Unit 20

NUCLEAR PHYSICS

Major Concepts (30 PERIODS)

- Composition of atomic nuclei
- Isotopes
- Mass spectrograph
- Mass defect and binding energy
- Radioactivity (properties of α, β and γ rays)
- Energy from nuclear decay
- Half-life and rate of decay
- Interaction of radiation with matter
- Radiation detectors (GM counter and solid state detector)
- Nuclear reactions
- Nuclear fission (fission chain reaction)
- Nuclear reactors (types of nuclear reactor)
- Nuclear fusion (nuclear reaction in the Sun)
- Radiation exposure
- Biological and medical uses of radiations (radiation therapy, diagnosis of diseases, tracers techniques)
- Basic forces of nature
- Elementary particles and particle classification (hadrons, leptons and quarks)

Conceptual Linkage

This chapter is built on Nuclear Physics X

Students Learning Outcomes

After studying this unit, the students will be able to:

- describe a simple model for the atom to include protons, neutrons and electrons.
- determine the number of protons, neutrons and nucleons it contains for the specification of a nucleus in the form $^{A}_{Z}X$.
- explain that an element can exist in various isotopic forms each with a different number of neutrons.
- explain the use of mass spectrograph to demonstrate the existence of isotopes and to measure their relative abundance.

- define the terms unified mass scale, mass defect and calculate binding energy using Einstein's equation.
- illustrate graphically the variation of binding energy per nucleon with the mass number.
- explain the relevance of binding energy per nucleon to nuclear fusion and to nuclear fission.
- identify that some nuclei are unstable, give out radiation to get rid of excess energy and are said to be radioactive.
- describe that an element may change into another element when radioactivity occurs.
- identify the spontaneous and random nature of nuclear decay.
- describe the term half-life and solve problems using the equation ($9=0.693/T_{1/2}$.
- determine the release of energy from different nuclear reactions.
- explain that atomic number and mass number conserve in nuclear reactions.
- describe energy and mass conservation in simple reactions and in radioactive decay.
- describe the phenomena of nuclear fission and fusion.
- describe the fission chain reaction.
- describe the function of various components of a nuclear reactor.
- describe the interaction of nuclear radiation with matter.
- describe the use of Geiger Muller counter and solid state detectors to detect the radiations.
- describe the basic forces of nature.
- describe the key features and components of the standard model of matter including hadrons, leptons and quarks.

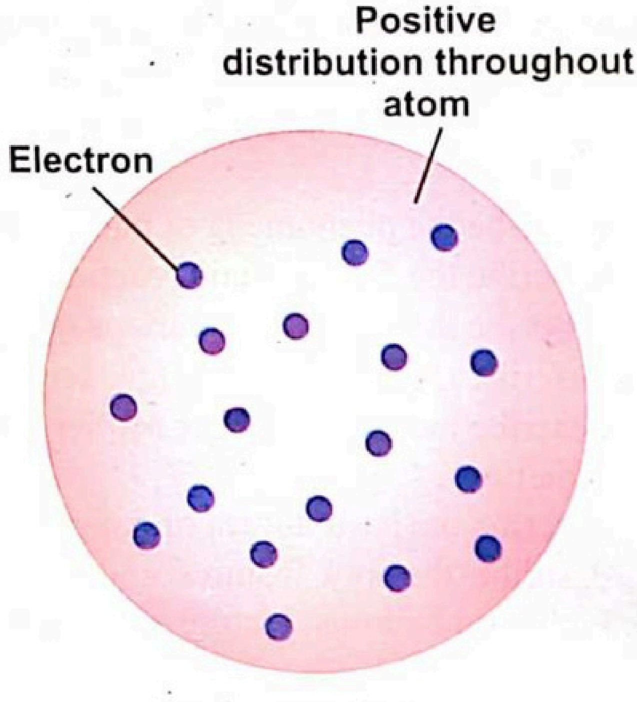
INTRODUCTION

The discovery of radioactivity by Henri Becquerel while investigating phosphorescence in uranium salts had prompted other scientists to describe the details of radioactivity and structure of the atomic nucleus. In this regard, Ernest Rutherford studying the properties of radioactive decay named the emitted radiations as alpha, beta particles and gamma rays. Also Rutherford discovered atomic nucleus by performing the alpha particle scattering experiments. He explained that the nucleus is a small, dense region at the centre of the atom. It consists of positive protons and neutral neutrons, so it has an overall positive charge. These experiments provided the basic properties of the nucleus of an atom such as; charge number, mass number etc.

In this unit we will not only discuss the structure of the nucleus but also explain its properties such as: charge number, mass number, isotopes, mass defect, binding energy etc. Similarly, we will study the radioactive nuclei i.e., unstable nuclei which emit radiations called radioactivity. We will also study the artificial radioactivity under the two chemical reactions i.e., fission reaction and fusion reaction. Some of the fundamental conservation laws are used in these nuclear reactions. The characteristics of nuclear fission reactions are discussed and applied to the example of a nuclear reactor used for the generation of electrical power. Energy can also be produced by nuclear fusion. Reference is made to the fusion reactions in stars, and some advantages and disadvantages of fusion as a future source of energy. In the last of this unit we will deal with forces of nature, various elementary particles and their classifications like Hadrons, Leptons and Quarks etc.

20.1 COMPOSITION OF ATOMIC NUCLEI

Rutherford designed an experiment to use the alpha particles emitted by a radioactive element to investigate atomic structure. He demonstrated that the atom has a central massive core which he called the nucleus. It has very small and very dense structure. It occupies only 10^{-12} of the total volume of the atom, i.e., its diameter is 10^{-14} m whereas the diameter of the atom is 10^{-10} m. The nucleus is positively charged, and its mass is about 99.9% of the total mass of the atom.



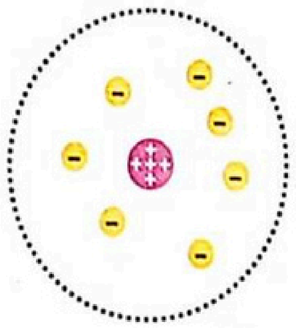
Early model of the atom.

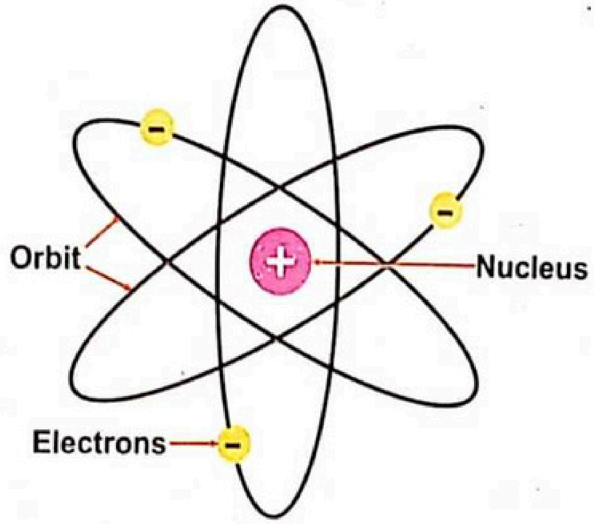
After the discovery of neutron in 1932, Dmitri and Heisenberg developed the model of a nucleus which is composed of protons and neutrons. That is an atom is composed of a positively-charged nucleus, with a cloud of negatively-charged electrons surrounding it, bound together by electrostatic force. The protons were also discovered by Rutherford, which carries a positive charge of magnitude 1.6×10^{-19}C with mass 1.673×10^{-27} kg. Similarly, the other particle of the nucleus is the neutron. It was discovered by Chadwick. It is a neutral particle i.e., it carries no charge and its mass is 1.675×10^{-27} kg. The mass of proton is almost equal to the mass of the neutron but it is approximately 1836 times as massive as the electron.

> *FOR YOUR INFORMATION*
>
> After performing the alpha particles scattering experiment, Rutherford concluded that most part of an atom is empty and that mass is concentrated in a very small region called nucleus.

The number of protons in a nucleus is called the atomic number or the charge number. It is represented by 'Z'. The total charges of a nucleus is Ze. Where 'e' is a charge on a proton or an electron.

Similarly, **the total number of protons and neutrons, called nucleons in a nucleus is termed as mass number.** It is denoted by 'A'. It is measured in terms of unified atomic mass unit (u) and this unit is defined as follows, the atom of carbon-12 is being considered the value of exactly 12u where 1u is equal to 1.6605×10^{-27} kg. On the basis of this scale, the proton rest mass and the neutron rest mass are both approximately 1u or 1a.m.u. The masses of some other important sub-atomic particles in terms of atomic mass unit are given in table 20.1. If both mass number "A" and charge number 'Z' are known, then the number of neutrons in the nucleus is (A – Z).





Rutherford's Atomic Model

Table.20.1

Obejct	Mass (kg)	Mass (u)	Mass (MeV/c²)
Neutron	1.674929×10^{-27}	1.008664	939.57
Proton	1.672623×10^{-27}	1.007276	938.28
Electron	9.109390×10^{-31}	0.0054858	0.511

The observations show that the simplest nucleus of the hydrogen atom contains only one proton and it has no neutron. Similarly, the number of protons and the number of neutrons in the initial light elements of the periodic table are almost equal. However, the number of neutrons in the heavy elements are greater than the number of protons. For example, in helium ${}^{4}_{2}He$, the number of neutrons is 2 and number of proton is also 2. In ${}^{235}_{92}U$, the number of protons 92 and number of neutrons 143.

In order to classify nuclei in terms of their atomic number and mass number, the symbol X is being used to represent a nucleus as;

$$^{\text{Mass number}}_{\text{atomic numbers}}X = {}^{A}_{Z}X$$

For example, the nucleus of helium atom is represented by ${}^{4}_{2}He$ similarly the nucleus of Hydrogen atom is represented by ${}^{1}_{1}H$ where Z=1 and A =1. The proton is also represented by ${}^{1}_{1}H$ and the neutron is represented by ${}^{1}_{0}n$.

20.2 ISOTOPES

Atoms of the same element that have the same number of protons but different numbers of neutrons are known as isotopes. In such cases, their mass numbers are also different. Hence, the nuclei of an element having identical values of atomic number (Z) but different values of mass number (A) are called isotopes. For example, hydrogen has three isotopes, i.e., ${}^{1}_{1}H$ -ordinary hydrogen or protium has only one proton in its nucleus, ${}^{2}_{1}H$ -heavy hydrogen or deuterium contains one proton and one neutron and ${}^{3}_{1}H$ -tritium contains one proton and two neutrons in its nucleus as shown in Fig.20.1.

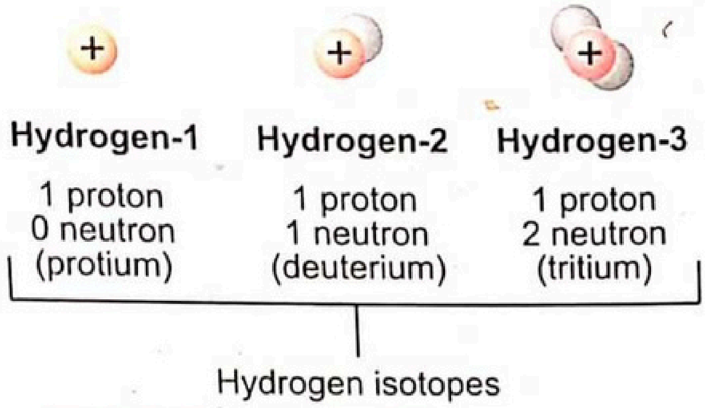


Fig.20.1. Three isotopes of hydrogen.

The natural abundance of isotopes can differ substantially. For example, carbon has four isotopes, ${}^{11}_{6}C$, ${}^{12}_{6}C$, ${}^{13}_{6}C$ and ${}^{14}_{6}C$. The natural abundance of the ${}^{12}_{6}C$ isotopes is approximately 98.9%, whereas that of the ${}^{13}_{6}C$ isotope is only about 1.1%, the rest isotopes, such as ${}^{11}_{6}C$ and ${}^{14}_{6}C$ are not natural occurring but can be produced by nuclear reaction in the laboratory or by cosmic rays.

> ***POINT TO PONDER***
> - What is the function of in the atomic nucleus?
> - What is the fate of neutron when it is along are distant from one or more protons?

The nuclei that have the same mass number, but have different atomic number are called isobars, e.g. ${}^{40}_{18}Ar$ and ${}^{40}_{20}C$. Similarly, the nuclei having the same number of neutrons are known as isotones (${}^{13}_{6}C$, ${}^{14}_{7}N$). The nuclei having identical atomic number and mass number but having different half-lives are called isomers. For example, ${}^{58}_{27}CO$ and $({}^{58}_{27}CO)^{m}$ both have same atomic number and mass number but the half-life of ${}^{58}CO$ is 71 days while the half-life of $({}^{58}_{27}CO)^{m}$ is 9 hours.

20.3 MASS SPECTROGRAPH

Mass spectrograph is used to determine the existence of isotopes and to measure their relative abundance or it is a device used to separate electrically charged particles according to their masses. A process in which the isotopes of any element can be separated, and their masses can be determined is called mass-spectrography. The mass of ions are determined from their deflection in a magnetic field. A mass spectrometer essentially consists of an ion source, a mass analyzer, and a detector as shown in Fig 20.2. Other minor components are two slits (S_1 and S_2); high voltage battery, applied magnetic field (B) in a vacuum chamber and a photographic plate.

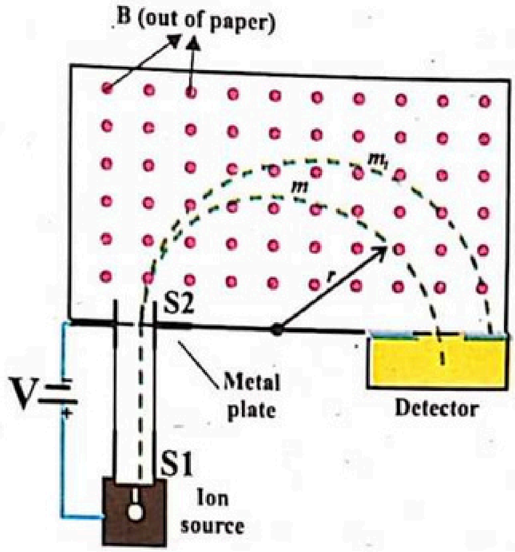


Fig.20.2. A schematic diagram for mass-spectrograph in which ions are deflected along the circular path by magnetic applied field.

In order to achieve the ionization of the given element in vapour from inside the source, one electron is removed from the particle, leaving with a net positive charge +e. The positive ions escaping the slits are accelerated through potential difference (V_o) applied between the two slits, the gain in K.E of the accelerated ions is given by

$$\frac{1}{2}mv^2 = eV_o \quad ......(20.1)$$

When this narrow beam of accelerated ions passes through slit S_2 and enters into a vacuum chamber then it will be exposed to a perpendicular uniform magnetic field B. As a result, the beam of ions is deflected into a circular path of radius 'r' as shown in fig 20.4. The centripetal force of this circular path is equal to the magnetic force due to the applied magnetic field. i.e.,

$$\frac{mv^2}{r} = evB$$

$$m = \frac{eBr}{V} \quad ......(20.2)$$

The value of v can be obtained from Eq. 20.1;

$$v^2 = \frac{2eV_0}{m}$$

$$v = \sqrt{\frac{2eV_0}{m}}$$

Thus

$$m = \frac{eBr}{\sqrt{\frac{2eV_o}{m}}}$$

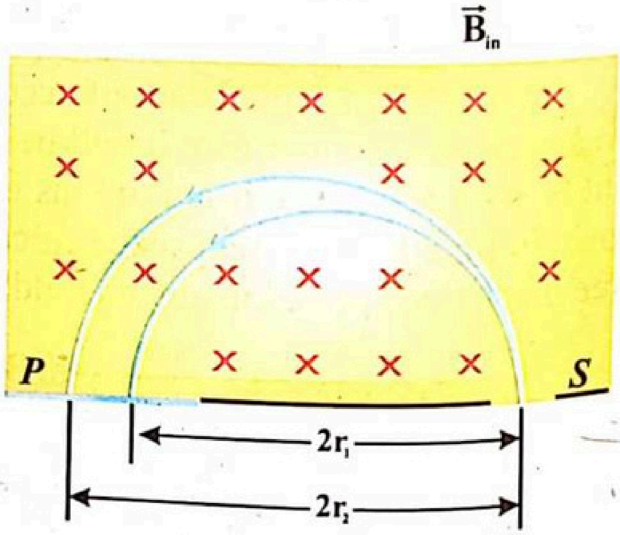
$$m^2 = e^2B^2r^2\left(\frac{m}{2eV_o}\right)$$

$$m = \left(\frac{er^2}{2V_o}\right)B^2 \quad \text{......(20.3)}$$

By using Eq.20.3, we can calculate the mass of the ion if the values of B, r, e and V_o are known. Finally, when the ions fall on the photographic plate, they cast the images on it. The brightness images on the photographic plate give us a very interesting result. i.e. when an element gives rise the two or more different beams in the process of spectrograph then we will observe the same number of radii on the photographic plate. Equation 20.3 also shows that the beams of different radii have different masses. Thus, it is concluded that nuclei of the same element may have different masses. For example, when a beam of ions obtained from pure chlorine is passed through the mass–spectrograph then we will observe two images on the photographic plate. This shows that chlorine consists of two types of nuclei with respect to their masses, m_1 and m_2 where m_1 = 34.97u and m_2 = 36.97u. Natural abundance of m_1 is 75.4% and m_2 is 24.6 %.

Example 20.1

In a mass spectrograph, the masses of ions are determined from their deflection in a magnetic field. Suppose that singly charged ions of chlorine are shot perpendicularly into a magnetic field 0.15T with a speed of 5×10^4 m s^{-1}. Chlorine has two major isotopes, of masses 34.97u and 36.97u. What would be the radii of the circular paths, described by the two isotopes in the magnetic field as shown in figure.



Solution:

Magnetic field = 0.15T

Speed (v) = 5×10^4 ms^{-1}

Mass of the 1st ion (m_1) = 34.97u = $(34.97\times1.66\times10^{-27})$kg

m_1 = 5.81×10^{-26} kg

Mass of the 2nd ion (m_2) = 36.97u = $(36.97\times1.66\times^{-27})$kg

m_2 = 6.14×10^{-26} kg

Radius of the 1st ion (r_1) = ?

Radius of the 2nd ion (r_2) = ?

To find the radii we have the following relation

$$r = \frac{mv}{eB}$$

Thus

$$r_1 = \frac{m_1 v}{eB}$$

$$r_1 = \frac{5.81 \times 10^{-26} kg \times 5 \times 10^4 m\ s^{-1}}{1.6 \times 10^{-19} C \times 0.15 T}$$

$$r_1 = \frac{2.905 \times 10^{-21}}{2.4 \times 10^{-20}} m$$

$$r_1 = 0.12 m$$

Similarly,

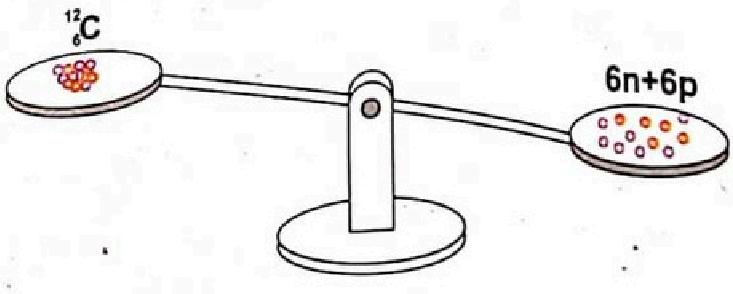
$$r_2 = \frac{6.14 \times 10^{-26} kg \times 5 \times 10^4 m\ s^{-1}}{1.6 \times 10^{-19} C \times 0.15 T}$$

$$r_2 = \frac{3.07 \times 10^{-21}}{2.4 \times 10^{-20}} m$$

$$r_2 = 0.13 m$$

20.4 MASS DEFECT AND BINDING ENERGY:

It has been observed experimentally that the mass of the nucleus is always less than the sum of masses of its free constituent i.e., protons and neutrons. The difference between mass of nucleus and the sum of masses of the nucleons of which it is composed is known as mass defect. It is represented by Δm and expressed as

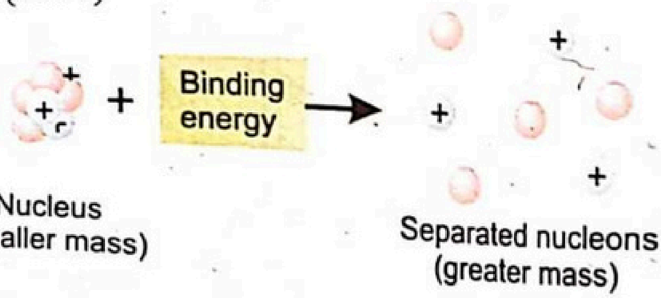


The mass of a nucleus is less than the total mass of its constituents i.e. protons and neutrons.

$$\Delta m = Zm_p + Nm_n - M_{nucleus}$$

$$\Delta m = Zm_p + (A - Z)m_n - M_{nucleus} \quad \ldots\ldots(20.4)$$

where 'Z' is the total number of protons and m_p is the mass of a proton. Therefore, Zm_p is the total mass of the protons. Similarly, (A–Z) is the total number of the neutrons and m_n is the



Binding Energy

mass of a neutron. So $(A-Z)m_n$ is the total mass of the neutrons and $M_{nucleus}$ is the mass of the nucleus.

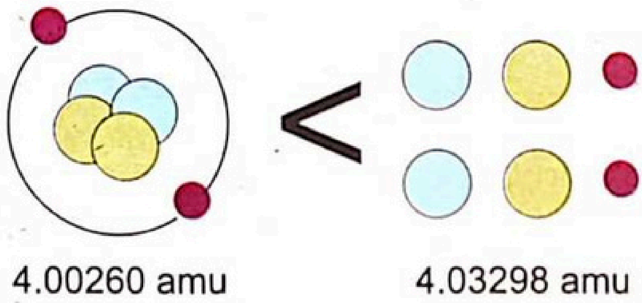
The mass defect 'Δm' is due to the conversion of the mass into energy when nucleons combine to form a nucleus. This energy is called binding energy of the nucleus and it is obtained by Einstein's mass-energy relation.

$$E = \Delta mc^2 \quad ......(20.5)$$

Substituting the value of Δm from equation 20.4 in equation 20.5 we get.

$$B.E = \left[Zm_p + (A-Z)m_n - M_{nucleus}\right]c^2 \quad ......(20.6)$$

This is a mathematical from of binding energy and it is defined as the amount of energy that holds the nucleons together with in the nucleus against the repulsive coulomb's force. In other words, **the minimum energy that would be required to break the nucleus of an atom into its constituent nucleus i.e. protons and neutrons is called its binding energy.**



Mass Defect

In order to study the stability of a nucleus of an atom, we use the concept of binding energy per nucleon E_b/A usually called binding fraction. It has been observed experimentally that the greater is the binding energy per nucleon, the more stable is

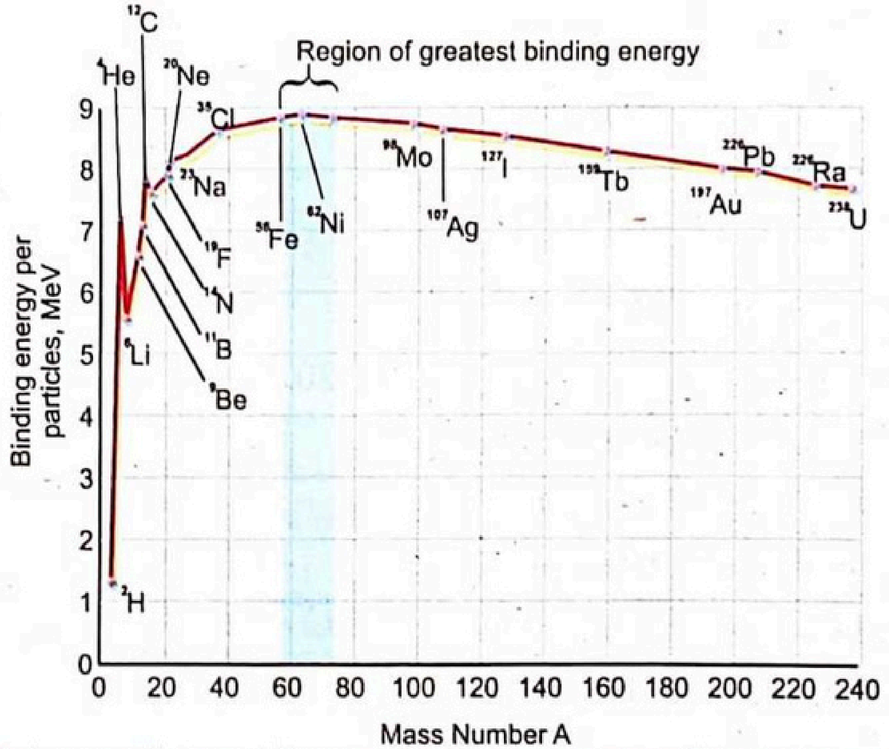


Fig.20.3. A curved line graph between binding energy per nucleon and mass number.

the nucleus and vice versa. This can be explained by drawing a graph between binding energy per nucleon and the mass number A.

The graph in the Fig 20.5 shows that when the mass number 'A' increases, the binding energy per nucleon increases rapidly up to the mass number of 50-60 i.e., for iron, nickel etc., and then decreases slowly. It means, the nucleons are bound most strongly in nuclei having mass numbers of the order of 50-60, the binding energy per nucleon for these nuclei reaches to its maximum value. i.e., 8.7 MeV per nucleon. On the other hand, the binding energy per nucleons is small for both light nuclei ($A < 30$) and heavy nucleis ($A > 170$).

Another important characteristic revealed by the graph 20.3 is that the binding energy per nucleon is approximately constant at around 8MeV per nucleon for nuclei having intermediate mass number (A = between 30 and 170). For these nuclei, the nuclear forces are said to be saturated.

Example 20.2

Calculate mass defect, binding energy and binding energy per nucleon of the $^{56}_{26}Fe$ nucleus. The mass of $^{56}_{26}Fe$ is 9.288×10^{-26} kg.

Solution:

$$\text{Mass of proton } (m_p) = 1.673 \times 10^{-27}\text{kg}$$
$$\text{Mass of neutron } (m_n) = 1.675 \times 10^{-27}\text{kg}$$
$$\text{Mass of } {}_{26}Fe^{56} \text{ nucleus } (m) = 9.288 \times 10^{-26}\text{kg}$$
$$Z = 26$$
$$A = 56$$
$$A\text{-}Z = 56 - 26 = 30$$

Mass defect $\Delta m = Zm_p + (A - Z)m_n - m_{nucleus}$

$$\Delta m = 26\,(1.673 \times 10^{-27}) + 30\,(1.675 \times 10^{-27}) - 9.288 \times 10^{-26}$$
$$\Delta m = 4.3498 \times 10^{-26} + 5.025 \times 10^{-26} - 9.288 \times 10^{-26}$$
$$\Delta m = 8.68 \times 10^{-28}\text{kg}$$
$$B.E. = \Delta mc^2 = (8.68 \times 10^{-28})(3 \times 10^8)^2$$
$$B.E. = 7.812 \times 10^{-11}\text{J}$$
$$B.E. = \frac{7.812 \times 10^{-11}}{1.6 \times 10^{-19}}\text{eV} = 4.88 \times 10^8\text{eV} \quad \therefore 1\text{eV} = 1.6 \times 10^{-19}\text{J}$$
$$B.E. = 488 \text{ MeV}$$
$$\text{Binding energy per nucleons} = \frac{BE}{A} = \frac{488\,\text{MeV}}{56}$$
$$\text{Binding energy per nucleon} = 8.71 \text{ MeV per nucleon}$$

20.5 RADIOACTIVITY

Henri Becquerel in 1896 accidentally discovered radioactivity. He observed that a uranium salt spontaneously emit radiations in the absence of any source of energy (light). He placed a photographic plate close to the uranium salt such that the plate was wrapped in a black paper to keep light out. He observed that the photographic plate was blackened, which indicates that the radiation has been emitted from the uranium salt. Thus, the term radioactivity is used to describe the spontaneous emission of radiation from the uranium salt or other substances called radioactive substances. These emissions of radiations are independent of physical conditions of the radioactive substance such as temperature and pressure.

Later, Marie curie and Pierre curie discovered two new radioactive elements which they named as radium and polonium. Similarly, Rutherford's experiment on α -particle scattering suggested that radioactivity is the result of the decay or disintegration of the radioactive elements. The work done on radioactivity by various scientists revealed that those elements whose atomic number (Z) is greater than 82

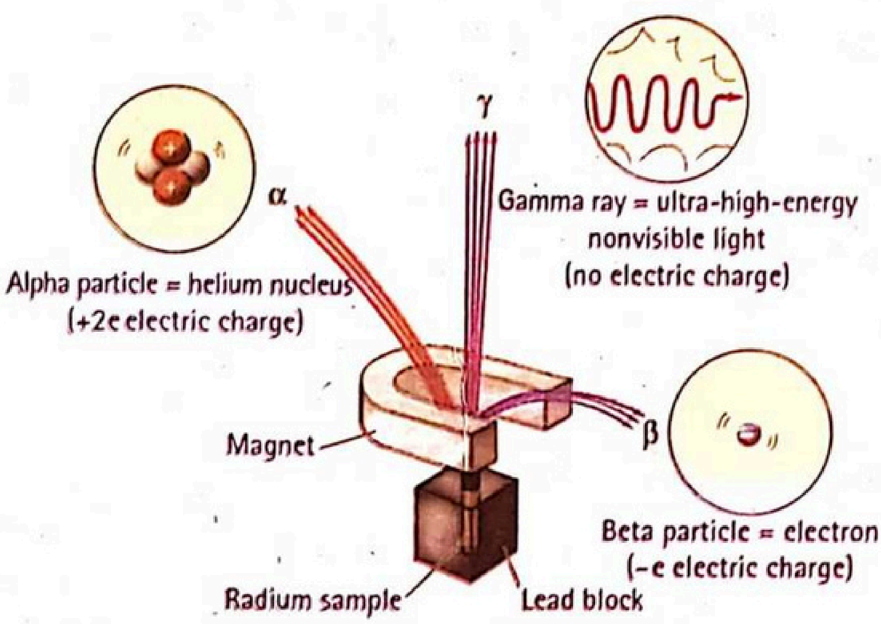


Fig. 20.4 The three emitted radioactive radiations, alpha, beta and gamma.

are unstable and they emit radiation spontaneously. The emissions consist of positively and negatively charged particles and neutral rays as shown in Fig.20.4, These three radiations were named as alpha (α), beta (β) and gamma (γ) respectively.

In the decay process, the original nucleus is usually called the parent nucleus. This parent nucleus is converted into the daughter nucleus by the emission of radiations. The daughter nucleus may also be unstable. In this connection a series of successive decays occurs until a stable configuration is reached i.e. the final nucleus is not radioactive. During the radioactive decay or nuclear decay all the laws of conservation such as: mass, energy momentum and charge must be conserved. These are termed as conservation of nucleons and it is stated as neutrons may be converted into protons and vice versa but total number of nucleons must remain constant.

20.5.1 Properties of α-Particles, β - Particles and γ – rays:

The three radiations α, β and γ have some most important properties which are explained as under:

Table.20.2

Type of Radiation	Nature	Mass amu	Charge
Alpha (α)	Helium ion (nucleus)	4	+2
Beta (β)	Fast moving electron	$\frac{1}{1800}$	-1
Gamma (γ)	High energy shortwave length light	0	0

Identity

α-Particles are identical to the nucleus of helium atom consisting of two protons and two neutrons having a mass of 4 units and charge of +2 units. The β-particles are fast moving electrons i.e., β-particles has the same mass and charge as an electron. γ-rays are form of electromagnetic radiations, having photon energies above 100keV. All these are explained in Table 20.2.

> **DO YOU KNOW**
> Once alpha and beta particles are slowed by collisions, they combine to become harmless helium atoms.

Charges

α -particles carry positive charges equal the charges of two protons whereas, β-particles carry negative charges equal to charge on an electron and γ-rays carry no charge. A summary of these characteristics is given in Table 20.2.

Effect of electric and magnetic fields

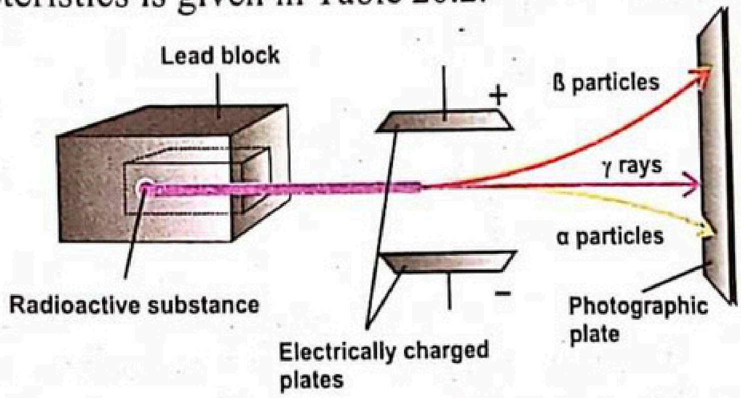


Fig.20.5. Deflection of alpha particles, beta particles and gamma rays in the presence of electric field.

Both α-particles and β-particles are deflected in the presence of electric and magnetic fields whereas the γ-rays do not deflect. The deflection of the alpha particles, beta particles and gamma rays in an electric field is shown in Fig.20.5.

Speed

As α-particles are the heaviest, so they are slow moving particles and their speed is almost $\frac{1}{200}$ of speed of light. The speed of β-particles is almost $\frac{2}{3}$ of speed of light. As γ-rays are electromagnetic waves therefore they move with the speed light.

Penetrating power

The penetrating power of α-particles is very small. They can penetrate only a few millimetres thickness of paper as shown in Fig 20.6. Similarly, β-particles can penetrate a few centimetres thickness of an Aluminum. On the other hand, the penetrating power of γ- rays is very large, it can penetrate more than 20 cm thickness of a lead.

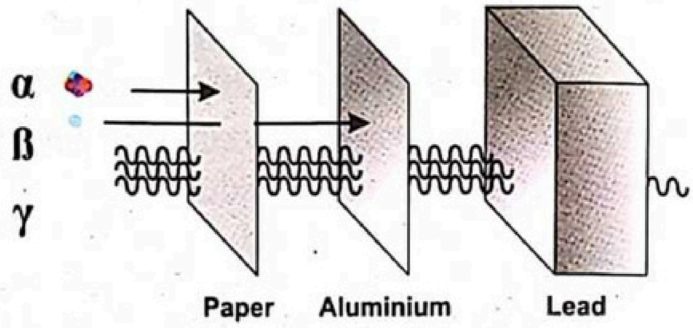


Fig.20.6. Penetrating power of alpha-particles, beta-particles and gamma-rays.

Ionization power

α-particles have highest ionization power because of their double positive charge and large mass. One alpha particle can ionize 10,000 atoms. The ionization power of β- particles is about $\frac{1}{100}$ that of the α-particles and practically the ionization power of γ- rays is zero

Photographic effect

All the three radiations α-particles, β-particles and γ-rays can blacken the photographic film.

Fluorescence

Though all the three radiations produce fluorescence when they fall on the fluorescence materials like zinc-sulphide but the fluorescence ability of γ-rays is less than the others two.

20.5.2 Laws of radioactive disintegration

We have studied that when a radioactive element disintegrates with time, it emits α-particles, β-particles and γ-rays. Rutherford and his colleague. Frederick introduced the disintegration theory of radioactivity and summarized it in the form of the following laws.

i The radioactive decay is spontaneous, and it does not depend upon the physical and external conditions.

iii The decay has different radiations such as: alpha, beta and gamma but all of them are not emitted simultaneously.

iii The rate of decay is different for different radioactive elements.

iv The rate of decay is directly proportional to the initial number of atoms of radioactive element.

v No element practically decays completely, when its atomic number is less than 81 i.e. these elements are stable.

vi When an element emits an α-particles ($^{4}_{2}He$), the nucleus of its atom loses four nucleons, i.e. two protons and two neutron.

Therefore, the charge number (Z) of the nucleus decreases by two and mass number (A) decreases by four. Hence the parent element $^{A}_{Z}X$ is converted into the daughter element $^{A-4}_{Z-2}Y$. This can be expressed by following equation.

$$^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$$

For example, when an α-particles is emitted from uranium $^{234}_{92}U$ then we have thorium $^{230}_{90}Th$ and this change can be represented by the following equation.

$$^{234}_{92}U \rightarrow {}^{230}_{90}Th + {}^{4}_{2}He$$

In this reaction we can observe the law of conservation of nucleons.

vii Similarly, when an element emits a β-particles, then there is no change in the number of nucleons i.e. its mass number (A) remains the same. However, its charge number (Z) increases by one. Hence, the parent element $^{A}_{Z}X$ is converted into a daughter element $^{A}_{Z+1}Y$ by the emission of β-particles. This change can be represented by the following reaction as,

$$^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e$$

As we know that electrons do not exist within the nucleus. However, the emission of electron from the nucleus is being thought that a neutron is converted to proton and an electron. It means that β-particles is formed at the time of its emission. It is a reason that why at the time of emission of β-particles the charge number of the nucleus increases by one but no change occurs in its mass number.

For example, if a β-particles is emitted from carbon $^{14}_{6}C$ then we have $^{14}_{7}N$ which may be written as:

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

viii If there is emission of γ-rays from an element then there is no change in its charge number (Z) and its mass number (A), because a γ- rays is simply a photon that having neither charge nor any mass. The nucleus is in the excited state i.e. ($^{A}_{Z}X$) and acquires ground state after the emission of γ-rays. Thus, the decay of γ-rays from the radioactive element is represented by this equation.

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

20.6 RADIOACTIVE DECAY EQUATION

Consider a radioactive element which has 'N' radioactive atoms at the starting point. After some time Δt the number of radioactive atoms of the element decreases by 'ΔN' due to radioactive disintegration process. If ΔN be the number of atoms which decay in time Δt, then according the law of decay, the rate of decay is directly proportional to the initial number of atoms of the element, i.e.,

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

$$\frac{\Delta N}{\Delta T} = \lambda N \quad \text{......(20.6)}$$

where 'λ' is a constant of proportionality and it is called decay constant or disintegration constant. Since the number of radioactive atoms decreases with time therefore a negative sign has to be introduced on the right hand side of Eq. 20.6.

> ***FOR YOUR INFORMATION***
> - Any quantity that decreases by half over equal time intervals is said to decay exponentially.
> - Any quantity that increases by twice over equal time interval is said to grow exponentially.

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

or

$$\frac{\Delta N}{N} = -\lambda \Delta t \quad \text{......(20.7)}$$

Eq.20.7 can be solved using a mathematical technique called integration and we have the following relation

$$N = N_0 e^{-\lambda t} \quad \text{......(20.8)}$$

where N_o is the number of atoms of radioactive element at $t = 0$. Equation 20.7 is known as radioactive decay equation and it shows that the number of atoms of a radioactive element decreases exponentially with time. Now if we draw a graph between undecayed number of atoms N and time 't' then we have a curved line as shown in Fig 20.7, which illustrates the exponential nature of the decay of a radioactive element.

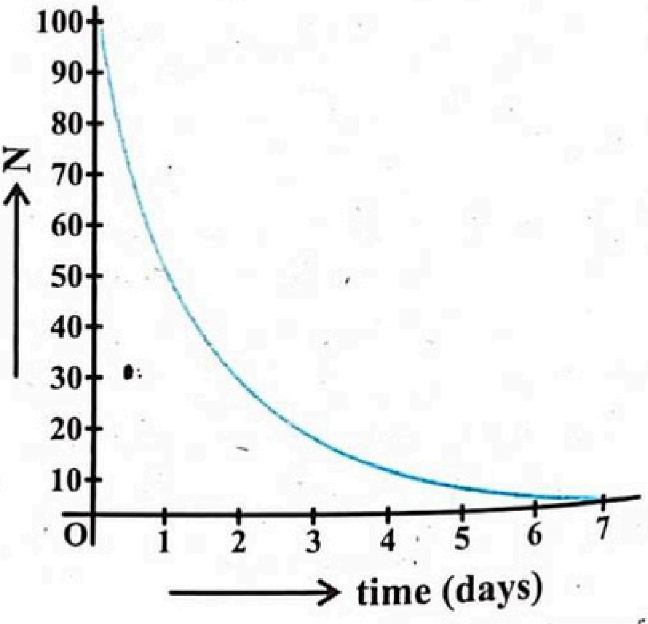


Fig.20.7. A graph between undecayed number of nucleons and time showing an exponential nature of decay.

20.6.1 Half-life of a radioactive element

Half-life of a radioactive element is a method which is being used to determine the rate of radioactivity and it is defined as; '**the time taken for the activity of a given amount of a radioactive substance to decay to half of its initial value' or the time interval during which half of the given number of radioactive nuclei decay.** It is represented by $T_{1/2}$ and its relation can be expresses as;

Let N_o be the initial number of radioactive atoms of an element. i.e. at $t = 0$ which reduces to $\frac{N_o}{2}$ after $t = T_{\frac{1}{2}}$ i.e. after one half-life. Mathematically

$$N = N_o, \text{ at } t = 0$$

and
$$N = \frac{N_o}{2}, \text{ at } t = T_{1/2} \text{ (half life).}$$

Thus Eq.20.8 becomes

$$\frac{N_o}{2} = N_o e^{-\lambda T_{1/2}}$$

$$\frac{1}{2} = e^{-\lambda T_{\frac{1}{2}}}$$

$$2 = e^{\lambda T_{\frac{1}{2}}}$$

$$\ln 2 = \lambda T_{1/2}$$

$$\lambda T_{1/2} = \ln 2$$

$$T_{1/2} = \frac{0.693}{\lambda} \quad \text{......(20.9)}$$

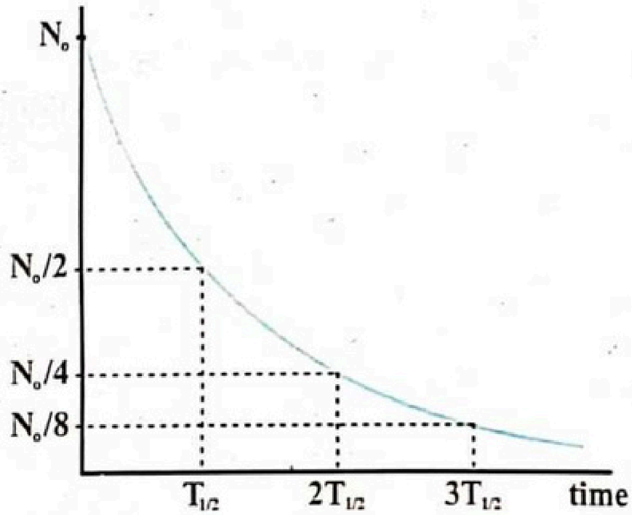


Fig.20.8. The decay of radioactive element in terms of half life.

Equation 20.9 gives the half-life of a radioactive element and it shows that the half-life of an element is inversely proportional to its decay constant.

Similarly, after two half-lives, the half-life of the rest nuclei has decayed and $\frac{N_o}{4}$ radioactive nuclei are left; after three half-lives, $\frac{N_o}{8}$ are left and so on. Graphically, the decay of a radioactive element in terms of half-life is shown in Fig 20.8.

The SI unit of a radioactivity is the Becquerel (Bq). That is, $1\text{Bq} = 1\text{decay s}^{-1}$ (Radioactive decay per second). The radioactivity is also being measured in terms of curie (Ci), where $1\text{Ci} = 3.7\times 10^{10}$ decay s^{-1}

Thus $1\text{Ci}=3.7\times10^{10}\text{Bq}$...(20.10)

It may be noted that the half-life of each radioactive element is different as given in Table 20.3.

Table.20.3 Half-life of some radioactive nuclei.

Radioactive nuclide	Nuclide notation	Half-life
Lithium-8	${}^{8}_{3}Li$	0.838s
Krypton-89	${}^{89}_{36}Kr$	3.16 minutes
Sodium-24	${}^{24}_{11}Na$	15 hours
Iodine-131	${}^{131}_{53}I$	8 days
Cobalt-60	${}^{80}_{27}Co$	5.27 years
Radium-228	${}^{226}_{88}Ra$	1600 years
Uranium-235	${}^{235}_{92}U$	703 million years

Example 20.3

The half-life of carbon ${}^{14}_{6}C$ is 5.7×10^3 years, what fraction of a sample of ${}^{14}_{6}C$ will remain undecayed after a period of five half-life times.

Solution:

Half-life of ${}^{14}_{6}C$ $T_{1/2} = 5.7 \times 10^3$ years

Time for five half–lives = $t = 5\ T_{1/2} = 5(5.7\times10^3 y) = 2.85\times10^4 y$

According to the relation for half life

$$T_{1/2} = \frac{0.693}{\lambda}$$

$$\lambda = \frac{0.693}{5.7\times10^3 y}$$

$$\lambda = 1.216\times 10^{-4}\ y^{-1}$$

According to exponential decay law

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

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

Substitute the values of λ and t in above equation

$$\frac{N}{N_o} = e^{-(1.216\times10^{-4} y^{-1})(2.85\times10^4 y)}$$

$$\frac{N}{N_o} = e^{-3.4656} = 0.03125$$

This is the desired fraction.

Alternate Method:

Times	Activity
0	1
T½	0.5
2 T½	0.25

Time	Activity
3T½	0.125
4T½	0.0625
5 T½	0.03125

Hence 0.03125 (or 3.125%) of sample of $^{14}_{6}C$ will remain undecayed after a period of five half-lives.

20.7 RADIATIONS DETECTORS

Radiation cannot be detected directly by human senses. The radiations detection is possible only when they interact with the matter and there are various methods by which we can detect the interaction of radiation with matter, such as, ionization of atoms, scattering from atoms or absorbing by atoms. In this regard, there are several devices which have been developed for detecting radiations, but we will explain two of them which are being used most commonly.

(1) GM – Counter

(2) Solid State detector.

Geiger – Muller counter

G.M. counter is a device designed by Geiger and Muller, used for the detection and measurement of all types of radiations. It detects ionizing radiations such as alpha, beta particles and gamma rays using the ionization effect produced in a G.M. tube. The apparatus consists of two parts, the tube and the counter. The G.M. tube consists of a pair of electrodes surrounded by a gas. It consists of a sealed metal tube whose boundary acts as a cathode. The anode is in the form of a thin wire lying along the control axis of the tube as shown in Fig.20.9. The tube is filled with a suitable mixture of Argon gas and Bromine vapours at low pressure i.e., at about one tenth of the atmospheric pressure. The Argon gas is called the detecting gas and Bromine act as a quenching gas. A high potential difference of about 1000V is applied across the anode and cathode through a high resistance. This potential difference is slightly less than the potential difference which would produce continuous discharge in the tube.

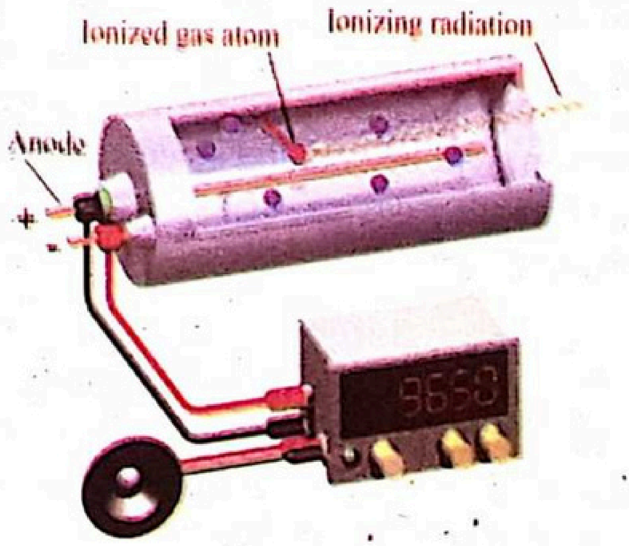


Fig.20.9. A schematic diagram of Geiger-Muller Counter.

When a radiation (or high energy particles) from a radioactive element enters into the tube through a thin window at the end, some of gas atoms are ionized. The electrons removed from these ionized gas atoms are attracted to the anode and positive ions towards cathode. The high potential difference between the anode and cathode accelerate the electrons and they collide with other atoms of gas, which produce further ionization. This secondary ionization results in an avalanche of electrons. The process produces a current pulse and is counted by a pulse counter.

On the other hand, further incoming particles cannot be counted, it is therefore, when the positive ions strike the cathode, secondary electrons are emitted from the surface. These electrons would be accelerated to give further spurious count. But it is represented by molecules of bromine gas, when they absorb the energy of the positive ions moving towards the cathode. Hence, bromine gas acts as a quenching agent and it is called quenching gas. The quenching gas must have an ionization potential lower than that of the principal gas (Argon gas).

G.M. counter can be used to determine the range or penetration power of ionizing particles. The reduction in the count rate by inserting metal plates of varying thickness between the source and the tube helps to estimate the penetration power of the incident radiation. Though Geiger Counter has ability to measure the accurate count, but it is not suitable for fast counting, because of its relative long dead time of the order of more than a million second which limit the counting rate to a few hundred count per second. If the particles are allowed to enter the tube at a faster rate, not all of them will be counted since some will arrive during the dead time. Alternately, we have another device such as a solid state detector which is fast enough, more efficient and accurate.

Solid state detector

A solid state detector is a semiconductor detector. It is used to detect, and fast counting of incident charged particles or photons. Its working is based on revere biasing in which electron hole pairs are formed by the incident particles which causes a current pulse to flow through the external circuit. It consists of PN-junction diode such that its two opposite sides are coated with a thin layer of gold as shown in fig 20.10.

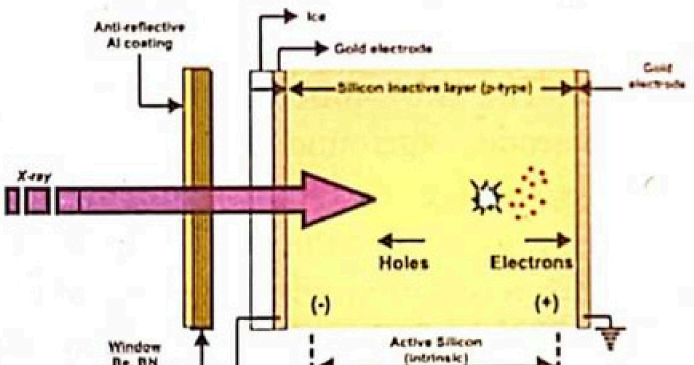
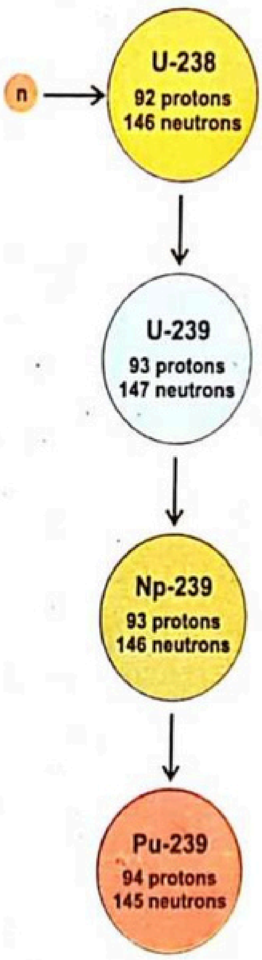


Fig.20.10. A schematic diagram of Solid State detector.

The thin gold layers make a good conducting contact with the external circuit. For radiation detection this device is connected in reverse biasing of the PN-junction. When the voltage is applied through the two conducting layers of gold then there is a large depletion region around the junction. The small current is due to only the flow of minority carries.

Now when the ionizing incident particles enter into PN-junction through the depletion region, then they form electron–hole pairs. These mobile charge carriers move towards their respective sides of the junction. This motion of charge carries (holes and electrons) produces a pulse of current which is amplified and measured with an electronic counter called scalar. In a typical device, the duration of the pulse is 10^{-8}s. The size of the pulse is found proportional to the energy of the incident particles. The energy needed to produce an electron hole pair is about 3eV to 9eV, which makes the device useful for detecting low energy particles. The collection time of the electrons and hole is much less than the gas filled counters and hence, a solid state defector can count very fast. It is small in size and operates at low voltage. The solid state detectors are more useful, for detecting α or β particles but specially designed detector can also be used for detecting high energy γ - rays.



A transmutation from the nucleus of $_{92}U^{238}$ into the nucleus of $_{94}Pu^{239}$ occurs in an induced nuclear reaction.

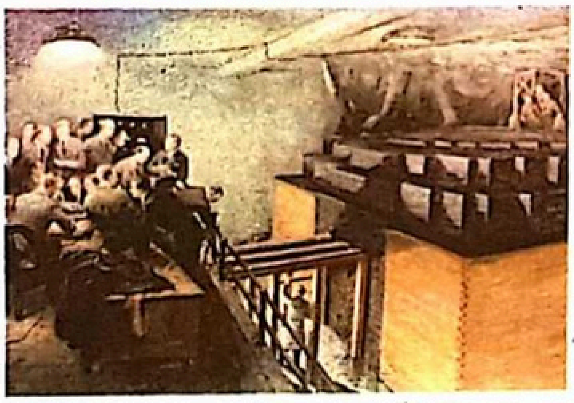
20.8 NUCLEAR REACTION

A nuclear reaction is a process in which two nuclear particles (two nuclei or a nucleus and a nucleon) interact to produce two or more nuclear particles or γ-rays (gamma rays). Or nuclear reaction is a process that occurs in an atomic nucleus, where a change occurs in a nucleus, such as a transformation of at least one nuclide to another. In the process of a nuclear reaction, when an element is converted to another by changing of its nucleus then such a conversion is called nuclear transmutation.

If 'a' is a nuclear particle 'X' is a target nucleus, 'Y' is resultant nucleus and 'b' is a emitted particle then the nuclear reaction can be represented by the following equation;

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

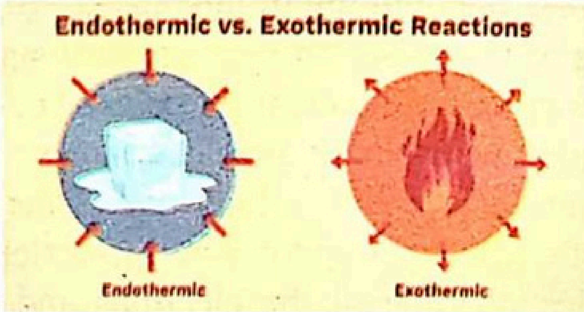
FIRST NUCLEAR REACTOR



An artist depiction of the setting in the sqush court beneath the stands at the University of Chicago's Stagg Field, where Enrico Fermi and his colleagues constructed the first nuclear reactor.

Rutherford, was the first who observed the nuclear reaction in 1919. He bombarded α-particles on a nitrogen (${}^{14}_{7}N$) then he got oxygen (${}^{17}_{8}O$) and emitted particle proton (${}^{1}_{1}H$) i.e.,

$${}^{14}_{7}N + {}^{4}_{2}He \rightarrow {}^{17}_{8}O + {}^{1}_{1}H$$



In a nuclear reaction charge number, mass number, energy, momentum all are conserved. The minimum energy required for a reaction to take place is called the threshold energy.

In nuclear reaction, energy is either absorbed or emitted which is called Q- value and it is equal to the mass defect. The value of Q is taken as positive when the energy is released, and its corresponding reaction is called exothermic. Similarly, the value of Q is taken as negative when the energy is absorbed, and its corresponding reaction is called endothermic. For example;

$${}^{1}_{1}H + {}^{7}_{3}Li \rightarrow {}^{4}_{2}He + {}^{4}_{2}He + 17.3MeV$$

In this reaction Q = + 17.3 MeV. Similarly,

$${}^{4}_{2}He - {}^{17}_{7}N \rightarrow {}^{17}_{8}O + {}^{1}_{1}H + 1.19MeV$$

In this reaction Q = - 1.19 MeV

There are two main kinds of nuclear reaction:

I Nuclear fission reaction II Nuclear fusion reaction

20.9 NUCLEAR FISSION

A process in which a heavy nucleus splits into two smaller nuclei with the release of energy is known as nuclear fission.

Nuclear fission was discovered in 1938 by Otto Hahn and Fritz strassman pursuing earlier work by Fermi. They bombarded uranium nucleus ${}^{238}_{92}U$ with a slow moving neutron and observed that the uranium nucleus had split into two lighter nuclei Barium (${}^{141}_{56}Ba$) and Krypton (${}^{92}_{36}Kr$) with emission of slow neutrons (typically two or three). On average, 2.5 neutrons are released per event as shown in Fig.20.11. They also observed that approximately 200MeV of energy was released in each fission reaction. The equation of above fission reaction is expressed as:

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

In nuclear fission, the absorption of the incident neutron creates an unstable nucleus and can change to a lower–energy configuration by splitting into two lighter nuclei.

The combined mass of the daughter nuclei is less than the mass of the parent nucleus and such difference in mass is called the mass defect. If we multiply this mass deflect by ^2C then it becomes equal to the binding energy of the nucleus. This binding energy must be released when the parent nucleus is splitted into two daughter small nuclei.

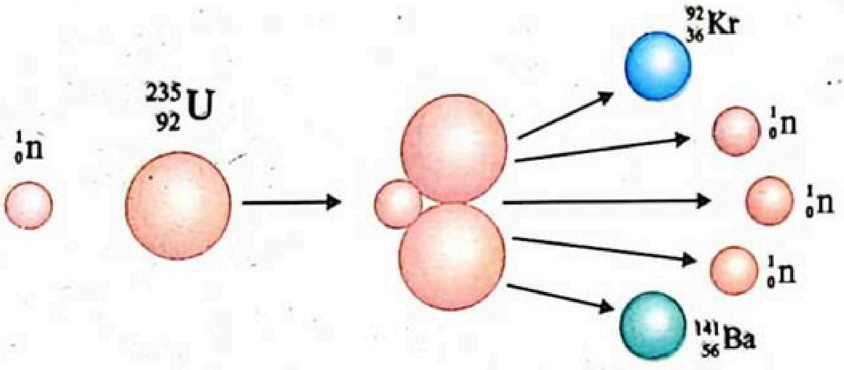


Fig.20.11. A schematic diagram for a nuclear fission reaction.

The experimental results show that such reaction releases large amount of energy. We have studied the graph between the binding energy per nucleon and mass number which shows that the intermediate elements in the periodic table have higher binding energy per nucleon. Whereas, the binding energy per nucleon of the heavy elements is little less i.e. the binding energy per nucleon for $^{235}_{92}U$ is 7.6 MeV per nucleon and 8.5 MeV per nucleon for Barium ($^{141}_{56}Ba$) and Krypton ($^{92}_{36}Kr$). It means that if the uranium $^{235}_{92}U$ nucleus is splitted into two nuclei of $^{141}_{56}Ba$ and $^{92}_{36}Kr$ then the amount of energy released will be $8.5 - 7.6 = 0.9$ MeV per nucleon. Thus, total energy $235 \times 0.9 = 200$ MeV is released in uranium fission reaction.

20.9.1 Chain Reaction

A process in which an induced fission reaction continues till all the atoms of the radioactive material have gone through the fission reaction is called chain reaction.

We have studied that when a slow moving neutron is bombarded at the nucleus of uranium-235 it undergoes fission. Beside the daughter nuclei, two or three neutrons are also released in this fission reaction. These neutrons can further induce fission in the other nuclei. This is the basis of the self-sustaining chain reaction as shown in Fig.20.12. If at least one neutron on average, results in another fission, the chain reaction is said to be critical. Because a sufficient amount of mass is required to increase the probability of a neutron being absorbed, a critical mass of fissionable material must be present. Similarly, if less than one neutron, on average, produces another fission, the reaction is termed as sub critical. If more than one neutron, on average, produces another fission, the reaction is said to be supercritical. An atomic bomb is an extreme example of a supercritical fission chain reaction.

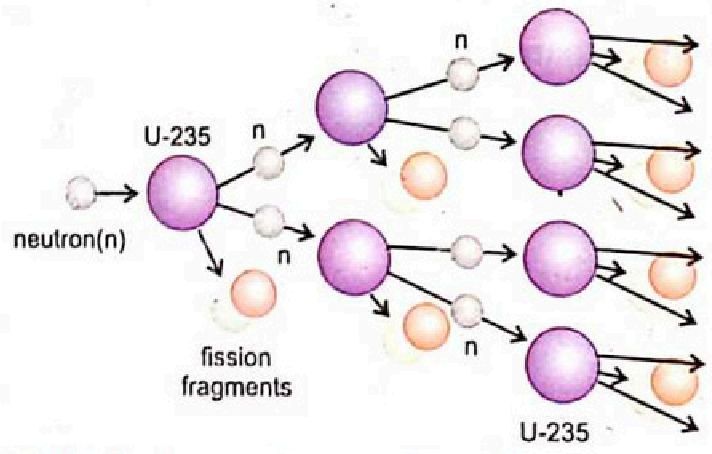


Fig.20.12. A schematic diagram of Chain fission reaction.

In chain reaction, the process proceeds very quickly and in very short interval of time, the whole radioactive element undergoes fission. The observations show that if the chain reaction is not controlled, it can result in a violent explosion with the sudden release of an enormous amount of energy. However, when the reaction is controlled, the released energy can be used for constructive purpose for example energy released during the process is converted into electrical energy.

20.9.2 Nuclear Reactor

A nuclear reactor is a system used to initiate and control nuclear chain reaction to produce heat. This heat energy is used to generate steam, which operates a turbine and turns an electrical generator. For example, when fission reaction is induced, then

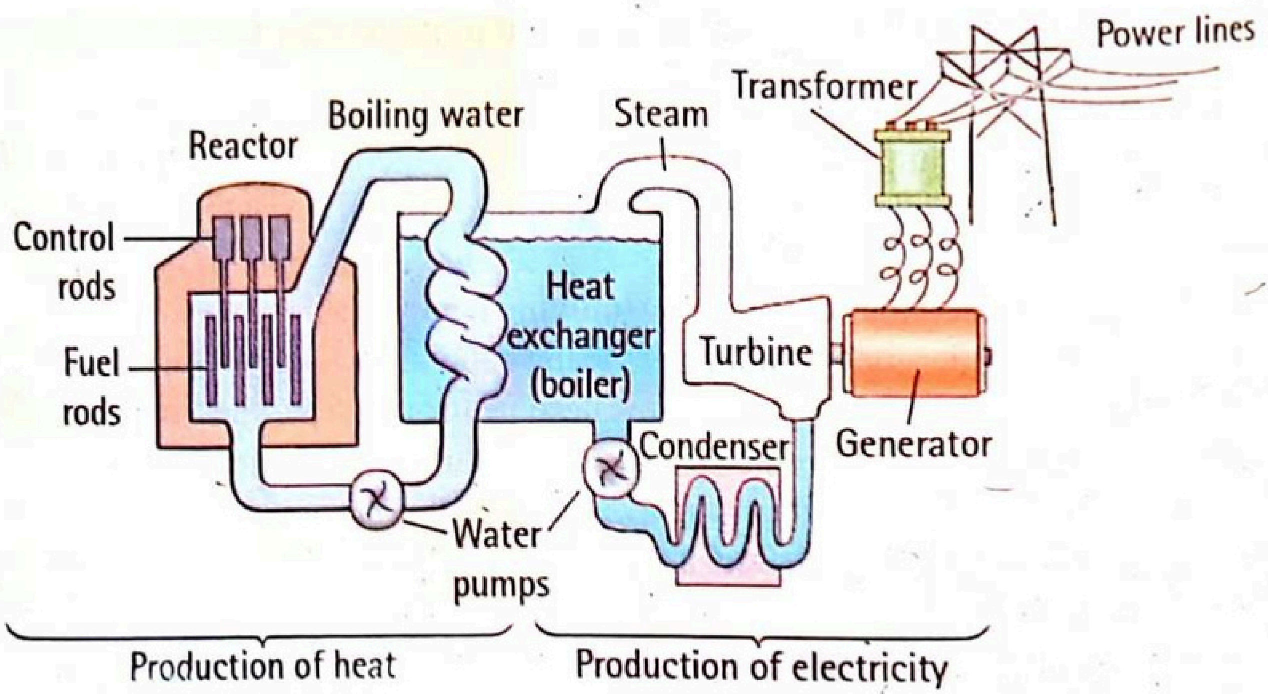


Fig.20.13. A schematic arrangement of nuclear power plant.

energy at the rate of 200 MeV per fission is produced. This energy appears in the form of kinetic energy of the fission fragment, these fast moving fragments besides colliding with one another also collide with the uranium atoms. In this way, their kinetic energy gets transformed into heat energy. This heat energy is used the produce steam which in turn rotates the turbine and then turbine operates generator to produce electricity. The whole process of the nuclear power plant is shown in Fig.20.13.

The nuclear reactor was introduced in 1942 by Enrico Fermi and his colleague. They used uranium as the fuel. A controlled nuclear reactor has the following important parts.

Fissionable fuel

Most reactors in operation use uranium as fuel. Natural uranium contains 0.7% of the $^{235}_{92}U$ isotope which is fissile. However, the remaining 99.3% of $^{238}_{92}U$ which does not contribute directly to fission process. It is noted that if the neutrons are slowed down, then they are much more likely to be captured by $^{235}_{92}U$ and induce fission. For this reason, the quantity of fuel $^{235}_{92}U$ is increased a few percent. The nuclear fuel is sealed in long, narrow metal aluminum tubes called fuel rods.

Moderator to slow down neutrons

The neutrons emitted by fission are moving very fast. At this high speed, the chance of a neutron being captured by another nucleus $^{235}_{92}U$ is very small, therefore, the high speed neutrons are slowed down by collision with the nuclei in the surrounding material called the moderator, so they are much more likely to cause further fissions. In nuclear power plants, heavy water or graphite is often used as moderators.

Control rods

Besides the moderator, there is an arrangement of control rods made of cadmium or boron which are very efficient in the absorption of fast moving neutrons without undergoing any additional reaction. Thus, the rate of reaction is controlled by inserting or withdrawing control rods in the core of the reactor.

Coolant

The fission reaction produces heat in the core of the reactor. This heat causes rise of temperature of the water contained in the primary loop which is maintained at high pressure to refrain the water from boiling. The hot water is pumped through a heat exchanger, where the internal energy of the water is transferred by conduction to the water contained in the secondary loop. The hot water in the secondary loop is converted to steam, which does work to drive a turbine generator system to produce electric power.

Protective shield

In a nuclear reactor, there are many types of harmful radiations emitted which are dangerous for all living things. In order to protect from these radiations, the reactor is surrounded by a massive biological shield.

Kinds of reactors

Basically, there are two kinds of nuclear reactors such as:

(i) Thermal or slowdown reactor (ii) Fast reactor

The neutrons which are slowed down by using moderator called thermal neutrons. These thermal neutrons can easily capture by the nucleus of $^{235}_{92}U$ to induces a fission reaction. Such reaction is called thermal or slowed down reaction, its corresponding reactor is called thermal reactor.

On the other hand, the fast moving neutrons can capture by the nucleus of $^{238}_{92}U$ to create a fission reactions, such reaction is called fast reaction. Some neutrons are allowed to escape and under suitable conditions they will be captured by nuclei of $^{238}_{92}U$ which are converted to plutonium ^{239}Pu i.e.,

$$^{1}_{0}n + ^{238}_{92}U \rightarrow ^{239}_{93}Np + ^{0}_{-1}e$$

$$^{239}_{93}Np \rightarrow ^{239}_{94}Pu + ^{0}_{-1}e$$

As more plutonium can be produced then the required to enrich the fuel in the core, so these are called fast reactors. In fast reactor, the moderator is being used. Because the nuclei of plutonium are fissioned by fast moving neutrons. The core of fast reactor contains a mixture of plutonium and uranium dioxide surrounded by a blanket of $^{238}_{92}U$.

20.10 NUCLEAR FUSION

A process in which two lighter nuclei fuse together to form a heavier nucleus and release a large amount of energy is known as nuclear fusion reaction. In this process, the mass of the resultant nucleus is always less than the sum of masses of the original nuclei which are fused. The missing mass is converted into energy which is released during the reaction. Though fusion

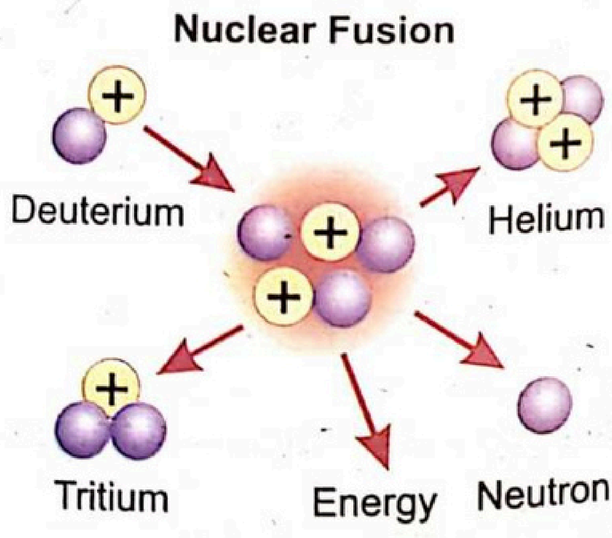


Fig.20.14. A schematic diagram of nuclear fusion reaction.

reactions release energy for the same reason as fission reaction, but the process of fusion reaction is essentially the opposite of the nuclear fission. The energy released per unit mass in nuclear fusion is more than the energy released per unit mass in nuclear fission. For example we have studied the graph between binding energy per nucleon and mass number, where the nuclei near A=56 have the highest binding energy per nucleon, therefore, when two light nuclei are fused together to form a heavy nucleus whose mass number 'A' is less than 50, then there will be huge amount of energy released. The observation shows that the most energy is released if two isotopes of hydrogen, ${}_1H^2$ and ${}_1H^3$ are fused together as shown in Fig.20.14 under the following reaction;

$$ {}_1^2H + {}_1^3H \rightarrow {}_2^4He + {}_0^1n + 17.6MeV $$

In this reaction Q-values is 17.6 Mev. Due to the strong binding of ${}_2^4He$, there is release of energy of about 3.5 MeV per nucleon in fusion reaction. On the other hand, 0.7 MeV per nucleon is released in fission reaction. Thus, this result shows that in nuclear fusion process, lighter nuclei fusing to form a heavier nucleus is a more prolific source of energy. But it is comparatively more difficult to produce fusion because of large electrostatic repulsive force between the two nuclei. The force becomes stronger, when the nuclei are brought very close for fusion. To overcome this repulsive force, the two nuclei must have high speed or kinetic energies. This high speed can be achieved by increasing the temperature. Typically, the temperature of order 10^8K is required for fusion to induce. At such a high temperature, a substance is a completely ionized plasma. This means a fusion reactor's fuel is in the form of plasma.

> ***FOR YOUR INFORMATION***
>
> The energy released in fusing a pair of hydrogen nuclei is less than in fissioning a uranium nucleus. But because there are more atoms in a gram of hydrogen than in a gram of uranium, gram for gram, the fusion of hydrogen releases several times more energy as the fission of uranium.

The induced fusion by high temperature is called thermonuclear fusion. Such a high temperature can be achieved by explosion of an atom bomb for short time.

Nuclear reaction in the sun

The sun is a star and is mostly composed of the elements hydrogen (75%), helium (25%) and other element (less than 0.1 %). The sun continuously generates its energy in the form of light and heat by nuclear fusion of hydrogen nuclei into helium nucleus. In its core, the Sun fuses 500 million metric tons of hydrogen each second. The temperature of its core is about 20 million degree Celsius. While its surface temperature is about 5 million degree Celsius. Most of its energy is due to the fusion of hydrogen to a nucleus of deuteron. Such reaction can be expressed as;

$$ {}_1^1H + {}_1^1H \rightarrow {}_1^2H + {}_1^0e + \text{energy} $$

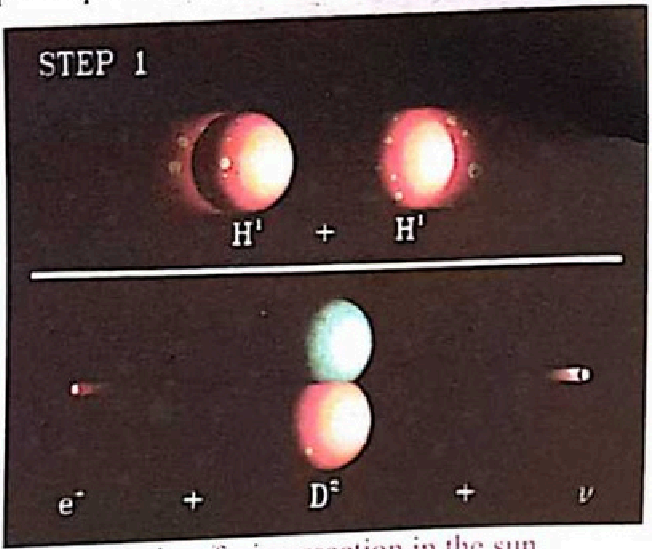
Similarly, the fusion reaction of deuteron ($^{2}_{1}H$) with the hydrogen ($^{1}_{1}H$) forms a helium ($^{3}_{2}He$) nucleus i.e.,

$$^{2}_{1}H + ^{1}_{1}H \rightarrow ^{3}_{2}He + \text{energy}$$

Now at the final stage, the fusion reaction of two nuclei of helium ($^{3}_{2}He$) is is represented by the following nuclear reaction.

$$^{3}_{2}He + ^{3}_{2}He \rightarrow ^{4}_{2}He + ^{1}_{1}H + ^{1}_{1}H + \text{energy}$$

This reaction shows that there are six hydrogen atoms take part in the reaction. Four hydrogen atoms have formed a helium nucleus and two hydrogen atoms are surplus. It has been measured that in the hydrogen-hydrogen reaction, there is a 25.7MeV energy is generated at the rate 6.4 MeV per nucleon which is quite a large amount of energy as compared to the energy obtained per nucleon from a fission reaction.



Nuclear fusion reaction in the sun.

20.11 RADIATION EXPOSURE

We have observed the detection of radiations using various instruments, like G.M tube etc. The radiations can also be detected in the open environment even when there is no radioactive source present near the instrument. This is due to background radiations i.e., the radiation which exist around us in the absence of deliberate radiation sources. Natural sources of background radiation include:

> ***FOR YOUR INFORMATION***
> Background radiation refers to radiation that is always present. It comes from sources such as the Sun, space, soil, living organisms, medical procedures and the materials used in buildings.

cosmic rays - radiation that reaches the Earth from space,
rocks and soil - some rocks are radioactive and give off radioactive radon gas,
living things - plants absorb radioactive materials from the soil and these are passed onwards through the food chain.

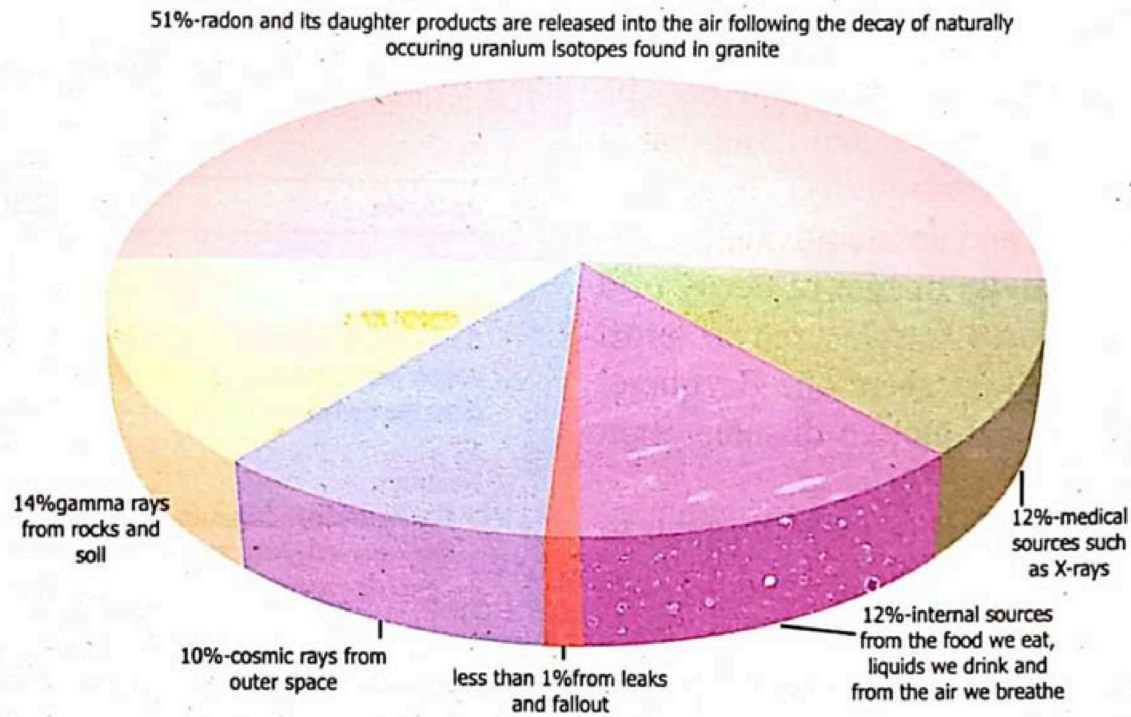
There are both low and high level background radiations which are due to the natural sources. Radiation exposure is a measure of the ionization of air due to ionizing radiation from high-energy photons (i.e. X-rays and gamma rays).

Instead of natural sources, the radiations exposure is also due to the human activities, such as the radiations from some materials used in building which contains some radioisotopes.

The X-rays and other radiation used in the medical diagnosis and therapeutic, radiation from burning of toxic materials or fuel in industries etc. are also sources of background radiation.

Low level background radiations from natural sources are being considered to be harmless, whereas, high level radiation exposure causes damage to any material, including the material that compose our bodies. Radiation damage is the effect of ionizing radiation on living things i.e. humans, animals and plants. Radiation exposure to even small amounts over a long time, raises your risk of cancer. One of the most common types of radiation damage to humans is due to the ultraviolet rays in sunlight. These lead to sunburn and tanning of skin. Though most of the sun's ultraviolet rays are absorbed by the ozone in the upper atmosphere. But it has been observed that excessive release of chemicals in atmosphere such as chlorofluorocarbon (CFC) deplete the ozone layer.

If the exposure is measured in terms of Sievert (Sv), then it has been estimated that, each person experiences a background radiation dose of 1mSv in a year, a lifetime exposure would reduce our life expectancy about 40 days.



Explaining the radiation from various sources that absorbed by a person.

20.12 BIOLOGICAL EFFECT OF RADIATIONS

Under the term radiation we include (α,β particles) and electromagnetic radiations (γ-rays x-rays, UV etc). These radiations have a great interaction with living organisms. When these radiations interact with the atoms of the matter, they may cause ionization which can damage the cells of the living tissues. The degree and type of damage depend on several factors, such as; strength and energy of the radiations as well as the property of the matter. For example, alpha particles cause extensive damage but have small penetration power. The neutrons penetrate deeper, causing significant damage. Gamma rays are high energy photons that can cause severe damage.

It is a well-known fact that excessive exposure to radiations can cause very severe illness or death by a variety of mechanism including alternations of genetic material and destruction of the components in bone marrow that produce red blood cells, the different biological effects of radiations can be classified into two classes; somatic effect and genetic effect.

Somatic effect is a radiation damage to any cell such as, skin cells, lung cells etc. but the productive cells are exempted from it. Somatic effect causes of cancer or seriously alter the characteristics of specific organisms. On the other hand, the genetic effect is a radiation damage to only reproductive cells. Due to damage the genes in the reproductive cells, genetic effect causes defective offspring or mutation.

20.13 MEASUREMENT OF RADIATIONS EXPOSURE AND DOSE

The effects of radiation can be measured using interrelated units that is in terms of radioactivity, exposure, absorbed dose, and dose equivalent.

The activity or rate of decay of a radioactive source is measured in terms of Becquerel (Bq), where one Becquerel is defined as, one atomic disintegration per second.

Its larger unit is curie (ci) which equals to 3.7×10^{10} atomic disintegration per second.

Table.20.4 Relative biological effectiveness (RBE)

Radiation	RBE
X-rays	1
Gamma rays	1
Beta particles	1
Alpha particles (into the body)	10 to 20
Neutrons:	
For immediate radiation injury	1
For cataracts, leukemia and genetic changes	4 to 10

Similarly, the exposure of X-rays and γ - rays are measured in term of roentgen (R), where the quantity of radiation which produces of 2.08×10^{9} ion pairs in 1 $cm^3$of dry air is known as one roentgen.

On the other hand, the effect of radiation on an absorbing body, which relates to a quantity called absorbed dose (D). It is the amount of energy absorbed from ionizing radiation per unit mass 'm' of the absorbing body, i.e.,

$$\text{Absorbed dose(D)} = \frac{\text{absorbed energy(E)}}{\text{Unit mass(m)}}$$

The SI unit of absorbed dose is gray (Gy) equals to the absorption of one joule of radiation energy per kilogram (1J per kg) of matter.
Another common unit for absorbed dose is rad. (radiation absorbed dose) 1 rad = 0.01 J kg^{-1} = 0.01 Gy.

The analysis shows that different kinds of radiation cause different biological effects, even if the absorbed dose is the same. For example, for the same absorbed dose, α-particles are 20 times more damaging than x-rays. This variation can be described by introducing the quality factor (QF). Some time, it is called the relative biological effectiveness (RBE) which is assigned to each type of radiation.

Table.20.5 Average radiation doses from a number of common sources of ionizing radiation.

Types of Exposure	mSv
Watching television for a year	10
Radiation from nuclear power stations for a year.	10
Wearing a radioactive luminous watch for a year (now not very common)	30
Having a chest X-ray	200
Radiation from a brick house per year	750
Maximum dose allowed to general public from artificial sources per year	1000
Working for a month in a uranium mine	1000
Typical dose received by a member of the general public in a year from all sources	2500
Maximum dose allowed to workers exposed to radiation per year.	50000

To measure the biological effect caused by exposure to radiation, we calculate the biologically equivalent dose (De) and it is defined as the product of absorbed dose and RBE. i.e.,

$$De = D \times RBE$$

The SI unit for biologically equivalent dose is Sievert (Sv)
where $1\ Sv = 1\ Gy \times RBE$

Another unit of biologically equivalent dose is rem (roentgen equivalent in men)

$$1\ rem = 0.01\ Sv$$

20.14 BIOLOGICAL AND MEDICAL USES OF RADIATIONS

Radiations are widely used in medicine, diagnostic examination, biological research and education for a range of purposes. We will explain a few of them, such as radiation therapy, diagnosis of diseases and tracer techniques.

I Radiation therapy

Radiation therapy is one of the most useful application of nuclear physics. It is used in cancer treatment as it works by destroying cancer cells and damaging a cancer cell's DNA so that it stops dividing and growing. The idea of radiation therapy is to supply enough radiation to destroy the intentional

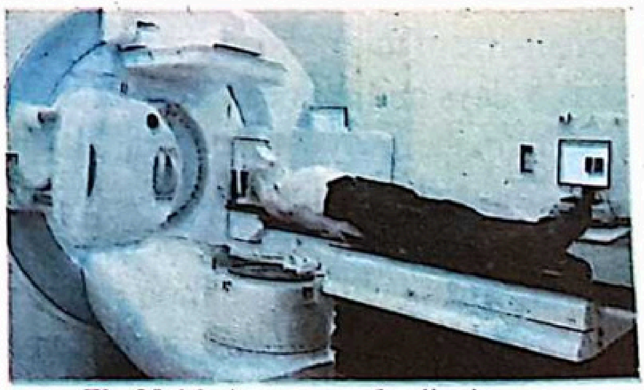


Fig.20.16. A process of radio therapy.

selective tissue such as tumors. The radiations can be applied internally or externally by using various mechanism. In case of the internal treatment, the radiation sources are placed very close to the tumor site, or sometimes they may be injected into the tumor. Similarly, in case of external treatment the sources are placed at a distance from the body and the radiation are directed toward the cancer site of the body. In this method a narrow beam of X- rays or γ- rays from Co^{60} is widely used as shown in Fig.20.16.

II Diagnosis of diseases

There are several nuclear medicine procedures for diagnostics and treatment of diseases. For example, some chemicals are absorbed by the organs, i.e iodine is absorbed by thyroid, phosphorus and strontium by bones, cobalt by liver and so many other. All these can serve as tracer, and they provide information about the functioning of a body's specific organs, or to treat diseases, for example, iodine is being used to check whether a person's thyroid gland is working properly. Similarly, radioactive isotope sodium 24 is being used to monitor the circulation of blood in the body. Liver gallbladder problems can be diagnosed using hepatobiliary iminodiacetic acid, technetium-99 is being used to diagnose cancer, embolisms (heart diseases) and other pathologies.

III Tracer techniques

Many radioactive isotopes are used as tracers, to follow the path that various chemicals take in the body. For example, it has already been explained that iodine, a nutrient needed by the human body is obtained largely through the intake of iodized salt and seafood. Nearly 70-80% of the iodine is stored in the thyroid. A small quantity of radioactive sodium iodide containing I-131 is fed or injected into the patient. The half-life of this radioactive isotopes I-131 is 8 days and it is carried directly to the point in the body where its radiation is needed in the treatment of thyroid cancer.

Radiation Counter

Similarly, radioactive sodium in the form of a solution is injected into a vein of an arm or leg and the time at which the radio isotope reaches at another part of the body is detected with a radiation counter. The elapsed time is a good indication of the absence or presence of constrictions in the circulatory system.

In the field of agriculture, tracers are being used to determine the best method of fertilizing a plant. A certain element in a fertilizer such as nitrogen can be tagged with one of its radioactive isotopes.

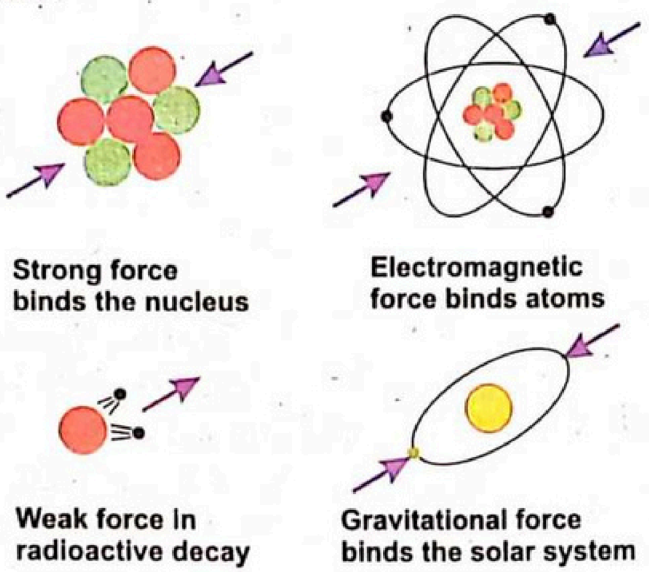
To measure pesticide levels, a pesticide can be identified with a radioisotope, such as chlorine-36. The tracer technique has also helped to explain the process of photosynthesis.

20.15 BASIC FORCES OF NATURE

All the natural phenomena or interaction can be described in terms of by the existed forces of nature. The four fundamental forces of nature are Gravitational force, Weak nuclear force, Electromagnetic force and Strong nuclear force.

> ***DO YOU KNOW***
> Without the nuclear strong force – strong interaction – there would be no atoms beyond hydrogen.

The strong nuclear force is an attractive force between nucleons, and it holds the neutrons and protons together in the nucleus. The nuclear force has a very short range and is negligible for separation distances between nucleons greater than approximately 10^{-15} m.



Four basic natural forces.

The electromagnetic force is the unification of the electric force and the magnetic force. These two forces were unified by Faraday and Maxwell. The electromagnetic force binds atoms and molecules together to form ordinary matter. It has a long range. It has a strength of approximately 10^{-2} times that of the nuclear force.

The weak nuclear force has a short range and it is much weaker than the strong nuclear force. Its strength is only about 10^{-5} times that of the strong nuclear force. The weak force produces instability in certain nuclei and hence it is responsible for decay processes.

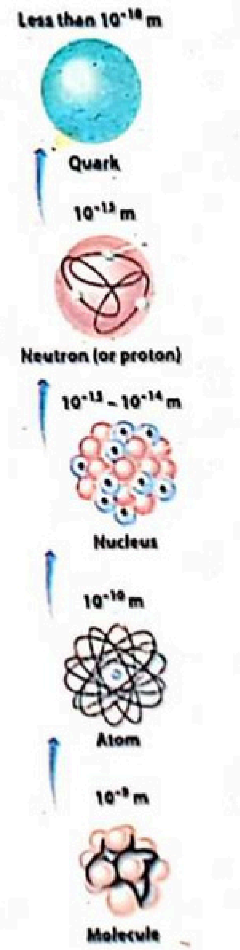
The gravitational force is an attractive force that acts on all forms of masses. It is a long range force. i.e., it has a strength of only about 10^{-39} times that of the nuclear force. The gravitational force holds the planets in their orbit around the Sun, stars and galaxies together in the universe. Its effect on elementary particles is negligible.

20.16 ELEMENTARY PARTICLES AND THEIR CLASSIFICATION

The idea that all matter is composed of elementary particles has a long history. In the early age about 400 B.C., the Greek philosophers believed that matter is made of indivisible particles. They were named them as atoms. But at the end of the 19th century, when the electron, proton and neutron were discovered, then these particles were considered as the fundamental constituents of matter. After 1935, the observations of several experiments pointed out that protons and neutrons are made up of extremely tiny particles called quarks. So the scientists had recognized that the protons and neutrons could not be the fundamental particles of the matter. Until the 1960s, there were a great number of subatomic particles including the two elementary particles were also discovered. Thus, according to the current theory, all matters are constructed from only the two families of particles: quarks and leptons. They are considered as elementary particles. Now all the sub-atomic particles can be classified into two classes.

Fermions (Quarks, Leptons)

Boson (gauge bosons and the Higgs bosons)



The building block of matter.

All these particles can be explained on the basis of the fundamental force between them as well as on the value of their spin momentum. e.g., the particles with half integral spin are called fermions and those with integral spin are called bosons.

The word Leptons is derived from the Greek word 'Leptos' which means thin or light. The leptons are the elementary particles and have no measurable size or internal structure. There are six types of leptons: electron, electron neutrino, muon, muon neutrino, tau and tau neutrino. For each of these, the neutrino brand carries a neutral charge, while their counterparts all have a negative charge. All leptons have weak and electromagnetic interactions. Since the spin of all leptons is equal to ½, so they are also called fermions.

Table.20.6. Classification of elementary particles.

Particle	Generic Name	Spin	Occupation Number
Electron	Fermion	1/2	1
Positron	Fermion	1/2	1
Proton	Fermion	1/2	1
Neutron	Fermion	1/2	1
Muon	Fermion	1/2	1
Quark	Parafermion	1/2	3
α particle	Boson	0	∞
He atom (ground state)	Boson	0	∞
π meson	Boson	0	∞
Photon	Boson	1	∞
Deuteron	Boson	1	∞

Boson is a particle that has a whole number spin and it carries energy. A photon is an example of a boson as it has a spin of 1.

POINT TO PONDER

Which quarks and laptons are found in an atom?

Hadrons derived from the Greek word 'hadros' means strong or robust. They are not considered elementary particles. Because they are composed of two or more quarks, i.e., hadron is a composite particle. The protons and neutrons in the nucleus of an atom are composite particles, as they are composed of quarks. However, electrons orbiting the nucleus are not composite particles. Hadrons have strong nuclear interaction. There are two classes of hadron's i.e., mesons and baryons. Mesons derived from the Greek word "meso" means middle. i.e., the mass of mesons lies between the masses of the electrons and the protons. Mesons have not only weak but also strong nuclear interaction. The spin of all the mesons is equal to 0 or 1, so that they are called bosons. Charged mesons decay into electrons and neutrinos while uncharged mesons may decay to photons.

FOR YOUR INFORMATION

The Big European Bubble Chamber (BEBC) at CERN, near Geneva typical of the large bubble chambers used in the 1970s to study particles produced by high-energy accelerators.

Baryons, the name baryon means heavy in Greek. All baryons have strong nuclear interaction and their spin is equal to $\frac{1}{2}$ or $\frac{3}{2}$, so that baryons are fermions. e.g., protons and neutrons are Baryons. All Baryons except protons are unstable and they decay in such a way that the end products include a proton.

SUMMARY

- **Atomic number:** The number of proton, inside the nucleus or the number of electrons in the allowed orbits around the nucleus is called atomic number. It is represented by 'Z'
- **Mass number:** The total number of protons and neutrons inside the nucleus is called atomic mass number it is represented by A.
- **Nucleons:** The protons and neutrons in a nucleus are collectively called nucleons.
- **Isotopes:** The nuclei of an element that have the same atomic number Z, but have different mass number A are called isotopes.

- **Isobars**: The nuclei that have the same mass number A, but have different the atomic numbers 'Z' are called Isobars.
- **Mass Spectrograph:** A process in which the isotopes of any element are separated is called mass spectrograph.
- **Mass defect:** The difference in mass between the mass of the nucleus and the sum of masses of its constituent nucleons is known as mass defect.
- **Binding energy:** The amount of energy that holds the nucleons in a nucleus or energy needed to break down the nucleus into its constituents is called binding energy
- **Radioactive elements:** The elements whose atomic numbers are greater than 82 are unstable and emit radiations. These elements are called radioactive elements.
- **Radio activity:** The process of spontaneous emission of radiations $(\alpha, \beta \text{ and } \gamma)$ from a radioactive element is called radioactivity.
- **Half-life:** The time in which half of the given number of radioactive nuclei decay is known as half-life of radioactive Elements.
- **Geiger – Muller Counter:** It is a device used to detect and count the ionizing particles.
- **Nuclear reaction:** A process in which a change occurs in a nucleus by approaching a nuclear particle is called nuclear reaction.
- **Fission reaction:** A reaction in which a heavy nucleus splits into two lighter nuclei with release of energy is called fission reaction.
- **Fusion reaction:** A reaction in which two light nuclei are fused to form a heavy nucleus with release of energy is called fusion reaction.
- **Elementary Particles:** The particles which made up the other sub atomic particles are known as elementary particles, these particles can be classified into two classes
  (1) Fermions (2) Bosons

EXERCISE

Multiple Choice Question.

1. Proton was discovered by
   (a) J.J Thomson (b) Chad wick (c) Ruther ford (d) Neil Bohr
2. Which of the following particle was discovered by Chadwick?
   (a) Electron (b) Proton (c) Neutron (d) Photon
3. Which of the following particle has the greatest mass?
   (a) Electron (b) Positron (c) Proton (d) Photon
4. The energy equivalent of one atomic mass unit (a.m.u) is
   (a) 1.6×10^{-19}J (b) 1.6×10^{19}J (c) 931 MeV (d) 9.31 MeV

5. The number of neutrons in the nucleus of $^{235}_{92}U$ is

(a) 92 (b) 143 (c) 235 (d) 327

6. The Nuclei $^{22}_{11}Na$ and $^{22}_{10}Ne$ are known as

(a) Isotopes (b) Isobars (c) Isotones (d) Isomers

7. Which of the following nucleus has the highest value of binding energy?

(a) $^{4}_{2}He$ (b) $^{56}_{26}Fe$ (c) $^{141}_{56}Ba$ (d) $^{235}_{92}U$

8. The binding energy per nucleon remains constant at

(a) 6 MeV per nucleon (b) 7 MeV per nucleon

(c) 8 MeV per nucleon (d) 9 MeV per nucleon

9. The nuclei have maximum binding energy per nucleon whose mass number lies between

(a) 50-60 (b) 100-150 (c) 150-200 (d) 200-235

10. Curie is the unit of

(a) Energy (b) Intensity (c) Radioactivity (d) Half life

11. The rate of decay depends upon

(a) Pressure (b) Temperature

(c) Intensity (d) Number of nuclei

12. Which rays have highest ionization power?

(a) α - rays (b) β - rays (c) γ - rays (d) X - rays

13. A radioactive element will decay when its atomic number is

(a) Equal to 82 (b) Less than 82

(c) Greater than 82 (d) does not depend upon number

14. When a radioactive element emits a β-particle the mass number of the atom will be

(a) increased by 1 (b) decreased by 1

(c) increased by 2 (d) remain the same

15. The unit of decay constant 'λ' is

(a) m (b) m^{-1} (c) s (d) s^{-1}

16. The energy released per fission reaction is

(a) 0.85 MeV (b) 28 MeV (c) 150 MeV (d) 200 MeV

17. Moderator used in a nuclear reactor is

(a) Ice (b) heavy water (c) boron rods (d) cadmium rods

18. The energy released in a fusion reaction is

(a) 0.85 MeV (b) 28 MeV (c) 200 MeV (d) 400 MeV

19. On average, the number of neutrons emitted per fission is

(a) 2 (b) 2.5 (c) 3 (d) 3.5

20. Which force has the negligible effect on elementary particles?
(a) Strong nuclear force (b) Weak nuclear force
(c) electromagnetic force (d) gravitational force

21. The particles with half integral spin are known as
(a) Fermion (b) Photon (c) Bosons (d) Meson

22. Which of the following particles have the highest value of mass?
(a) Photons (b) leptons (c) mesons (d) Baryons

SHORT QUESTIONS

1. Distinguish between atomic number and mass number.
2. What do you know about the atomic mass unit?
3. Why carbon atom is being used as a reference for atomic mass unit?
4. Differentiate between
(a) Isotopes and Isobars (b) Isotones and Isomers
5. Why the mass of the nucleus is always less than the sum of masses of its nucleons?
6. Describe briefly binding energy.
7. How does stability of a nucleus depend upon the binding energy per nucleon?
8. Express the relation between Curie and Becquerel.
9. What do you know about the radioactive elements?
10. Explain the conversion of parent nucleus into the daughter nucleus.
11. Why α - particles, β - particles and γ - rays are not emitted simultaneously?
12. What is the decay constant?
13. What is meant by nucleus transmutation?
14. What is the role of moderator in the nuclear reactor?
15. Why fusion reaction releases more energy per nucleon than fission reaction?
16. Why a fast reactor does not require moderator?
17. Why fusion reaction is more difficult than fission reaction?
18. What is process by which the Sun generates its energy?
19. How many forces of nature are there?
20. Distinguish between elementary and sub atomic particles.
21. What is the difference between Fermions and Bosons?
22. How many hadrons are there?

COMPREHENSIVE QUESTIONS

1. State and explain the composition of a nucleus of an atom with all its properties.
2. What do you know about the isotopes, isobars, isotone and isomers? Explain all them with examples.
3. Define mass spectrograph. How can we separate the isotopes of an element by this method?

4. What do you know about mass defect and binding energy? Discuss graphically, the relation between mass defect and binding energy.
5. State and explain radioactivity with all its properties.
6. Discuss various laws of radioactivity. Also derive equation for decay of a radioactive element.
7. State and explain the functions and working principles of the following two radiations detectors.
   1) GM-counter 2) Solid state detector
8. Discuss nuclear reaction with all its kinds.
9. State and explain nuclear fission and chain reaction. Also discuss the various parts of the nuclear reactor.
10. What is nucleus fusion reaction? Explain nuclear fusion reaction in the Sun.
11. State and explain radiation exposure and various methods used for its measurement.
12. How can we diagnose and treat the fatal diseases like cancer by using radioactive radiations?
13. What do you know about the basic forces of nature? Explain their interact
14. Discuss the elementary particles and their classifications.

NUMERICAL PROBLEMS

1. Calculate mass defect, binding energy and binding energy per nucleon of $^{14}_{7}N$. The mass of $^{14}_{7}N$ nucleus is 14.003074u. **(0.108513u, 101MeV and 7.2MeV)**
2. The half-life of $^{92}_{36}Kr$ is 3.16 minutes. Find its decay constant. **($3.66\times10^{-3}\ s^{-1}$)**
3. The half-life of radium is 1600 years. How many radium atoms decay in 1s in a 1g sample of radium? (Mass number of radium is 220 kg/k mol) **(Practically no atom of radium-220 will decay in 1s)**
4. The half-life of $^{14}_{6}C$ is 5700 years. What fraction of a sample of ^{14}C will remain unchanged after a period of five half-lives? **(0.0315)**
5. Determine the energy associated with the following nuclear reaction.

$$^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H$$

The relevant nuclear masses are:

$m\left(^{4}_{7}N\right) = 14.003074u$, $m\left(^{4}_{2}He\right) = 4.002603u$, $m\left(^{17}_{8}O\right) = 16.999131u$ and $m\left(^{1}_{1}H\right) = 1.007825u$

(–1.191MeV)

6. Calculate the energy associate with the given nuclear fusion reaction.

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$$

APPENDIX A

Some useful fundamental constants

Name	Symbol	Numerical Value
Speed of light	c	$2.9979\times10^{8}\ ms^{-1}$
Charge of electron	e	$1.602\times10^{-19}\ c$
Mass of electron	m_e	$9.109\times10^{-31}\ kg$
Mass of neutron	m_n	$1.675\times10^{-27}\ kg$
Mass of proton	m_p	$1.673\times10^{-27}\ kg$
Planck's constant	h	$6.626\times10^{-34}\ J\ s$
Planck's constant	$\hbar = h/2\pi$	$1.05\times10^{-34}\ J\ s$
Boltzmann constant	k	$1.381\times10^{-23}\ J\ K^{-1}$
Stefan-Boltzmann constant	σ	$5.67\times10^{-8}\ W\ m^{-2}\ k^{-2}$
Electron volt	eV_0	$1.602\times10^{-19}\ J$
Electron rest energy	m_0c^2	$0.5109989\ MeV_0$
$\frac{e}{m}$ for electron	$\frac{e}{m}$	$1.7588\times10^{11}\ kg^{-1}C$
Permittivity of free space	ε_0	$8.854\times10^{-12}\ C^2\ N^{-1}\ m$
Coulomb constant	$k = \frac{1}{4\pi\varepsilon_0}$	$8.99\times10^{9}\ N\ m^2\ C^{-2}$
Permeability of free space	μ_0	$4\pi\times10^{-7}\ wb\ A^{-1}\ m^{-1}$
Atomic mass unit	a.m.u (1u)	$1.66\times10^{-2}\ kg$
Rydberg constant	R_H	$1.097\times10^{7}\ m^{-1}$
Bohr radius	r	$5.29\times10^{-11}\ m$
Electron Compton wavelength	h/m_ec	$2.43\times10^{-12}\ m$

APPENDIX B

Particles of Atomic Physics

Particle	Charge	Mass (electron mass)	Mean Life (sec)
Electron	−e	1	Stable
Proton, $_1H^1$	+e	1,836	Stable
Antiproton	−e	1,836	
Neutron, $_0n^1$	0	1,837	~1,000
Antineutron	0	1,837	
Positron	+e	1	Stable
α -Particle, $_2He^4$	+2e	7,270	Stable
Duerron, $_1D^2$ or $_1H^2$	+e	3,630	Stable
Photon, γ	0	0	Stable
Neutrino, ν	0	0	Stable
Antineutrino	0	0	
Mesons:			
Mu meson, $\mu^\pm$	±e	207	$(2)(10^{-6})$
Pi meson, $\pi^\pm$	±e	273	$(2)(10^{-6})$
Pi meson, π^0	0	264	$\sim 10^{-16}$
Tau meson, $\tau^\pm$	±e	965	$\sim 10^{-9}$
Kappa meson, $\kappa^\pm$	±e	920 – 960	$\sim 10^{-9}$
Theta meson, θ^0	0	965	$(1.5)(10^{-10})$
Theta meson, $\theta^\pm$	±e	955	$\sim 10^{-9}$
Hyperons:			
Λ^0	0	2,180	$(3)(10^{-10})$
Σ^+	+e	2,300	$\sim 10^{-10}$
Σ^-	−e	2,300	$\sim 10^{-10}$
Ξ^-	−e	2,600	$\sim 10^{-10}$

GLOSSARY

Alternating Current	A current which changes periodically with time both in positive and negative directions.
A.C-Circuit	An electrical network which is powered by A.C Source.
A.C Generator	A device which converts mechanical energy into electrical energy
A.C Motor	A device which converts electrical energy into mechanical energy.
Ammeter	A device which is being used for the measurement of electric current.
Amorphous	The solids whose atoms, molecules and ions are not arranged in a regular manor.
Ampere	It is the SI unit of electric current.
Artificial Radioactivity	The emission of radiations or energy during the nuclear reaction either fission or fusion.
Atomic Number	The number of protons in the nucleus of an atom.
Avalanches	A process that the particles ionize the molecules of the gas.
Annihilation of matter	A process in which two anti-particles disappear to form two γ-rays photon.
Avometer	A multimeter which is being used for the measurement of current, voltage and resistance.
Absorb dose	The quantity of radiation absorbed per unit mass.
Back emf	The emf that induces during the rotation of motor and it opposes the applied emf.
Becquerel	It is the SI unit of radioactivity.
Binding energy	The energy which keeps the nucleons in a nucleus or the energy which breaks down the nucleus into its constituent protons and neutrons.
Blackbody	A body which absorbs all the radiations of all wavelength that fall on it and vice versa.
Black body radiation	Emission of radiation from a black body.
Baryons	A class of hadrons. These are heavy particles and their spins are half.
Bohr's radius	The radius of the first orbit of hydrogen atom.
Bosons	Those particles whose spin is a multiple integer e.g. electrons, protons etc.
Bulk Modulus	The ratio of volumetric stress to volumetric strain

Brittle substance	The solids which break down just passing the elastic limits.
Band Theory	Discrete energy levels of atoms that overlap to one another in the form of bands. These bands explain insulators, conductors and semiconductors of solids.
Capacitive reactance	Resistance of a capacitor is called capacitive reactance.
Capacitor	A device which is being used for storage of charges.
Chain reaction	A series of nuclear fission reactions initiated by a single neutron with $^{235}_{92}U$.
Charges	A property of a body such that attracts or repels the other charged particles.
Choke	It is a coil (inductor) that controls the current in an A.C. circuit.
Circuit	An electrical network which consists of a source of emf with a number of components connected across it.
Current	The rate of flow of charges.
Coherent light	The light with same frequency and phase.
Compass needle	A device which detect the presence of magnetic field.
Compressional strain	When a change occurs in a body in its volume due to deforming force then its corresponding strain is compressional strain.
Compton effect	An interaction of x-rays photon with an electron at rest, where photon transfer a fraction of its energy to the electron. So the energy of photon is decreased.
Compton shift	The wavelength of photon is increased when it interacts with an electron at rest.
Conservation of charges	In an isolated system, the total amount of charges remains constant.
Coulomb	It is the SI unit of charge.
Coulomb's law	The electrostatic force of attraction or repulsion between two point charges is directly proportional to the product of charges and inversely proportional to square of the distance between them.
Crystalline solids	The solids whose atoms, molecules and ions are arrange in a regular manner.
Curie	It is the unit of radioactivity.
Collector	It is a terminal of the transistor which collects the charge carries.

Conductor	The solids which allow the passage of current through them.
Conduction	The transfer of electric effect through a medium.
Conductance	The reciprocal of resistance.
Conductivity	The reciprocal of resistivity.
Conventional current	The current that flows from positive to negative terminal of the battery.
Critical mass	The minimum mass of a fissile material that will sustain a chain reaction.
Critical temperature	The temperature at which the resistance of the conductor becomes zero.
Curie Temperature	The temperature at which the ferromagnetic materials become paramagnetic materials.
Direct current	The current that flows in one direction with constant amplitude.
D.C. generator	A device which converts mechanical energy into direct current.
Daughter nucleus	A nucleus left behind after a decay process
Davisson-Germer experiment	An experiment whose result verifies the de-Broglie's hypothesis.
Decay constant	The probability per unit time of the radioactive decay of an unstable nucleus.
Deuterium	It is an isotope of hydrogen whose nucleus contains a single proton and a single neutron.
Dielectric	The insulating medium in an electric field is called dielectric.
Diffraction	The bending of light through a slit or through a crystal.
Diffusion	The flow of majority charge carries toward the junction.
Diode	A semiconductor device which allows the current in one direction.
Drift velocity	The average velocity of moving charges through a conductor.
Depletion region	The region at the PN-junction where the majority carriers recombine to one another.
Diamagnetic substance	The materials whose resultant magnetic moment of their atoms is zero.
Ductile substance	The substances which have ability (property) to roll like a wire.

Eddy current	The current that induces during the rotation of motor or generator.
Electrocardiography	The instrument that records the voltage pulses of heart.
Electrocardiogram	The recorded heart pulses pattern on a paper.
Elastic limit	The limit of deformation where the body comes back to its original position.
Electric field	The region around a charged particle in which another charged particle can experience force of attraction or repulsion.
Electric intensity	Electric force acting per unit charge at a point in an electric field.
Electric dipole	Two charges of same magnitude but of different signs separated by a small distance.
Electric potential	Work on a charge against the direction of electric field.
Electromagnetic waves	The wave which consists of electric and magnetic fields which are oscillating at right angle.
Electron volt	It is the unit of electrical energy.
Electric flux	The number of electric lines of force passing through an area held perpendicular.
Electrostatic force	It is a force of attraction or repulsion between two point charges.
Electrolytes	It is the ionized liquid.
Electromotive force	The work on the charges inside the source.
Electron microscope	A device which is used to get a highly magnified and resolved image of biological and non-biological specimens. It uses a beam of acceleration electrons as a source of illumination instead of light.
Endothermic reaction	A nuclear reaction in which the energy is absorbed
Exothermic	A nuclear reaction in which the energy is released.
Ether	An ideal (hypothetical) medium
Excited state	The orbit in which electron is excited and it cannot revolve too long in it.
Exponential charging	When a capacitor or other device is not charging with the same rate.
Exponential decay	When radioactive elements decay with different rates.
Electric polarization	The insulator in an electric field, such that the molecules of the insulator become in form of dipole.

Emitter	It is an electrode of a transistor which supplies the charge carriers.
Extrinsic semiconductor	When an impurity of either 3rd or 5th group is added into pure semiconductor.
Farad	It is the SI unit of capacitance
Faraday law of induction	The induced emf is directly proportional to the rate of change of magnetic flux.
Fermions	The elementary particles whose spin are half.
Ferromagnetic material	The solids which show a strong magnetic moment.
Fission reaction	A process in which a heavy nucleus is splited into small nuclei with releases of energy
Frame of reference	Co-ordinates system which is being used to describe the relative motion of body.
Forbidden gap	The gap between valance and conduction bands.
Galvanometer	It is an electrical device which detects a small current.
Gauss's law	The total flux through a closed surface is equal to $\frac{1}{\varepsilon_0}$ times of the total charges enclosed in it.
Gaussian surface	The surface which encloses the charges.
Geiger-Muller counter	It is a device which detects and counts ionized particles.
Germanium	It is a semiconductor material. The barrier potential for Germanium is 0.3v.
Generator	A device which converts mechanical energy into electrical energy.
Gravitational force	The force of attraction between two masses.
Hadron	Massive fundamental particle of matter.
Half life	A direction of time in which half number of atoms of radioactive elements decay
Heisenberg uncertainty principle	There is great uncertainty in the accurate and simultaneous determination of position and momentum of a particle.
Hook's law	Within elastic limit, the applied stress is directly proportional to the strain.
Hydrogen atom	The simplest atom which contains a single proton and a single electron.
Henry	It is the SI unit of inductance

Hysteresis	The lagging of magnetic field density 'B' behind magnetizing field 'H' in the process of magnetization or demagnetization.
Hysteresis loop	A closed path which is obtained due to the process of magnetization or demagnetization.
Impedance	The combined opposition of resistor, capacitor and inductor to flow of current in a circuit.
Induced emf	The emf that induces due to the changing of magnetic flux.
Inductance	The phenomenon in which changing current in a coil produces on emf in it.
Inductive reactance	The opposition of an inductor.
Inductor	It is a coil which stores magnetic potential energy.
Inertial frame of reference	A frame of reference which is at rest or moving with uniform velocity.
Internal resistance	The resistance inside the source. It is due to the electrolyte.
Ionization energy	The energy that ionized the atom.
Ionization potential	The potential which provides the ionization energy.
Isotopes	The nuclei that have same atomic number but different mass number.
Isobar	The nuclei which have same mass number but different atomic number
Isotones	The nuclei that have the same number of neutrons.
Isomers	The nuclei have same atomic number and same mass number but their half-lives are different.
Intrinsic semiconductor	A pure form of semiconductor (Ge & Si)
Junction diode	When P and N types semiconductors are combined such that there is junction between them.
Kirchhoff's current law	The sum of currents flowing towards the node is equal to sum of currents flowing away from the node.
Kirchhoff's voltage law	The total voltage drops across the closed loop is equal to zero.
LASER	Light amplification by stimulated emission of radiation: It is a coherent and monochromatic intense light.
Length contraction	The length of a moving object is decreased.
Leptons	Light fundamental particles of matter.
Load resistance	A resistance in the output of the circuit to check the presence of current.

Lenz's law	The direction of induced emf is always opposite to the action of emf.
Loop analysis	It is based upon Kirchhoff's voltage law
Magnetic domain	The volume in which the magnetic moments of a group of atoms are aligned in the same direction.
Magnetic field	The region around a magnet or region around the current carrying a conductor.
Magnetic flux	The magnetic lines of force passing through area held perpendicular
Magnetic flux density	The magnetic lines of force passing through a unit area.
Mass number	The number of protons and neutrons in the nucleus of an atom.
Mass defect	The mass of the nucleus is always less than the sum of masses of its separated nucleon
Mass-spectrography	A process in which the isotopes of an element is separated.
Mass variation	The increase in mass of a body in its velocity.
Mesons	The fundamental particle of matter which has an intermediate mass.
Metastable state	It is a 2^{nd} energy level in a laser and the life time of electron in it is 10^{-3}s
Metal detector	A device which detects the hidden metal.
Moderator	The materials used to slow down the fast neutrons for fission reaction.
Motional emf	The emf that induces due to the motion of a conductor in a magnetic field.
Modulus of elasticity	The ratio between stress to strain
Mutual inductance	A phenomenon in which a changing current in one coil produces emf in the other coil.
Monochromatic light	The light that have a same wavelengths
Natural radioactivity	The simultaneous emission of radiation from radioactive elements
Non-ohmic devices	The devices which do not obey the ohm's law
Node-analysis	It is based upon Kirchhoff's current law
Nuclear reaction	The interaction of nuclear particles with a nucleus
Nuclear force	It is a force between nucleon
Nuclear transmutation	A process in which a change occurs in a nucleus

N-type semiconductor	When an impurity of 5^{th} group is added into semiconductor material
Ohm's law	The applied voltage across the conductor is directly proportional to the current at constant temperature.
Ohm	It is the SI unit of resistance.
Ohmic devices	The devices which obey ohm's law
Parent nucleus	The original nucleus without any decay from it.
Photo cell	A device which converts light energy into electrical energy.
Phase angle	The angle between voltage and current in case of alternating current.
Phasor diagram	The graph between voltage and current in case of alternating current.
Photo electric effect	A phenomenon in which photo electrons are emitted from the metal surface due to light falling on it.
Photon	It is a small packet of energy and it behaves as a particle which is moving with a speed of light.
Planck's law	The energy of photon/quanta is directly proportional to its frequency
Plasma	A fourth state of matter e.g. ionized gas
Population inversion	When a large number of electrons are accumulated in the excited state than the ground state of a laser.
Positron	Anti-particle of electron
Potential difference	The work on a charge to displace against the direction of electric field.
Power factor	The ratio between real power to apparent power.
Projectiles	The nuclear particles i.e. proton, neutron, photon and α-particles which exist in a nucleus of an atom and they are known as projectiles.
Pair production	The conversion high energy γ-rays photon into electron and positron pair.
P-type semiconductor	When an impurity of 3^{rd} group is added into a pure semiconductor material
Plasticity	When permanent change occurs in a body by deforming force.
Polymeric solids	The solids whose atoms, molecules or ions are arranged neither like crystal nor like amorphous
Potentiometer	A device which measures the potential difference

Proportional limit	The limit in which the stress is propositional to the strain.
Protium	It is an ordinary hydrogen which contains a single proton in its nucleus.
Quarks	Quarks are the basic building block of matter
Q-values	It is the amount of energy which is released or absorbed in a nuclear reaction.
Resistance	Opposition to the flow of charges
Resistivity	The resistance of one metre cube of the conductor.
Roentgens	It is the unit of exposure of x-rays.
Reverse bias	When P-type is connected with negative terminal and N-type with positive terminal of the battery.
Radioactive elements	The elements whose atomic number are greater than 82 and they are unstable.
Rectification	A process in which A.C is converted into D.C by using diode.
Rem	It is the unit for biologically equivalent
Rheostat	It is a variable resistance used to regulate the current in the given circuit.
Self-inductance	The phenomenon in which emf is induced in the same coil in which the current is changing.
Semiconductor	Semiconductor materials have dual characteristics. They behave as insulators at low temperature as well as conductor at high temperature.
Shearing modulus	The ratio between shearing stress to shearing strain.
Shearing strain	When a change occurs the shape of the body.
Sinusoidal waves	These waves are either sine waves or cosine waves.
Solar cell	A device which converts solar energy into electrical energy.
Spectrum	When visible light is split into its seven continent colours. The group of seven colours is called spectrum.
Spontaneous emission	The emission of photon during the transition of electron from higher orbit to lower orbit.
Stefan-Boltzmann law	The energy emitted from a blackbody is directly proportional to the fourth power of its absolute temperature.
Step down transformer	When $N_P > N_S$ then $V_P > V_S$
Step up transformer	When $N_S > N_P$ then $V_S > V_P$

Stimulated emission	The emission of photon due to the transition of electron from metastable state to the ground state.
Stopping potential	The applied negative potential which is equal to the K.E of photo electrons.
Strain	A change that occurs in a body in its length, volume or shape.
Stress	The applied force or deforming force per unit area of the object.
Superconductor	The conductor whose resistance is zero at low temperature.
Sievert	It is the SI unit of equivalent dose.
Spectroscopy	The study of wavelengths of the spectral lines of the spectrum.
Tensile strain	The change in length per unit original length of a body.
Tesla	It is the SI unit of magnetic field density.
Thermocouple	A process in which e.m.f. is produced by heat.
Threshold frequency	The minimum value of frequency of light at which the photoelectrons are emitted from metal surface.
Transistor	A semiconductor device which changes a small input A.C signal into a large A.C signal.
Transmutation	A nuclear reaction in which a change occurs in the nucleus
Tritium	It is the isotope of hydrogen which contains two neutrons and a single proton in its nucleus.
Ultimate strength	The limiting stress, where the body reaches to its breaking point.
Volts	The SI unit of potential difference.
Voltmeter	An electrical device which is being used for the measurement of voltage.
Work function	The minimum energy required for emission of photo electrons from a metal.
Wien's displacement law	The wavelength having maximum intensity in the emitted radiation is inversely proportional to the temperature.
Wheat stone bridge diagram	An electrical network in a diamond shape used for the measurement of unknown resistance.
Wilson cloud chamber	A device that detects the ionized particles
Young's modulus	The ratio between tensile stress and tensile strain.

INDEX

S

T

- بڑوں کا ادب کرنا اچھی عادت ہے۔
- نیک بنو نیکی پھیلاؤ۔
- والدین کا احترام کرنا چاہیے۔
- سچ بولنا اچھی عادت ہے۔
- چوری کرنا گناہ ہے۔
- صبح سویرے اُٹھنا اچھی عادت ہے۔
- علم کی روشنی پھیلاؤ۔
- جھوٹ بولنا بُری بات ہے۔
- اساتذہ کا احترام کرنا چاہیے۔
- صفائی نصف ایمان ہے۔

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