Chapter 20

NUCLEAR PHYSICS

ATOMIC NUCLEUS

The nucleus is made up neutrons and protons, two particles which are about 1840 times more massive than electrons. They are collectively called as nucleons (figure 20.1).

ATOMIC NUMBER

The number of protons in a nucleus is equal to its atomic number Z.

MASS NUMBER

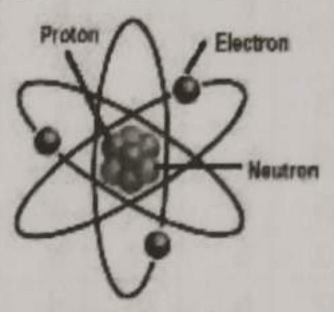

Figure 20.1

The total number of nucleons in a nucleus is called its mass number.

Hence the number of neutrons is A-Z. For example the nucleus of a sodium atom which has atomic number 11 and mass number 23, contains 11 protons and 12 neutrons.

In typical heavy nucleus e.g., ${}_{92}U^{235}$, which contains 92 protons and 143 neutrons, the mass of the nucleus is very nearly equal to the mass of the atom. It is the atomic weight divided by Avogadro's number.

NUCLIDE

A nuclide is a particular nucleus with a specified number of protons and neutrons. Any nuclide can be represented by its chemical symbol together with mass number A and atomic number Z. For any element X its nuclide is written as ${}_{Z}X^{A}$. For example ${}_{1}H^{1}$ has Z = 1 and A = 1.

RUTHERFORD'S NUCLEAR MODEL OF ATOM

The nucleus was first discovered in 1911 in experiment conducted by Rutherford and his students Geiger and Marsden on scattering of alpha particles by atom. He found that;

- The scattering pattern could be explained if atoms consist of a small nucleus
- The nuclear size is of the order of 10^{-14} m which is 10,000 times smaller than the diameter of atoms (10^{-10}m).
- The nucleus contains Ze charge, where Z is atomic number of the element and "e" is the fundamental charge (1.60×10^{-19} C).
- The mass of nucleus is of the order of 10^{-27} kg.

ISOTOPES

Definition

"Atoms of an element which have the same number of protons but have different number of neutrons are called as isotopes." OR

Explanation

All atoms of the same element contain the same number of protons in the nucleus of each atom. The number of neutrons in each atom of an element may differ. For example, natural uranium mostly consists of the isotopes $_{92}U^{238}$ and a small proportion of the isotopes $_{92}U^{235}$. Both types of atoms are uranium atoms, each nucleus containing 92 protons. However the isotope $_{92}U^{238}$ contains three more neutrons than the isotope $_{92}U^{235}$. Others examples include four isotopes of carbon i.e., $_6C''$, $_6C^{12}$, $_6C^{13}$, $_6C^{14}$ and three isotopes of hydrogen $_1H^1$, $_1H^2$, $_1H^3$.

Question: Explain the principle, construction, working and necessary mathematical theory of a mass spectrometer.

MASS SPECTROGRAPH

It is a device with which the isotopes of any element can be separated from one another and their masses can also be determined quite accurately.

Principle

A mass spectrograph is based upon the principle that a beam of ions when enters the magnetic field, suffers a deflection that depends upon the charge and masses of the ions.

Construction

The mass spectrograph consists of two main parts (fig 20.2);

1. Ion Source; produces ions.
2. Evacuated Chamber; bends ions in magnetic field.

The evacuated chamber also contains photographic plate which acts as a collection system for ions. A potential difference V_o is applied via battery and ions pass through slits S_1 and S_2 before entering the ion chamber. The slits serves as collimator. An external magnetic field out of the page perpendicular to direction of motion of ion beam is applied.

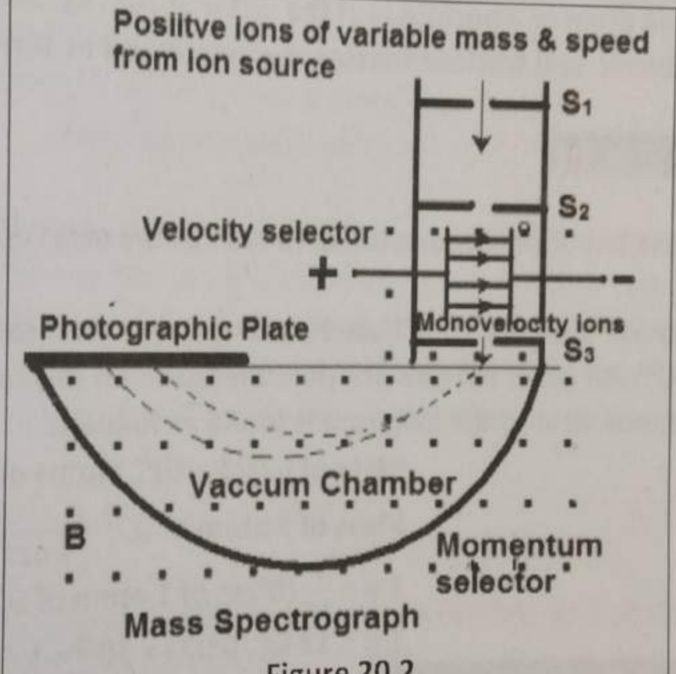

Figure 20.2

Working

The potential difference V_o of the battery provides kinetic energy to the ions i.e,

$$\Rightarrow \quad q V_o = \tfrac{1}{2} m v^2 \qquad (1)$$

$$\Rightarrow \quad v^2 = 2 q V_o / m$$

Eq.1 gives the velocity with which ions of different masses m enter the magnetic field. The ions are then subjected to a perpendicular and uniform magnetic field B in a vacuum chamber, where they are deflected in semi-circular paths towards a detector. The detector records the number of ions arriving per second. The centripetal force applied by magnetic fields is given by;

$$F_C = F_B$$

$$\Rightarrow \quad m v^2 / r = q v B$$

$$\Rightarrow \qquad v = \frac{qrB}{m} \qquad (2)$$

Squaring eq.2 and putting values of v^2 from eq.1, we get;

$$\frac{2q\,V_0}{m} = \frac{q^2r^2B^2}{m^2}$$

$$\Rightarrow \qquad m = \frac{q\,r^2B^2}{2\,V_0}$$

We can therefore, compute the mass m of the ions if r, B, q and V_o are known. Keeping V_o, B and q constant, r depends upon the mass m of the ions.

$$r \,\alpha\, \sqrt{m}$$

Thus ions of different masses will strike the photographic plate at different places. Therefore, different isotopes can be separated from one another.

NUCLEAR MASSES

The mass of an atom or a nucleus is of the order of 10^{-27} kg. Since it is a small number, therefore, atomic and nuclear masses are expressed in terms of unified (U) mass scale.

UNIFIED MASS SCALE

Definition

"An atomic mass unit or a.m.u. is equal to 1/12 of the mass of the carbon atom ${}_6C^{12}$."

Explanation

The unified mass scale is a scale based on assigning a mass exactly 12 to rest mass of an atom of C^{12}. All other masses are then measured in this unit by comparison. The relation of a.m.u. or u to the kilogram is found as follows:

$$\text{Mass of } 6.023 \times 10^{26} \text{ atoms of } {}_6C^{12} = 12 \text{ kg}$$

$$\text{Mass of 1 atom of } {}_6C^{12} = \frac{12kg}{6.023\,x\,10^{23}}$$

$$1\text{ u} = \frac{1}{12}(\text{Mass of 1 atom of } {}_6C^{12})$$

$$1\text{ u} = 12 \text{ kg}/6.023 \times 10^{26} = 1.66 \times 10^{-27} \text{ kg}$$

Energy Unit on Unified Mass Scale

It is often convenient, in nuclear physics to express certain masses in energy unit. According to Einstein mass-energy equivalence relation.

$$E = m\,c^2$$

Hence one energy unit u is;

$$1\text{ u} = 1.66 \times 10^{-27}\text{ kg} \times (3 \times 10^8 \text{ m / s})^2$$

$$1\text{ u} = 1.49 \times 10^{-10}\text{ J}$$

Since 1 eV = 1.6×10^{-19} J, so;

$$1\text{ u} = (1.49 \times 10^{-10} / 1.6 \times 10^{-19})\text{ eV}$$

$$1\text{ u} = 9.31 \times 10^8 \text{ e V} = 931 \text{ MeV}$$

Masses of electron, proton and neutron on unified mass scale are;

$$m_e = \frac{9.109\,x\,10^{-31}}{1.66\,x\,10^{-27}} = 0.000548\text{ u}$$

Similarly $m_e = 0.000548\text{ u} \times 931\text{ MeV} = 0.51\text{ MeV}$

and $m_P = 1.673\times10^{-27}\text{ kg} = 1.0078\text{ u} \times 931\text{ MeV} = 937\text{ MeV}$

$m_N = 1.675\times10^{-27}\text{ kg} = 1.009\text{ u} \times 931\text{ MeV} = 938\text{ MeV}$

Question: Explain the term mass defect and binding energy.

MASS DEFECT OR MASS DEFICIT

Definition

"The difference between mass of separated nucleons and combined mass of the nucleus is called mass defect.

Mathematical Form

Let Δm = mass defect,

m_P = mass of proton,

Z = number of protons

m_N = mass of neutron,

N = number of neutrons = $A-Z$

${}_ZM^A$ = nucleus of mass M with Z protons & A-Z (= N) neutrons

Then the relation for mass deficit in unit of a.m.u is given by;

$$\Delta m = (Zm_P + Nm_N) - {}_ZM^A \qquad (1)$$

Explanation

The mass of a nucleus is always less than the mass of the same number of separate neutrons and protons. For example, the mass of a helium nucleus which consists of two protons and two neutrons is 0.8% less than the mass of two protons and two neutrons separated from each other. This difference is called the mass defect of the nucleus and is due to binding of the protons and neutrons together when the nucleus was formed.

BINDING ENERGY

Definition

"The energy needed to separate a nucleus into separate neutrons and protons is referred to as the binding energy of the nucleus." OR

"The energy corresponding to mass deficit of a nucleus is called as its binding energy."

Explanation

The protons and the neutrons in a nucleus are held together by a strong attractive force. To separate the protons and neutrons from one another, energy must be supplied to them to overcome the strong nuclear force. This work is referred to as the binding energy of the nucleus. The greater the binding energy of a nucleus, the harder it is to separate the neutrons and the protons in the nucleus from each other.

Mathematical Form

The binding energy of the nucleus can be calculated from the mass defect using Einstein's famous equation $E = m c^2$.

$$\text{Binding energy} = \text{mass defect} \times c^2 \qquad (2)$$

$$E_b = \Delta m\, c^2$$

From eq.1, we can write; $E_b = (Z\,m_P + N\,m_N) - {}_ZM^A)\,c^2$ (3)

Nuclear masses are usually expressed in atomic mass unit (u). So eq.3 can be written as; $E_b = \Delta m \times 931\ \text{MeV/u}$ $(c^2 = 931\ \text{MeV/u})$

Packing Fraction (Binding fraction)

Definition

"The binding energy per nucleon of a nucleus is called as packing fraction"

OR

"The binding energy of a nucleus divided by the number of nucleons (i.e. protons and neutrons) in the nucleus is termed as packing fraction."

Symbol

Packing fraction is denoted by "f_b".

Mathematical Form

Packing fraction is a measure of the stability of a nucleus. It can be easily calculated for any nucleus ${}_ZX^A$ of known mass M by following the steps below:

1. Calculate the mass defect (a.m.u) of the nucleus by using equation;

$$\Delta m = (Z\,m_P + N\,m_N) - {}_ZM^A$$

2. Then calculate the binding energy by;

$$E_b = \Delta m \times 931\ \text{MeV/u}$$

3. The packing fraction or binding energy per nucleon is

$$f_b = E_b / A$$

GRAPH OF BINDING ENERGY PER NUCLEON NUMBER

A graph of binding energy per nucleon number A is shown in fig 20.3 Greater the binding energy per nucleon of a nucleus, more stable is the nucleus. The graph shows that;

1. The binding energy per nucleon increases as "A" increases to a maximum at about "A" = 50 to 60 then decreases gradually.

2. The most stable nuclei are A = 50 to 60 since this is where the binding energy per nucleons in greatest.

3. The binding energy per nucleons increases when light nuclei are fused together.

4. The decrease in binding energy per nucleon when Z > 82 shows that there is decrease in the stability of nucleus.

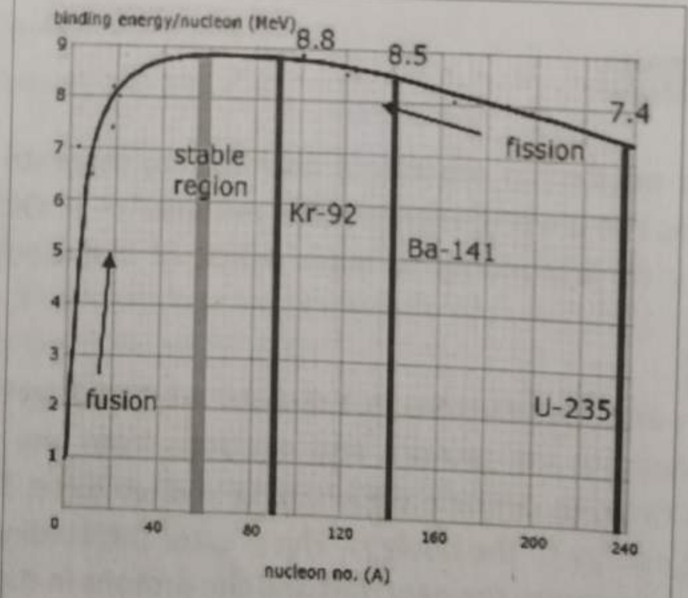

Figure 20.3

5. Heavy nuclei undergo fission to gain stability.

6. The binding energy per nucleon increases when nuclear fission of a uranium-235 nucleus occurs. When a ${}_{92}U^{235}$ nucleus undergoes fission, the two daughter nuclei each consists of about half the number of nucleons. Therefore the binding energy per nucleon increases from about 7.5 MeV per nucleon for ${}_{92}U^{235}$ to about 8.5 MeV per nucleon for the fragments. Thus the binding energy per nucleon increases by about 1 MeV for every fission fragment.

DISCOVERY OF RADIOACTIVITY

Following the discovery of x-rays in 1895, Henri Becquerel in 1896, had the idea (mistakenly) that minerals made phosphorescent by light might emit x-rays. Becquerel wrapped a photographic plate in a black paper to protect it from direct sunlight. Then he placed a phosphorescent uranium mineral on the photographic plate believing that the uranium absorbed the sun's energy and then emitted it as x-rays. When he developed the photographic plate, it bore a clear image of uranium mineral. He thought this as confirmation of his theory.

It was a coincidence that sun did not shine in Paris for several days. He stopped his experiment and placed the uranium mineral and wrapped photographic plate together in a drawer. After several days he developed the plate expecting a weak image but to his surprise the image was as strong as in the original sunlight experiment. He now drew the correct conclusion that the image had nothing to do with light but the exposure came from the uranium mineral itself. The radioactivity was discovered.

Further tests showed that the substance emits this radiation continuously even when stored in darkness for long period and that the radiation passes through glass but not through metal. The substance was described as "radioactive" and the process as radioactivity.

Phosphorescence is the ability of a crystal to absorb light and re-emit light after sometime when the exciting light has been switched off.

The Romans used phosphorescent minerals in the center of their roads to illuminate them at night.

Marie Curie was the first woman to be awarded a Nobel prize and the first person to obtain two Nobel prizes when she won the prizes for the discovery of polonium and radium in 1911.

Becquerel continued his research on X -rays and passed the investigation of radioactivity on to his research student, Marie Curie. Within two years, Marie curie and her husband Pierre had discovered other substances which were radioactive, including two new elements, radium and polonium and received Nobel Prize in 1903 for their discoveries.

Question: What is meant by natural radioactivity? How are the natural radioactive radiations classified into three types?

RADIOACTIVITY

Definition

"The phenomena of spontaneous disintegration of unstable_nuclei followed by emission of nuclear radiations is called as Radioactivity."

Explanation

Larger nuclei (Z >82) are unstable and hence in order to gain stability, three types of radiations are usually emitted by them. These three types of radiations are known as α-particles, β- particles and γ-rays. The elements which possess this property, are called radioactive elements.

1. Alpha Particle ($_2He^4$)

The α-particles consists of two protons and two neutrons i.e., these are positively charged helium nuclei. An α-particle is emitted by a very large unstable nucleus.

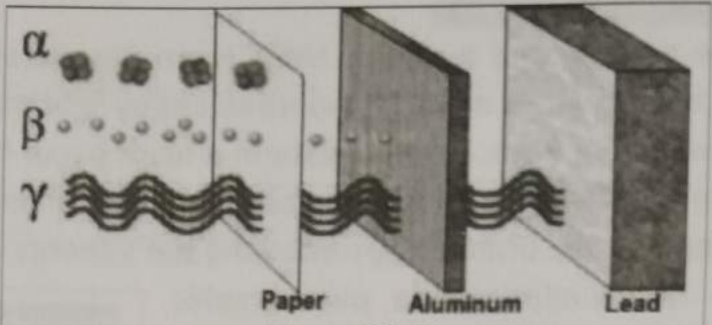

Figure 20.4

An Alpha particle;

a. Is easily stopped by cardboard or thin metal.
b. Has a range in air of no more than a few centimeters.
c. Ionizes air molecules much more strongly than the other two types of radioactive radiations.

2. Beta Particles

β-particles are fast moving electrons emitted when nucleus with too many neutrons disintegrates. A neutron in such a nucleus suddenly and unexpectedly changes to a proton. In the process, an electron is created and instantly emitted from the nucleus.

A beta particle;

a. Is stopped by 5-10 mm of metal.
b. Has a range in air of about 1 m.
c. Ionizes air molecules less strongly than alpha particles.

3. Gamma Radiation

γ-rays consists of high energy photons. A photon is a packet of electromagnetic waves. A ray gamma photon is emitted from a nucleus with surplus energy after it has emitted an α-particle or β-particle.

Gamma ray;

a. Is stopped only by several cm of lead.
b. Has a maximum range in air.
c. Ionizes air molecules very weakly.

ALPHA EMISSION

Whenever an atom $_ZX^A$ disintegrates by α-emission, its atomic number reduces by 2 and the mass number reduces by 4 units. The disintegration reaction is written as;

$$_ZX^A \rightarrow {}_{Z-2}X^{A-4} + {}_2He^4 + Q$$

Q is the disintegration energy. Which is always positive, as the process is spontaneous. The decay product $_{Z-2}X^{A-4}$ is called the daughter nucleus of the parent nucleus $_ZX^A$. The daughter nucleus may also remain unstable and undergo further disintegration till it attains stability.

Examples of α-emission

$$_{92}U^{238} \rightarrow {}_{90}Th^{234} + {}_{2}He^{4} + Q$$

$$_{88}Ra^{226} \rightarrow {}_{86}Rn^{222} + {}_{2}He^{4} + Q$$

BETA EMISSION

The process of beta emission involves no change in mass number A. However, it changes the atomic number Z by -1 or +1 depending upon whether the particle emitted is negative β-particle (electron) or positive β-particle (positron). Thus the β-disintegration may lead to either of the following disintegrations.

$$_{Z}X^{A} \rightarrow {}_{Z+1}X^{A} + {}_{-1}\beta^{0} + \text{antineutrino} + Q_1$$

$$_{Z}X^{A} \rightarrow {}_{Z-1}X^{A} + {}_{+1}\beta^{0} + \text{neutrino} + Q_2$$

Examples of β-emission

As an example of negative β-emission is the decay of thorium into protactinium:

$$_{90}Th^{234} \rightarrow {}_{91}Pa^{234} + {}_{-1}\beta^{0} + \overline{\upsilon} + Q_2$$

The best known example of β-decay is from the naturally occurring isotope of $_6C^{14}$.

$$_{6}C^{14} \rightarrow {}_{7}N^{14} + {}_{-1}\beta^{0} + \text{antineutrino}$$

Example of a positron emission is $_6C^{11}$, which decays by the reaction;

$$_{6}C^{11} \rightarrow {}_{5}B^{11} + {}_{+1}\beta^{0} + \upsilon$$

GAMMA EMISSION

Most frequently the alpha or beta emission leaves the daughter nuclide_in exited state. Such a nuclide may go back to a more stable configuration and eventually to its ground state by emitting one or more γ-rays. Since γ-rays are massless photons, their emission will cause no change either in A or Z of the parent nuclide. The γ-decay process is written as follows.

$$_{Z}X^{A} \rightarrow ({}_{Z}X^{A})^{*} \rightarrow {}_{Z}X^{A} + \gamma$$

Where $({}_{Z}X^{A})^{*}$ represents an excited state of the nucleus.

Spontaneous Nuclear Decay

We know that radioactive elements disintegrate and emit α, β and γ radiations. This process is called transmutation by spontaneous disintegration. In this process each of the nuclei of a radioactive sample has a probability of decay into a daughter nucleus. The per unit time probability of decay of all nuclei is the same and has a fixed value, which is the characteristics of material. However, the decay probability of one nucleus is quite independent of that of another nucleus. So in the natural spontaneous disintegration of a radioactive material not all the atoms disintegrate at the same time.

Random Nuclear Decay

Different atoms decay at different times. The process of disintegration takes place randomly. However, it is observed that, on the average the actual number of atoms which decay at any instant, is proportional to the number of atoms present. As time goes on, some nuclei disintegrate and other survive. So the activity continues but with ever decreasing rate.

Question: Define and explain the half -life of a radioactive element?

HALF-LIFE AND RATE OF DECAY

Definition

"The time taken by the atoms of a radioactive material to decay to half of the original number of atoms is called as half-life."

Explanation

Suppose 10000 atoms of a certain radioactive isotope "X" are present initially. The number of atoms decreases.

- From 10000 to 5000 after one half-life
- From 5000 to 2500 after a further half-life
- From 2500 to 1250 after a 3rd half-life etc.

The amount of the radioactive isotope therefore decreases with time as shown in the curve of figure 20.5. Half-life values of radioactive materials range from a fraction of second to billions of years.

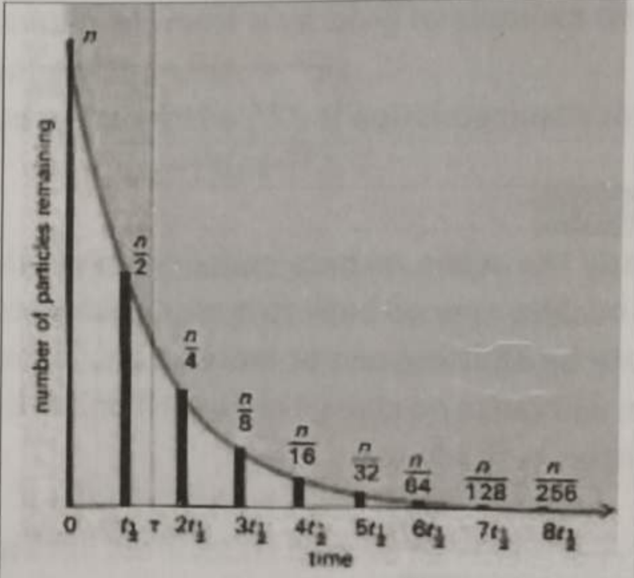

Figure 20.5

Examples

- Half-life of Radium = 1600 years
- Half-life of Radon = 4 days
- Half-life of Polonium = 8 mins

Radioactive disintegration is a random process. For a large number of atoms of a given radioactive sample, the proportion that disintegrate per second is constant. This follows because of the random nature of radioactive disintegration.

DECAY CONSTANT

Definition

"The activity per single nucleus is called as decay constant."

Symbol

It is denoted by "λ".

Mathematical Form

If a radioactive sample contains "N" radioactive nuclei at some instant, then the number of nuclei ΔN that decay in a time Δt is proportional to N.

$$\frac{\Delta N}{\Delta t} \propto -N$$

$$\Rightarrow \quad \frac{\Delta N}{\Delta t} = -\lambda N$$

$$\Rightarrow \quad \lambda = -\frac{1}{N}\frac{\Delta N}{\Delta t} \qquad (1)$$

Where λ is a constant of proportionality which depends on the nature of the element and is called decay constant and the negative sign signifies that N decreases with time, that is, ΔN is negative. The value of λ for any isotope determines the rate at which that isotope will decay.

Unit

Its unit is s^{-1}.

DECAY RATE or ACTIVITY or COUNT RATE

Definition

"The decay rate or activity R of a sample is defined as the number of decays per second."

Symbol

It is denoted by "R".

Mathematical Form

The decay rate is;

$$R = \frac{\Delta N}{\Delta t} = -\lambda N \tag{2}$$

Thus we see that isotopes with a large value of λ decay at a rapid rate and those with a small λ value decay slowly.

Unit

Its unit is s^{-1}.

RADIOACTIVE DECAY LAW

A general decay curve for a radioactive sample is shown in figure (20.5). The number of nuclei present varies with time according to the expression;

$$N = N_o\, e^{-\lambda t} \tag{3}$$

Where N is the number of radioactive nuclei present at time t, N_o is the number present at time t = 0, and e = 2 .718 is the base of the natural logarithm. Eq.3 is known as decay law of radioactive elements.

For Pre-Engineering Students only

since

$$\Delta N/\Delta t = -\lambda N$$

$$\Rightarrow \frac{1}{N} dN = -\lambda\, dt$$

$$\Rightarrow \int_{N_0}^{N} \frac{1}{N} dN = -\int_0^t \lambda\, dt$$

$$\Rightarrow \ln(N)\Big|_{N_0}^{N} = -\lambda\ (t)\Big|_0^t$$

$$\Rightarrow \ln N - \ln N_o = -\lambda\,(t-0)$$

$$\Rightarrow \ln(N/N_o) = -\lambda t$$

Taking exponent W.B.S

$$\Rightarrow (N/N_o) = e^{-\lambda t}$$

$$\Rightarrow N = N_o\, e^{-\lambda t}$$

Unit of Activity

The unit of activity is the curie (Ci), defined as;

$$1\text{ Ci} = 3.7\times10^{10}\text{ decay/sec}$$

This number of decay events per second was selected as the original activity unit because it is the approximate activity of 1 g of radium.

The S.I. unit of the activity is the Becquerel (Bq):

$$1\text{ Bq} = 1\text{ decay/sec}$$

$$1\text{ Ci} = 3.7\times10^{10}\text{ Bq}$$

RELATION BETWEEN HALF-LIFE AND DECAY CONSTANT

By substituting $N = \frac{1}{2} N_0$ and $t = T_{½}$ in the eq.3, we find that;

$$\tfrac{1}{2} N_0 = N_0\, e^{-\lambda T_{½}}$$

$$\Rightarrow \quad \tfrac{1}{2} = e^{-\lambda T_{½}} \qquad \text{take reciprocal}$$

$$\Rightarrow \quad 2 = e^{\lambda T_{½}}$$

Take natural logarithm of both sides and note that $\ell n(e) = 1$.

$$\Rightarrow \qquad \ell n(2) = \ell n(e)^{\lambda T\frac{1}{2}} = \lambda T\tfrac{1}{2}$$

$$\Rightarrow \qquad T\tfrac{1}{2} = \ell n(2) / \lambda$$

$$\Rightarrow \qquad T\tfrac{1}{2} = 0.693 / \lambda$$

This is the relation between the decay constant λ and the half-life $T\frac{1}{2}$.

The half-life for radioactive isotope C^{14} is 5730 years, it means in 5730 years the 10 g of carbon disintegrates to 5 g and 5 g remains in the given sample. As the time passes, the amount of remaining substance decreases but never reaches to zero because the rate gets slower as the time goes on. The value of half- life is constant for each radioactive element and it is possible to characterize the element by using its half-life value.

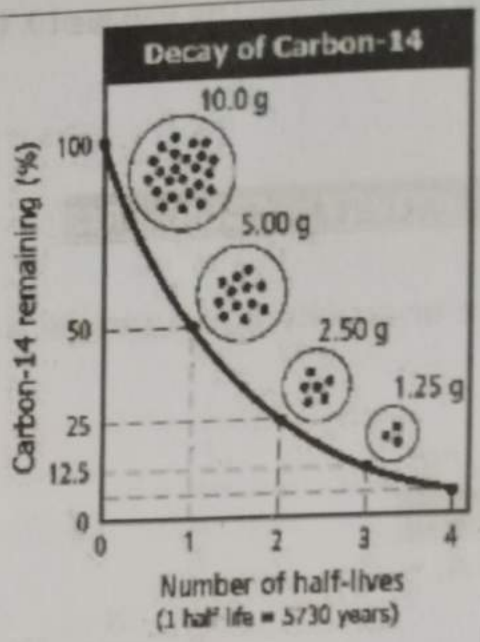

Figure 20.6

INTERACTION OF RADIATION WITH MATTER

1. Interaction of A-Particles with Matter

- An α-particle travels a small distance in a medium before coming to rest. This distance is called the range of the particle.
- As the particle passes through a solid, liquid or gas, it loses energy due to excitation and ionization of atoms and molecules in the matter.
- Ionization is the main interaction with matter to detect the particle or to measure its energy. The range depends on the;
  - i. Charge, mass and energy of the particle and
  - ii. Density of the medium ionization potentials of the atoms of medium.
- Since α-particle is about 7000 times more massive than an electron, so it does not suffer any appreciable deflection from its straight path, provided it does not approach too closely to the nucleus of the atom.
- Thus α-particle continues producing intense ionization along its straight path till it loses all its energy and comes almost to rest. It then captures two electrons from the medium and becomes a neutral helium atom.

2. Interaction of β-Particles with Matter

- β-particles also lose energy by producing ionization. However, its ionizing
- Ability is about 100 times less than that of α-particles. As a result, its range is about 100 times more than α-particles.
- β-particles are more easily deflected by collisions than heavy α-particles.
- Thus the path of β-particles in matter is not straight but an erratic path.
- The range of β-particles is measured by the effective depth of penetration into the medium not by the length of erratic path.
- If the density of the material is more through which the particle moves, the shorter will be its range.

- α and β-particles both radiate energy as X-ray photons when they are slowed down by the electric field of the charged particles in a solid material.

3. Interaction of Gamma Rays with Matter

- Photons of γ-rays are charge-less and have zero rest mass.
- They interact with matter in three distinct ways, depending mainly on their energy.
  - i. At low energies (less than about 0.1 MeV), the dominant process is photoelectric effect in which γ-ray photon provides all its energy to the electron and thus it is completely absorbed.
  - ii. If γ-ray photon has energy in the range 0.1 to 1 MeV, then the dominant process is Compton's effect in which γ-ray photon is scattered by collision with an electron.
  - iii. If the energy possessed by γ-ray photon is equal to or greater than 1.02MeV, then the photon transforms into electron-positron pair and hence causes pair production.
- In air γ-rays intensity falls off as the inverse square of the distance from the source, in the same manner as light from a lamp.
- In solids, the intensity decreases exponentially with increasing depth of penetration into the material.
- The intensity I_o of a beam after passing through a distance X in the medium is reduced to intensity *I* given by the relation;

$$I = I_o e^{-\mu x}$$

Where μ is the linear absorption coefficient of the medium. This co-efficient depends on the energy of the photon as well as on the properties of matter.

- All particles i.e, α or β and γ-radiation produce fluorescence or glow on striking some substances like zinc sulphide, sodium iodide or barium platinocyanide coated screens.
- "Fluorescence is a process of absorbing radiant energy of high frequency and re-emitting energy of low frequency in the visible region of electromagnetic spectrum.

4. Interaction of Neutrons with Matter

- Neutrons, being neutral, are extremely penetrating particles.
- To be stopped or slowed, a neutron must undergo a direct collision with a nucleus or some other particle that has mass comparable to it.
- Materials such as water or plastic, which contain more low mass nuclei per unit volume are used to stop neutrons.
- Neutrons produce a little indirect ionization when they interact with materials containing H -atoms and knock out protons.

Question: What is a radiation detector? Explain the principle and working of GM counter and solid state detector.

RADIATION DETECTORS

The devices used for detecting and measuring radioactivity are called radiation detectors. They are used for a variety of purposes including medical diagnosis, radioactive dating measurement and the measurement of background radiations.

GEIGER-MULLER COUNTER

Geiger-Muller counter (Fig 20.7) is the most common device used to detect radiations.

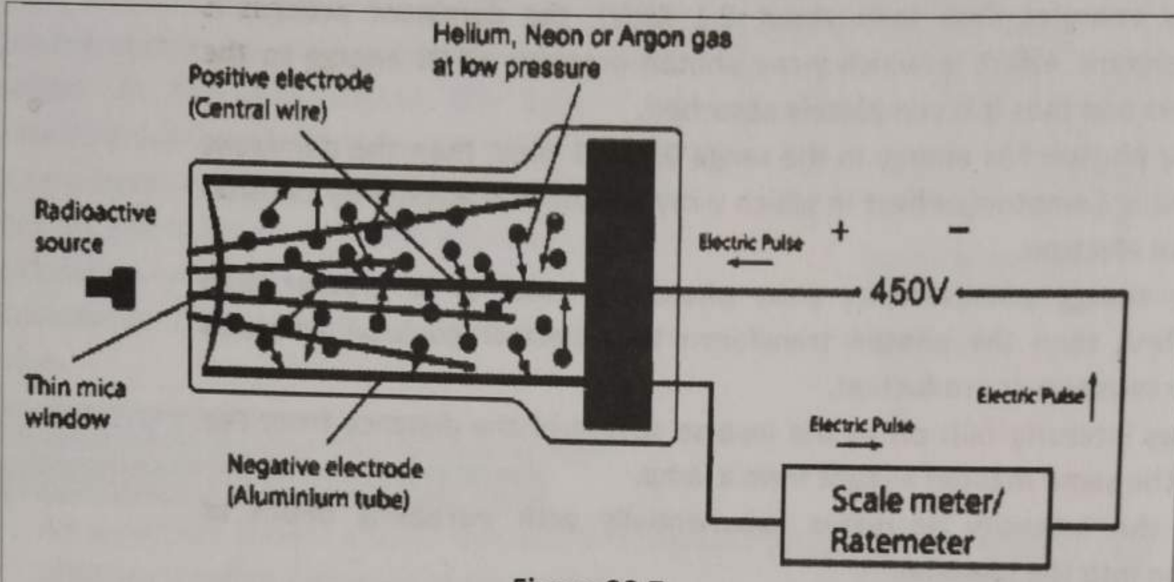

Figure 20.7

Principle

It works on the phenomenon of production of ions in a gaseous medium by incident photon.

Construction

It consists of a cylindrical metal tube filled with gas at low pressure and a long wire along the axis of the tube. The wire (anode) is maintained at a high positive potential (about 1000V) with respect to the cylindrical tube, acting as cathode.

Working

When a high energy particle or photon enters the tube through a thin window at one end, some of the atoms of the gas become ionized. The electrons removed from the atoms are attracted towards the wire, and in moving towards anode, they ionize other atoms in their path. This results in an avalanche of electrons, which produces a current pulse at the output of the tube. After the pulse is amplified, it can be either used to trigger an electronic counter or delivered to a loudspeaker, which clicks each time a particle enters the detector.

Its drawback is that it cannot distinguish between the energies or paths of incident particles as output pulses are same. Also it cannot suitable for fast counting because of its longer dead time.

SOLID STATE DETECTOR

It is a device used for detection and fast counting of nuclear radiation.

Principle

A solid state detector is a specially designed PN junction diode operated under reversed bias in which electron hole pairs are produced by incident radiation to cause a current pulse to flow through external circuit.

Construction

It is made from a P-type silicon or germanium. An N-type thin layer is produced by doping the top source with donor type impurity. The top and bottom surfaces are coated with a thin layer of gold to make good electrical contact with external circuit. The combined thickness of N-type and gold layer absorbs so less energy of the incident particle that the junction may be assumed to be situated at the front surface as shown in fig 20.8.

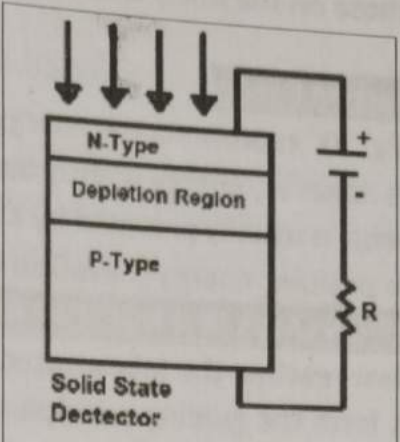

Figure 20.8

Working

When a reverse bias is applied through the conducting layers of gold, it enlarges the barrier region. But when incident particle enters the depletion region, it produces electron hole pairs. These mobile charge carriers move towards respective sides due to applied electric field. The arrival of these charges produces a potential drop across the junction. This gives rise to a current pulse through external circuit. Which is amplified and registered by scalar unit.

Advantages of this detector are that it can detect low energy particles. Also it can count very fast. It is smaller in size as compared to other detectors.

Question: Define and explain nuclear reactions.

NUCLEAR REACTIONS

Definition

"The collisions which change the identity or properties of the target nuclei, are called Nuclear Reactions."

Explanation

It is possible to change the structure of nuclei by bombarding them with energetic particles. When a nucleus "X" is bombarded with some light particle "a", nuclear reaction take place, the product nucleus "Y" and a light particle "b" will be obtained. This will be represented by the equation.

$$X + a \rightarrow Y + b$$

Rutherford was the first to observe nuclear reaction in 1919 using naturally occurring radioactive sources for the bombarding particles. He bombarded α-particles on nitrogen and observed that as result of this reaction, oxygen is obtained and a proton is emitted. That is;

$${}_7N^{14} + {}_2He^4 \rightarrow {}_8O^{17} + {}_1H^1 + Q$$

The energy equivalent of the difference between the rest masses of elements on the L.H.S and those on the R.H.S is called the nuclear reaction energy and is denoted by "Q".

Nuclear Reaction Energy

- Basically, "Q" represents the energy absorbed or evolved in any reaction.
- If "Q" is negative, energy is absorbed in the reaction (endothermic reaction) and this energy is usually provided by K.E of incoming particle.
- If "Q" is positive, energy is evolved in the reaction (exothermic reaction).

CONSERVATION LAWS IN A NUCLEAR REACTION

In any nuclear reaction the following conservation laws must be obeyed.
These laws form the guiding principles in determining which isotopes are formed during a nuclear reaction.

(i) CONSERVATION OF ATOMIC AND MASS NUMBER

Before and after any nuclear reaction the number of protons and neutrons must remain the same because protons and neutrons can neither be created nor destroyed.

Example Let $_7N^{14} + _2He^4 \rightarrow _8O^{17} + _1H^1 + Q$

Number of nucleons on L.H.S	Number of nucleons on R.H.S
Number of protons = 7 + 2 = 9	Number of protons = 8 + 1 = 9
Number of nucleons = 14 + 4 = 18	Number of nucleons = 17 + 1 = 18

(ii) CONSERVATION OF MASS AND ENERGY

The conservation of number of nucleons does not imply the conservation of mass because the mass numbers differ from the atomic masses and the difference provides the binding energy to nucleons in the nucleus. Further, from Einstein's mass-energy relation it is known that the conservation of mass is not a separate and independent principle but is a part of a more general principle of conservation of energy. Therefore, the principle of conservation of energy in mechanics is extended to the conservation of mass -energy in nuclear reactions. This will also include the energy difference due to changes of mass.

Based on the above conservation laws one can determine the following;
(i) Energy absorbed or liberated in any nuclear reaction and
(ii) The product nucleus formed.

Let us calculate the reaction energy for the reaction given below;

$$_7N^{14} + _2He^4 \rightarrow _8O^{17} + _1H^1 + Q$$

$_2He^4$ = 4.00263 u	$_8O^{17}$ = 16.999133 u
$_7N^{14}$ = 14.003074 u	$_1H^1$ = 1.007825 u
Sum = 18.005704 u	Sum = 18.006958 u

Difference in masses before and after reaction = -0.001254 u

Therefore the energy;

$$Q = -0.001254\ u \times 931\ MeV/u$$
$$Q = -1.17\ MeV$$

Since "Q" is negative, the α-particle must have K.E 1.17 MeV for this reaction to occur. If the particle has less energy, this transformation will not take place. Usually the α-particles having energy more than 1.17 MeV, appears, as the K.E of product particles or nuclei.

Question: Write a comprehensive note on nuclear fission.

NUCLEAR FISSION

Definition

"The process in which a heavier nucleus splits into fragments forming nuclei with small mass number is called as nuclear fission."

Explanation

Knowing the fact that the emission of a β-particle increases the atomic number by one, Fermi and his co-workers (1934) attempted to produce the elements beyond uranium ($Z = 92$) which at that time was the last element in the periodic table. They bombarded uranium with neutrons and found that β-particles with different half -lives were emitted. Therefore, they concluded that the elements with $Z > 92$, i.e., the elements heavier than uranium, had been formed.

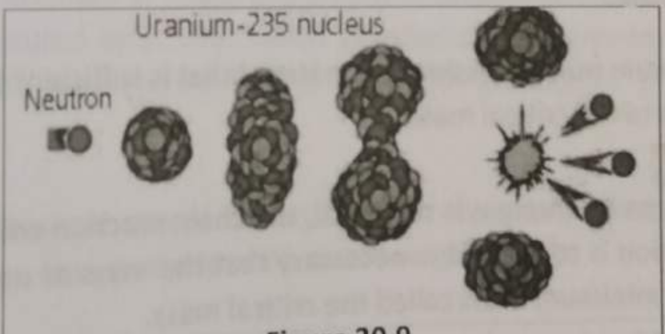

Figure 20.9

Hahn and Strassmann made similar experiments in 1939. After the chemical analysis of the products they concluded that neutron bombardment can cause a uranium nucleus to break apart, producing two or more fragments of moderate and comparable size. This process was called nuclear fission. Further they found that reaction is much more pronounced with thermal neutron. Only U^{235} undergoes this process of fission though naturally occurring uranium has 99.3 % of U^{238} and 0.7% of U^{235}.

In this process, there is a decrease in the mass of the system and hence energy is released. Since this process can be started automatically, it can be controlled and the energy liberated provides a good source of energy. It was observed that when one thermal neutron strikes a uranium nuclei, three neutrons are emitted (fig:20.9). In the reaction observed by Hahn that the product nuclei were ${}_{56}Ba^{141}$ and ${}_{36}Kr^{92}$. Therefore, the reaction can be written as;

$$\mathbf{{}_{0}n^{1} + {}_{92}U^{235} \rightarrow ({}_{92}U^{235})^{*} \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\ {}_{0}n^{1} + Q}$$

Therefore, when one atom of U^{235} undergoes fission 200 MeV of energy is released. If 1g of naturally occurring uranium, which has about 10^{19} atoms of U^{235} undergoes fission the total energy released would be 200 x 10^{19} MeV = 3.2 x 10^{8} J. It is found that 1.0 kg of uranium delivers as much energy as the combustion of about 3000 tons of coal.

FISSION CHAIN REACTION

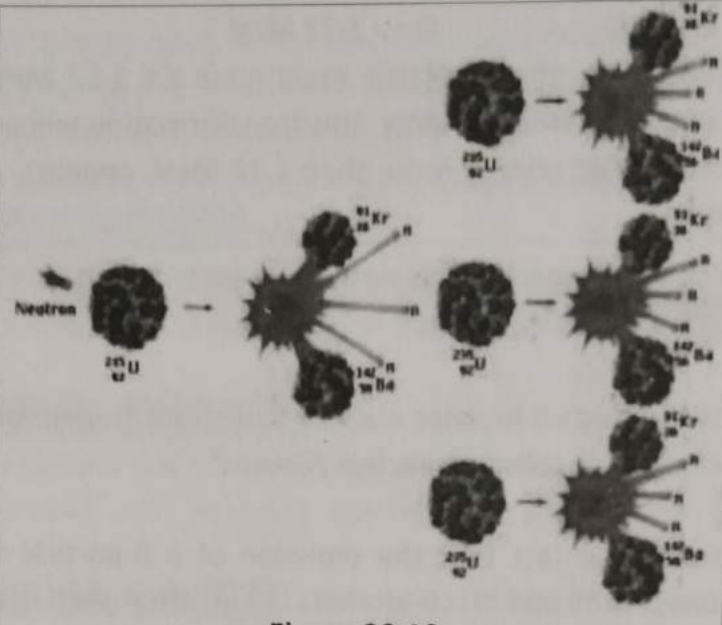

Figure 20.10

When one uranium atom undergoes fission, it releases three neutrons. These neutrons will cause fission in other nuclei and number of neutrons would increase rapidly. Thus a chain reaction can be set up (figure 20.10).

The fission produces neutrons at ever increasing rate and in a very short time the whole 0f Uranium would be transformed with the release of a large amount of energy. If such a chain reaction is not controlled, the large energy can cause a violent explosion and destroy everything that comes in its way.

This is the principle of the atom bomb.

CRITICAL MASS

Definition

"The minimum mass of fissionable material that is sufficient to sustain nuclear chain reaction, is called critical mass."

Explanation

If the amount of uranium is too small, the chain reaction will stop. Therefore, if the chain reaction is to start, it is necessary that the mass of uranium must be greater than some minimum mass called the critical mass.

Question: **What is a nuclear reactor? Write the principle, construction, working and uses of a typical nuclear reactor.**

NUCLEAR REACTOR

"A nuclear reactor is a device in which the fission chain reaction is used in a controlled manner to produced heat".

Purpose

Nuclear reaction energy can be used for any of the several purposes to produce power, to supply neutrons, to prepare radioisotopes, etc."

Principle

It acts on the principle of controlled chain reaction.

Construction & Working of Nuclear Reactor

(Fig 20.11) shows the schematic diagram of a nuclear reactor. It consists of five parts.

(i) A core of nuclear fuel,
(ii) A moderator for slowing down neutrons,
(iii) Control rods,
(iv) Coolant or heat exchanger and
(v) Radiation shielding.

(i) Core

It is the central part of the reactor which contains uranium and graphite rods alternatively. Nuclear fuel is a material that can be fissionable by thermal neutrons. It can be either one or all of the following isotopes. U^{233}, U^{235} and plutonium Pu^{239}. We shall see that when natural uranium is used, plutonium is produced in the nuclear reactor. The core is surrounded by a cover called as reflector. It serves to reflect neutrons produced in fission back and forth to increase the production of neutrons and start chain reaction.

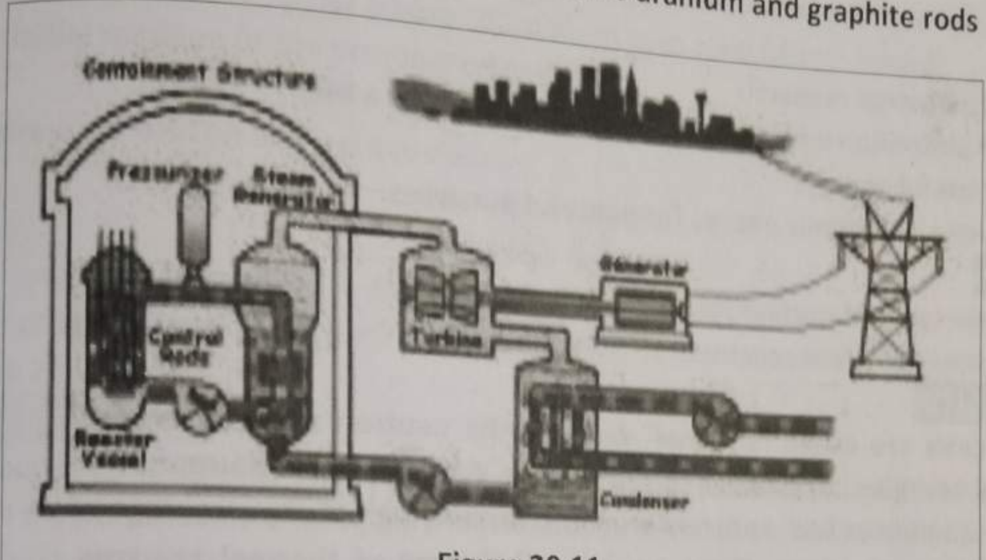

Figure 20.11

(ii) Moderator

In reactors, small pieces of graphite are spread throughout the material, called moderator, capable of slowing down the neutrons to thermal energies.

The material of moderator;
(a) Should be light, and
(b) Should not absorb neutrons.

Usually, graphite and heavy water (water containing deuterium instead of hydrogen) are used as moderators.

(iii) Control Rods

Whenever this chain reaction is to be stopped control rods of boron or cadmium which are strong absorbers of neutrons are inserted in the uranium container so that the neutrons are absorbed and the rate of reaction is slowed down.

(iv) Coolant

The coolant or heat exchanger, is used to cool the fuel rods and the moderator. It is capable of carrying away large amount of heat generated in the fission process. If the moderator, fuel rods, etc are not cooled, the heat generated can melt them.

The heat carried by the coolant produces steam that can run a turbine which in turn can run an electric generator as shown in (fig 20.10).

(v) Protective Shield

Since the neutrons and the fragments in a reactor undergo radioactive decay and produce radiations which are harmful to life, there must be some shielding device to absorb those radiations. For this purpose a concrete wall which is a few feet thick is used.

Uses

1. Scientific and industrial research
2. Production of plutonium which is used in atomic bombs as a fuel.
3. For obtaining useful energy.
4. For the production of atomic energy for peaceful purposes.

Types Of Reactors

There are two main types of nuclear reactors. These are:

(i) Thermal reactors (ii) Fast reactors.

(i) THERMAL REACTOR

The thermal reactors are called "thermal" because the neutron must be slowed down to "thermal energies" to produce further fission. They use natural uranium or slightly enriched uranium as fuel. Enriched uranium contains a greater percentage of U^{235} than natural uranium does. There are several designs of thermal reactors. Pressurized water reactor (PWR), are most widely used reactors in the world. In this type of reactor, the water is prevented from boiling, being kept under high pressure. This hot water is used to boil another circuit of water which produces steam for turbine rotation of electricity generators.

(ii) FAST REACTOR

Fast reactors are designed to make use of ${}_{92}U^{238}$, which is about 99% content of natural uranium. Each ${}_{92}U^{238}$ nucleus absorbs a fast neutron and changes into ${}_{94}Pu^{239}$. Plutonium can be fissionable by fast neutrons, hence, moderator is not needed in fast reactors. The core of fast reactors consists of a mixture of plutonium and uranium dioxide surrounded by a blanket of U^{238}. Neutrons that escape from the core interact with U^{238} in the blanket, producing ${}_{94}Pu^{239}$. Thus more plutonium fuel is bred in this way and natural uranium is used more effectively.

Question: What is meant by nuclear fusion? Discuss how can energy be released in the fusion process? Illustrate with examples.

NUCLEAR FUSION

Definition

"The process in which lighter nuclei combine to form heavy nuclei with the release of energy, is called Nuclear Fusion."

Explanation

The binding energy curve shows that the binding energy for light nuclei (those having a mass number less than 20) is much smaller than the binding energy for heavier nuclei. This suggests a possible process that is the reverse of fission.

Since the mass of final nucleus is less than rest masses of the parent nuclei, there is a loss of mass accompanied by a release of energy. The basic exothermic reaction in stars, including our own sun and hence the source of nearly all of the energy in the universe is the fusion of hydrogen nuclei into helium nucleus. This can take place under stellar conditions in two different series of processes.

1. PROTON-PROTON CYCLE

In one of them, the proton -proton cycle, direct collisions of protons result in the formation of heavier nuclei whose collisions in turn yield helium nuclei. The initial reaction in the proton-proton cycle is;

$${}_1H^1 + {}_1H^1 \rightarrow {}_1H^2 + e^+ + v$$

Where e^+ = Positron and v = neutrino.

$${}_1H^1 + {}_1H^2 \rightarrow {}_2He^3 + \gamma$$

Then;

$${}_2He^3 + {}_2He^3 \rightarrow {}_2He^4 + {}_1H^1 + {}_1H^1$$

The total energy evolved is Δmc^2 where Δm is the difference between the mass of four protons and the mass of an alpha particle plus two positrons, which turns out to be 24.7 MeV.

2. CARBON CYCLE

Carbon cycle is a series of steps in which carbon nuclei absorb a succession of protons until they ultimately disgorge alpha particles to become carbon nuclei once more. The carbon cycle proceeds in the following way.

$${}_1H^1 + {}_6C^{12} \rightarrow {}_7N^{13}$$
$${}_7N^{13} \rightarrow {}_6C^{13} + e^+ + v$$
$${}_1H^1 + {}_6C^{13} \rightarrow {}_7N^{14} + \gamma$$
$${}_1H^1 + {}_7N^{14} \rightarrow {}_8O^{15} + \gamma$$
$${}_8O^{15} \rightarrow {}_7N^{15} + e^+ + v$$
$${}_1H^1 + {}_7N^{15} \rightarrow {}_6C^{12} + {}_2He^4$$

The net result again is the formation of an alpha particle and two positrons from four protons, with the evolution of 24.7 MeV, Carbon ${}_6C^{'12}$ acts as a catalyst for the process, since it reappears at the end.

Self -sustaining fusion reactions can occur only under conditions of extreme temperature and pressure to ensure that the participating nuclei have enough energy to react despite their mutual electrostatic repulsion and that reactions occur frequently to counter balance losses of energy to the surrounding. Stellar interiors meet these specifications. In the sun, whose interior temperature is estimated to be 2×10^6 K, the carbon and proton-proton cycles have about equal probabilities for occurrence. In general, the carbon cycle is more efficient at high temperature, while the proton-proton cycle is more efficient at low temperature. Hence stars coolers than the sun obtain their energy from proton-proton cycle, while those hotter than the sun obtain the greater part of their energy from the carbon cycle.

The energy liberated in the fusion of light nuclei into heavier ones is often called thermonuclear energy. This thermonuclear energy is impossible to obtain on earth by nuclear fusion reaction because it needs very higher energy and temperature to fuse two nuclei. Hence this process has not yet been observed on earth on large scale in a controlled environment. However at laboratory scale it is possible.

RADIATION EXPOSURE

When a Geiger tube is used in any experiment, it records radiation even in the absence of radioactive source near it. This is caused by the radiation, called background radiation. It is partly due to cosmic radiation which comes to us from outer space and partly from naturally occurring radioactive substances in the Earth's crust. The cosmic radiation consists of high energy charged particles and electromagnetic radiation. The atmosphere acts as a shield to absorb some of these radiation as well as ultraviolet rays. In recent past, the depletion of ozone layer in upper atmosphere has been detected which particularly filters ultraviolet rays reaching us. This may result in increased eye and skin diseases. The depletion of ozone layer is suspected to be caused due to excessive release of some chemicals in the atmosphere such as chlorofluorocarbons (CFC) used in refrigeration, aerosol spray and plastic foam industry. Its use is now being replaced by environment friendly chemicals. Many building materials contain small amounts of radioactive isotopes, (radon) radioactive carbon gas enters buildings from the ground. It gets trapped inside the building which makes radiation levels much higher from radon inside than outside. A good ventilation can reduce radon level inside the building. All types of foods also contain a little radioactive substance. The most common are K^{40} and C^{14} isotopes.

Some radiation in environment is added by human activities. Medical practices, mostly diagnostic X-rays probably contribute the major portion to it. It is an unfortunate fact that many X-rays exposures such as routine chest X-rays and dental X-ray are made for no strong reason and may do more harm than good. The other sources include radioactive waste from nuclear facilities, hospitals, research and industrial establishments, color television, luminous watches and tobacco leaves. A smoker not only inhales toxic smoke but also hazardous radiation. Low level background radiation from natural sources is normally considered to be harmless. However, higher levels of exposure are certainly damaging. We cannot avoid unnecessary exposure to any kind of ionizing radiation.

BIOLOGICAL EFFECTS OF RADIATION

Excessive exposure to radiation can cause damage to living tissues, cells or organisms. The degree and kind of damage caused to a particular part of the body depends upon the type, energy and dose of radiation received. There is no lower limit below which radiation damage does not occur. A number of small doses received over long period of time may lead to fatal consequences.

Radiation damage to living organism is primarily due to ionization effects in the cells. The cell is the basic unit of life. Its normal metabolic function may be disrupted as a result of interaction with the ionizing radiation. Excessive radiation may cause death of individual cells, or produce chromosome abnormalities or genetic mutation. Biological effects are of two types.

i. **Somatic Effects**

Somatic effects affect an individual directly. Skin burns, loss of hair, drop in the white blood cells and induction of cancer are example of somatic effects.

ii. **Genetic Effects**

The genetic-effects may become apparent after a long time. The reason is that radiation can alter chemistry of the genes and may cause mutations. Even very low radiation doses reaching the reproductive organ of the body are potentially dangerous. Genetic effects may be passed on the future generations.

Question: Discuss the technique and use of radio isotopes in the different fields of human activities.

BIOLOGICAL AND MEDICAL USES OF RADIATION

Although, all the isotopes of an element chemically behave identically, but every isotope emits radiation due to which it is easy to identify it. It is this characteristic due to which the isotopes are being used in different fields of life.

(i) BIOLOGICAL USE

The chemical changes going on in an animal or a plant are very complex. The tracer method has been applied to study these changes. For example, the process of photosynthesis and the incorporation of carbon atoms in the CO_2 into giant and complex protein or carbohydrate molecules have been investigated by tracer techniques. Similarly information about complex process of metabolism is obtained by means of radioisotope tracers. The distribution of various elements such as hydrogen, sodium, iodine, phosphorous, strontium and iron etc in the body can be obtained by tracer technique. Genetic mutations are engineered by intense radioactivity.

(ii) RADIATION THERAPY

High energy radiations penetrate deep into the body and can be used for intentional selective destruction of tissues such as cancerous tumor. Radioisotope of Co^{60} which emits β-particles and high energy γ-rays is employed for the treatment of various types of cancers. Some radioisotopes are taken internally where they are selectively absorbed by certain organs and thus concentrate the radiation where it is most needed. For example, cancerous thyroid is treated with iodine I^{131} radioisotope. Sometimes pellets or capsules of radioisotopes are planted close to the tumor and can be removed after treatment.

(iii) MEDICAL DIAGNOSTICS

Hydrogen and sodium atoms are distributed uniformly throughout the body whereas iodine tends to concentrate in thyroids, phosphorous and strontium in bones and cobalt in liver. They can serve as tracers when injected or otherwise given to the patients. Radiation detectors may ascertain the passage of tracer through the body and their concentration in diseased tissues. The pattern of distribution of the radioactive tracers in a body can give a clue about normality or abnormality of the specific parts of the body.

(iv) TRACING TECHNIQUES

Radioactive particles can be used to trace chemicals participating in various reactions one of the most valuable uses of radioactive tracers is in medicine. For example, Iodine I^{131} is an artificially produced isotope of iodine. Iodine, which is a necessary nutrient for our bodies, is obtained largely through the intake of iodized salt and seafood. The thyroid gland plays a major role in the distribution of iodine throughout the body in order to evaluate the performance of the thyroid; the patient drinks a very small amount of radioactive sodium iodide. Two hours later, the amount of iodine in the thyroid gland is determined by measuring the radiation intensity at the neck area.

A second medical application is that a salt containing radioactive sodium is injected into a vein in the leg. The time at which the radioisotope arrives at another part of the body is detected with the radiation counter. The elapsed time is a good indication of the presence or absence of constriction in the circulatory system.

The tracer technique is also useful in agricultural research. Suppose, one wishes to determine the best method of fertilizing a plant. A certain material in the fertilizer, such as nitrogen, can be tagged with one of its radioactive isotopes. The fertilizer is then sprayed on one group of plants, sprinkled on the ground for second group, and raked into soil for a third. A Geiger counter is then used to track the nitrogen through the three types of plants.

BASIC FORCES OF NATURE

The key to understand the properties of elementary particles is to be able to describe the forces between them. All particles in nature are subjected to four fundamental forces.

1. Strong Nuclear Force
2. Electromagnetic Force
3. Weak Nuclear Force
4. Gravitational Force

STRONG NUCLEAR FORCE

- This force is very short range and negligible for separation $r > 10^{-14}$ m.
- It is responsible for the binding of neutrons and protons into nuclei.
- It is the strongest of all the fundamental forces.
- This strong force is mediated by the field particle called gluons between two quarks and by mesons between two nucleons.

ELECTROMAGNETIC FORCE

- The electromagnetic force is about 100 times smaller in strength than strong nuclear force.
- It is responsible for the binding of atoms and molecules.

- It is a long-range force that decreases in strength as the inverse square of the separation between interacting particles.
- The electromagnetic force is mediated by photons, which are the quanta of the electrometric field.

WEAK FORCE

- The weak force is a short range nuclear force that tends to produce instability in certain nuclei.
- It is responsible for most radioactive decay processes such as beta decay.
- Its strength is only about 10^{-9} times that of the strong nuclear force.
- Scientists now believe that the weak and electromagnetic forces are two manifestations of a single force called the electro weak force.
- The weak force is mediated by particles called the w-bosons and z-bosons

GRAVITATIONAL FORCE

The gravitational force is a long range force whose strength is about 10^{-38} times that of strong force.

- It holds the plants, stars and galaxies together.
- Its effect on elementary particles is negligible.
- The gravitational force is the weakest of all the fundamental forces.
- The gravitational force is mediated by quanta of the gravitational field called gravitons.

BUILDING BLOCKS OF MATTER

The word "atom" is from Greek word atomos, which means indivisible. At one time atoms were thought to be the indivisible constituents of matter, that is, they were regarded to be elementary particles. Discoveries in the early part of the 20th century revealed that the atom is not elementary, but consists of protons, neutrons and electrons. Until 1960s, physicists were puzzled by the large number and variety of elementary particles being discovered. In the last two decades, physicists have made tremendous advance in our knowledge regarding the structure of matter by recognizing that all particles (except electrons, photons etc) are made of smaller particles called quarks. Thus protons and neutrons, for example, are not truly elementary particles but are system of tightly bound quarks.

Question: Write a comprehensive note on hadrons, leptons and quarks.

CLASSIFICATION OF PARTICLES

HADRONS

- Particles that interact through the strong force are called hadrons.
- There are two classes of hadrons, known as mesons and baryons.
- Meson has mass between the mass of the electron and the mass of proton. All mesons are known to be decay finally into electrons, positrons, neutrinos and photons. Pion is lightest of known mesons.
- Baryons, which make the second class of hadrons, have mass equal to or greater than proton mass. Protons and neutrons are included in the baryon family. With

the exception of the proton, all baryons decay in such a way that the end products include a proton.

LEPTONS

- Leptons are a group of particles that participate in the weak interaction.
- Include in this group are electrons, muons, and neutrinos, which are all less massive than the lightest hadron.
- Since lepton has no internal structure, they appear to be truly elementary particles.
- Scientists believe that there are only six leptons.

QUARKS

According to quark theory, the quarks are proposed as the basic building blocks of the mesons and baryons. The quark model is based on the following assumptions.

1. There are six different types of quarks, the up quark, the down quark, the strange quark, the charmed quark, the bottom quark and the top quark referred to as u, d, s, c, b and t.
2. For every type of quark, there is a corresponding antiquark.
3. Quarks combine in threes to form particles like the protons and the neutrons. Antiquarks also combine in threes to form antiparticles like the antiproton and the antineutron.
4. A meson consists of a quark and an antiquark.

In terms of the charge of the electron, the u, c and t quarks each carry a charge of +2/3 e and the other three quarks carry a charge of – 1/3 e.

An antiquark carries an equal and opposite charge to its corresponding quark. The symbol for antiquark is the same as for a quark but with a bar over the top. For example, $\bar{d}$ represents the symbol for a down antiquark.

Thus

- A proton is composed of two up quarks and a down quark.
- A neutron consists of an up quark and two down quarks.