Chapter 12

Radioactivity

(F) Modern Physics

SYLLABUS

(i) Radioactivity and changes in the nucleus; background radiation and safety precautions.

Scope of syllabus : Brief introduction (qualitative only) of the nucleus, nuclear structure, atomic number (Z), mass number (A), radioactivity as spontaneous disintegration. α, β and γ - their nature and properties; changes within the nucleus. One example each of α and β decay with equations showing changes in Z and A. Uses of radioactivity - radio isotopes. Harmful effects. Safety precautions. Background radiation.

Radiation : X-rays, radioactive fall out from nuclear plants and other sources.

Nuclear energy : Working on safe disposal of waste. Safety measures to be strictly reinforced.

(ii) Nuclear fission and fusion; basic introduction and equations.

(A) ATOMIC STRUCTURE AND RADIOACTIVITY

12.1 STRUCTURE OF THE ATOM AND NUCLEUS

The discovery of electrons by Sir J.J. Thomson towards the end of the nineteenth century and the scattering experiments of alpha particles by Rutherford and others led to the following structure of an atom and its nucleus.

Structure of an atom : An atom consists of electrons, protons and neutrons. The protons and neutrons reside inside the nucleus of the atom which is at its centre, while the electrons revolve around the nucleus in some specific orbits in which they do not radiate out energy. Such orbits are called the *stationary orbits* (or staionary shells). In each stationary shell, the electron has a definite energy. The number of shells varies in atoms of different elements, depending upon the total number of electrons present in the atom of that element. The maximum number of electrons in a shell can be $2n^2$, where n is the number of that shell. The various shells around the nucleus for n = 1, 2, 3, 4, 5, 6, 7, ... are named as K, L, M, N, O, P, Q, ... respectively and these shells can accommodate at the most 2, 8, 18, 32, 50, 72, 98, ... electrons respectively. The electrons in different shells have different energy which increases with the increase in the number n of that shell.

The size of an atom is determined by the radius of the shell of its outermost electron and it is of the order of 10^{-10} m. The electron has a negative charge equal to $-1{\cdot}6 \times 10^{-19}$ C (or $-e$) and its mass (m_e) is nearly $9{\cdot}1 \times 10^{-31}$ kg which is approximately 1/1840 times the mass of a proton.

Structure of nucleus : The nucleus is at the centre of atom whose size is of the order of 10^{-15} m to 10^{-14} m (*i.e.*, 10^{-5} to 10^{-4} times the size of the atom). It consists of *protons* and *neutrons*. The proton has a positive charge equal to $+1{\cdot}6 \times 10^{-19}$ C (or $+e$) and its mass (m_p) is nearly $1{\cdot}67 \times 10^{-27}$ kg. The total number of protons in the nucleus determines the place of the atom in the periodic table and is called the ***atomic number*** of the element of that atom. The atomic number of an element is denoted by the symbol Z. The *neutron* is an electrically *neutral* particle (*i.e.*, charge = 0) and its mass (m_n) is also nearly $1{\cdot}67 \times 10^{-27}$ kg which is equal to that of a proton*. The protons and neutrons which are the main constituents of the nucleus, are called the *nucleons*. The total number of nucleons in the nucleus is called the ***mass number*** of the element and it is denoted by the symbol *A*. The nucleus is thus positively charged and its total charge is $+ Ze$. The mass of nucleus is approximately *A* times the mass of a proton.

> ***Note :*** The mass of an electron is negligible as compared to that of a proton (or a neutron). Hence total mass of an atom can be considered to be same as the mass of its nucleus.

Thus we can define the atomic number and man numbers as follows.

> **Atomic number :** The atomic number of an atom is equal to the number of protons in its nucleus (which is same as the number of electrons in a neutral atom). *i.e.*
>
> Z = number of protons in the nucleusof an atom.
>
> **Mass number :** The mass number of an atom is equal to the total number of nucleons (*i.e.*, number of protons and neutrons combined) in its nucleus. *i.e.*
>
> A = number of protons + number of neutrons in the nucleus of an atom.

Symbol, charge and mass of electron, proton and neutron

Parameter	Electron	Proton	Neutron
Symbol	e	p	n
Charge	$-1{\cdot}6 \times 10^{-19}$ C	$+1{\cdot}6 \times 10^{-19}$ C	zero
Mass	$9{\cdot}1 \times 10^{-31}$ kg	$1{\cdot}67 \times 10^{-27}$ kg	$1{\cdot}67{\times}10^{-27}$ kg

12.2 ATOMIC MODEL

An atom is electrically neutral, therefore the number of protons in the nucleus of an atom are equal to the number of electrons revolving around the nucleus of the atom.

If Z is the atomic number and A is the mass number of an atom, then the atom contains

$$\left.\begin{array}{l}\text{number of electrons} = Z \\ \text{number of protons} \;\; = Z \\ \text{number of neutrons} = A - Z.\end{array}\right\} \qquad ...(12.1)$$

* $m_p = 1{\cdot}6726 \times 10^{-27}$ kg; $m_n = 1{\cdot}6749 \times 10^{-27}$ kg

The atom is specified by the symbol $^{A}_{Z}X$ where X is the chemical symbol for the element.

The actual size of an atom is very small (nearly 10^{-10} m) which is invisible, but just to understand the distribution of its consitutents, we can draw the model of an atom not to the scale.

Examples : **(1)** The lightest atom is hydrogen whose mass number *A* is 1 and atomic number *Z* is also 1. It is represented as $^{1}_{1}H$ and it has one proton in the nucleus and one electron in the K shell as shown in Fig. 12.1.

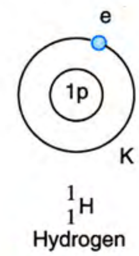

Fig. 12.1 Model of hydrogen atom

(2) The helium atom has the mass number $A = 4$ and the atomic number $Z = 2$. It is represented as $^{4}_{2}He$. It has 2 neutrons and 2 protons inside the nucleus and 2 electrons in the K shell.

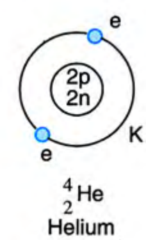

Fig. 12.2 Model of helium atom

(3) The sodium atom has atomic number $Z = 11$ and mass number $A = 23$. It will have $Z = 11$ protons and $A - Z = 23 - 11 = 12$ neutrons inside the nucleus and $Z = 11$ electrons distributed

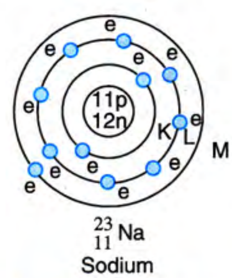

Fig. 12.3 Model of the sodium atom

in the K, L and M shells (2 in the K shell, 8 in the L shell and 1 in the M shell) as shown in Fig. 12.3. It is represented as $^{23}_{11}Na$.

Note : **(1)** If an atom undergoes a chemical change, there is a change in the number of orbital electrons of the atom, whereas if the atom undergoes a nuclear change, there is a change in the number of nucleons inside the nucleus of the atom.

(2) A nuclear change requires much higher energy, of the order of few MeV, which is nearly 10^6 times as compared to the energy required for a chemical change, which is of the order of few eV only.

(3) In a nuclear reaction, the atomic number (or number of protons) and the mass number (or total number of protons and neutrons) remain conserved. In other words, the total sum of atomic numbers of the reactants is equal to the sum of atomic numbers of the products. Similarly, the total sum of mass numbers of the reactants is equal to the sum of mass numbers of the products.

12.3 ISOTOPES

The atoms of the same element, having same atomic number Z, but different mass number A, are called isotopes.

Obviously, the isotopes have the same place in the periodic table as it depends on the atomic number Z.

The atoms of isotopes have the same number of protons (Z), but different number of neutrons (A – Z) in their nucleus. Since they have the same number of electrons outside the nucleus, so their chemical properties are also same.

In nature, different isotopes of an element occur in different proportion. In most of the cases, the relative abundance of one isotope is very high as compared to the others.

Examples : **(1)** Hydrogen has *three* isotopes, namely, protium ^1_1H (or ordinary hydrogen which is most abundent), deuterium ^2_1H (or heavy hydrogen) and tritium ^3_1H. Each isotope in its nucleus has one proton (Z = 1), but protium (^1_1H) has no neutron, deuterium (^2_1H) has one neutron and tritium (^3_1H) has two neutrons. There is one electron outside the nucleus in each isotope.

The table below gives the number of protons and neutrons in the nucleus of isotopes of hydrogen.

Parameter	Protium ^1_1H	Deuterium ^2_1H	Tritium ^3_1H
Values of Z and A	$Z = 1, A = 1$	$Z = 1, A = 2$	$Z = 1, A = 3$
Number of protons	1	1	1
Number of neutrons	0	1	2

(2) Carbon has *three* isotopes $^{12}_6C$, $^{13}_6C$ and $^{14}_6C$, out of which $^{12}_6C$ is most abundant. Each isotope in its nucleus has 6 protons (Z = 6). The isotope $^{12}_6C$ has 6 neutrons, the isotope $^{13}_6C$ has 7 neutrons and the isotope $^{14}_6C$ has 8 neutrons inside the nucleus. The number of electrons outside the nucleus in each isotope is 6.

(3) Chlorine has *two* isotopes $^{35}_{17}Cl$ and $^{37}_{17}Cl$. Their relative abundance in nature is in the ratio 3 : 1. Each isotope in its nucleus, has 17 protons. The isotope $^{35}_{17}Cl$ has 18 neutrons, while $^{37}_{17}Cl$ has 20 neutrons inside the nucleus. The number of electrons outside the nucleus of each isotope is 17.

Note : **(1)** Tin (Sn) has the largest number (= 10) of isotopes.

(2) The isotopes are of *two* kinds : (a) *stable isotopes* which have the number of neutrons nearly equal to the number of protons in their nucleus, and (b) *unstable* or *radioactive isotopes* which have number of neutrons much more than the number of protons in their nucleus. They undergo radioactive decay and are of great medical and industrial use.

Example : In $^{235}_{92}U$ and $^{238}_{92}U$, each isotope has 92 protons inside the nucleus, but $^{235}_{92}U$ has 143 neutrons while $^{238}_{92}U$ has 146 neutrons inside the nucleus. In both isotopes, the number of neutrons are more than the number of protons, so both are the radio isotopes. Similarly $^{14}_{6}C$ is a radio isotope out of the three isotopes $^{12}_{6}C$, $^{13}_{6}C$ and $^{14}_{6}C$ of carbon.

12.4 ISOBARS

The atoms of different elements which have the same mass number A, but different atomic number Z, are called isobars.

The atoms of isobars have the same number of nucleons (A) in their nucleus, but different number of protons (Z) and different number of neutrons (A − Z). The number of electrons outside the nucleus is always equal to the number of protons, so isobars have different number of electrons.

Examples : **(1)** $^{23}_{11}Na$ and $^{23}_{12}Mg$ are isobars. $^{23}_{11}Na$ contains 11 protons and 12 neutrons inside its nucleus, and 11 electrons outside the nucleus, while $^{23}_{12}Mg$ contains 12 protons and 11 neutrons inside its nucleus and 12 electrons outside the nucleus. The total number of protons and neutrons is 23 in each.

(2) Similarly $^{14}_{6}C$ and $^{14}_{7}N$ are isobars. $^{14}_{6}C$ has 6 protons and 8 neutrons inside its nucleus and 6 electrons outside the nucleus, while $^{14}_{7}N$ has 7 protons and 7 neutrons inside the nucleus and 7 electrons outside the nucleus.

Note : If the number of protons and neutrons get interchanged inside the nucleus, they are called *mirror isobars e.g.* $^{23}_{11}Na$ and $^{23}_{12}Mg$ are the mirror isobars.

13.5 ISOTONES

The atoms having different number of protons but same number of neutrons i.e., different Z and A, but same A–Z, are called isotones. They have different number of electrons.

Examples : **(1)** $^{23}_{11}Na$ and $^{24}_{12}Mg$ are the isotones. Each nucleus has 12 neutrons. $^{23}_{11}Na$ nucleus has 11 protons, while $^{24}_{12}Mg$ nucleus has 12 protons.

(2) $^{39}_{19}K$ and $^{40}_{20}Ar$ are the isotones (each having 20 neutrons in its nucleus).

12.6 RADIOACTIVITY

Henry Becquerel discovered the phenomenon of radioactivity in 1896. In a dark room he once left a uranium salt placed on a photographic plate wrapped in a black paper. After some days, he was surprised to found that the photographic plate had been affected. Later on, the same observation was made with the other salts of uranium. From these observations, he concluded that uranium and its salts by themselves emit some kind of radiations which can pass through the cover (*i.e.*, black paper, glass or wood, etc.) of the photographic plate and affect it. These radiations were called the ***Becquerel rays***. On further investigation, these radiations were found to be of *three* types : (1) positively charged, (2) negatively charged, and (3) uncharged which were named as α (alpha), β (beta) and γ (gamma) radiations respectively. The substances which emit these radiations were called the radioactive substances. Thus

The substances which disintegrate (or decay) by the spontaneous emission of radiations, are called the radioactive substances e.g. uranium, radium, polonium, thorium, actinium, etc.

The isotopes of nearly all the elements of atomic number higher than 82 (*i.e.*, after lead in the periodic table) are radioactive because in their nucleus, the number of neutrons is much more than the number of protons. These are called the *natural radioactive substances*.

Any physical change (such as change in pressure and temperature) or chemical change (such as excessive heating, freezing, action of strong electric and magnetic fields, chemical treatment, oxidation etc.) does not change the nature of radiation emitted by the substnace and its rate of decay. This clearly shows that the phenomenon of radioactivity cannot be due to the orbital electrons which could easily be affected by such changes. The radioactivity should therefore be the property of the nucleus. Thus

Radioactivity is a nuclear phenomenon. It is the process of spontaneous emission of α or β and γ radiations from the nucleus of atoms during their decay.

Note : From a radioactive substance containing a very large number of atoms, there is no way to know (or predict) when or which nucleus of the atom will decay at any moment, hence the radioactive decay is a *random phenomenon i.e.,* there is no law by which the disintegration of an individual nucleus can be known (or predicted).

12.7 RADIOACTIVITY AS EMISSION OF ALPHA (α), BETA (β) AND GAMMA (γ) RADIATIONS

In 1903, Rutherford experimentally studied the nature of radiations emitted by the radioactive substances. He found that on subjecting the radiations given out by a radioactive substance to a magnetic field in a direction perpendicular to their path, they separate out into *three* distinct constituents as shown in Fig. 12.4 in which magnetic field is normal to the plane of paper inwards. Those which turn to the left* must be positively charged and are called the ***alpha*** (or α) particles. Those which turn to the right must be negatively charged and are called the ***beta*** (or β) particles. The β particles are deviated more than the α particles. Those which pass undeviated, must be the uncharged (or neutral) and are called the ***gamma*** (or γ) radiations. Gamma radiations are the electromagnetic waves similar to light waves and are therefore not affected by the magnetic field.

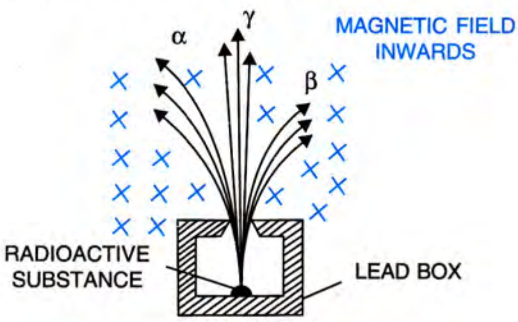

Fig. 12.4 Deflection of radioactive radiations in a magnetic field

Similarly, if the radiations given out by a radioactive substance are subjected to an electric field in a direction perpendicular to their path, they again separate out into the *three* constituents as shown in Fig. 12.5. Those which turn towards the negative plate, are the positively charged ***alpha*** **(α)** particles. Those which turn towards the positive plate, are the negatively charged ***beta*** **(β)** particles. Those which pass undeviated, are the uncharged ***gamma*** **(γ)** radiations. The beta particles are deviated more than the alpha particles.

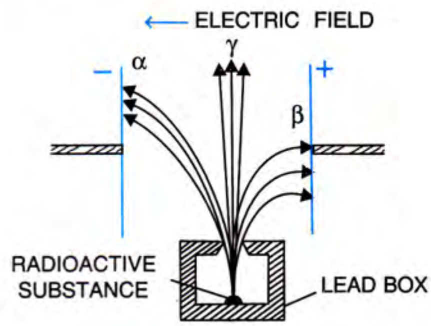

Fig. 12.5 Deflection of radioactive radiations in an electric field

12.8 PROPERTIES OF ALPHA PARTICLES

Some properties of alpha particles are given below.

(1) *An alpha particle consists of two protons and two neutrons*. It is same as a *doubly ionised helium atom**, *i.e., a helium nucleus* containing two protons and two neutrons. It is represented as $^{4}_{2}He$ or He^{2+}. Fig. 12.6(a) and (b) respectively represent the model of

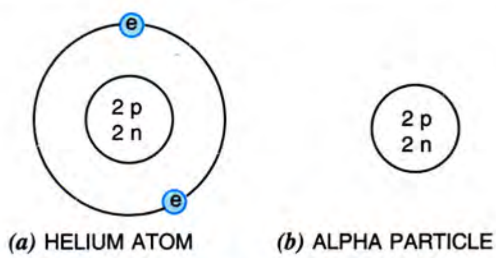

Fig. 12.6 Helium atom and alpha particle

* The direction of deflection in a magnetic field is given by Fleming's left hand rule.

* A helium atom which has lost its both the orbitat electrons, is called a doubly ionised helium atom.

a neutral helium atom and the helium nucleus (or the alpha particle).

If an alpha particle (He^{2+}) gains one electron, it changes to a singly ionised helium atom (He^{+}) and if it gains two electrons, it changes to the helium atom (He).

(2) The mass of an alpha particle is roughly *four times the mass of a proton* ($= 4m_p$) *i.e.*, $6{\cdot}68 \times 10^{-27}$ kg and its charge is *twice* the charge of a proton *i.e.*, $+ 3{\cdot}2 \times 10^{-19}$ C (or $+ 2e$). Thus its specific charge (*i.e.*, $\frac{q}{m}$ value) is $4{\cdot}79 \times 10^{7}$ C kg^{-1}.

(3) *The speed of α-particles is of the order of* 10^7 m s^{-1}. It is different for α-particles emitted from the different radioactive substances. Further, all the α-particles emitted from the nucleus of the same radioactive substance do not have the same energy (or speed), but they have energy distributed in a small range.

(4) *An alpha particle strongly ionises* the gas through which it passes*. The ionising power of α-particles is roughly 100 times that of β-particles and roughly 10^4 times that of γ-radiations.

(5) *An α-particle rapidly dissipates its energy as it moves through a medium and therefore its penetrating power is quite small*. It can penetrate only through 3 to 8 cm in air. It can easily be stopped by a thin card sheet or a thick paper. Its penetrating power is roughly 10^{-2} times that of a β-particle and 10^{-4} times that of γ radiation.

(6) *Alpha particles are positively charged, so they are deflected by the electric and magnetic fields*. The deflection of α-particle is less as compared to that of β-particle, because α-particle is of more mass than the β-particle.

(7) *α-particles affect a photographic plate.*

* An energetic particle when suffers collision with the atom of a gas, it knocks out the electron from the atom which now becomes a positive ion. This process is called ionisation.

(8) *Alpha particles cause fluorescence on striking a fluorescent material.*

(9) *Alpha particles have large kinetic energy and momentum with them*. They are used to bombard the nucleus of an atom of one element to convert it into another element (*i.e.*, for transmutation).

(10) *Alpha particles destroy the living cells and also cause biological damage.*

(11) *α-particles get scattered while passing through the thin mica (or gold) foils.*

12.9 PROPERTIES OF BETA PARTICLES

Some properties of beta particles are given below :

(1) *β-particles are the fast moving electrons emitted from the nucleus** of an atom. It is represented as ${}^{0}_{-1}\beta$ or ${}^{0}_{-1}e$.

(2) *The rest mass of a β-particle is* $9{\cdot}1 \times 10^{-31}$ kg ($= m_e$) *and its charge is* $-1{\cdot}6 \times 10^{-19}$ C (or $-e$). Thus the specific charge (or q/m value) of β-particle is $1{\cdot}76 \times 10^{11}$ C kg^{-1}.

(3) Although both the β-particles and cathode rays are the fast moving electrons, but they differ in their origin. β-particles are given out from the nucleus of the atom, while cathode rays are given out from its orbital electrons.

(4) *The speed of beta particles is of the order of* 10^8 m s^{-1} (but always less than 3×10^8 m s^{-1}). Different β-particles emitted from the same radioactive substance have different speeds**.

(5) *Beta particles ionise the gas through which they pass*. The ionising power of β-particles is roughly 1/100th times that of the α-particles, but nearly 100 times that of the γ-radiation.

* Inside the nucleus, the change of a neutron into a proton causes the emission of a β-particle (${}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e$). The beta particles do not reside inside the nucleus of atom in the form of electrons.

** β-particles emitted from a radioactive substance have energy distributed in a range from zero to a certain maximum value.

(6) *The penetrating power of β-particles is more than that of α-particles but less than that of γ-particles.* They can travel through nearly 5 m in air and pass through thin card sheet, and even through thin aluminium foil, but a 5 mm thick aluminium sheet can stop the β-particles.

(7) *Beta particles are negatively charged, so they get deflected by the electric and magnetic fields.* The deflection of a β-particle is in a direction opposite to that of an α-particle since the charge on β-particle is negative, while the charge on α-particle is positive. The deflection of β-particle is more than that of the α-particle since a β-particle is much lighter than an α-particle.

(8) *Beta particles affect a photographic plate.*

(9) *Beta particles cause fluorescence on striking a fluorescent material.*

(10) *Beta particles produce X-rays when they are stopped by the metals (such as tungsten) of high atomic number and high melting point.*

(11) *Beta particles cause more biological damage than the α-particles as they can easily pass through the skin of our body.*

12.10 PROPERTIES OF GAMMA RADIATIONS

Some properties of gamma radiations are given below :

(1) *Gamma radiations are the electromagnetic waves like X-rays and light,* but they differ from X-rays and light in wavelength. The wavelength of gamma radiations is of the order of 10^{-4} nm (or 10^{-13} m), whereas the wavelength of X-rays is in the range of 10^{-2} nm to 10 nm and that of light is in range of 400 nm to 800 nm.

(2) *The speed of γ-radiations is same as the speed of light* (*i.e.*, 3×10^8 m s^{-1} in vacuum or air).

(3) *The ionising power of γ-radiations is very low.* It is 10^{-4} times that of α-particles and 10^{-2} times that of β-particles.

(4) *The penetrating power of γ-radiations is high.* It is about 10^4 times that of α-particles and 10^2 times that of β-particles. They can travel through 500 m in air and pass through 30 cm thick sheet of iron. A thick sheet of lead is required to stop them.

(5) *Like X-rays and light, gamma radiations are not deflected by the electric and magnetic fields since they are not the charged particles.*

(6) *Gamma radiations affect a photographic plate.*

(7) *Gamma radiations cause fluorescence when they strike a fluorescent material.*

(8) *Gamma radiations are also diffracted by crystals like X-rays.*

(9) Although X-rays and gamma radiations are similar in properties, but their origin is quite different. X-rays are emitted when there is *transition of electrons in the inner orbits* of an atom, whereas gamma radiations are given out from the *nucleus*.

(10) *Gamma radiations can easily pass through the human body, therefore they cause immense biological damage.*

(11) Gamma radiations are very useful in the treatment of cancer.

Note : Out of the three radiations α, β and γ, the γ-radiations are most energetic and therefore they have a smaller rate of collisions with the atoms (or molecules) of the medium through which they pass. Thus they have least ionising power, but maximum penetrating power. On the other hand, α-particles are least energetic and therefore they suffer more collisions. Thus they have maximum ionising power, but least penetrating power. Their energy is soon dissipated.

12.11 DISTINCTION BETWEEN THE PROPERTIES OF α, β AND γ RADIATIONS

Property	α-particle	β-particle	γ-radiation
1. Nature	Stream of positively charged particles *i.e.*, helium nucleus.	Stream of negatively charged particles, *i.e.*, energetic electrons.	Highly energetic electromagnetic radiations.
2. Speed	Nearly 10^7 m s^{-1}	About 90% of the speed of light or $2{\cdot}7 \times 10^8$ m s^{-1}	3×10^8 m s^{-1} (in vacuum)
3. Rest mass	Four times the mass of proton *i.e.*, $6{\cdot}68 \times 10^{-27}$ kg	Equal to the mass of electron *i.e.*, $9{\cdot}1 \times 10^{-31}$ kg	No mass (rest mass is zero)
4. Charge	Positive charge (two times that of a proton) $= + 3{\cdot}2 \times 10^{-19}$ C (or + 2*e*)	Negative charge $= -1{\cdot}6 \times 10^{-19}$ C (or – *e*)	No charge
5. Specific charge (q/m)	$4{\cdot}79 \times 10^7$ C kg^{-1}	$1{\cdot}76 \times 10^{11}$ C kg^{-1}	—
6. Wavelength	—	—	10^{-4} nm or 10^{-13} m
7. Effect of electric and magnetic fields	Less deflected	More deflected than alpha particles, but in a direction opposite to those of α-particles	Unaffected
8. Ionising power	Maximum (10,000 times of γ)	Less than alpha particle (100 times of γ)	Minimum
9. Penetrating power Range in cm	Small 3 to 8 cm in air	Large up to few metre in air	Very large up to a few hundred metre in air
10. Stopping substance	Thin paper, human skin	About 1 mm thick lead or about 5 mm thick aluminium	About 30 cm thick iron or few metre thick concrete
11. Biological damage	Less damage	More damage	Immense damage

12.12 CHANGES WITHIN THE NUCLEUS IN ALPHA, BETA AND GAMMA EMISSION

We have read that the radioactive substances are not stable. Their nucleus undergoes spontaneous decay by the self emission of either alpha (α), beta (β), or gamma (γ) radiation to form a more stable nucleus. The emission of α (alpha), β (beta) and γ (gamma) radiation is a *nuclear change*. In the emission of alpha and beta radiation, there is a change in the number of protons and neutrons inside the nucleus, while in the emission of gamma radiation, there is only a change in the energy of the nucleus, and no change in the number of protons and neutrons inside the nucleus.

(1) *Alpha emission :* If an unstable nucleus contains much more neutrons than the number of protons, it may emit a particle containing *two protons* and *two neutrons* tightly bound together, known as *alpha particle.* A stream of α-particles is called α-rays.

If the nucleus X *of a radioactive element of mass number A and atomic number Z emits an α-particle, the daughter nucleus* Y *of a new element is formed which has mass number equal to (A – 4) and atomic number equal to (Z – 2).* Thus due to emission of an alpha particle, atomic number *Z* decreases by 2 units and mass number *A* decreases by 4 units. This change can be expressed in the form of a reaction as follows :

$$\underset{\text{Parent nucleus}}{{}^{A}_{Z}\text{X}} \rightarrow \underset{\text{Daughter nucleus}}{{}^{A-4}_{Z-2}\text{Y}} + \underset{(\alpha\text{-particle})}{{}^{4}_{2}\text{He}}$$

Thus, the resulting nucleus has 2 protons and 2 neutrons (total 4 nucleons) less than the original (or parent) nucleus.

Example : When a radioactive uranium nucleus ${}^{238}_{92}\text{U}$ emits an α–particle, a new nucleus thorium $^{234}_{90}Th$ is formed and the change is represented as follows :

$$\underset{\substack{(92\text{ protons and}\\146\text{ neutrons})}}{^{238}_{92}U} \longrightarrow \underset{\substack{(90\text{ protons and}\\144\text{ neutrons})}}{^{234}_{90}Th} + \underset{\substack{(2\text{ protons and}\\2\text{ neutrons})}}{^{4}_{2}He}$$

(2) *Beta emission :* When an unstable nucleus contains neutrons more than the protons, a neutron may change into a proton by emitting an electron (for charge conservation). The electron given out from the nucleus at a high speed is called a *beta particle.*

The change can be represented by the following equation :

$$\underset{(\text{neutron})}{^{1}_{0}n} \longrightarrow \underset{(\text{proton})}{^{1}_{1}p} + \underset{(\beta\text{-particle})}{^{0}_{-1}e}$$

A stream of β-particles is called β-rays.

> ***Note :*** Later on, to keep the number of particles either odd or even on both sides, another partice called anti-neutrino ($\bar{\upsilon}$), was also assumed to be emitted along with the β-particle. This particle is uncharged and its rest mass is zero. Then the complete transformation equation becomes
>
> $$^{1}_{0}n \longrightarrow {^{1}_{1}p} + {^{0}_{-1}e} + \bar{\upsilon}$$

Thus *in emitting a β-particle, the number of nucleons in the nucleus (i.e., sum of protons and neutrons) remains same, but the number of neutrons is decreased by one and the number of protons is increased by one.* In other words, by the emission of a β-particle, the mass number *A* does not change, but the atomic number *Z* is increased by one. It changes into a new nucleus of element with properties similar to those of an element *one place higher* in the periodic table. The daughter product is thus an ***isobar*** (same mass number, but different atomic number) of the parent atom.

If a radioactive nucleus P with mass number *A* and atomic number *Z* emits a beta-particle to form a daughter nucleus Q with mass number *A* and atomic number *Z* + 1, the change can be represented as follows :

$$\underset{\text{Parent nucleus}}{^{A}_{Z}P} \longrightarrow \underset{\text{Daughter nucleus}}{^{A}_{Z+1}Q} + \underset{(\text{Beta-particle})}{^{0}_{-1}e}$$

Example : A radioactive carbon nucleus $^{14}_{6}C$, having 14 nucleons (6 protons and 8 neutrons) emits a β-particle and changes to a new nucleus nitrogen $^{14}_{7}N$ having 14 nucleons (7 protons and 7 neutrons). The change is represented as follows:

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

(3) Gamma emission : In many cases an alpha or beta emission is found to be followed by the γ-emission. It occurs when the daughter or the parent nucleus is in a state of excitation (*i.e.*, it has an excess of energy). This extra energy is released in the form of electromagnetic radiation known as γ-radiation (or γ-ray photon). The γ-ray takes no mass and no electric charge from the nucleus *i.e.*, no neutrons or protons are lost, hence the nucleus does not decay into a different nucleus, *i.e., there is no change in the mass number A and atomic number Z of the nucleus in gamma emission.*

The gamma emission is represented as follows :

$$\underset{\text{Parent nucleus}}{^{A}_{Z}X^*} \longrightarrow \underset{\text{Daughter nucleus}}{^{A}_{Z}X} + \underset{(\text{gamma radiation})}{\gamma}$$

Here the star indicates the excited state of the nucleus. Thus in gamma emission, the excited nucleus comes to its ground state.

> ***Note :*** (i) The *electron emitted in β-decay does not exist in the nucleus*. It is created as a result of decay of one neutron into a proton inside the nucleus and is instantaneously emitted. It is not possible for electron to stay inside the nucleus.
>
> (2) *In a single radioactive decay, α and β particles are never emitted simultaneously.* There will be either an α-emission or a β-emission, which may be accompanied by the γ-emission.

(3) The daughter product after the emission of either α-particle or β-particle, may again be radioactive and it may further decay by emitting either the α-particle or the β-particle. This process continues till a stable nucleus is formed.

The table below shows the effect on atomic number Z and mass number A due to emission of α, β and γ radiations.

Effect on atomic number (Z) and mass number (A) due to α, β and γ emision

Quantity	α emission	β emission	γ emission
(i) Z	decreases by 2	increases by 1	no change
(ii) A	decreases by 4	no change	no change

12.13 USES OF RADIOACTIVITY – RADIO ISOTOPES

The isotopes of some elements with atomic number $Z < 82$ are also found to be radioactive. They are called the *radio isotopes*. The nucleus of an atom becomes radioactive when number of neutrons in the nucleus exceeds the number of protons inside it. For example, cobalt $^{60}_{27}Co$ ($Z = 27$, $A = 60$), carbon $^{14}_{6}C$ ($Z = 6$, $A = 14$), potassium $^{40}_{19}K$ ($Z = 19$, $A = 40$), phosphorus $^{32}_{15}P$ ($Z = 15$, $A = 32$), etc. are the radio isotopes. The radio isotopes are also prepared artificially by the nuclear transmutation. They find their vital use in (1) medical, (2) scientific, and (3) industrial fields.

(1) Medical use : (i) Many diseases such as leukemia, cancer, etc. are cured by radio therapy. Gamma radiations obtained from *cobalt–60* ($^{60}_{27}Co$) are used to treat cancer by killing the cells in the malignant tumour of the patient. For radio-therapy, radiations must be able to penetrate the human skin.

(ii) The salts of weak radioactive isotopes such as *radio-sodium chloride*, *radio-iron*, *radio-iodine* are used for diagnosis. Such radio isotopes are called the *tracers*. These tracers are used to detect the suspected brain tumours and blood clots before they become dangerous.

The tracers are also used to study the natural process in the human body. For example, radio-sodium chloride is injected with common sodium chloride in the human body and the radioactivity of the blood at different parts of the body is tested to study the blood circulation. The process is called *radio cardiology.*

(iii) γ-rays emitted by the radio isotopes are used to sterilize bandages, dressings, syringes and other equipments to make them free of germs. This method is quicker, more reliable and cheaper than the process of sterilization by heat.

(2) Scientific use : (i) Alpha particles emitted from the radio isotopes are used as projectiles for nuclear reactions. The scattering of alpha particles from the nucleus helps us in estimating the size of the nucleus and in understanding the nature of nuclear forces.

(ii) The radioactive tracers are used in agriculture science to study the growth of plants by using a particular chemical manure (e.g. to know how readily a plant takes in phosphate and to which part of the plant, the phosphate goes).

(iii) The age of excavated material of archaeological importance, rocks and hence of buried plants is estimated by the study of rate of decay of carbon –14($^{14}_{6}C$) in the remains of dead plants. The process is called *carbon dating*.

(3) Industrial use : (i) Radio isotopes such as $^{235}_{92}U$ are used as fuel for the atomic energy reactors.

(ii) Radio isotopes are used by engineers in factories to avoid the accumulation of charge on the moving parts of machines due to friction. The radiations emitted by the isotope ionise the air. The ions so produced take away with them the charge accumulated on the moving parts.

(iii) The ionising effect of radiations from the radio isotopes is used in making certain luminescent signs.

(iv) Knowing the penetrating power of the β-radiations emitted from the radio isotopes, they are used to control the thickness of paper, plastic and metal sheets during their manufacture.

12.14 SOURCES OF HARMFUL RADIATIONS

The main sources of harmful radiations are : (1) Radioactive fall out from the nuclear plants and other similar sources, (2) Nuclear waste, and (3) other sources *e.g.* cosmic radiation and X-rays.

(1) Radioactive fall out from the nuclear plants and other sources : The nuclear power plants are now a major source of electricity in the world. If somehow, there is an accident in the reactor of a power plant, a large amount of radioactive material and radiations will escape into the atmosphere. This will not only affect the population around the plant, but will also affect the life at far off places where they will reach due to air currents. *Three* such accidents have already occurred – (i) in U.S.A. on 28 March, 1979, (ii) in Ukraine in U.S.S.R. on 26 April, 1986, and (iii) in Japan on 11 March, 2011. These accidents caused damage to the reactor buildings and injuries to the persons working in the plants as well as in their vicinity.

(2) Nuclear waste : The fuel rods used in the nuclear power reactors are rejected when their activity decreases below a certain level. They then become a nuclear waste. These rods are still quite radioactive and are the source of harmful radiations therefore they should not be dumped in open garbage. They can contaminate water and soil and affect the human and living organisms.

(3) Other sources *e.g.* cosmic radiation and X-ray : The cosmic radiations from the sun enter the earth's atmosphere from the outer space. They contain a large number of high energy particles, out of which although the charged particles are deviated by the earth's magnetic field, but a substantial amount of uncharged radiations such as γ-rays and X-rays etc. reach the earth's atmosphere. These radiations are harmful for the human beings.

Apart from this, the high energy particle accelerators also produce the harmful X-rays.

12.15 HARMFUL EFFECTS OF RADIATION

The radiations produced in nuclear reaction includes alpha radiations, beta radiations, neutrons, gamma rays and X-rays. They interact with the living tissues within 10^{-14} s and cause biological damage.

The biological effects of nuclear radiations are of three types : (1) short term recoverable effects, like diarrhea, sore throat, loss of hair, nausea, etc. (2) long term irrecoverable effects like leukemia and cancer, and (3) genetic effects. The first and second effects are limited to the individuals who are actually exposed to the radiations, while the third effect appears in the later generations of the person exposed to the radiation. The genes in his cell get modified (or mutated).

The exposure to radiations can be acute if there is an accidental burst of radiations from an unshielded source. Similarly, it is chronic in case of persons working in atomic energy establishments when they get exposed to such radiations.

The exposure of pregnant woman to X-rays for a long time may affect the child in the womb. It increses the risk of cancer by 40%, of tumor and nervous system by 50% and of lukemia by 70%. The exposure of upper part of the body to X-rays may damage thyroid glands and can cause cancer.

The exposure to γ-rays destroys the cells of the body and affects the blood cells, gestro intestinal track, reproductive and hair cells. It can harm the DNA and RNA of the living cells also.

The uncharged neutrons also cause biological damage.

12.16 SAFETY PRECEDUTURE WHILE USING NUCLEAR ENERGY

We have read that now a days electricity is also generated by the use of nuclear energy obtained from the nuclear power plants. In a nuclear power plant, a radioactive source such as uranium-235 or plutonium-239 is used and the controlled chain fission reaction is carried out. Following require special care : (1) establishment of nuclear power plants, (2) handling of radioactive materials, and (3) safe disposal of nuclear waste.

(1) Safety measures while establishing a nuclear power plant : While establishing a nuclear power plant to generate electricity following precautions must be taken.

(i) Ensure that the people working in it are not exposed to nuclear radiations and in case of any accident there is a minimum spread of radiations.

(ii) The nuclear reactor of the power plant must be shielded with lead and steel walls so as to stop radiations from escaping out to the environment during its normal operation.

(iii) The nuclear reactor must be housed in an airtight building of strong concrete structure which can withstand the earthquakes, fires and explosions.

(iv) There must be a back-up of *cooling system* for the reactor core, so that in case of failure of one system, the other cooling system could take its place and the core is saved from over heating and melting.

(2) Safety measures while handling radio-active materials : People working with radioactive materials are required to follow strictly the *safety measures* given below :

(i) *They should put on special lead lined aprons and lead gloves.*

(ii) *They should handle the radioactive materials with long lead tongs.*

(iii) The safety limit for each type of radiation is known, therefore care must be taken to ensure that no one is exposed beyond the safety limit in any case. For this, *special film badges are used which are tested from time to time to know the amount of radiations to which a particular person has been exposed.*

(iv) *The radioactive substance must be kept in a thick lead container with a very narrow opening, so as to stop radiations coming out from other directions.* A container should be such that it absorbs the radiations which strike on its walls from inside. Alpha particles can easily be stopped by a thin metal sheet, but for β-particles we need a thick metal sheet, whereas gamma radiations need the very thick lead sheets.

(3) Safety measures in safe disposal of nuclear waste : *The radioactive material after its use is known as nuclear waste.* The nuclear waste obtained from laboratories, hospitals, scientific establishments or power plants must be first kept in thick casks and then they must be buried in the specially constructed deep underground stores. These stores must be made quite far from the populated areas. The casks can also be buried in useless mines and these mines must be sealed after storing the casks.

12.17 BACKGROUND RADIATIONS

The background radiations are the radioactive radiations (such as α, β and γ) to which we all are exposed, even in the absence of an actual radioactive source.

Sources : There are *two* sources of background radiations : **(1) the internal source** – the radioactive substances such as potassium (K-40), carbon (C-14), and radium present inside our body*, and **(2) external source** – cosmic rays, naturally occurring radioactive elements such as radon - 222 and solar radiations.

It is not possible for us to keep ourselves away from the background radiations. But the total background radiations from both the internal and external sources not exceed the maximum permissible dose** for human safety, so we need not worry.

* K-40 and C-14 are present in our entire body and they affect all parts equally, while radium is largely found in bones and so it affects only the bones and the reproductive organs.

** The effect of different radiations on human tissue is measured in unit **sieverts (Sv)** dose. In one exposure of X-rays for chest, the patient receives 0·2 milli sieverts dose of radiations.

EXAMPLES

1. State *two* differences between a chemical change and a nuclear change.

(i) A chemical change is due to change in orbital electrons, while a nuclear change is due to change in nucleons inside the nucleus.

(ii) A nuclear change requires much higher energy than a chemical change.

2. How is the radioactivity of an element affected when it undergoes a chemical change to form a chemical compound ? Give reason for your answer.

The radioactivity of the element remains unaffected.
Reason : Radioactivity is a nuclear phenomenon.

3. Compare the ionising power of α, β and γ radiations.

α-particles have the maximum ionising power, it is about 10^2 times that of β-particles and 10^4 times that of γ–radiation.

4. State the penetrating range in air for the α, β and γ radiations.

The penetrating range of α-particles is 3 cm to 8 cm of air, of β-particles is about 5 m of air and of γ-radiations is about 500 m of air. Thus the penetrating range of α-particles is the least and of γ-radiations is the most.

5. State the nature of infrared and γ-rays. How do they differ in their (i) wavelength, and (ii) penetrating power ?

Both infrared and γ-rays are the electromagnetic radiations.

Differences :

(1) γ-rays have much shorter wavelength ($\approx 10^{-13}$ m) as compared to the infrared rays whose wavelength is nearly 10^{-6} m or more.

(2) γ-rays are much more penetrating as compared to the infrared radiations.

6. State *two* similarities and *two* dissimilarities between the γ-rays and X-rays.

Similarities :

(1) Both the γ-rays and X-rays are the electromagnetic waves.

(2) Both the γ-rays and X-rays travel with a speed 3×10^8 m s^{-1} in air (or vaccum).

Dissimilarities :

(1) The wavelength of γ-rays is shorter than that of X-rays. The wavelength of γ-rays is 10^{-3} Å, while that of X-rays is 1 Å.

(2) γ-rays are more penetrating than X-rays.

7. Which of the radiations α, β and γ is similar to a beam of electrons ?

β-radiation is similar to a beam of electrons.

8. (a) State *three* properties which are common to both the beta rays and cathode rays.

(b) How do beta rays differ from cathode rays ?

(a) **Common properties :**

(1) Both are negatively charged with charge and mass equal to that of an electron.

(2) Both are deflected by the electric and magnetic fields.

(3) Both cause fluorescence on striking a fluorescent material.

(b) **Difference :**

Beta rays differ from cathode rays in their origin. Beta rays are given out from the nucleus of the atom, while cathode rays are given out from the orbital electrons.

9. One isotope of uranium has a mass number 235 and atomic number 92.

(i) What is the number of electrons in the neutral atom of this isotope ?

(ii) What is the number of protons and number of neutrons in its nucleus ?

(iii) Do all isotopes have the same number of neutrons ?

(iv) What is the number of protons and neutrons in $^{238}_{92}U$?

(i) Given : $A = 235$, $Z = 92$

Atomic number Z = number of protons

= number of electrons = 92.

∴ The neutral atom of $^{235}_{92}U$ will have **92 electrons.**

(ii) The number of protons $= Z =$ **92**

The number of neutrons $= A - Z$

$= 235 - 92 =$ **143**.

The nucleus of $^{235}_{92}U$ contains 92 protons and 143 neutrons.

(iii) **No.** Isotopes of an element have same atomic number, but different mass number as they have the same number of protons, but different number of neutrons.

(iv) In $^{238}_{92}U$, number of protons = Z = **92** and number of neutrons = $A - Z$ = 238 – 92 = **146**.

10. A certain nucleus P has a mass number 15 and atomic number 7.

(a) Find the number of neutrons.

(b) Write the symbol for the nucleus P.

(c) The nucleus P loses (i) one proton, (ii) one β-particle, (iii) one α-particle. Write the symbol of the new nucleus in each case and express each change by a reaction.

Given : For the nucleus P, $A = 15$, $Z = 7$

(a) Mass number A

= number of protons + number of neutrons

and atomic number Z = number of protons.

∴ Number of neutrons

= mass number A – atomic number Z

= 15 – 7 = **8**

(b) The nucleus P can be written as $^{15}_{7}P$.

(c) (i) After the loss of 1 proton, the mass number and atomic number of the nucleus $^{15}_{7}P$ will decrease by 1. The new nucleus will be $^{14}_{6}Q$ (say). The change can be written as :

$$^{15}_{7}P \longrightarrow ^{14}_{6}Q + ^{1}_{1}p$$

(ii) After the loss of one β-particle, the mass number will remain the same, but the atomic number will increase by 1. The nucleus $^{15}_{7}P$ changes to $^{15}_{8}R$ (say) as follows:

$$^{15}_{7}P \longrightarrow ^{15}_{8}R + ^{0}_{-1}e$$

(iii) After the loss of one α-particle, the mass number decreases by 4 and the atomic number decreases by 2. The nucleus $^{15}_{7}P$ changes to $^{11}_{5}S$ (say) as follows :

$$^{15}_{7}P \longrightarrow ^{11}_{5}S + ^{4}_{2}He$$

11. Uranium nucleus $^{238}_{92}U$ undergoes several disintegrations and ultimately decays to lead nucleus $^{206}_{82}Pb$. How many alpha and beta particles are emitted ?

When $^{238}_{92}U$ decays to $^{206}_{82}Pb$, the mass number decreases from 238 to 206 *i.e.*, it decreases by 32. Since the emission of beta particle does not change the mass number and with the emission of one alpha particle, mass number decreases by 4, so total number of alpha particles emitted will be $\frac{32}{4}$ = **8**.

In the decay of $^{238}_{92}U$ to $^{206}_{82}Pb$, the atomic number has decreased by 10. But due to emission of 8 alpha particles, the atomic number would have decreased by 2 × 8 = 16. Thus there is an increase in atomic number by 16 – 10 = 6, hence **6 beta** particles will be emitted (because in emission of one beta particle, atomic number increases by 1).

Thus $^{238}_{92}U$ decays to $^{206}_{82}Pb$ with the emission of **8 α-particles and 6 β-particles.**

12. Complete the following nuclear changes :

$$^{A}_{Z}X \xrightarrow{\beta} X_1 \xrightarrow{\gamma} X_2 \xrightarrow{\alpha} X_3 \xrightarrow{\beta} X_4$$

Due to emission of a β-particle, the atomic number increase by 1, but the mass number is unchanged. Due to emission of an α-particle, the atomic number decrease by 2 and the mass number decreases by 4. Due to emission of a γ-particle, there is no change in the atomic number and mass number.

The complete nuclear changes are :

$$^{A}_{Z}X \xrightarrow{\beta} {}_{Z+1}^{A}X_1 \xrightarrow{\gamma} {}_{Z+1}^{A}X_2 \xrightarrow{\alpha} {}_{Z-1}^{A-4}X_3 \xrightarrow{\beta} {}^{A-4}_{Z}X_4$$

13. Complete the following nuclear changes :

$$X \xrightarrow{\alpha} X_1 \xrightarrow{\gamma} X_2 \xrightarrow{\beta} X_3 \xrightarrow{\alpha} {}^{206}_{82}X_4$$

The daughter nucleus $^{82}_{206}X_4$ is formed after α decay of X_3, so atomic number of X_3 will be 2 units more and its mass number will be 4 units more *i.e.*, X_3 is $^{210}_{84}X_3$.

The nucleus $^{210}_{84}X_3$ is formed after the β decay of X_2, so atomic number of X_2 will be 1 unit less while its mass number will be same *i.e.*, X_2 is $^{210}_{83}X_2$.

The nucleus $^{210}_{83}X_2$ is formed after the γ decay of X_1, so X_1 will have no change in atomic number and mass number, but X_1 will be in excited state *i.e.*, X_1 is $^{210}_{83}X_1^*$.

The nucleus $^{210}_{83}X_1^*$ is the daughter product of α decay of X, so atomic number of X will be 2 units more and its mass number will be 4 units more *i.e.*, X will be $^{214}_{85}X$.

Thus the complete nuclear change is :

$$^{214}_{85}X \xrightarrow{\alpha} {}^{210}_{83}X_1^* \xrightarrow{\gamma} {}^{210}_{83}X_2 \xrightarrow{\beta} {}^{210}_{84}X_3 \xrightarrow{\alpha} {}^{206}_{82}X_4$$

14. A radioactive sample is kept at the centre of an evacuated spherical vessel.

(a) Out of the α, β and γ radiations, name the radiations which are (i) safe and (ii) unsafe.

(b) Suggest *two* ways for more safety.

(c) Does evacuation of vessel help in safety ?

(a) (i) α radiations have a less penetrating power and therefore they are stopped by the walls of vessel. Thus the vessel is safe for the α radiations. (ii) The β and γ radiations are not stopped by the walls of vessel, so the vessel is unsafe for the β and γ radiations.

(b) **Suggestions :**

(1) The sphere must have lead walls.

(2) The sphere must be of large radius.

(c) No. The vessel should not be evacuated. The air in it will help in absorbing the radiations.

15. (a) A mass of lead is embedded in a block of wood. Radiations from a radioactive source incident on the side of block produce a shadow on a fluorescent screen placed beyond the block. The shadow of wood is faint, but the shadow of lead is dark. Give reason for the difference.

(b) If the block of wood is replaced by a block of aluminium, will there be any change in the shadow?

(a) **Reason :** The shadow of wood is faint because only the α radiations are stopped by the wood (since α radiations are least penetrating). The shadow of lead is dark because β and γ radiations are also stopped by lead.

(b) If wood is replaced by aluminium (or any other light metal), the shadow of aluminium block will remain faint because aluminium will not stop the γ radiations.

16. State *one* use and *one* harmful effect of the radioactivity.

Use : The radiations given out in the decay process are used to cure certain diseases, like cancer.

Harmful effect : The radiations can damage the living tissues.

EXERCISE–12(A)

1. Name the *three* constituents of an atom and state mass and charge of each. How are they distributed in an atom ?

2. Define the terms :

   (a) atomic number, and (b) mass number.

3. What is nucleus of an atom ? Compare its size with that of the atom. Name its constitutents. How is the number of these constituents determined by the atomic number and mass number of the atom ?

4. State the atomic number and mass number of $^{23}_{11}Na$ and draw its atomic model.

5. What are isotopes ? Give *one* example.

6. What are isobars ? Give *one* example.

7. Name the atoms of a substance having same atomic number, but different mass numbers. Give *one* example of such a substance. How do the structures of such atoms differ ?

8. What is meant by radioactivity ? Name *two* radioactive substances.

9. A radioactive substance is oxidised. What changes would you expect to take place in the nature of radioactivity ? Explain your answer.

   Ans. no change because radioactivity is a nuclear phenomenon

10. A radioactive source emits *three* type of radiations.

    (a) Name the *three* radiations.

    (b) Name the radiations which are deflected by the electric field.

    (c) Name the radiation which is most penetrating.

    (d) Name the radiation which travels with the speed of light.

    (e) Name the radiation which has the highest ionising power.

    (f) Name the radiation consisting of the same kind of particles as the cathode rays.

11. A radioactive source emits *three* type of radiations.

    (a) Name the radiation of zero mass.

    (b) Name the radiation which has the lowest ionising power.

(c) Name the radiation which has the lowest penetrating power.

(d) Give the charge and mass of particles composing the radiation in part (c).

(e) When the particle referred to in part (c) becomes neutral, it is found to be the atom of a rare gas. Name this rare gas and draw a model of its neutral atom.

(f) From which part of the atom do these radiations come ?

12. The diagram in Fig. 12.7 shows a radioactive source S placed in a thick lead walled container. The radiations given out are allowed to pass through a magnetic field. The magnetic field (shown as ×) acts perpendicular to the plane of paper inwards. Arrows show the paths of the radiations A, B and C.

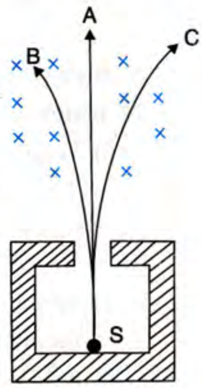

Fig. 12.7

(a) Name the radiations labelled A, B and C.

(b) Explain clearly how you used the diagram to arrive at the answer in part (a).

13. Fig. 12.8 shows a mixed source R of alpha and beta particles in a thick lead walled container. The particles pass through a magnetic field in a direction perpendicular to the plane of paper inwards as shown by ×. (a) Show in the diagram how the particles get affected. (b) Name the law used in part (a).

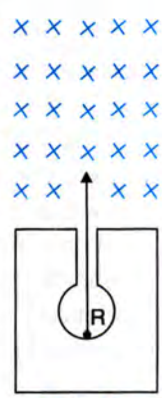

Fig. 12.8

[**Hint :** alpha particles will deflect to the left while beta particles to the right]

14. Fig. 12.9 shows a radioactive source S in a thick lead walled container having a narrow opening. The radiations pass through an electric field between the plates A and B.

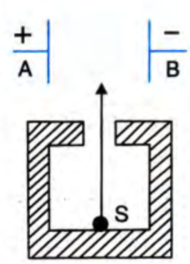

Fig. 12.9

(a) Complete the diagram to show the paths of α, β and γ radiations.

(b) Why is the source S kept in a thick lead walled container with a narrow opening ?

[**Hint :** α radiations will deflect towards the negative plate, β radiations towards the positive plate and γ radiations remain undeflected]

15. Explain why alpha and beta particles are deflected in an electric or a magnetic field, but gamma rays are not deflected in such a field.

[**Hint :** alpha and beta particles are charged, but gamma rays are uncharged]

16. Is it possible to deflect γ radiations in a way similar to α and β-particles, using the electric or magnetic field ? Give reason.

Ans. No. The reason is that γ radiations are uncharged

17. State following *four* properties each of α, β and γ radiations : (a) nature, (b) charge, (c) mass, and (d) effect of electric field.

18. Arrange the α, β and γ radiations in ascending order of their (i) ionising power, and (ii) penetrating power. **Ans.** (i) γ < β < α (ii) α < β < γ

19. State the speed of each of α, β and γ radiations.

Ans. 10^7 m s^{-1}, 2×10^8 m s^{-1}, 3×10^8 m s^{-1}

20. (a) What is the composition of α, β and γ radiations?

(b) Which one α, β or γ radiation has the least penetrating power ?

Ans. (a) α radiation is composed of $2p$ and $2n$, β radiation is composed of electron, while γ radiation is photon or electromagnetic wave. (b) α radiation has the least penetrating power.

21. How are γ radiations produced ? Mention *two* common properties of the gamma radiations and visible light.

22. An α-particle captures (i) one electron, (ii) two electrons. In each case, what does it change to ?

Ans. (i) singly ionised helium He^+
(ii) neutral helium atom

23. 'Radioactivity is a nuclear phenomenon'. Comment on this statement.

24. What kind of change takes place in a nucleus when a β-particle is emitted ? Express it by an equation. State whether (a) atomic number, and (b) mass number are conserved in a radioactive β-decay ?

25. A certain radioactive nucleus emits a particle that leaves its mass unchanged, but increases its atomic number by one. Identify the particle and write its symbol.

Ans. beta particle, ${}_{-1}^{0}e$ or ${}_{-1}^{0}\beta$

26. What happens to the (i) atomic number, (ii) mass number of an element when (a) an α-particle, (b) a β-particle, and (c) γ radiation, is emitted ?

Ans. (i) (a) decreases by 2, (b) increases by 1, (c) no change

(ii) (a) decreases by 4 (b) no change (c) no change

27. What happens to the position of an element in the periodic table when it emits (a) an α-particle, (b) a β-particle and (c) γ radiation ? Give reason for your answer.

Ans. (a) changes to two places earlier (b) changes to one place after, (c) no change

Reason : (a) atomic number decreses by 2.
(b) atomic number increases by 1.
(c) no change in atomic number.

28. What changes occur in the nucleus of a radioactive element when it emits (a) an alpha particle, (b) a beta particle, (c) gamma radiation ? Give *one* example, in each case (a) and (b) in support of your answer.

29. (a) An atomic nucleus A is composed of 84 protons and 128 neutrons. The nucleus A emits an α-particle and is transformed into a nucleus B. What is the composition of B ?

(b) The nucleus B emits a β-particle and is transformed into a nucleus C. What is the composition of C ?

(c) What is the mass number of the nucleus A ?

(d) Does the composition of nucleus C change if it emits the γ radiation ?

Ans. (a) 82 protons and 126 neutrons (b) 83 protons and 125 neutrons (c) 212 (d) no

30. A certain nucleus A (mass number 238 and atomic number 92) is radioactive and becomes a nucleus B (mass number 234 and atomic number 90) by the emission of a particle.

(a) Name the particle emitted.

(b) Explain how you arrived at your answer.

(c) State the change in the form of a reaction.

Ans. (a) α (b) atomic number has decreased by 2 and mass number has decreased by 4

(c) $^{238}_{92}A \rightarrow {}^{234}_{90}B + {}^{4}_{2}He$

31. State whether the following nuclear disintegrations are allowed or not (star indicates an excited state). Given reason if it is not allowed.

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

(b) $^{A}_{Z}X \rightarrow {}_{Z-2}^{A}X + {}^{4}_{2}He$

Ans. (a) allowed (b) not allowed

Reason : mass number is not conserved in (b)

32. A nucleus $^{24}_{11}Na$ is β-radioactive.

(a) What are the numbers 24 and 11 called ?

(b) Write the equation representing β-decay.

(c) What general name is given to the product nucleus with respect to $^{24}_{11}Na$?

Ans. (a) 24 – mass number, 11 – atomic number

(b) $^{24}_{11}Na \rightarrow {}^{24}_{12}Mg + {}^{0}_{-1}e$ (c) isobar

33. A nucleus of stable phosphorus has 15 protons and 16 neutrons.

(a) What is its atomic number and mass number ?

(b) The nucleus of radio phosphorus has one neutron more than the stable nucleus. What will be its atomic number and mass number ?

(c) What will be the atomic number and mass number of new nucleus formed by the decay of a β–particle by the radio phosporus in part (b) ?

Ans. (a) atomic number = 15, mass number = 31
(b) atomic number = 15, mass number = 32
(c) atomic number = 16, mass number = 32

34. An element P disintegrates by α emission and the new element suffers two further disintegrations, both by β emission, to form an element Q. Explain the fact that P and Q are isotopes.

Ans. The atomic number of P decreases by 2 due to the emission of one α-partcle and then increases by 1 due to the emission of each β-particle, so the atomic number of Q formed after the emission of one α and two β particles is same as that of P. Hence P and Q are isotopes. The mass number of Q is less by 4 than that of P.

35. A nucleus $^{A}_{Z}X$ emits 2 α particles and 1 β particle to form a nucleus $^{222}_{85}R$. Find the atomic number and mass number of X.

Ans. atomic number Z = 88, mass number A = 230

36. Complete the following sentences :

(a) The mass number and atomic number of an element are not changed when it emits ....

(b) The atomic number of a radioactive element is not changed when it emits ....

(c) During the emission of a beta particle, the .... number remains same.

Ans. (a) γ radiations (b) γ radiations (c) mass

37. Complete the following nuclear changes :

(a) ${}^{a}_{z}P \longrightarrow Q + {}^{0}_{-1}\beta$

(b) ${}^{238}_{92}U \longrightarrow {}^{234}_{90}Th + \ldots\ldots + \text{energy}$

(c) ${}^{238}_{92}P \xrightarrow{\alpha} Q \xrightarrow{\beta} R \xrightarrow{\beta} S$

(d) ${}^{A}_{Z}X \xrightarrow{\alpha} X_1 \xrightarrow{\gamma} X_2 \xrightarrow{2\beta} X_3$

(e) $X \xrightarrow{\beta} X_1 \xrightarrow{\alpha} X_2 \xrightarrow{\alpha} {}^{172}_{69}X_3$

Ans. (a) ${}^{a}_{z+1}Q$ (b) ${}^{4}_{2}He$ (c) ${}^{234}_{90}Q$, ${}^{234}_{91}R$, ${}^{234}_{92}S$

(d) ${}^{A-4}_{Z-2}X_1$, ${}^{A-4}_{Z-2}X_2$, ${}^{A-4}_{Z}X_3$ (e) ${}^{176}_{71}X_2$, ${}^{180}_{73}X_1$, ${}^{180}_{72}X$

38. What are radio isotopes ? Give *one* example of a radio isotope. State *one* use of radio isotopes.

39. Why are the alpha particles not used in radio therapy ?

[**Hint** : alpha particles cannot penetrate the human skin]

40. Why do we usually use isotopes emitting gamma radiations as radioactive tracers in medical science ?

[**Hint** : gamma radiations are most penetrating]

41. When does the nucleus of an atom become radioactive ?

42. Which of the following is the radio isotope in each pair (a), (b) and (c) ?

(a) ${}^{12}_{6}C$, ${}^{14}_{6}C$ (b) ${}^{30}_{15}P$, ${}^{32}_{15}P$ (c) ${}^{39}_{19}K$, ${}^{40}_{19}K$

Give reason for your answer.

Ans. (a) ${}^{14}_{6}C$, (b) ${}^{32}_{15}P$, (c) ${}^{40}_{19}K$

Reason : The number of neutrons exceeds the number of protons.

43. State the medical use of radioactivity.

44. Arrange the α, β and γ radiation in ascending order of their biological damage. Give reason.

Ans. $\alpha < \beta < \gamma$

Reason : γ radiation has the penetrating power more than the β radiation and the penetrating power of β radiation is more than that of the α radiation.

45. Name *two* main sources of nuclear radiations. How are the nuclear radiations harmful ?

46. State *two* safety measures to be taken while establishing a nuclear power plant.

47. What is meant by nuclear waste ? State *one* way for the safe disposal of nuclear waste.

48. State *three* safety precautions that you would take while handling the radioactive substances.

49. Why should a radioactive substance not be touched by hand ?

50. What do you mean by background radiations ? Name its *two* sources. Is it possible for us to keep ourselves away from it ?

MULTIPLE CHOICE TYPE

1. A radioactive substance emits radiations :

(a) α, β and γ simultaneously

(b) in the order α, β and γ one by one

(c) X-rays and γ-rays

(d) α or β.

Ans. (d) α or β

2. In β-emission from a radioactive substance, an electron is ejected. This electron comes from :

(a) the outermost orbit of atom

(b) the inner orbits of atom

(c) the surface of substance

(d) the nucleus of atom.

Ans. (d) the nucleus of atom

3. The least penetrating radiation is :

(a) α-particles (b) β-particles

(c) X-rays (d) γ radiations.

Ans. (a) α-particles

4. The radiation suffering the maximum deflection in a magnetic field is :

(a) α-particles (b) β-particles

(c) X-rays (d) γ radiations.

Ans. (b) β-particles

(B) NUCLEAR FISSION AND FUSION

12.18 NUCLEAR ENERGY

In a nuclear change due to a radioactive phenomena (such as decay, fission or fusion), the total sum of masses of product nuclei is always less than the total sum of the masses of reactant nuclei. Thus there is a *loss in mass*. In 1905, on the basis of theory of relativity Einstein suggested that *mass and energy are interchangeable*. Due to loss in mass Δm, the energy released is E where

$$E = (\Delta m)c^2 \qquad .....(12.2)$$

Here Δm is the loss in mass in kg, c is the speed of light (3×10^8 m s^{-1}) and E is the energy in joule (J).

When 1 kg mass is lost, the amount of energy released is

$$E = (\Delta m)\ c^2 = 1 \times (3 \times 10^8)^2 = 9 \times 10^{16}\ \text{J}$$

Since 1 kWh = $3{\cdot}6 \times 10^6$ J

$$\therefore \quad E = \frac{9\times10^{16}}{3{\cdot}6\times10^6}\ \text{kWh} = 2{\cdot}5 \times 10^{10}\ \text{kWh}.$$

Thus, 1 kg mass is equivalent to 9×10^{16} J or $2{\cdot}5 \times 10^{10}$ kWh of energy. The energy so obtained is called the *nuclear energy*.

In class IX, we have read that the mass of atomic particles is expressed in atomic mass unit (a.m.u) or unified unit (u) where

$$1\ \text{a.m.u.} = \frac{1}{12} \times \text{mass of one atom of carbon-12.}$$

$$\text{or } 1\ \text{a.m.u.} = \frac{1}{12} \times \frac{12\times10^{-3}\ \text{kg}}{6{\cdot}02\times10^{26}\ \text{per kg mol}}$$

$$= 1{\cdot}66 \times 10^{-27}\ \text{kg}$$

Due to loss in mass Δm = 1 a.m.u., the energy released is

$$E = (1{\cdot}66 \times 10^{-27}) \times (3 \times 10^8)^2\ \text{J}$$

$$= 1{\cdot}49 \times 10^{-10}\ \text{J}$$

But 1 MeV = $1{\cdot}6 \times 10^{-13}$ J

$$\therefore \quad E = \frac{1{\cdot}49\times10^{-10}}{1{\cdot}6\times10^{-13}}\ \text{MeV} = 931\ \text{MeV}$$

$$\text{or} \quad \boxed{1\ \text{a.m.u.} = 931\ \text{MeV}} \qquad ...(12.3)$$

Thus, 1 a.m.u. of mass is equivalent to 931 MeV of energy.

Note : The mass of an electron, proton and neutron in terms of kg, a.m.u. and MeV are as follow :

Mass of electron = $9{\cdot}1091 \times 10^{-31}$ kg
= $0{\cdot}00055$ a.m.u.
= $0{\cdot}511$ MeV

Mass of proton = $1{\cdot}6725 \times 10^{-27}$ kg
= $1{\cdot}00727$ a.m.u.
= $938{\cdot}3$ MeV

Mass of neutron = $1{\cdot}6748 \times 10^{-27}$ kg
= $1{\cdot}00865$ a.m.u.
= 939 MeV

12.19 NUCLEAR FISSION

Nuclear fission is the process in which a heavy nucleus is splitted into two light nuclei nearly of the same size by bombarding it with slow neutrons. In each fission reaction, a tremendous amount of energy ($\approx$ 190 MeV) is released.

The reason for the release of energy is that the sum of masses of the product nuclei is less than the sum of mass of the parent nucleus and neutron, *i.e.*, there is a loss of mass in this reaction. This loss in mass is converted into energy by the Einsten's mass-energy relation $E = (\Delta m)c^2$.

In 1939, Strassman and Otto-Hann found that when a slow neutron strikes the $^{235}_{92}$U nucleus, it gets absorbed in it and a most unstable isotope $^{236}_{92}$U is formed which splits into two nuclei (i) barium ($^{144}_{56}$Ba) and (ii) krypton ($^{89}_{36}$Kr), with the release of three neutrons and a tremendous amount of energy, as shown in Fig. 12.10. The fission reaction is expressed as follows :

$$\underset{\text{(uranium)}}{^{235}_{92}\text{U}} + \underset{\text{(neutron)}}{^1_0 n} \rightarrow (^{236}_{92}\text{U}) \rightarrow \underset{\text{(barium)}}{^{144}_{56}\text{Ba}} + \underset{\text{(krypton)}}{^{89}_{36}\text{Kr}} + \underset{\text{(neutrons)}}{3\ ^1_0 n} + \text{energy}$$

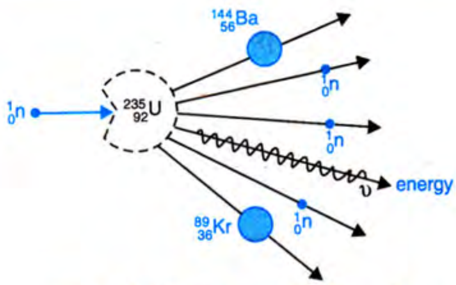

Fig. 12.10 Fission of $^{235}_{92}$U nucleus

Later on, it was found that $^{236}_{92}$U isotope decays not only into $^{144}_{56}$Ba and $^{89}_{36}$Kr fragments, but it can decay in different pairs of nuclei such as ($^{141}_{56}Ba$, $^{92}_{36}Kr$); ($^{148}_{57}La$, $^{85}_{35}Br$), etc. for which nuclear reactions are :

$$^{235}_{92}U + ^1_0n \rightarrow (^{236}_{92}U) \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^1_0n + \text{energy}$$

$$^{235}_{92}U + ^1_0n \rightarrow (^{236}_{92}U) \rightarrow ^{148}_{57}La + ^{85}_{35}Br + 3\,^1_0n + \text{energy}$$

> ***Note :*** (1) In each fission reaction, the atomic number (Z) and mass number (A) remain conserved.
>
> (2) The two fragments obtained on fission of one U-235 nucleus are unstable and they emit β-particles and γ rays to become stable.

Nuclear energy obtained in one fission reaction of $^{235}_{92}U$ nucleus : Due to fission of one uranium nucleus, nearly 190 MeV energy is released. The cause of emission of this energy is the loss in mass *i.e.*, the sum of masses of product nuclei is less than the sum of mass of the parent nucleus and neutron. Consider the fission reaction of $^{235}_{92}U$ nucleus as :

$$^{235}_{92}U + ^1_0n \rightarrow ^{144}_{56}Ba + ^{89}_{36}Kr + 3\,^1_0n + \text{energy}$$

If we take the mass of neutron = 1·01 a.m.u., mass of uranium-235 nucleus = 234·99 a.m.u., mass of barium-144 nucleus = 143·87 a.m.u., mass of krypton-89 nucleus = 88·90 a.m.u., then

Loss in mass in fission reaction of one nucleus

Δm = (mass of $^{235}_{92}U$ nucleus + mass of 1 neutron) – (mass of $^{144}_{56}Ba$ nucleus + mass of $^{89}_{36}Kr$ nucleus + mass of 3 neutrons)

= [(234·99 + 1·01) – (143·87 + 88·90 + 3 × 1·01)] a.m.u.

= (236·00 – 235·80) a.m.u = 0·20 a.mu.

But from the mass-energy equivalence $E = (\Delta m)c^2$

1 a.m.u. = 931 MeV

∴ Energy released E = 0·20 × 931 MeV = 190 MeV

Thus in the fission of one $^{235}_{92}U$ nucleus, nearly 190 MeV energy is released. The major part of this energy is obtained in form of the kinetic energy of the fragments obtained from the fission and the remaining part is obtained in the form of the kinetic energy of the neutrons emitted, γ-rays, heat and light.

Due to fission of 1 g of $^{235}_{92}U$ (= $2{\cdot}56 \times 10^{21}$ nucleus), nearly $4{\cdot}8 \times 10^{23}$ MeV energy is released from which $2{\cdot}1 \times 10^4$ kWh electrical energy can be obtained. Actually this much energy is generated due to the explosion of nearly 20 tonne of trinitrotoluene (TNT).

> ***Note :*** The ore of uranium found in nature contains two isotopes (99·3% $^{238}_{92}U$ and 0·7% $^{235}_{92}U$). Although both the isotopes are fissionable, but experimentally it is found that the isotope $^{235}_{92}U$ is more easily fissionable than the isotope $^{238}_{92}U$. The reason is that *the fission of $^{238}_{92}U$ nucleus is possible only by the fast neutrons, while the fission of $^{235}_{92}U$ nucleus can be even by the slow neutrons.*

Controlled and uncontrolled chain reactions

We have read that when slow neutrons are bombarded on uranium-235 ($^{235}_{92}U$), each uranium nucleus splits into two nearly equal fragments ($^{144}_{56}Ba$ and $^{89}_{36}Kr$), with a release of three new neutrons and tremendous amount of energy (nearly 190 MeV). These new neutrons can fission the other uranium nuclei under the suitable conditions. Thus a chain of fission of nuclei is formed which once started, continues till the entire uranium is consumed. Hence the energy obtained from the nuclear fission continuously increases. Due to such a chain reaction, a strong explosion of entire uranium occurs in a very short interval of time and tremendously high energy is released which can be very harmful. This is the *uncontrolled chain reaction*. A nuclear bomb is based on it.

If the chain reaction is *controlled* by absorbing some of the neutrons emitted in the fission process by means of moderators (such as graphite, heavy water, etc.), the energy obtained in fission can be utilised for the constructive purposes. This is the principle of a *nuclear reactor*.

Uses of fission : The tremendous amount of energy released in the process of fission can be used in *two* ways : (1) for the destructive use, and (2) for the constructive use.

(1) **For the destructive use :** The fission process is used in a *nuclear bomb* (sometimes also called an atom bomb, but the word atom bomb is a misnomer) where the energy released is fast and uncontrolled.

(2) **For the constructive use :** The fission process is used in a nuclear reactor where the rate of release of energy is slow and controlled. This energy is used to generate the electric power*.

12.20 DISTINCTION BETWEEN THE RADIOACTIVE DECAY AND NUCLEAR FISSION

Although both the radioactive decay and nuclear fission are the nuclear phenomena, but they differ as follows.

Radioactive decay	Nuclear fission
(1) It is a self process.	(1) It does not occur by itself. For it, neutrons are bombarded on a heavy nucleus.
(2) The nucleus emits either the α or β particles with the emission of energy in form of γ rays which is not very large.	(2) On bombardment of a heavy nucleus with neutrons, a tremendous amount of energy is released and the nucleus splits in two nearly equal fragments.
(3) The rate of radioactive decay can not be controlled.	(3) The rate of nuclear fission can be controlled.

12.21 NUCLEAR FUSION

Nuclear fusion is the process in which two light nuclei combine to form a heavy nucleus. In this process also, huge amount of energy is released.

The reason for the release of energy is that the mass of the product nucleus is less than the sum of masses of the two combining nuclei. This loss in mass is released in form of energy according to the mass-energy equivalence relation $E = (\Delta m)c^2$.

Example **:** When two deuterium nuclei ($^2_1$H) fuse, 3·3 MeV energy is released and the nucleus of helium isotope ($^3_2$He) is formed. This helium isotope again gets fused with one deuterium nucleus to form a helium nucleus ($^4_2$He) and 18·3 MeV energy is released in this process. The nuclear reactions are :

$$\underset{\text{(deuterium)}}{^2_1\text{H}} + \underset{\text{(deuterium)}}{^2_1\text{H}} \rightarrow \underset{\text{(helium isotope)}}{^3_2\text{He}} + \underset{\text{(neutron)}}{^1_0 n} + 3{\cdot}3 \text{ MeV}$$

$$\underset{\text{(helium isotope)}}{^3_2\text{He}} + \underset{\text{(deuterium)}}{^2_1\text{H}} \rightarrow \underset{\text{(helium)}}{^4_2\text{He}} + \underset{\text{(proton)}}{^1_1\text{H}} + 18{\cdot}3 \text{ MeV}$$

Thus in all, three deuterium nuclei fuse to form a helium nucleus with a release of 21·6 MeV energy. A part of this energy is obtained in form of the kinetic energy of neutron ($^1_0 n$) and proton ($^1_1$H).

Other examples of fusion reaction

(1) $\underset{\text{(proton)}}{^1_1\text{H}} + \underset{\text{(proton)}}{^1_1\text{H}} \rightarrow \underset{\text{(deuterium)}}{^2_1\text{H}} + 0{\cdot}42 \text{ MeV}$

* Refer chapter 6 of class IX Concise Physics

(2) $^{2}_{1}H$ (deuterium) + $^{2}_{1}H$ (deuterium) → $^{3}_{1}H$ (tritium) + $^{1}_{1}H$ (proton) + 4·0 MeV

(3) $^{2}_{1}H$ (deuterium) + $^{3}_{1}H$ (tritium) → $^{4}_{2}He$ (helium) + $^{1}_{0}n$ (neutron) + 17·6 MeV

(4) $^{2}_{1}H$ (deuterium) + $^{2}_{1}H$ (deuterium) → $^{3}_{2}He$ (helium isotope) + $^{1}_{0}n$ (neutron) + 3·3 MeV

(5) $^{3}_{2}He$ (helium isotope) + $^{2}_{1}H$ (deuterium) → $^{4}_{2}He$ (helium) + $^{1}_{1}H$ (proton) + 18·3 MeV

Nuclear fusion is not possible at ordinary temperature and ordinary pressure. The reason is that when two nuclei approach each other, due to their positive charge, the electrostatic force of repulsion between them becomes too strong that they do not fuse. Hence to make the fusion possible, a high temperature ($\approx 10^7$ K) and high pressure is required. At such a high temperature, both nuclei due to thermal agitations acquire sufficient kinetic energy so as to overcome the force of repulsion between them when they approach each other, and so they get fused. This is why the fusion reaction is also called the *thermo-nuclear reaction.*

Note : **(1)** The source of energy in sun and stars is the nuclear fusion of light nuclei (such as hydrogen) present in them in their inner part at a very high temperature ($\approx 10^7$ K) and high pressure, as a result of which helium nucleus is formed with a release of tremendous amount of energy. The reaction is :

$^{1}_{1}H + ^{1}_{1}H + ^{1}_{1}H + ^{1}_{1}H$ (four hydrogen) → $^{4}_{2}He$ (helium) + $2\,^{0}_{+1}\beta$ (positron) + 2υ (neutrino) + energy (26·7 MeV)

Thus in this process, four hydrogen nuclei fuse to form a helium nucleus with a release of 26·7 MeV energy.

(2) The working of hydrogen bomb is based on nuclear fusion in which a high temperature ($\approx 10^7$ K) required for the fusion reaction is obtained by the bombardment of the nuclear bomb.

(3) Although it appears that the energy released in nuclear fusion is much less than that released in nuclear fission, but indeed it is not so. For a given mass, the energy released due to fusion of light nuclei is much more than the energy released due to fission of same mass of a heavy nucleus. The reason is that for the same mass, the number of light nucleus is much more than the number of heavy nucleus. Hence the energy obtained per unit mass in fusion is much larger than the energy obtained per unit mass in fission. This is why scientist are engaged in getting energy by the process of fusion of deuterium which can be obtained in abundance from the sea water at a very low cost. But the main difficulty is that at 10^7 K, the substance get ionised *i.e.*, it is in the *plasma state* and it is very difficult to store it.

12.22 DISTINCTION BETWEEN THE NUCLEAR FISSION AND NUCLEAR FUSION

Nuclear fission	Nuclear fusion
(1) In fission when neutrons are bombarded on a heavy nucleus, it splits in two nearly equal light fragments.	(1) In fusion, at very high temperature and high pressure two light nuclei combine to form a heavy nucleus.
(2) This reaction is possible at ordinary temperature and ordinary pressure.	(2) This reaction is possible only at a very high temperature ($\approx 10^7$ K) and a very high pressure.
(3) In one fission reaction nearly 190 MeV energy is released.	(3) In one fusion reaction nearly 24·7 MeV energy is released.

(4) For the same mass, the energy released in the fission process is less than that in the fusion process.	(4) For the same mass, the energy released in fusion process is much more than that in fission process.
(5) The fissionable substance is radioactive, so it gives out the harmful radiations and it creates problem in disposal of its waste.	(5) The fusionable substance is not radioactive, so it does not give out any harmful radiation and disposal of its waste is also not difficult.
(6) The fissionable substance is found within limit.	(6) The fusionable substance is found in abundance.
(7) Fission process can be controlled. Nuclear reactor is based on the controlled fission reaction.	(7) Fusion reaction cannot be controlled. This is why fusion reactor could not be constructed so far.
(8) Nuclear bomb is based on the uncontrolled fission reaction.	(8) Hydrogen bomb is based on the uncontrolled fusion reaction.

EXAMPLES

1. Calculate the amount of energy released in MeV due to a loss of mass of 1 kg.

Given : $\Delta m = 1{\cdot}0$ kg, $c = 3 \times 10^8$ m s^{-1}

According to Einstein's mass-energy equivalence

$$\therefore \quad E = (\Delta m)c^2 = 1{\cdot}0 \times (3 \times 10^8)^2 = 9 \times 10^{16} \text{ joule}$$

$$= \frac{9\times10^{16}}{1{\cdot}6\times10^{-13}} \text{ MeV} = \mathbf{5{\cdot}625 \times 10^{29} \ MeV}$$

(since 1 MeV = $1{\cdot}6 \times 10^{-13}$ joule)

2. Calculate the loss in mass equivalent to the energy $1{\cdot}0 \times 10^6$ kWh.

Given : $E = 1{\cdot}0 \times 10^6$ kWh = $10^6 \times 3{\cdot}6 \times 10^6$ joule = $3{\cdot}6 \times 10^{12}$ joule

(since 1 kWh = $3{\cdot}6 \times 10^6$ joule)

From Einstein's mass-energy equivalence, loss in mass equivalent to energy E is $\Delta m = \dfrac{E}{c^2}$

$$\text{or} \quad \Delta m = \frac{3{\cdot}6\times10^{12}}{(3\times10^8)^2} = \mathbf{4 \times 10^{-5} \ kg}$$

3. If in nuclear fission of a piece of uranium, 0·5 g mass is lost, how much energy in kWh is obtained ?

Given : loss in mass $\Delta m = 0{\cdot}5$ g = $0{\cdot}5 \times 10^{-3}$ kg

The energy released in fission

$$E = (\Delta m)c^2 = (0{\cdot}5 \times 10^{-3}) \times (3 \times 10^8)^2 \text{ J} = 4{\cdot}5 \times 10^{13} \text{ joule}$$

Since 1 kWh = $3{\cdot}6 \times 10^6$ joule,

$$\therefore \quad E = \frac{4{\cdot}5\times10^{13}}{3{\cdot}6\times10^{6}} \text{ kWh} = \mathbf{1{\cdot}25 \times 10^7 \ kWh}$$

4. If 190 MeV energy is released due to fission of each nucleus of U-235, what mass of U-235 undergoes fission per hour in a reactor of power 300 MW ?

Take 1 a.m.u. = $1{\cdot}66 \times 10^{-27}$ kg.

Given : power of reactor = 300 MW = 300×10^6 W

Energy obtained in one hour (or 3600 s) from the reactor = power × time

$$= (300 \times 10^6) \times (3600) = 1{\cdot}08 \times 10^{12} \text{ J} \quad ...(i)$$

Energy released due to fission of one U-235 nucleus

$$= 190 \text{ MeV} = 190 \times 1{\cdot}6 \times 10^{-13} \text{ J} = 3{\cdot}04 \times 10^{11} \text{ J} \quad ...(ii)$$

From eqns. (i) and (ii),

Number of U-235 nuclei fissioned per hour

$$= \frac{1{\cdot}08\times10^{12}}{3{\cdot}04\times10^{-11}} = 3{\cdot}55 \times 10^{22}$$

Since mass of $6{\cdot}02 \times 10^{23}$ U-235 nuclei is 235 g

$\therefore$ Mass of $3{\cdot}55 \times 10^{22}$ nuclei

$$= \frac{235}{6{\cdot}02\times10^{23}} \times 3{\cdot}55 \times 10^{22} = \mathbf{13{\cdot}9 \ g}$$

5. In a nuclear fusion reaction, the loss in mass is 0·3%. How much energy is released in the fusion of 1 kg mass ?

Given : mass lost in fusion reaction $\Delta m = 0{\cdot}3\%$

$\therefore$ Loss in mass in fusion of 1 kg mass

$$= \frac{0{\cdot}3}{100} \times 1 \text{ kg} = 0{\cdot}003 \text{ kg}$$

Energy released $E = (\Delta m)c^2 = 0{\cdot}003 \times (3 \times 10^8)^2$

$= \mathbf{2{\cdot}7 \times 10^{14}}$ **joule.**

EXERCISE–12(B)

1. What do you mean by nuclear energy ? What is responsible for its release ?
2. Write down the Einstein's mass-energy equivalence relation, explaining the meaning of each symbol used in it.
3. (a) What is a.m.u ? Express 1 a.m.u. in MeV.
   (b) Write the approximate mass of a proton, neutron and electron in a.m.u.
4. What is nuclear fission ? Name the particle used for it. Write *one* fission reaction.
5. (a) Name *two* isotopes of uranium.
   (b) Which of the isotope mentioned in part (a) above is easily fissionable ? Give reason.
   (c) State whether the neutron needed for fission reaction of the isotope mentioned in part (b) above, is slow or fast ?
6. Write the approximate value of the energy released in the fission of one nucleus of $^{235}_{92}U$. What is the reason for it ?
7. Complete the following nuclear fission reactions :
   (a) $^{235}_{92}U + ^{1}_{0}n \rightarrow {}_{56}Ba + ^{92}Kr + 3\,^{1}_{0}n + ...$
   (b) $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{148}La + ^{85}_{35}Br + ...\,^{1}_{0}n + \text{energy}$
   Ans. (a) $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n + \text{energy}$
   (b) $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{148}_{57}La + ^{85}_{35}Br + 3^{1}_{0}n + \text{energy}$
8. What do you mean by the chain reaction in nuclear fission ? How is it controlled ?
9. State *two* uses of nuclear fission.
10. Give *two* differences between the radioactive decay and nuclear fission.
11. (a) What is nuclear fusion ? Give *one* example and write its nuclear reaction.
    (b) What other name is given to nuclear fusion ? Give reason.
12. Why is a very high temperature required for the process of nuclear fusion ? State the approximate temperature required.
13. (a) Write *one* nuclear fusion reaction.
    (b) State the approximate value of energy released in the reaction mentioned in part (a).
    (c) Give reason for the release of energy stated in part (b).
14. Complete the following fusion reactions :
    (a) $^{3}_{2}He + ^{2}_{1}H \rightarrow {}_{2}He + {}_{1}H + \text{energy}$
    (b) $^{2}_{1}H + ^{2}_{1}H \rightarrow {}_{2}He + ^{1}n + \text{energy}$
    Ans. (a) $^{3}_{2}He + ^{2}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{1}H + \text{energy}$
    (b) $^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + ^{1}_{0}n + \text{energy}$
15. (a) Name the process, nuclear fission or nuclear fusion, in which the energy released per unit mass is more ?
    (b) Name the process, fission or fusion which is possible at ordinary temperature.
16. (a) State *one* similiarity in the process of nuclear fission and fusion.
    (b) State *two* differences between the process of nuclear fission and fusion.
17. Give *two* examples of nuclear fusion.
18. What is the source of energy of sun or stars ?
19. Name the following nuclear reactions :
    (a) $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{90}_{38}Sr + ^{143}_{54}Xe + 3\,^{1}_{0}n + \gamma$
    (b) $^{3}_{1}H + ^{2}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + \gamma$
    Ans. (a) fission (b) fusion

MULTIPLE CHOICE TYPE

1. The particle used in nuclear fission for bombardment is :
   (a) alpha particle (b) proton
   (c) beta particle (d) neutron. **Ans.** (d) neutron
2. The temperature required for the process of nuclear fusion is nearly :
   (a) 1000 K (b) 10^4 K
   (c) 10^5 K (d) 10^7 K **Ans.** (d) 10^7 K

NUMERICALS

1. In fission of one uranium-235 nucleus, the loss in mass is 0·2 a.m.u. Calculate the energy released.
   Ans. 186·2 MeV
2. When four hydrogen nuclei combine to form a helium nucleus in the interior of sun, the loss in mass is 0·0265 a.m.u. How much energy is released ? **Ans.** 24·7 MeV