PERIOD-5

P12CH5

TOPIC

5

Atomic and Nuclear Physics

5.1 ATOMIC MASSES

The number of molecules in one mole of carbon is 6.02×10^{23} (Avogadro number). Since carbon is monatomic, therefore, there are 6.02×10^{23} atoms of carbon. These have a mass of 12 g.

$$\therefore \quad \text{Mass of 1 atom of carbon} = \frac{12}{6.02 \times 10^{23}}\text{ g} = \frac{12}{6.02 \times 10^{26}}\text{ kg}$$

$$\therefore \quad 1\text{ amu} = \frac{1}{12} \times \frac{12}{6.02 \times 10^{26}}\text{ kg} = 1.66 \times 10^{-27}\text{ kg}$$

Atomic masses are conventionally expressed in atomic mass units such that the mass of the most abundant type of carbon atom is, by definition, exactly 12.00 atomic mass unit.

5.2 COMPOSITION OF NUCLEUS—PROTONS AND NEUTRONS

Rutherford's experiment on the scattering of α-rays led us to conclude that an atom has a tiny central hard core. Nearly the whole mass of the atom is concentrated in this core. This central core is named as *nucleus*. The electrons revolve around the nucleus in different orbits in the same manner in which planets of our solar system revolve around the Sun. It is for this reason that electrons are sometimes called *planetary electrons*.

Every atomic nucleus contains basically two types of particles-protons and neutrons. The single exception is that of nucleus of hydrogen. This nucleus contains only one proton.

The total number of protons in atomic nucleus is equal to total number of electrons in atom. So, the total amount of negative charge present in atom is equal to the total amount of positive charge in the atom. This makes the atom, as a whole, electrically neutral.

A nucleus provides distinct individuality to an atom. Atoms of different elements possess different atomic nuclei. A nucleus has no well-defined boundary. However, for the sake of convenience, the nucleus is regarded as a hard sphere. It has been estimated that the size of the nucleus is of the order of 10^{-14} m. When compared with the size of atom (10^{-10} m), we conclude that an atom has a lot of empty space in it. A nucleus is symbolically represented as ${}^{A}_{Z}X$. Thus, Uranium nucleus is denoted by ${}^{235}_{92}U$. This indicates that there are 92 protons in Uranium nucleus and (235 – 92) *i.e.,* 143 neutrons. In other words, the mass number of Uranium nucleus is 235 and atomic number is 92. The mass number of a nucleus is the total number of nucleons in the nucleus. This determines the mass of the nucleus.

The number of neutrons in a nucleus is given by,

$$N = A - Z$$

where A is mass number and Z is atomic number of nucleus.

Proton is a fundamental particle. It may also be called the *nucleus of hydrogen.* It has positive charge of 1.6×10^{-19} C. Its mass is 1.67×10^{-27} kg. It is 1836 times heavier than an electron.

Neutron is also a fundamental particle. It is an integral constituent of all nuclei except that of hydrogen. It is an electrically neutral entity which was discovered in 1932. Its mass is 1.675×10^{-27} kg. So, it is 1840 times heavier than an electron.

5.3 SIZE OF NUCLEUS

It has been confirmed by various experiments that the nucleus does not have a sharp or well-defined boundary.

However, the nuclear radius R can be given by $R = R_0 A^{1/3}$, where R_0 (= 1.2×10^{-15} m) is a constant which is the same for all nuclei and A is the mass number of the nucleus.

The unit of nuclear radius is fermi of the order of 1 fm = 10^{-15} m

The nuclear radii range from 1 fm to 10 fm.

Nuclear volume, $$V = \frac{4}{3}\pi R^3 = \frac{4}{3}\pi (R_0 A^{1/3})^3 = \frac{4}{3}\pi R_0^3 A$$

It is clear from here that the nuclear volume is proportional to mass number.

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*This is, roughly speaking, atomic weight.

**Nucleons are the particles present in the nucleus.

5.4 NUCLEAR DENSITY

Consider a nucleus of mass number A and radius R.

$$\text{Mass of nucleus} = \text{A amu} = \text{A} \times 1.66 \times 10^{-27}\ \text{kg}$$

$$\text{Volume of nucleus} = \frac{4}{3}\pi R_0{}^3 A = \frac{4}{3} \times \frac{22}{7} \times (1.2 \times 10^{-15})^3\ \text{A m}^3$$

$$= 7.24 \times 10^{-45}\ \text{A m}^3$$

$$\text{Density of nucleus,}\quad \rho = \frac{A \times 1.66 \times 10^{-27}}{7.24 \times 10^{-45} \times A}\ \text{kg m}^{-3}$$

$$= 2.29 \times 10^{17}\ \text{kg m}^{-3}$$

Discussion. **(i)** The nuclear density does not depend upon mass number. So, we can safely conclude that all nuclei possess nearly the same density.

(ii) The nuclear density has extremely large value. Such high densities are found in white dwarf stars which contain mainly the nuclear matter.

(iii) The nuclear density is *not uniform* throughout the nucleus. It has maximum value at the centre and decreases gradually as we move away from the centre of the nucleus.

Example 2: *Find the density of nuclear mass in* ${}^{238}_{92}U$ *nucleus. Given :* $R_0 = 1.5$ *fermi, mass of each nucleon* $= 1.67 \times 10^{-27}$ *kg.*

Solution: Mass number of ${}^{238}_{92}\text{U} = 238$

$$R_0 = 1.5\ \text{fm} = 1.5 \times 10^{-15}\ \text{m}$$

Mass of each nucleon

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

$$\text{Density,}\quad \rho = \frac{\text{Mass}}{\text{Volume}} = \frac{1.67 \times 10^{-27} \times A}{\frac{4}{3}\pi R^3}$$

$$= \frac{1.67 \times 10^{-27} \times A \times 3 \times 7}{4 \times 22\,(R_0 A^{1/3})^3}$$

$$\text{or}\quad \rho = \frac{1.67 \times 10^{-27} \times 21 \times A}{88 \times (1.5 \times 10^{-15})^3\ A}\ \text{kg m}^{-3}$$

$$= \mathbf{1.18 \times 10^{17}\ kg\ m^{-3}}$$

5.5 ISOTOPES

These are the atoms of the same element having the same atomic number but different atomic weights. Such nuclides having same number of protons but different number of neutrons are called *isotopes*. In other words, they have same atomic number Z, but different mass number A.

The number of orbital electrons is the same in isotopes of elements. This explains as to why they possess identical chemical properties.

The isotopes of an element may have same name or different names. As an example, the three isotopes ${}_1^1H$, ${}_1^2H$, and ${}_1^3H$ of hydrogen are known as Hydrogen, Deuterium and Tritium.

5.6 ISOBARS

In Greek language, 'bar' means weight and 'iso' means equal. Two elements which are chemically different, but have physically the same mass are called *isobars.* So, isobars are atoms of different elements having the same atomic mass but different atomic number. Since Z number of isobars are different therefore they do not occupy the same place in periodic table. Also, for the same reason, their chemical properties are widely different from each other.

Examples of isobars. (i) ${}_{18}^{40}Ar$ and ${}_{20}^{40}Ca$ **(ii)** ${}_{26}^{58}Fe$ and ${}_{27}^{58}Ni$.

5.7 MASS DEFECT

Consider a nucleus of mass number A and atomic number Z. It will contain Z protons and (A – Z) neutrons. The mass of the constituent nucleons will be $[Zm_p + (A - Z)m_n]$. Here m_p and m_n are the masses of proton and neutron respectively.

It has been observed that the rest mass M of the nucleus is always less than the mass of the constituent particles. *The difference between the rest mass of the nucleus and the sum of the masses of the nucleons composing a nucleus is known as* ***mass defect.*** *It is given by,*

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

As an example, consider the mass defect in the case of deuteron. It is an isotope of hydrogen. It contains one proton and one neutron.

$$m_p = \text{mass of proton} = 1.007825 \text{ amu}$$
$$m_n = \text{mass of neutron} = 1.008665 \text{ amu}$$
$$m_p + m_n = 2.016490 \text{ amu}$$
$$\text{M} = \text{mass of deuteron} = 2.014103 \text{ amu}$$

Mass defect, $\Delta m = m_p + m_n - \text{M} = 0.002387$ amu

Thus, when a proton and neutron are brought together to form a deuteron, a part of their masses is lost.

5.8 BINDING ENERGY

It is the energy required to break up a nucleus into its constituent parts and place them at an infinite distance from one another.

The binding energy is related to mass defect by Einstein's mass-energy relation. If Δm be the mass defect, then

Binding energy = Δmc^2, where c is the speed of light.

In the case of deuteron:

Binding energy = 0.002387 × 931 MeV = **2.22 MeV**

Thus, an energy of 2.22 MeV is required to separate by an infinite distance a neutron from proton. This has been confirmed experimentally.

5.9 UNITS OF ENERGY

The nuclear energy is generally measured in electron volt. It is defined as the amount of energy acquired by an electron when accelerated through a potential difference of 1 volt.

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ C} \times 1 \text{ V} = 1.6 \times 10^{-19} \text{ J}$$

The megaelectron volt (MeV) is a larger energy and is defined as 1 million eV.

So, $1 \text{ MeV} = 1.6 \times 10^{-13} \text{ J}$

If another unit of energy is needed, then one may use a unit of mass, since mass and energy are interchangeable. The atomic mass unit is defined as 1/12th of the mass of the carbon atom ${}^{12}_{6}\text{C}$. Now the number of molecules in 1 mole of carbon is 6.02×10^{23} (Avogadro constant) and since carbon is monatomic, therefore, there are 6.02×10^{23} atoms of carbon. These have a mass 12 g.

$$\therefore \quad \text{Mass of 1 atom of carbon} = \frac{12}{6.02 \times 10^{23}}\,\text{g} = \frac{12}{6.02 \times 10^{26}}\,\text{kg}$$

$$\therefore \quad 1 \text{ amu} = \frac{12}{12 \times 6.02 \times 10^{26}}\,\text{kg} = 1.66 \times 10^{-27}\,\text{kg (approx.)}$$

1 kg change in mass produces 9×10^{16} joule.

Again, $E = mc^2 = 1.66 \times 10^{-27} \times 9 \times 10^{16}$ joule

$$= \frac{1.66 \times 10^{-27} \times 9 \times 10^{16}}{1.6 \times 10^{-13}}\,\text{MeV} \quad (\because \ 1\,\text{MeV} = 1.6 \times 10^{-13}\,\text{J})$$

$$= 931 \text{ MeV (approx.)}$$

$\therefore$ 1 amu = 931 MeV (approx.)

5.10 RADIOACTIVITY

Henry Becquerel discovered the phenomenon of radioactivity in 1896. He found that certain compounds of uranium emitted invisible radiations which affected photographic plates. Later on, Thorium and its compounds were also found to behave in a similar way. Piere Curie and Madame Curie discovered a new element, called radium, which showed these properties. They also discovered another similar element which they named as 'polonium'. All these elements possess the property of emitting certain rays, spontaneously of their own accord. This phenomenon of emitting radiations spontaneously is called **radioactivity,** and the substance, which does so, is called a radioactive material.

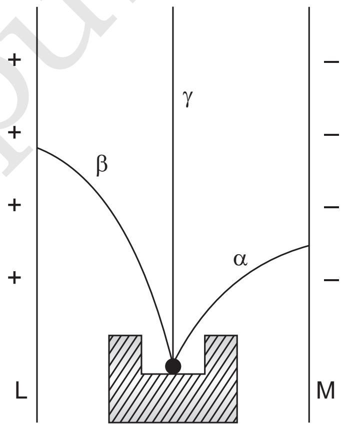

Fig. 5.1. Experimental set-up to demonstrate that there are three types of radiations.

The radiations emitted by a radioactive body are not homogeneous but consist of three distinct types of radiations. These are named as α, β and γ-rays. Also all the radiations are not emitted simultaneously. The nucleus emits a radiation (α or β) and changes into a new nucleus (hence a new element). To balance the energy, γ-radiations are emitted.

To show that there are three types of radiations, let us have the experimental set-up shown in Fig. 5.5. In a thick block of lead with a small hole in its centre, we place a radioactive material. The rays issue out upwards. In the region above, we create a strong electric field by placing two parallel plates connected to positive and negative terminals of a battery. We see that α-rays are deflected towards negative plate and β-rays towards positive plate. This shows that α-rays are positively charged particles. γ-rays go out straight, undeflected. These rays are like light. α and β-rays can be similarly deflected by a suitable magnetic field.

5.11 PROPERTIES OF α-RAYS

1. These are positively charged particles, each having a mass equal to four times the mass of hydrogen atom and charge $+ 2e$ (twice the charge of an electron). **2.** These are deflected by electric and magnetic fields. **3.** These affect photographic plates and cause fluorescence. **4.** These produce strong ionisation. **5.** These have small penetrating power. A piece of paper or a thin aluminium foil can stop them. **6.** These move with comparatively small velocities. These are nuclei of helium atoms ; and an α-particle consists of a closely packed group of two protons and two neutrons.

5.12 PROPERTIES OF β-RAYS

1. These are negatively charged particles, each having a mass and a charge equal to that of an electron. **2.** These are deflected by electric and magnetic fields. **3.** These affect photographic plates and cause fluorescence in various materials. **4.** These produce less ionisation than α-particles. **5.** These have a large penetrating power, greater than that of α-particles. An aluminium sheet 1 cm thick can stop β-rays. **6.** These move with greater velocities, sometimes up to 90% of the velocity of light. **7.** The mass of a β-particle increases with its velocity according to Einstein's relativistic mass relation.

5.13 PROPERTIES OF γ-RAYS

1. These are electromagnetic waves like light or X-rays, only having much greater energy, $h\nu$, and much smaller wavelength λ, than X-rays. **2.** These are undeflected by electric or magnetic fields. **3.** These produce little or no ionisation. **4.** These have the strongest penetrating power. These can pass through many centimetre of lead. **5.** These affect photographic plates and cause fluorescence similar to X-rays. **6.** These travel with the velocity of light. **7.** These are very harmful to human tissues. **8.** These produce photoelectric effect when these are made incident on solid surfaces.

5.14 SODDY'S DISPLACEMENT LAW OF RADIOACTIVE TRANSFORMATIONS

1. When a nucleus ejects an α-particle, the mass becomes less by 4 units and charge decreases by 2 units. Thus, the nucleus ${}^{A}_{Z}Y$ on emission of α-particle gets transformed into a new nucleus ${}^{A-4}_{Z-2}Y$.

$$\therefore \qquad {}^{A}_{Z}Y \xrightarrow{\alpha} {}^{A-4}_{Z-2}Y$$

Thus, the substance shifts or is displaced from its original position in the periodic table, two steps backwards.

2. When a nucleus ejects a β-particle, the mass remains unchanged and the charge increases by 1 unit. So a material ${}^{A}_{Z}Y$ on emission of β-particle gets transformed into a new nucleus as ${}^{A}_{Z+1}Y$.

Thus, the original substance shifts or is displaced one step higher in the periodic table.

Thus, $${}^{A}_{Z}Y \xrightarrow{\beta} {}^{A}_{Z+1}Y$$

3. When a nucleus emits γ-rays, the mass or the charge or the position of the nucleus in the periodic table are not affected. Only some energy is radiated and the original nucleus shifts from higher energy level to lower energy level.

5.15 RUTHERFORD AND SODDY'S LAWS OF RADIOACTIVE DECAY

1. The disintegration of radioactive material is purely a random process and it is merely a matter of chance, which nucleus will suffer disintegration, or decay first.

2. The rate of decay is completely independent of the physical composition and chemical condition of the material.

3. The rate of decay is directly proportional to the quantity of material actually present at that instant. Thus, as the decay goes on, the original material goes on decreasing in quantity and the rate of decay consequently goes on decreasing.

Thus from the third law, if N is the number of radioactive atoms present at any instant, then the rate of decay,

$$-\frac{dN}{dt} \propto N \quad \text{or} \quad -\frac{dN}{dt} = \lambda N,$$

where λ is the decay constant or the disintegration constant.

$$\therefore \qquad \frac{dN}{dt} = -\lambda N$$

On rearranging, $$\frac{dN}{N} = -\lambda\, dt$$

On integration $$\log_e N = -\lambda t + C$$

where C is the integration constant.

If at $t = 0$, we had N_0 atoms, $\log_e N_0 = 0 + C$

Thus, we get $$\log_e N - \log_e N_0 = -\lambda t$$

or $$\log_e \frac{N}{N_0} = -\lambda t$$

or $$\frac{N}{N_0} = e^{-\lambda t} \quad \text{or} \quad \boxed{N = N_0\, e^{-\lambda t}.}$$

This equation represents the radioactive decay law. It gives the number of active nuclei left after time t.

5.16 RADIOACTIVE DISINTEGRATION CONSTANT λ

According to the laws of radioactive decay, we have

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

If $dt = 1$ second, then $$\frac{dN}{N} = -\lambda$$

Thus, λ may be defined as the *relative number of atoms decaying per second.*

Again, since $N = N_0\, e^{-\lambda t}$

and if $$t = \frac{1}{\lambda}, \text{ we get } N = N_0\, e^{-1} = \frac{N_0}{e}$$

Thus, λ is also defined as *the reciprocal of the time when* $\frac{N}{N_0}$ *falls to* $\frac{1}{e}$.

5.17 HALF-LIFE PERIOD

Consider the situation when the decaying material is reduced to exactly $\frac{1}{2}$ of its original quantity. The time taken for this decay $\left(\frac{\mathrm{N}}{\mathrm{N_0}} = \frac{1}{2}\right)$ is called the half-life period of the material. *It is defined as the time required for the disappearance of half of the amount of the radioactive substance originally present.*

If T represents the half-life period, then

$$\frac{\mathrm{N}}{\mathrm{N_0}} = \frac{1}{2} = e^{-\lambda \mathrm{T}} \text{ or } e^{\lambda \mathrm{T}} = 2$$

$$\therefore \quad \lambda \mathrm{T} = \log_e 2 = 0.6931$$

$$\therefore \quad \mathrm{T} = \frac{0.6931}{\lambda} \quad \text{or} \quad \boxed{\lambda = \frac{0.6931}{\mathrm{T}}}$$

Combining these relations, we obtain

$$\frac{\mathrm{N}}{\mathrm{N_0}} = e^{-\lambda t}$$

$$\text{or} \quad \frac{\mathrm{N_0}}{\mathrm{N}} = e^{\lambda t}$$

$$\therefore \quad \log_e \frac{\mathrm{N_0}}{\mathrm{N}} = \lambda t$$

$$\text{or} \quad 2.303 \log_{10} \frac{\mathrm{N_0}}{\mathrm{N}} = \frac{0.6931}{\mathrm{T}}\, t$$

$$\text{or} \quad t = \frac{2.303}{0.6931}\, \mathrm{T} \log_{10} \frac{\mathrm{N_0}}{\mathrm{N}}$$

$$\text{or} \quad \boxed{t = 3.323\, \mathrm{T} \log_{10} \frac{\mathrm{N_0}}{\mathrm{N}}}$$

This relation shows that a material with a half-life period T changes in quantity from $\mathrm{N_0}$ to N in time t.

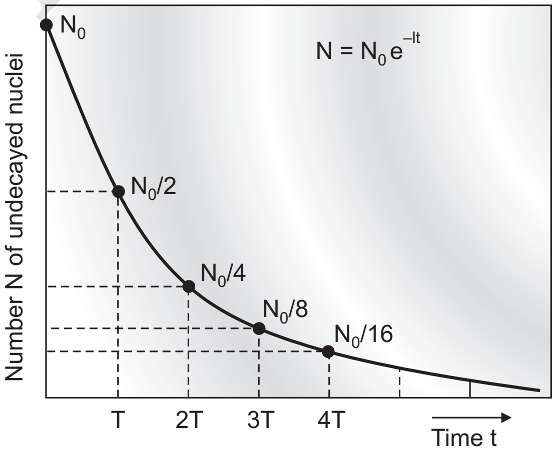

Fig. 5.2. Exponential decay of a radioactive species. After a lapse of T, population of the given species drops by a factor of 2.

5.18 UNITS OF RADIOACTIVITY

The activity of a radioactive sample is generally expressed in terms of its rate of decay. In other words, the activity of a radioactive sample is expressed in terms of the number of disintegrations per unit time. The radioactivity is measured in the following three units.

(i) The curie (Ci). This was originally defined as the activity of 1 g of radium in equilibrium with its by-products. But it is now defined as under :

The activity of a radioactive substance is said to be one curie if it undergoes 3.7×10^{10} *disintegrations per second.*

$$1 \text{ curie} = 3.7 \times 10^{10} \text{ disintegrations/s}$$

Smaller units are millicurie and microcurie.

$$1 \text{ millicurie} = 3.7 \times 10^{7} \text{ disintegrations/s}$$

$$1 \text{ microcurie} = 3.7 \times 10^{4} \text{ disintegrations/s}$$

(ii) The rutherford (Rd). *The activity of a radioactive substance is said to be one rutherford if it undergoes* 10^6 *disintegrations per second.*

$$1 \text{ rutherford} = 10^{6} \text{ disintegrations s}^{-1}$$

Smaller units are millirutherford and microrutherford.

$$1 \text{ millirutherford} = 10^{3} \text{ disintegrations s}^{-1}$$

$$1 \text{ microrutherford} = 1 \text{ disintegration s}^{-1}$$

(iii) The becquerel (Bq). *It is the SI unit for activity. The activity of a radioactive substance is said to be one becquerel if it undergoes 1 disintegration per second.*

$$1 \text{ becquerel} = 1 \text{ disintegration s}^{-1}$$

Relation between different units

$$1 \text{ curie} = 3.7 \times 10^{4} \text{ rutherford}$$

$$= 3.7 \times 10^{10} \text{ becquerel.}$$

5.19 NUCLEAR REACTIONS

When a nucleus is bombarded with nucleons or other sub-atomic particles, it undergoes a change in composition. A nuclear reaction indicates that change. ***A nuclear reaction may be defined as the***

transformation in nuclei brought about by their interaction with elementary particles or with different nuclei themselves.

Most nuclear reactions involve a nucleus A and a particle ‘*a*’, This pair is known as *parent pair.* After a collision between these two, a new nucleus B is formed and another particle ‘*b*’ is ejected. This pair is called the *final pair*. The nuclear reaction may be expressed as under :

$$A + a \longrightarrow B + b$$

In some reactions, energy Q is evolved. Such a reaction is known as **exothermic or exoergic reaction**. In a reaction in which energy is absorbed, the reaction is known as **endothermic or endoergic reaction**. So, in the final analysis, a nuclear reaction may be written as under :

$$A + a \longrightarrow B + b + Q$$

Here, in the usual expression, *a* is the bullet fired on a target A. This results in the recoil nucleus B and giving the product particle *b* with a release or absorption of reaction energy Q. Q is known as the reaction energy or Q-value of nuclear raction. *The absorption or evolution of energy in a nuclear reaction takes place in accordance with Einstein’s mass-energy equivalence relation.*

5.20 CONSERVATION LAWS IN NUCLEAR REACTIONS

Broadly, the following conservation laws are obeyed in nuclear reactions.

(i) Conservation of number of nucleons.

(ii) Conservation of charge. In a reaction, the total electric charge is conserved. This ultimately means that the total Z number, the atomic number is conserved.

(iii) Conservation of linear momentum. Like all physical processes involving collisions, the total momentum along any direction, before and after the event, is always conserved.

(iv) Conservation of angular momentum.

(v) Conservation of mass-energy. According to mass-energy equivalence in the theory of relativity, mass and energy are equivalent. So the principle of conservation of energy in mechanics has to be extended to the conservation of mass-energy in nuclear reactions. The mass-energy equation for the nuclear reaction may be written as :

$$m_1c^2 + E_{k_1} + m_2c^2 + E_{k_2} = m_3c^2 + E_{k_3} + m_4c^2 + E_{k_4}$$

where m_1, m_2, m_3 and m_4 are the rest masses and $E_{k_1}, E_{k_2}, E_{k_3}$ and E_{k_4} are their respective kinetic energies.

5.21 NUCLEAR FISSION

In 1939, German Scientists Otto Hahn and Strassmann while studying nuclear reactions, discovered that when a uranium nucleus is bombarded with a neutron, it explodes into two nearly equal fragments, Barium and Krypton. Since this process somewhat resembles fission of cells in biology, therefore this phenomenon of nuclear disintegration was also called fission.

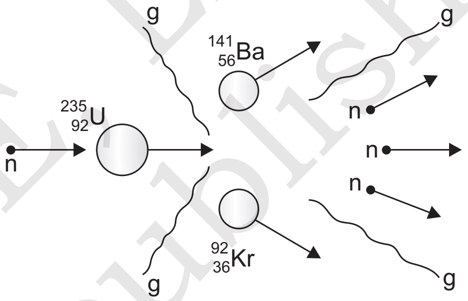

Fig. 5.3. Nuclear fission.

***Nuclear fission** is defined as a type of nuclear disintegration in which a heavy nucleus splits up into two nuclei of nearly comparable masses with liberation of energy.*

The fission is accompanied by the release of three neutrons and radiation energy in the form of γ-rays. The reaction is represented as :

$${}^{1}_{0}n + {}^{235}_{92}\text{U} \longrightarrow [{}^{236}_{92}\text{U}] \longrightarrow {}^{141}_{56}\text{Ba} + {}^{92}_{36}\text{Kr} + 3{}^{1}_{0}n + \gamma$$

The diagrammatic sketch is given in Fig. 5.7. A neutron strikes the ^{235}U nucleus and in the process two nuclides ^{141}Ba and ^{92}Kr are formed with the release of 3 neutrons as shown. The wavy lines indicate the energy released in the form of γ-radiations. An important point to note here is that a *slow* neutron is used to cause fission. Further whereas one neutron is lost in the process to produce fission, three neutrons are produced as a product of the fission. This fact has a tremendous significance in the construction of nuclear bomb.

Energy released in fission. The fission fragments Barium, Krypton and neutrons are released with high velocities. Also energy is released in the form of γ-rays. An estimate can be made as in the example given below :

Before the reaction:

$$\text{Mass of } {}^{235}_{92}\text{U} = 235.0439 \text{ amu ; Mass of } {}^{1}_{0}n = 1.0087 \text{ amu}$$

$$\text{Total mass} = 236.0526 \text{ amu} \qquad \ldots(i)$$

After the reaction:

$$\text{Mass of } {}^{141}_{56}\text{Ba} = 140.9129 \text{ amu ; Mass of } {}^{92}_{36}\text{Kr} = 91.8973 \text{ amu}$$

$$\text{Mass of three } {}^{1}_{0}n = 3.0261 \text{ amu}$$

$$\text{Total mass} = 235.8363 \text{ amu} \qquad \ldots(ii)$$

$$\text{Mass defect} = 0.2163 \text{ amu} \qquad [(i) - (ii)]$$

Since 1 amu = 931 MeV,

$\therefore$ The energy released = 931 × 0.2163 = 201.37 MeV ≈ 200 MeV

This is a huge figure. Calculations reveal that 235 g of Uranium, on complete fission, releases energy equivalent to the burning of about 600 tonnes of coal. However, this 200 MeV consists of K.E. of fission fragments, of released neutrons and of the γ-rays. Eventually, it is transferred to the surrounding matter appearing as heat.

5.22 NUCLEAR FUSION

We know 'fission' to be a process in which a heavy nucleus breaks up into two lighter nuclei. Fusion, on other hand, is the reverse of fission. Thus, fusion *is a process in which lighter nuclei merge into one another to form a heavier nucleus.* As in fission, fusion also is accompanied by a release of energy.

The binding energy per nucleus thus formed is greater than the binding energy per nucleon of the lighter elements, which fuse to form the single nucleus. Taking an example, let us consider the fusion of the deuterium nuclei to form a single helium nucleus :

We know that mass of a deuteron = 2.01471 amu

$\therefore$ Mass of two deuterons = 4.02942 amu

Mass of α-particle (*i.e.*, a Helium nucleus) = 4.00388 amu

$\therefore$ Δm, mass defect = 0.02554 amu

Since 1 amu = 931 MeV,

$$\therefore \quad \text{The energy liberated} = 0.02554 \times 931 \text{ MeV}$$
$$= 23.78 \text{ MeV} \approx 24 \text{ MeV}$$

Thus, a single helium nucleus formed out of fusion of two deuterons (*i.e.*, deuterium nuclei) releases 24 MeV energy. In case a large number of helium nuclei are fused, we readily see that a tremendous amount of energy is released.

Since both the deuterons are similarly charged (+ 1), therefore, we require a large amount of energy to bring the two together for fusion against Coulomb repulsion. Though theoretically this energy may be given to them by accelerating them through strong electric field, practically it is not easy or convenient. The other alternative is to give them high thermal energies. In the Sun and the stars, such high temperatures (≈ 10 Million K) are available which impart enough energy to the fusing particles which are protons or deuterons. Thus, such a fusion process is called a *thermonuclear fusion*.

5.23 ENERGY SOURCE OF STARS AND SUN

Proton-Proton Cycle. The interior of Sun is at about 27 million K. The thermonuclear reactions taking place are as follows :

$${}_1^1\text{H} + {}_1^1\text{H} \longrightarrow {}_1^2\text{H} + {}_1^0e + 0.4 \text{ MeV} \qquad \ldots(i)$$

$${}_1^1\text{H} + {}_1^2\text{H} \longrightarrow {}_2^3\text{He} + 5.5 \text{ MeV} \qquad \ldots(ii)$$

$${}_2^3\text{He} + {}_2^3\text{He} \longrightarrow {}_2^4\text{He} + 2{}_1^1\text{H} + 12.9 \text{ MeV} \qquad \ldots(iii)$$

The reactions (*i*) and (*ii*) occur twice. So, the net reaction is :

$$4{}_1^1\text{H} \longrightarrow {}_2^4\text{He} + 2{}_1^0\text{e} + 24.7 \text{ MeV}$$

Thus at that high temperature available in the core of the Sun, four protons fuse into a Helium nucleus with the release of two positrons and 24.7 MeV of energy.

Example 4: *A neutron is absorbed by a* ${}_3^6Li$ *nucleus with the subsequent emission of an alpha particle.*

(i) Write the corresponding nuclear reaction.

(ii) Calculate the energy released, in MeV, in this reaction.

Given : mass $^{6}_{3}Li$ *= 6.015126 u ; mass (neutron) = 1.0086654 u ; Mass (alpha particle) = 4.0026044 u and mass (triton) = 3.0100000 u. Take 1 u = 931 MeV/*c^2*.*

Solution: $^{6}_{3}\text{Li} + ^{1}_{0}n \longrightarrow ^{4}_{2}\text{He} + ^{3}_{1}\text{H} + Q$

$$\begin{aligned}\text{Total initial mass} &= 6.015126 + 1.0086654\\ &= 7.0237914 \text{ amu}\\ \text{Total final mass} &= 4.0026044 + 3.01\\ &= 7.0126044 \text{ amu}\\ \text{Mass defect, } \Delta m &= 7.0237914 - 7.0126044\\ &= 0.0111870 \text{ amu}\\ \text{Energy released, Q} &= 0.0111870 \times 931 \text{ MeV}\\ &= \mathbf{10.415\ MeV}.\end{aligned}$$

Example 6: *How many α and β-particles are emitted when* $^{238}_{92}U$ *changes into* $^{206}_{82}Pb$ *through a series of radioactive decays ?*

or

How many α and β-particles are lost when $^{238}_{92}U$ *changes into* $^{206}_{82}Pb$ *?*

Solution: Since the emission of β-particle has no effect on mass number, therefore, the change of mass number is purely due to the emission of α-particles. The emission of one α-particle reduces the mass number by 4.

$$\therefore \quad \text{Number of } \alpha\text{-particles emitted} = \frac{238 - 206}{4} = \frac{32}{4} = \mathbf{8}$$

Due to the emission of 8 α-particles, the charge number reduces by 8 × 2 *i.e.,* 16. So, due to the emission of 8 α-particles, the charge number becomes (92 – 16) *i.e.,* 76. But the charge number of the end product is 82. Clearly, the number of β-particles emitted is (82 – 76) *i.e.,* **6.**

Example 8: *If 200 MeV energy is released in the fission of a sample nucleus of* $^{235}_{92}U$ *, how many fissions must occur per second to produce a power of 1 kW ?*

Solution: Energy released by the fission of one nucleus of $^{235}_{92}U$

$$= 200 \text{ MeV} = 200 \times 1.6 \times 10^{-13} \text{ J}$$

$$= 3.2 \times 10^{-11} \text{ J}$$

$$1 \text{ kW} = 1000 \text{ W} = 1000 \text{ J s}^{-1}$$

If x be the number of fissions per second required to generate a power of 1 kW, then

$$x \times 3.2 \times 10^{-11} = 1000$$

or

$$x = \frac{1000}{3.2 \times 10^{-11}} = \mathbf{3.125 \times 10^{13}}$$

5.24 RADIATION HAZARDS

After the invention of the nuclear reactions as a pure scientific study, man developed the atomic and hydrogen bombs in an attempt to gain supremacy over other men. But in this process, the large amount of radiated energy to which mankind as a whole is exposed is really posing a problem even for human existence. These radiations are causing great dangers to human organism.

For instance, let us see how γ-ray acts on a human system. When γ-ray or any high energy nuclear particle passes through any material, it knocks out electrons from its atoms and ionises them. With the atom thus broken and ionised, the complex molecular structure of the organism becomes weak and may break up. This breaking up of the molecules disrupts the entire normal functioning of the biological system. This leads to a permanent damage of the tissues, and ultimately leads to death.

The extent to which a human organism is damaged depends upon (*i*) the dose and the rate at which the radiation is being given, (*ii*) the part of the body exposed to it. Our hands and feet, not being vital organs, can receive much greater dose than other parts of the body. The damage itself can be either (*i*) **pathological** or (*ii*) **genetic.**

In the **pathological damage,** the organism exposed to the radiation may ultimately die. This happens when the body is exposed to about 600 *r*. Smaller dose of 100 *r* approximately may cause a start of leukemia (death of red blood corpuscles in the blood) or cancer, which on spreading causes death ultimately.

The **genetic damage** is still worse. The radiations cause injury to genes in the reproductive cells. This gives rise to mutations which pass on from generation to generation. Mutations are always harmful and are irreversible. There is no way to escape from the results of this damage. In a simple language, it may mean that a person exposed to such damage may have a certain disorder; and all his subsequent generations will continue having the same disorder in their systems. The only hope and prayer is that when one is exposed to these radiations, the exposure is too small to cause any serious damage.

When an atom bomb explodes nearby, the radiations are extremely intense and sudden. This causes immediate death and destruction of life, pathologically, and damage to the heredity, by genetic damage.

5.25 CATHODE RAY

A cathode-ray tube (CRT) is a vacuum tube in which an electron beam, deflected by applied electric or magnetic fields, produces a trace on a fluorescent screen.

Cathode Ray Tube

The cathode ray tube (CRT), invented in 1897 by the German physicist Karl Ferdinand Braun, is an evacuated glass envelope containing an electron gun a source of electrons and a fluorescent light, usually with internal or external means to accelerate and redirect the electrons. Light is produced when electrons hit a fluorescent tube.

The electron beam is deflected and modulated in a manner that allows an image to appear on the projector. The picture may reflect electrical wave forms (oscilloscope), photographs (television, computer monitor), echoes of radar-detected aircraft, and so on. The single electron beam can be processed to show movable images in natural colours.

Cathode Ray Tube

J. J. Thomson designed a glass tube that was partly evacuated, *i.e.,* all the air had been drained out of the building. He then applied a high electric voltage at either end of the tube between two electrodes. He observed a particle stream (ray) coming out of the negatively charged electrode (cathode) to the positively charged electrode (anode). This ray is called a cathode ray and is called a cathode ray tube for the entire construction.

The experiment Cathode Ray Tube (CRT) conducted by J. J. Thomson, is one of the most well-known physical experiments that led to electron discovery. In addition, the experiment could describe characteristic properties, in essence, its affinity to positive charge, and its charge to mass ratio. This paper describes how J is simulated. J. Thomson experimented with Cathode Ray Tube.

The major contribution of this work is the new approach to modelling this experiment, using the equations of physical laws to describe the electrons' motion with a great deal of accuracy and precision. The user can manipulate and record the movement of the electrons by assigning various values to the experimental parameters.

Apparatus Setup

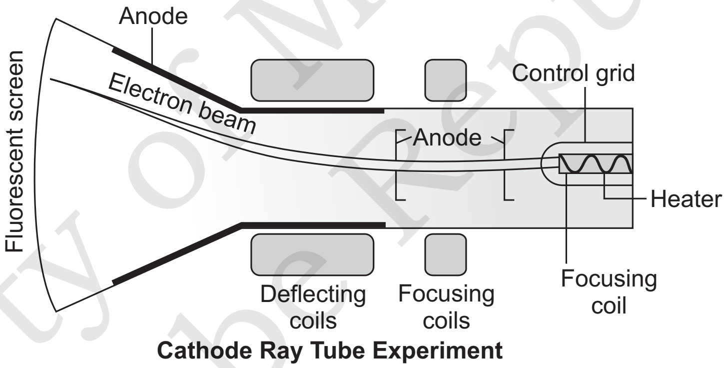

Fig. 5.4. A Diagram of JJ.Thomson Cathode Ray Tube Experiment showing Electron Beam – A cathode-ray tube (CRT) is a large, sealed glass tube.

The apparatus of the experiment incorporated a tube made of glass containing two pieces of metals at the opposite ends which acted as an electrode. The two metal pieces were connected with an external voltage. The pressure of the gas inside the tube was lowered by evacuating the air.

Uses of Cathode Ray Tube

1. Used as a most popular television (TV) display.
2. X-rays are produced when fast-moving cathode rays are stopped suddenly.

3. The screen of a cathode ray oscilloscope, and the monitor of a computer, are coated with fluorescent substances. When the cathode rays fall off the screen are visible on the screen.

5.26 BASIC PHYSICS OF X-RAY

In X-ray diagnostics, radiation that is partly transmitted through and partly absorbed in the irradiated object is utilised. An X-ray image shows the variations in transmission caused by structures in the object of varying thickness, density or atomic composition. In Fig. 5.9, the necessary attributes for X-ray imaging are shown: X-ray source, object (patient) and a radiation detector (image receptor).

After an introductory description of the nature of X-rays, the most important processes in the X-ray source, the object (patient) and radiation detector for the generation of an X-ray image will be described.

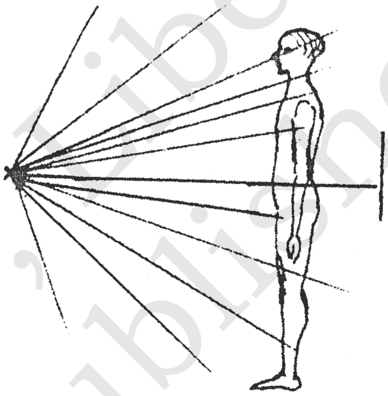

Fig. 5.5. The necessary attributes for X-ray imaging: X-ray source, object (patient) and radiation detector

The Physics of the X-ray Source: The X-ray Tube

(*a*) The nature of X-rays: X-rays are like radio waves and visible light electromagnetic radiation. X-rays, however, have higher frequency, ν, and shorter wavelength, λ, than light and radio waves. The radiation can be considered as emitted in quanta, photons, each quantum having a well-defined energy, $h\nu$, where h is a physical constant, Plancks constant, and ν is the frequency. The energy of X-ray photons are considerably higher than those of light.

A number of the phenomena, which are observed with X-rays are most conveniently described by the wave properties of the radiation while other phenomena can be more easily understood if the X-rays are considered as being composed of particles (photons) with well-defined energies and momentum. The rest mass of a photon is zero. This means that photons can never be found at rest. All photons move at the same velocity, c, in a vacuum, given by $c = 2.998\ 10^8$ m/s.

(*b*) Relationship between wave length and frequency: The wave length multiplied with the frequency (number of wave lengths per unit time) equals the velocity of light

$$\lambda \upsilon = c \qquad \text{...(1)}$$

(*c*) The propagation of X-rays: Similarly to visible light, X-rays propagate linearly. The rays from a point source form a divergent beam. The number of photons passing per unit area perpendicular to the direction of motion of the photons is called the fluence, ϕ . The fluence in a vacuum decreases following the inverse square law, given by

$$\phi(r) = \phi(1)\frac{1}{r^2} \qquad \text{...(2)}$$

where r is the distance from the point source and $\phi(1)$ is the fluence at r = 1 (relative units). The inverse square law is illustrated in Fig. 5.10.

(*d*) Refraction of X-rays: When visible light passes from one medium to another it is refracted due to the different velocities of the rays in different media and interference of waves. The velocity of propagation of X-rays varies much less in different materials and the refraction of X-rays is negligible. For this reason, X-rays cannot be focussed be means of lenses.

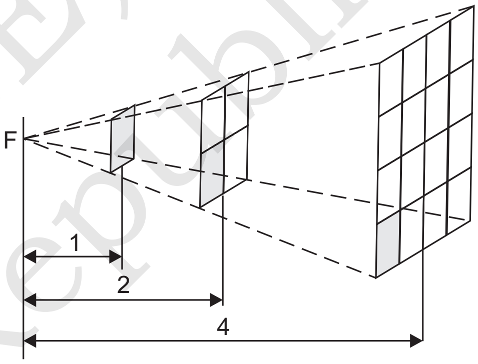

Fig. 5.6. The fluence, ϕ, of X-rays decreases with the square of the distance from the source.

(*e*) Diffraction of X-rays: Another wave phenomenon is diffraction. This means that the wave can be bent when passing an edge or a slit. The slit can then be regarded as a new source of waves propagating in all directions. If there is a periodic system of slits (lattice), interference effects will occur. That is, waves which are in phase will be amplified and those that are out of phase will be weakened. In order to demonstrate diffraction with X-rays the lattice constant (distance between the scattering slits) must be of the order of 0.1 nm. Such distances exist between the atomic planes in crystals. Crystals are frequently used for X-ray spectrometry.

***(f)* Generation of X-rays:** An X-ray tube consists of two electrodes, one negative, glow cathode, which upon being heated emits electrons, and one positive, anode. The electrodes are incapsuled in a vacuum. By applying an acceleration potential (20-200 kV), the electrons are accelerated towards the anode. The electrons gain kinetic energy which is the product of their charge and the potential difference. As a measure of the kinetic energy of the electrons and X-ray photons, the unit of 1 eV is used.

Definition: One electron volt (1 eV) is the kinetic energy, that a charged particle of one elementary charge (the charge of an electron) achieves when being accelerated in a potential difference of one volt (1 V); 1 eV = $1.602\ 10^{-19}$ J (joule). (See Fig. 5.7).

If the potential difference is 100 kV, each electron gets a kinetic energy of 100 keV (1000 eV = 1 keV).

When the electron reaches the anode it imparts the main part of its energy to the atoms of the anode by ionisations and excitations. This energy will finally appear as heat energy. If an electron passes close to an atomic nucleus, it will change its direction of motion, *i.e.,* exhibits an acceleration. At each such acceleration there is a small probability that the electron looses energy in the form of a photon, Fig. 5.8. These photons are called bremsstrahlung photons and constitute the main part of the X-rays being used in X-ray diagnostic imaging.

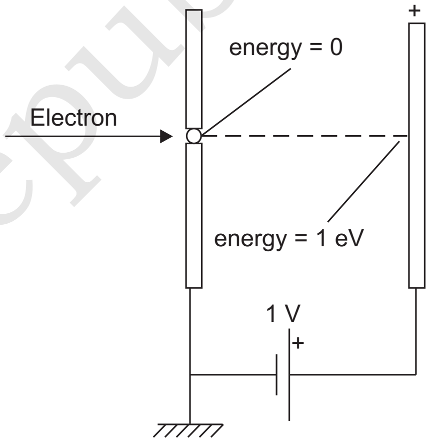

Fig. 5.7. One electron volt (1 eV) is the kinetic energy of an electron which has been accelerated through a potential difference of 1 volt.

The bremsstrahlung photon can obtain an arbitrary energy between zero and the whole of the kinetic energy of the electron, T.

$$h\nu_{\max} = \mathrm{T} \qquad \ldots(3)$$

The relative amount of bremsstrahlung emitted increases with increasing electron kinetic energy and with increasing atomic number, Z, of the anode material.

Since the major part of the energy of the electrons is converted into heat in the anode (about 1% will appear as X-rays), the anode material should have a high melting point and good heat conduction ability. To get a high relative amount of X-ray energy, the anode material should be of high atomic number. Tungsten is the dominating anode material and is in modern X-ray tubes often mixed with renium ($Z_W = 74$; $Z_{Re} = 75$).

Modern X-ray imaging requires a small focal spot and high X-ray fluence rates (number of photons per unit area and unit time). To meet these requirements, technical solutions with a line shaped focal spot and rotating anode have been introduced.

The Energy Spectrum of X-rays

(*a*) Dependence of the energy spectrum on tube potential: Fig. 5.13 shows energy spectra from an X-ray tube, the glass envelope of which gives a filtration corresponding to 2 mm Al (aluminium). The X-rays are then additionally filtered by an extra layer of 1 mm Al. The energy spectra show the number of photons per unit energy interval, (keV), emitted within a unit interval of the solid angle, (steradian), when the charge 1 mAs passes through the X-ray tube. The energy spectra have been measured at constant acceleration potential differences of 40, 70, 100 and 130 kV (Mika and Reiss 1969). As can be seen from Fig. 5.9, there are only few photons close to the maximum energy.

The number of X-rays emitted in the anode per unit energy interval increases with decreasing energy.

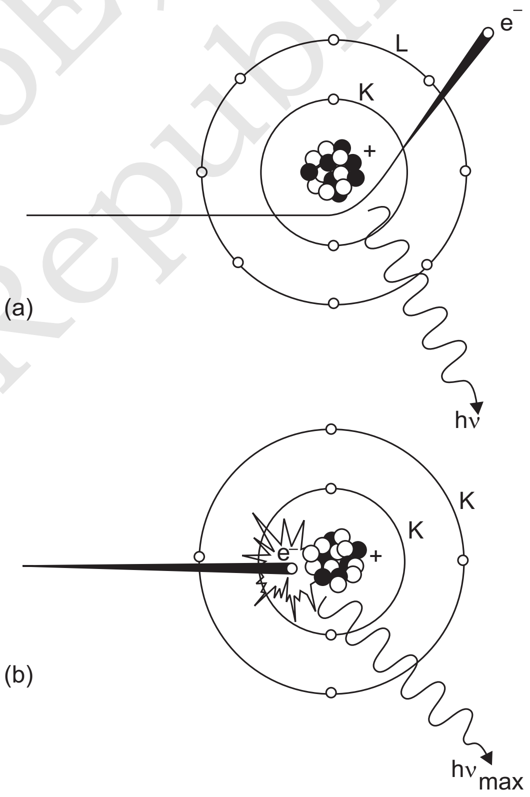

Fig. 5.8. Bremsstrahlung is generated when an electron with high energy changes its direction of motion in the neighbourhood of an atomic nucleus and thereby looses energy.

The attenuation of the photons in the anode itself, the glass envelope and additional filter increases, however, still more with decreasing energy such that the number of low energy photons is heavily reduced. There are practically no photons with energies less than 10 keV, which are emitted from an X-ray tube with the above mentioned filters (Fig. 5.9).

The sharp peaks shown in the energy spectra at 100 and 130 kV acceleration potential differences (Fig. 5.9) are characteristic Kα and Kβ photons from tungsten.

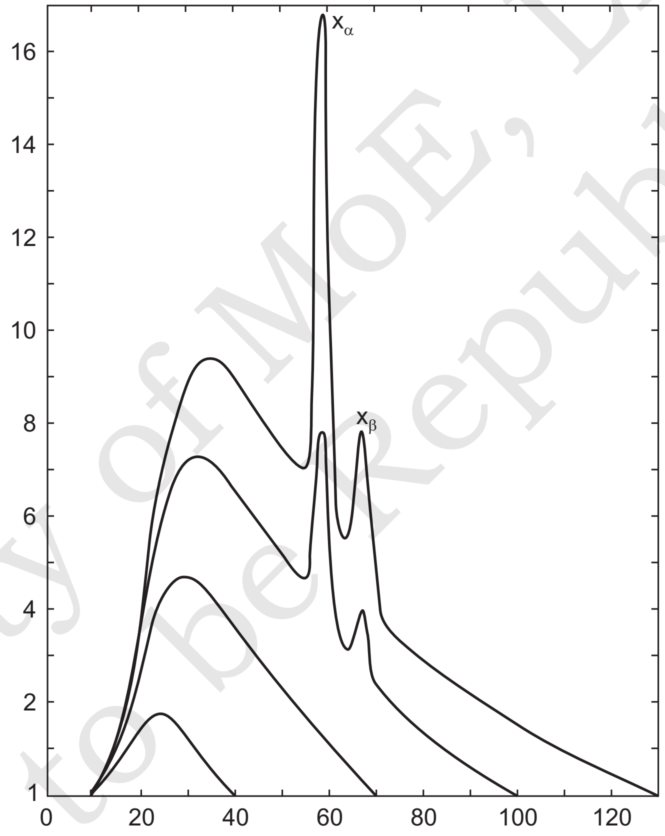

Fig. 5.9. Energy spectra of X-rays at different (constant) acceleration potential differences (Mika and Reiss 1969). Total filtration 3 mm Al

Characteristic roentgen rays (fluorescence radiation) are emitted when a vacancy in an electron shell (here the K-shell) is filled with an electron from an outer shell. The emitted energy equals the difference in binding energy of the electron in the two shells. Vacancies in the K-shell can result from either ionisations caused by the accelerated electrons or from photoelectric absorption of bremsstrahlung photons (with energies higher than the binding energy of the electrons in the K shell) in the anode itself. In order to ionise the K-shell of tungsten an energy of 69.5 keV is needed. For characteristic K-photons to be emitted, the acceleration potential difference must exceed 70 kV.

From Fig. 5.9 it can be seen that the relative proportion of characteristic K-radiation increases with increasing tube potential. This means that the imaging properties of the X-rays is only slowly varying with variations in the tube potential at tube potentials above 130 kV. Fig. 5.9 shows how the number of photons varies at constant value of the tube charge (mAs-value = the product of tube current, mA and exposure time, s).

If instead the acceleration potential difference is kept constant and the charge through the X-ray tube (mAs) is increased, the shape of the energy spectrum remains the same, *i.e.*, the relationship between the number of photons in the different energy intervals. The number of photons in each interval is proportional to the mAs-value.

REVIEW EXERCISE

A. MULTIPLE CHOICE QUESTIONS (MCQs)

1. In the nuclear decay given below :

$${}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y \longrightarrow {}^{A-4}_{Z-1}B^{*} \longrightarrow {}^{A-4}_{Z-1}B,$$

the particles emitted in the sequence are :

(*a*) α, β, γ (*b*) β, α, γ (*c*) γ, β, α (*d*) β, γ, α.

2. An element A decays into an element C by a two step process

A → B + ${}^{4}_{2}$He and B → C + $2e^{-}$.

Then,

(*a*) A and C are isotopes. (*b*) A and C are isobars.

(*c*) B and C are isotopes. (*d*) A and B are isobars.

3. If the radius of a nucleus of ^{256}X is 8 fermi, then the radius of ^{4}He nucleus will be

(*a*) 16 fermi (*b*) 2 fermi (*c*) 32 fermi (*d*) 4 fermi.

4. A radioactive element x converts into another stable element y. Half-life of x is 2 h, initially only x is present. After time t, the ratio of atoms of x and y is found to be 1 : 4, then t in hour is

(*a*) 2 (*b*) 4

(*c*) between 4 and 6 (*d*) 6.

5. A radioactive isotope has a half-life of 2 yr. How long will it take the activity to reduce to 3% of its original value?

(*a*) 4.8 yr (*b*) 7 yr (*c*) 10 yr (*d*) 9.6 yr.

6. A radioactive isotope A with a half-life of 1.25×10^{10} years decays into B which is stable. A sample of rock from a planet is found to contain both A and B present in the ratio 1 : 15. The age of the rock is (in years)

(*a*) 9.6×10^{10} (*b*) 4.2×10^{10} (*c*) 5×10^{10} (*d*) 1.95×10^{10}.

7. A radioactive isotope has a half-life of T years. How long will it take the activity to reduce to 1% of its original value?

(*a*) 3.2T years (*b*) 4.6T years (*c*) 6.6T years (*d*) 9.2T years.

8. The density of a nucleus of mass number A is proportional to

(*a*) A^3 (*b*) $A^{1/3}$ (*c*) A^1 (*d*) A^0.

9. The fraction of a sample of radioactive nuclei that remains undecayed in one mean life is

(*a*) $\frac{1}{e}$ (*b*) $1 - \frac{1}{e}$ (*c*) $\frac{1}{e^2}$ (*d*) $1 - \frac{1}{e^2}$.

10. Half-life of a radioactive substance is 20 minute. The time between 20% and 80% decay will be

(*a*) 20 min (*b*) 30 min (*c*) 40 min (*d*) 25 min.

B. FILL IN THE BLANKS

1. The nucleus which has radius one-third of the radius of ^{189}Os is ....

2. If half-life of radio isotope is 2 second and number of atoms is only 4, then after one half-life, the remaining atoms are ....

3. The energy released by the fission of one uranium atom is 200 MeV. The number of fissions per second required to produce 3.2 W of power is .... (Take 1 eV = 1.6×10^{-19} J)

4. The half-life of a radioactive isotope X is 50 years. It decays to another element Y which is stable. The two elements X and Y were found to be in the ratio of 1 : 15 in a sample of a given rock. The age of the rock was estimated to be ....

5. The power obtained in a reactor using ^{235}U disintegration is 1000 kW. The mass decay of ^{235}U per hour is ....

6. A radioactive nucleus of mass M emits a photon of frequency n and the nucleus recoils. The recoil energy will be ....

7. If the binding energy per nucleon of deuteron is 1.115 MeV, its mass defect in atomic mass unit is ....

8. A uranium nucleus $^{238}_{92}$U emits an α-particle and β-particle in succession. The atomic number and mass number of the final nucleus will be ....

9. In the nuclear reaction $^{14}_{7}\text{N} + \text{X} \longrightarrow {}^{14}_{6}\text{C} + {}^{1}_{1}\text{H}$, the X will be ....

10. If the nuclear radius of ^{27}Al is 3.6 fermi, the approximate nuclear radius of ^{64}Cu in fermi is ....

C. VERY SHORT ANSWER TYPE QUESTIONS

1. Name three nuclei which are on the ‘bottom points’ of binding energy curve.

2. Name five nuclei which lie on the peaks in binding energy curve.

3. Why electron capture is more common in heavy atoms?

4. How many joule are contained in 1 kWh?

5. What exactly makes large nuclei unstable?

6. What is one roentgen?

7. Name two elementary particles which have almost infinite life time.

8. Is free neutron a stable particle?

9. Cadmium rods are provided in a reactor. Why?

10. Name one physical quantity which can be said to be the source of binding energy.

D. SHORT ANSWER TYPE QUESTIONS

1. In a natural uranium reactor, heavy water is a preferred moderator to ordinary water.

2. Very high temperatures as those obtained in the interior of the sun are required for fusion reaction to take place.

3. The half-lives of radioactive nuclides that emit α-rays vary from microsecond to billion year. What is the reason for this large variation in the half-life of α-emitters ?

4. Which of the two is more stable—$^{7}_{3}$Li or $^{4}_{3}$Li?

5. It is said that a very powerful crane is required to lift a nuclear mass of microscopic size. Comment on this.

E. LONG ANSWER TYPE QUESTIONS

1. Explain, with the help of a nuclear reaction in each of the following cases, how the neutron to proton ratio changes during (*i*) alpha decay (*ii*) beta decay?

2. The nucleus of an atom of $^{235}_{92}Y$, initially at rest, decays by emitting an α-particle as per the equation :

$$^{235}_{92}Y \longrightarrow {}^{231}_{90}x + {}^{4}_{2}He + \text{Energy}$$

3. Prove that the instantaneous rate of change of the activity of a radioactive substance is inversely proportional to the square of its half-life.

4. A radioactive material is reduced to $\frac{1}{16}$th of its original amount in 4 days. How much material should one begin with so that 4×10^{-3} kg of the material is left after 6 days.

5. Define the term 'Activity' of a radioactive substance. State its SI unit. Two different radioactive elements with half-lives T_1 and T_2 have N_1 and N_2 (undecayed) atoms respectively present at a given instant. Determine the ratio of their activities at this instant.