NUCLEI

1. **Nucleons.** *Protons and neutrons which are present in the nuclei of atoms are collectively known as nucleons.*

2. **Atomic number.** *The number of protons in the nucleus is called the atomic number of the element.* It is denoted by Z.

3. **Mass number.** *The total number of protons and neutrons present in a nucleus is called the mass number of the element.* It is denoted by *A*.

Hence *for a neutral atom,* we have the following relations :

Number of protons in an atom $= Z$
Number of electrons in an atom $= Z$
Number of nucleons in an atom $= A$
Number of neutrons in an atom $= N = A - Z.$

4. **Nuclear mass.** *The total mass of the protons and neutrons present in a nucleus is called the nuclear mass.*

5. **Nuclide.** When an atom is talked of with particular reference to its nuclear composition, it is called a nuclide. *Thus a nuclide is a specific nucleus of an atom characterised by its atomic number Z and mass number A.*

It is symbolically represented as

$$^{A}_{Z}X$$

where, X = chemical symbol of the element,
Z = atomic number, and
A = mass number.

For example, gold nucleus is represented as $^{197}_{79}\text{Au}$. It contains 197 nucleons, of which 79 are protons and 118 neutrons.

Atomic mass unit

Atomic mass unit. The mass of the carbon-12 atom is 1.992678×10^{-26} kg, which is very small. Therefore, it is useful to choose a convenient unit for expressing the mass of atoms. This unit is defined by taking mass of carbon-12 atom equal to 12 atomic mass units.

One atomic mass unit is defined as $\frac{1}{12}$th of the actual mass of carbon-12 atom.

Atomic mass unit is denoted by *amu* or just by *u*.

Thus

$$1 \text{ amu} = \frac{1}{12} \times \text{Mass of carbon-12 atom}$$

$$= \frac{1}{12} \times 1.992678 \times 10^{-26} \text{ kg}$$

or $\mathbf{1\ amu = 1.660565 \times 10^{-27}\ kg}$

We can now express different masses in terms of amu.

Mass of an electron,

$$m_e = 0.00055 \text{ amu} = 9.11 \times 10^{-31} \text{ kg}$$

Mass of a proton,

$$m_p = 1.0073 \text{ amu} = 1.6726 \times 10^{-27} \text{ kg}$$

Mass of a neutron,

$$m_n = 1.0086 \text{ amu} = 1.6749 \times 10^{-27} \text{ kg}$$

Mass of a hydrogen atom,

$$m_H = m_p + m_e = 1.0078 \text{ amu}$$

The atomic masses can be measured accurately by using an instrument called mass spectrometer.

Nuclear Size

Experimental observations show that *the volume of a nucleus is directly proportional to its mass number.*

If R is the radius of a nucleus having mass number A, then

$$\frac{4}{3}\pi R^3 \propto A$$

or $$R \propto A^{1/3}$$

Thus, *the radius R of a nucleus is proportional to cube root of its mass number.* We can write

$$R = R_0 A^{1/3}$$

Here R_0 is a constant, which is of the order of the range of nuclear force.

$$R_0 = 1.2 \times 10^{-15} \text{m} = 1.2 \text{ fm}$$

Electron Volt. *It is defined as the energy acquired by an electron when it is accelerated through a potential difference of 1 volt and is denoted by eV.*

$$1\,eV = 1.602 \times 10^{-19}\,J$$

It is a convenient unit of energy used commonly in atomic physics. For example, 13.6 eV energy is needed to remove an electron from a hydrogen atom. A bigger unit called *million electron volt* (MeV) is used for measuring energy changes in nuclear reactions. For example, about 2.2 MeV energy is needed to separate neutron and proton in a deuterium nucleus.

$$1\,MeV = 10^6\,eV = 1.602 \times 10^{-13}\,J$$

Nucleon Density

Nuclear density. **The density of nuclear matter is the ratio of the mass of a nucleus to its volume.**

Let A be the mass number and R be the radius of a nucleus. If m is the average mass of a nucleon, then

Mass of nucleus $= mA$

Volume of nucleus

$$= \frac{4}{3}\pi R^3$$

$$= \frac{4}{3}\pi (R_0 A^{1/3})^3 = \frac{4}{3}\pi R_0^3 A$$

$\therefore$ Nuclear density,

$$\rho_{nu} = \frac{\text{Mass of nucleus}}{\text{Volume of nucleus}}$$

or

$$\rho_{nu} = \frac{mA}{\frac{4}{3}\pi R_0^3 A} = \frac{3m}{4\pi R_0^3}$$

Clearly, *nuclear density is independent of mass number A or the size of the nucleus.*

Taking $m = 1.67 \times 10^{-27}$ kg

and $R_0 = 1.2 \times 10^{-15}$ m, we get

$$\rho_{nu} = \frac{3 \times 1.67 \times 10^{-27}}{4 \times 3.142 \times (1.2 \times 10^{-15})^3}$$

$$= 2.30 \times 10^{17}\ \text{kg m}^{-3}$$

Thus the nuclear mass density is of the order 10^{17} kg m^{-3}. This density is very large as compared to the density of ordinary matter, say water, for which $\rho = 1.0 \times 10^3$ kg m^{-3}.

Nuclear Force

Nuclear force is a strong attractive force that binds the protons and neutrons together inside a tiny nucleus.

Properties of nuclear force :

1. **Strongest interaction.** Nuclear force is the strongest interaction known in nature that holds the nucleons together despite the strong electrostatic repulsion between the protons.

2. **Short-range force.** Unlike gravitational and electrostatic forces, nuclear force is a short-range force. It operates only upto a very short distance of about 2-3 fm from a nucleon.

3. **Variation with distance.** The graph of P.E. of a pair of nucleons as a function of their separation r is shown in Fig. 13.4. The P.E. is minimum at a distance $r_0 = 0.8$ fm.

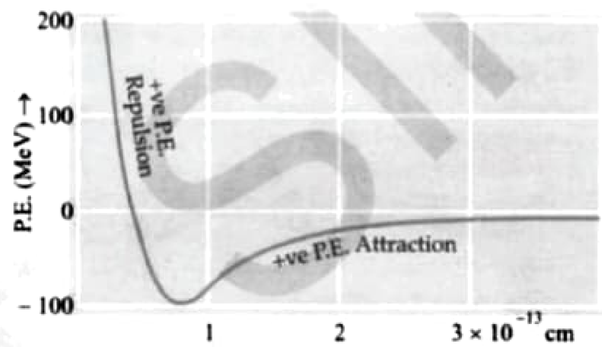


Fig. 13.4 **Graph of P.E. a pair of nucleons as a function of their separation.**

(*i*) For $r < r_0$, the P.E. increases rapidly with decreasing r. It indicates a strong repulsive nuclear force.

(*ii*) For $r > r_0$, the P.E. gradually decreases to zero with increasing r. It indicates attractive nuclear force. The attraction is maximum at $r_0 = 0.8$ fm and varies inversely not as the square of distance but depends on some higher power of distance.

(*iii*) For $r \simeq 4$ fm, the nuclear force becomes zero. It indicates that nuclear force is a short range force.

The negative sign of P.E. signifies that the nuclear force is attractive.

4. **Charge independent character.** It is seen from experiments that the attractive force between two neutrons (*nn-force*) is nearly equal to that between two protons (*pp-force*) or between a proton and a neutron (*pn-force*). Thus the nuclear force does not depend on the charge of the particles.

In case of *pp-nuclear force,* there is a repulsive force between two protons, but this is weak compared to the strong nuclear force.

5. **Saturation effect.** Nuclear forces show saturation effect, *i.e.,* a nucleon interacts only with its neighbouring nucleon. This property is supported by the fact that the binding energy per nucleon is same over a wide range of mass numbers.

6. **Spin dependent character.** The nuclear force between two nucleons having parallel spins is stronger than that between two nucleons having antiparallel spins.

8. **Non-central forces.** The nuclear force between two nucleons does not act along the line joining their centres.

Mass energy Relation

Einstein's mass-energy equivalence. In his special theory of relativity, Einstein showed that $E = mc^2$

Here c is the speed of light in vacuum and is equal to $3 \times 10^8 \text{ ms}^{-1}$. The above equation expresses equivalence between mass and energy. This equation suggests that even when a particle is at rest (having zero kinetic energy), it still possesses an enormous amount of energy because of its mass. *The mass of a particle measured in a frame of reference in which the particle is at rest, is called* ***rest mass*** and is denoted by m_0. Thus the total energy of a particle is sum of (*i*) its rest mass energy m_0c^2 and (*ii*) its kinetic energy T. That is $E = m_0c^2 + T$

The law of conservation of mass-energy *states that the sum of the mass-energy of a system of particles is the same before and after their interaction.*

Mass Defect

3

Mass defect. It is found that the mass of a stable nucleus is always less than the sum of the masses of its constituent protons and neutrons in their free state.

The difference between the rest mass of a nucleus and the sum of the rest masses of its constituent nucleons is called its **mass defect**.

Consider the nucleus $^A_Z X$. It has Z protons and $(A - Z)$ neutrons. Therefore, its mass defect will be

$$\Delta m = Zm_p + (A - Z)m_n - m$$

where m_p, m_n and m are the rest masses of a proton, neutron and the nucleus $^A_Z X$ respectively.

Packing Fraction

Packing fraction. *The packing fraction of a nucleus is its mass defect per nucleon.* Thus

$$\text{P.F. of a nucleus} = \frac{\text{Mass defect}}{\text{Mass number}} = \frac{\Delta m}{A}$$

If P.F. is *positive* (as in case of nuclei with mass number less than 20 and above 200), then the nucleus is *unstable*. If P.F. is *negative* (as in case of nuclei with mass number between 20 and 200), then it indicates that some mass has been converted into energy which binds the nucleons together and so the nucleus is *stable*. *Thus the P.F. is directly related to the availability of nuclear energy and the stability of the nucleus.*

Binding Energy

The ***binding energy*** *of a nucleus may be defined as the energy required to break up a nucleus into its constituent protons and neutrons and to separate them to such a large distance that they may not interact with each other.*

Expression for binding energy. The nucleus $^A_Z X$ contains Z protons and $(A - Z)$ neutrons. Its mass defect is

$$\Delta m = Zm_p + (A - Z)m_n - m_N \qquad \text{...(1)}$$

where m_N is the nuclear mass of $^A_Z X$. From Einstein's mass-energy equivalence, the binding energy of the nucleus is

$$\Delta E_b = \Delta m \times c^2 = [Zm_p + (A - Z)m_n - m_N]\,c^2 \qquad \text{...(2)}$$

Now, in an atom the electrons are bound to the nucleus by electrostatic forces. So they have a binding energy of their own, which from the mass-energy equivalence is given by

$$(\Delta E_b)_e = [(m_N + Zm_e) - m({}^A_Z X)]\,c^2 \qquad ...(3)$$

where $m({}^A_Z X)$ is the atomic mass. The binding energy of electrons ($\approx$ eV to keV) is negligible compared to the binding energy of nucleons ($\approx 10^3$ MeV). It will be a safe approximation to take,

$$(\Delta E_b)_e = 0$$

$$\therefore \qquad m_N + Zm_e - m({}^A_Z X) = 0$$

or

$$m_N = m({}^A_Z X) - Zm_e$$

Thus, in terms of atomic mass the equation (2) becomes

$$\Delta E_b = [Zm_p + (A - Z)m_n - m({}^A_Z X) + Zm_e]\,c^2$$

$$= [Z(m_p + m_e) + (A - Z)m_n - m({}^A_Z X)]\,c^2 \qquad ...(4)$$

But $m_p + m_e = m_H$ = mass of a hydrogen atom.

$\therefore$ The equation (4) can be written in terms of m_H as

$$\Delta E_b = [Zm_H + (A - Z)m_n - m({}^A_Z X)]\,c^2 \qquad ...(5)$$

Binding energy per nucleon. *The binding energy per nucleon is the average energy required to extract one nucleon from the nucleus. It is obtained by dividing the binding energy of a nucleus by its mass number. The expression for binding energy per nucleon can be written as*

$$\Delta E_{bn} = \frac{\Delta E_b}{A} = \frac{[Zm_H + (A - Z)m_n - m({}^A_Z X)]\,c^2}{A} \qquad ...(6)$$

The binding energy per nucleon gives a measure of the force which binds the nucleons together inside a nucleus.

Binding Energy Curve

Binding energy curve. The value of **binding energy** per nucleon of a nucleus gives **a measure of the stability of that nucleus. Greater is the binding energy per nucleon of a nucleus, more stable is the nucleus.**

Fig. 13.5 shows the graph of binding energy per nucleon drawn against mass number *A*.

The binding energy curve reveals the following important features :

1. Except for some nuclei like ${}^4_2$He, ${}^{12}_6$C and ${}^{16}_8$O, the values of binding energy per nucleon lie on or near a smooth curve.

2. The B.E. /nucleon is small for light nuclei like ${}^1_1$H, ${}^2_1$H and ${}^3_1$H.

3. In the mass number range 2 to 20, there are well defined maxima and minima on the curve. The maxima occur for ${}^4_2$He, ${}^{12}_6$C and ${}^{16}_8$O, indicating the higher stability of these nuclei than the neighbouring ones. The minima, corresponding to low stability, occur for ${}^6_3$Li, ${}^{10}_5$B and ${}^{14}_7$N.

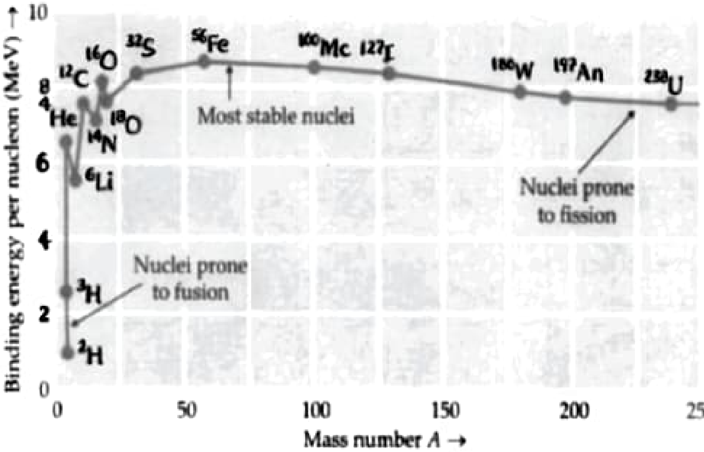
4. The curve has a broad maximum close to the value 8.5 MeV/nucleon in the mass number range from about 40 to 120. It has a peak value of 8.8 MeV/nucleon for ${}^{56}_{26}$Fe.

5. As the mass number increases further, the B.E. / nucleon shows a gradual decrease and drops to 7.6 MeV/nucleon for ${}^{238}_{92}$U. This decrease is due to coulomb repulsion between the protons which makes the heavier nuclei less stable.

Importance of binding energy curve. The binding energy curve can be used to explain the phenomena of nuclear fission and nuclear fusion as follows :

1. **Nuclear fission.** Binding energy per nucleon is smaller for heavier nuclei than the middle ones, *i.e.*, heavier nuclei are less stable. When a heavier nucleus splits into the lighter nuclei, the B.E./nucleon changes from about 7.6 MeV to 8.4 MeV. Greater binding energy of the product nuclei results in the liberation of energy. This is what happens in nuclear fission which is the basis of the atom bomb.

2. **Nuclear fusion.** The binding energy per nucleon is small for light nuclei, *i.e.*, they are less stable. So when two light nuclei combine to form a heavier nucleus, the higher binding energy per nucleon of the latter results in the release of energy. This is what happens in a nuclear fusion which is the basis of the hydrogen bomb.



Radioactivity

Radioactivity. *Radioactivity is the phenomenon of spontaneous disintegration of the nucleus of an atom with the emission of one or more penetrating radiations like α-particles, β-particles or γ-rays.*

Electrical nature of the radioactive radiation. *Rutherford* and *Villiard* were the first to analyse the radiation emitted by radium. This radiation was found to consist of three components :

1. A component which could hardly pass through 0.1 cm thick aluminium foil, called α-rays.
2. A component which was stopped by 5 mm thick aluminium sheet, called β-rays.
3. A component which could pass through even 30 cm thickness of an iron piece, called γ-rays.

A simple experimental arrangement to demonstrate the analysis of Becquerel radiation into three components is shown in Fig. 13.8.

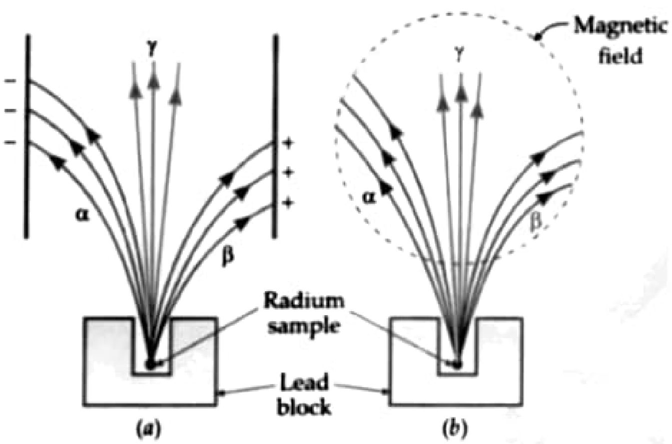


Fig. 13.8 **Bending of Becquerel rays in (*a*) an electric field and (*b*) a magnetic field.**

Soddy Fajan's Rule

On the basis of these rules, *Soddy* and *Fajan* in 1913, gave simple **displacement laws for radioactive transformations**, which can be stated as follows :

1. *When a radioactive nucleus emits an α-particle, its atomic number decreases by 2 and mass number decreases by 4.*
2. *When a radioactive nucleus emits a β-particle, its atomic number increases by 1 but mass number remains the same.*
3. *The emission of a γ-particle does not change the mass number or the atomic number of the radioactive nucleus.*

In addition, the following points about radioactive disintegration may also be noted :

1. No *individual atom* can simultaneously emit both α- and β-particles.
2. *Different atoms* of the same element can emit either an α-particle or a β-particle.
3. This emission of a β-particle is usually accompanied by the emission of a γ-ray photon.

1. **Becquerel (Bq).** The SI unit for activity is ***becquerel***, named after the discoverer of radioactivity, *Henry Becquerel. One becquerel is defined as the decay rate of one disintegration per second.*

1 becquerel = 1 Bq = 1 decay per second

Property	α-Rays	β- Rays	γ-Rays
1. *Nature*	Helium nuclei	Electrons of nuclear origin	High energy e.m. radiations
2. *Mass*	6.67×10^{-27} kg or 4 amu	9.11×10^{-31} kg	Rest mass is zero
3. *Charge*	+ 2e	−e	0
4. *Deflection by $\vec{E}$ and $\vec{B}$*	Deflected towards −ve pole	Deflected towards +ve pole	Nil
5. *Speed*	$\approx 10^7$ ms^{-1}	$\approx 10^8$ ms^{-1} but variable	3×10^8 ms^{-1}
6. *Ionising power*	10^4 times that of γ-rays	10^2 times that of γ-rays	Minimum
7. *Penetrating power*	Minimum	10^2 times that of α-rays	10^4 times that of γ-rays
8. *Effect on photographic plate and ZnS phosphor*	Strong effect	Less effect	Least effect

Nuclear fission

Nuclear fission. *The phenomenon in which a heavy nucleus ($A > 230$) when excited splits into two smaller nuclei of nearly comparable masses is called nuclear fission.*

In 1938, German scientists *Otto Hahn* and *Fritz Strassmann* found that when uranium is bombarded by slow moving neutrons, a $^{235}_{92}U$ nucleus gets excited by capturing a slow moving neutron and splits into two nearly equal fragments like $^{141}_{56}Ba$ and $^{92}_{36}Kr$ alongwith the emission of 3 neutrons. The nuclear reaction involved can be written as

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n + Q$$

The Q-value of this reaction is about 200 MeV.

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + 2\,^{1}_{0}n$$

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{95}_{42}Mo + ^{139}_{57}La + 2\,^{1}_{0}n$$

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{137}_{53}I + ^{97}_{39}Y + 2\,^{1}_{0}n$$

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{144}_{55}Cs + ^{90}_{37}Pb + 2\,^{1}_{0}n$$

Nuclear fission as a source of energy. In a nuclear fission, the sum of the masses of the final products is less than the sum of the masses of the reactant components. The difference in masses, called *mass defect*, is converted into energy according to Einstein's mass-energy relationship ($E = mc^2$). Thus an enormous amount of energy is released in a nuclear fission, as can be seen from the following example :

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n + Q$$

Initial masses		Final masses	
$^{235}_{92}U$	235.0439 amu	$^{141}_{56}Ba$	140.9139 amu
$^{1}_{0}n$	1.0087 amu	$^{92}_{36}Kr$	91.8973 amu
		$3\,^{1}_{0}n$	3.0261 amu
	236.0526 amu		235.8373 amu

Mass defect $= 236.0526 - 235.8373 = 0.2153$ amu

As 1 amu $= 931$ MeV

$\therefore$ Energy released, $Q = 0.2153 \times 931$ MeV

$= \mathbf{200\ MeV}$

This energy appears in the form of kinetic energy of the fission products and as γ-rays.

Thus in the fission of a single nucleus of $^{235}_{92}U$, about 200 MeV energy is released which is equivalent to 0.9 MeV/nucleon. The total energy released in the fission of 1 kg of naturally occurring uranium, which contains about 2.56×10^{24} atoms of $^{235}_{92}U$ isotope, will be $200 \times 2.56 \times 10^{24}$ MeV $= 10^{14}$ J. This is a very huge amount of energy which is equal to the energy obtained by burning of 3 tons of coal.

Nuclear chain Reaction

Nuclear chain reaction. Nuclear fission is a peculiar type of reaction which, besides the other fission products, produces the same kind of particles that initiate it, *viz.*, neutrons.

When a single $^{235}_{92}U$ nucleus captures a neutron, its fission produces 2.5 neutrons. These freshly produced electrons can further cause the fission of more uranium nuclei, producing still more neutrons, which can further cause the fission of a larger number of nuclei, and so on. *The number of fissions taking place at each successive stage goes on increasing at a rapid rate* (*rather in a geometric progression*). *Thus a chain reaction is set up*, as illustrated in Fig. 13.16. *Enrico Fermi* first suggested the possibility of such a reaction in 1939.

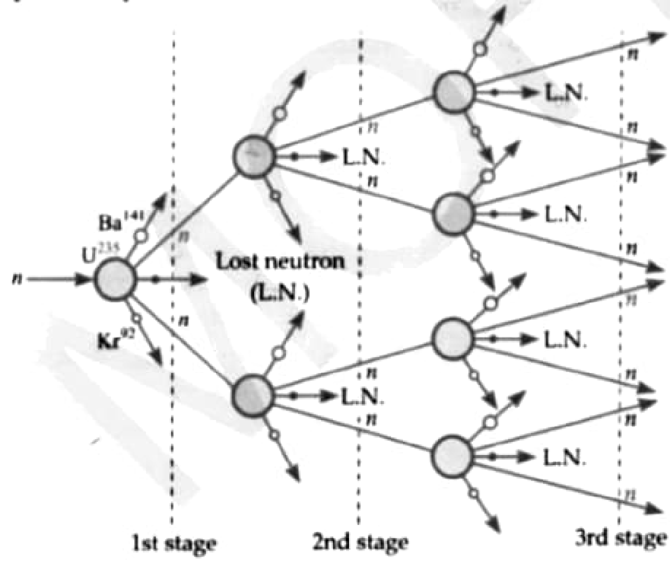


Fig. 13.16 **A chain reaction in $^{235}_{92}U$.**

Uncontrolled chain reaction. If a chain reaction is started in a fissionable material having mass greater than certain critical mass, then the reaction will accelerate at such a rapid rate that the whole material will explode within a microsecond, liberating a huge amount of energy. Such a chain reaction is called *uncontrolled chain reaction*. It forms the underlying principle of the *atomic bombs*.

Controlled chain reaction. The chain reaction can be controlled and maintained steady by absorbing a suitable number of neutrons at each stage of the reaction, so that on an average one neutron remains available for exciting further fission. Such a reaction is called controlled chain reaction. Here the energy released does not get out of control. A ***nuclear reactor*** works on the principle of a controlled chain reaction.

Nuclear Reactor

Nuclear reactor. *It is a device in which a nuclear chain reaction is initiated, maintained and controlled.* It works on the principle of controlled chain reaction and provides energy at a constant rate.

Main parts of a nuclear reactor :

1. **Nuclear fuel.** It is the material that can be fissioned by neutrons. The isotopes like U-235, Th-232 and Pu-239 can be used as the reactor fuel. A certain mass of the fuel is taken in the form of rods, tightly sealed in aluminium containers. The rods, separated by moderator, are placed in the *core* of the reactor.

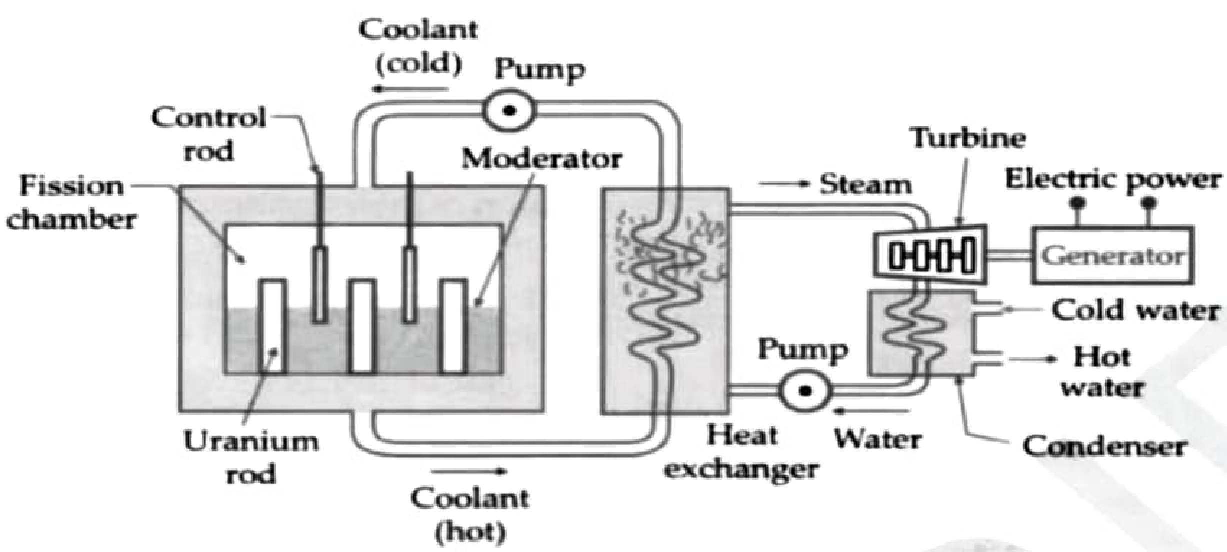
2. **Moderator.** In the fission of uranium, fast neutrons of energy 2 MeV are released. These fast neutrons have more tendency to escape instead of triggering another fission reaction. Also, slow neutrons are more efficient in inducing fission in $^{235}_{92}U$ nuclei than fast neutrons. By the use of a moderator, the fast neutrons are slowed to thermal velocities. Usually, heavy water, graphite and beryllium oxide are used as moderators.

3. **Control rods.** To start, stop or control the chain reaction, rods of neutron absorbing material like cadmium or boron are inserted into the reactor core. The rate of neutron production is controlled by adjusting the depth of control rods.

4. **Coolant.** It is the material used to cool the fuel rods and the moderator and is capable of carrying away large amount of heat produced in the fission process. The coolant transfers heat to the working liquid like water and produces steam. The steam drives a turbine which, in turn, runs a generator to generate electric power. *The coolant must have high boiling point and high specific heat.* Heavy water and liquid sodium are good coolants.

5. **Shielding.** The intense neutrons and gamma radiations produced in nuclear reactor are harmful for human body. To protect the workers from these radiations, the reactor core is surrounded by a thick concrete wall, called the *reactor shield.*

Working. Initially, some neutrons are produced by the action of α-particles on polonium or beryllium. They are slowed down and are used to start fission of $^{235}_{92}U$ nuclei. Fast neutrons are released in these fissions which are slowed down to thermal velocities by passing them through the moderator. These slow neutrons cause fission of more $^{235}_{92}U$ nuclei and thus the chain reaction builds up. By raising or lowering the control rods, the chain reaction is suitably controlled.



Nuclear fusion

Nuclear fusion. *The process in which two light nuclei combine (at extremely high temperature) to form a single heavier nucleus is called nuclear fusion.*

The mass of the heavier nucleus formed is less than the sum of the masses of the combining nuclei. The *mass defect* is released as energy in accordance with Einstein's mass-energy relation $E = \Delta m \cdot c^2$. For example, two protons combine to form a deuteron and a positron with release of 0.42 MeV energy :

$$_1^1H + _1^1H \longrightarrow _1^2H + e^+ + \nu + 0.42 \text{ MeV}$$

Similarly, two deuterons combine either to form the light isotope of helium and a neutron or a triton and a proton :

$$_1^2H + _1^2H \longrightarrow _2^3He + _0^1n + 3.27 \text{ MeV}$$

$$_1^2H + _1^2H \longrightarrow _1^3H + _1^1H + 4.03 \text{ MeV}$$

In all the above reactions, two positively charged particles combine to form a heavier nucleus. The fusing nuclei have to overcome very high electrostatic repulsion between them at extremely small distances. This repulsion prevents the two nuclei from getting close enough to be within the range of their attractive nuclear forces and thus 'fusing'. The height of this *coulomb barrier* depends on the charges and the radii of the two colliding nuclei.

To carry nuclear fusion in a bulk material, the temperature of the material has to be raised to 10^6 K, so that the colliding nuclei have enough energy due to their thermal motion and they can penetrate the coulomb barrier. This process is called ***thermonuclear fusion***.

Necessary conditions for nuclear fusion. The fusion reactions take place under the conditions of extreme temperature and density due to the following reasons :

1. The ***high temperature*** is necessary for the light nuclei to have sufficient kinetic energy so that they can overcome their mutual coulombic repulsions and come closer than the range of nuclear force. That is why a fusion reaction is also called a **thermonuclear reaction.**

2. ***High density*** or pressure increases the frequency of collision of light nuclei and hence increases the rate of fusion.

These conditions exist in the interior of the sun where the temperature is about 2×10^6 K. Such conditions cannot be easily met in a laboratory.

Isotopes, Isobars, Isotones, Isomers

Isotopes. ***The atoms of an element which have the same atomic number but different mass number are called isotopes.*** **Such atoms contain the same number of protons and electrons but different number of neutrons. Because of** their similar electronic configuration, isotopes of an element exhibit similar chemical properties

Hydrogen has three isotopes : *Hydrogen (protium)* $_1^1H$ – its nucleus has just one proton ; *deuterium* ($_1^2H$) – its nucleus has one proton and one neutron ; and *tritium* ($_1^3H$) – its nucleus has one proton and two neutrons

The different isotopes of an element are found to have different relative abundances. So the weighted average of the atomic masses of all the isotopes of an element is taken as its average atomic mass. For example, normal chlorine contains 75% of $_{17}^{35}Cl$ and 25% of $_{17}^{37}Cl$.

$\therefore$ Average atomic mass of chlorine

$$= \frac{35 \times 75 + 37 \times 25}{75 + 25} = 35.50$$

Isobars. *The atoms having the same mass number but different atomic number are called isobars.* Such atoms contain different number of protons and electrons. So they differ in the chemical properties and occupy different positions in the periodic table. Some examples of isobars are :

1. $_1^3H$ and $_2^3He$, as both have same $A = 3$.
2. $_{17}^{37}Cl$ and $_{16}^{37}S$, as both have same $A = 37$.
3. $_{20}^{40}Ca$ and $_{18}^{40}Ar$, as both have same $A = 40$.

Isotones. *The nuclides having the same number of neutrons are called isotones.* For example,

1. $_{17}^{37}Cl$ and $_{19}^{39}K$ are isotones, as both contain the same number of neutrons *i.e.*, for both

$$N = A - Z = 20.$$

2. $_{80}^{198}Hg$ and $_{79}^{197}Pu$ are isotones, as for both

$$N = A - Z = 118.$$

Isomers. *These are the nuclei with same atomic number and same mass number but existing in different energy states.* For example, a nucleus in its ground state and the identical nucleus in metastable excited state are isomers.