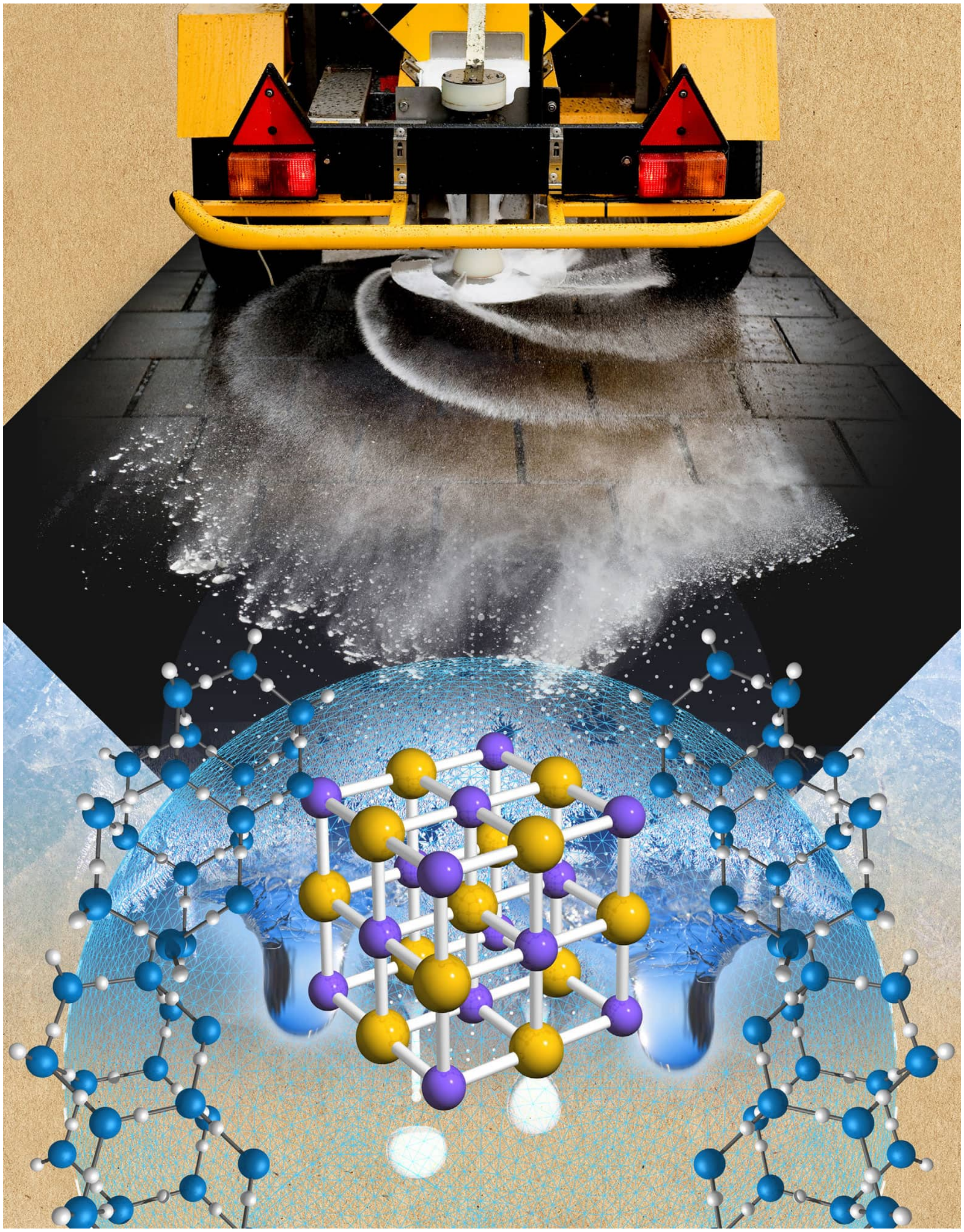
1737–1816

Professor of Chemistry at the University of Cambridge who first carried out experimental measurements studying the properties of aqueous salt solutions

30-SECOND TEXT

Ali O. Sezer

> ***Salt water solutions have a lower freezing point than pure water, which is why salt is used to reduce snow and ice build-up on roads and pathways.***



CHEMICAL REACTIONS & ENERGETICS

CHEMICAL REACTIONS & ENERGETICS

GLOSSARY

acid A substance that produces H^+ ions in solution. Acids neutralize bases, producing water as a product.

base A substance that produces OH^- ions in solution. Bases neutralize acids, producing water as a product.

catalyst A substance that increases the rate of a reaction without being consumed by the reaction.

chemical energy The energy that can be obtained from a chemical reaction when the reactants have greater potential energy than the products.

chemical reaction A process in which the atoms in one or more substances (the reactants) rearrange to form different substances (the products).

electrolysis The use of electrical current to drive a chemical reaction that would not happen spontaneously.

electrolyte A substance that produces an electrically conductive solution when dissolved in water.

entropy A thermodynamic quantity related to the amount of energy dispersed into a substance at a given temperature.

enzyme A protein that acts as a biological catalyst to increase the rate of a biochemical reaction.

exothermic A reaction that emits energy into the surroundings.

filtration A process of separation in which a solid is separated from a liquid using a filtration device such as a funnel and filter paper.

greenhouse gas An atmospheric gas that is transparent to visible light, but absorbs infrared light. These atmosphere gases act like glass in a greenhouse, allowing light to enter but preventing heat energy from escaping. The three most important greenhouse gases in Earth’s atmosphere are water vapour, carbon dioxide and methane.

hydrocarbon An organic compound containing only carbon and hydrogen.

Kelvin scale An absolute scale used for measuring temperature. On the Kelvin scale, water freezes at 273 K and boils at 373 K. The lowest possible temperature (at which point molecular motion stops) is zero on the Kelvin scale.

kinetic energy The energy associated with the motion of an object or particle.

neutralization A chemical reaction between an acid and a base that typically produces water and a salt.

oxide An oxygen-containing compound.

potential energy The energy associated with the position (within a field) or composition of an object.

precipitation A reaction between two solutions in which a solid (or precipitate) forms.

reactant Any one of the substances that undergoes a chemical reaction. In a reaction, reactants react to form products.

thermal energy The energy associated with the random thermal motion of atoms and molecules.

thermodynamics The study of energy and its conversions from one form to another.

transition-metal oxides Compounds containing a transition metal and oxygen.

voltaic cell A chemical cell that employs a spontaneous chemical reaction to produce electrical current.

CHEMICAL EQUATIONS

the 30-second chemistry

Chemists must move seamlessly between three related worlds: the macroscopic world that exists in the lab within beakers, flasks and test tubes; the atomic and molecular world, which we can't see but are constantly trying to imagine and understand; and the symbolic world, which is how we represent the atomic and molecular world on paper. A chemical equation is a way to symbolically represent changes that occur in the atomic and molecular world. These changes are called chemical reactions and they often (although not always) result in significant changes in the macroscopic world. For example, the burning of natural gas is a chemical reaction. In this reaction methane gas combines with oxygen to form carbon dioxide and water. In the macroscopic world, we see the reaction as a blue flame on our stove top. In the molecular world, methane molecules combine with oxygen molecules and transform into carbon dioxide molecules and water molecules. In the symbolic world, we represent the reaction with the following chemical equation:

$$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O.$$

Chemical equations must be balanced: they must contain the same number of each type of atom on either side of the equation. Why? Because in a chemical reaction, matter is conserved. Atoms can't just vanish or form out of nothing.

3-SECOND NUCLEUS

A chemical equation is a way to precisely represent a chemical reaction, a change in which the atoms that compose one or more substances rearrange to form one or more different substances.

3-MINUTE VALENCE

Chemical reactions occur all around us all the time. For example, our cars are powered by chemical reactions; cooking is a chemical reaction; and our bodies maintain a myriad of reactions that allow us to think, move, eat and reproduce. Chemical equations not only represent the identities of the reactants and products in a chemical reaction; they also give us quantitative relationships between the amounts that react.

RELATED TOPICS

See also
BONDING ATOMS TOGETHER

COMBUSTION REACTIONS & ENERGY SOURCES

NEUTRALIZING: ACIDS & BASES

3-SECOND BIOGRAPHIES

ROBERT BOYLE

1627–91

Anglo-Irish chemist who formulated some of the earliest ideas about chemical reactions

ANTOINE LAVOISIER

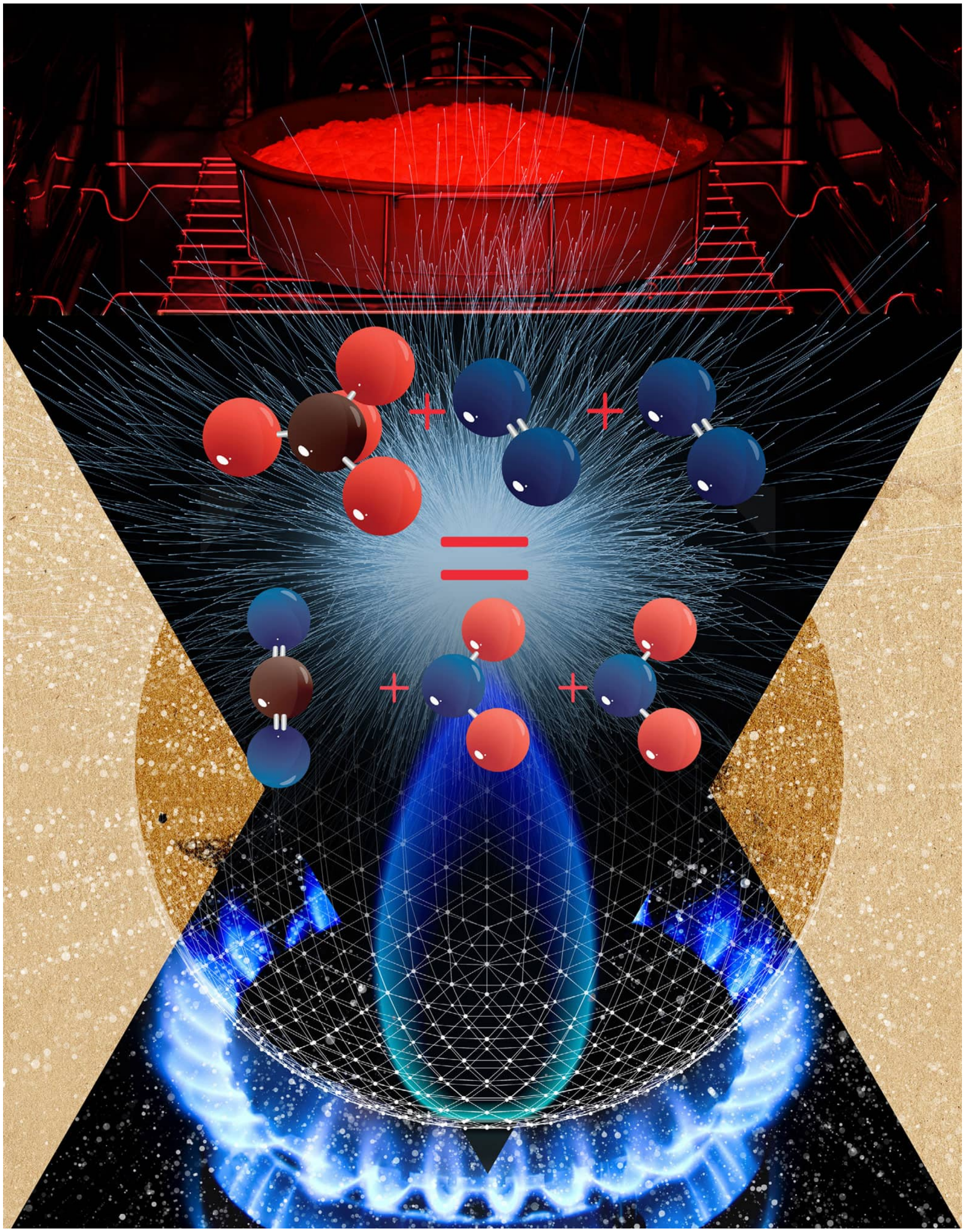
1743–94

French chemist who contributed significantly to our understanding of chemical reactions, especially combustion

30-SECOND TEXT

Nivaldo Tro

> ***We witness chemical reactions, such as the burning of natural gas, every day.***



COMBUSTION REACTIONS & ENERGY SOURCES

the 30-second chemistry

The first chemical reaction that early humans used was burning or combustion. In a combustion reaction, a substance combines with oxygen and most commonly produces carbon dioxide, water and other oxide products. Combustion reactions are useful because they emit heat as they occur – they are exothermic. Certain molecules, especially hydrocarbons, have an inherently high potential energy that can be released through combustion. For this reason, our society's fuels are largely based on hydrocarbons. Natural gas is primarily methane (CH_4). Liquefied petroleum (LP) gas is a mixture of propane (C_3H_8) and butane (C_4H_{10}). Petrol is a mixture of hydrocarbons, such as octane (C_8H_{18}), containing five or more carbon atoms. Coal is also a major part of our energy equation: it is mostly carbon and combines with oxygen to form carbon dioxide. Together these fuels are known as fossil fuels because they originated from ancient plant and animal life. However, the combustion of fossil fuels is not without problems. The most vexing problem is probably the emission of carbon dioxide, a greenhouse gas that is affecting Earth's climate. Since the Industrial Revolution, atmospheric carbon dioxide levels have risen by about 38 per cent, and average global temperatures have risen by about 0.8°C (1.4°F).

3-SECOND NUCLEUS

Our society's energy comes largely from the combustion of fossil fuels, which produce large amounts of energy when burned.

3-MINUTE VALENCE

Energy is critical to a society's standard of living. In general, as the standard of living rises, so does energy consumption. Our current energy sources are dwindling, however, and creating environmental problems. The shift to alternative energy sources – such as solar power or wind power – has been slow, but steady. The main challenges of the alternative sources are their cost and their inherent intermittence.

RELATED TOPICS

See also

CHEMICAL EQUATIONS

3-SECOND BIOGRAPHY

ANTOINE LAVOISIER

1743–94

French chemist who contributed significantly to our understanding of chemical reactions, especially combustion

30-SECOND TEXT

Nivaldo Tro

> ***Combustion or burning is common in energy generation and industry.***

NEUTRALIZING: ACIDS & BASES

the 30-second chemistry

Most of us experience acids by taste – they are sour. Citrus fruits, vinegar, carbonated beverages, yoghurt and sour sweets all owe their tangy deliciousness to the acids they contain. Chemists prefer not to taste their work and often define acids as chemicals that produce the hydrogen ion (H^+) when dissolved in water. If acids are a chemical yin, then bases are the yang. Bases tend to taste bitter and produce hydroxide (OH^-) in water, the chemical opposite of H^+. When an acid and base are mixed, the hydrogen ion combines with the hydroxide ion to form HOH (water):

$$H^+ + OH^- \rightarrow H_2O.$$

This type of chemical reaction is called neutralization. If exactly equal amounts of H^+ and OH^- are mixed, the resulting solution will contain neither (because all of the H^+ and OH^- ions reacted to form water), and it won't be acidic or basic. Our stomachs use hydrochloric acid (HCl) to help digest our food. If we eat too much, especially acidic or fatty foods, our stomachs can produce too much HCl, causing us to feel uncomfortable (sometimes called 'sour stomach'). To neutralize the excess acid, we can take an antacid. Antacids are bases like aluminium hydroxide ($Al(OH)_3$), magnesium hydroxide ($Mg(OH)_2$) and calcium carbonate ($CaCO_3$) that neutralize the excess stomach acid.

3-SECOND NUCLEUS

Acids produced H^+ in water while bases produce OH^-. An acid and a base react to produce water, effectively neutralizing each other.

3-MINUTE VALENCE

The pH scale is used to measure the acidity or basicity of a solution. The lower the pH value, the higher the concentration of H^+, and the more acidic the solution. The higher the pH value, the higher the concentration of OH^-, and the more basic the solution. Pure water is neutral and has a pH of 7. Stomach acid is pH 1.6, tomato juice 4.2, sea water 8.2 and milk of magnesia ($Mg(OH)_2$) 10.4.

RELATED TOPICS

See also

OPPOSITES ATTRACT

SOLUTIONS

CHEMICAL EQUATIONS

3-SECOND BIOGRAPHIES

SVANTE ARRHENIUS

1859–1927

Swedish winner of the Nobel Prize for Chemistry (1903), who first suggested the acid/base definitions given here

JOHANNES BRØNSTED & MARTIN LOWRY

1879–1947 & 1874–1936

Danish and British chemists who defined acids and bases on how they react

30-SECOND TEXT

Jeff C. Bryan

> ***Antacids contain bases that neutralize stomach acid, the cause of heartburn.***

CREATING SOLIDS: PRECIPITATION REACTIONS

the 30-second chemistry

Two friends are out for a night on the town, both looking for love. One is drawn to an incredibly attractive stranger. Once together, the friend and the stranger never separate, because the attraction is so strong. They drop out of sight, losing touch with their old friends. This scenario is similar to a particular type of chemical reaction called a precipitation reaction. When two or more ions are mixed in water, they are initially attracted to nearby water molecules. However, as they move around (due to thermal energy), the ions encounter each other and are drawn together. If the attraction is strong enough, the two ions will stick together and fall out of solution (form a solid). If the attraction isn't very strong, the ions don't get together and just stay in solution. As examples, when silver (Ag^+) and chloride (Cl^-) are mixed they stick together and form a solid precipitate. However, sodium (Na^+) is much less attractive to chloride, so they don't form a precipitate. The 'bathtub ring' that you sometimes see if you bathe in hard water is due to a precipitation reaction between the ions in hard water and the ions in soap.

3-SECOND NUCLEUS

A precipitation reaction occurs when two ions are so strongly attracted to each other that they form a solid.

3-MINUTE VALENCE

Precipitation reactions are particularly useful when something needs to be removed from a solution. For example, water treatment plants can use precipitation reactions to remove undesirable contaminants from our water. If a chemical reaction takes place in a solution, and the product is insoluble in that solution, then it falls out of solution as a solid and can be isolated by filtration.

RELATED TOPICS

See also

OPPOSITES ATTRACT

THE SOLID STATE

CERAMICS

3-SECOND BIOGRAPHY

LINUS PAULING

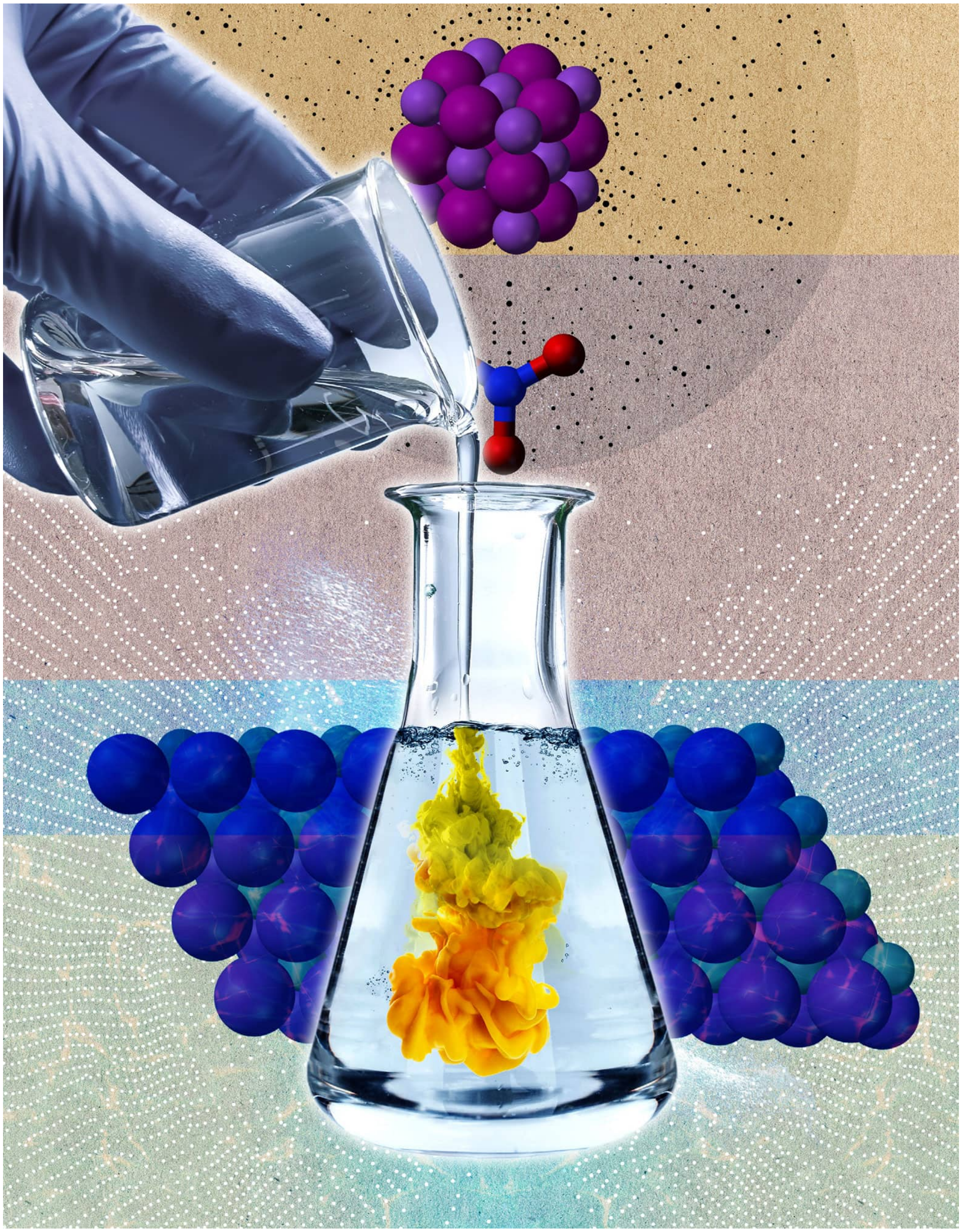
1901–94

American winner of the 1954 Nobel Prize in Chemistry, who developed our understanding of how atoms and molecules are attracted to each other. He was also a peace activist and won the 1962 Nobel Peace Prize

30-SECOND TEXT

Jeff C. Bryan

In a precipitation, a solid forms when two liquid solutions are mixed.



USING CHEMISTRY TO GENERATE ELECTRICITY

the 30-second chemistry

Chemical reactions in which electrons migrate from one chemical substance to another are called oxidation-reduction reactions. These types of reactions can be used to generate electricity by arranging the chemical substances so that the substance gaining electrons (being reduced and called the oxidizing agent) is not in physical contact with the substance losing electrons (being oxidized and called the reducing agent). The electrons are then forced to travel through an external circuit to get from the reducing agent to the oxidizing agent. This arrangement is called a voltaic cell. Self-contained voltaic cells – either by themselves or connected in series – function as batteries. They produce electricity. The lead storage battery used to start a car engine is comprised of six voltaic cells containing lead and lead oxide immersed in a solution of sulfuric acid (battery acid). Dry cell batteries, such as those used in torches, use zinc and magnesium dioxide. Button batteries (used in calculators or watches) also use zinc, but they have mercuric oxide or silver oxide substituted as the oxidizing agent. Lithium ion batteries use lithium between planes of graphite as the reducing agent and a lithium metal oxide as the oxidizing agent.

3-SECOND NUCLEUS

Loss of electrons is oxidation, while gain of electrons is reduction; reactions that involve transfer of electrons between reactants are oxidation-reduction or redox reactions.

3-MINUTE VALENCE

Corrosion results from oxidation of metals exposed to oxidizing agents in the environment. When the metal is iron, the process is rusting. Rust is hydrated forms of iron(III) oxide generated when iron is exposed to moisture and oxygen. The rate of rusting depends on the acidity of the environment and the presence of electrolytes to help carry electric current. Having a metal that is more easily oxidized (a sacrificial electrode) in contact with iron can retard rusting.

RELATED TOPIC

See also

CHEMICAL EQUATIONS

3-SECOND BIOGRAPHIES

MICHAEL FARADAY

1791–1867

English scientist who developed the system of oxidation numbers and coined many terms associated with electrochemistry

WALTHER HERMANN NERNST

1864–1941

German chemist who developed the equation for the relationship between concentration and voltage

30-SECOND TEXT

John B. Vincent

Batteries use chemical reactions that involve the transfer of electrons to produce electricity.

REACTION RATES & CHEMICAL KINETICS

the 30-second chemistry

Chemical reactions occur at a variety of speeds or rates. Chemical explosions occur rapidly, with the creation of large volumes of hot gas. Many chemicals are stable, however; they react so slowly that they can be placed in a bottle. Fortunately, the rates (or speeds) at which chemical reactions occur can be controlled – and studying these processes is the field of chemical kinetics. One way to increase the rate of a reaction is by increasing the temperature. For this reason, the reactions that cook food happen faster the higher the temperature. Increasing the concentration of the reactant substances or surface area also increases the rates of chemical reactions. You can hold an iron nail in your hand, but if it is ground to a fine powder (greatly increasing its surface area) the iron can burst into flames in air. The concentration of many chemicals in your body must be carefully regulated for you to remain healthy. Your body accomplishes this by regulating the rates of a wide range of chemical reactions. The rates of slow reactions are accelerated by proteins called enzymes; these biological molecules are catalysts (substances that change the rate of a chemical reaction without being consumed by the reaction).

3-SECOND NUCLEUS

The rate of a chemical reaction is the speed at which the reaction occurs and depends on reactant concentration, temperature and whether or not a catalyst is present.

3-MINUTE VALENCE

Although nitrogen and oxygen gas are stable, at the temperature of a car engine they react to produce nitric oxide gas (NO), an air pollutant that is a cause of acid rain and smog. NO is removed from a car's exhaust gas by a catalytic converter. In the converter, the exhaust passes over a honeycomb-like structure of alumina impregnated with solid transition-metal oxides that catalyse the conversion of NO back to O_2 and N_2.

RELATED TOPICS

See also

CHEMICAL EQUATIONS

USING CHEMISTRY TO GENERATE ELECTRICITY

3-SECOND BIOGRAPHIES

JACOBUS HENRICUS VAN ’T HOFF

1852–1911

Dutch chemist who won the first Nobel Prize in Chemistry in part for determining graphical methods to establish that reaction rates depend on the concentrations of the reactants

HENRY TAUBE

1915–2005

American chemist who won the 1983 Nobel Prize in Chemistry for relating rates of chemical reactions to electronic structure

30-SECOND TEXT

John B. Vincent

Controlling how fast a chemical reaction occurs allows us to reduce pollution and create new molecules.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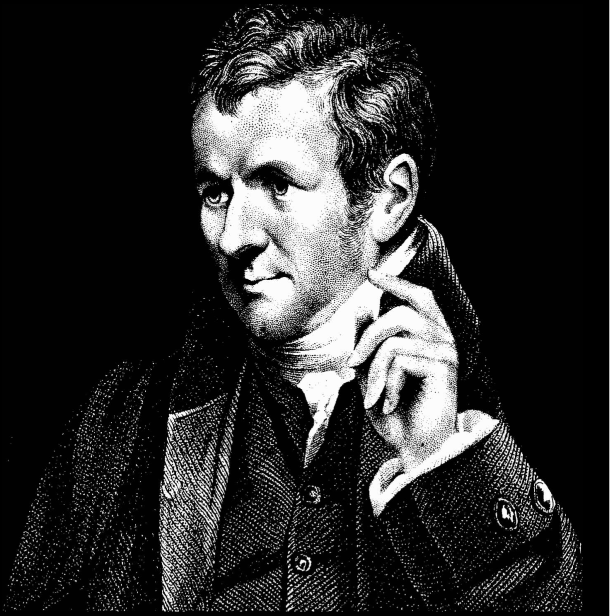
HUMPHRY DAVY



Humphry Davy, ‘full of mischief, with a penchant for explosions … a born chemist’, spent his youth fishing, hunting, reading, storytelling and writing poetry. As a teenager he loved fireworks and other explosive chemical reactions. He was apprenticed to a surgeon and apothecary, but reluctantly gave this up to become director of Thomas Beddoes’s Pneumatic Institute in Bristol. This clinic, established to study the effect of gases on improving human health, gave Davy the opportunity to prepare, characterize and purify nitrous oxide – which earlier researchers had thought caused the plague. Davy was not convinced and took a small whiff for himself. Noting that he did not meet his demise, he soon discovered that this sweet-smelling gas was thoroughly intoxicating. Fellow partakers giggled and laughed out loud, and Davy called it ‘laughing gas’.

In Bristol, Davy became friends with a broad cross-section of intellectuals. His good looks, personal charm, and storytelling abilities, combined with his startling discoveries, made him a rising star. Although it soon became clear that Beddoes’s clinic would be short-lived, Davy had matured into an excellent chemist. Luckily he soon found an electrifying new field of study occasioned by Alessandro Volta’s invention of a chemical battery, known then as a Voltaic pile. Characteristically, one of the first things he did was to build his own pile and shock himself to gauge its effectiveness!

In 1801, Davy was invited to be a lecturer at the newly minted Royal Institution in London. Here he quickly produced a series of immensely popular lectures augmented by striking demonstrations. He was an extremely handsome young man with a gift for working audiences, so he attracted huge crowds that included many of the young ladies of that day. One such admirer admitted that ‘those eyes were made for something besides poring over crucibles.’ Active in the electrolysis of metal oxides, he discovered six elements (sodium, potassium, magnesium, calcium, strontium and barium) in two years (1807–08) and became the leading chemist of his day.

His penchant for self-experimentation caused debilitating injuries that resulted in his hiring of Michael Faraday as his assistant. Davy often claimed that Faraday was his most important ‘discovery’. In 1812 Davy was knighted, married and embarked on a Grand Tour of Europe. Upon his return he invented the coal miner’s safety lamp that saved many lives. He was essentially an invalid for the last third of his life and died shortly after his 50th birthday.

Nevertheless, during his short and exciting lifetime, he was one of the best practitioners of and spokesmen for the new science of chemistry.

Glen E. Rodgers

1778
Born in Penzance, in southwestern England

1795
Apprenticed to a surgeon and apothecary

1797
Studies chemistry by reading in French the recently guillotined Antoine Lavoisier's *Traité élémentaire de chimie*

1798
Becomes the director of Thomas Beddoes' Pneumatic Institute in Bristol

1799
Prepares and imbibes nitrous oxide, which he nicknames 'laughing gas'

1800
Publishes *Researches, Chemical and Philosophical; chiefly concerning nitrous oxide or dephlogisticated nitrous air, and its respiration*

1800
The news of Alessandro Volta's 1796 discovery of a chemical battery, known as the 'Voltaic Pile', comes to England

1801
Invited to be a lecturer at the newly formed Royal Institution in London

1802
Appointed professor of chemistry at the Royal Institution; soon builds a giant Voltaic pile in the basement

1807-1808
Using his Voltaic pile, discovers six elements (sodium, potassium, magnesium, calcium, strontium and barium) in two years

1810
'Discovers' and launches Michael Faraday on a stellar chemistry career

1812
Knighted, marries, retires and with his new wife and Faraday, tours the continent visiting major laboratories

1815

Invents the coal miner's safety lamp

1829

After a lengthy period of debilitation, dies in Geneva, Switzerland

ENERGY & THE FIRST LAW OF THERMODYNAMICS

the 30-second chemistry

The universe has a quantity we call energy. Objects can possess it and can transfer it to other objects, but it can neither be created nor destroyed. The total amount of energy that exists is constant. This principle is known as the first law of thermodynamics. (A more nuanced treatment includes mass/energy as the constant, but we simplify a bit here.) We formally define energy as the capacity that an object has to exert a force on another object across a distance. For example, a moving car has energy because it has the capacity to strike another object and exert a force on it over a distance. Energy can come in many different forms. The moving car has kinetic energy, the energy associated with its motion. All substances above zero kelvin have thermal energy, a type of kinetic energy associated with the random, temperature-dependent motion of the particles that compose the substance. The higher the temperature, the greater the thermal energy. The book you are holding contains potential energy, the energy associated with an object's position. Chemical substances have chemical energy, a type of potential energy associated with the positions of all of their electrons and protons. Energy can be transferred or exchanged but, according to the first law, it can never be created or destroyed.

3-SECOND NUCLEUS

Energy can be transferred or exchanged but, according to the first law of thermodynamics, it can never be created or destroyed.

3-MINUTE VALENCE

The first law of thermodynamics implies that energy cannot be made out of nothing. Any human attempt to create energy out of thin air has failed. The law has not, of course, prevented humans from trying. But as far as we know, the spontaneous creation of energy is impossible. In other words, when it comes to energy, you can't win – you can't get something for nothing.

RELATED TOPICS

See also

ENTROPY & THE SECOND LAW OF THERMODYNAMICS

ENTROPY & THE THIRD LAW OF THERMODYNAMICS

ENTROPY & SPONTANEOUS PROCESSES

3-SECOND BIOGRAPHY

RUDOLF CLAUSIUS

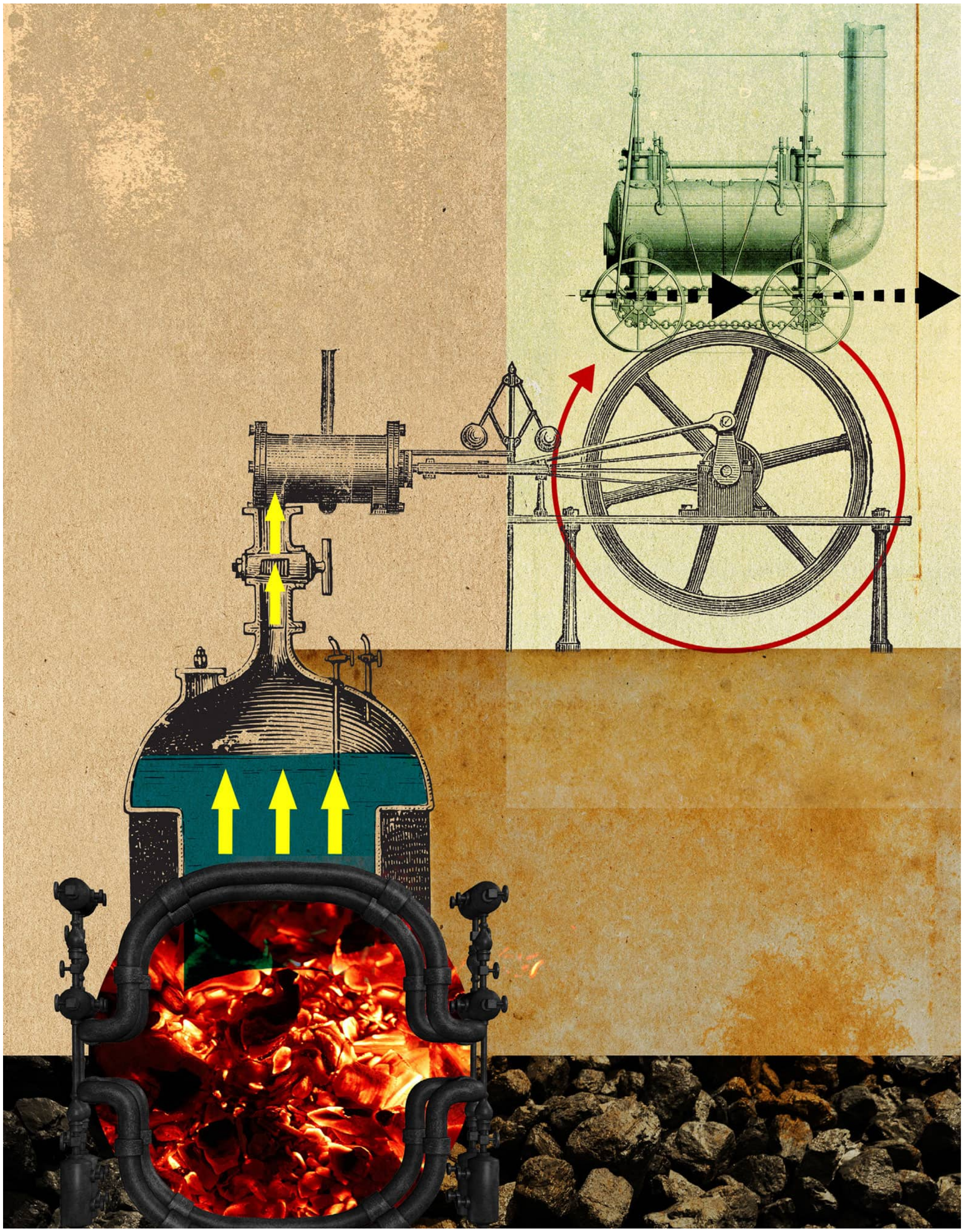
1822–88

German physicist who formulated one of the earliest versions of the first law of thermodynamics

30-SECOND TEXT

Nivaldo Tro

A steam engine is powered by the energy transferred from burning fuel.



ENTROPY & THE SECOND LAW OF THERMODYNAMICS

the 30-second chemistry

We have seen that in energy transactions, you can’t win – you can’t get energy out of nothing. But it gets worse – you can’t even break even. In our universe, energy always spreads out or randomizes itself as much as possible. The second law of thermodynamics describes this pervasive tendency: in any spontaneous process, a quantity called entropy (which you can think of as a measure of energy randomization or energy dispersion) always increases. You have no doubt experienced the second law every time you hold a warm drink. The thermal energy in the drink disperses itself into the surroundings – the drink spontaneously cools down (and the air surrounding the drink warms up a bit). Imagine a universe in which the hot drink gets hotter (and the surroundings slightly cooler) as energy transfers from the surroundings into the drink! Not possible according to the second law. The second law implies that, in any energy transaction, some energy must be dispersed if the transaction is to occur at all. In other words, nature always takes a heat tax. For example, recharging a battery will always take more energy than the amount of energy you can use as you discharge the battery. Such is the second law – when it comes to energy, you can’t break even.

3-SECOND NUCLEUS

For all spontaneous processes entropy increases.

3-MINUTE VALENCE

The second law of thermodynamics implies that a perpetual motion machine – one that keeps on moving forever without the need for energy input – is impossible. With each cycle of the machine’s motion, some energy must be dispersed in order for the motion to occur at all. As a result, the energy of the machine must necessarily decrease over time, and it must eventually stop moving.

RELATED TOPICS

See also

ENERGY & THE FIRST LAW OF THERMODYNAMICS

ENTROPY & THE THIRD LAW OF THERMODYNAMICS

3-SECOND BIOGRAPHIES

NICOLAS LÉONARD SADI CARNOT

1796–1832

French physicist instrumental in the development of thermodynamics

RUDOLF CLAUSIUS

1822–88

German physicist who was instrumental in formulating the second law of thermodynamics

30-SECOND TEXT

Nivaldo Tro

> ***A perpetual motion machine cannot exist according to the second law of thermodynamics.***

ENTROPY & THE THIRD LAW OF THERMODYNAMICS

the 30-second chemistry

According to the first law of thermodynamics, you can't win – you can't get something for nothing. According to the second law, you can't break even – every energy transaction necessarily results in a loss to the surroundings. According to the third law of thermodynamics, you can't get out of the game. In the case of thermodynamics 'getting out of the game' means getting to the lowest possible temperature, zero kelvin or absolute zero. Absolute zero is the temperature at which atomic and molecular motion essentially stops. The third law of thermodynamics states that the entropy of a perfect crystal is zero at zero kelvin. This law has two implications. The first one is that entropy, unlike other thermodynamic quantities, can be measured on an absolute scale. All perfect crystals have zero entropy at zero kelvin. As the temperature rises, energy is dispersed into the crystal and its temperature and entropy increases. The second implication is that absolute zero can never be reached in a finite number of steps. It would take an infinite number of cooling steps to arrive at the absolute zero of temperature, so it can never be achieved.

3-SECOND NUCLEUS

The absolute entropy of a perfect crystal at zero kelvin is zero.

3-MINUTE VALENCE

Entropy is a measure of the energy dispersed into a system per unit temperature. For this reason, dispersing the same amount of energy into a system at a colder temperature produces greater entropy than dispersing that energy into a warmer system. As we will see in the next entry, this is the reason that ice melts above its melting point but not below it.

RELATED TOPICS

See also

ENERGY & THE FIRST LAW OF THERMODYNAMICS

ENTROPY & THE SECOND LAW OF THERMODYNAMICS

ENTROPY & SPONTANEOUS PROCESSES

3-SECOND BIOGRAPHY

WALTHER HERMANN NERNST

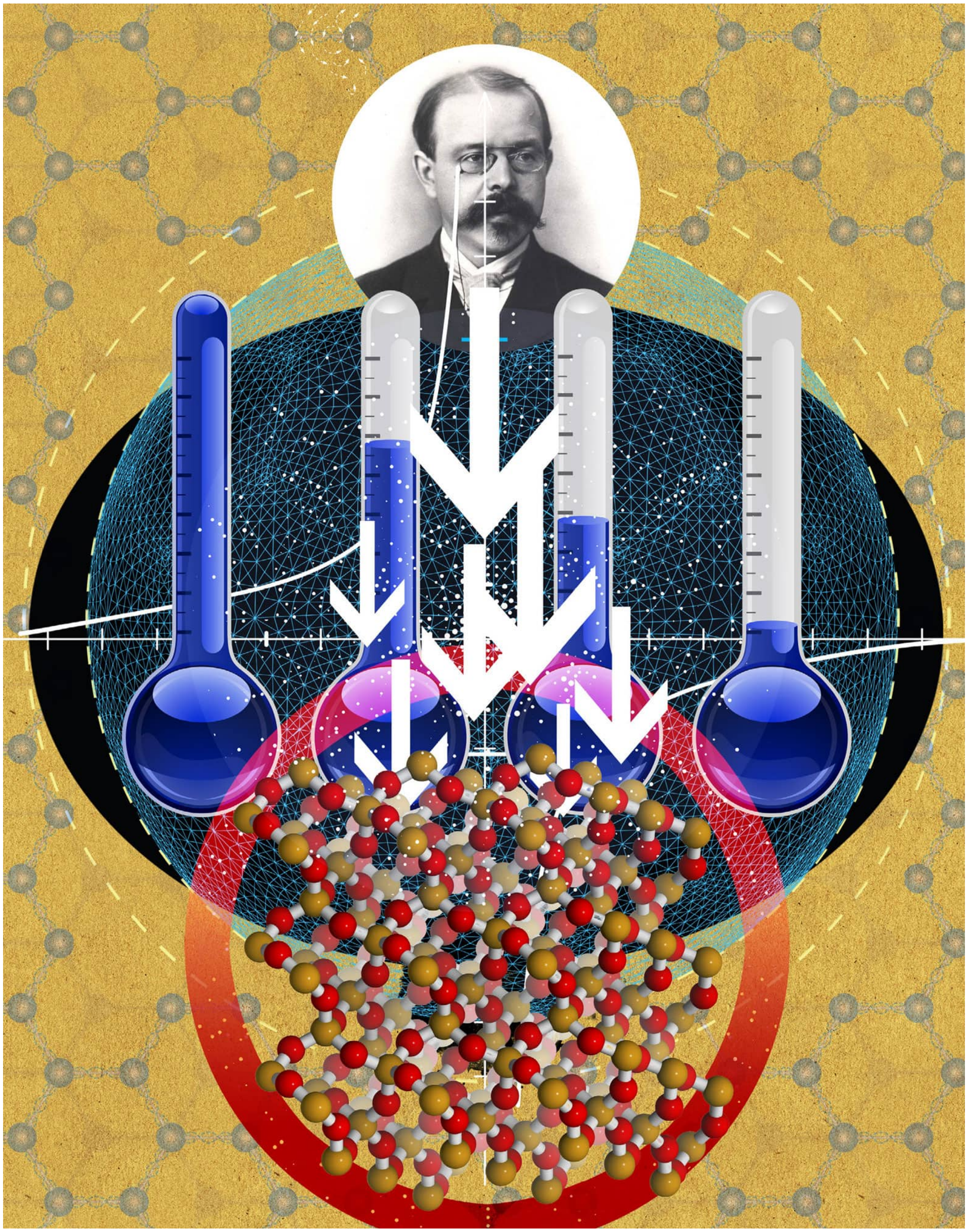
1864–1941

German chemist who formulated the third law of thermodynamics and received the 1920 Nobel Prize in Chemistry for his work

30-SECOND TEXT

Nivaldo Tro

> ***The third law of thermodynamics, as formulated by Walther Nernst, implies that the absolute zero of temperature cannot be reached.***



ENTROPY & SPONTANEOUS PROCESSES

the 30-second chemistry

The criteria for determining whether any process will happen is simple: will the process result in an increase in entropy? Consider the freezing of water. Water freezes spontaneously below 0°C (32°F). Why? When water freezes, the water molecules become more organized, and the energy they contain becomes less randomized - their entropy decreases. How then is this process ever spontaneous? Because when water freezes it gives off heat (energy is dispersed) and the resulting entropy increase in the surroundings is temperature-dependent. We can understand this with a simple analogy. If you give a poor person £1,000, you significantly increase his or her net worth. But if you give a rich person the same £1,000, the impact is negligible. Similarly, if you disperse a given amount of energy into cold surroundings, you significantly increase its entropy, but if you disperse the same amount of energy into warm surroundings, the increase is less. When the freezing of water occurs below 0°C, the heat emitted into the surroundings is enough to increase the entropy of the surroundings so much that it more than compensates for the decrease in entropy of the water molecules themselves, resulting in an overall increase in entropy of the universe and therefore a spontaneous process.

3-SECOND NUCLEUS

A process is spontaneous if it increases the entropy (energy dispersion) of the universe.

3-MINUTE VALENCE

Processes that result in a decrease in entropy are not impossible, they just don’t happen spontaneously. Iron spontaneously reacts with oxygen to form iron oxide (rust). This process causes an increase in the entropy of the universe. However, iron oxide can be turned back into iron. In fact, the manufacture of iron metal from iron oxide depends on it.

RELATED TOPICS

See also

ENERGY & THE FIRST LAW OF THERMODYNAMICS

ENTROPY & THE SECOND LAW OF THERMODYNAMICS

ENTROPY & THE THIRD LAW OF THERMODYNAMICS

3-SECOND BIOGRAPHIES

JOSIAH WILLARD GIBBS

1839–1903

American physicist who developed the main criteria for the spontaneity of a process

LUDWIG EDUARD BOLTZMANN

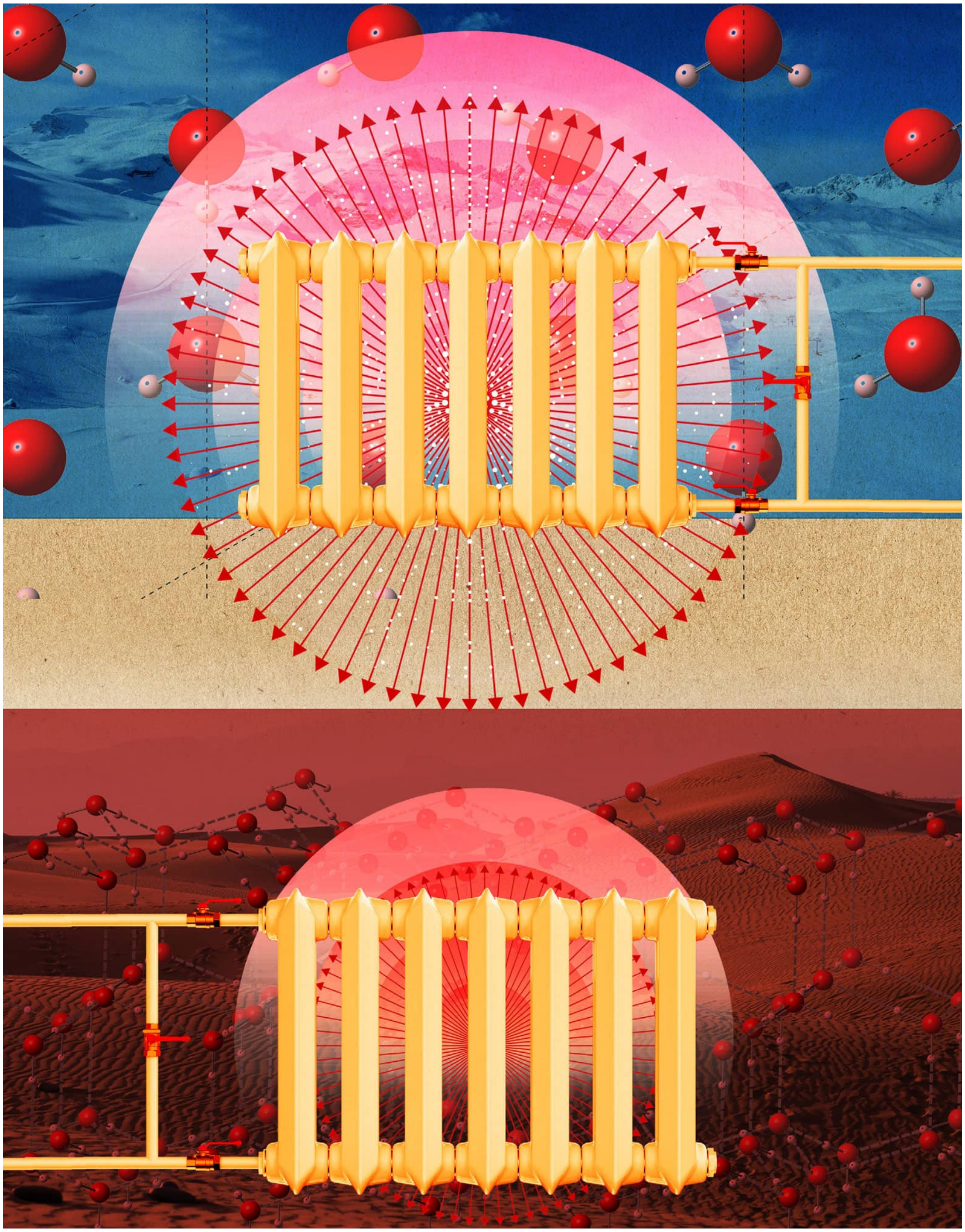
1844–1906

Austrian physicist who developed a statistical description of the second law of thermodynamics

30-SECOND TEXT

Nivaldo Tro

> ***When ice melts at a temperature above its melting point, the entropy of the universe increases.***



INORGANIC CHEMISTRY

INORGANIC CHEMISTRY

GLOSSARY

allotropes Two or more forms of the same element, but with different structures (and therefore different properties).

catalytic properties To have the ability to act as a catalyst (a substance that increases the rate of chemical reaction without being consumed by the reaction).

CFCs Chlorofluorocarbons. These compounds were common in air conditioning and refrigeration, but are now banned due to their harmful effect on the Earth's ozone layer.

colour wheel A circle or wheel that contains different colours and shows how they are related. You can use a colour wheel to predict the colour of an object based on what colours the object absorbs.

complementary colours Two colours opposite each other on a colour wheel. Complementary colours have high contrasts between one another.

complex (transition metal complex) A compound or ion consisting of a transition metal linked to one or more ligands.

concatenated atoms Atoms that have been linked to form a chain structure.

crystal field theory (also ligand field theory) A bonding theory in inorganic chemistry in which ligands donate an electron pair to a central metal ion.

diffraction grating A surface engraved with a series of closely spaced lines that reflects different wavelengths of light at different angles. Diffraction gratings can split white light up into its constituent colours.

electromagnetic spectrum The range of frequencies of electromagnetic radiation bounded by radio waves at low frequencies and gamma rays at high frequencies.

fuel cell An electrochemical cell that produces electrical current from the continuous input of a fuel.

fullerenes Carbon molecules that have spherical, tubular or other similar structures.

graphene A form of carbon consisting of a sheet of carbon atoms one atom thick.

graphite A form of carbon composed of carbon atoms bound together in sheets, which are stacked on top of one another.

ligand A molecule or ion that donates an electron pair to a central metal ion in transition metal complex.

metalloid An element that falls along the boundary between metals and non-metals on the periodic table. Metalloids have properties intermediate between metals and non-metals.

oxidation state The charge an atom would have in a chemical compound if all of the bonding electrons were assigned to the more electron negative atom (the atom that most strongly attracts electrons).

photosynthesis The process by which plants convert carbon dioxide, water and sunlight into glucose and oxygen.

prism A clear optical element that is usually triangular in shape and can bend light of different wavelengths by different amounts. When white light travels through a prism, it is broken up into its constituent colours.

reactant Any one of the substances that undergoes a chemical reaction. In a reaction, reactants react to form products.

silicate Compound containing silicon, oxygen and sometimes various metal atoms. Silicates form network covalent structures with high melting points.

stratosphere An atmospheric layer that begins about 10 km (just over 6 miles) above the Earth's surface and is sandwiched between the troposphere below and the mesosphere above.

substrate The molecule on which an enzyme (a biological catalyst) acts.

transition metals Those metals found in the large centre block of the periodic table (the d-block). Transition metals (in contrast to main group metals) tend to have properties that are less predictable based on their exact position on the periodic table.

valence electrons The highest energy electrons (and therefore the most important in bonding) in an atom.

Zintl ions Ionic clusters of main group elements.

THE UNIQUENESS PRINCIPLE

the 30-second chemistry

The periodic table contains a dividing line that is never marked. The invisible line occurs between the table's second and third rows, where boron meets aluminium; carbon meets silicon; and so on until fluorine meets chlorine. Elements above the line cannot form bonds to as many atoms as those below the line, being strictly limited to a total of eight 'valence' or bonding-level electrons. Thus, while oxygen forms the mono- and dioxides with itself (that is, O_2 and O_3), sulfur, selenium and tellurium form mono-, di- and trioxides, of which SO, SO_2 and SO_3 are examples. Similarly, nitrogen forms the trichloride NCl_3 while phosphorous, arsenic and antimony form both tri- and pentachlorides such as PCl_3 and PCl_5. However, unlike later elements, the non-metals of the second row are small enough to form strong multiple bonds, a quality that enables them to form compact molecules where a heavier element would form an extended structure of linked atoms. Carbon, for instance, forms the triple and doubly bonded oxides CO and CO_2, while its heavier counterparts – silicon, germanium, tin and lead – react with oxygen to form three-dimensional solid networks held together exclusively by single bonds.

3-SECOND NUCLEUS

Elements in the periodic table's second row behave differently from heavier elements because they form strong multiple bonds and are limited to eight valence electrons.

3-MINUTE VALENCE

One consequence of the uniqueness principle is that planetary atmospheres largely consist of first- and second-row elements. Earth's atmosphere is comprised mostly of nitrogen and oxygen; Mars's atmosphere mostly of CO_2; and those of the gas giants are mostly hydrogen, helium, CH_4 and NH_3. In contrast, the planetary crusts of planets such as Earth and Mars contain large amounts of silicate minerals, many of which contain chains, sheets and 3D networks held together by silicon-oxygen single bonds.

RELATED TOPICS

See also

PERIODIC PATTERNS

THE LEWIS MODEL FOR CHEMICAL BONDING

CARBON: IT’S NOT JUST FOR PENCILS

3-SECOND BIOGRAPHIES

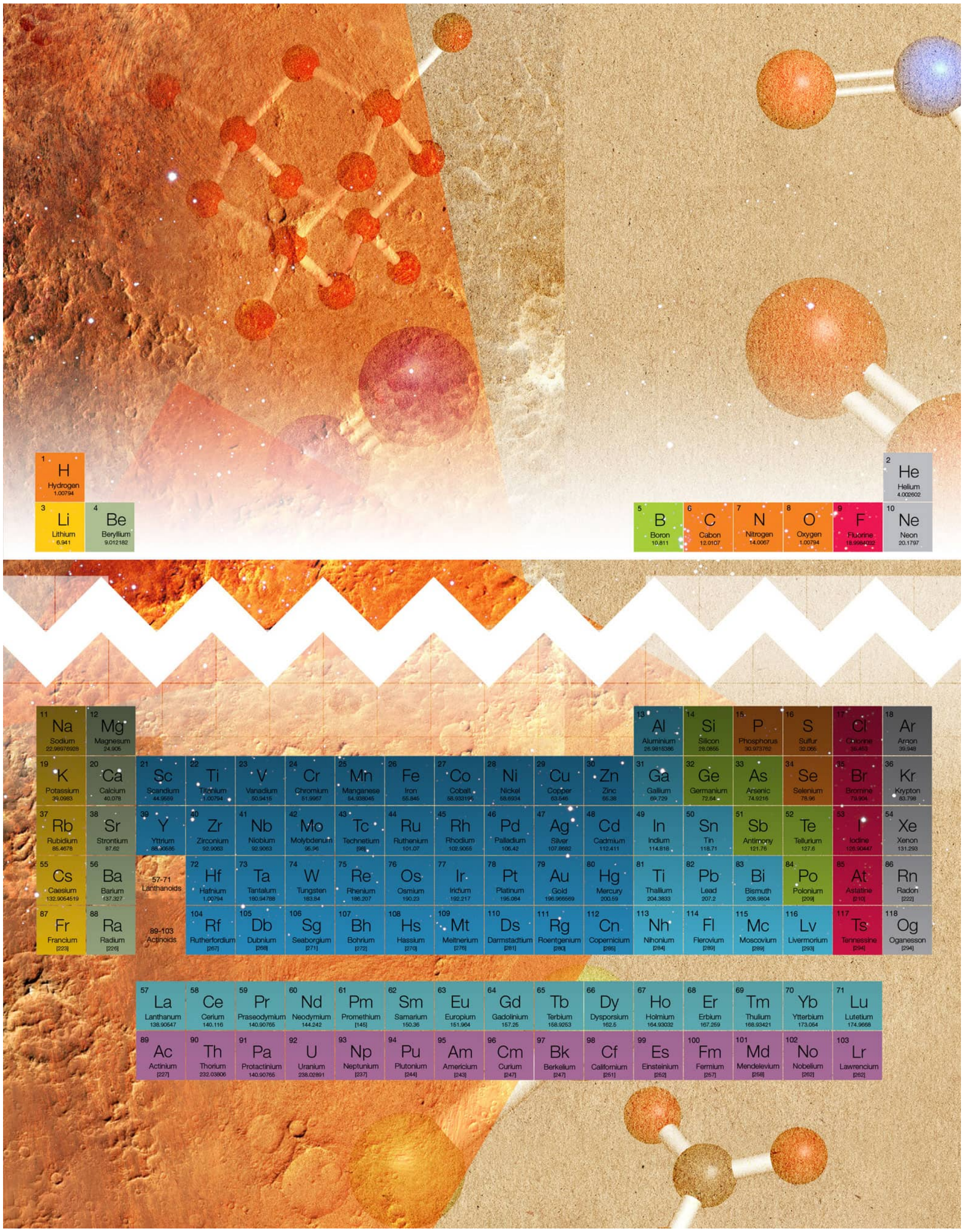
VICTOR GOLDSCHMIDT
1888–1947
Swiss crystal chemist who classified elements by their dominant geologic locations

THOM DUNNING
1943–
American chemist who explained first-row anomalies in terms of recoupled pair bonds

30-SECOND TEXT

Stephen Contakes

> ***The second-row elements are unique – they are very different from the elements that lie below them in the periodic table.***



1 H Hydrogen 1.00794																	2 He Helium 4.002602
3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Cabon 12.0107	7 N Nitrogen 14.0067	8 O Oxygen 1.00794	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
11 Na Sodium 22.98976928	12 Mg Magnesum 24.305											13 Al Aluminium 26.9815386	14 Si Silicon 28.0855	15 P Phosphorus 30.973762	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.9559	22 Ti Titanium 1.00794	23 V Vanadium 50.9415	24 Cr Chromium 51.9967	25 Mn Manganese 54.938045	26 Fe Iron 55.845	27 Co Cobalt 58.933195	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.9216	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.798
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 92.9063	41 Nb Niobium 92.9063	42 Mo Molybdenum 95.96	43 Tc Technetium [98]	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.9055	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.6	53 I Iodine 126.90447	54 Xe Xenon 131.293
55 Cs Caesium 132.9054519	56 Ba Barium 137.327	57-71 Lanthanoids	72 Hf Hafnium 1.00794	73 Ta Tantalum 180.94788	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.084	79 Au Gold 196.966569	80 Hg Mercury 200.59	81 Ti Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.9804	84 Po Polonium [209]	85 At Astatine [210]	86 Rn Radon [222]
87 Fr Francium [223]	88 Ra Radium [226]	89-103 Actinoids	104 Rf Rutherfordium [267]	105 Db Dubnium [268]	106 Sg Seaborgium [271]	107 Bh Bohrium [272]	108 Hs Hassium [270]	109 Mt Meitnerium [276]	110 Ds Darmstadtium [281]	111 Rg Roentgenium [280]	112 Cn Copernicium [285]	113 Nh Nihonium [284]	114 Fl Flerovium [289]	115 Mc Moscovium [289]	116 Lv Livermorium [293]	117 Ts Tennessine [294]	118 Og Oganesson [294]
		57 La Lanthanum 138.90547	58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.242	61 Pm Promethium [145]	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.9253	66 Dy Dysporsium 162.5	67 Ho Holmium 164.93032	68 Er Erbium 167.259	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.9668	
		89 Ac Actinium [227]	90 Th Thorium 232.03806	91 Pa Protactinium 140.90765	92 U Uranium 238.02891	93 Np Neptunium [237]	94 Pu Plutonium [244]	95 Am Americium [243]	96 Cm Curium [247]	97 Bk Berkelium [247]	98 Cf Californium [251]	99 Es Einsteinium [252]	100 Fm Fermium [257]	101 Md Mendelevium [258]	102 No Nobelium [262]	103 Lr Lawrencium [262]	

COLOUR

the 30-second chemistry

When white light passes through a prism, the light is dispersed into a spectrum of colours. The colours range from red at the lowest frequencies through orange, yellow, green, blue and finally violet at the highest. Substances that absorb all frequencies of visible light appear black, while substances that reflect all frequencies of visible light appear white. Coloured objects appear to an observer to have a colour because they absorb certain frequencies (or wavelengths) of visible light while reflecting or transmitting (allowing to pass) others. The precise colour a substance has depends on which frequencies are absorbed. In general, a substance will appear to have a colour complementary to the one absorbed (and opposite it on a colour wheel). For example, a substance that appears yellow absorbs violet light (the complement of yellow). Transition metal complexes are often deeply coloured because they strongly absorb certain frequencies of light in the visible region. These complexes often have unfilled outer-level orbitals that can receive an electron excited by specific frequencies of visible light. The colour absorbed depends on the separations between the d-orbitals, which in turn depend on the ligands attached to the metal.

3-SECOND NUCLEUS

Coloured objects appear to have colour because they absorb some frequencies of visible light and reflect or transmit the others.

3-MINUTE VALENCE

Our eyes can detect a narrow range of frequencies in the electromagnetic spectrum. This range of frequencies is responsible for all of the colours that we see. Our brains have evolved to use colour as a way to help distinguish one substance from another. Modern spectrometers, which precisely measure the frequencies absorbed by substances, are among the most powerful scientific tools in substance identification.

RELATED TOPICS

See also

CLUSTER CHEMISTRY

TRANSITION METAL CATALYSTS

3-SECOND BIOGRAPHIES

ALFRED WERNER

1866–1919

Swiss chemist who won the 1913 Nobel Prize in Chemistry for predicting the three-dimensional structure of many transition metal complexes before modern structural methods

JOHN HASBROUCK VAN VLECK

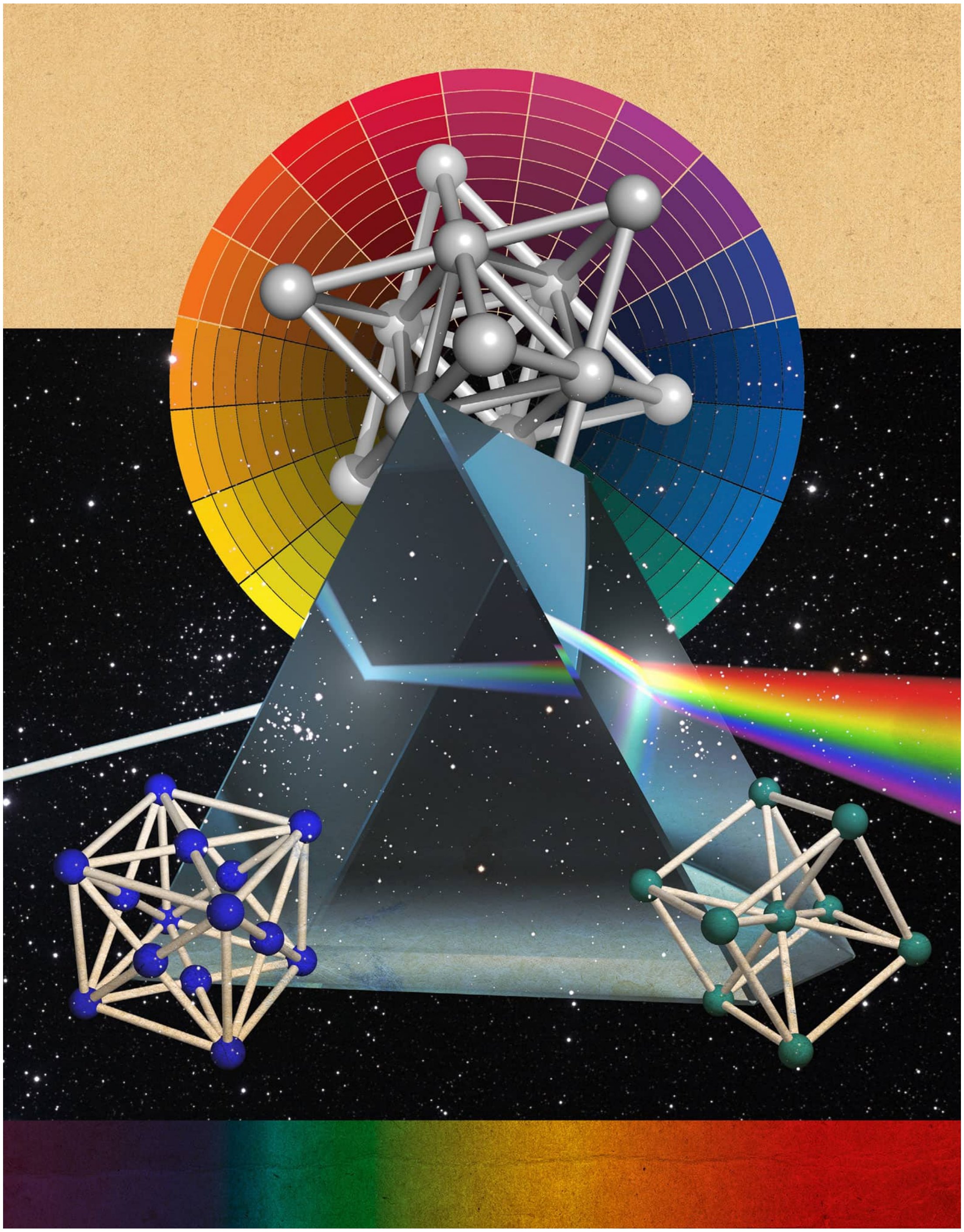
1899–1980

American physicist who won the 1977 Nobel Prize in Physics and was instrumental in the development of crystal field theory, the precursor to ligand field theory

30-SECOND TEXT

John B. Vincent

> ***White light separates into its component colours when passed through a prism.***



CLUSTER CHEMISTRY

the 30-second chemistry

In some molecules, ions and materials the electrons that hold the atoms together are shared between a group of clustered atoms. For instance, some metals and metalloids can be reduced to liquid-soluble fragments of metal while many transition metals form clusters when combined with chlorine, sulfur or carbon monoxide under the right conditions. Some of the latter clusters catalyze commercially important reactions, although none has yet found industrial use. Sometimes clusters exist as discrete units; in other cases they are linked together in a network. Solid $MoCl_2$, for example, consists of octahedral clusters of $Mo_6Cl_8^{4+}$ bridged by intervening Cl^- ions. However, when heated in the presence of additional chloride, the connections are broken to give discrete $Mo_6Cl_{14}^{2-}$ units. The ratio of electrons to atoms in a cluster affects its shape. When clusters have just enough electrons to hold together, they form as compact a shape as possible – that of the smallest polyhedron that can accommodate all the core atoms. In contrast, clusters with more electrons tend to open up and take on the shape of larger polyhedra with unoccupied vertices, giving clusters that sometimes look like a molecular nest or a web.

3-SECOND NUCLEUS

Cluster compounds form when atoms and ions share electrons and bunch together in a polyhedral shape.

3-MINUTE VALENCE

Many of the most important reactions for life on Earth are facilitated by metal-containing clusters located within proteins. For example, clusters containing iron and sulfur facilitate the movement of electrons through many biological systems, including the respiratory chain our cells use to harvest energy by converting oxygen to water. In photosynthesis plants reverse this process, harvesting even more energy from sunlight to produce oxygen at a cluster containing four manganese ions and one calcium ion.

RELATED TOPICS

See also

WHERE ELECTRONS ARE WITHIN AN ATOM

THE LEWIS MODEL FOR CHEMICAL BONDING

NANOTECHNOLOGY

3-SECOND BIOGRAPHIES

WILLIAM N. LIPSCOMB

1919–2011

American chemist who pioneered study of the structure and bonding in borane clusters

KENNETH WADE

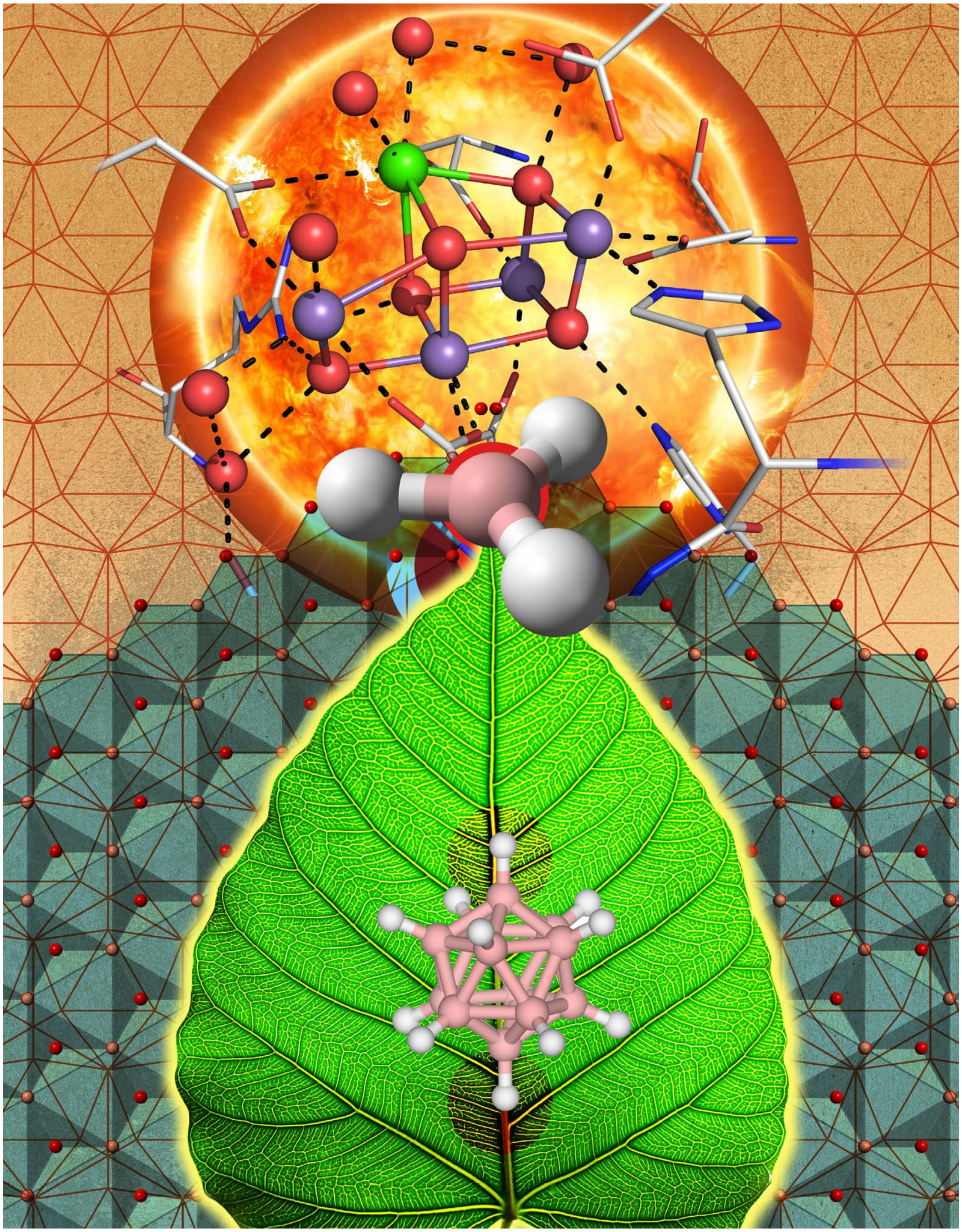
1932–2014

British chemist who developed ‘Wade’s Rules’ for predicting cluster compounds’ shapes and stability

30-SECOND TEXT

Stephen Contakes

Cluster compounds have polyhedral shapes and unique properties.



TRANSITION METAL CATALYSTS

the 30-second chemistry

Many industrial chemicals are produced by combining small organic molecules or substrates with catalysts composed of transition metals (such as cobalt, chromium or iron) which are themselves bound to small molecules called ligands. In these processes the metals speed up reactions between the substrates by acting as platforms where substrates can bind and then break into smaller molecular fragments, rearrange how their atoms are bound together and form new bonds with other substrates. The new molecules and fragments that result can then be released from the metal to yield the reaction products and regenerate the original metal complex. In fact, from the viewpoint of the metal the entire process involves a cyclic series of reactions or ‘catalytic cycle’ in which the metal complex adds reactants and spits out products. Some metal catalysts do not even need to bind their substrates, but instead function by pushing electrons around. For instance, some biological iron clusters facilitate the movement of electrons between reactants, alternatively gaining an electron from one substrate and passing it to another. Other complexes can harvest energy from light and use it to push electrons into or out of molecules, generating unstable intermediates that then quickly react with other nearby molecules.

3-SECOND NUCLEUS

Transition metal compounds facilitate chemical reactions between small molecules that bind to the metal, rearrange and get released as new products.

3-MINUTE VALENCE

Many biological and industrial processes involve transition metals acting as catalysts, substances that speed up chemical reactions without being changed themselves. Without metal catalysts we could not use the oxygen we breathe or produce enough food to sustain current population levels. Perhaps we wouldn’t even be around today, because one hypothesis about the origin of life involves catalysis by iron minerals.

RELATED TOPICS

See also

REACTION RATES & CHEMICAL KINETICS

COLOUR

AMINO ACIDS & PROTEINS

3-SECOND BIOGRAPHIES

HUMPHRY DAVY

1779–1829

British chemist who discovered that platinum was useful as a heterogeneous catalyst

KARL ZIEGLER & GIULIO NATTA

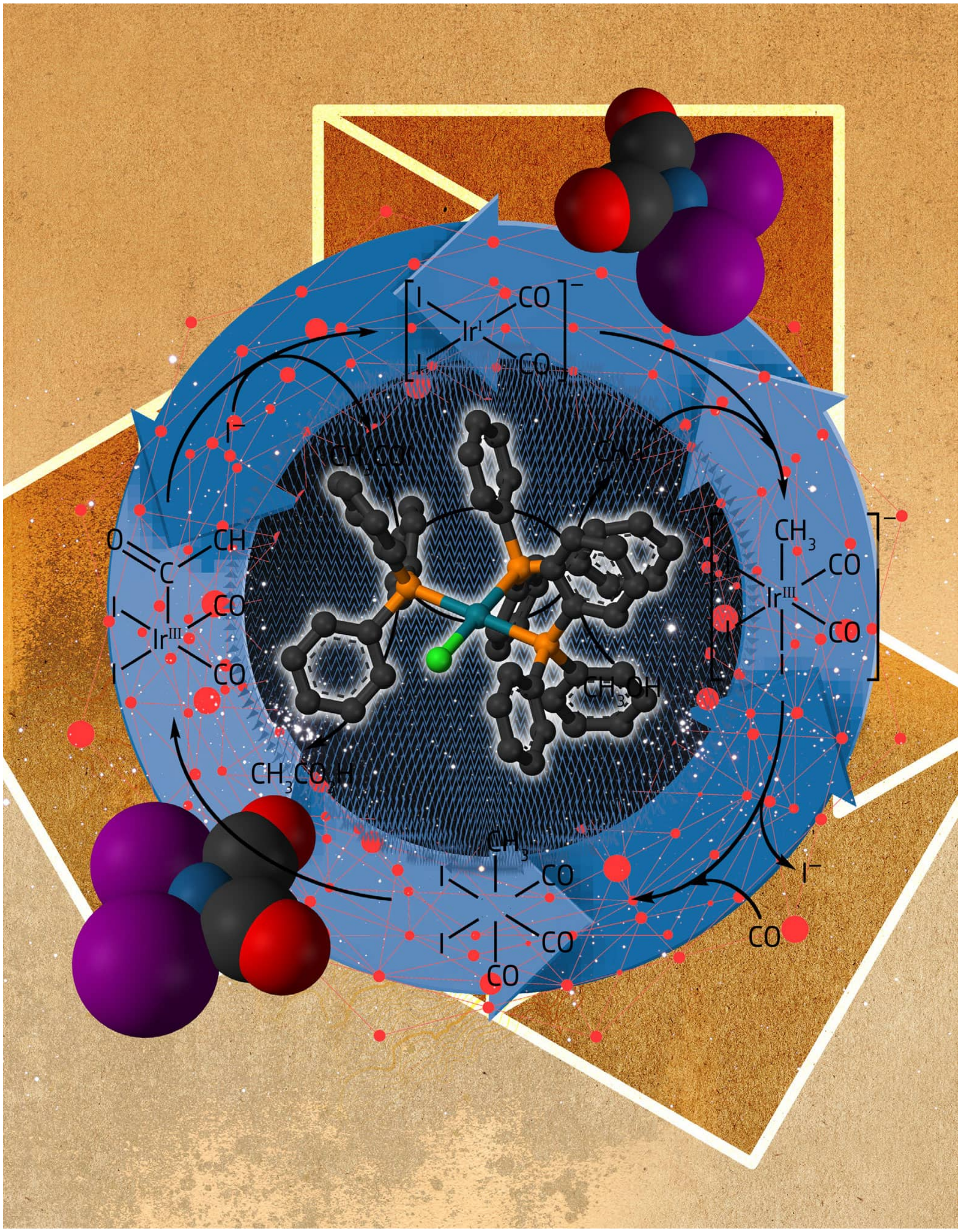
1898–1973 & 1903–79

German and Italian chemists who developed a catalyst for making commercial plastics with specific properties

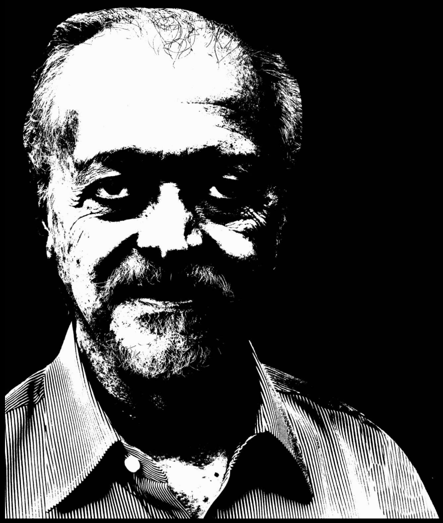
30-SECOND TEXT

Stephen Contakes

> ***Transition metal compounds can act as catalysts in chemical reactions.***


[I Ir^I CO I CO]^−
CH3I
[CH3 I CO Ir^III CO I I]^−
I^−
CO
CH3 I CO Ir I CO CO
O C CH3 I Ir^III CO CO I
I^−
CH3COI
CH3OH
CH3CO2H

MARIO J. MOLINA



Born to a Mexican family of highly educated professionals, Mario J. Molina is a Nobel Prize-winning chemist whose work on the detrimental effects of chlorofluorocarbons (CFCs) – a class of industrial chemicals commonly used in refrigeration, aerosol cans and plastic manufacturing – on the stratospheric ozone layer provides an excellent example of how fundamental research can have tremendous practical implications, greatly improving the quality of life on Earth. His research findings, published in the journal *Nature* in 1974, led to an international ban on CFC emissions into the atmosphere (the 1985 Vienna Convention and the Montreal Amendment).

Encouraged by his aunt Esther Molina, also a chemist, Mario developed a strong fascination with natural sciences, which became stronger when he observed the living organisms in a drop of pond water with his first microscope. This thrilling experience drew him to acquire chemistry sets and to build his own laboratory in an unused bathroom of his family home. Recognizing how excited he was about chemistry, Molina's parents briefly sent him to a Swiss boarding school at the age of 11 to learn German, a language then quite useful for a successful career in chemistry.

After studying chemical engineering at the Autonomous National University of Mexico, Molina spent more than two years in Germany and France strengthening his engineering and mathematics knowledge before completing his doctoral degree under the supervision of Professor George Pimentel at the University of California, Berkeley.

In 1973, Molina joined Professor Rowland's group as a postdoctoral researcher at the University of California, Irvine, where he discovered that CFCs break down in the stratosphere, producing elemental chlorine, which destroys the ozone layer that protects living things on Earth from the Sun's dangerous rays. Molina and Rowland met with fierce opposition from industrial producers of CFCs until the British Antarctic Survey detected a large and growing gap in the ozone layer in 1985. Molina, now a full-time researcher at the Jet Propulsion Laboratory at the California Institute of Technology, further demonstrated that polar ice crystals in the stratosphere amplified the destructive effect of CFCs on the ozone layer. By the end of 1985, most of the CFC-producing countries signed the Vienna Convention, which was soon amended by the Montreal Protocol, to end CFC emissions into the atmosphere. Mario Molina received the 1995 Nobel Prize in Chemistry for 'contributing to our salvation from a potential global environmental catastrophe'.

Ali O. Sezer

19 March 1943
Born in Mexico City, Mexico

1972
Receives his PhD in chemistry from the University of California, Berkeley

1973
Joins Professor Rowland’s research group at the University of California, Irvine

1974
Co-authors a paper in the journal *Nature* highlighting the damaging effects of CFCs to the ozone layer in the stratosphere

1982
Moves to the Jet Propulsion Laboratory at the California Institute of Technology to carry out experiments on the effect of CFCs on the ozone layer

1985
Demonstrates that ice crystals in the polar stratosphere amplify the ozone destruction capability of CFCs

1989
Moves to Massachusetts Institute of Technology to continue his research in atmospheric sciences

1995
Receives the Nobel Prize in Chemistry for ‘contributing to our salvation from a potential global environmental catastrophe’

2005
Moves to the University of California, San Diego, and the Centre of Atmospheric Sciences at Scripps Institution of Oceanography

2013
Receives the Presidential Award of Freedom from President Obama

CARBON: IT’S NOT JUST FOR PENCILS

the 30-second chemistry

The major common allotropes of carbon include shiny, transparent and super-hard diamond and soft black graphite. Graphene (isolated in 2010 by Andre Geim) is a one-atom-thick sheet of carbon atoms densely packed into a chicken-wire-shaped structure. Graphite is many sheets of these graphene layers stacked together. Since these layers are only weakly bound to each other they are readily rubbed off onto paper and therefore used in pencils. In 1985, Harry Kroto discovered a new form of carbon (C_{60}) when he and his colleagues Richard Smalley and Robert Curl simulated chemical reactions that might occur in the atmosphere of red giant stars. C_{60} is one of a larger family of carbon forms known as fullerenes. Fullerenes are molecules in the form of hollow spheres, ellipsoids or cylinders. Since C_{60} looks much like the famous geodesic domes of R. Buckminster Fuller, it was dubbed ‘buckminsterfullerene’. Spherical or ellipsoidal fullerenes are fondly known as ‘buckyballs’. Graphene layers can also wrap around and form cylindrical tubes called ‘nanotubes’ or ‘buckytubes’. Fullerenes are flexible, strong and stable, with an ever-increasing number of practical uses – for example, as catalysts, in energy generation and storage devices, as MRI and X-ray contrast agents and in flexible electronics.

3-SECOND NUCLEUS

Carbon allotropes include diamond, graphite and fullerenes. Fullerenes, named after Buckminster Fuller, come in the form of hollow spheroids (‘buckyballs’) and nanotubes (‘buckytubes’).

3-MINUTE VALENCE

Carbon is a unique element. Not only is it the central element on which all life is based, but in its elemental state it also exists in several fascinating and useful allotropes (different molecular forms of a given element).

RELATED TOPICS

See also

BONDING ATOMS TOGETHER

THE LEWIS MODEL FOR CHEMICAL BONDING

THE FORCES THAT HOLD MATTER TOGETHER

3-SECOND BIOGRAPHIES

R. BUCKMINSTER FULLER

1895–1983

American inventor, architect and author who popularized the geodesic dome

HARRY KROTO

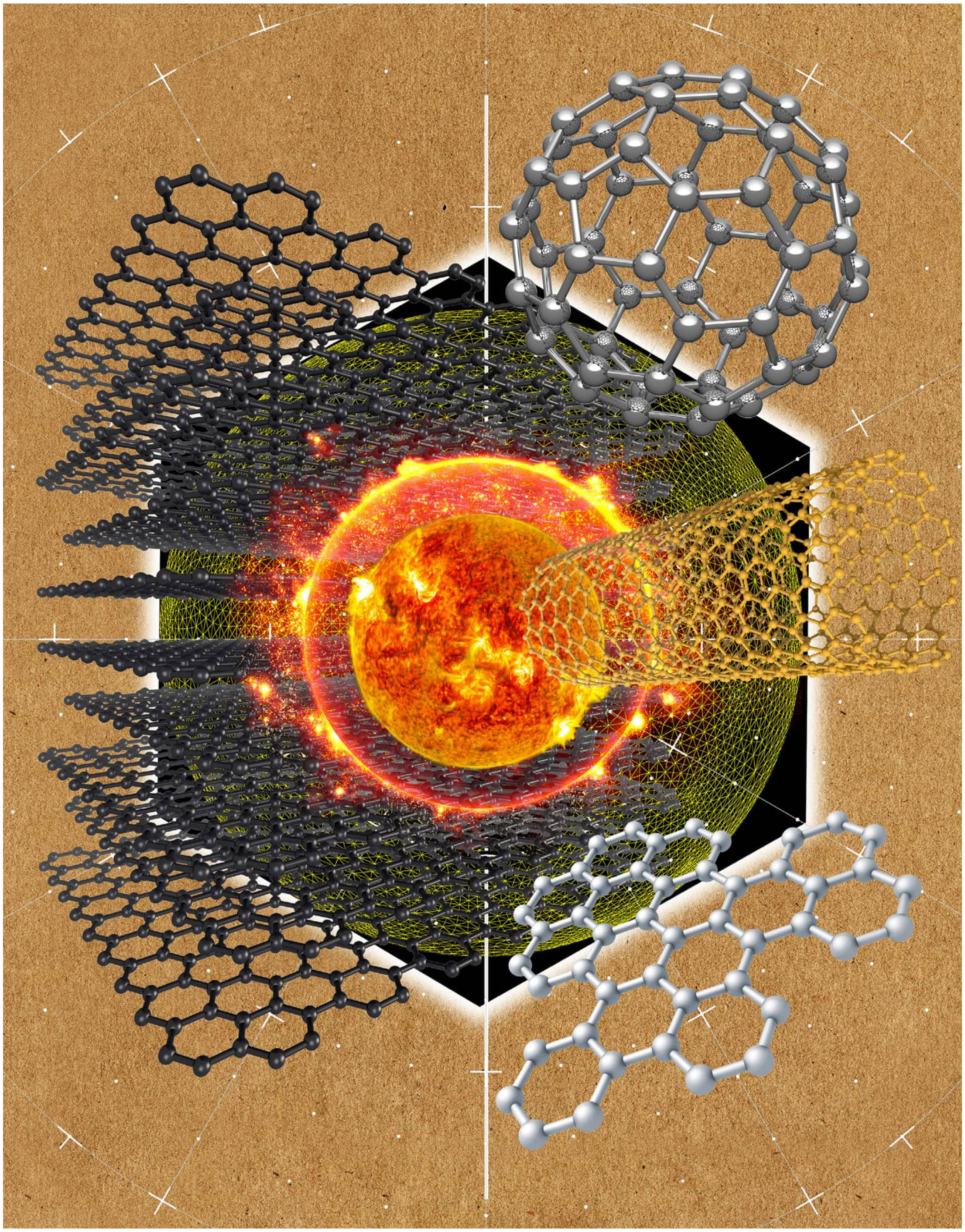
1939–2016

English chemist, winner of the 1996 Nobel Prize in Chemistry for discovering fullerenes

30-SECOND TEXT

Glen E. Rodgers

> ***Carbon comes in many forms including familiar graphite and new forms such as graphene.***



NANOTECHNOLOGY

the 30-second chemistry

Nanotechnology is the study of matter where the basic structure has at least one of its dimensions less than or equal to 100 nanometres (1 nanometre is one-billionth of a metre.) This would therefore include almost all of chemistry, since most molecules meet such a requirement. However, what is different about nanochemistry is that it uses bottom-up molecular routes to reach the larger domains, coupling molecule to molecule to make larger structures. This is in contrast to the traditional top-down approaches in which large structures are cut into smaller pieces. The bottom-up route permits the precision of chemical synthesis to affect larger materials properties. As an example of this bottom-up approach, different molecules that are about 0.1 nanometre in size can be attached together using synthetic chemical techniques to make tiny structures such as nanocars. A single nanocar is 2 nm x 3 nm in size with four wheels, fully rotating axles, chassis and light-activated motors. These nanocars may be able to perform work, such as bringing in molecules or atoms through selective voltage pulse commands to further construct larger entities or to deliver drugs to cells. Molecularly built nanocars are so small that 25,000 of them lined up end to end would only span a distance the diameter of a human hair.

3-SECOND NUCLEUS

Nanotechnology is the science of building tiny structures from the molecular size up.

3-MINUTE VALENCE

Nanochemistry can also be used to construct nanoparticles of precise size and shape with unique catalytic properties for processes such as converting hydrogen and oxygen to water in a fuel cell to generate electricity. Other nanoparticles can be used to split water, using sunlight, to the requisite hydrogen and oxygen needed by the fuel cell. Combined, such a system could potentially supply the world’s energy needs in a far cleaner manner than using fossil fuels – as we do today.

RELATED TOPICS

See also

CLUSTER CHEMISTRY

3-SECOND BIOGRAPHIES

RICHARD FEYNMAN

1918–88

American physicist who first suggested building molecular structures one atom at a time; he won the 1965 Nobel Prize in Physics

RICHARD SMALLEY

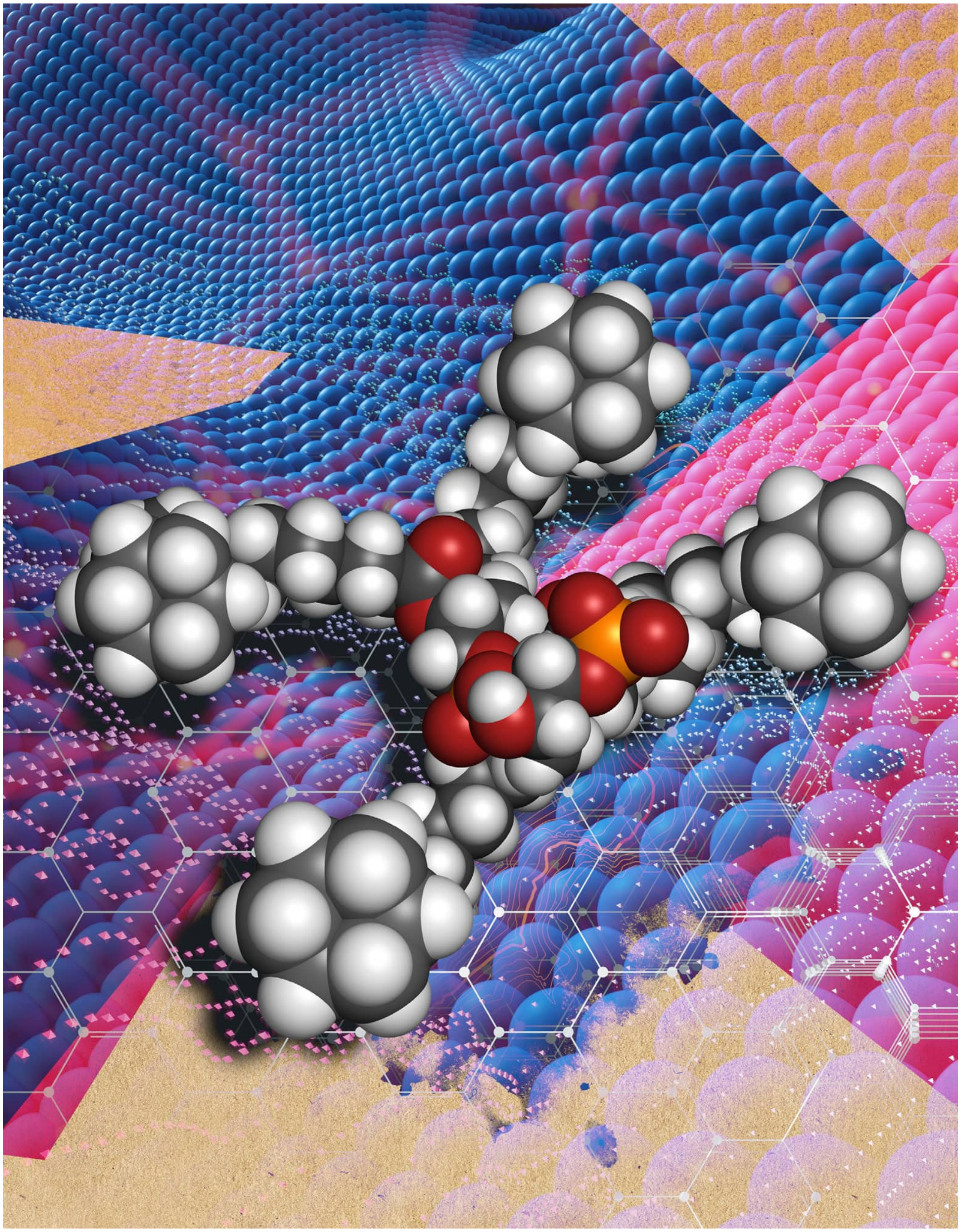
1943–2005

American chemist and foundational figure in nanotechnology who was awarded a share of the 1996 Nobel Prize in Chemistry

30-SECOND TEXT

James Tour

> ***Molecular machines such as nanocars have the potential to perform vital tasks in medicine and energy supply.***



ORGANIC CHEMISTRY

ORGANIC CHEMISTRY

GLOSSARY

aldehydes A family of organic compounds containing a terminal C=O functional group.

aldosterone A hormone responsible for the regulation of sodium and potassium.

alkaloids Organic bases found in plants; often poisonous.

amines Organic compounds containing a nitrogen atom bonded to one or more carbon atoms.

aromatic ring A flat, ring-shaped chain of carbon atoms containing alternating single and double bonds.

carbonyl The C=O functional group.

carboxylic acid An organic compound containing the–COOH functional group.

covalent bond The joining of atoms by the sharing of one or more electrons.

cross-linked structure A common structure in polymers in which long chain-like molecules form bonds between the neighbouring chains.

cyclic structures Any structure containing one or more rings of atoms bonded together.

distillation A process by which a mixture of compounds with differing boiling points can be separated by heating the mixture and recondensing the gases that vaporize.

ester An organic compound containing the –COO –functional group.

functional group A characteristic atom or group of atoms present in a family of organic compounds that give the compounds certain characteristics.

homologous series A series of organic compounds that differ in length by one carbon atom.

hydrocarbon An organic compound containing only carbon and hydrogen.

hydroxyl group An –OH group characteristic of the organic family of alcohols.

isomers Two molecules with the same chemical formula but different structures.

ketone A family of organic compounds that contain the C=O functional group sandwiched between two other carbon atoms.

linear structure A chemical structure in which the atoms that compose the structure fall on a continuous line.

macromolecule A very large molecule, such as a polymer, typically containing thousands of atoms.

molar mass The mass of one mole of an element or compound.

monomer Repeating unit in a polymer.

organic compounds Compounds that contain carbon bonded to hydrogen, nitrogen, oxygen or sulfur.

paraffin wax A soft, flammable solid composed of a mix of long chain hydrocarbons.

progesterone A female sex hormone with the formula $C_{21}H_{30}O_2$ that plays a role in the menstrual cycle and pregnancy.

testosterone A male sex hormone with the formula $C_{19}H_{28}O_2$.

ORGANIC CHEMISTRY & VITALISM

the 30-second chemistry

Early chemists divided compounds into two distinct types: organic and inorganic. Organic compounds were isolated from living organisms and tended to be quite fragile. For example, sugar is an organic compound (isolated from sugar cane or the sugar beet). If you heat sugar in a pan, it quickly decomposes. Inorganic compounds came from the Earth and tended to be more durable. For example, table salt is an inorganic compound (isolated from salt mines or from oceans). If you heat salt in a pan, the salt does not decompose – you simply get hot salt. Furthering the divide, early chemists were able to synthesize inorganic compounds in the laboratory, but not organic compounds. This divide fitted well with an eighteenth-century belief called vitalism, which suggested that all living organisms contained a vital force that separated them from non-living things. The vital force allowed living organisms to synthesize organic compounds, but a chemist could not synthesize an organic compound in a beaker because no vital force was present. Vitalism died a slow death in the middle of the nineteenth century because chemists began to synthesize organic compounds from inorganic ones. Today, hundreds of thousands of organic compounds have been synthesized, including many compounds central to life itself.

3-SECOND NUCLEUS

Vitalism, the belief that living things contained some unique force not contained in non-living things, was proved false and abandoned in the nineteenth century.

3-MINUTE VALENCE

The downfall of vitalism is significant because it meant that living things could be studied from a chemical point of view. The reactions that happen in living organisms are not qualitatively different from those that happen outside of living organisms. The revolution that has occurred in biology over the last half-century is largely due to understanding life from a molecular perspective.

RELATED TOPICS

See also
HYDROCARBONS

ALCOHOLS

ALDEHYDES, KETONES & ESTERS

3-SECOND BIOGRAPHIES

GEORG ERNST STAHL

1659–1734

German chemist and advocate of vitalism

FREDERICH WÖHLER

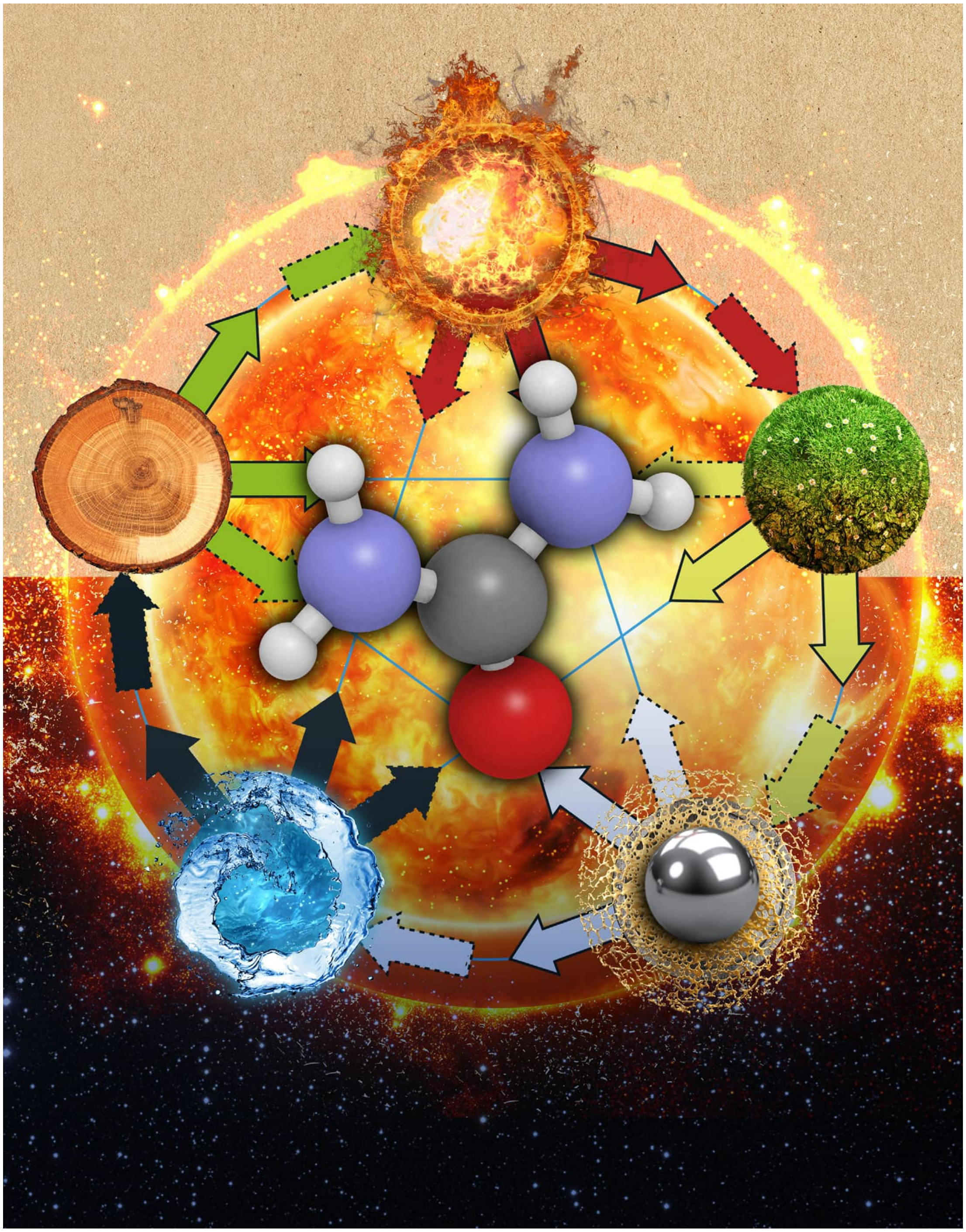
1800–82

German chemist who, in 1828, synthesized urea, an organic compound, from inorganic starting materials

30-SECOND TEXT

Nivaldo Tro

Urea (centre) was one of the first organic compounds synthesized from inorganic compounds.



HYDROCARBONS

the 30-second chemistry

Hydrocarbons, the principle constituents of petroleum and natural gas, are organic compounds of hydrogen and carbon. Because carbon can bond, not only to other atoms like hydrogen, but also to itself (a process called ‘catenation’), there are many naturally occurring and synthetically produced hydrocarbon compounds. Hydrocarbons have had an unmatched influence on the economic, social and environmental development of modern society. They are a convenient source of energy and the starting materials to make many common products such as polymers, textiles and pharmaceuticals. Hydrocarbons in all physical forms find their way into our lives every day – in gas (natural gas), liquid (petrol) and solid (paraffin wax) forms. They are, in general, classified as ‘saturated’ (only single covalent bonds are present), ‘unsaturated’ (at least one double or triple covalent bond exists between carbon atoms) or ‘aromatic’ (at least one aromatic ring is present). Long chains of hydrocarbons can form linear, cross-linked or cyclic structures, with the number of carbon atoms ranging from one (methane) to thousands. Hydrocarbons have high potential energy, which can be released upon combustion – generating energy convenient for applications such as transportation and heating.

3-SECOND NUCLEUS

Petrol, a potpourri of many hydrocarbons, packs a large amount of energy in a small volume, which makes it a convenient source of fuel for transportation.

3-MINUTE VALENCE

Hydrocarbon-based ‘fossil fuels’ provide more than 80 per cent of the world’s energy – mainly as coal, petroleum and natural gas. They are the most convenient and economical sources of energy for most practical applications. However, hydrocarbons are non-renewable, with limited resources globally. The search for alternative and renewable sources of energy will reduce the global dependence on fossil fuels and help reduce their adverse impact on the environment.

RELATED TOPICS

See also

CARBON: IT’S NOT JUST FOR PENCILS

ORGANIC CHEMISTRY & VITALISM

3-SECOND BIOGRAPHIES

JAMES YOUNG

1811–83

Scottish chemist known as the father of the petrochemical industry who first distilled paraffin, a saturated hydrocarbon, from petroleum

EDWIN L. DRAKE

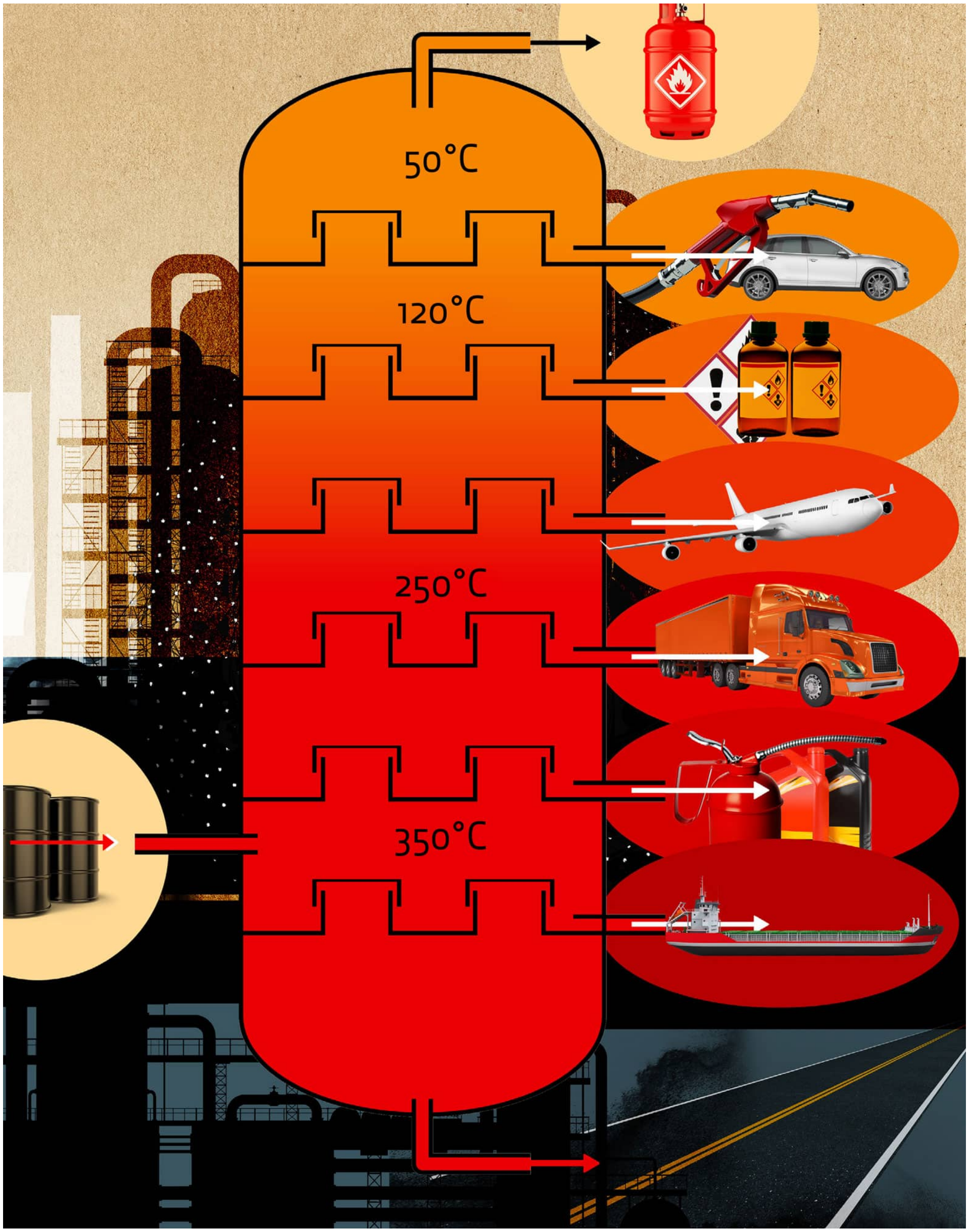
1819–80

An American railroad conductor credited with drilling the first modern oil well, near Titusville, Pennsylvania

30-SECOND TEXT

Ali O. Sezer

> ***Petroleum is separated into its hydrocarbon components due to the differences in the boiling points of those components.***


50°C
120°C
250°C
350°C

ALCOHOLS

the 30-second chemistry

Isopropanol (C_3H_7OH), a popular antiseptic known as rubbing alcohol, and ethanol (C_2H_5OH), the intoxicating component of alcoholic drinks, belong to a very important class of organic compounds called alcohols. Alcohols contain the hydroxyl (–OH) functional group. The smaller alcohols are clear, volatile and flammable liquids with a biting odour. The alcohol family contains a homologous series of compounds from hydrocarbons in which a hydrogen atom is replaced by an –OH group. Methanol, ethanol and propanol are the first three members of this series. The –OH functional group is directly bonded to a carbon atom, which is also connected to one (primary alcohol), two (secondary alcohol) or three (tertiary alcohol) other carbon atoms. Ethanol and isopropanol are examples of primary and secondary alcohols, respectively. The –OH group makes alcohols highly polar, and the smaller ones are all miscible with water – meaning that they form homogenous solutions with water in all proportions. Water-solubility decreases noticeably as the number of carbon atoms (molecular mass) increases. Today alcohols find a wide range of uses, from perfume-making through food and pharmaceutical products to medical applications.

3-SECOND NUCLEUS

Beyond being the intoxicating component of alcoholic drinks, alcohols have an important place in organic chemistry – with many applications benefitting human life.

3-MINUTE VALENCE

Polyalcohols, also known as sugar alcohols, are alcohols with more than one –OH group in their molecular structure. These white, water-soluble solid compounds are industrially important – they are used as thickeners and sweeteners. Sorbitol, erythritol, xylitol and maltitol are popular polyalcohols commonly used in hard candy and artificial sweeteners. They do not get completely absorbed into the bloodstream so they are incapable of rapidly raising blood sugar.

RELATED TOPICS

See also

OPPOSITES ATTRACT

3-SECOND BIOGRAPHIES

JOHANN TOBIAS LOWITZ

1757–1804

German-born Russian chemist who first obtained pure ethanol by filtering distilled ethanol through activated carbon

ARCHIBALD SCOTT COUPER

1831–92

Scottish chemist who first published the structural formula of ethanol, one of the first structural formulas determined

30-SECOND TEXT

Ali O. Sezer

Alcohols are a common family of organic compounds that includes substances such as ethanol (the alcohol in alcoholic beverages).

ALDEHYDES, KETONES & ESTERS

the 30-second chemistry

The pleasant odour and flavour of fresh almonds and peppermint are mainly due to benzaldehyde and menthone, two naturally occurring compounds whose molecule contains the carbonyl functional group (–C=O). Benzaldehyde is an example of a family of organic compounds called aldehydes. In an aldehyde, the –C=O group is at the end of a carbon chain. Menthone is an example of a family of organic compounds called ketones. In a ketone, the carbonyl group is in the middle of the carbon chain. Another common family of organic compounds is the ester family. In an ester, an oxygen atom interrupts the bonding of the carbonyl group to the carbon chain ($–CO_2C–$). Benzyl acetate, a component in the smell of strawberries, pears and jasmine, is an ester. Small aldehydes and ketones (those with low molar masses), such as formaldehyde (an important industrial solvent) and acetone (nail-polish remover), have a strongly pungent odour. But aldehydes with increasing molar masses generally have more pleasant and fruity odours. Aldehydes, ketones and esters are commonly found naturally and manufactured industrially as odours and flavours in food and pharmaceutical products. Many solvents used in adhesives, paints, perfumes, plastics and fabrics also contain aldehydes, ketones and esters.

3-SECOND NUCLEUS

Aldehydes, ketones and esters are naturally occurring organic compounds responsible for the pleasant odours and flavours of many natural and synthetic products.

3-MINUTE VALENCE

Aldehydes, ketones and esters are found abundantly in living organisms. Humans and animals store energy as esters known as fats and oils. Testosterone and progesterone (the male and female sex hormones, respectively), aldosterone (which regulates blood sodium level) and pheromone (which is released by animals to trigger a social response) are all ketones. Retinal (retinaldehyde) is an aldehyde forming the basis of vision. Acetaldehyde causes the ‘hangover’ feeling after alcohol is metabolized in the liver.

RELATED TOPICS

See also

ALCOHOLS

CARBOXYLIC ACIDS & AMINES

3-SECOND BIOGRAPHIES

LEOPOLD GMELIN

1788–1853

German chemist who first introduced the terms ‘ester’ and ‘ketone’

JUSTUS VON LIEBIG

1803–73

German chemist considered the father of organic chemistry, who first used the term ‘aldehyde’

30-SECOND TEXT

Ali O. Sezer

> ***Many of the odours you smell every day come from the naturally occurring families of aldehydes, ketones and esters.***


OH
CH3
CH3
O
CH3
OH
HO

CARBOXYLIC ACIDS & AMINES

the 30-second chemistry

Carboxylic acids and amines are important and familiar families of organic compounds. Carboxylic acids are organic acids and can be identified by their –COOH functional group. Like all acids, carboxylic acids taste sour. Acetic acid, the active component of vinegar, is a carboxylic acid. The word vinegar originates from the French for wine (*vin)* and sour (*aigre)*. When wine is left exposed to air, the ethanol oxidizes to form carboxylic acid, ruining the wine. Citric acid is another carboxylic acid; it is responsible for the sour taste of lemons and limes. Amines are organic bases and contain a nitrogen atom bonded to one or more carbon atoms. Many amines have an unpleasant odour. When living things die, their proteins are broken down into amines, which evaporate into the air. For example, the smell of rotting fish is due to trimethylamine, and that of decaying animal flesh to caderverine, both foul-smelling amines. Some plant-based amines, known as alkaloids, have the ability to alter sensory pathways. Caffeine, nicotine and cocaine are all alkaloids that stimulate the central nervous system, resulting in feelings of increased alertness and energy. Other alkaloids, such as morphine and codeine, have the opposite effect: they depress the central nervous system. Morphine is a powerful depressant used to treat extreme pain.

3-SECOND NUCLEUS

Carboxylic acids and amines are naturally occurring acids and bases, respectively.

3-MINUTE VALENCE

The reaction between a carboxylic acid and an amine is an acid-base reaction that links the two molecules together and forms water as a byproduct. This reaction is important in biochemistry because it is responsible for the linking of amino acids – which are molecules that have a carboxylic acid group on one side and an amine group on the other – to form proteins, the workhorse molecules in living organisms.

RELATED TOPICS

See also

ORGANIC CHEMISTRY & VITALISM

ALCOHOLS

ALDEHYDES, KETONES & ESTERS

3-SECOND BIOGRAPHY

HERMANN KOLBE

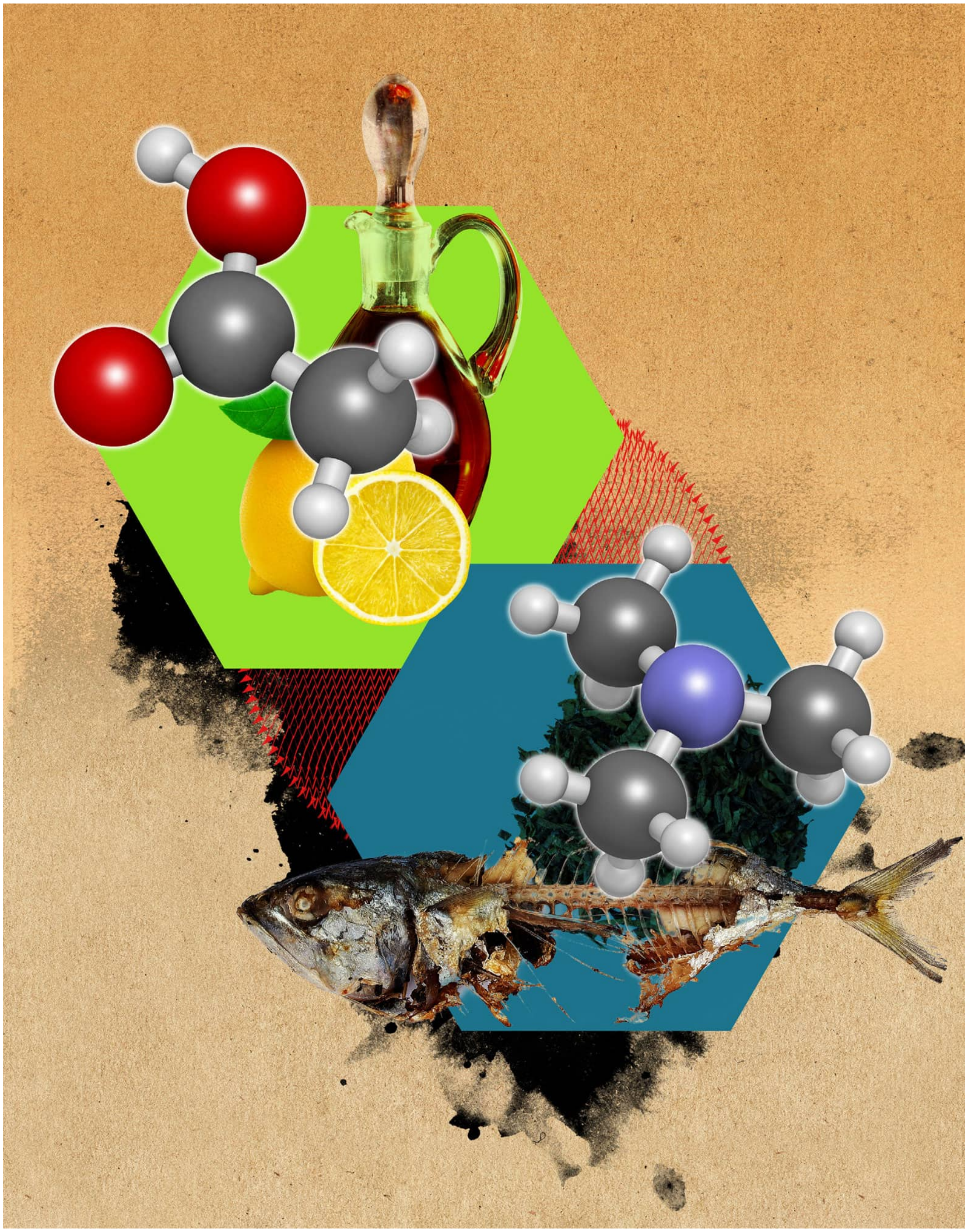
1818–84

German chemist who greatly contributed to the development of organic chemistry and was the first to synthesize acetic acid

30-SECOND TEXT

Nivaldo Tro

Acetic acid (top) is responsible for the smell of vinegar. Trimethylamine (bottom) is responsible for the foul smell of rotten fish.



FRIEDRICH WÖHLER

Friedrich Wöhler is known not only for his pioneering research in chemistry but also for his model teaching laboratories that revolutionized how experimental chemistry is taught around the world today. His interest in chemistry and mineralogy developed in the early years of his education in Frankfurt, Germany. Although Wöhler went on to receive a medical degree from the University of Heidelberg, his real interest was always in chemistry. Leopold Gmelin, one of the best-known chemists of the nineteenth century, was Wöhler's instructor at Heidelberg. He quickly realized that Wöhler was too advanced for his courses and sent him to study with Jons Jacob Berzelius, the world-famous Swedish chemist who is considered to be one of the fathers of modern chemistry.

Wöhler spent a year studying mineralogy with Berzelius. He not only received the best available education but also developed a life-long friendship with his tutor. Wöhler later translated much of Berzelius's work into German, including his well-known *Textbook of Chemistry*. Wöhler himself wrote a number of textbooks on organic and inorganic chemistry later in his career, including *Outlines of Organic Chemistry* in 1840.

Wöhler returned to Germany in 1825, and took a position at the newly founded Berlin Gewerbeschule (trade school), where he conducted ground-breaking research that won him international fame. In 1827 he isolated pure aluminium for the first time from its compounds. The following year, he announced his second discovery in a famous letter to Berzelius, where he explained how he had synthetically isolated urea in the laboratory without the need of a living kidney, and that this compound had the same chemical composition as another compound called ammonium cyanate. This discovery was significant, as researchers then believed that a 'vital force' in living things was necessary to make organic compounds.

Two years after Wöhler's letter, Berzelius explained these discoveries and coined the term isomerism, a tremendously important concept in modern chemistry. From 1832 until his death in 1882, Wöhler served as a chemistry professor at the University of Göttingen, where he developed, in parallel with Justus Freiherr von Liebig at the University of Giessen, today's widely adopted laboratory-based methods of science teaching. Wöhler is also credited with having inaugurated the tradition of establishing scientific research groups in which students can also carry out research activities.

Ali O. Sezer

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31 July 1800
Born in Eschersheim, Germany

1823
Receives a medical degree from the University of Heidelberg, Germany

1827
Prepares the first pure sample of aluminium from its compounds

1828
Discovers how to make urea synthetically in the laboratory and isolates the elements beryllium and yttrium

1832
Starts working as a chemistry professor at the University of Göttingen, Germany

1834
Elected foreign member of the Royal Swedish Academy of Sciences

1854
Elected foreign member of the Royal Society of London

1855
Elected member of the Royal Academy of Berlin

1862
Produces calcium carbide and acetylene gas

1872
Awarded the Copley Medal by the Royal Society of London

23 September 1882
Dies in Göttingen, Germany

CHEMISTRY COPYING NATURE

the 30-second chemistry

The Pacific yew tree is rather unremarkable. It grows in the Pacific Northwest to heights of about 10–15 m (30–50 ft) and has flat, green needles and red berries. However, its bark contains the miracle drug Taxol, now used to treat ovarian, lung, breast and colon cancer. The biological action of the yew tree has been known since Greek times, and Native Americans used the tree for medicinal purposes. Because of this known history, researchers in the 1960s included the tree in large-scale screening for cancer-fighting agents. The positive results eventually led researchers to isolate the active ingredient Taxol. But the amount of Taxol needed to treat a single cancer patient required the harvesting of several trees that were around 100 years old, creating environmental problems. As often happens with natural products, however, researchers came up with another way to obtain the compound: Taxol is now synthesized from a precursor found in the needles of the European yew tree. Because the trees don't have to be cut down to harvest the needles, this route is sustainable. Today, millions of cancer patients have benefitted from this natural product. The story of Taxol is representative of the field of natural products research, an active area that produces many novel and useful compounds.

3-SECOND NUCLEUS

Plants, animals and microbes are sources of valuable and often healing chemical compounds.

3-MINUTE VALENCE

Natural products researchers scour living organisms for the useful chemicals they might contain. For example, penicillin (an antibiotic) was extracted from microbes, and the early form of aspirin was extracted from the bark of the willow tree. Often chemists later find ways to synthesize these compounds in the laboratory, but the myriad of compounds in nature often shows us the way.

30-SECOND TEXT

Nivaldo Tro

RELATED TOPICS

See also

ORGANIC CHEMISTRY & VITALISM

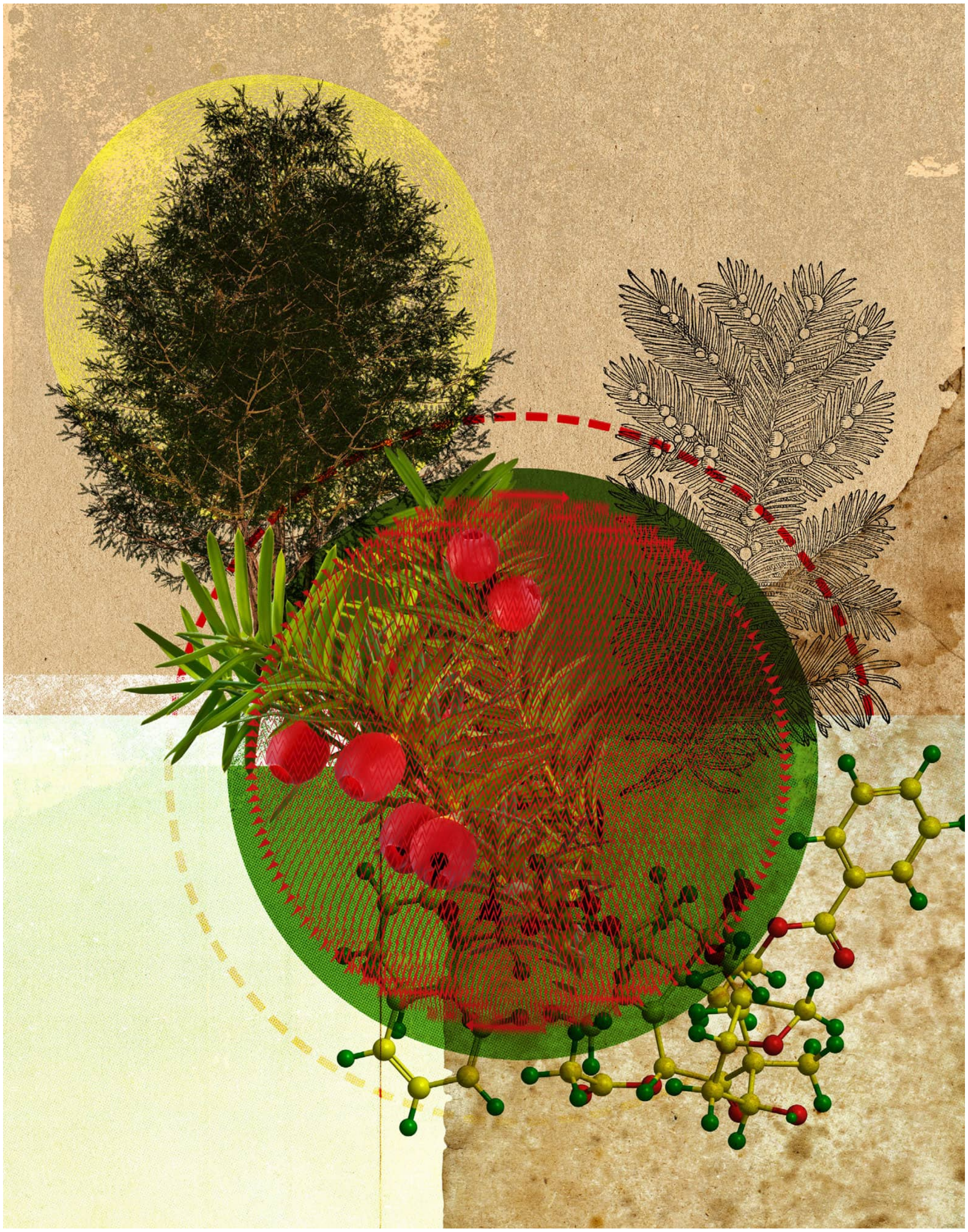
BIOTECH DRUG SYNTHESIS

3-SECOND BIOGRAPHIES

MONROE ELIOT WALL
1916–2002
American chemist credited with the co-discovery of Taxol

MANSUKH C. WANI
1925–
Indian American chemist credited with the co-discovery of Taxol

The yew tree is the source of the cancer-fighting agent Taxol.



POLYMERS

the 30-second chemistry

Polymers permeate most of human life. It is hard to imagine society without them, given the significant role natural and synthetic polymers play – from medicine to food packaging, and from clothing to housewares. German chemist Hermann Staudinger first demonstrated the existence of macromolecules (polymers) as large, chain-like molecules of smaller repeating units called monomers. Humans have known natural polymers, such as cotton and rubber, for thousands of years. But their chemical structure was long subject to debate until Staudinger proved the macromolecular structure of natural rubber – a Nobel Prize-winning discovery in 1953. The term polymer is derived from the Greek *poly meros*, meaning many parts. Many molecules can act as monomers, making it possible to create a wide range of polymeric materials with desired characteristics. Polyethylene, for example – one of the most common plastic materials found in packaging bags and bottles – is a chain-like molecule consisting of an ethylene monomer backbone. Polymers can have high molecular mass as monomers can link in a variety of ways to grow into very large molecules. Some are light, hard, strong and flexible; others exhibit unique chemical, thermal, electrical and optical characteristics.

3-SECOND NUCLEUS

Polymers, chain-like macromolecules consisting of chemically linked repeating units (monomers), play an unmatched role providing convenience in many aspects of human life.

3-MINUTE VALENCE

Polymers are in general known as electrical insulators. However, some organic polymers – consisting of monomer units linked by alternating single and double bonds in the carbon backbone – exhibit a low, inherent electrical conductivity, which can significantly be improved by chemically mixing in electron-donating and/or -receiving agents, a process called doping. Doped polymers, such as organic light emitting diodes (OLED), have revolutionized the electronics industry.

RELATED TOPICS

See also

THE LEWIS MODEL FOR CHEMICAL BONDING

3-SECOND BIOGRAPHIES

HERMANN STAUDINGER

1881–1965

German chemist who won the 1953 Nobel Prize in Chemistry for discovering the macromolecular structure of natural rubber

HIDEKI SHIRAKAWA

1936–

Japanese chemist who won the 2000 Nobel Prize in Chemistry for co-discovering the existence of conductive polymers

30-SECOND TEXT

Ali O. Sezer

> ***Polymers are chain-like molecules that compose a range of substances such as plastics.***


8:12 AM
May 22nd
10 AM
Hand in Report and send memo
Phone
Explore
Tools
Applications

BIOCHEMISTRY

BIOCHEMISTRY

GLOSSARY

acid group A functional group consisting of –COOH.

adenosine triphosphate A biomolecule with the formula $C_{10}H_{16}N_5O_{13}P_3$ that is used as a main vessel for energy transport in living organisms.

alkanes Hydrocarbons with the general formula C_nH_{2n+2}.

amine group In an amino acid, the $-NH_2$ group.

amino acids The individual units that, when linked together in a specified order, form proteins. Amino acids have a central carbon atom, an amine group, an acid group and a side chain (that varies in structure from one amino acid to another).

base pair The two parts of nucleic acids that uniquely pair together to form the double helix in DNA and allow precise copying. In DNA, adenine pairs with thymine and guanine pairs with cytosine.

carboxylic acid group The –COOH group in organic and biochemical compounds. The group is polar and acidic.

cellulose A complex carbohydrate composed of repeating glucose units. Cellulose is the main structural material in plants.

DNA Deoxyribonucleic acid, a biomolecule composed of repeating units (called nucleotides) responsible for carrying the genetic information in all known living organisms.

disaccharides A class of sugars composed of two monosaccharides linked together.

esters A class of organic compounds consisting of a –COO– group sandwiched between two or more carbon atoms.

flash photolysis A technique to study light-activated chemical reactions in which a flash of light is used to initiate the chemical event which is then monitored as a function of time.

genome The complete set of genetic material of an organism.

glucose A carbohydrate with the formula $C_6H_{12}O_6$ that circulates in the blood of animals and humans.

hormones Biochemical compounds that are transported in the blood to targets where they stimulate and regulate biochemical processes.

modular polymers Polymers that can be built up one unit (or monomer) at a time.

monosaccharides A carbohydrate composed of three to eight carbon atoms and one aldehyde or ketone group.

nonpolar A substance composed of molecules with uniform charge distribution. Nonpolar substances generally do not mix well with water.

nucleotide The individual unit that, when linked with other nucleotides, forms a nucleic acid (such as DNA). Each nucleotide contains a phosphate group, a sugar and a base.

polar A substance composed of molecules with an asymmetric charge distribution.

polynucleotide A chain of nucleotides bonded together found in hereditary molecules such as DNA and RNA.

recombinant DNA Synthetic DNA that contains genetic material from different sources.

ribonucleotide The monomer that, when linked to other ribonucleotides, forms RNA.

sucrose A carbohydrate with the formula $C_{12}H_{22}O_{11}$.

triglyceride A type of fat that has a three-carbon backbone with three fatty acids attached (one to each carbon atom).

CARBOHYDRATES

the 30-second chemistry

Carbohydrates are so named because their general formula is a multiple of one carbon atom and one water molecule, $(CH_2O)_n$. Structurally, the carbon atoms are arranged in a ring (that can interconvert into a straight chain) and have multiple hydroxyl (OH) groups attached, making simple carbohydrates polar and therefore soluble in water. The ability to dissolve in water is important to one of the main functions of carbohydrates: storing and transporting energy for living organisms. The carbohydrate glucose ($C_6H_{12}O_6$) is typical. It must be easily transported in the blood to places in the body where energy is being used. Carbohydrates such as glucose (which are also called monosaccharides, meaning one sugar) can link together to form disaccharides, such as sucrose ($C_{12}H_{22}O_{11}$), which is table sugar. They can also link together to form long, chain-like molecules called complex carbohydrates such as starch, glycogen and cellulose. Starch (think potatoes) is the main energy storage medium for plants, and glycogen is used by animals as a compact way to store glucose in the muscles. Cellulose is the most common organic substance on Earth. It is more rigid than the other complex carbohydrates and is the main structural component in plants.

3-SECOND NUCLEUS

Carbohydrates are multi-carbon aldehydes or ketones with many OH groups attached; they act as short-term energy stores and the main structural components of plants.

3-MINUTE VALENCE

Carbohydrates are common in the foods we eat. Monosaccharides can pass directly through our intestinal wall and enter the bloodstream as ready sources of energy. Disaccharides and complex carbohydrates, however, must be broken down into monosaccharides before they can pass into the bloodstream. Our bodies can break down sugars and starches, but we lack the enzyme to break down cellulose (also known as dietary fibre), which is why cellulose passes through the digestive tract, giving bulk to stools and preventing constipation.

RELATED TOPICS

See also

LIPIDS

AMINO ACIDS & PROTEINS

3-SECOND BIOGRAPHIES

ANDREAS MARGGRAF

1709–82

German chemist who first isolated glucose from raisins

EMIL HERMANN FISCHER

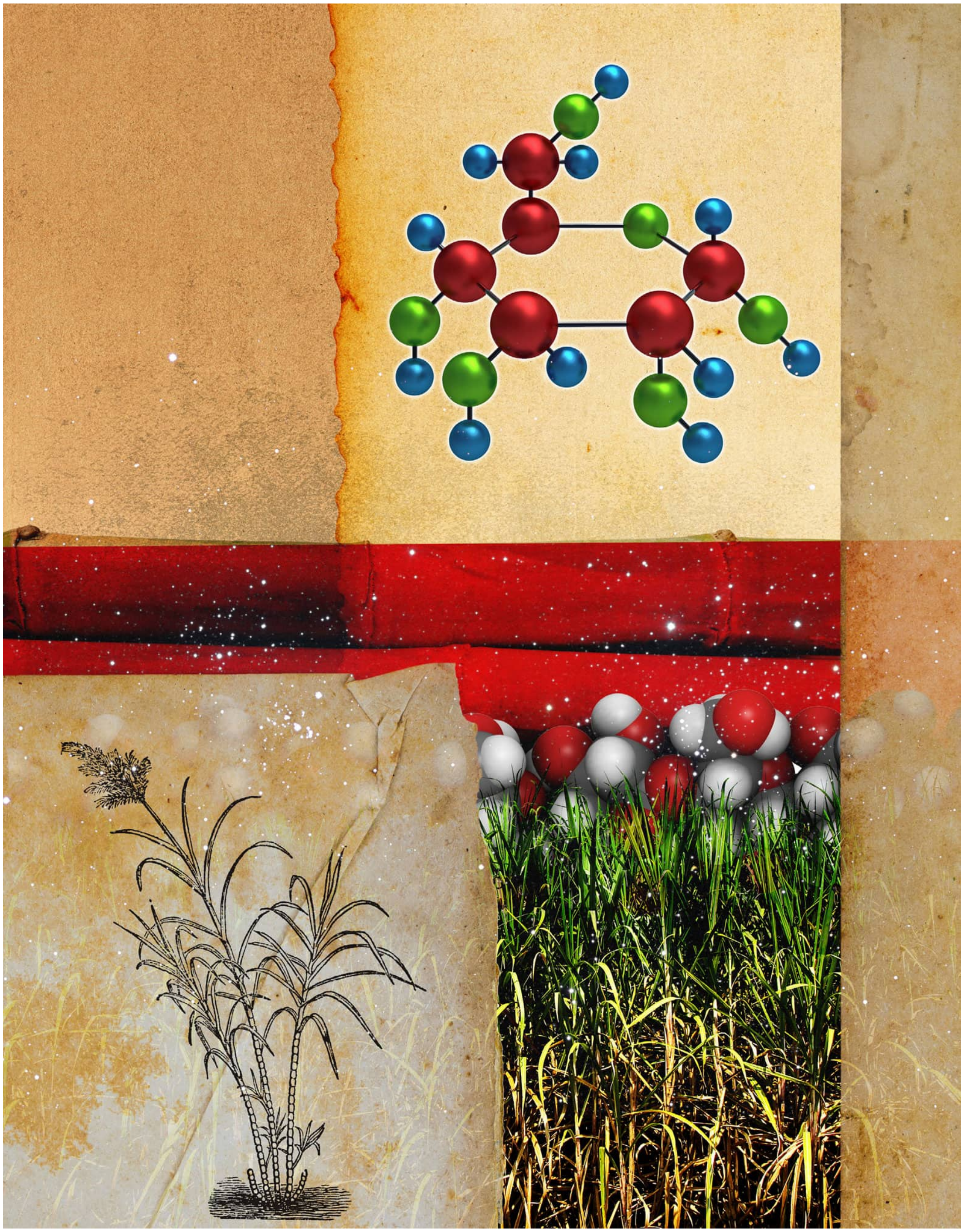
1852–1919

German chemist and winner of the 1902 Nobel Prize in Chemistry for his pioneering work on sugars

30-SECOND TEXT

Nivaldo Tro

Carbohydrates include simple sugars such as glucose (top) and complex carbohydrates such as cellulose (bottom).



LIPIDS

the 30-second chemistry

Lipids are the only biomolecule defined by what they are not: lipids are not able to dissolve in water. This insolubility enables lipids to form thin, oily membranes and to clump together into oily droplets that serve as high-density stores of metabolic energy. In fact, many lipids contain a large, burnable hydrocarbon group similar to the alkanes in gasoline. In fatty acids (a type of lipid), for instance, a long hydrocarbon chain is attached to a single polar carboxylic acid group. In tryglycerides (another type of lipid) three long hydrocarbon chains are attached to a short three-carbon head. This highly nonpolar structure causes tryglycerides to glob together into oily 'fat' droplets. Another type of lipid has only two long hydrocarbon chains attached to a more polar head (a three-carbon unit containing a phosphate group). The result is a rod-like molecule with a charged water-loving 'head' and oily tail. These form sheets with the tails lined up in oily sheets on the one side and the 'heads' all facing to the other. To keep the oily surface of the tails out of water, two sheets line up to give a bilayer membrane, with the tails on the inside and the heads forming the water-facing surfaces. These bilayer membranes are the fundamental barriers that encapsulate living cells.

3-SECOND NUCLEUS

Lipids' insolubility in water enables them to form extended membranes that enclose biological solutions and to function as particularly dense stores of metabolic energy.

3-MINUTE VALENCE

Even though they cannot be built up into modular polymers in the same way that other biomolecules can, lipids perform many varied biological functions. Lipid membranes act as barriers between the insides and outsides of cells while triglyceride 'fats' function as long-term energy stores in plants and animals. Other lipids called hormones act as biological messengers, being secreted by glands and carried to target cells where they trigger a physiological response.

RELATED TOPICS

See also

THE FORCES THAT HOLD MATTER TOGETHER

HYDROCARBONS

CARBOXYLIC ACIDS & AMINES

3-SECOND BIOGRAPHIES

MICHEL CHEVREUL

1786–1889

French chemist who was a pioneer in studying the chemistry of soaps, fats and oils

CHARLES ERNEST OVERTON

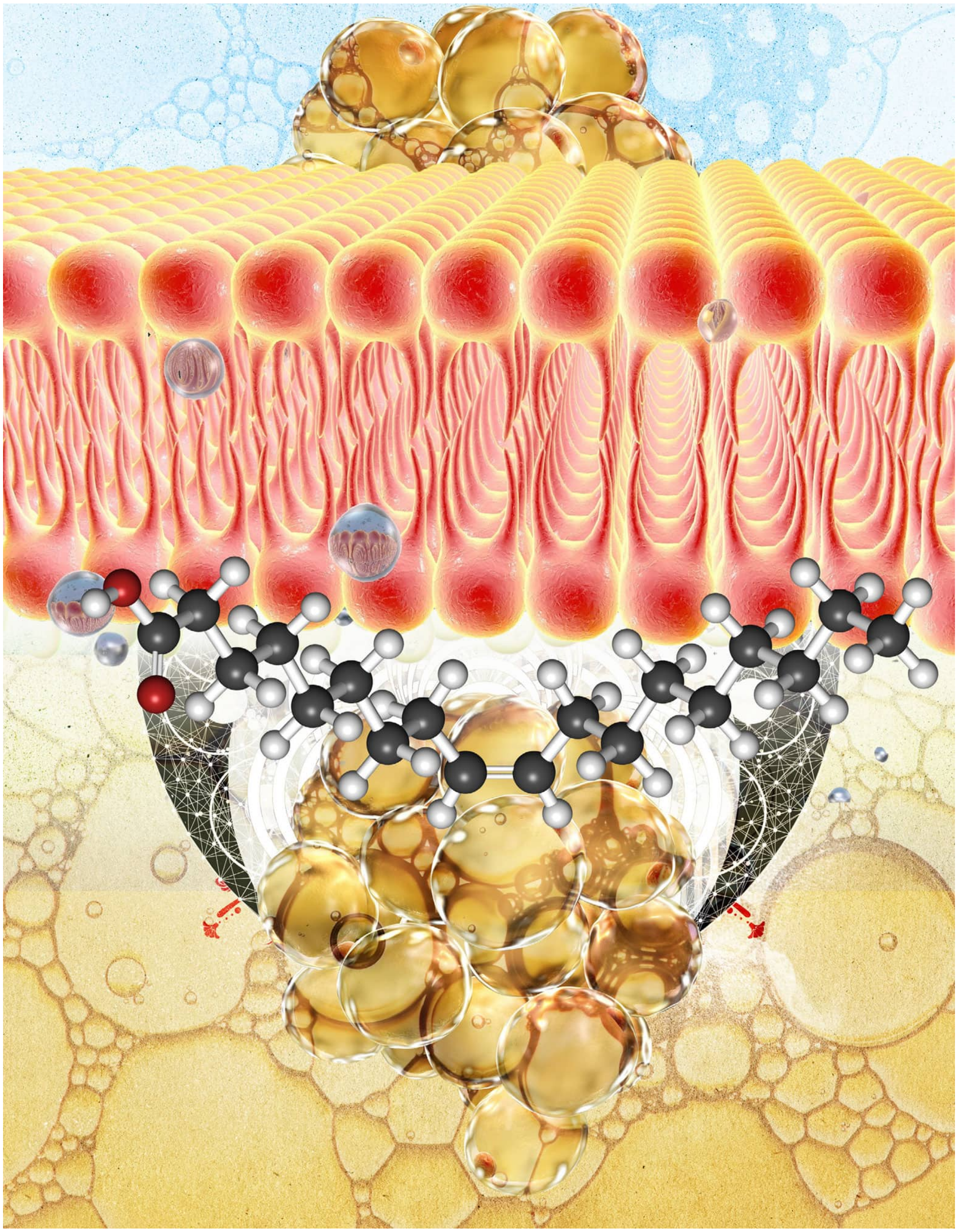
1865–1933

British biologist who first proposed that lipids might act as a cell membrane

30-SECOND TEXT

Stephen Contakes

> ***One of the many functions of lipids is to encapsulate cells by forming a bilayer.***



AMINO ACIDS & PROTEINS

the 30-second chemistry

Proteins are chain-like biomolecules that carry out a bewildering array of functions. Some, like the collagen in your skin, serve as structural supports. Others, like the motor protein myosin, enable muscles to relax and contract. Others adopt compact ‘globular’ shapes and can store or transport smaller molecules around, control cellular metabolism by speeding up particular chemical reactions or even recognize and bind other molecules. Some proteins, like insulin, act as intercellular signals, while others regulate bodily processes by chemically modifying other proteins to adjust how they function. Yet proteins are comprised of only 20 basic building blocks called amino acids, so named because they all contain a central carbon atom bonded to an amine group and an acid group. The central carbon is also bonded to a third variable group called a side chain, which may be polar, nonpolar, small, large, acidic, or basic. Amino acids can string together to form long polymers whose properties can vary widely based on the exact sequence of these side chains. Interactions between the side chains at different points along the polymer with each other and with surrounding water causes the protein to wriggle and fold into specific shapes, which in turn determine the functions they can perform.

3-SECOND NUCLEUS

Amino acids can be strung together into protein chains that fold into a diverse array of shapes and carry out many biological functions.

3-MINUTE VALENCE

When you take a breath the oxygen you breathe becomes bound to a protein called haemoglobin in your red blood cells, which transports the oxygen to your muscles and other tissues where it is used to ‘burn’ fats and carbohydrates in interconnected sequences of protein-catalyzed reactions. These generate the energy your body needs to move, synthesize other biomolecules and produce the electrical signals needed for nerve cells to function.

RELATED TOPICS

See also

REACTION RATES & CHEMICAL KINETICS

CARBOXYLIC ACIDS & AMINES

CHEMISTRY COPYING NATURE

3-SECOND BIOGRAPHIES

GERARDUS JOHANNES MULDER

1802–80

Dutch chemist who first described the composition of proteins

JOHN KENDREW & MAX PERUTZ

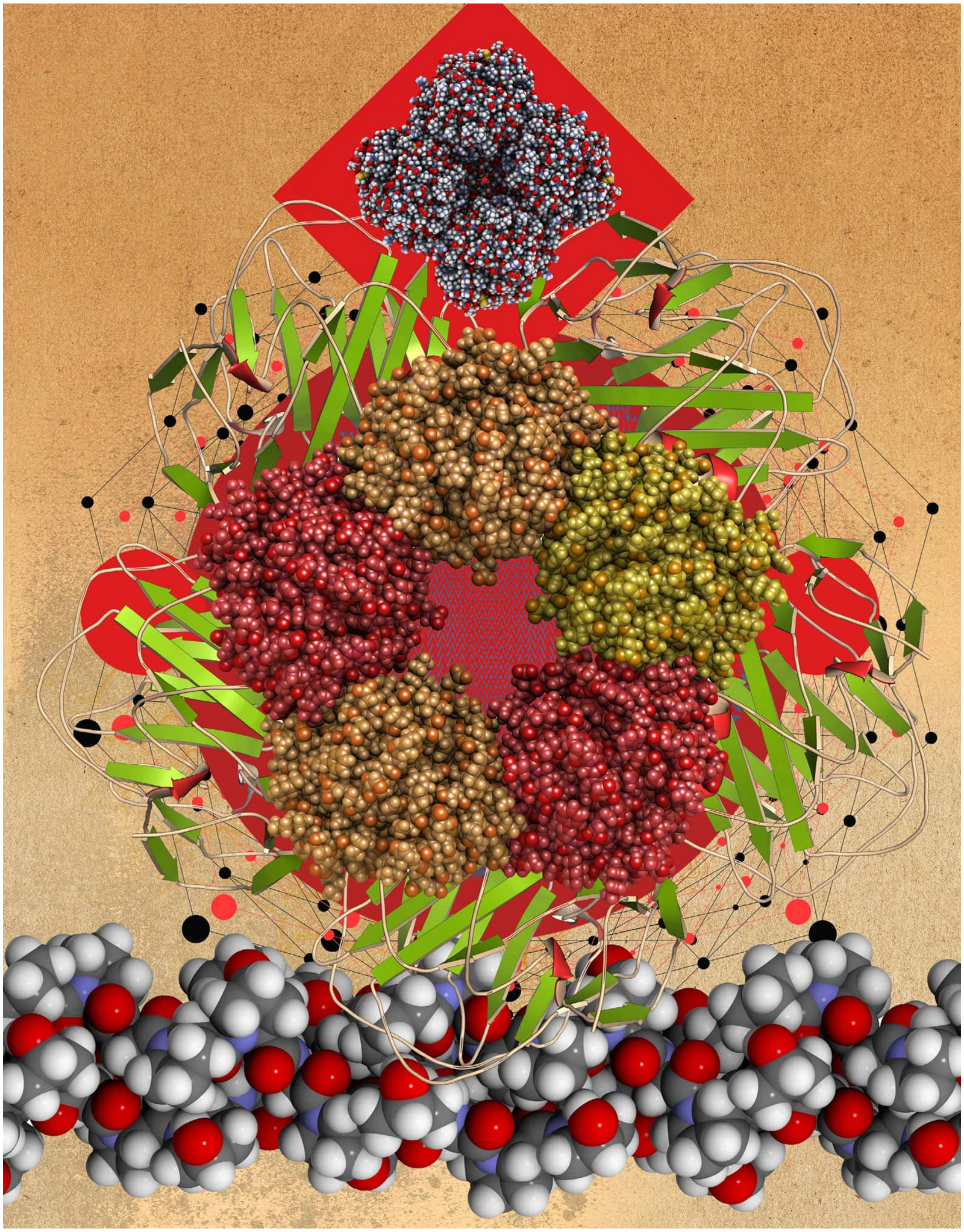
1917–97 & 1914–2002

British biochemist and Austrian-born molecular biologist who determined the first 3D structures of proteins

30-SECOND TEXT

Stephen Contakes

> ***Some proteins fold into globular shapes (centre), while others have more linear structures (bottom).***



ANNA J. HARRISON

Anna Jane Harrison was an American chemist and educator who believed in the importance of improving science education and increasing public awareness of science. Born to a family of farmers in Benton City, Missouri, Harrison took an interest in chemistry from as early as elementary school and by high school this had turned to fascination. She received all her advanced degrees from the University of Missouri-Columbia, including two BA degrees (in chemistry and education) and a PhD in physical chemistry. After five years of teaching at the Sophie Newcomb College of Tulane University in New Orleans, she took a position as a chemistry professor at Mount Holyoke College in Massachusetts, where she taught until her retirement in 1979. She continued to teach even after her retirement, at the US Naval Academy in Annapolis, Maryland.

At Mount Holyoke College, Harrison had a chance to work with renowned chemistry professor Emma Perry Carr on the spectroscopic study of molecular structure. She carried out research using a technique called flash photolysis to study chemical reactions by monitoring the dissociation and association of different molecular compounds. Her research activities also included work carried out with the A. J. Griner Company of Kansas City on field kits for the detection of toxic smoke for soldiers in the Second World War.

Harrison is perhaps better known today for her skills in science education. She is credited with helping change the chemistry profession from being a male-dominated profession to one that is more welcoming of diversity in gender, race and ethnicity. More than 100 years after its foundation, the American Chemical Society elected Harrison as its first female president in 1978. Harrison had a natural talent for making complicated concepts clear and comprehensible to her students. Her approach to education included helping students acquire better knowledge of how to make good public policy decisions related to science. In the 1970s, Harrison became an outspoken advocate of improved communication of science to the public, particularly to public officials. She served on many advisory boards including the National Science Board, and travelled to different parts of the world sharing her experience in public education of science.

Ali O. Sezer

---

23 December 1912
Born in Benton City, Missouri

1933
Receives a BA degree in chemistry from the University of Missouri-Columbia

---

1935
Receives a BA degree in education from the same institution

1937
Receives an MA degree in chemistry, again from the University of Missouri-Columbia

---

1940
Receives a PhD degree in physical chemistry, once again from the University of Missouri-Columbia

---

1945
Joins the chemistry department at Mount Holyoke College in Massachusetts

---

1960
Receives the Citation of the University of Missouri College of Arts and Sciences

---

1969
Receives the Manufacturing Chemists Association Award in College Chemistry Teaching

---

1978
Becomes the first female president of the American Chemical Society

---

1982
Receives the Chemical Education Award from the American Chemical Society

---

1983
Serves as the president of the American Association for the Advancement of Science

---

1989
Co-authors a textbook with Edwin S. Weaver entitled *Chemistry: A Search to Understand*

---

8 August 1998
Dies in Holyoke, Massachusetts

THE BIOLOGICAL BLUEPRINT: NUCLEIC ACIDS

the 30-second chemistry

DNA is a long, chain-like molecule containing units called nucleotides. Each nucleotide unit contains a negatively charged phosphate group attached to a carbohydrate ring, which is itself attached to a wedge-like nitrogen-containing group called a base. Bases come in four varieties, all of which are flat and nonpolar on top and bottom, but have specific patterns of polar nitrogen, oxygen and hydrogen atoms along their edges. These patterns allow bases to recognize 'complementary' bases, namely those which have the right pattern of polar groups to interact strongly, giving a base pair. Therefore, when deoxyribonucleic acids' sugar-phosphate groups are linked together into long polynucleotide chains, the bases along the chain can generate another polynucleotide strand with a sequence of bases complementary to the first. Some base sequences in DNA encode instructions for making proteins. These, along with nearby base sequences that tell the cell's machinery when to make those proteins, make up the units of heredity called genes. However, nucleic acids aren't only used to store and transmit genetic information. The cell's main energy currency, adenosine triphosphate (ATP), is a ribonucleotide in which the phosphate has been replaced by a chain of three linked phosphate groups.

3-SECOND NUCLEUS

Nucleic acids form chains of alternating phosphates and carbohydrates with attached wedge-like nitrogen-containing bases, the sequence of which encodes biological information.

3-MINUTE VALENCE

Life's information-bearing molecule is deoxyribonucleic acid or DNA. DNA contains within it the chemical code for protein synthesis and is passed from parent to offspring, which is why you have characteristics similar to your parents. In 2003, scientists successfully mapped the entire human genome, a chemical code containing about 3 billion units (base pairs).

RELATED TOPICS

See also

THE FORCES THAT HOLD MATTER TOGETHER

CARBOXYLIC ACIDS & AMINES

CARBOHYDRATES

3-SECOND BIOGRAPHIES

OSWALD AVERY

1877–1955

Canadian-born medical researcher who demonstrated that DNA is genetic material

JAMES WATSON & FRANCIS CRICK

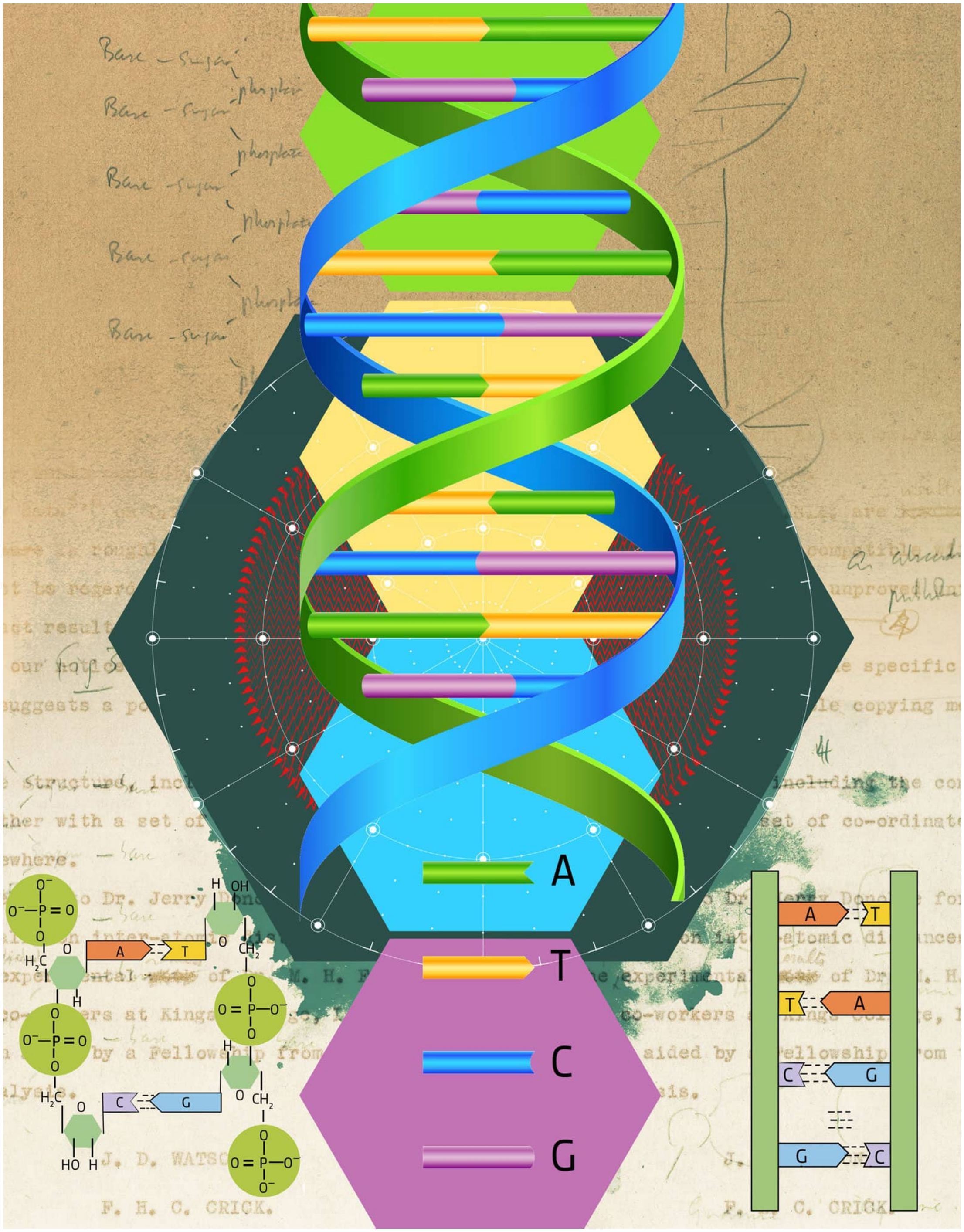
1928– & 1916–2004

American and British molecular biologists who determined DNA’s double-helical structure

30-SECOND TEXT

Stephen Contakes

> ***DNA has a double helical structure in which complementary bases connect along the middle.***


Base – sugar
phosphate
Base – sugar
phosphate
Base – sugar
phosphate
Base – sugar
phosphate
Base – sugar
A
T
C
G
O⁻
O⁻–P=O
O
H₂C
O
H
A
T
H OH
O
CH₂
O=P–O⁻
O
H
O⁻–P=O
O
H₂C
O
C
G
O CH₂
HO H
O=P–O⁻
O⁻
A T
T A
C G
G C
J. D. WATSON
F. H. C. CRICK

BIOTECH DRUG SYNTHESIS

the 30-second chemistry

Before 1922, diabetes was fatal. Then a 14-year-old diabetes patient on the verge of death was given insulin (a protein that regulates blood sugar) derived from animal sources. The patient recovered – and survived. Soon insulin (harvested mostly from pigs) became available for widespread use, changing diabetes into a manageable long-term disease. However, some patients did not tolerate pig insulin very well. In the 1980s a company called Genentech figured out a way to synthesize human insulin by inserting the gene for human insulin into the DNA of bacterial cells. When the bacteria reproduced, they copied the human insulin gene and passed it on to their offspring. Furthermore, as the genetically modified bacteria synthesized the proteins they needed to survive and reproduce, they also synthesized human insulin. The insulin was harvested from the bacterial cultures, purified and administered to diabetics. Today diabetics take human insulin, synthesized in this way. The DNA instructions for making desired proteins can also be inserted into the DNA of plants or animals. For example, in 2015 the FDA approved a drug to treat Wolman disease, a rare but fatal disease caused by a deficiency of an enzyme called LAL. The drug is harvested from the eggs of chickens that have been genetically modified to produce LAL.

3-SECOND NUCLEUS

Human proteins can be synthesized by inserting the human gene for the desired protein into bacterial, plant or animal cells. As these cells grow and divide, they synthesize the desired protein.

3-MINUTE VALENCE

Genetic engineering – the process of modifying an organism’s genome for a particular purpose – has been used, not only to produce life-saving medicines but also to produce animals or plants with desirable characteristics. Genetic modification of soybeans, tomatoes and rice has resulted in crops with more resilience and higher nutritional value. In spite of rigorous scientific testing, the controversy surrounding some of these products has resulted in increased scrutiny of their safety.

RELATED TOPICS

See also

AMINO ACIDS & PROTEINS

THE BIOLOGICAL BLUEPRINT: NUCLEIC ACIDS

3-SECOND BIOGRAPHIES

FREDERICK BANTING

1891–1941

Canadian physician who was awarded the 1923 Nobel Prize in Medicine for his discovery of insulin

FREDERICK SANGER

1918–2013

British biochemist who was awarded the Nobel Prize in Chemistry in 1958 for his determination of the structure of insulin

PAUL BERG

1926–

American biochemist awarded the 1980 Nobel Prize in Chemistry for his work on recombinant DNA technology

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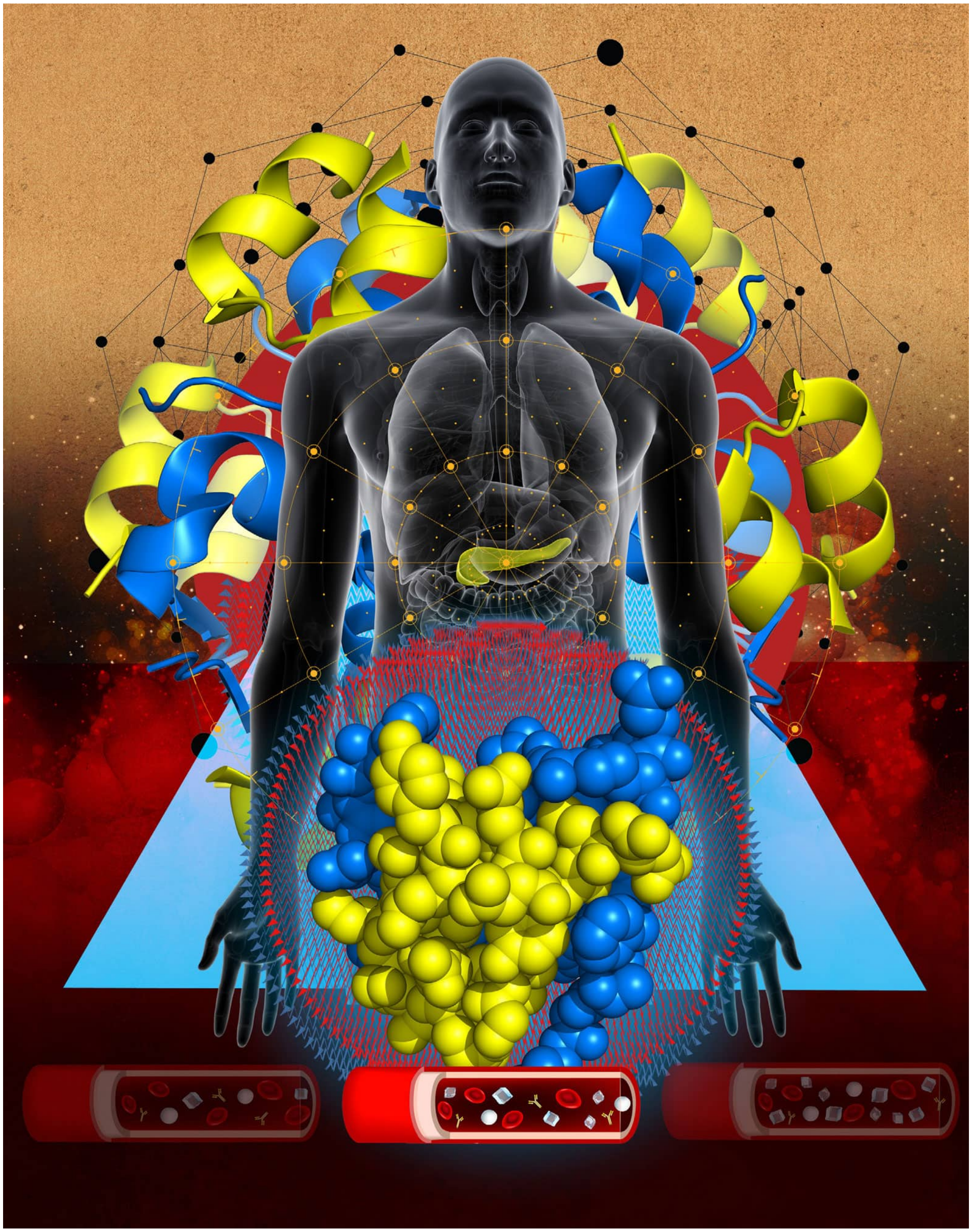
30-SECOND TEXT

Nivaldo Tro

> ***Human insulin is synthesized by the genetic modification of bacteria.***



NUCLEAR CHEMISTRY

NUCLEAR CHEMISTRY

GLOSSARY

alpha particle A type of particle given off in one type of radioactive decay. An alpha particle contains 2 protons and 2 neutrons and is symbolized as ${}^{4}_{2}\text{He}$.

amu A unit of mass used for subatomic particles. 1 amu = 1.66 x 10^{-27} kg.

beta particle A type of particle given off in one type of radioactive decay. A beta particle is an electron and is symbolized as ${}^{0}_{-1}e$.

chemical reaction A process in which the atoms in one or more substances (the reactants) rearrange to form different substances (the products).

critical mass In nuclear fission, the minimum mass of fissile material needed to maintain a self-sustaining nuclear reaction.

Einstein's equation $E=mc^2$ An equation that relates mass to energy, which means that the two are interconvertible.

electron A subatomic particle with a negative charge and a mass of 0.00055 amu.

gamma ray A high energy photon given off in one type of radioactive decay and often in conjunction with other types. A gamma ray is symbolized as ${}^{0}_{0}\gamma$.

gene A strand of DNA that codes for a single protein.

isotope An atom that has the same number of protons as another atom, but a different number of neutrons.

metabolism The process by which living organisms convert certain compounds into the energy needed to survive and reproduce.

neutron A subatomic particle with no charge and a mass of 1 amu.

nuclear fission A nuclear reaction in which a large nucleus splits into smaller fragments and releases energy.

plutonium A synthetic chemical element with atomic number 94 used in nuclear chemistry, especially nuclear power and atomic bombs.

proton A subatomic particle with a positive charge and a mass of 1 amu.

radioactivity The emission of small energetic particles from the nuclei of certain unstable isotopes.

radiocarbon dating A method of determining the age of previously living material by measuring the C-14 content in the material.

radiopharmaceutical Pharmaceutical agents that are radioactive and used in the diagnosis and treatment of disease.

tracers A chemical compound where one or more atoms have been replaced with a radioactive isotope that allows a scientist to trace where the atom goes in a particular process.

uranium A radioactive chemical element with atomic number 92 used in nuclear chemistry, especially nuclear power and atomic bombs.

X-rays A form of electromagnetic radiation with wavelengths slightly longer than gamma rays and used to image bones and organs.

RADIOACTIVITY

the 30-second chemistry

As a scientific poet once wrote ‘Atoms … fly to bits with utmost facility’. Counterintuitively, some atoms spontaneously fall apart to produce rays and particles that can penetrate through various materials, including metals and our own bodies. Antoine Becquerel and Pierre and Marie Curie, working in Paris in the last decade of the nineteenth century, were the first to recognize this phenomenon in uranium minerals. Madame Curie called this ‘radioactivity’ (from the Latin *radius*, meaning ‘ray’) and soon found two mysterious, previously unknown elements (‘radium’ and ‘polonium’) that emitted more intense ‘radiation’ than uranium itself. Initially radioactivity was thought to exist in two types, designated logically enough by Ernest Rutherford as alpha and beta. (Gamma rays were discovered several years later.) Positively charged alpha particles, soon found to be energetic helium nuclei, He^{2+}, had less ability to penetrate various substances. Negatively charged beta particles, soon found to be energetic electrons, were much lighter and able to penetrate a variety of materials well. Gamma rays, the most penetrating of all, were high-energy electromagnetic radiation. Most remarkably, it is now clear that certain types of atoms spontaneously ‘decay’ and spit out tiny charged particles and highly intense radiation.

3-SECOND NUCLEUS

Some atoms spontaneously ‘decay’, producing alpha and beta particles and gamma rays that can penetrate through various materials. This is called radioactivity.

3-MINUTE VALENCE

Radioactive elements can be used as ‘tracers’ to follow the pathway of a chemical reaction or monitor concentrations of elements in research, environmental, agricultural and medical settings. Radioactive elements are also used to establish the ages of various objects including once-living systems (carbon-14), early humanoids (potassium-40) and the Moon, Earth and various rocks and minerals (uranium and thorium isotopes).

RELATED TOPICS

See also

MATTER IS MADE OF PARTICLES

THE STRUCTURE OF THE ATOM

SPLITTING THE ATOM

3-SECOND BIOGRAPHY

WILLIAM RAMSAY

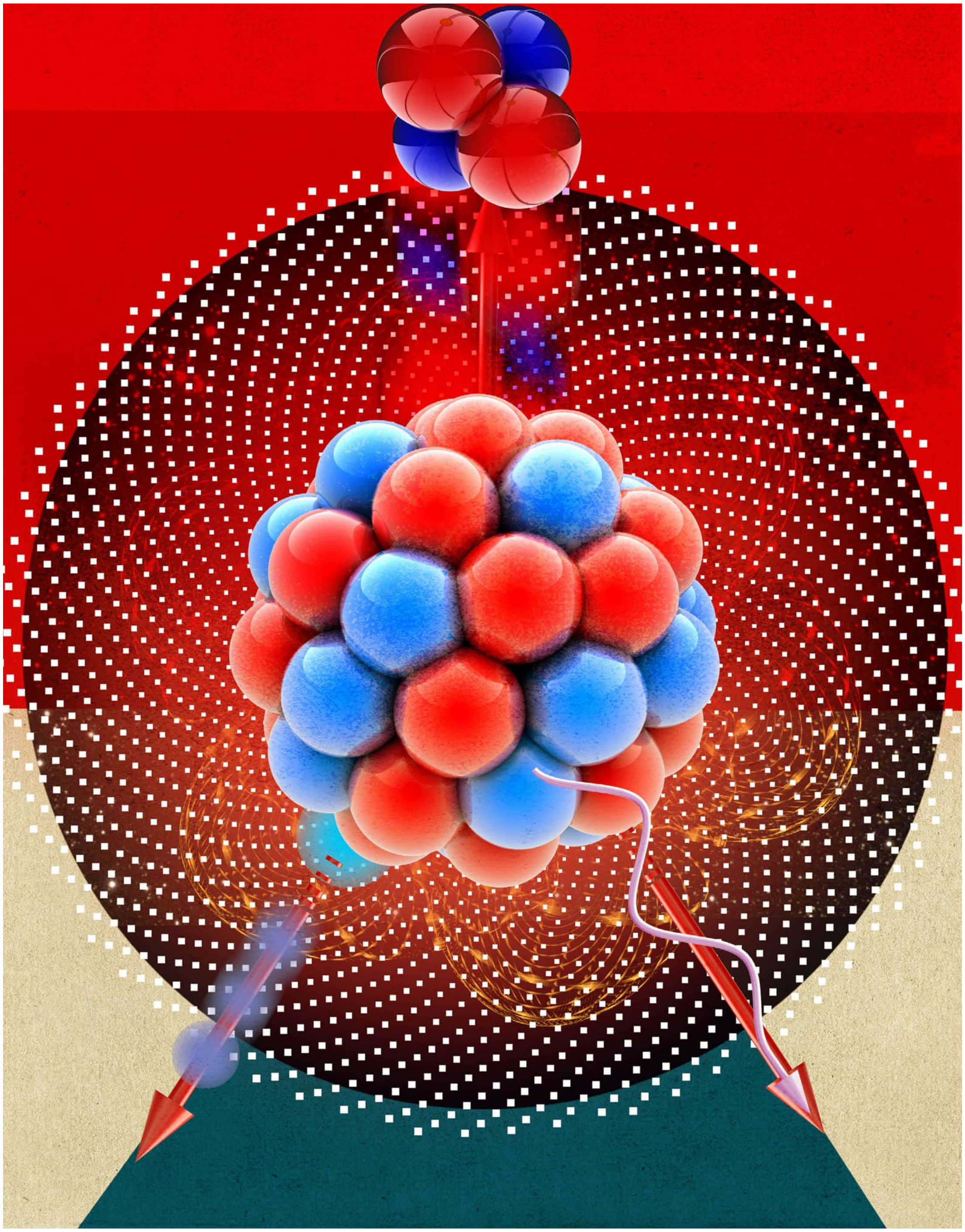
1852–1916

Scottish chemist who wrote the 1902 poem ‘The Death Knell of an Atom’, which contains the following stanza ‘So the atoms, in turn, we now clearly discern,/Fly to bits with the utmost facility;/ They wend on their way, and in splitting, display/An absolute lack of stability.’

30-SECOND TEXT

Glen E. Rodgers

When atoms emit radiation they change their identity.



SPLITTING THE ATOM

the 30-second chemistry

In 1938 Otto Hahn shot neutrons at uranium atoms and was amazed to discover that they appeared to split roughly in half. He had discovered nuclear fission, whereby a large nucleus splits to form two smaller nuclei and several more neutrons. If a ‘critical mass’ of a sufficiently pure isotope of uranium or plutonium is present, these additional neutrons can go on to hit other fissionable nuclei and cause a chain reaction which, as calculated using Einstein’s equation $E=mc^2$, releases inordinate amounts of energy, far in excess of that obtained from conventional chemical reactions. This energy can be harnessed to create electricity (nuclear energy) or to create explosions (nuclear bombs). The uranium-based bomb dropped on Hiroshima, Japan, on August 6, 1945, was called ‘Little Boy’. In this ‘gun-type’ assembly, the critical mass was obtained by firing a uranium ‘bullet’ into a hollow cylinder of uranium. The plutonium-based bomb dropped on Nagasaki, Japan, on August 9, 1945, was called ‘Fat Man’. In this implosion-type assembly, the critical mass was obtained using a lens assembly that fired small bits of plutonium all towards the centre of the bomb.

3-SECOND NUCLEUS

Firing neutrons into critical masses of fissionable materials splits the atoms apart and produces additional neutrons; the resulting chain reaction releases large amounts of energy.

3-MINUTE VALENCE

Why don’t atomic nuclei, particularly those containing dozens of positively charged and therefore mutually repulsive protons, just burst apart? It turns out that some do. Large nuclei of certain types of atoms of uranium or plutonium atoms act like wobbly drops of liquid tenuously held together by a nuclear surface tension that can be easily disrupted.

RELATED TOPICS

See also

THE STRUCTURE OF THE ATOM

INSIDE THE ATOM

OTTO HAHN

3-SECOND BIOGRAPHIES

MARIE CURIE

1867–1934

Polish-born French chemist who developed the theory of radioactivity

OTTO HAHN

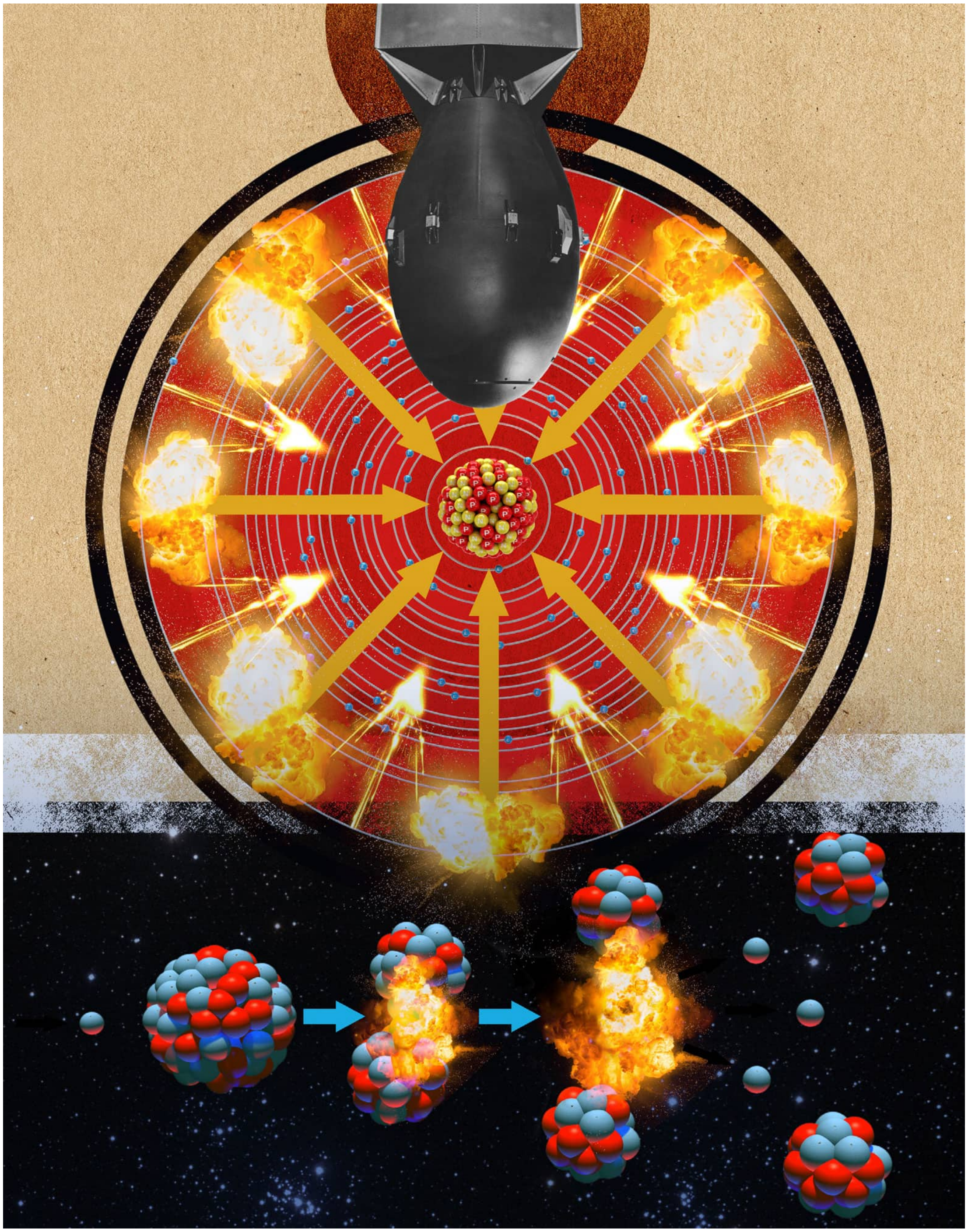
1879–1968

German winner of the 1944 Nobel Prize in Chemistry, who discovered nuclear fission

30-SECOND TEXT

Glen E. Rodgers

> ***In nuclear fission, a neutron causes an unstable nucleus to split, releasing large amounts of energy.***



NUCLEAR WEIGHT LOSS

the 30-second chemistry

When an atom splits, either in a nuclear power plant or during the detonation of a nuclear weapon, a tremendous amount of energy is released. Where does all of this energy come from? The answer lies in Einstein's remarkably simple equation that relates energy and matter: $E=mc^2$ – energy equals mass times the speed of light squared. This equation states that energy and matter are really two different forms of the same thing. In other words, if energy is being released (created), then matter must disappear. That's exactly what happens during nuclear fission. A large nucleus splits into two smaller ones, a little bit of the total mass is destroyed – and lots of energy is produced. Does this mean one or two protons or neutrons get vaporized? No, the fascinating part of this is that all of the protons and neutrons lose a little bit of their mass. However remarkable it may seem, this means that protons and neutrons do not always have the same mass. A proton in a uranium nucleus weighs more than a proton in an iron nucleus. After splitting, the same total number of protons and neutrons exist; they all weigh just a bit less. This is not a recommended weight loss programme for humans.

3-SECOND NUCLEUS

Protons and neutrons each lose a tiny bit of mass when nuclear fission occurs. This mass is converted into energy.

3-MINUTE VALENCE

If matter and energy are two sides of the same coin, then is it appropriate to imagine protons and neutrons as hard spheres? Is it better to think of them as little balls of energy? Because matter and energy are interconvertible, perhaps it doesn't really matter. This is another indication that the subatomic universe is a very strange place.

RELATED TOPICS

See also

INSIDE THE ATOM

RADIOACTIVITY

SPLITTING THE ATOM

3-SECOND BIOGRAPHIES

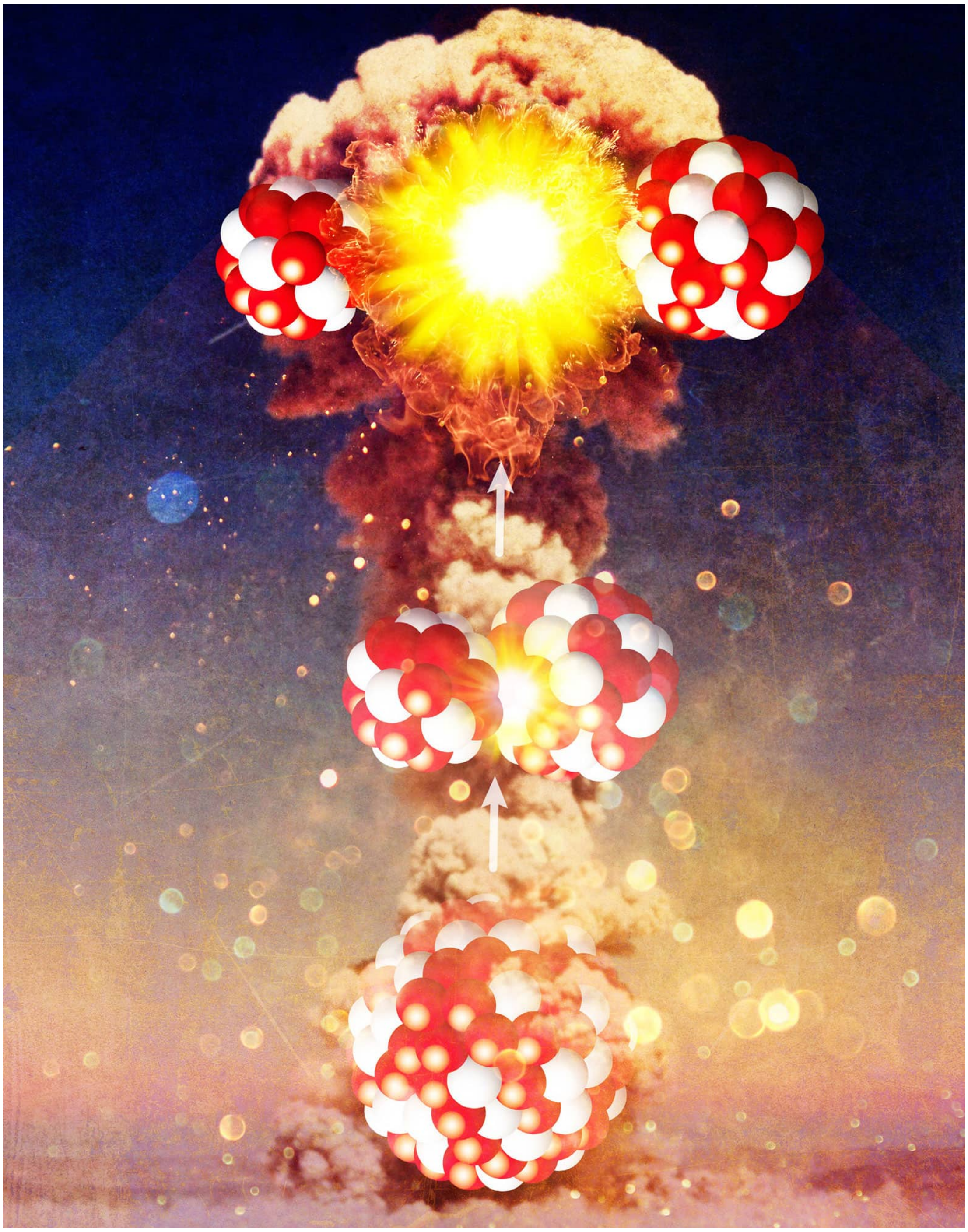
LISE MEITNER
1878–1968
Austrian physicist who performed the first mass/energy calculations on nuclear fission

ALBERT EINSTEIN
1879–1955
German-born physicist who provided mathematical equivalence to mass and energy

30-SECOND TEXT

Jeff C. Bryan

> ***When an atom splits through nuclear fission, some of its mass is converted into energy.***



THE EFFECT OF RADIATION ON LIFE

the 30-second chemistry

The types of radiation discussed in this chapter are rather unusual in that they have the power to knock electrons loose from atoms and molecules. As the radiation travels through matter, it transfers some of its energy to the molecules it passes by, much like a bullet fired into a pile of pea gravel. Since electrons bind atoms together in molecules, this subatomic violence can lead to broken chemical bonds. If enough radiation damage occurs in a single cell, a large number of molecules get broken and the cell could die. If it's less damaged, it can repair itself. However, if the cell's DNA is damaged, the cell could change (or mutate) in ways that cause it to grow abnormally (because DNA directs how cells grow). These mutations and abnormal cell growth can lead to cancer. This sounds bad, especially since humans, like all living things and the planet, are naturally radioactive. Fortunately, we've evolved with rather efficient cell repair mechanisms. It appears that below a certain threshold, radiation produces no negative health effects. Some set this threshold at 100 mSv (millisieverts, a unit of dose). For reference, the global average annual dose for natural and anthropogenic radiation is 2.8 mSv.

3-SECOND NUCLEUS

Radiation can break chemical bonds in living things, possibly leading to cell death or cancer.

3-MINUTE VALENCE

Radiation damage to DNA typically takes place indirectly. The most common chemical in living things is water, making it the odds-on favourite to have one of its electrons knocked loose. This forms H_2O^+, which falls apart into H^+ and $HO\cdot$. $HO\cdot$ is known as hydroxyl radical, and is very reactive. If it bumps into a DNA molecule, it will likely disrupt a chemical bond in the DNA.

RELATED TOPICS

See also

BONDING ATOMS TOGETHER

THE BIOLOGICAL BLUEPRINT: NUCLEIC ACIDS

3-SECOND BIOGRAPHIES

HERMANN J. MÜLLER

1890–1967

American biologist and winner of the 1946 Nobel Prize in Medicine who first observed changes in genes after exposure to X-rays

L. HAROLD GRAY

1905–65

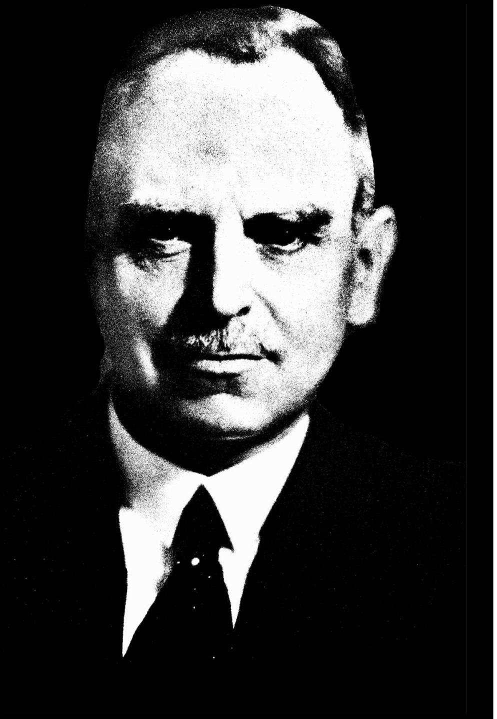
English physicist and radiobiologist who pioneered studies of radiation effects on living things

30-SECOND TEXT

Jeff C. Bryan

DNA can be damaged by ionizing radiation.

OTTO HAHN



Otto Hahn was often ill as a child, managing to survive both diphtheria and severe pneumonia. He never regarded himself as a good student, but both his health and grades improved dramatically in his early teens. At about the same time, he and a friend started performing simple chemical reactions with materials they could find around the house. This interest intensified when he took an evening course on the chemistry of dyes. He went on to study chemistry at the universities of Marburg and Munich.

After earning his PhD, and a year of military service, Hahn returned to Marburg for a position assisting with lectures. Hahn was interested in working in Germany's chemical industry, and learned of a position that involved international travel. His potential employer wanted Hahn to spend some time in England before they would consider him, so Hahn's advisor arranged for him to work with William Ramsay in London.

Ramsay gave Hahn a couple of radioactivity puzzles to research, and, although they were outside of Hahn's area of expertise (organic chemistry), he excelled in solving both. Ramsay was so impressed that he convinced Hahn he should pursue an academic career in nuclear science. Hahn was interested, but felt he needed more depth in this new field. After a year in London, he went to Montreal to spend a year working with Ernest Rutherford.

Ramsay then helped Hahn get a position at the University of Berlin; arriving shortly after Hahn, was Austrian physicist Lise Meitner. Hahn and Meitner worked together for more than 30 years and were immensely productive in identifying many of the decay products of uranium and thorium, including the element protactinium. Meitner had to leave Germany in 1938, and shortly after that Hahn, working with Fritz Strassmann, observed nuclear fission. They didn't understand what they were seeing, so they wrote to Meitner about it. Meitner and her nephew Otto Frisch figured out it was nuclear fission. Hahn and Strassmann published their observations in January 1939, and Meitner and Frisch their interpretation a month later.

This discovery shook the scientific community, and eventually led to the Manhattan Project (the research project in the United States that produced the first nuclear weapons) as well as the development of nuclear power plants. During the Second World War, Hahn continued his work identifying the many products of fission. After the war, he discontinued his research and served as president of the Max Planck Society until 1960.

Jeff C. Bryan

8 March 1879
Born in Frankfurt, Germany

1901
Earns a doctorate in organic chemistry at the University of Marburg

1904–5
Works with William Ramsay at University College, London

1905–6
Works with Ernest Rutherford at McGill University in Montreal, Canada

1907
Qualifies as a university lecturer at the University of Berlin

1914–18
Serves as a chemical warfare specialist in the German army

1918
Discovers protactinium and nuclear isomerism with Lise Meitner

1928
Appointed director of the Kaiser Wilhelm Institute

1938
Observes nuclear fission, with Fritz Strassmann

1944
Awarded the Nobel Prize in Chemistry for the discovery of fission

1966
Shares the Enrico Fermi Award with Lise Meitner and Fritz Strassmann for the discovery of fission

28 July 1968
Dies in Göttingen, West Germany

NUCLEAR MEDICINE

the 30-second chemistry

Nuclear medicine involves the injection of a radioactive material (a radiopharmaceutical) into a patient to diagnose or treat a disease. An example is ^{18}F-fluorodeoxyglucose (FDG), a radioactive sugar molecule. In our bodies, sugars tend to go to sites of metabolism. They also collect in cancerous tumours, because cancer is a sugar hog. Once the radiopharmaceutical is allowed to localize, radiation detectors can be positioned around the patient to generate three-dimensional images of the organs where the radiopharmaceutical has accumulated. The data collected from a nuclear medicine scan typically tells us more about how well the organ is functioning (physiology) than what it looks like (anatomy). By changing the chemical nature (size, shape, charge) of the radiopharmaceutical, we can obtain images from any organ in the body and determine how well it's working. Nuclear medicine scans make patients more radioactive. But remember that we are all naturally radioactive; nuclear medicine simply adds more that concentrates in part of the body. The radiation dose is typically low enough not to have any measurable adverse effects, and the benefits of diagnosing or treating a disease you already have outweighs any nearly negligible risk that the radiation might pose.

3-SECOND NUCLEUS

Nuclear medicine uses radiopharmaceuticals to examine physiology and to treat diseases.

3-MINUTE VALENCE

As we gain a better understanding of human physiology, radiopharmaceuticals are becoming so sophisticated they can generate images and perform therapy at the cellular and molecular level. Imagine being able to kill cancer when it is so small that it can't even be located by conventional means. We may soon be able to detect and treat cancer before any outward symptoms are apparent.

RELATED TOPICS

See also

CHEMISTRY COPYING NATURE

3-SECOND BIOGRAPHIES

GEORGE DE HEVESY

1885–1966

Hungarian-born winner of the 1943 Nobel Prize in Chemistry who first recognized that radioactive isotopes could be used to study complex chemical processes such as metabolism

HAL ANGER

1920–2005

American electrical engineer and biophysicist who invented the cameras that are still widely used in nuclear medicine

30-SECOND TEXT

Jeff C. Bryan

Radioactive substances can be used to image internal organs.

ENJOYMENT OF WINE

RESOURCES

BOOKS

Cathedrals of Science: The Personalities and Rivalries that Made Modern Chemistry
Patrick Coffey
(Oxford University Press, 2008)

Chemistry: A Molecular Approach
Nivaldo J. Tro
(Pearson, ed. 4, 2017)

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Chemistry: Structure and Properties
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The Disappearing Spoon: And Other True Tales of Madness, Love, and the History of the World from the Periodic Table of the Elements
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(Little, Brown and Co, 2010)

The Elements: A Visual Exploration of Every Known Atom in the Universe
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Penny Le Couteur and Jay Burreson
(Penguin, 2003)

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(Oxford University Press, 2007)

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Peter Atkins and Julio de Paula
(Oxford University Press, ed. 9, 2010)

Stuff Matters
Mark Miodownik (Penguin, 2013)

Uncle Tungsten: Memories of a Chemical Boyhood

Oliver Sacks
(Alfred A. Knopf, 2001)

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https://www.nobelprize.org/nobel_prizes/chemistry/laureates/

NOTES ON CONTRIBUTORS

EDITOR

Nivaldo Tro is a Professor of Chemistry at Westmont College in Santa Barbara, California. He received his B.S. in Chemistry from Westmont College and his Ph.D. in Chemistry from Stanford University. He then went on to the University of California at Berkeley, where he did postdoctoral research on ultrafast reaction dynamics in solution. Professor Tro has authored over 20 journal articles and has been awarded grants from the American Chemical Society, the Petroleum Research Fund, Research Corporation, and the National Science Foundation to study the dynamics of various processes occurring in thin adlayer films adsorbed on dielectric surfaces. He has been honoured as Westmont's outstanding teacher of the year three times and has also received the college's outstanding researcher of the year award. Professor Tro is best known for his chemistry textbooks, which are used at more than 600 colleges and universities around the world. About one third of all college students taking chemistry today use a textbook written by Professor Tro.

CONTRIBUTORS

Jeff C. Bryan earned an A.B. in Chemistry from the University of California, Berkeley and a Ph.D. in Chemistry from the University of Washington. He is a Professor in the Chemistry faculty of the University of Wisconsin–La Crosse, where he teaches nuclear and general chemistry courses, and his scholarship focuses on making nuclear science more accessible to students with limited science and maths backgrounds. He has written a textbook titled *Introduction to Nuclear Science*, and co-authored a lab manual titled *Experiments in Nuclear Science*.

Stephen Contakes is Associate Professor of Chemistry at Westmont College in Santa Barbara, California, where he teaches courses in inorganic, analytical, and physical chemistry. With a background in synthetic organometallic and bioinorganic chemistry, his research interests involve the preparation of redox-active hydrogen bonded assemblies and photoactive nanoparticle catalysts for use in pollutant remediation.

Dr. Glen E. Rodgers is a Professor emeritus of Chemistry at Allegheny College in Meadville, Pennsylvania. Educated at Tufts University and Cornell University, he taught for five years at Muskingum College in Ohio and 30 years at Allegheny. He taught introductory chemistry on several levels, plus inorganic chemistry, and numerous interdisciplinary courses with colleagues in other faculties. He is the author of the third edition (2012) of the popular sophomore-level textbook *Descriptive Inorganic, Coordination, and Solid-State Chemistry* (Cengage Learning, International Edition 2011). Dr. Rodgers and his wife have led science travel tours around the world, taking students to key locations in the history of science.

Ali O. Sezer is a Professor of Physical Chemistry at California University of Pennsylvania. After graduating from Yildiz Technical University in Istanbul, Turkey, Sezer went to the U.S.A. to pursue an advanced degree in chemical and materials engineering. Dr. Sezer's research interests are in the area of conducting polymers; particularly nano composites of these polymers with transition metal oxides for electronics, optical, medical, bio-sensing and corrosion protection applications. He believes in 'hands-on' undergraduate teaching, especially involving students in cutting edge research activities.

James M. Tour is a Professor of Chemistry, Professor of Computer Science and Professor of Materials Science and NanoEngineering at Rice University in Texas. Tour's scientific research areas include nanoelectronics, graphene electronics, green carbon research for enhanced oil recovery and environmentally friendly oil and gas extraction, carbon supercapacitors and synthesis of single-molecule nanomachines which includes molecular motors and nanocars. He has also developed strategies for retarding chemical terrorist attacks. For pre-college education, Tour developed the *NanoKids* concept for K–12 education in nanoscale science. Tour has over 600 research publications and over 120 patents.

Dr. John B. Vincent received a B.S. in Chemistry and Mathematics from Murray State University and a Ph.D. in Chemistry from Indiana University. He was a NIH postdoctoral fellow at The University of Virginia before joining the faculty of The University of Alabama, where he is currently Professor of Chemistry. His research interests are in bioinorganic chemistry, with a particular focus on the nutritional biochemistry of chromium(III). Dr. Vincent is author or coauthor of over 130 peer-reviewed publications, over 15 book chapters, 8 books, and 9 patents. Dr. Vincent is currently co-editor-in-chief of *Biological Trace Element Research.*

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This paperback edition published in the UK in 2020 by
Ivy Press
An imprint of the Quarto Group
The Old Brewery, 6 Blundell Street
London N7 9BH, United Kingdom
T (0)20 7700 6700
www.QuartoKnows.com

First published in hardback in 2017

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

Digital edition: 978-1-78240-618-1
Softcover edition: 978-1-78240-972-4

This book was conceived, designed and produced by
Ivy Press
Publisher **Susan Kelly**
Creative Director **Michael Whitehead**
Editorial Director **Tom Kitch**
Commissioning Editor **Stephanie Evans**
Project Editors **Jamie Pumfrey, Joanna Bentley**
Designer **Ginny Zeal**