

NUCLEAR, INDUSTRIAL CHEMISTRY AND METALLIC STATE

Unit I

NUCLEAR CHEMISTRY

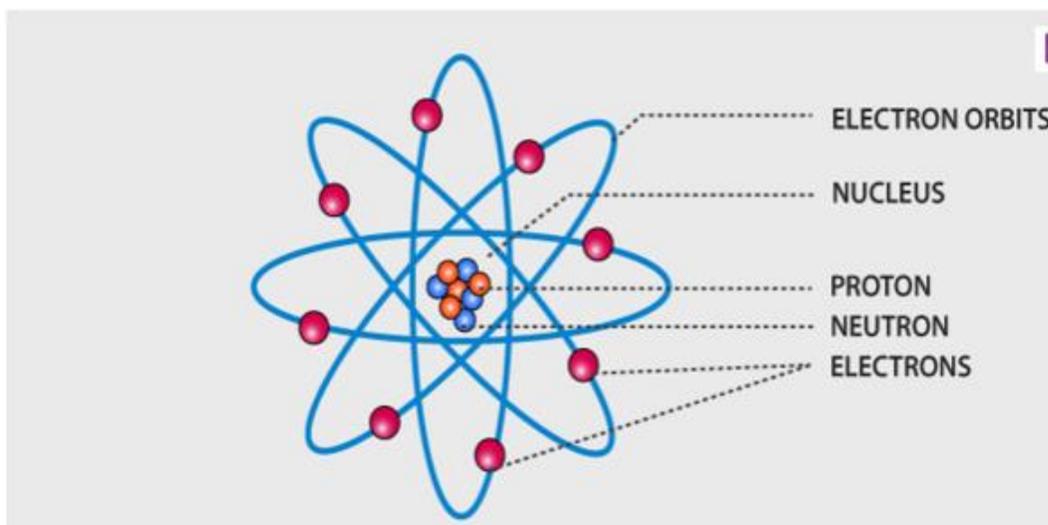
Nuclear structure

Atomic Structure Definition. Inside the nucleus, protons and neutrons are present which are collectively called nucleons. The electrons are revolving around the nucleus in fixed orbits. The mass of an atom is concentrated inside the nucleus of an atom. Atom is electrically neutral.

The three particles of the atom are the proton, neutron and electron. The proton and neutron both reside in the nucleus of the atom and are positively charged and neutral, respectively.

Atomic structure refers to the structure of atom comprising of a nucleus (center) in which the protons (positively charged) and neutrons (neutral) are present. The negatively charged particles called electrons revolve around the center of the nucleus.

The history of atomic structure and quantum mechanics dates back to the times of Democritus, the man who first proposed that matter is composed of atoms.



The atomic structure of an element refers to the constitution of its nucleus and the arrangement of the electrons around it. Primarily, the atomic structure of matter is made up of **protons**, electrons, and neutrons.

The protons and neutrons make up the nucleus of the atom, which is surrounded by the electrons belonging to the atom. The atomic number of an element describes the total number of protons in its nucleus.

Neutral atoms have equal numbers of protons and electrons. However, atoms may gain or lose electrons in order to increase their stability, and the resulting charged entity is called an ion.

Atoms of different elements have different atomic structures because they contain different numbers of protons and electrons. This is the reason for the unique characteristics of different elements.

Atomic Models

In the 18th and 19th centuries, many scientists attempted to explain the structure of the atom with the help of atomic models. Each of these models had their own merits and demerits and were pivotal to the development of the modern atomic model. The most notable contributions to the field were by the scientists John Dalton, J.J. Thomson, Ernest Rutherford, and Niels Bohr. Their ideas on the structure of the atom are discussed in this subsection.

Dalton's Atomic Theory

The English chemist John Dalton suggested that all matter is made up of atoms, which were indivisible and indestructible. He also stated that all the atoms of an element were exactly the same, but the atoms of different elements differ in size and mass.

Chemical reactions, according to Dalton's atomic theory, involves a rearrangement of atoms to form products. According to the postulates proposed by Dalton, the atomic structure comprised of atoms, the smallest particle responsible for the chemical reactions to occur.

The following are the postulates of his theory:

- Every matter is made up of atoms.
- Atoms are indivisible.
- Specific elements have only one type of atoms in them.
- Each atom has its own constant mass that varies from element to element.
- Atoms undergo rearrangement during a chemical reaction.
- Atoms can neither be created nor be destroyed but can be transformed from one form to another.

Dalton's atomic theory successfully explained the Laws of chemical reactions, namely, the Law of conservation of mass, Law of constant properties, Law of multiple proportions, and Law of reciprocal proportions

Demerits of Dalton's Atomic Theory

- The theory was unable to explain the existence of isotopes.
- Nothing about the structure of atom was appropriately is explained.
- Later, the scientists discovered particles inside the atom that proved, the atoms are divisible.

The discovery of particles inside atoms led to a better understanding of chemical species, these particles inside the atoms are called subatomic particles. The discovery of various subatomic particles is as follows:

Subatomic Particles

Protons

- Protons are positively charged subatomic particles. The charge of a proton is $1e$, which corresponds to approximately 1.602×10^{-19}
- The mass of a proton is approximately 1.672×10^{-24}
- Protons are over 1800 times heavier than electrons.
- The total number of protons in the atoms of an element is always equal to the atomic number of the element.

Neutrons

- The mass of a neutron is almost the same as that of a proton i.e. 1.674×10^{-24}
- Neutrons are electrically neutral particles and carry no charge.
- Different isotopes of an element have the same number of protons but vary in the number of neutrons present in their respective nuclei.

Electrons

- The charge of an electron is $-1e$, which approximates to -1.602×10^{-19}
- The mass of an electron is approximately 9.1×10^{-31} .
- Due to the relatively negligible mass of electrons, they are ignored when calculating the mass of an atom.

Bohr's Atomic Theory

Neils Bohr put forth his model of the atom in the year 1915. This is the most widely used atomic model to describe the atomic structure of an element which is based on Planck's theory of quantization.

Postulates:

- The electrons inside atoms are placed in discrete orbits called "stationery orbits".
- The energy levels of these shells can be represented via quantum numbers.
- Electrons can jump to higher levels by absorbing energy and move to lower energy levels by losing or emitting its energy.
- As long as, an electron stays in its own stationery, there will be no absorption or emission of energy.
- Electrons revolve around the nucleus in these stationery orbits only.
- The energy of the stationary orbits is quantized.

Limitations of Bohr's Atomic Theory:

- Bohr's atomic structure works only for single electron species such as H, He⁺, Li²⁺, Be³⁺,
- When the emission spectrum of hydrogen was observed under a more accurate spectrometer, each line spectrum was seen to be a combination of no of smaller discrete lines.
- Both Stark and Zeeman effects couldn't be explain using Bohr's theory.

Heisenberg's uncertainty principle: Heisenberg stated that no two conjugate physical quantities can be measured simultaneously with 100% accuracy. There will always be some error or uncertainty in the measurement.

Drawback: Position and momentum are two such conjugate quantities which were measured accurately by Bohr (theoretically).

Stark effect: Phenomenon of deflection of electrons in the presence of an electric field.

Zeeman effect: Phenomenon of deflection of electrons in the presence of a magnetic field.

Dual Nature of Matter

The electrons which were treated to be particles, the evidence of photoelectric effect shows they also have wave nature. This was proved by Thomas young with the help of his double slit experiment.

De-Broglie concluded that since nature is symmetrical, so should be light or any other matter wave.

Quantum Numbers

- **Principal Quantum number (n):** It denotes the orbital number or shell number of electron.
- **Azimuthal Quantum numbers (l):** It denotes the orbital (sub-orbit) of the electron.
- **Magnetic Quantum number:** It denotes the number of energy states in each orbit.
- **Spin Quantum number(s):** It denotes the direction of spin, $S = -\frac{1}{2} =$ Anticlockwise and $\frac{1}{2} =$ Clockwise.

Electronic Configuration of an Atom

The electrons have to be filled in the s, p, d, f in accordance with the following rule.

1. Aufbau's principle: The filling of electrons should take place in accordance with the ascending order of energy of orbitals:

- Lower energy orbital should be filled first and higher energy levels.
- The energy of orbital $\propto (n + l)$ value if two orbitals have same $(n + l)$ value, $E \propto n$
- Ascending order of energy 1s, 2s, 2p, 3s, 3p, 4s, 3d, . . .

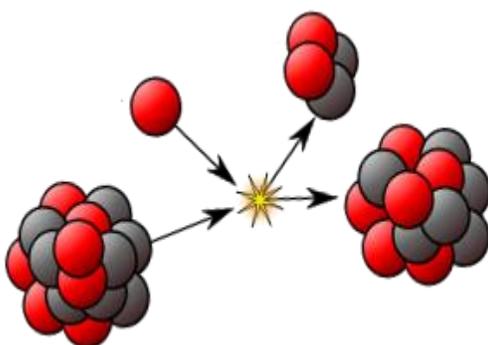
2. Pauli's exclusion principle: No two electrons can have all the four quantum numbers to be the same or, if two electrons have to be placed in an energy state they should be placed with opposite spins.

3. Hund's rule of maximum multiplicity: In case of filling degenerate (same energy) orbitals, all the degenerate orbitals have to be singly filled first and then only pairing has to happen.

Nuclear Force

The nuclear force (or nucleon–nucleon interaction or residual strong force) is a force that acts between the protons and neutrons of atoms. Neutrons and protons, both nucleons, are affected by the nuclear force almost identically. Since protons have charge $+1e$, they experience an electric force that tends to push them apart, but at short range the attractive nuclear force is strong enough to overcome the electromagnetic force. The nuclear force binds nucleons into atomic nuclei.

The nuclear force is a force that acts between the protons and neutrons of atoms.



The nuclear force is the force that binds the protons and neutrons in a nucleus together. This force can exist between protons and protons, neutrons and protons or neutrons and neutrons. This force is what holds the nucleus together.

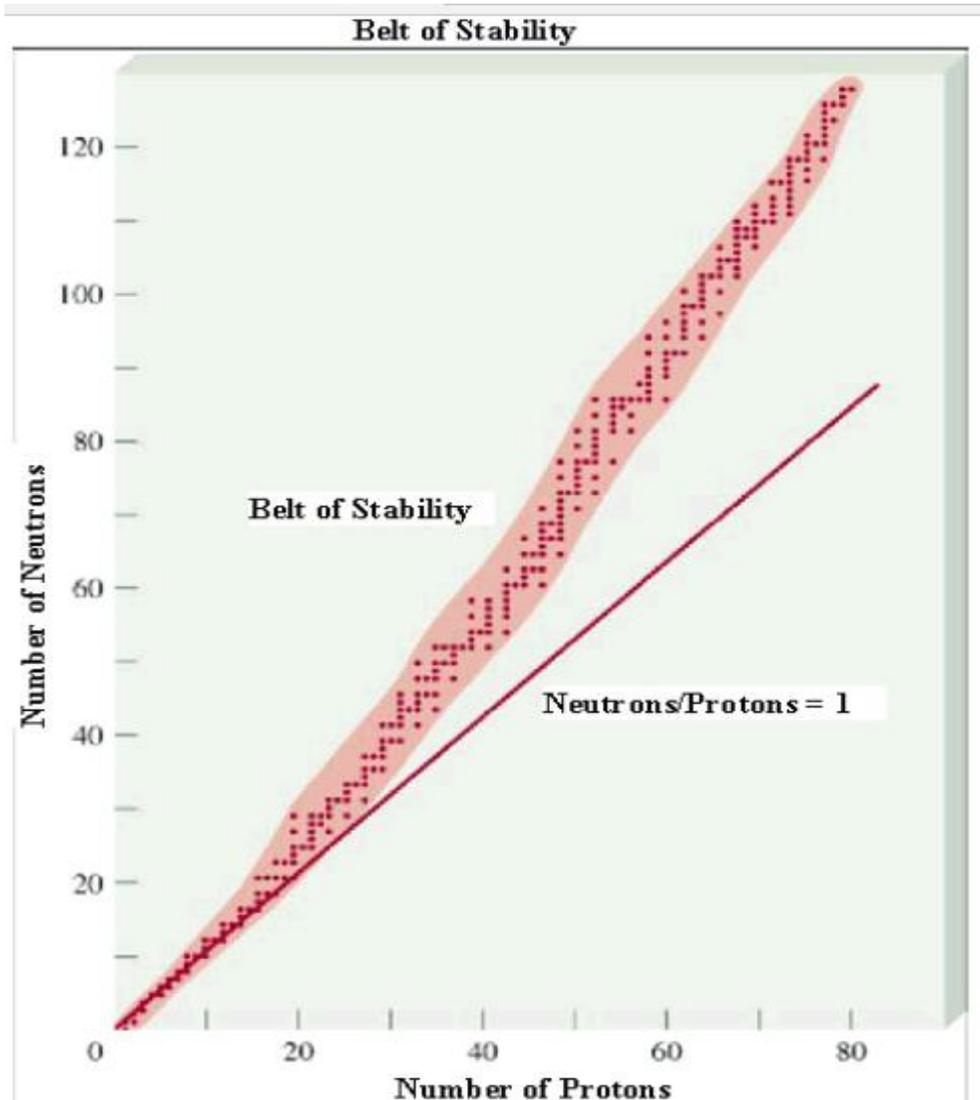
The charge of protons, which is $+1e$, tends to push them away from each other with a strong electric field repulsive force, following Coulomb's law. But nuclear force is strong enough to keep them together and to overcome that resistance at short range.

Nuclear Stability

A concept that helps to identify the stability of an isotope. To identify the stability of an isotope it is needed to find the ratio of neutrons to protons. To determine the stability of an isotope you can use the ratio neutron/proton (N/Z). Also to help understand this concept there is a chart of the nuclides, known as a Segre chart. This chart shows a plot of the known nuclides as a function of their atomic and neutron numbers. It can be observed from the chart that there are more neutrons than protons in nuclides with Z greater than about 20 (Calcium). These extra neutrons are necessary for stability of the heavier nuclei. The excess neutrons act somewhat like nuclear glue

Atomic nuclei consist of protons and neutrons, which attract each other through the nuclear force, while protons repel each other via the electric force due to their positive charge. These two forces compete, leading to various stability of nuclei. There are only certain combinations of neutrons and protons, which forms stable nuclei.

Neutrons stabilize the nucleus, because they attract each other and protons, which helps offset the electrical repulsion between protons. As a result, as the number of protons increases, an increasing ratio of neutrons to protons is needed to form a stable nucleus. If there are too many or too few neutrons for a given number of protons, the resulting nucleus is not stable and it undergoes radioactive decay. Unstable isotopes decay through various radioactive decay pathways, most commonly alpha decay, beta decay, or electron capture. Many other rare types of decay, such as spontaneous fission or neutron emission are known. It should be noted that all of these decay pathways may be accompanied by the subsequent emission of **gamma radiation**. Pure alpha or beta decays are very rare.



mass defect

the amount by which the mass of an atomic nucleus differs from the sum of the masses of its constituent particles, being the mass equivalent of the energy released in the formation of the nucleus.

Calculation of Mass Defect The mass defect can be calculated using Equation 10-1. In calculating the mass defect, it is important to use the full accuracy of mass measurements because the difference in mass is small compared to the mass of the atom. Rounding off the masses of atoms and particles to three or four significant digits prior to the calculation will result in a calculated mass defect of zero.

mass defect of zero.

$$\Delta m = [Z(m_p + m_e) + (A - Z)m_n] - m_{\text{atom}} \quad (10-1)$$

where:

Δm = mass defect (amu)

m_p = mass of a proton (1.007277 amu)

m_n = mass of a neutron (1.008665 amu)

m_e = mass of an electron (0.000548597 amu)

m_{atom} = mass of nuclide X^A_Z (amu)

Z = atomic number (number of protons)

A = mass number (number of nucleons)

Nuclear binding energy

An example that illustrates nuclear binding energy is the nucleus of ^{12}C (carbon-12), which contains 6 protons and 6 neutrons. The protons are all positively charged and repel each other, but the nuclear force overcomes the repulsion and causes them to stick together. The nuclear force is a close-range force (it is strongly attractive at a distance of 1.0 fm and becomes extremely small beyond a distance of 2.5fm), and virtually no effect of this force is observed outside the nucleus. The nuclear force also pulls neutrons together, or neutrons and protons.

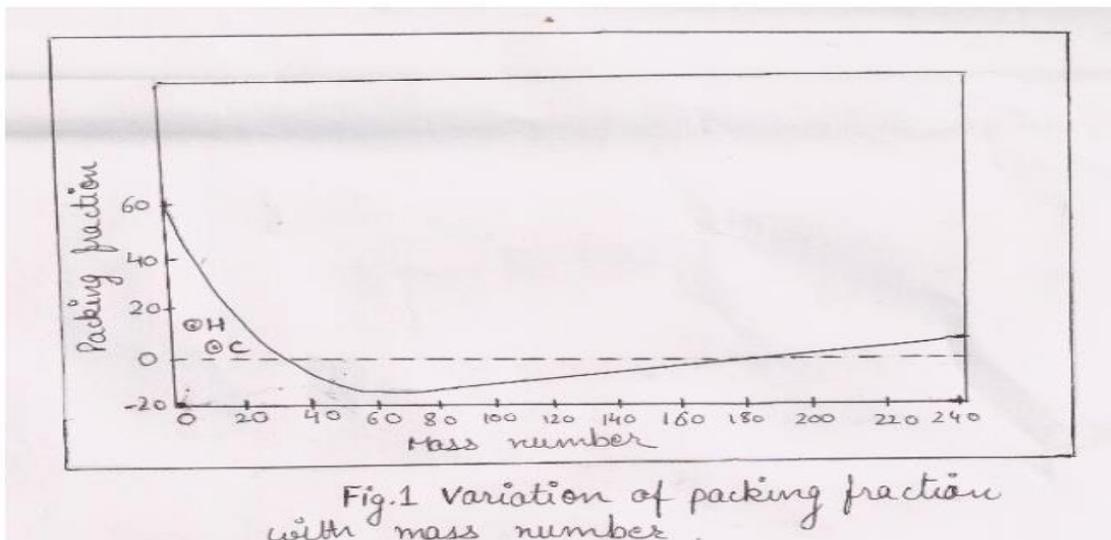
The energy of the nucleus is negative with regard to the energy of the particles pulled apart to infinite distance (just like the gravitational energy of planets of the solar system), because energy must be utilized to split a nucleus into its individual protons and neutrons. Mass spectrometers have measured the masses of nuclei, which are always less than the sum of the masses of protons and neutrons that form them, and the difference—by the formula $E = m c^2$ —gives the binding energy of the nucleus.

What is Packing Fraction?

Packing fraction is defined as a way of expressing the variation of isotopic mass from whole mass number (atomic mass).

$$\text{Packing fraction} = \frac{\text{Isotopic mass} - \text{Mass number}}{\text{Mass number}} * 10^4$$

This fraction can have positive or can have negative sign. A positive packing fraction describes a tendency towards instability. A negative packing fraction means isotopic mass is less than actual mass number. This difference is due to the transformation of mass into energy in the formation of nucleus. A plot of packing fraction against corresponding mass no's of various elements is as shown.



From figure it is clear that the elements which have less atomic mass (hydrogen, helium, carbon) do not fall on this curve. Therefore, these are stable atoms. Oxygen is highly stable. The packing fraction beyond mass number 200 becomes positive and increases with increase in mass number. It increases instability of these elements.

Even and odd rule

In nuclear physics, properties of a nucleus depend on evenness or oddness of its atomic number Z , neutron number N and, consequently, of their sum, the mass number A . Most importantly, oddness of both Z and N tends to lower the nuclear binding energy, making odd nuclei generally less stable. This effect is not only experimentally observed, but is included in the semi-empirical mass formula and explained by some other nuclear models, such as the nuclear shell model. This difference of nuclear binding energy between neighbouring nuclei, especially of odd- A isobars, has important consequences for beta decay.

Also, the nuclear spin is integer (mostly 0) for all even-*A* nuclei and non-integer (half-integer) for all odd-*A* nuclei.

Even vs. odd mass number (*A*).

	Even	Odd	Total
Stable	151	101	252
Long-lived	25	9	34
All primordial	176	110	286

The neutron–proton ratio is not the only factor affecting nuclear stability. Adding neutrons to isotopes can vary their nuclear spins and nuclear shapes, causing differences in neutron capture cross sections and gamma spectroscopy and nuclear magnetic resonance properties. If too many or too few neutrons are present with regard to the nuclear binding energy optimum, the nucleus becomes unstable and subject to certain types of nuclear decay. Unstable nuclides with a nonoptimal number of neutrons or protons decay by beta decay (including positron decay), electron capture, or other means, such as spontaneous fission and cluster decay.

Even mass number

Nuclei with even mass number are relatively more stable. Even-mass-number nuclides, which comprise $151/252 = \sim 60\%$ of all stable nuclides, are bosons, i.e. they have integer spin. 146 of the 151 are even-proton, even-neutron (EE) nuclides, which necessarily have spin 0 because of pairing. The remainder of the stable bosonic nuclides are 5 odd-proton, odd-neutron stable nuclides

Even/odd *Z*, *N* (Hydrogen-1 included as OE)

<i>p,n</i>	EE	OO	EO	OE	Total
Stable	146	5	53	48	252
Long-lived	21	4	4	5	34
All primordial	167	9	57	53	286

Odd proton, even neutron

These 48 stable nuclides, stabilized by their even numbers of paired neutrons, form most of the stable isotopes of the odd-numbered elements; the very few odd–odd nuclides comprise the others. There are 41 odd-numbered elements with $Z = 1$ through 81, of which 30 (including hydrogen, since zero is an even number) have one stable odd-even isotope, the elements technetium

$^{87}_{37}\text{Rb}$, $^{115}_{49}\text{In}$, $^{187}_{75}\text{Re}$, $^{151}_{63}\text{Eu}$, and $^{209}_{83}\text{Bi}$.

Odd neutron number

Actinides with odd neutron number are generally fissile (with thermal neutrons), while those with even neutron number are generally not, though they are fissionable with fast neutrons. have odd neutron number and are the most naturally abundant isotope of their element.

$^{195}_{78}\text{Pt}$, ^9_4Be and $^{14}_7\text{N}$

Liquid Drop Model

According to this model, the atomic nucleus behaves like the molecules in a drop of liquid. But in this nuclear scale, the fluid is made of nucleons (protons and neutrons), which are held together by the strong nuclear force. The liquid drop model of the nucleus takes into account the fact that the nuclear forces on the nucleons on the surface are different from those on nucleons in the interior of the nucleus. The interior nucleons are completely surrounded by other attracting nucleons. Here is the analogy with the forces that form a drop of liquid.

In the ground state the nucleus is spherical. If the sufficient kinetic or binding energy is added, this spherical nucleus may be distorted into a dumbbell shape and then may be splitted into two fragments. Since these fragments are a more stable configuration, the splitting of such heavy nuclei must be accompanied by energy release. This model does not explain all the properties of the atomic nucleus, but does explain the predicted nuclear binding energies.

The nuclear binding energy as a function of the mass number A and the number of protons Z based on the liquid drop model can be written as:

$$E_b(\text{MeV}) = a_V A - a_S A^{\frac{2}{3}} - a_C \frac{Z^2}{A} - a_A \frac{(A - 2Z)^2}{A} \pm \delta(A, Z)$$

$$\delta(A, Z) = \begin{cases} +\delta_0 & \text{for } Z, N \text{ even} \\ 0 & \\ -\delta_0 & \text{for } Z, N \text{ odd} \end{cases}$$



Nuclear shell model

The shell model is partly analogous to the atomic shell model which describes the arrangement of electrons in an atom, in that a filled shell results in greater stability. When adding nucleons (protons or neutrons) to a nucleus, there are certain points where the binding energy of the next nucleon is significantly less than the last one. This observation, that there are certain magic numbers of nucleons (2, 8, 20, 28, 50, 82, 126) which are more tightly bound than the next higher number, is the origin of the shell model.

The shells for protons and for neutrons are independent of each other. Therefore, "magic nuclei" exist in which one nucleon type or the other is at a magic number, and "doubly magic nuclei", where both are. Due to some variations in orbital filling, the upper magic numbers are 126 and, speculatively, 184 for neutrons but only 114 for protons, playing a role in the search for the so-called island of stability. Some semi-magic numbers have been found, notably $Z = 40$ giving nuclear shell filling for the various elements; 16 may also be a magic number.

The magic numbers are then S

- 2
- $8=2+6$
- $20=2+6+12$
- $28=2+6+12+8$
- $50=2+6+12+8+22$
- $82=2+6+12+8+22+32$
- $126=2+6+12+8+22+32+44$
- $184=2+6+12+8+22+32+44+58$
-

What are Isotopes?

Isotopes are atoms with the same number of protons, but differing numbers of neutrons. A number of protons in the atom is the atomic number of that atom. A particular chemical element has a fixed number of protons. Hence, the atomic number of the atoms of the same chemical element is similar to each other. Therefore, isotopes are atoms of the same chemical element. The total number of protons and neutrons is known as the atomic mass. Isotopes have different atomic masses.

An isotope is named using the name of the chemical element and the atomic mass of the isotope. For example, the two isotopes of Helium are noted as "helium-2" and "helium-4".

What are Isobars?

Isobars are atoms of different chemical elements having equal values for atomic mass. Atomic mass is the sum of protons and neutrons in the nucleus of an atom. A proton or a neutron is known as a **nucleon**. Therefore, isobars have the same number of nucleons.

The atomic numbers of these isobars are different from each other because different chemical elements have different atomic numbers. The Mattauch isobar rule states that if two adjacent elements on the periodic table have isotopes of the same mass number (isobars), one of these isotopes must be radioactive. If there are isobars of three sequential elements exist, first and last isobars are stable, and the middle one may undergo radioactive decay. An isobar series is a collection of different isotopes that have the same atomic mass.

Isobar Series	Members of the series
40	^{40}S , ^{40}Cl , ^{40}Ar , ^{40}K , and ^{40}Ca
58	^{58}Fe and ^{58}Ni
76	^{76}Ce and ^{76}Se

What are Isotones?

Isotones are atoms of different elements having an equal number of neutrons in the atomic nucleus. Isotones have different atomic numbers (number of protons in the nucleus is different from each other) as well as different atomic masses. It can be expressed as below;

Atomic number = Z

Atomic mass = A

Number of neutron = N

For all isotones in one series, $A \neq Z$ but $(A-Z)=N$ (N is equal for all the isotones in one series). Some examples for isotones are given below.

Isotone Series	Members of the series
20	^{36}S , ^{37}Cl , ^{38}Ar , ^{39}K , and ^{40}Ca
50	^{86}Kr , ^{88}Sr , ^{89}Y , ^{90}Zr and ^{92}Mo
82	^{138}Ba , ^{139}La , ^{140}Ce , ^{141}Pr , ^{142}Nd and ^{144}Sm

Isotopes

Isotopes are two atoms with the same number of protons, but a different number of neutrons. Because they have the same number of proton they are atoms of the same element, but with different masses. ... Isomers are two molecules with the same atoms joined together in a different shape.

Isotopes differ from one another in the number of neutrons they possess. Because of their differing number of neutrons, isotopes also differ in their mass numbers, the total number of protons and neutrons.

Isomers

The structures of these isomers differ in the orientation of the two chloride ions around the Co^{3+} ion. In the trans isomer, the chlorides occupy positions across from one another in the octahedron. In the cis isomer, they occupy adjacent positions.

Isotopes	Isobars
Isotopes are the atoms of the same element with similar atomic number but different atomic mass.	Isobars are the atoms of different elements with same mass number but different atomic numbers.
They shares same chemical properties and different physical properties.	They have different chemical properties and different physical properties because these are the atoms of different elements.

Isotopes, Isomers, Isobars

- Isotopes = elements having the same Z but different A , e.g., ^{131}I , ^{125}I , ^{127}I
- Isomers = identical elements, but different nuclear energy states, e.g., ^{99m}Tc , ^{99}Tc
- Isobars = elements having the same A but different Z
- Isotones = elements having the same N

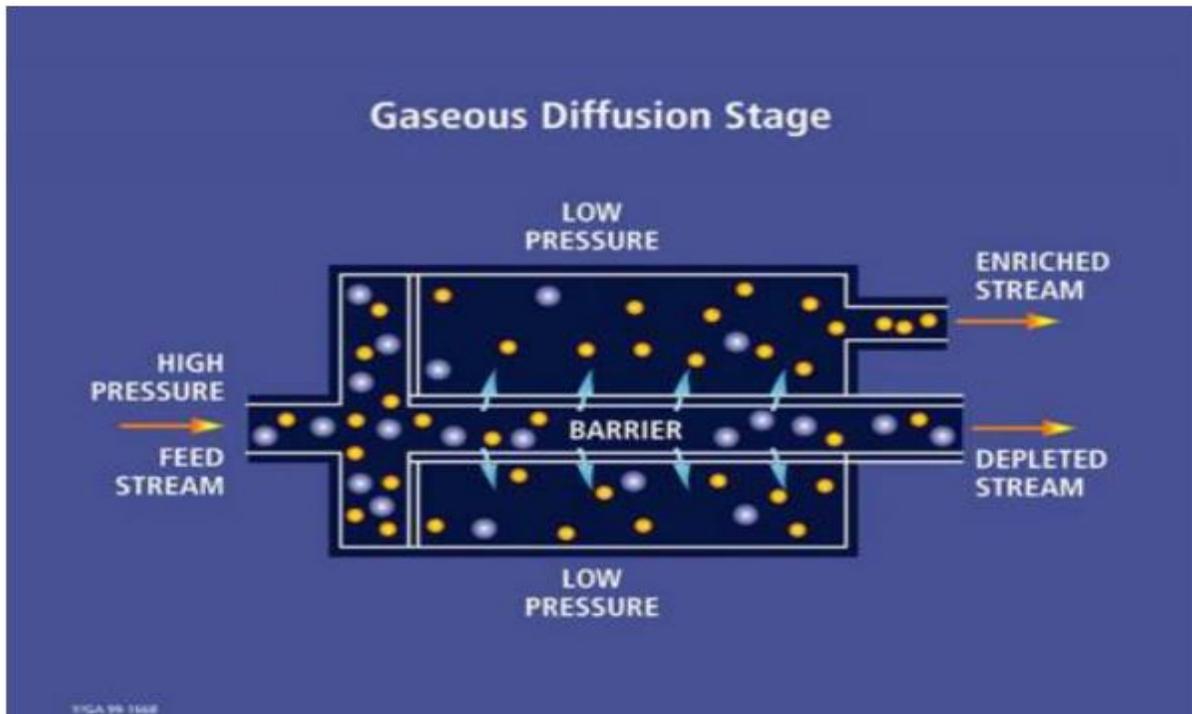
Isotope identification devices are usually quite compact and very sensitive radiation isotope identification device, which enables detection, localization and identification of radioactive and nuclear materials. Isotope types are detected by their neutron and gamma radiation along with their amplitude gamma spectra.

Isotope Separation Methods

Once the power that was hidden in uranium became evident, the emphasis shifted to methods to separate the much more potent U-235 from its abundant relative, U-238. This question consumed thousands of hours and millions of dollars.

Scientists had concluded that enriched samples of uranium-235 were necessary for further research and that the isotope might serve as an efficient fuel source for an explosive device. "Enrichment" meant increasing the proportion of U-235, relative to U-238, in a uranium sample. This required separating the two isotopes and discarding U-238. Uranium-235 occurred in a ratio of 1:139 in natural uranium ore. Since they were chemically identical, they could not be separated by chemical means. Furthermore, with their masses differing by less than 1 percent, separation by physical means would be extremely difficult and expensive.

Nevertheless, scientists pressed forward on several complicated techniques of physical separation, all based on the small difference in atomic weight between the uranium isotopes. Manhattan Project director General Leslie Groves wanted to investigate as many possibilities as possible, and had the resources to simultaneously pursue multiple speculative projects.



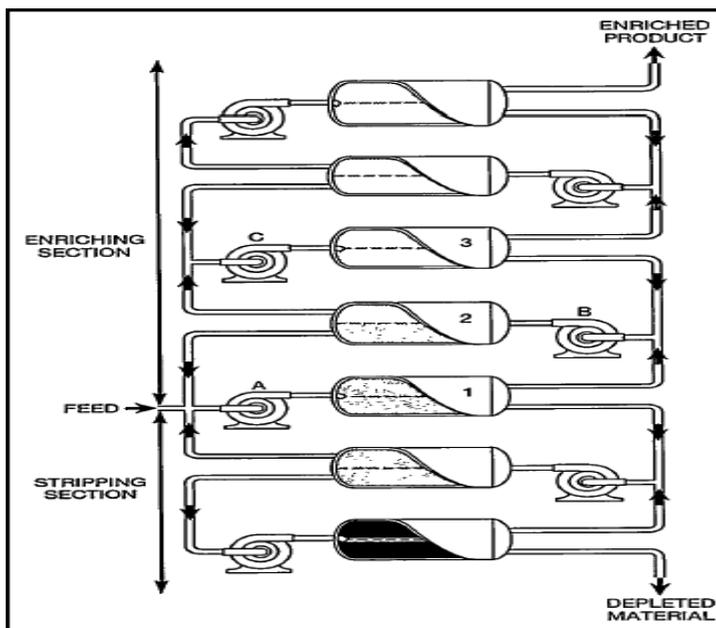
Electromagnetic Separation

The electromagnetic method, pioneered by Alfred Nier of the University of Minnesota, used a mass spectrometer, or spectrograph, to send a stream of charged particles through a strong magnetic field. Atoms of the lighter isotope (U-235) would be deflected more by the magnetic field than those of the heavier isotope (U-238), resulting in two streams that could then be collected by different receivers.

The electromagnetic method as it existed in 1940, however, would have taken too long to separate quantities sufficient to be used in the current war. In fact, 27,000 years would have been required for a single spectrometer to separate 1 gram of uranium-235.

Ernest O. Lawrence of the Radiation Lab at the University of California at Berkeley favored this method and converted his giant cyclotron to accomplish this form of separation more efficiently. This model led to the eventual design and construction of the huge Y-12 Plant complex at Oak Ridge, Tennessee. Because of its exorbitant cost, electromagnetic separation was largely abandoned after the war for weapons production, but it played an important role in the development of the field of nuclear medicine.

Gaseous Diffusion



Gaseous diffusion's principle was simple: molecules of a lighter isotope would pass through a porous barrier more readily than those of a heavier isotope. The tiny weight difference between U-235 and U-238 meant that initial separation would be negligible. Repeat the process hundreds of times in sequential "cascades," though, and the end product would be significantly enriched uranium.

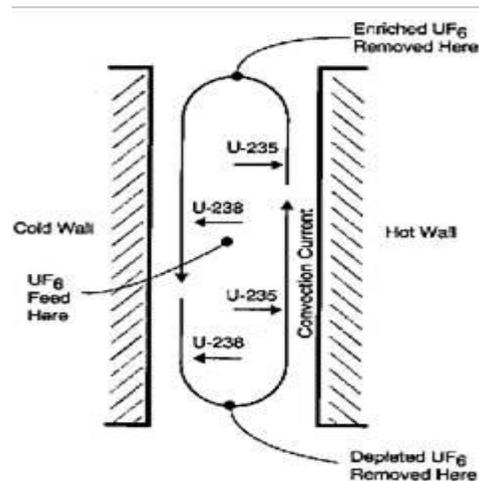
Gaseous diffusion seemed promising in theory, but would clearly be difficult to implement on an industrial scale. Besides the massive scale involved, it was completely unclear in 1940 and 1941 how to construct a satisfactory apparatus for gaseous diffusion. Because of these problems, the S-1 committee did not make this method a priority.

Significant early work on gaseous diffusion happened in Britain, primarily at chemical conglomerate Imperial Chemical Industries (ICI) and the University of Birmingham. Both succeeded in producing a prototype of gaseous diffusion. Starting in 1941, a team at Columbia University in New York also researched gaseous diffusion, and produced a slightly different model.

Centrifuge research faltered in 1942, and General Leslie Groves pushed for more research into gaseous diffusion. In mid-1943, Roosevelt and Churchill signed the Quebec Agreement, under which British nuclear research was subsumed into the Manhattan Project; this meant full exchange of information. But serious problems remained. Besides the need for a porous barrier, component design would have to accommodate uranium hexafluoride, one of the most corrosive gases in the world.

Groves soon ordered the construction of K-25, but as construction crews cleared the site and poured the foundation it was still unclear what exactly was going to go inside the plant. To protect the pipes from corrosion, contractors undertook the new process of nickel coating. Sealing the pipes was also a problem, as grease would interfere with the process and uranium hexafluoride could not be permitted to leak out. The eventual solution was a completely novel seal material: Teflon.

Kellex Corporation undertook the barrier problem: developing a thin metal membrane with millions of tiny openings. After months of research and competition with an incomplete design from the team at Columbia, Groves accepted the Kellex design and ordered it installed in K-25. K-25, the largest roofed building in the world upon construction, would eventually serve as an intermediary step between S-50 and Y-12. Gaseous diffusion was important throughout the Cold War, but uses far more energy than centrifuges, and is now nearly obsolete.



Liquid Thermal Diffusion

The Uranium Committee briefly demonstrated an interest in a fourth enrichment process during 1940, only to conclude that it would not be worth pursuing. This process, liquid thermal diffusion, was being investigated by Philip Abelson at the Carnegie Institution in Washington. Abelson placed pressurized liquid uranium hexafluoride into the space between two concentric vertical pipes. With the outer wall cooled by a circulating water jacket and the inner wall heated by high-pressure steam, the lighter U-235 isotope tended to concentrate near the hot wall and the heavier U-238 near the cold. Over time, convection would carry the lighter isotope to the top of the column where it could be drawn off. Taller columns would produce more separation.

Like other enrichment methods, liquid thermal diffusion was at an early stage in 1940. Abelson eventually relocated his experimentation to the Naval Research Laboratory in Washington, DC, whereupon money was obtained to construct a pilot plant at the Philadelphia Navy Yard. When Oppenheimer learned the Navy was using liquid thermal diffusion for enriched uranium in submarines, the Manhattan Project subsequently built the S-50 Plant, which enriched uranium slightly before it was sent to K-25 and Y-12 for further enrichment. The inefficiency of this method meant that, like electromagnetic separation, it was obsolete after the war.

Radioactivity

the emission of ionizing radiation or particles caused by the spontaneous disintegration of atomic nuclei.

- **Radioactive decay** (also known as nuclear decay, radioactivity, radioactive disintegration or nuclear disintegration) is the process by which an unstable atomic nucleus loses energy by radiation. A material containing unstable nuclei is considered radioactive. Three of the most common types of decay are alpha decay, beta decay, and gamma decay, all of which involve emitting one or more particles or photons. The weak force is the mechanism that is responsible for Alpha decay occurs when the nucleus ejects an alpha particle (helium nucleus).

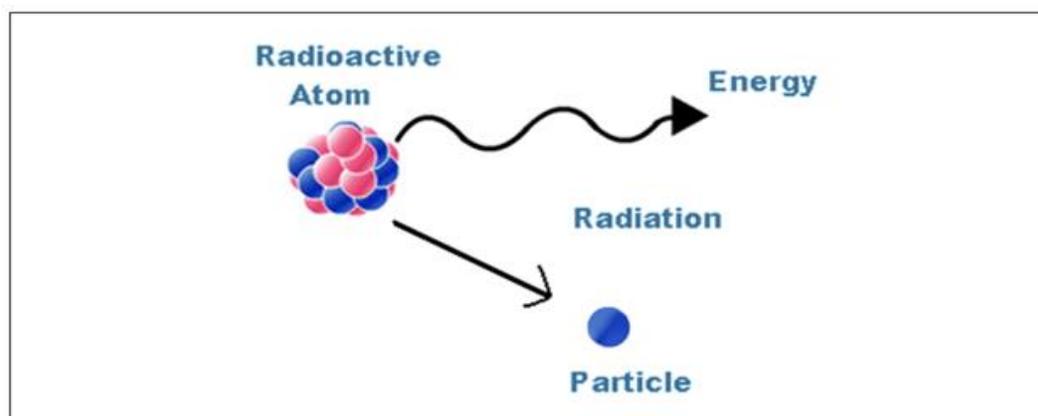
- Beta decay occurs in two ways;
 - (i) beta-minus decay, when the nucleus emits an electron and an antineutrino in a process that changes a neutron to a proton, or
 - (ii) beta-plus decay, when the nucleus emits a positron and a neutrino in a process that changes a proton to a neutron.
- In gamma decay a radioactive nucleus first decays by the emission of an α or β particle. The daughter nucleus that results is usually left in an excited state and it can decay to a lower energy state by emitting a gamma ray photon.
- In Neutron emission highly excited neutron-rich nuclei, formed due to other types of decay, occasionally lose energy by way of neutron emission, resulting in a change from one isotope to another of the same element.
- In Electron capture The nucleus may capture an orbiting electron, causing a proton to convert into a neutron in a process called electron capture. All of these processes result in a well-defined nuclear transmutation.

beta decay.

Radioactive emanation.

A **radioactive gas** given off by certain radioactive elements; all of these gases are isotopes of the element radon. Also known as emanation.

Properties of Alpha, Beta and Gamma Rays



During radioactivity, particles like alpha, beta & gamma rays are emitted by an atom, due to unstable atom trying to gain stability. Hence, the atoms eventually decay by emitting a particle that transforms when they are unstable and transforms the nucleus into a lower energy state. This process of decaying continues till the nucleus attains a stable stage.

There exist three major types of radiations emitted by the radioactive particles namely:

- Alpha
- Beta
- Gama

These radiations are released from the nucleus of an atom. Their behavior differs from one another, though all the three causes some ionization and carry some penetration power. Let's discuss the properties of beta, alpha and gamma one by one.

Alpha Rays

Alpha rays are the positively charged particles. Alpha-particle is highly active and energetic helium atom that contains two neutrons and protons. These particles have the minimum penetration power and highest ionization power. They can cause serious damage if get into the body due to their high ionization power. They are capable of ionizing numerous atoms by a short distance. It is due to the fact that the radioactive substances that release alpha particles are required to be handled after wearing rubber gloves.

Beta Rays

Beta particles are extremely energetic electrons that are liberated from the inner nucleus. They bear negligible mass and carry the negative charge. A neutron in the nucleus splits into a proton and an electron on the emission of a beta particle. Hence, it is the electron that is emitted by the nucleus at a rapid pace. Beta particles have a higher penetration power when compared to alpha particles and can travel through the skin with ease. Beta particles can be dangerous and any contact with the body must be avoided, though their ionization power is low.

Gamma Rays

The waves arising from the high-frequency end of the electromagnetic spectrum that has no mass are known as gamma rays. They hold the highest power of penetration. They are the most penetrating but least ionizing and very difficult to resist them from entering the body. The Gamma rays carry a large amount of energy and can also travel via thick concrete and thin lead.

The below table describes the characteristics of beta, alpha and gamma radiations and compares the masses and charges of the three rays.

Property	α ray	β ray	γ ray
Nature	Positive charged particles, ${}^4_2\text{He}$ nucleus	Negatively charged particles (electrons).	Uncharged ?~0.01a, electromagnetic radiation
Charge	+2e	-e	0
Mass	6.6466×10^{-27} kg	9.109×10^{-31} kg	0
Range	~10 cm in air, can be stopped by 1mm of Aluminium	Upto a few m in air, can be stopped by a thin layer of Aluminium	Several m in air, can be stopped by a thick layer of Lead
Natural Sources	By natural radioisotopes e.g. ${}^{238}\text{U}$	By radioisotopes e.g. ${}^{60}\text{Co}$	Excited nuclei formed as a result of Gamma decay

Stay tuned with Byju's to learn more about characteristics of alpha, beta and gamma rays along with their differentiation and common features.

Radioactive decay rates

Constant quantities:

- The *half-life*— $t_{1/2}$, is the time taken for the activity of a given amount of a radioactive substance to decay to half of its initial value; see List of nuclides.
- The *decay constant*— λ , "lambda" the reciprocal of the mean lifetime (in s^{-1}), sometimes referred to as simply *decay rate*.
- The *mean lifetime*— τ , "tau" the average lifetime (1/e life) of a radioactive particle before decay.

Although these are constants, they are associated with the statistical behavior of populations of atoms. In consequence, predictions using these constants are less accurate for minuscule samples of atoms.

In principle a half-life, a third-life, or even a $(1/\sqrt{2})$ -life, can be used in exactly the same way as half-life; but the mean life and half-life $t_{1/2}$ have been adopted as standard times associated with exponential decay.

Time-variable quantities:

- *Total activity*— A , is the number of decays per unit time of a radioactive sample.
- *Number of particles*— N , is the total number of particles in the sample.
- *Specific activity*— S_A , number of decays per unit time per amount of substance of the sample at time set to zero ($t = 0$). "Amount of substance" can be the mass, volume or moles of the initial sample.

$$t_{1/2} = \frac{\ln(2)}{\lambda} = \tau \ln(2)$$

$$A = -\frac{dN}{dt} = \lambda N$$

$$S_A a_0 = -\frac{dN}{dt} \Big|_{t=0} = \lambda N_0$$

where N_0 is the initial amount of active substance — substance that has the same percentage of unstable particles as when the substance was formed.

Half-life

A more commonly used parameter is the half-life. Given a sample of a particular radionuclide, the half-life is the time taken for half the radionuclide's atoms to decay. For the case of one-decay nuclear reactions:

$$N = N_0 e^{-\lambda t} = N_0 e^{-t/\tau},$$

the half-life is related to the decay constant as follows: set $N = N_0/2$ and $t = T_{1/2}$ to obtain

$$t_{1/2} = \frac{\ln 2}{\lambda} = \tau \ln 2.$$

This relationship between the half-life and the decay constant shows that highly radioactive substances are quickly spent, while those that radiate weakly endure longer. Half-lives of known radionuclides vary widely, from more than 10^{24} years for the very nearly stable nuclide ^{128}Te , to 2.3×10^{-23} seconds for highly unstable nuclides such as ^7H .

The factor of $\ln(2)$ in the above relations results from the fact that the concept of "half-life" is merely a way of selecting a different base other than the natural base e for the lifetime expression. The time constant τ is the $e-1$ -life, the time until only $1/e$ remains, about 36.8%, rather than the 50% in the half-life of a radionuclide. Thus, τ is longer than $t_{1/2}$. The following equation can be shown to be valid:

$$N(t) = N_0 e^{-t/\tau} = N_0 2^{-t/t_{1/2}}.$$

Since radioactive decay is exponential with a constant probability, each process could as easily be described with a different constant time period that (for example) gave its "(1/3)-life" (how long until only 1/3 is left) or "(1/10)-life" (a time period until only 10% is left), and so on. Thus, the choice of τ and $t_{1/2}$ for marker-times, are only for convenience, and from convention. They reflect a fundamental principle only in so much as they show that the *same proportion* of a given radioactive substance will decay, during any time-period that one chooses.

Mathematically, the n^{th} life for the above situation would be found in the same way as above—by setting $N = N_0/n$, $t = T_{1/n}$ and substituting into the decay solution to obtain

$$t_{1/n} = \frac{\ln n}{\lambda} = \tau \ln n.$$

Example for carbon-14

Carbon-14 has a half-life of 5,730 years and a decay rate of 14 disintegrations per minute (dpm) per gram of natural carbon.

If an artifact is found to have radioactivity of 4 dpm per gram of its present C, we can find the approximate age of the object using the above equation:

$$N = N_0 e^{-t/\tau},$$

where: $\frac{N}{N_0} = 4/14 \approx 0.286,$

$$\tau = \frac{T_{1/2}}{\ln 2} \approx 8267 \text{ years},$$

$$t = -\tau \ln \frac{N}{N_0} \approx 10356 \text{ years}.$$

DISINTEGRATION SERIES

“All the disintegration steps involved in the formation of a non-radioactive element from a radioactive element constitute the disintegration series.”

Types of Disintegration Series- There are four disintegration series.

4. **i) Thorium Series or 4n series-** The mass number of all the elements of this series are divisible by 4. The various steps of this series are given below:



- 2) **Neptunium Series or (4n+1) Series-** The mass number of the elements of this series are divided by 4, the remainder is always one. The elements formed in this series are not found in nature. It is called artificial series. The various steps of this series are as-



- 3) **Uranium Series or (4n+2) Series-** The mass number of the elements of this series are divided by 4, remainder is always 2, This series starts from U^{238} and ends at Pb^{206} .

4) Actiuranium Series or (4n+3) series- The mass number of the elements of this series are divided by 4, remainder is always 3. This series starts from ${}_{92}\text{U}^{235}$. The name actiuranium (ACU) was given to the isotope ${}_{92}\text{U}^{235}$ earlier. Therefore the series is called actinium series

Therefore the series is called actinium series

Disintegration Series	Parent Element	Last Stable element	Total No.1 of α - and β -particles emitted
1. Thorium Series or 4n series	${}_{90}\text{Th}^{232}$	${}_{82}\text{Pb}^{208}$	6 α and 4 β
2. Neptunium Series or (4n+1) series	${}_{93}\text{Np}^{237}$	${}_{83}\text{Bi}^{209}$	7 α and 4 β
3. Uranium Series or (4n+2) series	${}_{92}\text{U}^{238}$	${}_{82}\text{Pb}^{206}$	8 α and 6 β
4. Actinium Series or (4n+3) series	${}_{92}\text{U}^{235}$	${}_{82}\text{Pb}^{207}$	7 α and 4 β

Geiger–Nuttall law

The Geiger–Nuttall law or Geiger–Nuttall rule relates the decay constant of a radioactive isotope with the energy of the alpha particles emitted. Roughly speaking, it states that short-lived isotopes emit more energetic alpha particles than long-lived ones. The relationship also shows that half-lives are exponentially dependent on decay energy, so that very large changes in half-life make comparatively small differences in decay energy, and thus alpha particle energy

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The relationship also shows that half-lives are exponentially dependent on decay energy, so that very large changes in half-life make comparatively small differences in decay energy, and thus alpha particle energy. In practice, this means that alpha particles from all alpha-emitting isotopes across many orders of magnitude of difference in half-life, all nevertheless have about the same decay energy.

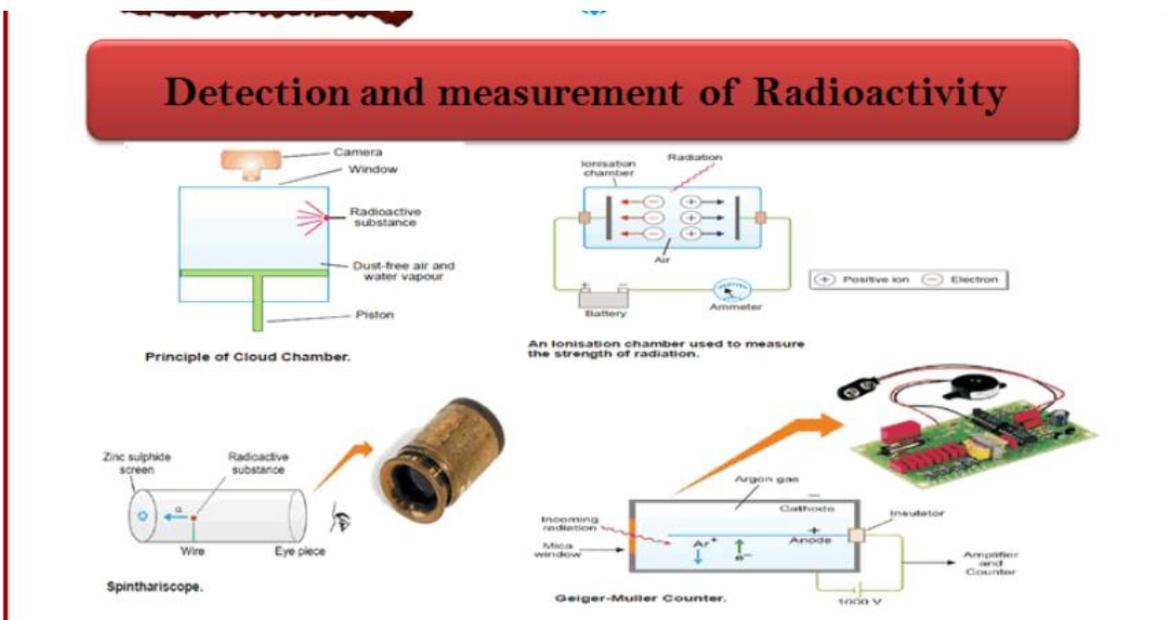
Formulated in 1911 by Hans Geiger and John Mitchell Nuttall as a relation between the decay constant and the range of alpha particles in air, in its modern form the Geiger–Nuttall law is

$$\log_{10} \lambda = -a_1 \frac{Z}{\sqrt{E}} + a_2$$

where λ is the decay constant ($\lambda = \ln 2 / \text{half-life}$), Z the atomic number, E the total kinetic energy (of the alpha particle and the daughter nucleus), and a_1 and a_2 are constants. The law works best for nuclei with even atomic number and even atomic mass. The trend is still there for even-odd, odd-even, and odd-odd nuclei but not as pronounced.

UNIT II

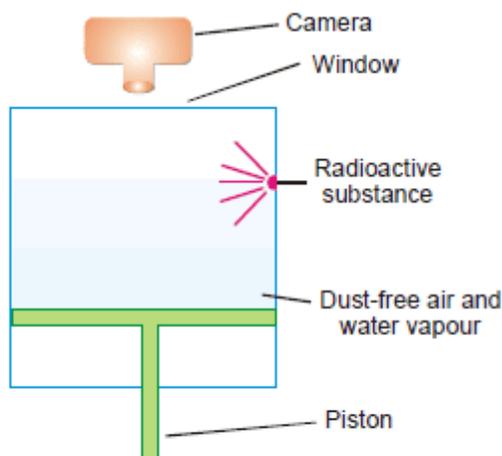
NUCLEAR CHEMISTRY II



The radioactive radiation can be detected and measured by a number of methods. The important ones used in modern practice are listed below.

(1) *Cloud Chamber*

- ** This technique is used for detecting radioactivity.
- ** The chamber contains air saturated with water vapour.
- ** When the piston is lowered suddenly, the gas expands and is supercooled.
- ** As an α - or β -particle passes through the gas, ions are created along its path. These ions provide nuclei upon which droplets of water condense.
- ** The trail or cloud thus produced marks the track of the particle. The track can be seen through the window above and immediately photographed.
- ** Similarly, α - or β -particles form a trail of bubbles as they pass through liquid hydrogen.
- ** The bubble chamber method gives better photographs of the particle tracks.



Principle of Cloud Chamber.

(2) Ionization Chamber

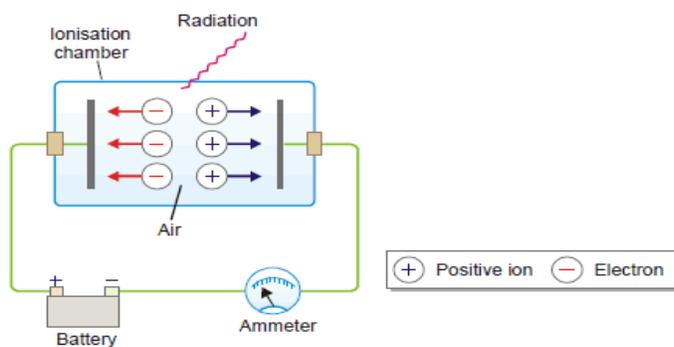
** This is the simplest device used to measure the strength of radiation.

** An ionization chamber is fitted with two metal plates separated by air.

** When radiation passes through this chamber, it knocks electrons from gas molecules and positive ions are formed.

** The electrons migrate to the anode and positive ions to the cathode. Thus a small current passes between the plates. This current can be measured with an ammeter, and gives the strength of radiation that passes through the ionization chamber.

** In an ionization chamber called Dosimeter, the total amount of electric charge passing between the plates in a given time is measured. This is proportional to the total amount of radiation that has gone through the chamber.



An Ionisation chamber used to measure the strength of radiation.

(3) Geiger-Muller Counter

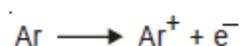
** This device is used for detecting and measuring the rate of emission of α - or β particles.

** It consists of a cylindrical metal tube (cathode) and a central wire (anode).

** The tube is filled with argon gas at reduced pressure (0.1 atm).

** A potential difference of about 1000 volts is applied across the electrodes.

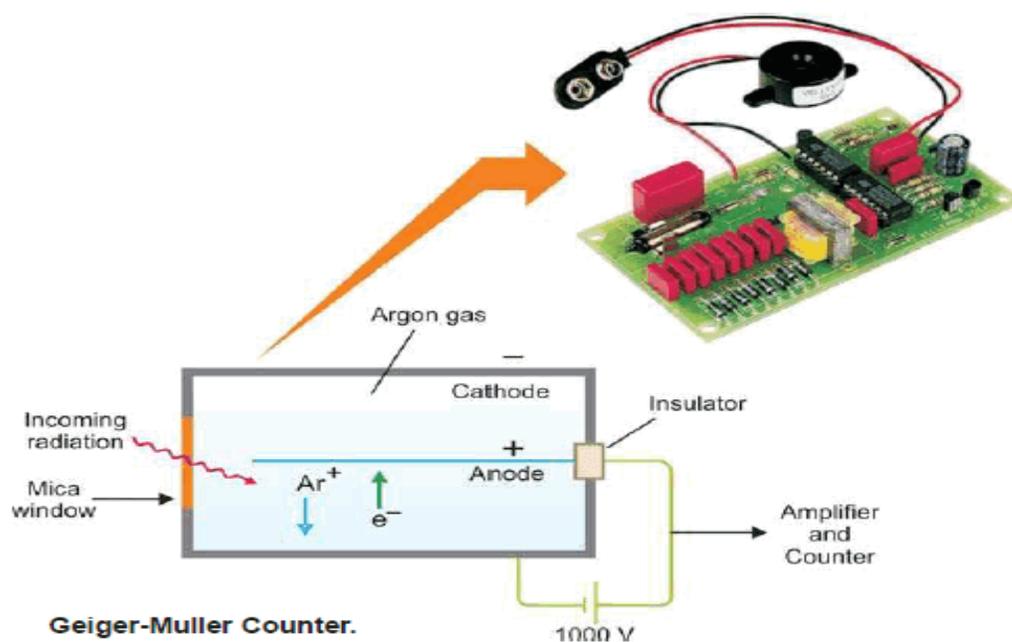
** When an α - or β -particle enters the tube through the mica window, it ionizes the argon atoms along its path.



** The argon ions (Ar^+) are drawn to the cathode and electrons to anode. Thus for a fraction of a second, a pulse of electrical current flows between the electrodes and completes the circuit around.

** Each electrical pulse marks the entry of one α - or β -particle into the tube and is recorded in an automatic counter.

** The number of such pulses registered by a radioactive material per minute, gives the intensity of its radioactivity.



particle accelera

A particle accelerator is a machine that uses electromagnetic fields to propel charged particles to very high speeds and energies, and to contain them in well-defined beams.

There are two basic classes of accelerators: electrostatic and electrodynamic (or electromagnetic) accelerators.^[3] Electrostatic accelerators use static electric fields to accelerate particles. The most common types are the Cockcroft–Walton generator and the Van de Graaff generator. A small-scale example of this class is the cathode ray tube in an ordinary old television set. The achievable kinetic energy for particles in these devices is determined by the accelerating voltage, which is limited by electrical breakdown. Electrodynamic or electromagnetic accelerators, on the other hand, use changing electromagnetic fields (either magnetic induction or oscillating radio frequency fields) to accelerate particles. Since in these types the particles can pass through the same accelerating field multiple times, the output energy is not limited by the strength of the accelerating field. This class, which was first developed in the 1920s, is the basis for most modern large-scale accelerators.

Linear induction accelerator

Linear induction accelerators utilize ferrite-loaded, non-resonant induction cavities. Each cavity can be thought of as two large washer-shaped disks connected by an outer cylindrical tube. Between the disks is a ferrite toroid. A voltage pulse applied between the two disks causes an increasing magnetic field which inductively couples power into the charged particle beam.

The linear induction accelerator was invented by Christofilos in the 1960s. Linear induction accelerators are capable of accelerating very high beam currents (>1000 A) in a single short pulse. They have been used to generate X-rays for flash radiography (e.g. DARHT at LANL), and have been considered as particle injectors for magnetic confinement fusion and as drivers for free electron lasers.

In a linear particle accelerator (linac), particles are accelerated in a straight line with a target of interest at one end. They are often used to provide an initial low-energy kick to particles before they are injected into circular accelerators. The longest linac in the world is the Stanford Linear Accelerator, SLAC, which is 3 km (1.9 mi) long. SLAC is an electron-positron collider.

Linear high-energy accelerators use a linear array of plates (or drift tubes) to which an alternating high-energy field is applied. As the particles approach a plate they are accelerated towards it by an opposite polarity charge applied to the plate. As they pass through a hole in the plate, the polarity is switched so that the plate now repels them and they are now accelerated by it towards the next plate. Normally a stream of "bunches" of particles are accelerated, so a carefully controlled AC voltage is applied to each plate to continuously repeat this process for each bunch.

As the particles approach the speed of light the switching rate of the electric fields becomes so high that they operate at radio frequencies, and so microwave cavities are used in higher energy machines instead of simple plates.

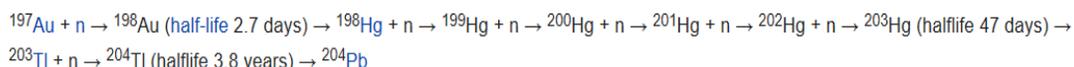
Linear accelerators are also widely used in medicine, for radiotherapy and radiosurgery. Medical grade linacs accelerate electrons using a klystron and a complex bending magnet arrangement which produces a beam of 6-30 MeV energy. The electrons can be used directly or they can be collided with a target to produce a beam of X-rays. The reliability, flexibility and accuracy of the radiation beam produced has largely supplanted the older use of cobalt-60 therapy as a treatment tool.

Nuclear transmutation

Nuclear transmutation is the conversion of one chemical element or an isotope into another chemical element.^[1] Because any element (or isotope of one) is defined by its number of protons (and neutrons) in its atoms, i.e. in the atomic nucleus, nuclear transmutation occurs in any process where the number of protons or neutrons in the nucleus is changed.

Natural transmutation by stellar nucleosynthesis in the past created most of the heavier chemical elements in the known existing universe, and continues to take place to this day, creating the vast majority of the most common elements in the universe, including helium, oxygen and carbon. Most stars carry out transmutation through fusion reactions involving hydrogen and helium, while much larger stars are also capable of fusing heavier elements up to iron late in their evolution.

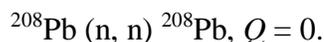
Artificial transmutation may occur in machinery that has enough energy to cause changes in the nuclear structure of the elements. Such machines include particle accelerators and tokamak reactors. Conventional fission power reactors also cause artificial transmutation, not from the power of the machine, but by exposing elements to neutrons produced by fission from an artificially produced nuclear chain reaction. For instance, when a uranium atom is bombarded with slow neutrons, fission takes place. This releases, on average, 3 neutrons and a large amount of energy. The released neutrons then cause fission of other uranium atoms, until all of the available uranium is exhausted. This is called a chain reaction.



Types of Nuclear Reaction

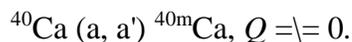
- **Elastic Scattering**

When no energy is transferred between the target nucleus and the incident particle, the process is known as ${}^{208}\text{Pb}$ **elastic scattering**



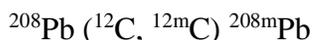
- **Inelastic Scattering**

When energy is transferred, the process is called **inelastic scattering**



- where α and α' have different kinetic energies.

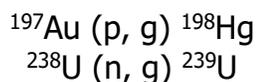
In cases when the incident particle is a complicated nuclide, it may also be left in excited state,



This process is called mutual excitation.

- **Capture Reactions**

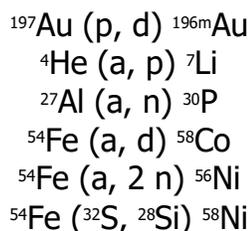
Both charged and neutral particles can be captured by nuclei. For example,



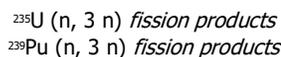
Neutron capture reactions are used to produce many radioactive nuclides.

- **Rearrangement Reactions**

The absorption of a particle accompanied by the emission of one or more particles is called a rearrangement reaction.



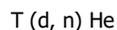
- Various rearrangement reactions change the number of neutrons and the number of protons of the target nuclide.
- **Fission Reactions**
Typical and well-known neutron-induced fission reactions are:



These reactions release energy. The released neutrons induce further reactions, causing continuous chain reactions.

- **Fusion Reactions**

The fusion reaction of deuterium and tritium is particularly interesting because of its potential of providing energy for the future.



Nuclear Fission

Nuclear fission is a nuclear reaction or a radioactive decay process in which the nucleus of an atom splits into two or more smaller, lighter nuclei. The fission process often produces gamma photons, and releases a very large amount of energy even by the energetic standards of radioactive decay.

The other basic type of nuclear weapon produces a large proportion of its energy in nuclear fusion reactions. Such fusion weapons are generally referred to as **thermonuclear weapons** or more colloquially as **hydrogen bombs** (abbreviated as **H-bombs**), as they rely on fusion reactions between isotopes of hydrogen (deuterium and tritium). All such weapons derive a significant portion of their energy from fission reactions used to "trigger" fusion reactions, and fusion reactions can themselves trigger additional fission reactions.^[13]

Only six countries—United States, Russia, United Kingdom, China, France, and India—have conducted thermonuclear weapon tests. (Whether India has detonated a "true" multi-staged thermonuclear weapon is controversial.)^[14] North Korea claims to have tested a fusion weapon as of January 2016, though this claim is disputed. Thermonuclear weapons are considered much more difficult to successfully design and execute than primitive fission weapons. Almost all of the nuclear weapons deployed today use the thermonuclear design because it is more efficient.

Thermonuclear bombs work by using the energy of a fission bomb to compress and heat fusion fuel. In the Teller-Ulam design, which accounts for all multi-megaton yield hydrogen bombs, this is accomplished by placing a fission bomb and fusion fuel (tritium, deuterium, or lithium deuteride) in proximity within a special, radiation-reflecting container. When the fission bomb is detonated, gamma rays and X-rays emitted first compress the fusion fuel, then heat it to thermonuclear temperatures. The ensuing fusion reaction creates enormous numbers of high-speed neutrons, which can then induce fission in materials not normally prone to it, such as depleted uranium. Each of these components is known as a "stage", with the fission bomb as the "primary" and the fusion capsule as the "secondary". In large, megaton-range hydrogen bombs, about half of the yield comes from the final fissioning of depleted uranium.

Virtually all thermonuclear weapons deployed today use the "two-stage" design described above, but it is possible to add additional fusion stages—each stage igniting a larger amount of fusion fuel in the next stage. This technique can be used to construct thermonuclear weapons of arbitrarily large yield, in contrast to fission bombs, which are limited in their explosive force.

Edward Teller, often referred to as the "father of the hydrogen bomb"

Fusion reactions do not create fission products, and thus contribute far less to the creation of nuclear fallout than fission reactions, but because all thermonuclear weapons contain at least one fission stage, and many high-yield thermonuclear devices have a final fission stage, thermonuclear weapons can generate at least as much nuclear fallout as fission-only weapons.

A hydrogen bomb or H-bomb is a type of nuclear weapon that explodes from the intense energy released by nuclear fusion. Hydrogen bombs may also be called thermonuclear weapons.

Nuclear reactor

A nuclear reactor, formerly known as an atomic pile, is a device used to initiate and control a self-sustained nuclear chain reaction. Nuclear reactors are used at nuclear power plants for electricity generation and in nuclear marine propulsion. Heat from nuclear fission is passed to a working fluid, which in turn runs through steam turbines. These either drive a ship's propellers or turn electrical generators' shafts. Nuclear generated steam in principle can be used for industrial process heat or for district heating. Some reactors are used to produce isotopes for medical and industrial use, or for production of weapons-grade plutonium. As of early 2019, the IAEA reports there are 454 nuclear power reactors and 226 nuclear research reactors in operation around the world.

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A nuclear reactor produces and controls the release of energy from splitting the atoms of certain elements. In a nuclear power reactor, the energy released is used as heat to make steam to generate electricity. (In a research reactor the main purpose is to utilise the actual neutrons produced in the core. In most naval reactors, steam drives a turbine directly for propulsion.)

The principles for using nuclear power to produce electricity are the same for most types of reactor. The energy released from continuous fission of the atoms of the fuel is harnessed as heat in either a gas or water, and is used to produce steam. The steam is used to drive the turbines which produce electricity (as in most fossil fuel plants).

The world's first nuclear reactors operated naturally in a uranium deposit about two billion years ago. These were in rich uranium orebodies and moderated by percolating rainwater. The 17 known at Oklo in west Africa, each less than 100 kW thermal, together consumed about six tonnes of that uranium. It is assumed that these were not unique worldwide.

Today, reactors derived from designs originally developed for propelling submarines and large naval ships generate about 85% of the world's nuclear electricity. The main design is the pressurised water reactor (PWR) which has water at over 300°C under pressure in its primary cooling/heat transfer circuit, and generates steam in a secondary circuit. The less numerous boiling water reactor (BWR) makes steam in the primary circuit above the reactor core, at similar temperatures and pressure. Both types use water as both coolant and moderator, to slow neutrons. Since water normally boils at 100°C, they have robust steel pressure vessels or tubes to enable the higher operating temperature. (Another type uses heavy water, with deuterium atoms, as moderator. Hence the term 'light water' is used to differentiate.)

Components of a nuclear reactor

There are several components common to most types of reactors:

Fuel. Uranium is the basic fuel. Usually pellets of uranium oxide (UO_2) are arranged in tubes to form fuel rods. The rods are arranged into fuel assemblies in the reactor core.* In a 1000 MWe class PWR there might be 51,000 fuel rods with over 18 million pellets.

* In a new reactor with new fuel a neutron source is needed to get the reaction going. Usually this is beryllium mixed with polonium, radium or other alpha-emitter. Alpha particles from the decay cause a release of neutrons from the beryllium as it turns to carbon-12. Restarting a reactor with some used fuel may not require this, as there may be enough neutrons to achieve criticality when control rods are removed.

Moderator. Material in the core which slows down the neutrons released from fission so that they cause more fission. It is usually water, but may be heavy water or graphite.

Control rods. These are made with neutron-absorbing material such as cadmium, hafnium or boron, and are inserted or withdrawn from the core to control the rate of reaction, or to halt it.* In some PWR reactors, special control rods are used to enable the core to sustain a low level of power efficiently. (Secondary control systems involve other neutron absorbers, usually boron in the coolant – its concentration can be adjusted over time as the fuel burns up.) PWR control rods are inserted from the top, BWR cruciform blades from the bottom of the core.

* In fission, most of the neutrons are released promptly, but some are delayed. These are crucial in enabling a chain reacting system (or reactor) to be controllable and to be able to be held precisely critical.

Coolant. A fluid circulating through the core so as to transfer the heat from it. In light water reactors the water moderator functions also as primary coolant. Except in BWRs, there is secondary coolant circuit where the water becomes steam. (See also later section on primary coolant characteristics.) A PWR has two to four primary coolant loops with pumps, driven either by steam or electricity – China's Hualong One design has three, each driven by a 6.6 MW electric motor, with each pump set weighing 110 tonnes.

Pressure vessel or pressure tubes. Usually a robust steel vessel containing the reactor core and moderator/coolant, but it may be a series of tubes holding the fuel and conveying the coolant through the surrounding moderator.

Steam generator. Part of the cooling system of pressurised water reactors (PWR & PHWR) where the high-pressure primary coolant bringing heat from the reactor is used to make steam for the turbine, in a secondary circuit. Essentially a heat exchanger like a motor car radiator.* Reactors have up to six 'loops', each with a steam generator. Since 1980 over 110 PWR reactors have had their steam generators replaced after 20-30 years service, 57 of these in USA.

* These are large heat exchangers for transferring heat from one fluid to another – here from high-pressure primary circuit in PWR to secondary circuit where water turns to steam. Each structure weighs up to 800 tonnes and contains from 300 to 16,000 tubes about 2 cm diameter for the primary coolant, which is radioactive due to nitrogen-16 (N-16, formed by neutron bombardment of oxygen, with half-life of 7 seconds). The secondary water must flow through the support structures for the tubes. The whole thing needs to be designed so that the tubes don't vibrate and fret, operated so that deposits do not build up to impede the flow, and maintained chemically to avoid corrosion. Tubes which fail and leak are plugged, and surplus capacity is designed to allow for this. Leaks can be detected by monitoring N-16 levels in the steam as it leaves the steam generator.

Containment. The structure around the reactor and associated steam generators which is designed to protect it from outside intrusion and to protect those outside from the effects of radiation in case of any serious malfunction inside. It is typically a metre-thick concrete and steel structure.

Newer Russian and some other reactors install core melt localisation devices or 'core catchers' under the pressure vessel to catch any melted core material in the event of a major accident.

There are several different types of reactors as indicated in the following table.

Nuclear power plants in commercial operation or operable

Reactor type	Main countries	Number	GWe	Fuel	Coolant	Moderator
Pressurised water reactor (PWR)	USA, France, Japan, Russia, China, South Korea	300	284	enriched UO ₂	water	water
Boiling water reactor (BWR)	USA, Japan, Sweden	65	65	enriched UO ₂	water	water
Pressurised heavy water reactor (PHWR)	Canada, India	48	24	natural UO ₂	heavy water	heavy water
Gas-cooled reactor (AGR)	UK	14	8	natural U (metal), enriched UO ₂	CO ₂	graphite
Light water graphite reactor (LWGR)	Russia	13	9	enriched UO ₂	water	graphite
Fast neutron reactor (FBR)	Russia	2	1.4	PuO ₂ and UO ₂	liquid sodium	none
	TOTAL	442	391			

For reactors under construction, see information paper on [Plans for New Reactors Worldwide](#)

Fuelling a nuclear power reactor

Most reactors need to be shut down for refuelling, so that the reactor vessel can be opened up. In this case refuelling is at intervals of 12, 18 or 24 months, when a quarter to a third of the fuel assemblies are replaced with fresh ones. The CANDU and RBMK types have pressure tubes (rather than a pressure vessel enclosing the reactor core) and can be refuelled under load by disconnecting individual pressure tubes.

If graphite or heavy water is used as moderator, it is possible to run a power reactor on natural instead of enriched uranium. Natural uranium has the same elemental composition as when it was mined (0.7% U-235, over 99.2% U-238), enriched uranium has had the proportion of the fissile isotope (U-235) increased by a process called enrichment, commonly to 3.5 - 5.0%. In this case the moderator can be ordinary water, and such reactors are collectively called light water reactors. Because the light water absorbs neutrons as well as slowing them, it is less efficient as a moderator than heavy water or graphite.

During operation, some of the U-238 is changed to plutonium, and Pu-239 ends up providing about one-third of the energy from the fuel.

In most reactors the fuel is ceramic uranium oxide (UO_2 with a melting point of 2800°C) and most is enriched. The fuel pellets (usually about 1 cm diameter and 1.5 cm long) are typically arranged in a long zirconium alloy (zircaloy) tube to form a fuel rod, the zirconium being hard, corrosion-resistant and transparent to neutrons.* Numerous rods form a fuel assembly, which is an open lattice and can be lifted into and out of the reactor core. In the most common reactors these are about 4 metres long. A BWR fuel assembly may be about 320 kg, a PWR one 655 kg, in which case they hold 183 kg uranium and 460 kgU respectively. In both, about 100 kg of zircaloy is involved.

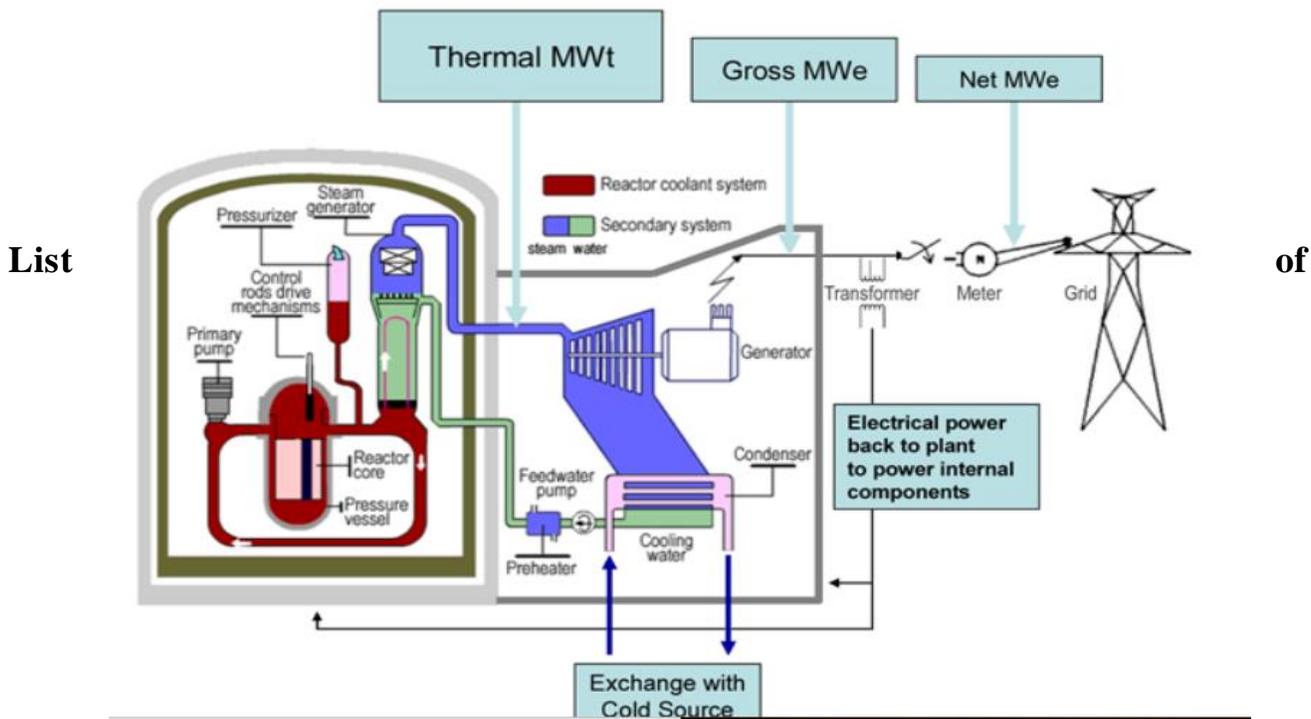
* Zirconium is an important mineral for nuclear power, where it finds its main use. It is therefore subject to controls on trading. It is normally contaminated with hafnium, a neutron absorber, so very pure 'nuclear grade' Zr is used to make the zircaloy, which is about 98% Zr plus about 1.5% tin, also iron, chromium and sometimes nickel to enhance its strength.

A significant industry initiative is to develop accident-tolerant fuels which are more resistant to melting under conditions such as those in the Fukushima accident, and with the cladding being more resistant to oxidation with hydrogen formation at very high temperatures under such conditions.

Burnable poisons are often used in fuel or coolant to even out the performance of the reactor over time from fresh fuel being loaded to refuelling. These are neutron absorbers which decay under neutron exposure, compensating for the progressive build up of neutron absorbers in the fuel as it is burned, and hence allowing higher fuel burn-up (in terms of GW days per tonne of U)*. The best known is gadolinium, which is a vital ingredient of fuel in naval reactors where installing fresh fuel is very inconvenient, so reactors are designed to run more than a decade between refuellings (full power equivalent – in practice they are not run continuously). Gadolinium is incorporated in the ceramic fuel pellets. An alternative is zirconium diboride integral fuel burnable absorber (IFBA) as a thin coating on normal pellets.

* Average burn-up of fuel discharged from US reactors has increase to nearly 50 GWd/t, from half that in the 1980s.

Gadolinium, mostly at up to 3g oxide per kilogram of fuel, requires slightly higher fuel enrichment to compensate for it, and also after burn-up of about 17 GWd/t it retains about 4% of its absorptive effect and does not decrease further. The ZrB₂ IFBA burns away more steadily and completely, and has no impact on fuel pellet properties. It is now used in most US reactors and a few in Asia. China has the technology for AP1000 reactors.



Atomic Power Stations in India

India is one of the powerful countries in the world that uses nuclear and other advances rocket technologies to protect the country. But this list is of power plants which uses atomic power to generate electricity. Usually india generate the electricity from hydro and coal, The Atomic power stations is located in different state of the country. India faces power problems constantly nowadays because of population and lack of income, corruption too.

1. Kakrapar Atomic Power Station, Kakrapara (Gujarat)
2. Kaiga Atomic Power Plant, Kaiga (Karnataka)
3. Madras Atomic Power Station, Kalpakkam (Tamil Nadu)
4. Narora Atomic Power Station, Norora (Uttar Pradesh)
5. Rana Pratap Sagar Atomic Power Station (RAPS), Rawatbhatta (Rajasthan)
6. Tarapur Atomic Power Plant (TAPS), Tarapur (Maharashtra)

Radioisotope application

A **synthetic radioisotope** is a radionuclide that is not found in nature: no natural process or mechanism exists which produces it, or it is so unstable that it decays away in a very short period of time. Examples include technetium-95 and promethium-146. Many of these are found in, and harvested from, spent nuclear fuel assemblies. Some must be manufactured in particle accelerators.

Most synthetic radioisotopes have a short half-life. Though a health hazard, radioactive materials have many medical and industrial uses.

Nuclear medicine

The field of nuclear medicine covers use of radioisotopes for diagnosis or treatment.

Diagnosis

Radioactive tracer compounds, radiopharmaceuticals, are used to observe the function of various organs and body systems. These compounds use a chemical tracer which is attracted to or concentrated by the activity which is being studied. That chemical tracer incorporates a short lived radioactive isotope, usually one which emits a gamma ray which is energetic enough to travel through the body and be captured outside by a gamma camera to map the concentrations. Gamma cameras and other similar detectors are highly efficient, and the tracer compounds are generally very effective at concentrating at the areas of interest, so the total amounts of radioactive material needed are very small.

The metastable nuclear isomer Tc-99m is a gamma-ray emitter widely used for medical diagnostics because it has a short half-life of 6 hours, but can be easily made in the hospital using a technetium-99m generator. Weekly global demand for the parent isotope molybdenum-99 was 440 TBq (12,000 Ci) in 2010, overwhelmingly provided by fission of uranium-235

Treatment

Several radioisotopes and compounds are used for medical treatment, usually by bringing the radioactive isotope to a high concentration in the body near a particular organ. For example, iodine-131 is used for treating some disorders and tumors of the thyroid gland.

Industrial radiation sources

Alpha particle, beta particle, and gamma ray radioactive emissions are industrially useful. Most sources of these are synthetic radioisotopes. Areas of use include the petroleum industry, industrial radiography, homeland security, process control, food irradiation and underground

Detection.

Radiolabeling is not necessary for some applications. For some purposes, soluble ionic salts can be used directly without further modification (e.g., gallium-67, gallium-68, and radioiodine isotopes). These uses rely on the chemical and biological properties of the radioisotope itself, to localize it within the organism or biological system.

Molecular imaging is the biomedical field that employs radiotracers to visualize and quantify biological processes using positron emission tomography (PET) and single-photon emission computed tomography (SPECT) imaging. Again, a key feature of using radioactivity in life science applications is that it is a quantitative technique, so PET/SPECT not only reveals where a radiolabelled molecule is but how much is there.

Radiobiology (also known as radiation biology) is a field of clinical and basic medical sciences that involves the study of the action of radioactivity on biological systems. The controlled action of deleterious radioactivity on living systems is the basis of radiation therapy.

Phosphorus

Phosphorus-33 is used to label nucleotides. It is less energetic than P-32 and does not require protection with plexi glass. A disadvantage is its higher cost compared to P-32, as most of the bombarded P-31 will have acquired only one neutron, while only some will have acquired two or more. Its maximum specific activity is 5,118 Ci/mmol (189.4 PBq/mol).

Phosphorus-32 is widely used for labeling nucleic acids and phosphoproteins. It has the highest emission energy (1.7 MeV) of all common research radioisotopes. This is a major advantage in experiments for which sensitivity is a primary consideration, such as titrations of very strong interactions (i.e., very low dissociation constant), footprinting experiments, and detection of low-abundance phosphorylated species. ^{32}P is also relatively inexpensive. Because of its high energy, however, its safe use requires a number of engineering controls (e.g., acrylic glass) and administrative controls. The half-life of ^{32}P is 14.2 days, and its maximum specific activity is 9131 Ci/mmol.

Iodine

Iodine-125 is commonly used for labeling proteins, usually at tyrosine residues. Unbound iodine is volatile and must be handled in a fume hood. Its maximum specific activity is 2,176 Ci/mmol (80.51 PBq/mol)

Radioisotopes in Industry

Industrial tracers

Radioisotopes are used by manufacturers as tracers to monitor fluid flow and filtration, detect leaks, and gauge engine wear and corrosion of process equipment. Small concentrations of short-lived isotopes can be detected whilst no residues remain in the environment. By adding small amounts of radioactive substances to materials used in various processes it is possible to study the mixing and flow rates of a wide range of materials, including liquids, powders, and gases and to locate leaks.

Radiotracers are used widely in industry to investigate processes and highlight the causes of inefficiency. They are particularly useful where process optimization can bring material benefits, such as in the transport of sediments. Radiotracers are also used in the oil and gas industry to help determine the extent of oil fields.

Inspection

Radioactive materials are used to inspect metal parts and the integrity of welds across a range of industries. Industrial gamma radiography exploits the ability of various types of radiation to penetrate materials to different extents. Gamma radiography works in much the same way as X-rays screen luggage at airports. Instead of the bulky machine needed to produce X-rays, all that is needed to produce effective gamma rays is a small pellet of radioactive material in a sealed titanium capsule.

The capsule is placed on one side of the object being screened, and some photographic film is placed on the other side. The gamma rays, like X-rays, pass through the object and create an image on the film. Just as X-rays show a break in a bone, gamma rays show flaws in metal castings or welded joints. The technique allows critical components to be inspected for internal defects without damage.

X-ray sets can be used when electric power is available and the object to be scanned can be taken to the X-ray source and radiographed. Radioisotopes have the supreme advantage that they can be taken to the site when an examination is required – and no power is needed. However, they cannot be simply turned off, and so must be properly shielded both when in use and at other times.

Carbon dating

Analyzing the relative abundance of particular naturally-occurring radioisotopes is of vital importance in determining the age of rocks and other materials that are of interest to geologists, anthropologists, hydrologists, and archaeologists, among others.

Naturally-occurring radioisotopes

Carbon-14 (half-life: 5730 yr):

Used to measure the age of wood, other carbon-containing materials (up to 20,000 years), and subterranean water (up to 50,000 years).

Chlorine-36 (301,000 yr):

Used to measure sources of chloride and the age of water (up to 2 million years).

Lead-210 (22.3 yr):

Used to date layers of sand and soil up to 80 years.

Tritium, H-3 (12.3 yr):

Used to measure 'young' groundwater (up to 30 years).

Artificially-produced radioisotopes

Americium-241 (half-life: 432 yr):

Used in backscatter gauges, smoke detectors, fill height detectors, and in measuring ash content of coal.

Caesium-137 (30.17 yr):

Used for radiotracer technique for identification of sources of soil erosion and deposition, as well as in density and fill height level switches. Also for low-intensity gamma sterilisation.

Chromium-51 (27.7 yr):

Used to label sand to study coastal erosion, also a tracer in study of blood.

Cobalt-60 (5.27 yr), lanthanum-140 (1.68 d), scandium-46 (83.8 d), silver-110m (250 d), gold-198 (2.7 d):

Used together in blast furnaces to determine resident times and to quantify yields to measure the furnace performance.

Cobalt-60 (5.27 yr):

Widely used for gamma sterilisation, industrial radiography, density, and fill height switches.

Gold-198 (2.7 d) & technetium-99m (6 hr):

Used to study sewage and liquid waste movements, as well as tracing factory waste causing ocean pollution, and to trace sand movement in river beds and ocean floors.

Gold-198 (2.7 d):

Used to label sand to study coastal erosion.

Hydrogen-3 (in tritiated water) (12.3 yr):

Used as a tracer to study sewage and liquid wastes.

Iridium-192 (73.8 d):

Used in gamma radiography to locate flaws in metal components.

Krypton-85 (10.756 yr):

Used for industrial gauging.

Manganese-54 (312.5 d):

Used to predict the behaviour of heavy metal components in effluents from mining waste water.

Nickel-63 (100 yr)

Used in light sensors in cameras and plasma display, also electronic discharge prevention and in electron capture detectors for thickness gauges. Also for long-life beta-voltaic batteries. Made from nickel-62 by neutron capture.

Selenium-75 (120 d):

Used in gamma radiography and non-destructive testing.

Strontium-90 (28.8.yr):

Used for industrial gauging.

Thallium-204 (3.78 yr):

Used for industrial gauging.

Ytterbium-169 (32 d):

Used in gamma radiography and non-destructive testing.

Zinc-65 (244 d):

Used to predict the behaviour of heavy metal components in effluents from mining wastewater

Radiation Hazards.

Exposure to radiation is safe in small amounts and when it is strictly controlled during a medical exam such as an X-ray, for example. However, long-term exposure to small amounts of radiation can lead to **gene mutations** and increase the risk of **cancer** and exposure to a large amount over a brief period can lead to radiation...

S. National Library of Medicine(0.00 / 0 votes)Rate this definition: Radioactive Hazard Release. Uncontrolled release of radioactive material from its containment. This either threatens to, or does, cause exposure to a radioactive hazard. Such an incident may occur accidentally or deliberately.

The effect of radiation in the environment can be dangerous and fatal to humans and animals. The damage it causes depends on the level of radiation and the resiliency of the organism. Radiation causes molecules to lose electrons thus destroying it. Killing certain enzymes in the body can simply make you sick.

Radiological hazards are chemical hazards. Radioactive chemicals emit harmful radiation that at large doses is harmful soon after exposure and at small doses is harmful years or decades later. Our food may become contaminated through the absorption of rad

For example:

- Someone who has had many CT scans starting at a young age is more likely to get cancer later in life than someone who hasn't had any or as many of these tests. CT scans generally use more radiation than other X-ray tests. The risk of an adult getting cancer from a CT scan is less than 1 in 1,000. The risk of a child getting cancer from the same CT scan can be much higher.
- A child who was treated with radiation for cancer is more likely to get another cancer later in life.
- A person who has been exposed to large amounts of radiation from a nuclear accident is more likely to get cancer than someone who has not been exposed.

Exposure to small amounts of radiation doesn't cause any symptoms. But exposure to large amounts all at once may cause radiation sickness and death.

How do different sources of radiation compare?

Some sources of radiation give off larger amounts than others. For example, when you go through a full-body airport scanner, you're exposed to very small amounts of radiation. But if you live near the site of a nuclear accident, you're exposed to large amounts of radiation.

You may be exposed to more radiation than other people if you:

- Live at high altitude.
- Have certain medical tests (such as X-rays or CT scans) or treatments (such as radiation treatment for cancer).
- Are exposed to radon gas in your home.

To understand more about radiation exposure, you may find it helpful to compare some common sources of radiation to a standard dose from a chest X-ray. A chest X-ray gives off very small amounts of radiation.

UNIT III

METALLIC STATE

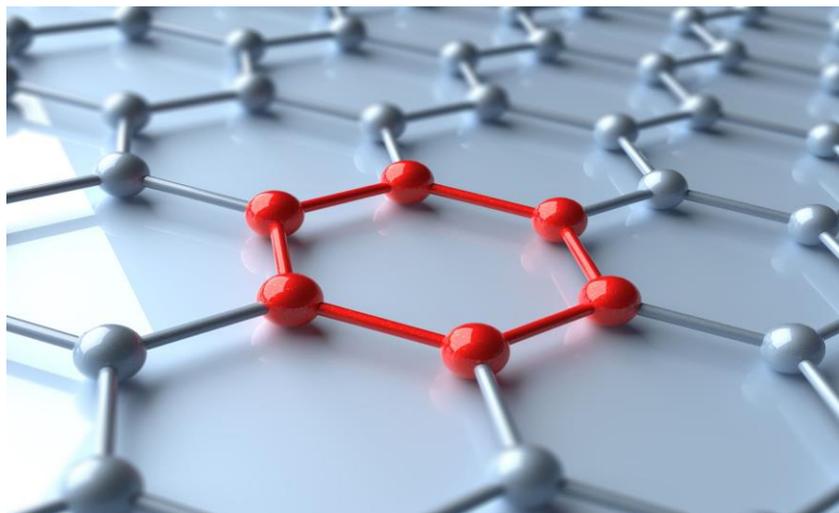
A metallic bond is a type of chemical bond formed between positively charged atoms in which the free electrons are shared among a lattice of cations. In contrast, covalent and ionic bonds form between two discrete atoms. Metallic bonding is the main type of chemical bond that forms between metal atoms.

[Science, Tech, Math > Science](#)

Metallic Bond: Definition, Properties, and Examples

Understand How Metallic Bonding Works

A metallic bond is a type of chemical bond formed between positively charged atoms in which the free electrons are shared among a lattice of cations. In contrast, covalent and ionic bonds form between two discrete atoms. Metallic bonding is the main type of chemical bond that forms between metal atoms.



Metallic bonds are seen in pure metals and alloys and some metalloids. For example, graphene (an allotrope of carbon) exhibits two-dimensional metallic bonding. Metals, even pure ones, can form other types of chemical bonds between their atoms. For example, the mercurous ion (Hg_2^{2+}) can form metal-metal covalent bonds. Pure gallium forms covalent bonds between pairs of atoms that are linked by metallic bonds to surrounding pairs.

Metallic Bond: Definition, Properties, and Examples

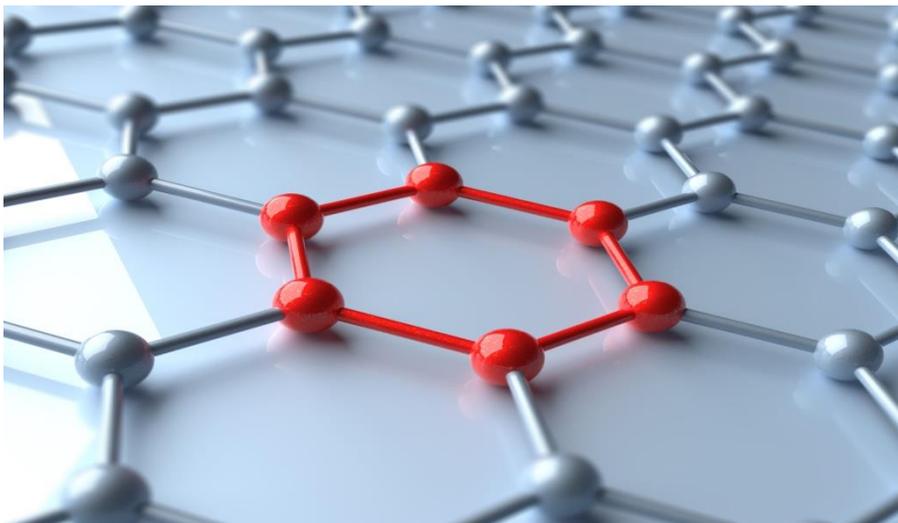
Understand How Metallic Bonding Works



Science

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 - Basics
 - Chemical Laws
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 - Projects & Experiments
 - Scientific Method
 - Biochemistry
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 - Activities for Kids
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- Biology
- Physics
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- Weather & Climate

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MARK GARLICK/SCIENCE PHOTO LIBRARY / Getty Images

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How Metallic Bonds Work

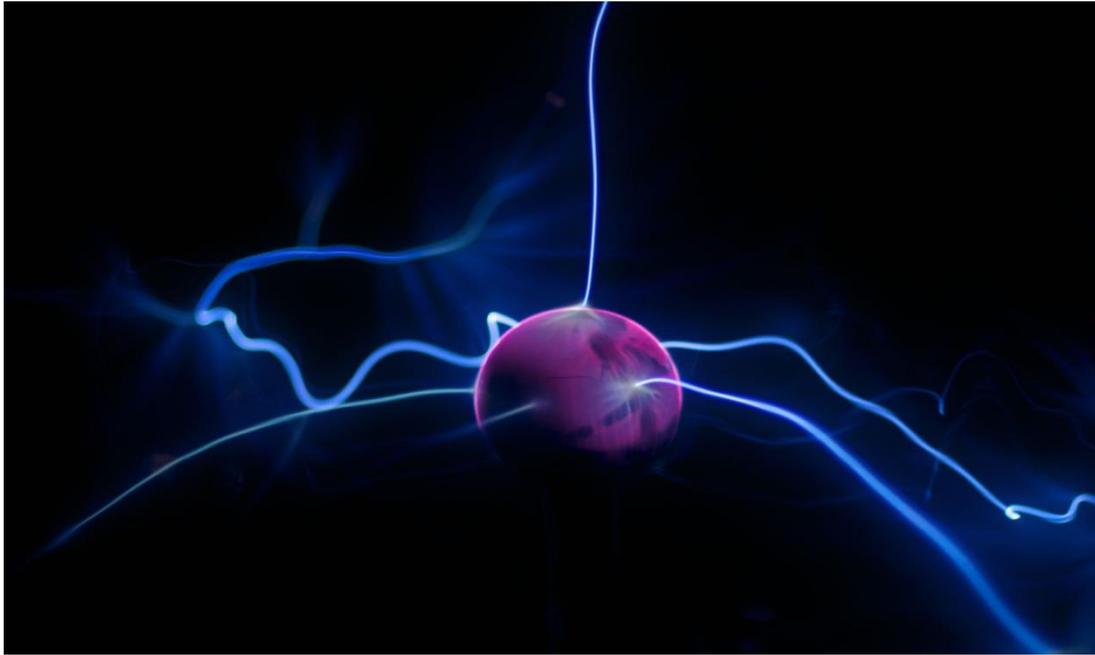
The outer energy levels of metal atoms (the *s* and *p* orbitals) overlap. At least one of the valence electrons participating in a metallic bond is not shared with a neighbor atom, nor is it lost to form an ion. Instead, the electrons form what may be termed an "electron sea" in which valence electrons are free to move from one atom to another.

The electron sea model is an oversimplification of metallic bonding. Calculations based on electronic band structure or density functions are more accurate. Metallic bonding may be seen as a consequence of a material having many more delocalized energy states than it has delocalized electrons (electron deficiency), so localized unpaired electrons may become delocalized and mobile. The electrons can change energy states and move throughout a lattice in any direction.

Bonding can also take the form of metallic cluster formation, in which delocalized electrons flow around localized cores. Bond formation depends heavily on conditions. For example, hydrogen is a metal under high pressure. As pressure is reduced, bonding changes from metallic to nonpolar covalent.

Relating Metallic Bonds to Metallic Properties

Because electrons are delocalized around positively charged nuclei, metallic bonding explains many properties of metals.



ImageGap / Getty Images

Electrical conductivity: Most metals are excellent electrical conductors because the electrons in the electron sea are free to move and carry charge. Conductive nonmetals (such as graphite), molten ionic compounds, and aqueous ionic compounds conduct electricity for the same reason—electrons are free to move around.

Thermal conductivity: Metals conduct heat because the free electrons are able to transfer energy away from the heat source and also because vibrations of atoms (phonons) move through a solid metal as a wave.

Ductility: Metals tend to be ductile or able to be drawn into thin wires because local bonds between atoms can be easily broken and also reformed. Single atoms or entire sheets of them can slide past each other and reform bonds.

Malleability: Metals are often malleable or capable of being molded or pounded into a shape, again because bonds between atoms readily break and reform. The binding force between metals is nondirectional, so drawing or shaping a metal is less likely to fracture it. Electrons in a crystal may be replaced by others. Further, because the electrons are free to move away from each other, working a metal doesn't force together like-charged ions, which could fracture a crystal through the strong repulsion.

Metallic luster: Metals tend to be shiny or display metallic luster. They are opaque once a certain minimum thickness is achieved. The electron sea reflects photons off the smooth surface. There is an upper-frequency limit to the light that can be reflected.

The strong attraction between atoms in metallic bonds makes metals strong and gives them high density, high melting point, high boiling point, and low volatility. There are exceptions. For example, mercury is a liquid under ordinary conditions and has a high vapor pressure. In fact, all of the metals in the zinc group (Zn, Cd, and Hg) are relatively volatile.

FCC. BCC and HCP Metals

Introduction

The majority of common metals have either a Face Center Cubic Structure, fig 1a, a Body Centered Cubic Structure, fig.1b or an Hexagonal Close Packed structure fig.1c. These are usually abbreviated to FCC, BCC or HCP structures respectively. The major differences between these structures is the Unit Cell, the building block. These are shown in fig.1. The different cells leads to different physical properties of bulk metals. For example, FCC metals, Cu, Au, Ag, are usually soft and 'ductile', which means they can be bent and shaped easily. BCC metals are less ductile but stronger, eg iron, while HCP metals are usually brittle. Zinc is HCP and is difficult to bend without breaking, unlike copper. Many other features depend upon the crystal structure of metals, such as density, deformation processes, alloying behavior, and much more. Thus, it is important to understand metal structures.

Face Center Cubic Structure

Face Center Cubic Structure consists of an atom at each cube corner and an atom in the center of each cube face. A hard sphere concept can be used to describe atomic packing in unit cells. The FCC structure is shown in fig.1a. The distance along unit cell edges is called the lattice parameter, a_0 . For cubic crystals the lattice parameter is identical in all three crystal axes. If a corner atom of the FCC unit cell is removed, six atoms are revealed in a hexagonal array. These atoms are close packed, ie they cannot be packed any tighter, and each atom touches its neighbor in any direction. Since a close packed plane such as this can be achieved by removing each of the eight corner atoms and because eight such planes form an octahedron, they are called the 'Octahedral' planes. Thus the FCC structure has four sets of two parallel planes.. As parallel planes with the same atomic arrangement are equivalent the FCC structure has four equivalent close packed planes. Using Miller indices from the previous crystallography experiment show them to be $\{111\}$ planes. Thus the FCC structure has four $\{111\}$ close packed planes. The atomic arrangement is shown in fig.2a. Three close packed directions are shown as well. These correspond to (110) directions diagonally across cube faces. There are three of these for each $\{111\}$ plane. Therefore, FCC structures have twelve possible combinations of $\{111\}$ and (110).

Body Centered Cubic Structure

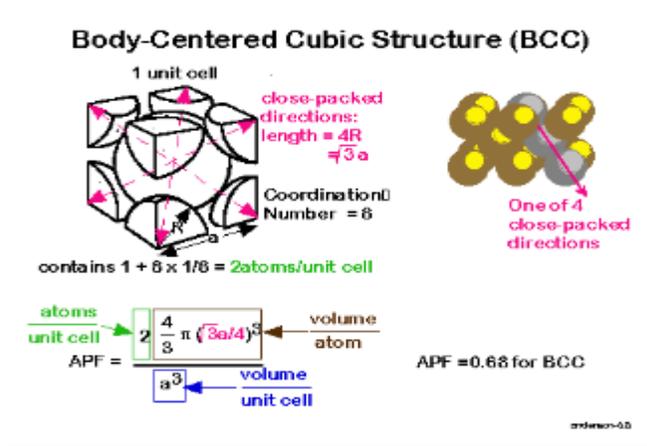
In this structure, atoms exist at each cube corner and one atom is at the center of the cube, fig 1b. Comparison of figs, 1a and 1b show that the BCC is much emptier than the FCC structure. In this case there are no close packed planes only close packed directions. Fig.2b shows the atomic arrangement of {110} planes in a BCC structure which are the planes of highest atomic density. There are 6 planes of this type, and each contains two close packed directions. Consideration of fig. 1b and 2b shows the closed packed direction joins diagonally opposite corners of the BCC unit cell. It is therefore a (111) direction. As there are two (111) for each {110} plane there is a total of 12 possible combinations of {110} and (111).

Hexagonal Close Packed Structure

The hexagonal structure is shown in fig. 1c. A close packed plane at the bottom and top of the unit cell is separated by 3 atoms in the cell center, which are also part of a closed packed plane. Closed packed planes are of the {001} family of which there is only 1 equivalent

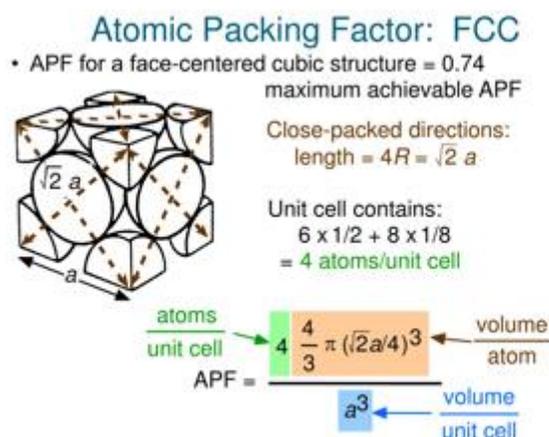
type. Fig.2c shows the atomic arrangement and directions of close packing. These are of the (2TTO) family and there are three for each {0001}. Thus, hexagonal structures have only three combinations of {0001} and (2TTO).

It should be noted that the lattice parameter differs with direction in HCP structures. Along a_1, a_2 and a_3 , the lattice parameter is identical, but along the c axis it is always greater. This gives rise to the



c/a

ratio.



NUMBER OF ATOMS PER UNIT CELL IN A CUBIC LATTICE

- Simple cubic cell: 1 atom/unit cell of sc
e.g. Polonium
- Body-centered cell: 2 atoms/unit cell of bcc
e.g. CsCl, CsBr
- Face-centered cell: 4 atoms/unit cell of fcc
e.g. NaCl, NaF, KBr, MgO
- End face-centered cell: 2 atoms/unit cell

Electron gas theory

Free-electron theory of metals. The treatment of a metal as containing a gas of electrons completely free to move within it. The theory was originally proposed in 1900 to describe and correlate the electrical and thermal properties of metals.

Given its simplicity, it is surprisingly successful in explaining many experimental phenomena, especially

- the Wiedemann–Franz law which relates electrical conductivity and thermal conductivity;
 - the temperature dependence of the electron heat capacity;
 - the shape of the electronic density of states;
 - the range of binding energy values;
 - electrical conductivities;
 - the Seebeck coefficient of the thermoelectric effect;
-
- thermal electron emission and field electron emission from bulk metals

- Free electron approximation: The interaction between the ions and the valence electrons is mostly neglected, except in boundary conditions. The ions only keep the charge neutrality in the metal. Unlike in the Drude model, the ions are not necessarily the source of collisions.
- Independent electron approximation: The interactions between electrons are ignored. The electrostatic fields in metals are weak because of the screening effect.
- Relaxation-time approximation: There is some unknown scattering mechanism such that the electron probability of collision is inversely proportional to the relaxation time, which represents the average time between collisions. The collisions do not depend on the electronic configuration.
- Pauli exclusion principle: Each quantum state of the system can only be occupied by a single electron. This restriction of available electron states is taken into account by Fermi–Dirac statistics (see also Fermi gas). Main predictions of the free-electron model are derived by the Sommerfeld expansion of the Fermi–Dirac occupancy for energies around the Fermi level.

The name of the model comes from the first two assumptions, as each electron can be treated as free particle with a respective quadratic relation between energy and momentum.

PAULING THEORY

The nature of the chemical bond led to his introduction of the concept of orbital hybridization. While it is normal to think of the electrons in an atom as being described by orbitals of types such as *s* and *p*, it turns out that in describing the bonding in molecules, it is better to construct functions that partake of some of the properties of each. Thus the one 2*s* and three 2*p* orbitals in a carbon atom can be (mathematically) 'mixed' or combined to make four equivalent orbitals (called sp^3 hybrid orbitals), which would be the appropriate orbitals to describe carbon compounds such as methane, or the 2*s* orbital may be combined with two of the 2*p* orbitals to make three equivalent orbitals (called sp^2 hybrid orbitals), with the remaining 2*p* orbital unhybridized, which would be the appropriate orbitals to describe certain unsaturated carbon compounds such as ethylene.^{[57]:111–120} Other hybridization schemes are also found in other types of molecules. Another area which he explored was the relationship between ionic bonding, where electrons are transferred between atoms, and covalent bonding, where electrons are shared between atoms on an equal basis. Pauling showed that these were merely extremes, and that for most actual cases of bonding, the quantum-mechanical wave function for a polar molecule AB is a combination of wave functions for covalent and ionic molecules.^{[44]:66} Here Pauling's *electronegativity* concept is particularly useful; the electronegativity difference between a pair of atoms will be the surest predictor of the degree of ionicity of the bond

The Band theory

These bands and band gaps by examining the allowed quantum mechanical wave functions for an electron in a large, periodic lattice of atoms or molecules. Band theory has been successfully used to explain many physical properties of solids, such as electrical resistivity and optical absorption, and forms the foundation of the understanding of all solid-state devices (transistors, solar cells, etc.). ature of the chemical bond" was the accounting of the structure of aromatic hydrocarbons,

Assumptions and limits of band structure theory

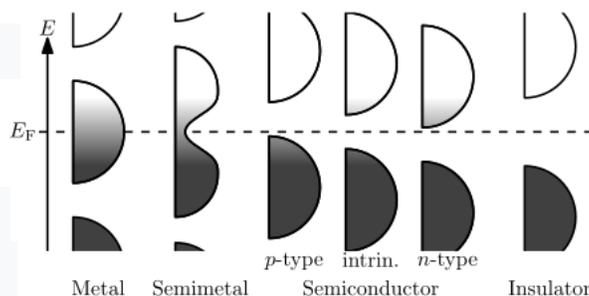
Band theory is only an approximation to the quantum state of a solid, which applies to solids consisting of many identical atoms or molecules bonded together. These are the assumptions necessary for band theory to be valid:

- *Infinite-size system*: For the bands to be continuous, the piece of material must consist of a large number of atoms. Since a macroscopic piece of material contains on the order of 10^{22} atoms, this is not a serious restriction; band theory even applies to microscopic-sized transistors in integrated circuits. With modifications, the concept of band structure can also be extended to systems which are only "large" along some dimensions, such as two-dimensional electron systems.
- *Homogeneous system*: Band structure is an intrinsic property of a material, which assumes that the material is homogeneous. Practically, this means that the chemical makeup of the material must be uniform throughout the piece.
- *Non-interactivity*: The band structure describes "single electron states". The existence of these states assumes that the electrons travel in a static potential without dynamically interacting with lattice vibrations, other electrons, photons, etc.

Energy band gaps can be classified using the wavevectors of the states surrounding the band gap:

- Direct band gap: the lowest-energy state above the band gap has the same k as the highest-energy state beneath the band gap.
- Indirect band gap: the closest states above and beneath the band gap do not have the same k value.

Filling of bands



Filling of the electronic states in various types of materials at equilibrium. Here, height is energy while width is the density of available states for a certain energy in the material listed. The shade follows the Fermi–Dirac distribution (black = all states filled, white = no state filled). In metals and semimetals the Fermi level E_F lies inside at least one band. In insulators and semiconductors the Fermi level is inside a band gap; however, in semiconductors the bands are near enough to the Fermi level to be thermally populated with electrons or holes.

At thermodynamic equilibrium, the likelihood of a state of energy E being filled with an electron is given by the Fermi–Dirac distribution, a thermodynamic distribution that takes into account the Pauli exclusion principle:

$$f(E) = \frac{1}{1 + e^{(E-\mu)/k_B T}}$$

where:

- $k_B T$ is the product of Boltzmann's constant and temperature, and
- μ is the total chemical potential of electrons, or *Fermi level* (in semiconductor physics, this quantity is more often denoted E_F). The Fermi level of a solid is directly related to the voltage on that solid, as measured with a voltmeter
- The density of electrons in the material is simply the integral of the Fermi–Dirac distribution times the density of states:

- $$N/V = \int_{-\infty}^{\infty} g(E) f(E) dE$$

- Although there are an infinite number of bands and thus an infinite number of states, there are only a finite number of electrons to place in these bands. The preferred value for the number of electrons is a consequence of electrostatics: even though the surface of a material can be charged, the internal bulk of a material prefers to be charge neutral. The condition of charge neutrality means that N/V must match the density of protons in the material. For this to occur, the material electrostatically adjusts itself, shifting its band structure up or down in energy (thereby shifting $g(E)$), until it is at the correct equilibrium with respect to the Fermi level.

Semiconductor

A semiconductor material has an electrical conductivity value falling between that of a conductor, such as metallic copper, and an insulator, such as glass. Its resistance falls as its temperature rises; metals are the opposite. Its conducting properties may be altered in useful ways by introducing impurities ("doping") into the crystal structure. Where two differently-doped regions exist in the same crystal, a semiconductor junction is created. The behavior of charge carriers which include electrons, ions and electron holes at these junctions is the basis of diodes, transistors and all modern electronics. Some examples of semiconductors are silicon, germanium, gallium arsenide, and elements near the so-called "metalloid staircase" on the periodic table. After silicon, gallium arsenide is the second most common semiconductor and is used in laser diodes, solar cells, microwave-frequency integrated circuits and others. Silicon is a critical element for fabricating most electronic circuits.

Semiconductor devices can display a range of useful properties such as passing current more easily in one direction than the other, showing variable resistance, and sensitivity to light or heat. Because the electrical properties of a semiconductor material can be modified by doping, or by the application of electrical fields or light, devices made from semiconductors can be used for amplification, switching, and energy conversion.

The conductivity of silicon is increased by adding a small amount (of the order of 1 in 10^8) of pentavalent (antimony, phosphorus, or arsenic) or trivalent (boron, gallium, indium) atoms. This process is known as doping and resulting semiconductors are known as doped or extrinsic semiconductors. Apart from doping, the conductivity of a semiconductor can equally be improved by increasing its temperature. This is contrary to the behaviour of a metal in which conductivity decreases with increase in temperature.

The modern understanding of the properties of a semiconductor relies on quantum physics to explain the movement of charge carriers in a crystal lattice.^[1] Doping greatly increases the number of charge carriers within the crystal. When a doped semiconductor contains mostly free holes it is called "p-type", and when it contains mostly free electrons it is known as "n-type". The semiconductor materials used in electronic devices are doped under precise conditions to control the concentration and regions of p- and n-type dopants. A single semiconductor crystal can have many p- and n-type regions; the p–n junctions between these regions are responsible for the useful electronic behavior.

Some of the properties of semiconductor materials were observed throughout the mid 19th and first decades of the 20th century. The first practical application of semiconductors in electronics was the 1904 development of the cat's-whisker detector, a primitive semiconductor diode used in early radio receivers. Developments in quantum physics in turn led to the development of the transistor in 1947,^[2] the integrated circuit in 1958, and the MOSFET (metal–oxide–semiconductor field-effect transistor) in 1959.

What is semiconductor used for?

Semiconductors are used extensively in electronic circuits. As its name implies, a semiconductor is a material that conducts current, but only partly. ... Semiconductors are made out of such crystals, usually silicon crystals. Here, each circle represents a silicon atom, and the lines between the atoms represent the shared electrons.

What are some examples of semiconductors?

Semiconductors can conduct electricity at a certain level without being damaged. Also, the conductivity of a semiconductor increases with increase in temperature. Examples of semiconductors: Silicon (Si) and Germanium (Ge) are two most common examples of semiconductors.

A semiconductor material has an electrical conductivity value falling between that of a conductor, such as metallic copper, and an insulator, such as glass. Its resistance falls as its temperature rises; metals are the opposite.

Silicon (Si) and gallium arsenide (GaAs) are the two most common semiconductor materials used in electronic and electro-optic devices. In some cases other elements, such as aluminum (Al), indium (In) and phosphorus (P), are added to the base semiconductor material to modify the semiconductor properties.

Semiconductors are used extensively in electronic circuits. As its name implies, a semiconductor is a material that conducts current, but only partly. The conductivity of a semiconductor is somewhere between that of an insulator, which has almost no conductivity, and a conductor, which has almost full conductivity.

Types of Semiconductor

There are two basic types of semiconductors; the intrinsic and the extrinsic. The material comprising an intrinsic semiconductor is in a generally pure state. The extrinsic semiconductor can be further categorized as either n-type or p-type. This is one to which impurities have been added to produce a desired state. N-type and p-type semiconductors are extrinsic semiconductors to which different impurities have been added, and consequently have different conductive properties.

A semiconductor is usually a crystalline solid in which conductivity due to electron flow is between that of a metal and an insulator. Intrinsic semiconductors are such materials with little or no impurity, silicon being the most widely used. The atomic lattice structure of silicon crystals is made up of perfect covalent bonds, which means there are few free electrons to move around. The crystal is almost an insulator. As temperatures rise above absolute zero, the likelihood of inducing electron flow in the material increases.

This effect can be greatly increased by introducing impurities into the lattice structure that make a greater number of free electrons available. The process of adding certain impurities to semiconductors is referred to as doping. The impurity added is termed the dopant. The amount of dopant added to an intrinsic semiconductor proportionally changes its level of conductivity. Extrinsic semiconductors are the products of the doping process.

N-type semiconductors

N-type semi conductors are extrinsic semiconductors in which donor dopants have been used. An increase in negative electron charge carriers results. Negative charge carriers are called the majority carrier in the n-type, while positive charge carriers are called the minority.

P-type semiconductors

P-Type semi conductor are the result of using acceptor dopants. As the covalent bonds of the lattice reform, holes are left in the valence bands of the surrounding material. The increase in holes increases the concentration of positive charge carriers. The majority carrier for the p-type would be positive and the minority negative.

By doping, semiconductors can be produced with different and complementary conductive properties. An important application of this is the p-n junction, where p-type and n-type semiconductors are brought into close contact. One effect of the junction is to permit the holes and the electrons to combine, producing light. This is a light emitting diode (LED). The p-n junction also forms a diode where electricity can flow in one direction through the junction but not in the other, a requirement for digital electronics.

Structure of an alloy

An alloy is a combination of metals or of a metal and another element. Alloys are defined by a metallic bonding character. An alloy may be a solid solution of metal elements (a single phase) or a mixture of metallic phases (two or more solutions). Intermetallic compounds are alloys with a defined stoichiometry and crystal structure.

Alloying elements are added to a base metal, to induce hardness, toughness, ductility, or other desired properties. Most metals and alloys can be work hardened by creating defects in their crystal structure. These defects are created during plastic deformation by hammering, bending, extruding, et cetera, and are permanent unless the metal is recrystallized. Otherwise, some alloys can also have their properties altered by heat treatment. Nearly all metals can be softened by annealing, which recrystallizes the alloy and repairs the defects, but not as many can be hardened by controlled heating and cooling. Many alloys of aluminium, copper, magnesium, titanium, and nickel can be strengthened to some degree by some method of heat treatment, but few respond to this to the same degree as does steel.

The base metal iron of the iron-carbon alloy known as steel, undergoes a change in the arrangement (allotropy) of the atoms of its crystal matrix at a certain temperature (usually between 1,500 °F (820 °C) and 1,600 °F (870 °C), depending on carbon content). This allows the smaller carbon atoms to enter the interstices of the iron crystal. When this diffusion happens, the carbon atoms are said to be in *solution* in the iron, forming a particular single, homogeneous, crystalline phase called austenite. If the steel is cooled slowly, the carbon can diffuse out of the iron and it will gradually revert to its low temperature allotrope. During slow cooling, the carbon atoms will no longer be as soluble with the iron, and will be forced to precipitate out of solution, nucleating into a more concentrated form of iron carbide (Fe_3C) in the spaces between the pure iron crystals. The steel then becomes heterogeneous, as it is formed of two phases, the iron-carbon phase called cementite (or carbide), and pure iron ferrite. Such a heat treatment produces a steel that is rather soft. If the steel is cooled quickly, however, the carbon atoms will not have time to diffuse and precipitate out as carbide, but will be trapped within the iron crystals. When rapidly cooled, a diffusionless (martensite) transformation occurs, in which the carbon atoms become trapped in solution. This causes the iron crystals to deform as the crystal structure tries to change to its low temperature state, leaving those crystals very hard but much less ductile (more brittle).

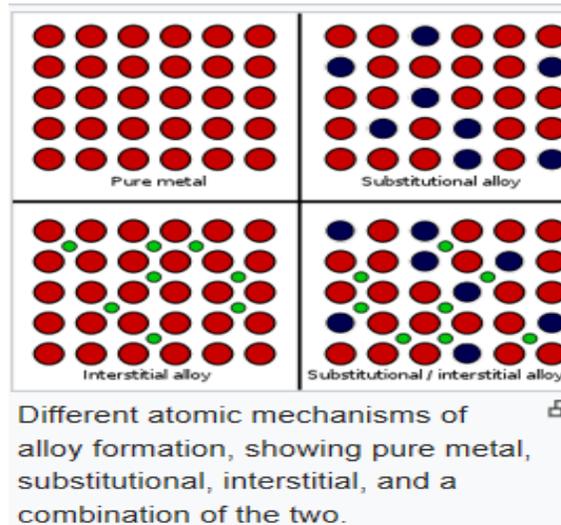
While the high strength of steel results when diffusion and precipitation is prevented (forming martensite), most heat-treatable alloys are precipitation hardening alloys, that depend on the diffusion of alloying elements to achieve their strength. When heated to form a solution and then cooled quickly, these alloys become much softer than normal, during the diffusionless transformation, but then harden as they age. The solutes in these alloys will precipitate over time, forming intermetallic phases, which are difficult to discern from the base metal. Unlike steel, in which the solid solution separates into different crystal phases (carbide and ferrite), precipitation hardening alloys form different phases within the same crystal. These intermetallic alloys appear homogeneous in crystal structure, but tend to behave heterogeneously, becoming hard and somewhat brittle.

Substitutional and interstitial alloys

When a molten metal is mixed with another substance, there are two mechanisms that can cause an alloy to form, called atom exchange and the interstitial mechanism. The relative size of each element in the mix plays a primary role in determining which mechanism will occur. When the atoms are relatively similar in size, the atom exchange method usually happens, where some of the atoms composing the metallic crystals are substituted with atoms of the other constituent. This is called a substitutional alloy. Examples of substitutional alloys include bronze and brass, in which some of the copper atoms are substituted with either tin or zinc atoms respectively.

In the case of the interstitial mechanism, one atom is usually much smaller than the other and can not successfully substitute for the other type of atom in the crystals of the base metal. Instead, the smaller atoms become trapped in the spaces between the atoms of the crystal matrix, called the interstices. This is referred to as an interstitial alloy. Steel is an example of an interstitial alloy, because the very small carbon atoms fit into interstices of the iron matrix.

Stainless steel is an example of a combination of interstitial and substitutional alloys, because the carbon atoms fit into the interstices, but some of the iron atoms are substituted by nickel and chromium atoms.¹



Hume-Rothery ratio

Substitutional solid solution rules

For substitutional solid solutions, the Hume-Rothery rules are as follows:

1. The atomic radius of the solute and solvent atoms must differ by no more than 15%:

$$\% \text{ difference} = \left(\frac{r_{\text{solute}} - r_{\text{solvent}}}{r_{\text{solvent}}} \right) \times 100\% \leq 15\%$$

2. The crystal structures of solute and solvent must be similar.
3. Complete solubility occurs when the solvent and solute have the same valency. A metal with lower valency is more likely to dissolve in a metal of higher valency
4. The solute and solvent should have similar electronegativity. If the electronegativity difference is too great, the metals tend to form intermetallic compounds instead of solid solutions.

Interstitial solid solution rules

1. Solute atoms should have radius no larger than 15% of the radius of solvent atoms
2. The solute and solvent should have similar electronegativity.
3. They should show a wide range of composition.
4. Valency factor: two elements should have the same valence. The greater the difference in valence between solute and solvent atoms, the lower the solubility.

crystal defect

Crystal defect, imperfection in the regular geometrical arrangement of the atoms in a crystalline solid. These imperfections result from deformation of the solid, rapid cooling from high temperature, or high-energy radiation (X-rays or neutrons) striking the solid.

Various types of point defects are: 1. Vacancy 2. Interstitialcy 3. Frenkel Defect 4. Impurity Atoms.

A point defect is a very localised disruption in the regularity of a lattice. It is a defect of dimensions just like a point (zero dimensions). The size of the defect could be one atom, or two atomic diameters, which is just like a point. A point defect extends its influence only a few atomic diameters beyond its lattice position.

Type # 1. Vacancy (Schottky Defect in Metals):

When an atom is missing from its lattice site in a crystal structure of a metal, it is called a vacancy (or vacant lattice site) as illustrated in Fig. 4.1. It may be indicated by a square symbol. The atoms surrounding a vacancy experience a slight displacement into the empty lattice site, and thus, a vacancy is a centre of approximately spherical distortion in the lattice, Fig. 4.1.

There could be di-vacancies (an association of two vacancies) or even tri-vacancies. A thermodynamic argument shows that vacancies are not only the normal constituent of metals and alloys (above absolute zero degree temperature), but their equilibrium concentration in a metal increases (exponentially) with the increase of temperature Fig. 4.8.

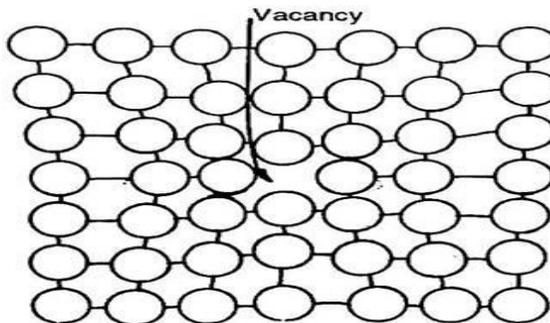


Fig. 4.1. A vacancy

Even a grain boundary acts as a source of vacancy as well as its sink. The creation of vacancies becomes easier with the increase of temperature of the metal as thermal energy helps in the diffusion of the atoms. A reverse phenomenon can occur if a given region of a metal is supersaturated with vacancies.

Vacancies play an important role in the diffusion of atoms in common industrial processes like homogenisation, annealing, precipitation hardening, sintering, surface hardening, oxidation and creep of metals. The climb of dislocation is possible because of the presence of vacancies in metals.

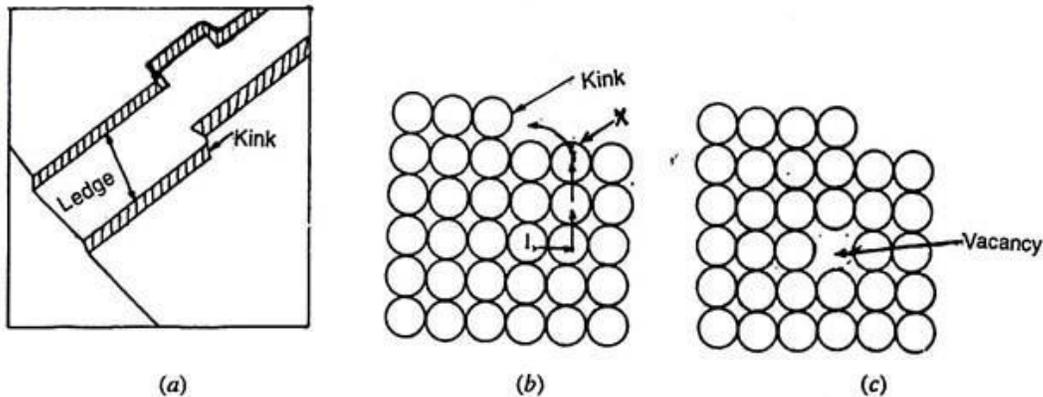


Fig. 4.2. Schematic creation of a vacancy. (a) Schematic model of a polished metal surface having ledges and kinks, (b) Section of perfect lattice near the surface having kink, (c) The same lattice as (b) after a sequence of atomic jumps as indicated.

1. A solid hot metal after fast quenching retains the vacancies.
2. Cold working creates vacancies particularly at jogs.
3. Oxidation of some metals such as Cu, Ni, Zn, etc. causes lattice vacancies.
4. Vacancies as well as interstitials are created in metals by the bombardment of high energy nuclear particles.

3. Frenkel Defect:

When an atom is shifted from a normal lattice site (thus creating vacancy) and is forced into interstitial position, the resulting pair of point defects (a vacancy as well as the interstitialcy) together is called a Frenkel defect, as illustrated in Fig. 4.5.

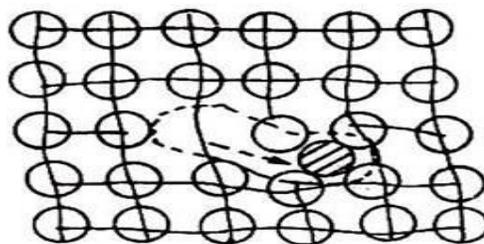


Fig. 4.5. Frenkel defect (a vacancy plus an interstitialcy)

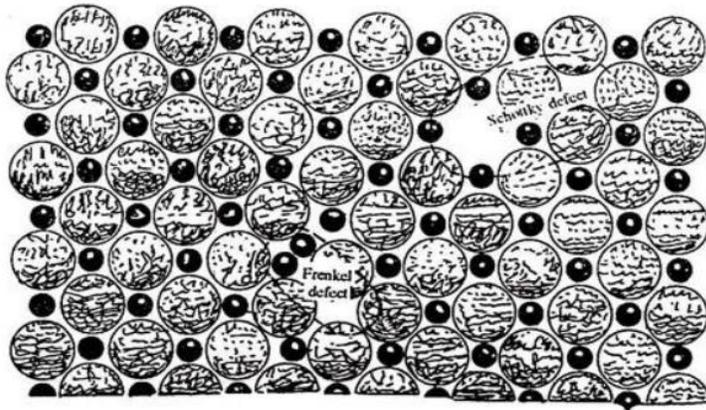


Fig. 4.6. Schottky and Frenkel defects in ionic crystals. In an ionic crystal, if there is a vacancy in a positive-ion site, charge neutrality requires creation of a vacancy in a neighbouring negative-ion site (the pair constitutes a Schottky defect), or by having a positive ion in an interstitial nearby position (this pair constitutes a Frenkel defect).

4. Impurity Atoms (Substitutional or Interstitial Type):

As there are two types of solid solutions, an impurity (outside) atom if present on the lattice by substituting the lattice site atom, then this substitutional impurity atom is a point defect in the crystal structure of pure metal.

Substitutional atoms may either be larger than the normal atom in the lattice (in which case, the surrounding atoms are compressed, Fig. 4.7 a), or smaller (causing the surrounding atoms to be in tension, Fig. 4.7 b). In either case, the substitutional defect distorts the surrounding lattice. As such a defect can be introduced either as an impurity, or as a deliberate alloying addition, and once introduced, the number of defects is relatively independent of temperature.

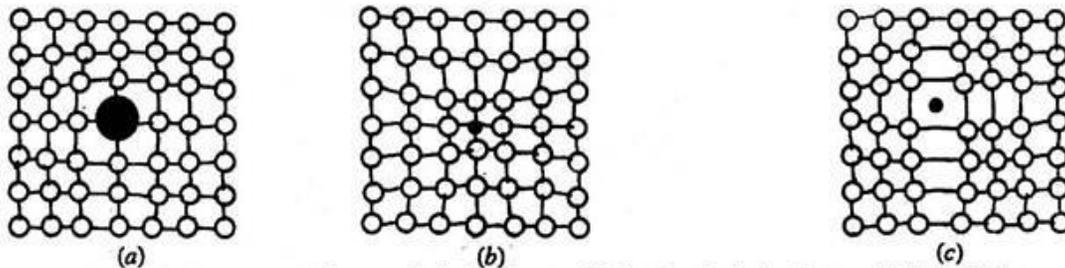


Fig. 4.7. Impurity atoms. (a) Large substitutional atom, (b) Small substitutional atom, (c) Interstitial atom

An interstitial defect is produced if any of the small sized atoms (of B, C, H, N, O) is present in the interstitial site. The sizes of their atoms are larger than the interstitial site they occupy. Consequently, the surrounding lattice is compressed and distorted, Fig. 4.7 (c). Once these atoms are introduced in the structure (impurity such as hydrogen, or alloying addition such as carbon), the number of interstitial atoms in the structure remains nearly constant, even when the temperature is changed. Normally, the concentration of these atoms in a very pure metal is lower than the concentration of vacancies.

As the defects interact with conduction electrons, their number in a crystal is vital in semi-conductors. Foreign atoms also play a role in changing the electrical conductivity of the semi-conductors.

UNIT IV

INORGANIC POLYMERS AND THERMO ANALYTICAL METHODS

Inorganic Polymer

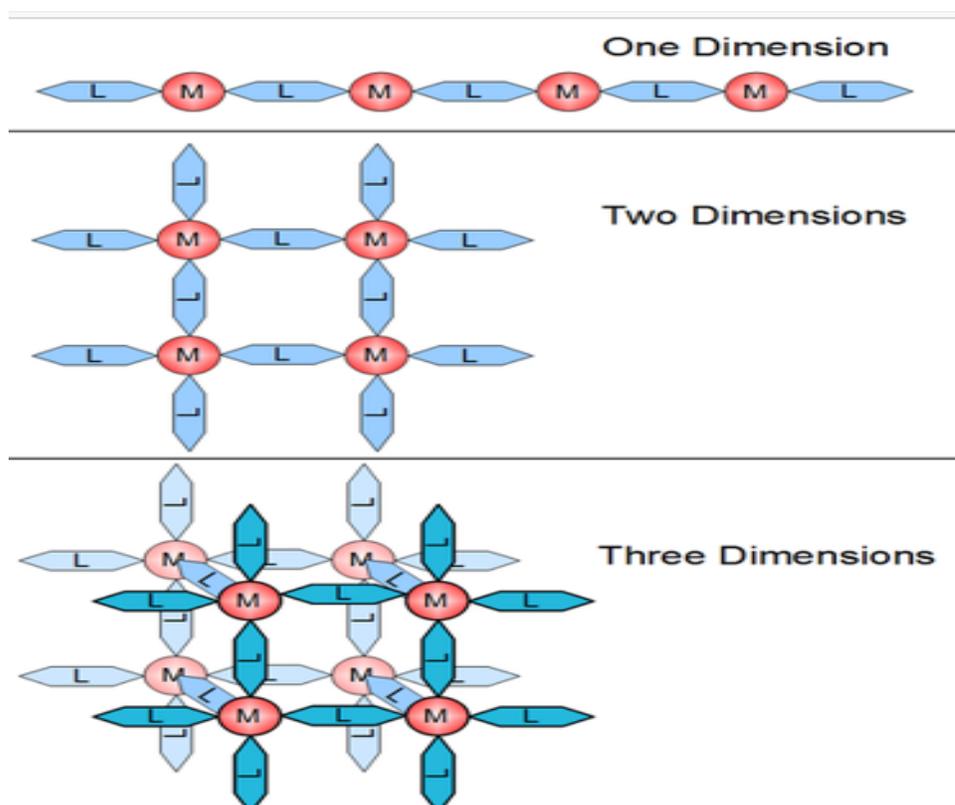
Inorganic polymers are polymers with a skeletal structure that does not include carbon atoms in the backbone. Polymers containing inorganic and organic components are sometimes called hybrid polymers, and most so-called inorganic polymers are hybrid polymers. One of the best known examples is polydimethylsiloxane, otherwise known commonly as silicone rubber. Inorganic polymers offer some properties not found in organic materials including low temperature flexibility, electrical conductivity, and nonflammability. The term inorganic polymer refers generally to one-dimensional polymers, rather than to heavily crosslinked materials such as silicate minerals. Inorganic polymers with tunable or responsive properties are sometimes called smart inorganic polymers. A special class of inorganic polymers are geopolymers, which may be anthropogenic or naturally occurring.

The difference between organic and inorganic polymers is that the organic polymers essentially contain carbon atoms in the backbone whereas the inorganic polymers do not contain carbon atoms in the backbone. Inorganic polymers are polymers with a skeletal structure that does not include carbon atoms. Polymers containing inorganic and organic components are named hybrid polymers. One of the best known examples is polydimethylsiloxane, otherwise known commonly as silicone rubber. Examples of inorganic substances include all metals, ammonia, hydrogen sulfide, chlorine, salt, minerals such as gypsum and generally all compounds that do not contain carbon-hydrogen bonds. By definition, an inorganic substance is a substance that does not contain carbon.

Coordination polymer

A coordination polymer is an inorganic or organometallic polymer structure containing metal cation centers linked by ligands. More formally a coordination polymer is a coordination compound with repeating coordination entities extending in 1, 2, or 3 dimensions.

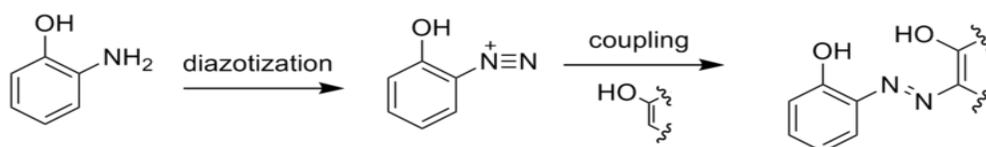
Coordination polymers can be classified in a number of different ways according to their structure and composition. One important classification is referred to as dimensionality. A structure can be determined to be one-, two- or three-dimensional, depending on the number of directions in space the array extends in. A one-dimensional structure extends in a straight line (along the x axis); a two-dimensional structure extends in a plane (two directions, x and y axes); and a three-dimensional structure extends in all three directions



(x, y, and z)

The crystal structure and dimensionality of the coordination polymer is determined by the functionality of the linker and the coordination geometry of the metal center. Dimensionality is generally driven by the metal center which can have the ability to bond to as many as 16 functional sites on linkers; however this is not always the case as dimensionality can be driven by the linker when the linker bonds to more metal centres than the metal centre does linkers. The highest known coordination number of a coordination polymer is 14, though coordination numbers are most often between 2 and 10. Examples of various coordination numbers are shown in planar geometry in Figure 2. In Figure 1 the 1D structure is 2-coordinated, the planar is 4-coordinated, and the 3D is 6-coordinated.

Applications Coordination polymers are commercialized as dyes. Particularly useful are derivatives of aminophenol. Metal complex dyes using copper or chromium are commonly used for producing dull colors. Tridentate ligand dyes are useful because they are more stable than their bi- or mono-dentate counterparts.





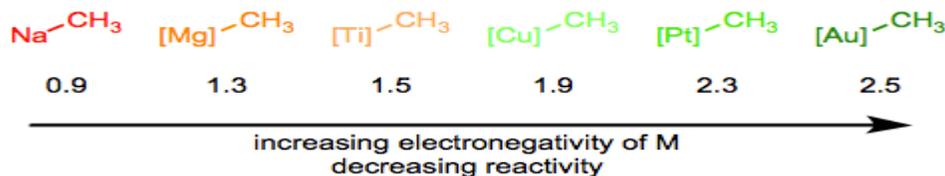
Metal Alkyls

Metal alkyls feature a metal-carbon σ bond and are usually actor ligands, although some alkyl ligands behave as spectators. Our aim will be to understand the general dependence of the behavior of alkyl ligands on the metal center and the ligand's substituents. Using this knowledge, we can make meaningful comparisons between related metal alkyl complexes and educated predictions about their likely behavior. Because alkyl ligands are central to organometallic chemistry, I've decided to spread this discussion across multiple posts. We'll deal first with the general properties of metal alkyls.



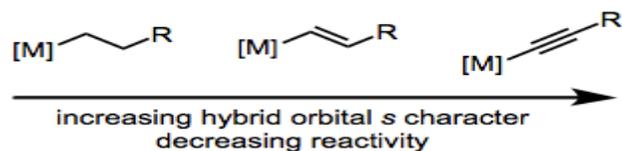
General Properties

In the Simplifying the Organometallic Complex series, we decomposed the M–C bond into a positively charged metal and negatively charged carbon. This deconstruction procedure is consistent with the relative electronegativities of carbon and the transition metals. It can be very useful for us to imagine metal alkyls essentially as stabilized carbanions—but it's also important to understand that M–C bonds run the gamut from extremely ionic and salt-like ($NaCH_3$) to essentially covalent ($[HgCH_3]^+$). The reactivity of the alkyl ligand is inversely related to the electronegativity of the metal center.



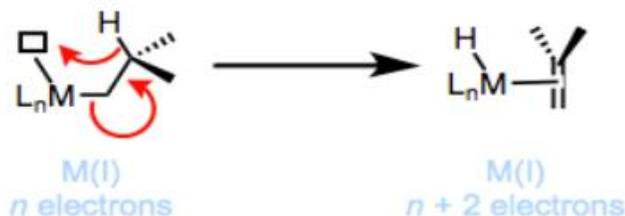
Reactivity decreases as the metal's electronegativity increases. Values given are Pauling electronegativities.

The hybridization of the carbon atom is also important, and the trend here follows the trend in nucleophilicity as a function of hybridization in organic chemistry. sp -Hybridized ligands are the least nucleophilic, followed by sp^2 and sp^3 ligands respectively.



Note that this trend is similar to the nucleophilicity of carbanions as a function of hybridization.

Synthesis of Alkyl Complexes



1. The β -carbon must bear a hydrogen.
2. M–C and C–H must be *syn coplanar*.
- 3a. The metal must possess a vacant coordination site and an accessible empty orbital.
- 3b. The metal must possess 16 or fewer total electrons.
4. For rapid elimination, the metal must be at least d^2 .

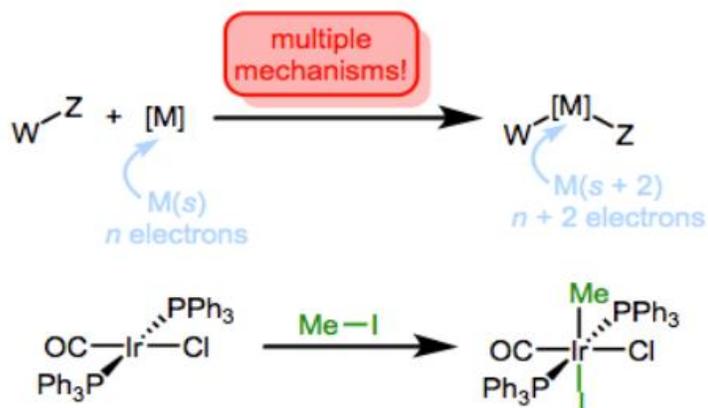
Synthesis of Alkyl Complexes

Metals bearing good leaving groups are analogous to organic electrophiles, and are susceptible to nucleophilic attack by organolithiums, Grignard reagents, and other polarized organometallics. These reactions can be viewed as a kind of transmetalation, as the alkyl ligand moves from one metal to another. Electron-withdrawing X-type ligands like –Cl and –Br should jump out as good leaving groups. On the other hand, clean substitution of L-type ligands by anionic nucleophiles is much more rare (anionic complexes would result).



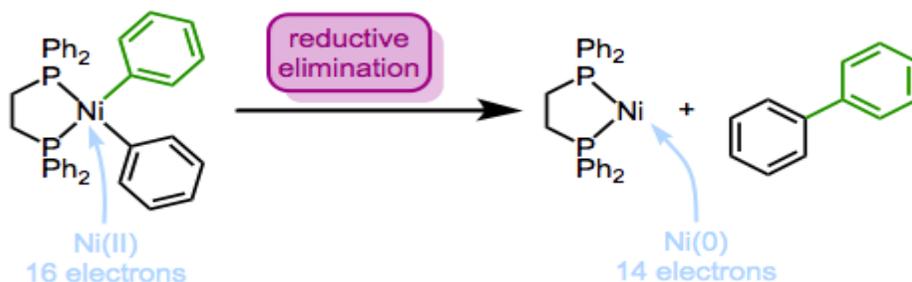
Simple and straightforward: nucleophile attacks electrophilic metal.

Oxidative a

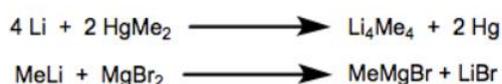


reductive elimination

The microscopic reverse of oxidative addition. The metal loses two covalent ligands, its formal oxidation state decreases by two units, total electron count decreases by two units, and an R–X bond forms. Reductive elimination is favorable when the R–X bond in the organic product is more stable than the M–R and M–X bonds in the starting complex (a thermodynamic issue). It should be noted, however, that the kinetics of reductive elimination depend substantially on the steric bulk of the eliminating ligands. Concerted reductive elimination of R–H usually possesses a lower activation energy than R–R elimination.



Silicate



Reaction	E° (V)
$\text{Hg}_2^{2+} + 2 e^- \longrightarrow 2 \text{ Hg}(0)$	+0.85
$\text{Mg}^{2+} + 2 e^- \longrightarrow \text{Mg}(0)$	-2.37
$\text{Li}^+ + e^- \longrightarrow \text{Li}(0)$	-3.05

Silicate

A salt in which the anion contains both silicon and oxygen, especially one of the anion SiO_4^{2-} .

- any of the many minerals consisting primarily of SiO_4^{2-} combined with metal ions, forming a major component of the rocks of the earth's crust.

Silicates are also used to make glass and ceramics. To do so, hard, formless material like sand or ceramic clay is heated to high temperatures, turning it into malleable material that can be formed to make drinking glasses, for example, or when lead is added to the molten liquid--crystal glass.

The most common silicate minerals fall into four types of structures, described in more detail below: isolated tetrahedra, chains of silica tetrahedra, sheets of tetrahedra, and a framework of interconnected tetrahedra. The link below opens a page in a new window, which contains 3-dimensional versions of these different structures.

1) ORTHO SILICATES

Ortho silicates (or Neso or Island silicates) are the simplest silicates which contain discrete SiO_4^{4-} tetrahedral units. Structural unit of ortho silicate unit is shown below.



The ortho silicate ion is the strong conjugate base of weak orthosilicic acid as well as it will not persist in aqueous solutions. Hence in nature, ortho silicate minerals are rare and only found with cations which form highly insoluble salts.

Examples of Ortho silicates:

1) Phenacite (also known as phenakite) - Be_2SiO_4

2) Willemite - Zn_2SiO_4 - A minor silicate ore of zinc. Highly fluorescent (green) under shortwave UV.

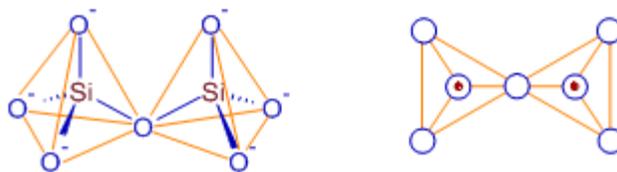
Note: The Be^{2+} and Zn^{2+} ions are tetrahedrally surrounded by the oxygen atoms of silicate.

3) Olivine - $(\text{Fe}/\text{Mg})_2\text{SiO}_4$: Typically green in color. The cations are octahedrally coordinated to the oxygen atoms of the silicate.

4) Zircon - ZrSiO_4 : The oldest mineral on Earth. The coordination number of Zr^{4+} is 8.

2) PYRO SILICATES

Pyro silicate (or Soro silicate or disilicate) contain $\text{Si}_2\text{O}_7^{6-}$ ions which are formed by joining two tetrahedral SiO_4^{4-} which share one oxygen atom at one corner (one oxygen is removed while joining). Structure of pyrosilicate is shown below.

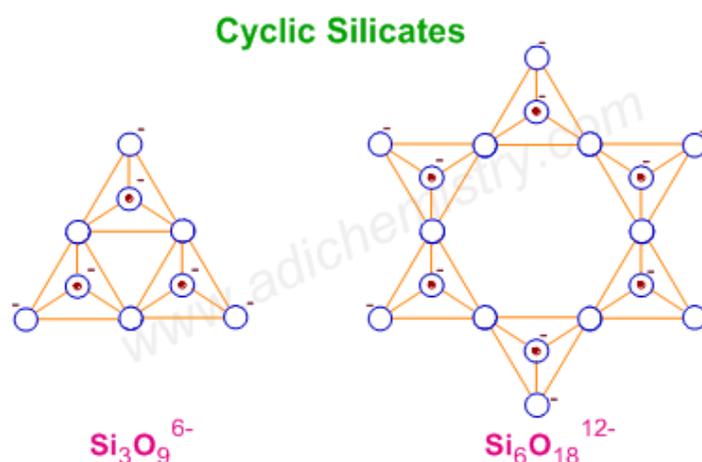


The pyrosilicate ion is less basic than orthosilicate ion. There only one mineral in nature containing pyrosilicate ion.

E.g. 1) Thortveitite - $\text{Sc}_2\text{Si}_2\text{O}_7$

3) CYCLIC SILICATES

Cyclic silicates contain $(\text{SiO}_3)_n^{2n-}$ ions which are formed by linking three or more tetrahedral SiO_4^{4-} units cyclically. Each unit shares two oxygen atoms with other units.



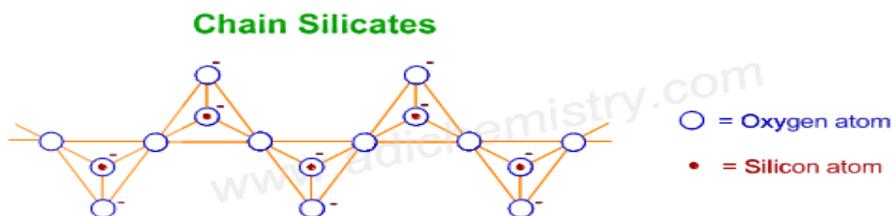
E.g.

1) Benitoite - $\text{BaTi}(\text{SiO}_3)_3$: containing three tetrahedra arranged cyclically $[\text{Si}_3\text{O}_9]^{6-}$.

2) Beryl - $\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$: containing six-silicate rings $[\text{Si}_6\text{O}_{18}]^{12-}$. It is an aluminosilicate. Each aluminium is surrounded by 6 oxygen atoms octahedrally. Well-known varieties of beryl include emerald and aquamarine.

4) CHAIN SILICATES (PYROXENES)

Chain silicates or pyroxenes contain $(\text{SiO}_3)_n^{2n-}$ ions which are formed by linking 'n' number of tetrahedral SiO_4^{4-} units linearly. Each unit shares two oxygen atoms with other units.



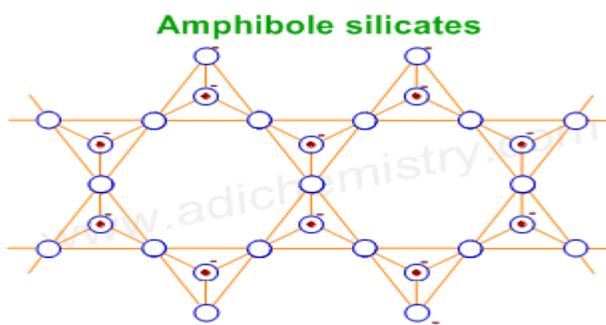
Examples of chain silicates:

- 1) Spodumene - $\text{LiAl}(\text{SiO}_3)_2$ - a pyroxene mineral consisting of lithium aluminium inosilicate
- 2) Diopside - $\text{CaMg}(\text{SiO}_3)_2$
- 3) Wollastonite - $\text{Ca}_3(\text{SiO}_3)_3$

Note: The formula of cyclic silicates as well as chain silicates is $(\text{SiO}_3)_n^{2n-}$. Hence these are considered as an oligomers of the unknown SiO_3^{2-} ion.

5) DOUBLE CHAIN SILICATES (AMPHIBOLES)

The general formula of **double chain silicates (or Amphiboles)** is $(\text{Si}_4\text{O}_{11})_n^{6n-}$. There are two types of tetrahedra: those sharing 3 vertices and those sharing only 2 vertices.



E.g.

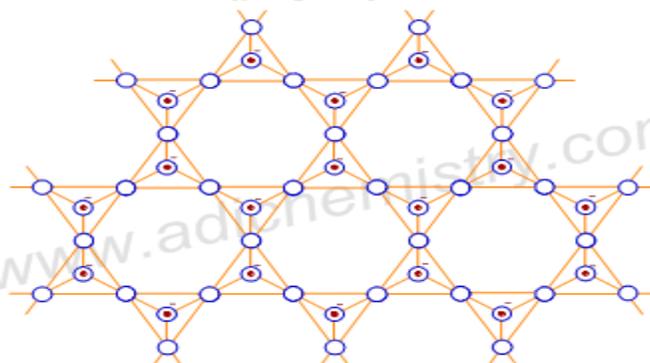
- 1) Asbestos - These are noncombustible fibrous silicates. They have been used for thermal insulation material, brake linings, construction material and filters. These are carcinogenic amphiboles affecting the lungs. Hence their applications are restricted nowadays.
- 2) Tremolite - $\text{Ca}_2\text{Mg}_5(\text{Si}_4\text{O}_{11})_2(\text{OH})_2$

Note: The single and double chain silicates are collectively known as Inosilicates.

6) SHEET SILICATES (PHYLLO SILICATES)

The general formula of Sheet or Phyllo or two dimensional (2-D) silicates is $(\text{Si}_2\text{O}_5)_n^{2n-}$. Each SiO_4 tetrahedron shares three oxygen atoms with others and thus by forming two-dimensional sheets. These silicates can be cleaved easily just like graphite. The layers are held together by weak van der Waal's forces.

Sheet (phyllo) Silicates



E.g.

1) Talc - $\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$: It is the main ingredient of soap stone. It is the softest material with a smooth and greasy touch.

2) Micas : General formula is $\text{X}_2\text{Y}_{4-6}\text{Z}_8\text{O}_{20}(\text{OH},\text{F})_4$

Where X = K, Na, or Ca

Y = Al, Mg, or Fe

Z = Si or Al

E.g. Muscovite mica - $\text{KAl}_2(\text{AlSi}_3\text{O}_{10})(\text{F},\text{OH})_2$ - split into thin layers extremely easily and Lepidolite - $\text{KLi}_2\text{Al}(\text{Al},\text{Si})_3\text{O}_{10}(\text{F},\text{OH})_2$

3) Clay : It is an aluminosilicate with sheet structure.

4) Kaolinite - $\text{AlSiO}_5(\text{OH})_5$

7) THREE DIMENSIONAL SILICATES (TECTO SILICATES)

The general formula of three dimensional (3-D) or tecto or Framework silicates is $(\text{SiO}_2)_n$. All the oxygen atoms of SiO_4 are shared with other tetrahedra and thus by forming three-dimensional network.

E.g. SiO_2 - Quartz, Tridymite and Cristobalite - These are the crystalline forms of silica.

When SiO_4^{4-} units are replaced by AlO_4^{5-} units, three dimensional aluminosilicates are formed.

E.g. Feldspar, Zeolites, Ult etc.,

- * Silicate minerals are very common in the Earth crust since Oxygen and Silicon are the most abundant elements.
- * The degree of polymerization is denoted by Oxygen to Silicon ratio (O/Si). Greater the degree of polymerization, lower will be the O/Si ratio. The values of O/Si for ortho silicates (least polymerized) = 4:1 while for tecto silicates (most polymerized silicate) = 2:1.
- * With increase in the degree of polymerization, there is decrease in the charge per silicon atom as well as the basicity of silicate mineral. Indeed, silica (SiO₂) is an acidic oxide.
- * The basic silicate minerals readily react with weak acids and undergo weathering.

Bery

Beryl is a mineral composed of beryllium aluminium cyclosilicate with the chemical formula Be₃Al₂Si₆O₁₈. Well-known varieties of beryl include emerald and aquamarine. Naturally occurring, hexagonal crystals of beryl can be up to several meters in size, but terminated crystals are relatively rare. Pure beryl is colorless, but it is frequently tinted by impurities; possible colors are green, blue, yellow, red (the rarest), and white. Beryl is also an ore source of beryllium.

Beryl belongs to the hexagonal crystal system. Normally Beryl forms hexagonal columns but can also occur in massive habits. As a cyclosilicate beryl incorporates rings of silicate tetrahedra that are arranged in columns along the C axis and as parallel layers perpendicular to the C axis, forming channels along the C axis. These channels permit a variety of ions, neutral atoms, and molecules to be incorporated into the crystal thus disrupting the overall charge of the crystal permitting further substitutions in Aluminium, Silicon, and Beryllium sites in the crystal structure. These impurities give rise to the variety of colors of beryl that can be found. Increasing alkali content within the silicate ring channels causes increases to the refractive indices and birefringence.

Beryl is a beryllium compound that is a known carcinogen with acute toxic effects leading to pneumonitis when inhaled. Care must thus be used when mining, handling, and refining these gems.

Beryl is a highly sedative stone. If taken as an elixir and gargled, Beryl crystal water can help heal throat problems and asthma. This stone is also used to treat problems with kidney stones and the bladder. It can strengthen your intestinal tract and boost your cardiovascular system.

1. Emerald Emerald gemstone is a variety of mineral beryl in green color. It is a precious gemstone. Beryl has a hardness of 7.5 to 8 on Mohs scale. The emerald is the sacred stone of the goddess Venus.
2. Green Beryl Beryl is a most and popular mineral. It has a great variety of colors, and has several important gemstone. It is a semi-precious gemstone. Its hardness on 7.5-8 Mohs Scale.
3. Emerald Category= Beryl variety Formula= Be₃Al₂(SiO₃)₆ Specific gravity= Average 2.76 Color= Green shades to colorless
4. Green Beryl Category= Cyclosilicate Formula= Be₃Al₂(Si O₃)₆ Specific gravity= Average 2.76 Color= Green, blue, yellow, colorless, pink and others

5. between Emerald & Green Beryl Color Variations: The color of Emerald can be green to greenish- blue. While, the color of Green Beryl is pale green or very light green. They are belonging to the same mineral species Beryl.
6. Inclusions :• Emeralds are generally heavily included which makes them less resistance to breakage or stretch. • In comparison, Green Beryl's are very less included.
7. Rarity: • Emeralds are very rare to be found as compared to Green Beryl. • As it is a rare event when Beryl is formed in a location where it is directly exposed to either chromium or vanadium.
8. Crystal Structure:• The Crystal Structure of both of these gemstone are hexagonal in nature. • Green Beryl is colored by traces of iron are frequently heated to remove the green component and marketed as Aquamarine. • Thus, Aquamarine is sold at much higher prices than Green Beryl.
9. Refractive Index:• It is an indication of the amount light rays are bent by the mineral. • The refractive index of Emerald is 1.565- 1.602 • Green Beryl has refractive index of 1.58- 1.59.
10. _Origin Sources: • Emeralds are mined from the countries like Colombia, Brazil, Zambia and Zimbabwe. Green Beryl's are mined from the countries like Afghanistan, Pakistan, South Africa, South America and many more.

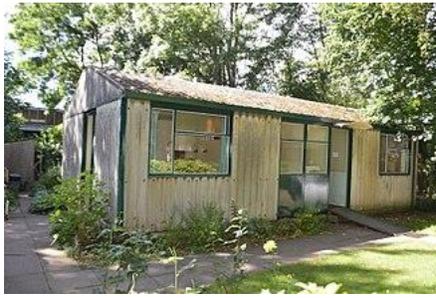
Asbestos

Asbestos is a term used to refer to six naturally occurring silicate minerals. All are composed of long and thin fibrous crystals, each fiber being composed of many microscopic 'fibrils' that can be released into the atmosphere by abrasion and other processes. Asbestos is an excellent electrical insulator and is highly heat-resistant, so for many years it was used as a building material. However, it is now a well-known health and safety hazard and the use of asbestos as a building material is illegal in many countries. Inhalation of asbestos fibres can lead to various serious lung conditions, including asbestosis and cancer.

Serpentine group



In London Hospital, England, 1941, nurse arranges an asbestos blanket over an electrically heated frame to create a hood over this patient to help warm them quickly



Example of asbestos cement siding and lining on a post-war temporary house in Yardley, Birmingham. Nearly 40,000 of these structures were built between 1946 and 1949 to house families.

Serpentine minerals have a sheet or layered structure. Chrysotile (commonly known as white asbestos) is the only asbestos mineral in the serpentine group. In the United States, chrysotile has been the most commonly-used type of asbestos. According to the U.S. Environmental Protection Agency (EPA) Asbestos Building Inspectors Manual, chrysotile accounts for approximately 95% of asbestos found in buildings in the United States.^[49] Chrysotile is often present in a wide variety of products and materials, including:

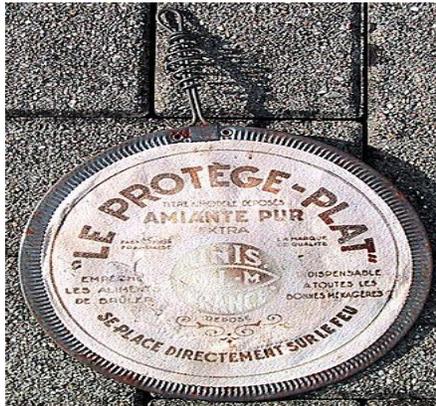
- Chlor Alkali diaphragm membranes used to make chlorine (currently in the US)^[50]
- Drywall and joint compound (including texture coats)
- Plaster
- Gas mask filters pre-1960s and gas mask filters from the USSR
- Vinyl floor tiles, sheeting, adhesives
- Roofing tars, felts, siding, and shingles^[51]
- "Transite" panels, siding, countertops, and pipes
- Popcorn ceilings, also known as acoustic ceilings
- Fireproofing



An asbestos glove

- Caulk
- Industrial and marine gaskets
- Brake pads and shoes
- Stage curtains

- Fire blankets
- Interior fire doors
- Fireproof clothing for firefighters
- Thermal pipe insulation
- Filters for removing fine particulates from chemicals, liquids and wine
- Dental cast linings
- HVAC flexible duct connectors
- Drilling fluid additives



A household heat spreader for cooking on gas stoves, made of asbestos (probably 1950s; "Amiante pur" is French for "Pure Asbestos")



Gasket, containing nearly unbound asbestos.

Amphibole group

Amphiboles including amosite (brown asbestos) and crocidolite (blue asbestos) were formerly used in many products until the early 1980s Tremolite asbestos constituted a contaminant of many if not all naturally occurring chrysotile deposits. Some products that included amphibole types of asbestos included the following:

- Low density insulating board (often referred to as AIB or asbestos insulating board) and ceiling tiles;
- Asbestos cement sheets and pipes for construction, casing for water and electrical/telecommunication services;
- Thermal and chemical insulation (e.g., fire rated doors, limpet spray, lagging and gaskets).

Cigarette manufacturer Lorillard (Kent's filtered cigarette) used crocidolite asbestos in its "Micronite" filter from 1952 to 1956. While mostly chrysotile asbestos fibers were once used in automobile brake pads, shoes, and clutch discs, contaminants of amphiboles were present. Since approximately the mid-1990s, brake pads, new or replacement, have been manufactured instead with linings made of ceramic, carbon, metallic and aramid fiber (Twaron or Kevlar—the same material used in bulletproof vests).

Artificial Christmas snow, known as flocking, was previously made with asbestos. It was used as an effect in films including *The Wizard of Oz* and department store window displays and it was marketed for use in private homes under brand names that included "Pure White", "Snow Drift" and "White Magic"

The use of asbestos in new construction projects has been banned for health and safety reasons in many developed countries or regions,

Removal of asbestos building components can also remove the fire protection they provide, therefore fire protection substitutes are required for proper fire protection that the asbestos originally provided.

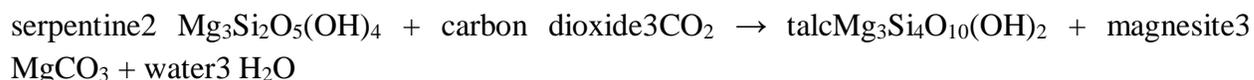
Talc

Talc is a clay mineral composed of hydrated magnesium silicate with the chemical formula $\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$. Talc in powdered form, often in combination with corn starch, is widely used as baby powder. This mineral is used as a thickening agent and lubricant, is an ingredient in ceramics, paint and roofing material, and is also one of the main ingredients in many cosmetic products.^[5] It occurs as foliated to fibrous masses, and in an exceptionally rare crystal form. It has a perfect basal cleavage, uneven flat fracture and it is foliated with a two dimensional platy form.

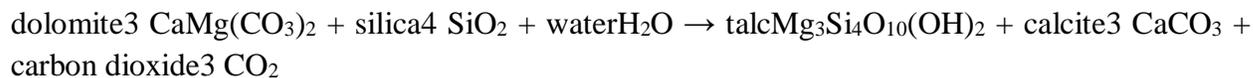
Formation

Talc is a mineral that results from the metamorphism of magnesian minerals such as serpentine, pyroxene, amphibole, and olivine, in the presence of carbon dioxide and water. This is known as "talc carbonation" or "steatization" and produces a suite of rocks known as talc carbonates.

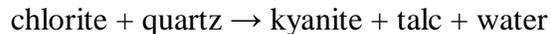
Talc is primarily formed by hydration and carbonation by this reaction:



Talc can also be formed via a reaction between dolomite and silica, which is typical of skarnification of dolomites by silica-flooding in contact metamorphic aureoles:



Talc can also be formed from magnesian chlorite and quartz in blueschist and eclogite metamorphism by the following metamorphic reaction:



In this reaction, the ratio of talc and kyanite depends on aluminium content, with more aluminous rocks favoring production of kyanite. This is typically associated with high-pressure, low-temperature minerals such as phengite, garnet, and glaucophane within the lower blueschist facies. Such rocks are typically white, friable, and fibrous, and are known as whiteschist.

Talc is a trioctahedral layered mineral; its structure is similar to pyrophyllite, but with magnesium in the octahedral sites of the composite layers.

Uses

Talc is used in many industries, including paper making, plastic, paint and coatings, rubber, food, electric cable, pharmaceuticals, cosmetics, and ceramics. A coarse grayish-green high-talc rock is soapstone or steatite, used for stoves, sinks, electrical switchboards, etc. It is often used for surfaces of laboratory table tops and electrical switchboards because of its resistance to heat, electricity and acids. In finely ground form, talc finds use as a cosmetic (talcum powder), as a lubricant, and as a filler in paper manufacture. It is used to coat the insides of inner tubes and rubber gloves during manufacture to keep the surfaces from sticking. Talcum powder, with heavy refinement, has been used in baby powder, an astringent powder used to prevent diaper rash. The American Academy of Pediatrics recommends that parents not use baby powder because it poses a risk of respiratory problems, including breathing trouble and serious lung damage if the baby inhales it. The small size of the particles makes it difficult to keep them out of the air while applying the powder. Zinc oxide-based ointments are a much safer alternative.

It is also often used in basketball to keep a player's hands dry. Most tailor's chalk, or French chalk, is talc, as is the chalk often used for welding or metalworking.

Talc is also used as food additive or in pharmaceutical products as a glidant. In medicine, talc is used as a pleurodesis agent to prevent recurrent pleural effusion or pneumothorax. In the European Union, the additive number is **E553b**.

Talc may be used in the processing of white rice as a buffing agent in the polishing stage.

Due to its low shear strength, talc is one of the oldest known solid lubricants. Also a limited use of talc as friction-reducing additive in lubricating oils is made.

The United States Food and Drug Administration considers talc (magnesium silicate) generally recognized as safe (GRAS) to use as an anticaking agent in table salt in concentrations smaller than 2%

Mica

The **mica** group of sheet silicate (phyllosilicate) minerals includes several closely related materials having nearly perfect basal cleavage. All are monoclinic, with a tendency towards pseudo-hexagonal crystals, and are similar in chemical composition. The nearly perfect cleavage, which is the most prominent characteristic of mica, is explained by the hexagonal sheet-like arrangement of its atoms.

Classification

Chemically, micas can be given the general formula



in which

X is K, Na, or Ca or less commonly Ba, Rb, or Cs;

Y is Al, Mg, or Fe or less commonly Mn, Cr, Ti, Li, etc.;

Z is chiefly Si or Al, but also may include Fe^{3+} or Ti.

Structurally, micas can be classed as dioctahedral (Y = 4) and trioctahedral (Y = 6). If the X ion is K or Na, the mica is a common mica, whereas if the X ion is Ca, the mica is classed as a brittle mica.

Mica is widely distributed and occurs in igneous, metamorphic and sedimentary regimes. Large crystals of mica used for various applications are typically mined from granitic pegmatites

Ground mica is used in the well-drilling industry as an additive to drilling fluids. The coarsely ground mica flakes help prevent the loss of circulation by sealing porous sections of the drill hole.

Dry-ground mica is used in the production of rolled roofing and asphalt shingles, where it serves as a surface coating to prevent sticking of adjacent surfaces. The coating is not absorbed by freshly manufactured roofing because mica's platy structure is unaffected by the acid in asphalt or by weather conditions. Mica is used in decorative coatings on wallpaper, concrete, stucco, and tile surfaces. It also is used as an ingredient in flux coatings on welding rods, in some special greases, and as coatings for core and mold release compounds, facing agents, and mold washes in foundry applications. Dry-ground phlogopite mica is used in automotive brake linings and clutch plates to reduce noise and vibration (asbestos substitute); as sound-absorbing insulation for coatings and polymer systems; in reinforcing additives for polymers to increase strength and stiffness and to improve stability to heat, chemicals, and ultraviolet (UV) radiation; in heat shields and temperature insulation; in industrial coating additive to decrease the permeability of moisture and hydrocarbons; and in polar polymer

Flexible plate is used in electric motor and generator armatures, field coil insulation, and magnet and commutator core insulation. Mica consumption in flexible plate

Sheet mica is used principally in the electronic and electrical industries. Its usefulness in these applications is derived from its unique electrical and thermal properties and its mechanical properties, which allow it to be cut, punched, stamped, and machined to close tolerance

Zeolite

Zeolite, any member of a family of hydrated aluminosilicate minerals that contain alkali and alkaline-earth metals. The zeolites are noted for their lability toward ion-exchange and reversible dehydration. They have a framework structure that encloses interconnected cavities occupied by large metal cations (positively charged ions) and water molecules.

structural properties

The essential structural feature of a zeolite is a three-dimensional tetrahedral framework in which each oxygen atom is shared by two tetrahedra. If all tetrahedra contained silicon the framework would be neutral; substitution of aluminum for silicon creates a charge imbalance and requires other metal ions to be present in relatively large cavities of the framework. In naturally occurring zeolites these metal ions are typically mono- or di-valent ions such as sodium, potassium, magnesium, calcium, and barium. Zeolites are similar to feldspar minerals except that cavities are larger in zeolites and water is generally present. Structurally, zeolites are classified by the types of structural units that compose the framework, such as rings or polyhedra types. The cavities formed by the framework units have diameters ranging from about 2 to 8 angstroms, which permits relatively easy movement of ions between cavities.

This ease of movement of ions and water within the framework allows reversible dehydration and cation exchange, properties which vary considerably with chemical and structural differences. Dehydration character varies with the way water is bound in the structure. For those zeolites in which water is tightly bound, dehydration occurs at relatively high temperatures; by contrast, in certain zeolites with large cavities, some of the water can be released at low temperatures. The rate of ion exchange depends on the size and connections between cavities. Some ions are excluded because of specific structural properties.

uses

Some commercial uses include separation of hydrocarbons, such as in petroleum refining; drying of gases and liquids; and pollution control by selective molecular adsorption.

Feldspar

Feldspar, any of a group of aluminosilicate minerals that contain calcium, sodium, or potassium. Feldspars make up more than half of Earth's crust, and professional literature about them constitutes a large percentage of the literature of mineralogy.

Two important rock-forming materials that are not minerals are major components of a few rocks. These are glass and macerals. Glass forms when magma (molten rock material) is quenched—i.e., cooled so rapidly that the constituent atoms do not have time to arrange themselves into the regular arrays characteristic of minerals. Natural glass is the major constituent of a few volcanic rocks—e.g., obsidian. Macerals are macerated bits of organic matter, primarily plant materials; one or more of the macerals are the chief original constituents of all the diverse coals and several other organic-rich rocks such as oil shales.

Classification

In the classification of igneous rocks of the International Union of Geological Sciences (IUGS), the feldspars are treated as two groups: the alkali feldspars and the plagioclase feldspars. The alkali feldspars include orthoclase, microcline, sanidine, anorthoclase, and the two-phase intermixtures called perthite. The plagioclase feldspars include members of the albite-anorthite solid-solution series. Strictly speaking, however, albite is an alkali feldspar as well as a plagioclase feldspar.

Chemical composition

All the rock-forming feldspars are aluminosilicate minerals with the general formula AT_4O_8 in which A = potassium, sodium, or calcium (Ca); and T = silicon (Si) and aluminum (Al), with a Si:Al ratio ranging from 3:1 to 1:1. Microcline and orthoclase are potassium feldspars ($KAlSi_3O_8$), usually designated Or in discussions involving their end-member composition. Albite ($NaAlSi_3O_8$ —usually designated Ab) and anorthite ($CaAl_2Si_2O_8$ —An) are end-members of the plagioclase series. Sanidine, anorthoclase, and the perthites are alkali feldspars whose chemical compositions lie between Or and Ab. As is apparent from the preceding statements, solid solution plays an important role in the rock-making feldspars. (Members of solid-solution series are single crystalline phases whose chemical compositions are intermediate to those of two or more end-members.) The alkali (Or-Ab) series exhibits complete solid solution at high temperatures but only incomplete solid solution at low temperatures; substitution of potassium for sodium is involved. The plagioclase (Ab-An) series exhibits essentially complete solid solution at both high and low temperatures; coupled substitution of sodium and silicon by calcium and aluminum occurs. The An-Or system has only limited solid-solution tendencies.

Production and uses

Feldspar is a common raw material used in glassmaking, ceramics, and to some extent as a filler and extender in paint, plastics, and rubber. In glassmaking, alumina from feldspar improves product hardness, durability, and resistance to chemical corrosion. In ceramics, the alkalis in feldspar (calcium oxide, potassium oxide, and sodium oxide) act as a flux, lowering the melting temperature of a mixture. Fluxes melt at an early stage in the firing process, forming a glassy matrix that bonds the other components of the system together. In the US, about 66% of feldspar is consumed in glassmaking, including glass containers and glass fiber. Ceramics (including electrical insulators, sanitaryware, pottery, tableware, and tile) and other uses, such as fillers, accounted for the remainder.

sciences and archaeology, feldspars are used for potassium-argon dating, argon-argon dating, and luminescence dating.

UNIT V

INDUSTRIAL CHEMISTRY

LPG

LPG is a predominant mixture of propane and Butane with a small percentage of unsaturates (Propylene and Butylene) and some lighter C₂ as well as heavier C₅ fractions. Included in the LPG range are propane (C₃H₈), Propylene(C₃H₆), normal and iso-butane (C₄H₁₀) and Butylene(C₄H₈). LPG may be defined as those hydrocarbons, which are gaseous at normal atmospheric pressure, but may be condensed to the liquid state at normal temperature, by the application of moderate pressures. Although they are normally used as gases, they are stored and transported as liquids under pressure for convenience and ease of handling. Liquid LPG evaporates to produce about 250 times volume of gas. LPG vapour is denser than air: butane is about twice as heavy as air and propane about one and a half times as heavy as air. Consequently, the vapour may flow along the ground and into drains sinking to the lowest level of the surroundings and be ignited at a considerable distance from the source of leakage. In still air vapour will disperse slowly. Escape of even small quantities of the liquefied gas can give rise to large volumes of vapour / air mixture and thus cause considerable hazard. To aid in the detection of atmospheric leaks, all LPG's are required to be odorized. There should be adequate ground level ventilation where LPG is stored. For this very reason LPG cylinders should not be stored in cellars or basements, which have no ventilation at ground level.

Natural Gas

Methane is the main constituent of Natural gas and accounting for about 95% of the total volume. Other components are: Ethane, Propane, Butane, Pentane, Nitrogen, Carbon Dioxide, and traces of other gases. Very small amounts of sulphur compounds are also present. Since methane is the largest component of natural gas, generally properties of methane are used when comparing the properties of natural gas to other fuels. Natural gas is a high calorific value fuel requiring no storage facilities. It mixes with air readily and does not produce smoke or soot. It has no sulphur content. It is lighter than air and disperses into air easily in case of leak. Atypical comparison of carbon contents in oil, coal and gas.

	Fuel Oil	Coal	Natural Gas
Carbon	84	41.11	74
Hydrogen	12	2.76	25
Sulphur	3	0.41	-
Oxygen	1	9.89	Trace
Nitrogen	Trace	1.22	0.75
Ash	Trace	38.63	-
Water	Trace	5.98	-

Water gas

Water gas is a mixture of carbon monoxide and hydrogen produced from synthesis gas. Synthesis gas is a useful product, but requires careful handling due to its flammability and the risk of carbon monoxide poisoning. The water-gas shift reaction can be used to reduce the carbon monoxide while producing additional hydrogen, resulting in water gas.

Production

Synthesis gas is made by passing steam over a red-hot carbon fuel such as coke:



The reaction is endothermic, so the fuel must be continually re-heated to keep the reaction going. In order to do this, an air stream, which alternates with the vapor stream, is introduced for the combustion of carbon to take place.



Theoretically, to make 6 L of water gas, 5 L of air is required.

Or, alternatively, to prevent contamination with nitrogen, energy can be provided by using pure oxygen to burn carbon into carbon monoxide.



In this case 1 L of oxygen will create 5.3 L of pure water gas.

Variations

Carburetted water gas

Water gas has a lower heat of combustion than coal gas, so the calorific value was often boosted by passing the gas through a heated retort, into which oil was sprayed. The resulting mixed gas was called *carburetted water gas*. The average composition of carburated water gas is as follows: H₂-34-38%, CO=23-28%; saturated hydrocarbon=17-21%; unsaturated hydrocarbon=13-16%; CO₂=0.2-2.2%; N₂=2.5-5.0% It is used as a source of heat since it has a high calorific value

Semi-water gas

Semi-water gas is a mixture of water gas and producer gas made by passing a mixture of air and steam through heated coke. The heat generated when producer gas is formed keeps the temperature of the coke high enough to allow water gas to be formed.

Water gas shift reaction

Pure hydrogen can be obtained from water gas by using the water-gas shift reaction, after subsequent removal of the carbon dioxide formed when carbon monoxide reacts with water.

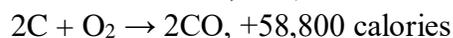
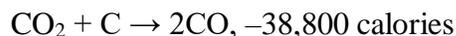
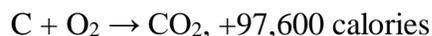
Uses

- Used to remove carbon monoxide from fuel cell applications.
- Used in Fischer–Tropsch process.
- Reaction with producer gas to produce fuel gas.
- Used to gain pure hydrogen for synthesis of ammonia.

Producer gas

Producer gas is fuel gas that is manufactured from material such as coal, as opposed to natural gas. It can be produced from various fuels by partial combustion with air, usually modified by simultaneous injection of water or steam to maintain a constant temperature and obtain a higher heat content gas by enrichment of air gas with hydrogen.

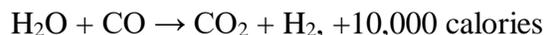
Formation of producer gas from air and carbon:



Reactions between steam and carbon:



Reaction between steam and carbon monoxide:



- Air gas: a.k.a. “power gas,” “generator gas” or “Siemens’ producer gas.” Produced from various fuels by partial combustion with air. Air gas consists principally of carbon monoxide with nitrogen from the air used and a small amount of hydrogen. This term is not commonly used, and tends to be used synonymously with wood gas.
- Producer gas: Air gas modified by simultaneous injection of water or steam to maintain a constant temperature and obtain a higher heat content gas by enrichment of air gas with H₂. Current usage often includes air gas.
- Semi-water gas: Producer gas.
- Blue water-gas: Air, water or producer gas produced from clean fuels such as coke, charcoal and anthracite which contain insufficient hydrocarbon impurities for use as illuminating gas. Blue gas burns with a blue flame and does not produce light except when used with a Welsbach gas mantle.
- Lowe’s Water Gas: Water gas with a secondary pyrolysis reactor to introduce hydrocarbon gasses for illuminating purposes.
- Carbutetted gas: Any gas produced by a process similar to Lowe’s in which hydrocarbons are added for illumination purposes.
- Wood gas: produced from wood by partial combustion. Sometimes used in a gasifier to power cars with ordinary internal combustion engines.

Fertilizer

A fertilizer or fertiliser is any material of natural or synthetic origin that is applied to soil or to plant tissues to supply one or more plant nutrients essential to the growth of plants. Many sources of fertilizer exist, both natural and industrially produced.

- three main macronutrients:
 - Nitrogen (N): leaf growth
 - Phosphorus (P): Development of roots, flowers, seeds, fruit;
 - Potassium (K): Strong stem growth, movement of water in plants, promotion of flowering and fruiting;
- three secondary macronutrients: calcium (Ca), magnesium (Mg), and sulfur (S);
- micronutrients: copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), zinc (Zn), boron (B). Of occasional significance are silicon (Si), cobalt (Co), and vanadium (V).

The nutrients required for healthy plant life are classified according to the elements, but the elements are not used as fertilizers. Instead compounds containing these elements are the basis of fertilizers. The macro-nutrients are consumed in larger quantities and are present in plant tissue in quantities from 0.15% to 6.0% on a dry matter (DM) (0% moisture) basis. Plants are made up of four main elements: hydrogen, oxygen, carbon, and nitrogen. Carbon, hydrogen and oxygen are widely available as water and carbon dioxide. Although nitrogen makes up most of the atmosphere, it is in a form that is unavailable to plants. Nitrogen is the most important fertilizer since nitrogen is present in proteins, DNA and other components (e.g., chlorophyll). To be nutritious to plants, nitrogen must be made available in a "fixed" form. Only some bacteria and their host plants (notably legumes) can fix atmospheric nitrogen (N_2) by converting it to ammonia. Phosphate is required for the production of DNA and ATP, the main energy carrier in cells, as well as certain lipids.

NPK fertilizers

NPK fertilizers are three-component fertilizers providing nitrogen, phosphorus, and potassium.

NPK rating is a rating system describing the amount of nitrogen, phosphorus, and potassium in a fertilizer. NPK ratings consist of three numbers separated by dashes (e.g., 10-10-10 or 16-4-8) describing the chemical content of fertilizers. The first number represents the percentage of nitrogen in the product; the second number, P_2O_5 ; the third, K_2O . Fertilizers do not actually contain P_2O_5 or K_2O , but the system is a conventional shorthand for the amount of the phosphorus (P) or potassium (K) in a fertilizer. A 50-pound (23 kg) bag of fertilizer labeled 16-4-8 contains 8 lb (3.6 kg) of nitrogen (16% of the 50 pounds), an amount of phosphorus equivalent to that in 2 pounds of P_2O_5 (4% of 50 pounds), and 4 pounds of K_2O (8% of 50 pounds). Most fertilizers are labeled according to this N-P-K convention, although Australian convention, following an N-P-K-S system, adds a fourth number for sulfur, and uses elemental values for all values including P and K.

Micronutrients

The main micronutrients are molybdenum, zinc, boron, and copper. These elements are provided as water-soluble salts. Iron presents special problems because it converts to insoluble (bio-unavailable) compounds at moderate soil pH and phosphate concentrations. For this reason, iron is often administered as a chelate complex, e.g., the EDTA derivative. The micronutrient needs depend on the plant and the environment. For example, sugar beets appear to require boron, and legumes require cobalt,^[1] while environmental conditions such as heat or drought make boron less available for plants.

Table 1. Essential plant nutrients and their elemental (chemical) symbol

Nutrients Supplied by Air and Water	Nutrients Supplied by the Soil System		
	Primary or Macronutrients	Secondary	Micronutrients
Carbon - C	Nitrogen - N	Calcium - Ca	Zinc - Zn
Hydrogen - H	Phosphorus - P	Magnesium - Mg	Chlorine - Cl
Oxygen - O	Potassium - K	Sulfur - S	Boron - B
			Molybdenum - Mo
			Copper - Cu
			Iron - Fe
			Manganese - Mn
			Cobalt - Co
			Nickel - Ni

Table 3. Functions and available forms of nutrients

Nutrient Element	Functions in Plants	Plant Available From Soil Solution Complex	
		Form(s)	Symbol(s)
Nitrogen	Promotes rapid growth, chlorophyll formation and protein synthesis.	Anion and Cation	NO_3^- NH_4^+
Phosphorus	Stimulates early root growth. Hastens maturity. Stimulates blooming and aids seed formation.	Anion	H_2PO_4^- HPO_4^{2-}
Potassium	Increases resistance to drought and disease. Increases stalk and straw strength. Increases quality of grain and seed.	Cation	K^+
Calcium	Improves root formation, stiffness of straw and vigor. Increases resistance to seedling diseases.	Cation	Ca^{++}
Magnesium	Aids chlorophyll formation and phosphorus metabolism. Helps regulate uptake of other nutrients.	Cation	Mg^{++}
Sulfur	Amino acids, vitamins. Imparts dark green color. Stimulates seed production.	Anion	SO_4^{--}
Boron	Aids carbohydrate transport and cell division.	Anion	H_2BO_3 H_2BO_3^- HBO_3^{--} BO_3^{---} $\text{B}_4\text{O}_7^{--}$

Copper	Enzymes, light reactions.	Cation*	Cu^{++}
Iron	Chlorophyll formation.	Cation*	Fe^{++} Fe^{+++}
Manganese	Oxidation-reduction reactions. Hastens germination and maturation.	Cation*	Mn^{++}
Zinc	Auxins, enzymes.	Cation*	Zn^{++}
Molybdenum	Aids nitrogen fixation and nitrate assimilation.	Anion	MoO_4^{--}
Cobalt	Essential for nitrogen fixation.	Cation	Co^{++}
Nickel	Grain filling, seed viability	Cation	Ni^{++} Ni^{+++}
Chlorine	Water use.	Anion	Cl^-
Oxygen	Component of most plant compounds.	Obtained from air and water.	
Hydrogen	Component of most plant compounds.		
Carbon	Component of most plant compounds.		

Safty Match

A match is a tool for starting a fire. Typically, matches are made of small wooden sticks or stiff paper. One end is coated with a material that can be ignited by frictional heat generated by striking the match against a suitable surface. Wooden matches are packaged in matchboxes, and paper matches are partially cut into rows and stapled into matchbooks. The coated end of a match, known as the match "head", consists of a bead of active ingredients and binder; often colored for easier inspection. There are two main types of matches: safety matches, which can be struck only against a specially prepared surface, and strike-anywhere matches, for which any suitably frictional surface can be used.

The dangers of white phosphorus in the manufacture of matches led to the development of the "hygienic" or "safety match". The major innovation in its development was the use of red phosphorus, not on the head of the match but instead on a specially designed striking surface.

The industrial process for large-scale manufacture of red phosphorus after Schrötter's discoveries became known. The company was producing the substance by heating white phosphorus in a sealed pot at a specific temperature.

Paints

Paints are used to protect metals, timber, or plastered surfaces from the corrosive effects of weather, heat, moisture or gases etc and to improve their appearance. Fundamental components of an oil-based paint are:

1. **Body**
2. **Vehicle**
3. **Pigment**
4. **Thinner**
5. **Dryer**

1.Body

- Forming the main body of a paint
- Make the paint film harder and more resistant to abrasion
- Reduce shrinkage cracks on drying

In white paint body is also the pigment

Commonly used bases (body) are White lead, Zinc oxide, Iron oxide, Metallic powder such as Al, Cu, Br. Paints more often named after the base as Lead paint, Zinc paint, and Aluminum paint. The binder, or resin, is the actual film forming component of paint. It imparts adhesion, binds the pigments together, and strongly influences such properties as gloss potential, exterior durability, flexibility, and toughness. Binders include synthetic or natural resins such as acrylics, polyurethanes, polyesters, melamine resins, epoxy, or oils.

Typical binders include synthetic or natural resins such as acrylics, polyurethanes, polyesters, melamines, epoxy, or oils. Typical diluents include organic solvents such as petroleum distillate, alcohols, ketones, esters, glycol ethers, and the like. Water is a common diluent.

2. Vehicle

- Oily liquid in which the body and pigment are soluble
- Facilitates the paint to be conveniently spread over the surface
- Oils most commonly used as vehicle are

The main purpose of the vehicle is to adjust the viscosity of the paint. It is volatile and does not become part of the paint film. It can also control flow and application properties. Its main function is as the carrier for the non volatile components. Water is the main vehicle for water based paints.

Solvent based, sometimes called oil based, paints can have various combinations of solvents as the vehicle, including aliphatics, aromatics, alcohols, and ketones. These include organic solvents such as petroleum distillate, alcohols, ketones, esters, glycol ethers, and the like. Sometimes volatile low-molecular weight synthetic resins also serve as diluents. Linseed oil, Soya bean oil, Fish oil, dehydrated castor oil

3. Pigment

Pigments are materials which gives the paint its color. In white paint the body is the pigment. Natural pigments (natural iron oxides, chrome oxides). Synthetic pigments (phthalocyanines ► coal tar derivatives)

Pigments impart such qualities as color and opacity (sometimes inappropriately called 'hiding'), and influences properties such as gloss, film flow, and protective abilities. Pigment can generally be categorized into two main types: Prime, or hiding, pigments, and Inert, or extender, pigments. The main modern white hiding pigment is Titanium dioxide. Zinc oxide is a weaker white pigment with some important usages. Color hiding pigments fall also into two main categories, those being Inorganic, mostly duller earth tone colors, and Organic, generally brighter but more expensive colors.

Inert pigments break down into natural or synthetic types. Natural pigments include various clays, calcium carbonate, mica, silicas, and talcs. Synthetics would include calcined clays, blanc fix, precipitated calcium carbonate, and synthetic silicas. Pigments, usually insoluble powders, are used both to provide color, and to make paint opaque, thus protecting the substrate from the harmful effects of ultraviolet light while also increasing a paint's hiding power.

Some pigments are toxic, such as those used in lead paint. Paint manufacturers replaced lead white with a less toxic substitute, which can even be used to color food **titanium white** (titanium dioxide) which was first used in paints in the 19th century. The titanium white used in most paints today is often coated with silicon or aluminum oxides for various reasons such as better exterior durability, or better hiding performance via better efficiency promoted by more optimal spacing within the paint film.

4. Thinner

Liquid thinner is added in the paint to

- Increase fluidity
- Making paint more smooth
- Help penetration into porous surfaces

Common thinner ► turpentine (made by distilling gum from a number of pine trees)

5. Dryers

- Added to quicken the drying of vehicle
- Organic salts of Iron, zinc, lead, manganese, Ca
- To accelerate the oxidation and hardening of vehicle

Additives Used in Paints

Besides the three main categories of ingredients, paint can have a wide variety of miscellaneous additives, usually added in very small amounts. Some examples include additives to improve wet edge, to impart antifreeze properties, control foaming, control skinning, fight bacterial growth, or improve pigment stability. There are various additives, which are added to improve some properties, such as color opacity and matness, pigment dispersion, or stability.

Varnishes

Definition

Varnishes are more or less transparent liquids which are used to provide a protective surface coating in much the same way as paints do” At the same time they allow the original surface to show but add a lustrous and glossy finish to it. All varnishes have basically the same components as paints.

What is Varnish? Varnish is a transparent, hard, protective finish or film primarily used in wood finishing but also for other materials. Varnish is traditionally a combination of a drying oil, a resin, and a thinner or solvent. Varnish finishes are usually glossy but may be designed to produce satin or semi-gloss sheens by the addition of "flatting" agents.

Types of Varnishes

Natural Resin Varnishes:

Body made from natural resin obtained from certain trees. Natural resin obtained from living trees or from fossils(which are superior) Vehicle in varnish is the same as used in oil-based paint. Resins dissolved in oil ► mixture heated to temperature (500-600OF) depending on the amount of gloss required. Oil and natural resin varnish ► OLEO RESINOUS varnish. Thinner and dryers used in varnish are the same as used in oil based paints

Modified natural-resin varnishes:

Made from natural resin ► altered by chemical action. Common resin is heat treated with glycerin to form a gum. This gum is treated as the body for the varnish. Less expensive varnish than the oleo resinous varnish

Synthetic resin varnish:

- Synthetic varnish produced by plastic industry
- Chemicals used include nitrocellulose, amino resins, silicon etc
- Vehicle most often the same as for oleo resinous varnish
- Coal tar derivatives may be used as thinners
- Dryer is also the same as for other types of varnishes

Classification of Varnishes

1. **Long oil varnish:**

- Long oil contain 40 to 100 gal of oil per 100 lbs of resin
- Takes longer time to dry
- Moderate gloss
- Marine and spar varnish belongs to this group
- Tung oil used ► impervious to water

2. **Medium oil varnish:**

- Medium-oil contain 12 to 40 gal of oil per 100 lbs of resin
- They dry faster ► harder
- Harder film than long-oil varnish but are not impervious to water
- Floor varnish belongs to this group

3. **Short oil resins:**

Short-oil contain 5 to 12 gal of oil per 100 lbs of resin. Dry rapidly ► form a hard, brittle film that withstand much rough usage. Polishing varnish belongs to this group

- How to Varnish
- Varnish Finish
- Floor Varnish
- Oil Varnish

Distempers

They are paints used for the treatment of masonry walls. Water instead of oil is used as a vehicle ► known as water-paint too. Powdered white chalk and glue boiled in water are mixed. Usually colored by mixing different pigments. All Distempers mixed with water only before being used. Distemper affected by weathering condition and takes off if washed ► to be used only in interior works. Cheap, durable and easy interior finish. Should be applied on clean and dry surface.

Glass

Glass, an inorganic solid material that is usually transparent or translucent as well as hard, brittle, and impervious to the natural elements. Glass has been made into practical and decorative objects since ancient times, and it is still very important in applications as disparate as building construction, housewares, and telecommunications. It is made by cooling molten ingredients such as silica sand with sufficient rapidity to prevent the formation of visible crystals. Glass is the name given to any amorphous (non-crystalline) solid that displays a *glass transition* near its melting point. This is related to the *glass transition temperature*, which is the temperature where an amorphous solid becomes soft near its melting point or a liquid becomes brittle near its freezing point.

Glass is a type of matter. Sometimes the term *glass* is restricted to inorganic compounds, but more often now a glass may be an organic polymer or plastic or even an aqueous solution.

[Science, Tech, Math](#) › [Science](#)

The Composition and Properties of Glass



A precious moldavite gemstone in its non-crystalline, glass form.



Science

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When you hear the term "glass" you may think of window glass or a drinking glass. However, there are many other types of glass.

Glass is the name given to any amorphous (non-crystalline) solid that displays a *glass transition* near its melting point. This is related to the *glass transition temperature*, which is the temperature where an amorphous solid becomes soft near its melting point or a liquid becomes brittle near its freezing point.

Glass is a type of matter. Sometimes the term *glass* is restricted to inorganic compounds, but more often now a glass may be an organic polymer or plastic or even an aqueous solution.

Silicon Dioxide and Glass

The glass you encounter most often is silicate glass, which consists mainly of silica or silicon dioxide, SiO_2 . This is the type of glass you find in windows and drinking glasses. The crystalline form of this mineral is quartz. When the solid material is non-crystalline, it is a glass.

You can make glass by melting silica-based sand. Natural forms of silicate glass also exist. Impurities or additional elements and compounds added to the silicate change the color and other properties of the glass.

Glass Examples

Several types of glass occur in nature:

- Obsidian (volcanic silicate glass)
- Fulgurites (sand that has been vitrified by a lightning strike)
- Moldavite (green natural glass likely resulting from meteorite impacts)

Man-made glass includes:

- Borosilicate glass (e.g., Pyrex, Kimax)
 - Isinglass
 - Soda-lime glass
 - Trinitite (radioactive glass formed by heating of the desert floor by the Trinity nuclear test)
 - Fused quartz
 - Fluoro-aluminate
 - Tellurium dioxide
 - Polystyrene
 - Rubber for tires
 - Polyvinyl acetate (PVA)
 - Polypropylene
 - Polycarbonate
 - Some aqueous solutions
 - Amorphous metals and alloys
 - Properties of Glass
 - Chemical Composition of Glass
-
- Glass is an amorphous material, which means that the structure of glass lies between that of a crystalline material and a liquid. Glass is often considered as a super-cooled liquid. At high temperature, glass changes into liquid form where the glass atoms are free to move around. When this liquid glass is cooled down, the atoms rearrange themselves into more efficient packing. However, below a specific temperature, called fictive temperature, atoms do not rearrange themselves. This leads to a short-range order of glass atoms.

- The chief raw material used in the manufacture of glass consists of silicon dioxide, limestone, and soda ash.
- The primary reason for the popularity of glass is that its properties can be varied according to requirements. The correct combination of raw material and processing technique can be used to yield the desired properties. Glass can be made as strong as steel or more delicate than paper. It can be woven like the web of a spider or it can be molded into a mirror that would weigh in tons. It can be made into a transparent material or given any color.

The properties of glass are governed chiefly by its composition. To manufacture glass, you need the following types of ingredients:

- Formers
- Fluxes
- Stabilizers

Interdependency in Properties of Glass

Forming of Glass

Properties of Glass

Interdependency in Properties of Glass

The properties of glass are usually inter-dependent. This means that it is not easy to vary one property of glass without changing its other property. A brief on electrical, thermal, mechanical and optical properties of glass is as follows:

Electrical

Electrical properties of glass include the volume resistivity, tangent loss and electrical permittivity.

- Volume resistivity: Glass is an electric insulator. This means that it provides high amount of resistance to the flow of electricity through itself. The property that measures the resistance to the flow of electricity in the body of glass is known as volume resistivity. The volume resistivity of glass is almost 10¹⁸ times of the best electric conductor, copper.
- Tangent loss: This property measures the amount of electricity lost in any glass while the electricity is flowing through it.
- Electrical Permittivity: This property is a measure of the amount of electricity that a glass can store in itself without conducting any.
- Note to view the electrical properties of different types of glass.

Mechanical

Mechanical properties of glass are a measurement of the behavior of glass when subjected to different types of forces. The properties that are used to depict the mechanical behavior of different types of glass are as follows:

- Tensile strength: This property measures the maximum amount of stress that the glass can take without breaking.
- Poisson's ratio: When stress is applied to any glass, lateral and axial strain is introduced in it.

Composition of cement

Introduction

Portland cement gets its strength from chemical reactions between the cement and water. The process is known as hydration. This is a complex process that is best understood by first understanding the chemical composition of cement.

Manufacture of cement

Portland cement is manufactured by crushing, milling and proportioning the following materials:

- Lime or calcium oxide, CaO: from limestone, chalk, shells, shale or calcareous rock
- Silica, SiO₂: from sand, old bottles, clay or argillaceous rock
- Alumina, Al₂O₃: from bauxite, recycled aluminum, clay
- Iron, Fe₂O₃: from from clay, iron ore, scrap iron and fly ash
- Gypsum, CaSO₄.2H₂O: found together with limestone

The materials, without the gypsum, are proportioned to produce a mixture with the desired chemical composition and then ground and blended by one of two processes - dry process or wet process. The materials are then fed through a kiln at 2,600° F to produce grayish-black pellets known as clinker. The alumina and iron act as fluxing agents which lower the melting point of silica from 3,000 to 2600° F. After this stage, the clinker is cooled, pulverized and gypsum added to regulate setting time. It is then ground extremely fine to produce cement.

Chemical shorthand

Because of the complex chemical nature of cement, a shorthand form is used to denote the chemical compounds. The shorthand for the basic compounds is:

Compound	Formula	Shorthand form
Calcium oxide (lime)	CaO	C
Silicon dioxide (silica)	SiO ₂	S
Aluminum oxide (alumina)	Al ₂ O ₃	A
Iron oxide	Fe ₂ O ₃	F
Water	H ₂ O	H
Sulfate	SO ₃	<u>S</u>

Chemical composition of clinker

The cement clinker formed has the following typical composition:

Compound	Formula	Shorthand form	% by weight ¹
Tricalcium aluminate	$\text{Ca}_3\text{Al}_2\text{O}_6$	C_3A	10
Tetracalcium aluminoferrite	$\text{Ca}_4\text{Al}_2\text{Fe}_2\text{O}_{10}$	C_4AF	8
Belite or dicalcium silicate	Ca_2SiO_5	C_2S	20
Alite or tricalcium silicate	Ca_3SiO_4	C_3S	55
Sodium oxide	Na_2O	N)Up to 2
Potassium oxide	K_2O	K	
Gypsum	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	C_2SH_2	5

Representative weights only. Actual weight varies with type of cement.

Source: Mindess & Young

Properties of cement compounds

These compounds contribute to the properties of cement in different ways

Tricalcium aluminate, C_3A :-

It liberates a lot of heat during the early stages of hydration, but has little strength contribution. Gypsum slows down the hydration rate of C_3A . Cement low in C_3A is sulfate resistant.

Tricalcium silicate, C_3S :-

This compound hydrates and hardens rapidly. It is largely responsible for portland cement's initial set and early strength gain.

Dicalcium silicate, C_2S :

C_2S hydrates and hardens slowly. It is largely responsible for strength gain after one week.

Ferrite, C_4AF :

This is a fluxing agent which reduces the melting temperature of the raw materials in the kiln (from $3,000^\circ F$ to $2,600^\circ F$). It hydrates rapidly, but does not contribute much to strength of the cement paste. By mixing these compounds appropriately, manufacturers can produce different types of cement to suit several construction environments.