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4

Nuclear Chemistry

CHAPTER

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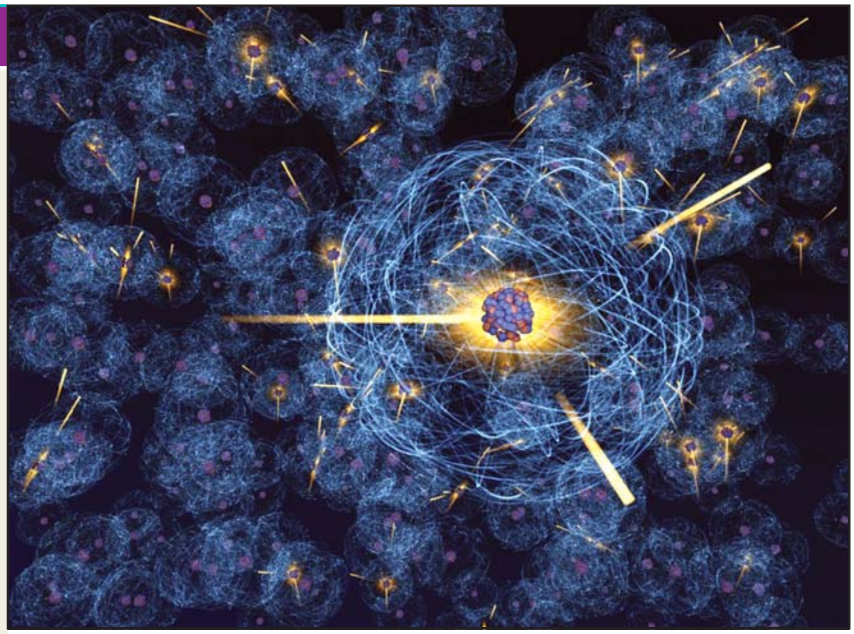


A nuclear reaction is different from a chemical reaction. In a chemical reaction, atoms of the reactants combine by a rearrangement of extranuclear electrons but the nuclei of the atoms remain unchanged. In a nuclear reaction, on the other hand, it is the nucleus of the atom which is involved. The number of protons or neutrons in the nucleus changes to form a new element. **A study of the nuclear changes in atoms is termed Nuclear Chemistry.**

RADIOACTIVITY

A number of elements such as uranium and radium are unstable. Their atomic nucleus breaks of its own accord to form a smaller atomic nucleus of another element. The protons and neutrons in the unstable nucleus regroup to give the new nucleus. This causes the release of excess particles and energy from the original nucleus, which we call **radiation.** The elements whose atomic nucleus emits radiation are said to be **radioactive.** The spontaneous breaking down of the unstable atoms is termed **radioactive disintegration or radioactive decay.**

The disintegration or decay of unstable atoms accompanied by emission of radiation is called Radioactivity.

TYPES OF RADIATIONS

The radioactive radiations are of three types. These were sorted out by Rutherford (1902) by passing them between two oppositely charged plates (Fig. 4.1). The one bending towards the negative plate carried positive charge and were named α **(alpha) rays.** Those bending towards the positive plate and carrying negative charge were called β **(beta) rays.** The third type of radiation, being uncharged, passed straight through the electric field and were named γ **(gamma) rays.** α, β and γ rays could be easily detected as they cause luminescence on the zinc sulphide screen placed in their path.

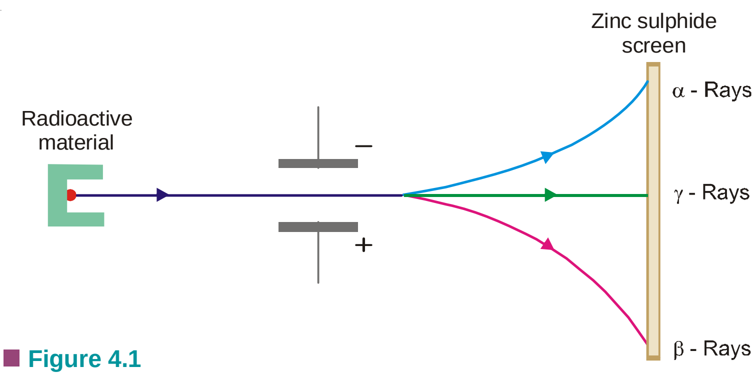


Figure 4.1
Detection of α, β and γ-Rays.

PROPERTIES OF RADIATIONS

Alpha (α), beta (β) and gamma (γ) rays differ from each other in nature and properties. There chief properties are : (*a*) Velocity; (*b*) Penetrating power; (*c*) Ionisation.

ALPHA RAYS

(1) Nature. They consist of streams of α-particles. **By measurement of their e/m, Rutherford showed that they have a mass of 4 amu and charge of +2.** They are **helium nuclei** and may be represented as $^4_2\alpha$ or ^4_2He .

(2) Velocity. α-particles are ejected from radioactive nuclei with very high velocity, about one-tenth that of light.

(3) Penetrating power. Because of their charge and relatively large size, α-particles have **very little power of penetration** through matter. They are stopped by a sheet of paper, 0.01 mm thick aluminium foil or a few centimetres of air.

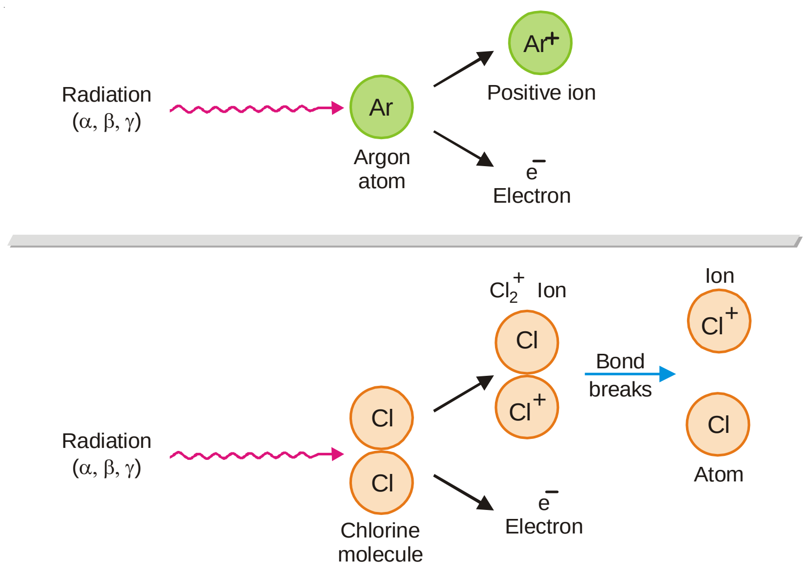
(4) Ionisation. They cause **intense ionisation** of a gas through which they pass. On account of their high velocity and attraction for electrons, α-particles break away electrons from gas molecules and convert them to positive ions.

BETA RAYS

(1) Nature. They are streams of β-particles emitted by the nucleus. From their deflection electric and magnetic fields, Becquerel showed that **β-particles are identical with electrons.** They have very small mass (1/1827 amu) and charge of – 1. A β-particle is symbolized as $^{0}_{-1}\beta$ or $^{0}_{-1}e$.

(2) Velocity. They travel about **10 times faster than α-particles.** Their velocity is about the same as of light.

(3) Penetrating power. **β-Particles are 100 times more penetrating in comparison to α-particles.** This is so because they have higher velocity and negligible mass. β-particles can be stopped by about 1 cm thick sheet of aluminium or 1 m of air.



■ **Figure 4.2**
Radiation energy knocks electrons out of atoms or molecules. This produces positive ions. Bond breaking often occurs in unstable molecular ions.

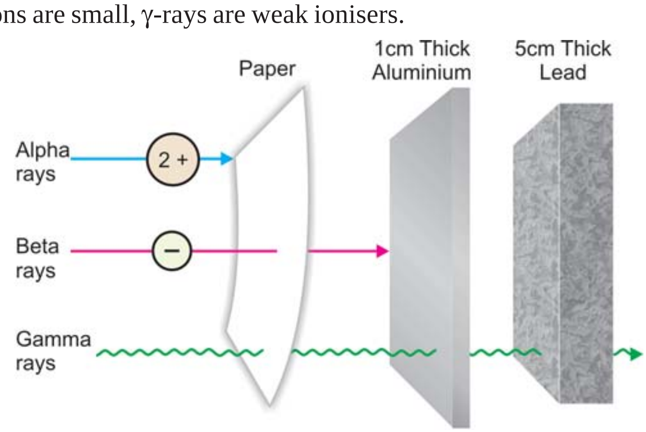
(4) Ionisation. The ionisation produced by β-particles in a gas is about **one-hundredth of that of α-particles.** Though the velocity of β-particles is higher but the mass being smaller, their kinetic energy is much less than α-particles. Hence they are poor ionisers.

GAMMA RAYS

(1) Nature. Unlike α and β-rays, they do not consist of particles of matter. **γ-Rays are a form of electromagnetic radiation** of shorter wavelength than X-rays. They could be thought of as high-energy photons released by the nucleus during α- or β-emissions. They have no mass or charge and may be symbolized as ${}^{0}_{0}\gamma$.

(2) Velocity. Like all forms of electromagnetic radiation, **γ-rays travel with the velocity of light.**

(3) Ionising power. Their ionising power is very weak in comparison to α- and β-particles. A γ-photon displaces an electron of the gas molecule to yield a positive ion. Since the chances of photon-electron collisions are small, γ-rays are weak ionisers.



■ **Figure 4.3**
Penetrating powers of alpha, beta and gamma rays.

(4) Penetrating power. Because of their high velocity and non-material nature, **γ-rays are most penetrating.** They cannot be stopped even by a 5 cm thick sheet of lead or several metres thick layer of concrete.

TABLE 4.1. COMPARISON OF PROPERTIES OF α, β AND γ-RAYS

Property	α-rays	β-rays	γ-rays
Nature	helium nuclei ^4_2He	fast electrons $^{0}_{-1}e$	electromagnetic radiation
Velocity	one-tenth of velocity of light	velocity of light	velocity of light
Penetrating Power	low	moderate	high
Stopped by	paper or 0.01 mm thick aluminium sheet	1 cm of aluminium	several cm thick lead/ concrete layer

DETECTION AND MEASUREMENT OF RADIOACTIVITY

The radioactive radiation can be detected and measured by a number of methods. The important ones used in modern practice are listed below.

(1) Cloud Chamber

This technique (Fig. 4.4) is used for detecting radioactivity. The chamber contains air saturated with water vapour. When the piston is lowered suddenly, the gas expands and is supercooled. As an α- or β-particle passes through the gas, ions are created along its path. These ions provide nuclei upon which droplets of water condense. The trail or cloud thus produced marks the track of the particle. The track can be seen through the window above and immediately photographed. Similarly, α- or β-particles form a trail of bubbles as they pass through liquid hydrogen. The **bubble chamber method** gives better photographs of the particle tracks.

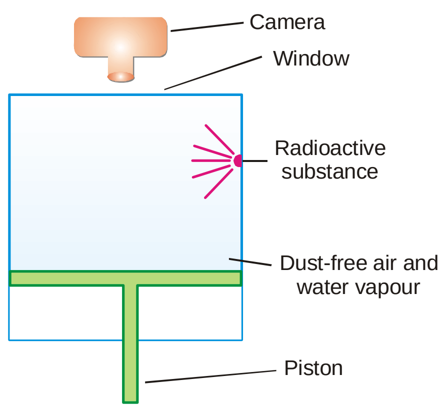


Figure 4.4
Principle of Cloud Chamber.

(2) Ionisation Chamber

This is the simplest device used to measure the strength of radiation. An ionisation chamber is fitted with two metal plates separated by air. When radiation passes through this chamber, it knocks electrons from gas molecules and positive ions are formed. The electrons migrate to the anode and positive ions to the cathode.

Thus a small current passes between the plates. This current can be measured with an ammeter, and gives the strength of radiation that passes through the ionisation chamber. In an ionisation chamber called **Dosimeter,** the total amount of electric charge passing between the plates in a given time is measured. This is proportional to the total amount of radiation that has gone through the chamber.

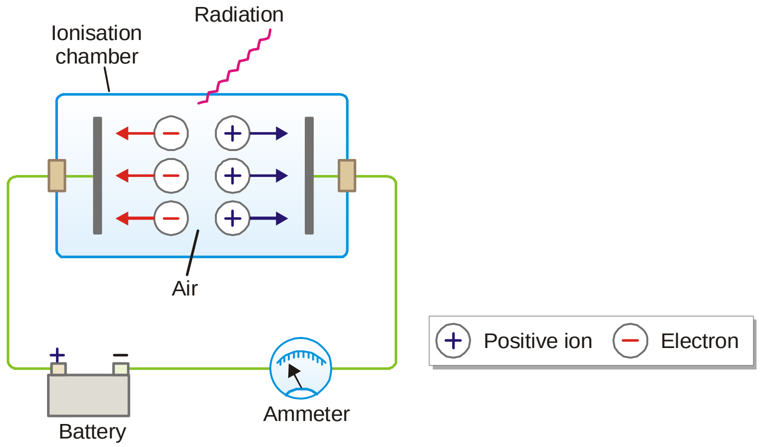


Figure 4.5
An Ionisation chamber used to measure the strength of radiation.

(3) Geiger-Muller Counter

This device (Fig. 4.6) is used for detecting and measuring the rate of emission of α- or β-particles. It consists of a cylindrical metal tube (cathode) and a central wire (anode). The tube is filled with argon gas at reduced pressure (0.1 atm). A potential difference of about 1000 volts is applied across the electrodes. When an α- or β-particle enters the tube through the mica window, it ionises the argon atoms along its path.

$$Ar \longrightarrow Ar^{+} + e^{-}$$

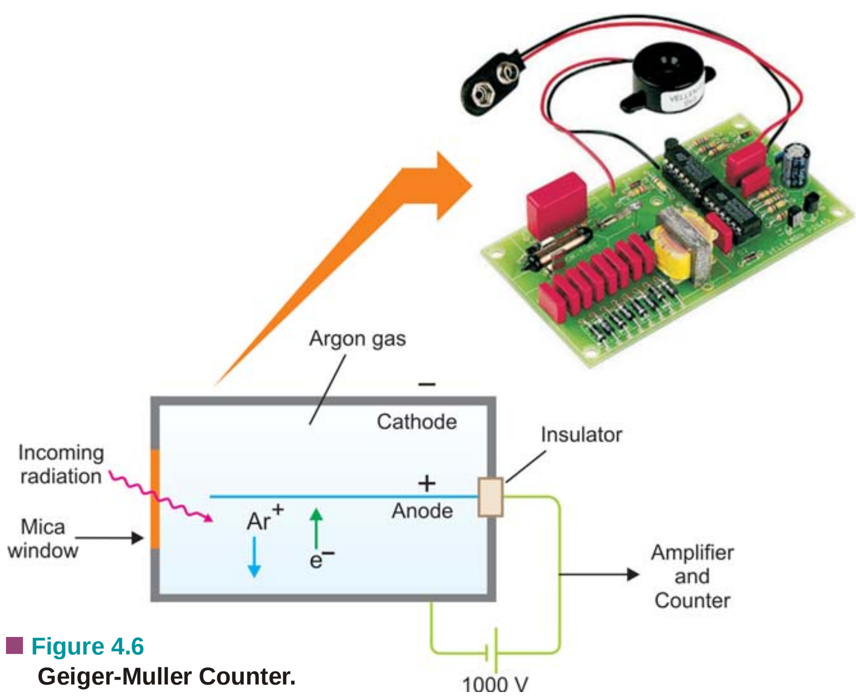


Figure 4.6
Geiger-Muller Counter.

The argon ions (Ar^+) are drawn to the cathode and electrons to anode. Thus for a fraction of a second, a pulse of electrical current flows between the electrodes and completes the circuit around. **Each electrical pulse marks the entry of one α- or β-particle into the tube and is recorded in an automatic counter.** The number of such pulses registered by a radioactive material per minute, gives the intensity of its radioactivity.

(4) Scintillation Counter

Rutherford used a spinthariscope (Fig. 4.7) for the detection and counting of α-particles. The radioactive substance mounted on the tip of the wire emitted α-particles. Each particle on striking the zinc sulphide screen produced a flash of light. These flashes of light (scintillations) could be seen through the eye-piece. With this device it was possible to count α-particles from 50 to 200 per second.

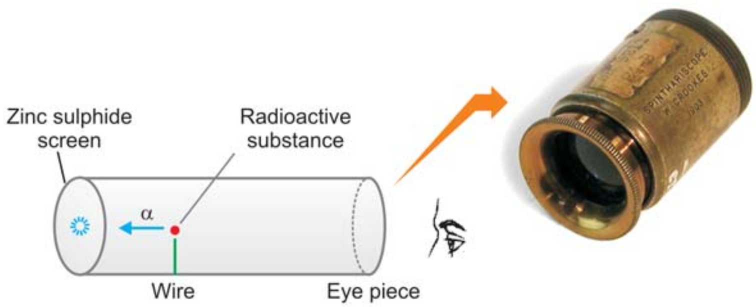


Figure 4.7
Spinthariscope.

A modern scintillation counter also works on the above principle and is widely used for the measurement of α- or β-particles. Instead of the zinc sulphide screen, a crystal of sodium iodide with a little thallium iodide is employed. The sample of the radioactive substance contained in a small vial, is placed in a 'well' cut into the crystal. The radiation from the sample hit the crystal wall and produce scintillations. **These fall on a photoelectric cell which produces a pulse of electric current for each flash of light.** This is recorded in a mechanical counter. Such a scintillation counter can measure radiation upto a million per second.

(5) Film Badges

A film badge consists of a photographic film encased in a plastic holder. When exposed to radiation, they darken the grains of silver in photographic film. The film is developed and viewed under a powerful microscope.

As α- or β-particles pass through the film, they leave a track of black particles. These particles can be counted. In this way the type of radiation and its intensity can be known. However, γ-radiation darken the photographic film uniformly. The amount of darkening tells the quantity of radiation.

A film badge is an important device to monitor the extent of exposure of persons working in the vicinity of radiation. The badge-film is developed periodically to see if any significant dose of radiation has been absorbed by the wearer.

TYPES OF RADIOACTIVE DECAY

According to the theory put forward by Rutherford and Soddy (1903), radioactivity is a nuclear property. The nucleus of a radioactive atom is unstable. It undergoes decay or disintegration by spontaneous emission of an α- or β-particle. This results in the change of proton-neutron composition of the nucleus to form a more stable nucleus. **The original nucleus is called the parent nucleus and the product is called the daughter nucleus.**

As evident from above, there are two chief types of decay:

(1) α-decay (2) β-decay

α-Decay

When a radioactive nucleus decays by the emission of an α-particle (α-**emission**) from the nucleus, the process is termed α-decay. An alpha particle has four units of atomic mass and two units of positive charge. If Z be the atomic number and M the atomic mass of the parent nucleus, the daughter nucleus will have

$$\text{atomic mass} = M - 4$$
$$\text{atomic number} = Z - 2$$

Thus an α-emission reduces the atomic mass by 4 and atomic number by 2.

For example, Radium decays by α-emission to form a new element Radon,

$$^{226}_{88}\text{Ra} - {}^{4}_{2}\alpha = {}^{222}_{86}\text{Rn}$$

(parent) (daughter)

β-Decay

When a radioactive nucleus decays by β-particle emission (β-**emission**), it is called β-decay. A free β-particle or electron does not exist as such in the nucleus. It is produced by the conversion of a neutron to a proton at the moment of emission.

$$\text{Neutron} = \text{p} + \text{e}$$

This results in the increase of one positive charge on the nucleus. The loss of a β-particle from the nucleus does not alter its atomic mass. For a parent nucleus with atomic mass M and atomic number Z, the daughter nucleus will have

$$\text{atomic mass} = M$$
$$\text{atomic number} = Z + 1$$

Thus a β-emission increases the atomic number by 1 with no change in atomic mass.

An example of β-decay is the conversion of lead-214 to bismuth-214,

$$^{214}_{82}\text{Pb} - {}^{0}_{-1}\beta = {}^{214}_{83}\text{Bi}$$

(parent) (daughter)

It is noteworthy that a β-emission results in the production of an isobar. Thus, $^{214}_{82}\text{Pb}$ and $^{214}_{83}\text{Bi}$ are isobaric as they have the same mass number 214 but different atomic numbers (82 and 83).

One α-emission and two β-emissions yield an isotope. Let us consider the following series of changes.

$$^{218}_{84}\text{Po} \xrightarrow{\alpha} {}^{214}_{82}\text{Pb} \xrightarrow{\beta} {}^{214}_{83}\text{Bi} \xrightarrow{\beta} {}^{214}_{84}\text{Po}$$

(parent) (isotope)

The parent element $^{218}_{84}\text{Po}$ emits an α-particle and subsequently two β-particles, resulting in the formation of $^{214}_{84}\text{Po}$ which is an isotope of the parent. Both the parent and the end-product have the same atomic number 84 but different mass numbers (218 and 214).

SOLVED PROBLEM 1. How many α and β particles are emitted in passing down from ${}^{232}_{90}Th$ to ${}^{208}_{82}Pb$.

SOLUTION. Let *a* be the number of α particles and *b* be the number of β particles emitted during the radioactive transformation. It can be represented as

$${}^{232}_{90}Th \longrightarrow {}^{208}_{82}Pb + a\,{}^{4}_{2}He + b\,e^{0}_{-1}$$

Comparing the mass numbers, we get

$$232 = 208 + 4 \times a + b \times 0$$

or $4a = 232 - 208 = 24$

or $a = 6$

Comparing the atomic numbers, we get

$$90 = 82 + 2 \times a + b\,(-1)$$

Substituting the value of a, we get

$$90 = 82 + 2 \times 6 - b$$

or $b = 94 - 90$

or $b = \mathbf{4}$

Thus the number of α particles emitted = 6 and the number of β particles emitted = 4

SOLVED PROBLEM 2. ${}^{210}_{82}Pb$ is a β-emitter and ${}^{226}_{88}Ra$ is an α-emitter. What will be the atomic masses and atomic numbers of daughter elements of these radioactive elements ? Predict the position of daughter elements in the periodic table.

SOLUTION. (*a*) ${}^{210}_{82}Pb$ undergoes β-decay *i.e.*

$${}^{210}_{82}Pb \longrightarrow {}^{0}_{-1}e + {}^{b}_{a}X$$

Comparing the atomic masses, we have

$$210 = 0 + b$$

or $b = \mathbf{210}$

and comparing the atomic numbers, we get

$$82 = -1 + a \quad \text{or} \quad a = \mathbf{83}$$

Thus the daughter element will have the same atomic mass **210** and its atomic number will be **83.** It will occupy **one position right** to the parent element.

(*b*) ${}^{236}_{88}Ra$ undergoes α decay *i.e.*

$${}^{236}_{88}Ra \longrightarrow {}^{4}_{2}He + {}^{b}_{a}X$$

Comparing the atomic masses, we get

$$236 = 4 + b \quad \text{or} \quad b = \mathbf{232}$$

and comparing the atomic number, we get

$$88 = 2 + a \quad \text{or} \quad a = \mathbf{86}$$

Thus the daughter element will have atomic mass **232** and its atomic number will be **86.** It will occupy **two positions to the left** of the parent element.

THE GROUP DISPLACEMENT LAW

The position number of an element in a Group of the Periodic Table corresponds to its atomic number. If the atomic number of a given element is changed, its Group also changes accordingly. We know that an α-emission decreases the atomic number of the parent element by 2 and a β-emission increases the atomic number by 1. Thus : **in an α-emission, the parent element will be displaced to a Group two places to the left and in a β-emission, it will be displaced to a Group one place to the right.**

This is called the **Group Displacement Law.** It was first stated by Fajans and Soddy (1913) and is often named after them as '*Fajans-Soddy Group Displacement Law*'.

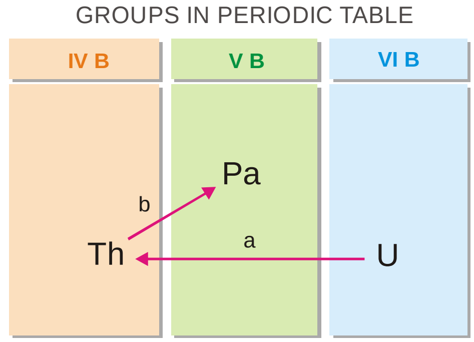


Figure 4.8
Illustration of Group Displacement Law.

RADIOACTIVE DISINTEGRATION SERIES

A radioactive element disintegrates by the emission of an α- or β- particle from the nucleus to form a new '*daughter element*'. This again disintegrates to give another '*daughter element*'. The process of disintegration and formation of a new element continues till a non-radioactive stable element is the product.

The whole series of elements starting with the parent radioactive element to the stable end-product is called a Radioactive Disintegration Series.

Sometime, it is referred to as a **Radioactive Decay Series** or simply **Radioactive Series.** All the natural radioactive elements belong to one of the three series :

(1) The Uranium Series
(2) The Thorium Series
(3) The Actinium Series

The Uranium Series

It commences with the parent element uranium-238 and terminates with the stable element lead-206. It derives its name from uranium-238 which is the prominent member of the series and has the longest half-life. The Uranium series is illustrated in Fig. 4.9.

The Thorium Series

It begins with the parent element thorium-232 and ends with lead-208 which is stable. This series gets its name from the prominent member thorium-232.

The Actinium Series

It starts with the radioactive element uranium-235. The end-product is the stable element lead-207. This series derives its name from the prominent member actinium-227.

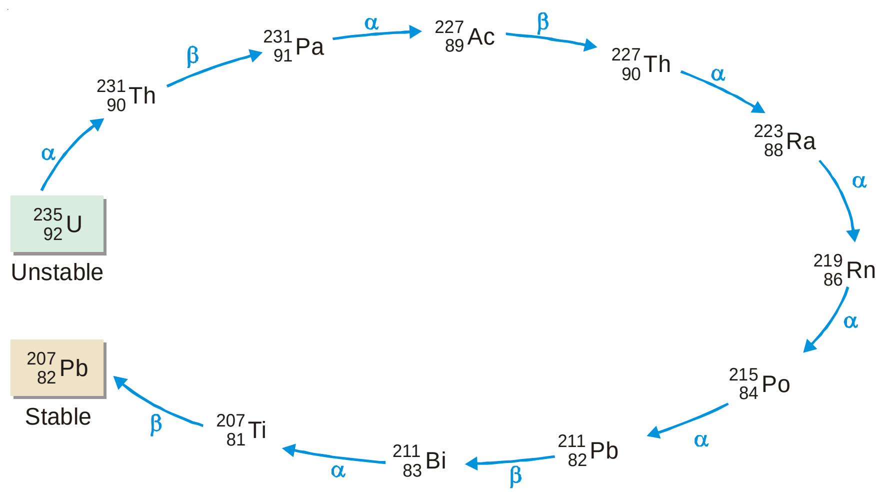
THE URANIUM DISINTEGRATION SERIES

NUCLIDE	PARTICLE PRODUCED	HALF-LIFE
Uranium-238 ($^{238}_{92}U$)	α	4.51×10^9 years
↓		
Thorium - 234 ($^{234}_{90}Th$)	β	24.1 days
↓		
Protactinium-234 ($^{234}_{91}Pa$)	β	6.75 hours
↓		
Uranium-234 ($^{234}_{92}U$)	α	2.48×10^5 years
↓		
Thorium-230 ($^{230}_{90}Th$)	α	8.0×10^4 years
↓		
Radium-226 ($^{226}_{88}Ra$)	α	1.62×10^3 years
↓		
Radon-222 ($^{222}_{86}Rn$)	α	3.82 days
↓		
Polonium-218 ($^{218}_{84}Po$)	α	3.1 minutes
↓		
Lead-214 ($^{214}_{82}Pb$)	β	26.8 minutes
↓		
Bismuth-214 ($^{214}_{83}Bi$)	β	19.7 minutes
↓		
Polonium-214 ($^{214}_{84}Po$)	α	1.6×10^{-4} second
↓		
Lead-210 ($^{210}_{82}Pb$)	β	20.4 years
↓		
Bismuth-210 ($^{210}_{83}Bi$)	β	5.0 days
↓		
Polonium-210 ($^{210}_{84}Po$)	α	138.4 days
↓		
Lead-206 ($^{206}_{82}Pb$)	—	Stable

Figure 4.9.
The Uranium Series.

The Neptunium Series

This series consists of elements which do not occur naturally. It commences with neptunium-237 and terminates at bismuth-200. It derives its name from the prominent member neptunium-237.



THE ACTINIUM SERIES

RATE OF RADIOACTIVE DECAY

The decay of a radioactive isotope takes place by disintegration of the atomic nucleus. It is not influenced by any external conditions. Therefore the rate of decay is characteristic of an isotope and depends only on the number of atoms present. If *N* be the number of undecayed atoms of an isotope present in a sample of the isotope, at time *t*,

$$-\frac{dN}{dt} \propto N$$

or

$$-\frac{dN}{dt} = \lambda N \qquad \text{... (1)}$$

where $-\frac{dN}{dt}$ means the rate of decrease in the number of radioactive atoms in the sample; and λ is the proportionality factor. This is known as the **decay constant** or **disintegration constant.** Putting $dt = 1$ in equation (1) we have

$$-\frac{dN}{N} = \lambda \qquad \text{... (2)}$$

Thus decay constant may be defined as the proportion of atoms of an isotope decaying per second.

UNITS OF RADIOACTIVITY

The standard unit of radioactivity (*i.e.* rate of disintegration) is *Curie* (c). A curie is a quantity of radioactive material decaying at the same rate as 1 g of Radium (3.7×10^{10} dps). Rutherford is a more recent unit.

$$1 \text{ Rutherford} = 10^6 \text{ dps}$$

The S.I. unit is Becquerel

$$1 \text{ Bq} = 1 \text{ dps}$$

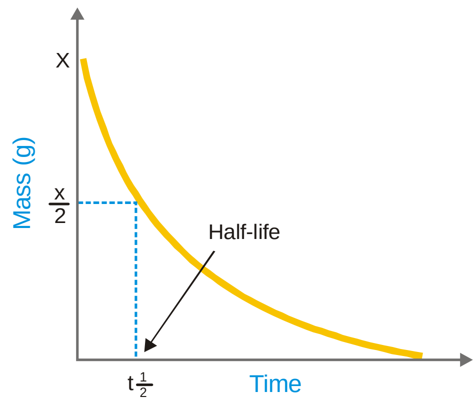
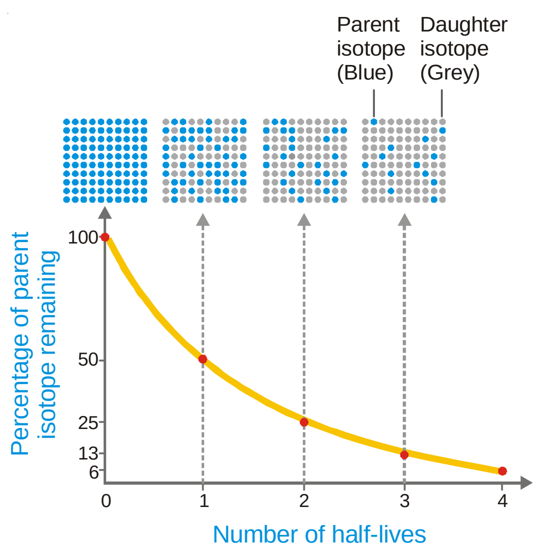


Figure 4.10
Decay curve of a radioactive isotope of mass x.

HALF-LIFE

The half-life or half-life period of a radioactive isotope is the time required for one-half of the isotope to decay. Or, it may be defined as the time for the radioactivity of an isotope to be reduced to half of its original value. Half-life period is characteristic of a radioactive element. For example, the half-life of radium is 1620 years. This means that 1g of radium will be reduced to 0.5 g in 1620 years and to 0.25 g in further 1620 years; and so on. Some other radioactive elements may have half-life of a fraction of a second and for others it may be millions of years. The unit of half-life period is time^{-1}.



THE ACTIVITY OF A RADIOACTIVE SUBSTANCE

It is defined as the **rate of decay or the number of disintegrations per unit time.** The activity of a sample is denoted by *A*. It is given by the expression :

$$A = \frac{dN}{dt} = \lambda N$$

The unit of activity is the **curie (Ci)** which is the rate of decay of 3.7×10^{10} disintegrations per second. The SI unit of activity is **becquerel (Bq)** which is defined as one disintegration per second.

The activity of a radioactive sample is usually determined experimentally with the help of a Geiger-Muller counter.

CALCULATION OF HALF-LIFE

From equation (1) we can write

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

On integration,

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

or $$-\text{In } N = \lambda t + X \text{ (constant)} \qquad ...(3)$$

If N_0 is the number of atoms at time $t = 0$, X = – In N_0

Substituting the value of X in (3)

$$-\text{In } N = \lambda t - \text{In } N_0$$

or $$\text{In}\left(\frac{N_0}{N}\right) = \lambda t$$

Using ordinary logs,

$$2.303 \log\left(\frac{N_0}{N}\right) = \lambda t \qquad ...(4)$$

At half-life time ($t_{1/2}$), $N = 1/2\ N_0$

∴ $$2.303 \log\left(\frac{N_0}{\frac{1}{2}N_0}\right) = 2.303 \log 2 = \lambda t_{1/2}$$

or $$0.693 = \lambda t_{1/2}$$

or $$t_{1/2} = \frac{0.693}{\lambda} \qquad ...(5)$$

The value of λ can be found experimentally by finding the number of disintegrations per second with the help of a Geiger-Muller counter. Hence, half-life of the isotope concerned can be calculated by using the relation (5).

SOLVED PROBLEM 1. Calculate the half-life of radium-226 if 1 g of it emits 3.7×10^{10} alpha particles per second.

SOLUTION

Rate of decay = Rate of emission of α-particles

We know that

$$\frac{dN}{dt} = \lambda N = 3.7 \times 10^{10} \text{ per second} \qquad ...(1)$$

The number of atoms of radium present (N) in 1g of sample, $= \frac{6.023 \times 10^{23}}{226}$

From equation (5) stated earlier $\lambda = \frac{0.693}{t_{1/2}}$

Substituting the value of λ and N in equation (1) above

$$\frac{dN}{dt} = \frac{0.693}{t_{1/2}} \times \frac{6.023 \times 10^{23}}{226} = 3.7 \times 10^{10}$$

Hence

$$t_{1/2} = \frac{0.693 \times 6.023 \times 10^{23}}{3.7 \times 10^{10} \times 226 \times 60 \times 60 \times 24 \times 365}$$

$$= \mathbf{1583\ years}$$

SOLVED PROBLEM 2. Calculate the disintegration constant of cobalt 60 if its half-life to produce nickel – 60 is 5.2 years.

SOLUTION

From equation (5) stated earlier $t_{1/2} = \dfrac{0.693}{\lambda}$

or

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

Substituting the value of $t_{1/2}$, we have $\lambda = \dfrac{0.693}{5.2\ \text{yr}} = 0.13\ \text{yr}^{-1}$

SOLVED PROBLEM 3. The half-life period of radon is 3.825 days. Calculate the activity of radon. (atomic weight of radon = 222)

SOLUTION

We know that

$$dN = \lambda N \qquad \text{...(2)}$$

where dN is the number of atoms disintegrating per second, λ is the decay constant and N is the number of atoms in the sample of radon.

Calculation of λ :

$$\lambda = \frac{0.693}{t_{1/2}} = \frac{0.693}{3.825 \times 24 \times 60 \times 60} = 2.096 \times 10^{-6}\ \text{sec}^{-1}$$

Calculation of N :

From expression (1) above

$$N = \frac{dN}{\lambda} = \frac{3.7 \times 10^{10}}{2.096 \times 10^{-6}} = 1.7653 \times 10^{16}\ \text{atoms}$$

Mass of 6.02×10^{23} atoms of radon = 222 g

$$\text{Mass of } 1.7653 \times 10^{16} \text{ atoms of radon} = \frac{222}{6.02 \times 10^{23}} \times 1.7653 \times 10^{16}$$

$$= 6.51 \times 10^{-6}\ \text{g}$$

By definition, the activity of radon is its mass in grams which gives 3.7×10^{10} disintegrations per second. Therefore **activity of radon** = **6.51×10^{-6} g curie.**

CALCULATION OF SAMPLE LEFT AFTER TIME *T*

It follows from equation (4) stated earlier that

$$\log\left(\frac{N_0}{N}\right) = \frac{\lambda t}{2.303}$$

Knowing the value of λ, the ratio of N_0/N can be calculated. If the amount of the sample present to start with is given, the amount left after lapse of time t can be calculated.

SOLVED PROBLEM 1. Cobalt-60 disintegrates to give nickel-60. Calculate the fraction and the percentage of the sample that remains after 15 years. The disintegration constant of cobalt-60 is 0.13 yr^{-1}.

SOLUTION

$$\log \frac{N_0}{N} = \frac{\lambda t}{2.303} = \frac{(0.13\text{yr}^{-1})(15\text{yr})}{2.303} = 0.847$$

$$\frac{N_0}{N} = \text{antilog } 0.847 = 7.031$$

The fraction remaining is the amount at time t divided by the initial amount.

$$\frac{N}{N_0} = \frac{1}{7.031} = \mathbf{0.14}$$

Hence the fraction remaining after 15 years is 0.14 or 14 per cent of that present originally.

SOLVED PROBLEM 2. How much time would it take for a sample of cobalt-60 to disintegrate to the extent that only 2.0 per cent remains ? The disintegration constant λ is 0.13 yr^{-1}.

SOLUTION

$$\frac{N}{N_0} = \frac{2}{100} = 0.02$$

or $$\frac{N_0}{N} = \frac{1}{0.02} = 50$$

From equation (4) stated earlier

$$\log\left(\frac{N_0}{N}\right) = \frac{\lambda t}{2.303}$$

$$\log 50 = \frac{(0.13\, yr^{-1})t}{2.303}$$

or $$t = \frac{2.303 \log 50}{0.13\ yr^{-1}} = \mathbf{30\ years}$$

SOLVED PROBLEM 3. A sample of radioactive ^{133}I gave with a Geiger counter 3150 counts per minute at a certain time and 3055 counts per unit exactly after one hour later. Calculate the half life period of ^{133}I.

SOLUTION. Here $N_0 = 3150$; $N = 3055$; $t_{\frac{1}{2}} = 1$hour.

We know $$\lambda = \frac{0.693}{t_{\frac{1}{2}}} \text{ and } \lambda = \frac{2.303}{t} \log \frac{N_0}{N}$$

or $$\frac{0.693}{t_{1/2}} = \frac{2.303}{t} \log \frac{N_0}{N} = \frac{2.303}{1} \log \frac{3150}{3055}$$

or $$t_{1/2} = \mathbf{22.63\ years}$$

AVERAGE LIFE

In a radioactive substance, some atoms decay earlier and others survive longer. **The statistical average of the lives of all atoms present at any time is called the Average life.** It is denoted by the symbol τ and has been shown to be reciprocal of decay constant, λ.

$$\tau = \frac{1}{\lambda}$$

The average life of a radioactive element is related to its half-life by the expression :

Average life = 1.44 × Half-life

or $$\tau = 1.44 \times t_{1/2}$$

The average life is often used to express the rate of disintegration of a radioactive element. The average life of radium is 2400 years.

RADIOACTIVE EQUILIBRIUM

Let a radioactive substance A decay to give another radioactive substance B which decays to form substance C. If λ_A and λ_B are the decay constants for the two changes, we can write

$$A \xrightarrow{\lambda_A} B \xrightarrow{\lambda_B} C$$

The rate of disintegration of A is also the rate of formation of B. When the rate of disintegration of A (or formation of B) is equal to the rate of disintegration of B, the amount of B does not change with lapse of time. Then the radioactive equilibrium is said to be established between the substance A and the substance B. At this stage

$$\frac{dN_A}{dt} = \frac{dN_B}{dt}$$

where N_A and N_B are atoms of A and B present at the equilibrium.

Since $$\lambda_A N_A = \lambda_B N_B, \quad \frac{N_A}{N_B} = \frac{\lambda_B}{\lambda_A}$$

But $$\lambda \propto t_{1/2}$$

$\therefore$ $$\frac{N_A}{N_B} = \frac{t_{1/2} \text{ of } B}{t_{1/2} \text{ of } A}$$

Thus the atoms of A and B are present in the ratio of their half-lives.

The radioactive equilibrium differs from a chemical equilibrium in that it is irreversible.

RADIOACTIVE DATING

The age of an old piece of wood can be determined by radioactive dating technique. The atmosphere contains radioactive carbon dioxide, $^{14}CO_2$, and ordinary carbon dioxide, $^{12}CO_2$, in a fixed ratio. A plant while alive takes up both types of carbon dioxide and converts them to carbon-14 and carbon-12 photosynthesis. Thus a living plant contains radioactive carbon-14 and stable carbon-12 in a fixed ratio. When the plant dies, the uptake of carbon from the atmosphere stops. Now onward, carbon-12 remains unchanged but carbon-14 decays by beta-emission.

$$\underset{\text{(radioactive)}}{{}^{14}_{6}C} \longrightarrow {}^{14}_{7}N + {}^{0}_{-1}\beta \quad \text{(Half-life} = 5730 \text{ yr)}$$

$$\underset{\text{(stable)}}{{}^{12}_{6}C} \longrightarrow \textit{No change}$$

As a result, $^{14}C/^{12}C$ decreases with lapse of time.

Therefore the concentration of carbon-14 declines with time. The concentration of carbon-14 can be measured by counting radioactivity. Knowing the concentration of carbon-14 in a given sample of old wood and that in a living plant, the age of the sample can be calculated.

SOLVED PROBLEM. The amount of carbon-14 in a piece of wood is found to be one-sixth of its amount in a fresh piece of wood. Calculate the age of old piece of wood.

SOLUTION

Calculation of Decay constant :

The half-life of carbon-14 = 5730 years

$$\therefore \qquad \lambda = \frac{0.693}{t_{1/2}} = \frac{0.693}{5730\ yr}$$

Calculation of Age of Wood :

From expression (4) on page 89

$$t = \log \frac{^{14}C_0}{^{14}C_t} \times \frac{2.303}{\lambda}$$

or

$$t = \log \frac{1}{1/6} \times \frac{2.303 \times 5730}{0.693}$$

$$= \log 6 \times \frac{2.303 \times 5730}{0.693}$$

$$= \frac{0.7782 \times 2.303 \times 5730}{0.693}$$

$$= \mathbf{14818.5\ years}$$

In a new method for determining the age of old wood (or fossil) the measurement of radioactivity is avoided. The ratio $^{14}C/^{12}C$ is found with the help of a mass spectrometer in the old wood and fresh wood from a living plant. It is assumed that the ratio $^{14}C/^{12}C$ in the fresh wood today is the same as it was at the time of death of the plant.

Let the ratio in the fresh plant at $t = 0$ be

$$\frac{^{14}C_0}{^{12}C_0} = x \qquad ...(1)$$

Let the ratio in the old piece of wood at time t be

$$\frac{^{14}C_t}{^{12}C_t} = y \qquad ...(2)$$

Dividing (1) by (2) $\dfrac{^{14}C_0}{^{12}C_0} \times \dfrac{^{12}C_t}{^{14}C_t} = \dfrac{x}{y}$

The concentration of carbon-12 does not change with time and $^{12}C_0 = {}^{12}C_t$

Therefore $\dfrac{^{14}C_0}{^{14}C_t} = \dfrac{x}{y} = \dfrac{1}{y/x}$

where the ratio in the old wood is y/x times the ratio in the living plant.

Knowing the value of y/x, the value of t can be found from the expression

$$t = \log \frac{^{14}C_0}{^{14}C_t} \times \frac{2.303}{\lambda}$$

SOLVED PROBLEM. A bone taken from a garbage pile buried under a hill-side had $^{14}C/^{12}C$ ratio 0.477 times the ratio in a living plant or animal. What was the date when the animal was buried?

SOLUTION

Half-life of carbon-14 is 5730 years

$$\therefore \qquad \lambda = \frac{0.693}{t_{1/2}} = \frac{0.693}{5730\ yr}$$

Substituting values in the expression

$$t = \log \frac{^{14}C_0}{^{14}C_t} \times \frac{2.303}{\lambda}$$

$$= \log \frac{1.0}{0.477} \times \frac{2.303 \times 5730}{0.693} = 6.1 \times 10^3$$

$$= \mathbf{6100\ yr}$$

The animal was buried 6100 years ago.

NUCLEAR REACTIONS

In a chemical reaction there is merely a rearrangement of extranuclear electrons. The atomic nucleus remains intact. A nuclear reaction involves a change in the composition of the nucleus. The number of protons and neutrons in the nucleus is altered. The product is a new nucleus of another atom with a different atomic number and/or mass number. Thus,

A nuclear reaction is one which proceeds with a change in the composition of the nucleus so as to produce an atom of a new element.

The conversion of one element to another by a nuclear change is called **transmutation.**

We have already considered the nuclear reactions of radioactive nuclei, producing new isotopes. Here we will consider such reactions caused by artificial means.

DIFFERENCES BETWEEN NUCLEAR REACTIONS AND CHEMICAL REACTIONS

Nuclear Reactions	Chemical Reactions
1. Proceed by redistribution of nuclear particles.	**1.** Proceed by the rearrangement of extra-nuclear electrons.
2. One element may be converted into another.	**2.** No new element can be produced.
3. Often accompanied by release or absorption of enormous amount of energy.	**3.** Accompanied by release or absorption of relatively small amount of energy.
4. Rate of reaction is unaffected by external factors such as concentration, temperature, pressure and catalyst.	**4.** Rate of reaction is influenced by external factors.

NUCLEAR FISSION REACTIONS

In these reactions an atomic nucleus is broken or fissioned into two or more fragments. This is accomplished by bombarding an atom by alpha particles (^4_2He), neutrons (^1_0n), protons (^1_1H), deutrons (^2_1H), etc. All the positively charged particles are accelerated to high kinetic energies by a device such as a *cyclotron*. This does not apply to neutrons which are electrically neutral. The projectile enters the nucleus and produces an unstable '**compound nucleus**'. It decomposes instantaneously to give the products. For example, ${}^{14}_{7}N$ when struck by an α-particle first forms an intermediate unstable compound nucleus, ${}^{18}_{9}F$, which at once cleaves to form stables ${}^{17}_{8}O$.

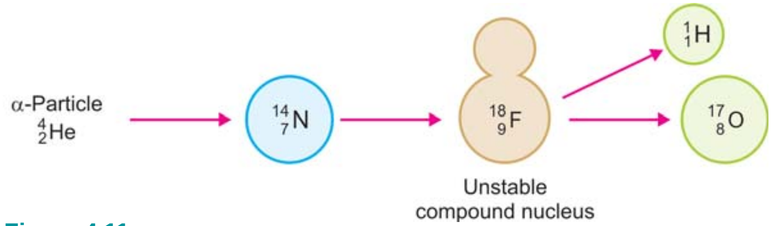


Figure 4.11
Mechanism of a Nuclear fission reaction.

Other examples are,

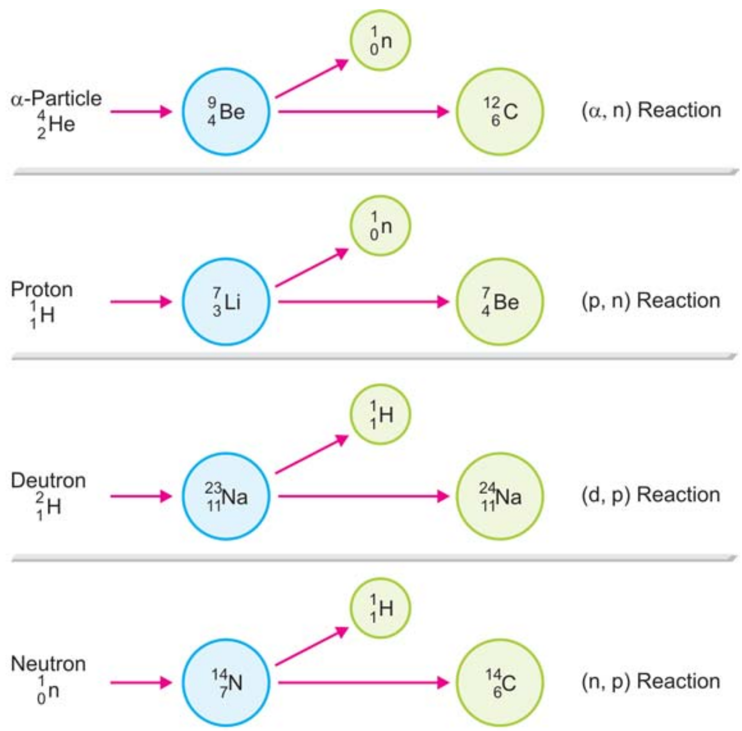


Figure 4.12
Representation of some Nuclear Fission reactions. Unstable compound nucleus is not shown.

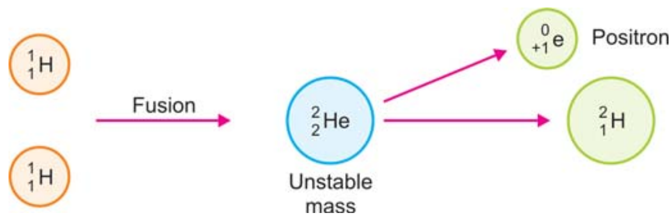
Nuclear fission reactions are classified according to the projectile used and the particle that is emitted. In Fig. 4.12 the type of the reaction has been stated.

It is noteworthy that neutrons are particularly useful as projectile. Sir James Chadwick obtained these by bombarding beryllium-9 with α-particles. Being electrically neutral, neutrons pierce the positive nucleus easily.

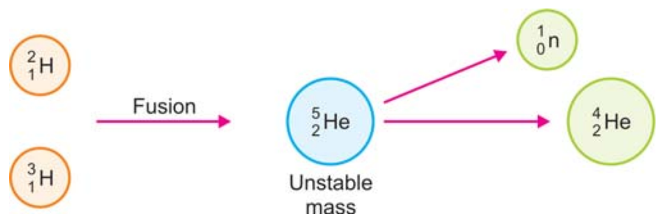
NUCLEAR FUSION REACTIONS

These reactions take place by combination or fusion of two small nuclei into a larger nucleus. At extremely high temperatures the kinetic energy of these nuclei overweighs the electrical repulsions between them. Thus they coalesce to give an unstable mass which decomposes to give a stable large nucleus and a small particle as proton, neutron, positron, etc. For example :

(1) Two hydrogen nuclei, ${}^{1}_{1}H$, fuse to produce a deuterium nucleus, ${}^{2}_{1}H$.



(2) Deuterium nucleus, ${}^{2}_{1}H$, and tritium nucleus, ${}^{3}_{1}H$, combine to give helium nucleus, ${}^{4}_{2}He$ with the expulsion of a neutron.



DIFFERENCES BETWEEN NUCLEAR FISSION AND NUCLEAR FUSION

Nuclear Fission	Nuclear Fusion
1. A bigger (heavier nucleus splits into smaller (lighter) nuclei.	**1.** Lighter nuclei fuse together to form the heavier nucleus.
2. It does not require high temperature.	**2.** Extremely high temperature is required for fusion to take place.
3. A chain reaction sets in.	**3.** It is not a chain reaction.
4. It can be controlled and energy released can be used for peaceful purposes.	**4.** It cannot be controlled and energy released cannot be used properly.
5. The products of the reaction are radioactive in nature.	**5.** The products of a fusion reaction are non-radioactive in nature.
6. At the end of the reaction nuclear waste is left behind.	**6.** No nuclear waste is left at the end of fusion reaction.

NUCLEAR EQUATIONS

Similar to a chemical reaction, nuclear reactions can be represented by equations. **These equations involving the nuclei of the reactants and products are called nuclear equations.** The nuclear reactions occur by redistribution of protons and neutrons present in the reactants so as to form the products. Thus the total number of protons and neutrons in the reactants and products is the same. Obviously, **the sum of the mass numbers and atomic numbers on the two sides of the equation must be equal.**

If the mass numbers and atomic numbers of all but one of the atoms or particles in a nuclear reaction are known, the unknown particle can be identified.

How to write a Nuclear equation?

(1) Write the symbols of the nuclei and particles including the mass numbers (superscripts) and atomic numbers (subscripts) on the left (reactants) and right (products) of the arrow.

(2) Balance the equation so that the sum of the mass numbers and atomic numbers of the particles (including the unknown) on the two sides of the equation are equal. Thus find the atomic number and mass number of the unknown atom, if any.

(3) Then look at the periodic table and identify the unknown atom whose atomic number is disclosed by the balanced equation.

Examples of Nuclear equations

(*a*) **Disintegration of radium-236** by emission of an alpha particle ($^{4}_{2}He$),

$$^{236}_{88}Ra \longrightarrow ^{232}_{86}Rn + ^{4}_{2}He$$

Mass Nos :	Reactants = 236 ;	Products = 232 + 4 = 236
Atomic Nos :	Reactants = 88 ;	Products = 86 + 2 = 88

(*b*) **Disintegration of phosphorus-32** by emission of a beta particle ($^{0}_{-1}e$),

$$^{32}_{15}P \longrightarrow ^{0}_{-1}e + ^{32}_{16}S$$

Mass Nos :	Reactants = 32 ;	Products : 0 + 32 = 32
Atomic Nos :	Reactants = 15 ;	Products : 16 – 1 = 15

(*c*) **Fission of argon-40** by bombardment with a proton $^{1}_{1}H$,

$$^{40}_{18}Ar + ^{1}_{1}H \longrightarrow ^{40}_{19}K + ^{1}_{0}n$$

Mass Nos :	Reactants = 40 + 1 = 41 ;	Products = 40 + 1 = 41
Atomic Nos :	Reactants = 18 + 1 = 19 ;	Products = 19 + 0 = 19

(*d*) **Fission of uranium-235** by absorption of a neutron ($^{1}_{0}n$),

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

Mass No :	Reactants = 235 + 1 = 236;	Products = 141 + 92 + 3 = 236
Atomic Nos :	Reactants = 92 + 0 = 92;	Products = 56 + 36 + 0 = 92

(*e*) **Fusion of lithium-7** and proton, $^{1}_{1}H$,

$$^{7}_{3}Li + ^{1}_{1}H \longrightarrow 2\,^{4}_{2}He$$

Mass Nos :	Reactants = 7 + 1 = 8 ;	Products = 2 × 4 = 8
Atomic Nos :	Reactants = 3 + 1 = 4 ;	Products = 2 × 2 = 4

SOLVED PROBLEM 1. Write the nuclear equation for the change that occurs in radium-226 when it emits an alpha particle.

SOLUTION

Step 1 Write the symbol of the parent atom with its mass number and atomic number (from periodic table) on the left-hand side of the equation.

$$^{226}_{88}Ra \longrightarrow$$

Step 2 Write the symbol for the alpha particle on the right-hand side of the equation.

$$^{226}_{88}Ra \longrightarrow ^{4}_{2}He + ?$$

Step 3 Complete the equation by writing the symbol of an isotope that has an atomic number 88 – 2 = 86 and mass number 226 – 4 = 222. As shown by the periodic table, the isotope with atomic number 86 is radon, Rn. Thus,

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

Step 4 Check that the mass numbers and atomic numbers on the two sides of the equation are balanced.

$$\textit{Mass Nos}: \quad 226 = 4 + 222$$
$$\textit{Atomic Nos}: \quad 88 = 2 + 86$$

SOLVED PROBLEM 2. Cobalt–60 decays by emission of a beta particle. Predict the atomic number, mass number, and name of the isotope formed.

SOLUTION

Step 1 Write the symbol of the cobalt with mass number and atomic number (from the periodic table) on the left-hand side of the equation.

$$^{60}_{27}\text{Co} \longrightarrow$$

Step 2 If the unknown product isotope is *X* with mass number *M* and atomic number *A*, the nuclear equation may be written as

$$^{60}_{27}\text{Co} \longrightarrow {}^{M}_{A}X + {}^{0}_{-1}e$$

Step 3 Since the sum of mass numbers and atomic numbers are equal on the two sides of the equation,

$$M = 60$$
$$A = 27 + 1 = 28$$

Step 4 Consult the periodic table and find the element whose atomic number is 28. This is nickel, Ni. Therefore, the complete equation for the decay of cobalt-60 is

$$^{60}_{27}\text{Co} \longrightarrow {}^{60}_{28}\text{Ni} + {}^{0}_{-1}e$$

SOLVED PROBLEM 3. Complete the nuclear equation

$$^{238}_{92}\text{U} + {}^{4}_{2}\text{He} \longrightarrow ? + {}^{1}_{0}n$$

SOLUTION

Let the unknown atom be *X* with mass number *M* and atomic number *A*.

We can write the above nuclear equation as

$$^{238}_{92}\text{U} + {}^{4}_{2}\text{He} \longrightarrow {}^{M}_{A}\text{X} + {}^{1}_{0}n$$

But the sum of mass numbers on the two sides of the equation is equal. Thus,

$$238 + 4 = M + 1$$

or, $M = 242 - 1 = 241$

Also $92 + 2 = A + 0$

or $A = 94$

Find the isotope of atomic number 94 from the periodic table. It is plutonium, Pu. Thus the completed nuclear equation is

$$^{238}_{92}\text{U} + {}^{4}_{2}\text{He} \longrightarrow {}^{241}_{94}\text{Pu} + {}^{1}_{0}n$$

ARTIFICIAL RADIOACTIVITY

Many stable nuclei when bombarded with high speed particles produce unstable nuclei that are radioactive. The radioactivity produced in this manner by artificial means is known as **artificial radioactivity** or **induced radioactivity.** The artificial isotopes disintegrate in a definite fashion and have specific half-life. For example, aluminium-27 when bombarded with a neutron emits an alpha particle and forms sodium-24 which is radioactive. It disintegrates spontaneously by emission of a beta particle ($_{-1}^{0}e$) and the product is magnesium-24. Sodium-24 has half-life of 24 hours.

$$_{0}^{1}n + _{13}^{27}Al \longrightarrow \underset{\text{radioactive}}{_{11}^{24}Na} + _{2}^{4}He$$

$$_{11}^{24}Na \longrightarrow _{12}^{24}Mg + _{-1}^{0}e$$

NUCLEAR ISOMERISM

Sometimes α and β-decays may produce a pair of nuclei that have the same number of protons and neutrons but different radioactive properties.

A pair of nuclei having same number of protons and neutrons but different half-lives are called nuclear isomers. The phenomenon is called **nuclear isomerism.**

Example of Nuclear isomerism

Uranium-Z and Uranium-X_2 constitute a pair of nuclear isomers. Both nuclei contain 91 protons and 143 neutrons, and are isotopes. They exhibit β-ray activity with half-lives 6.7 hr and 1.14 min respectively.

Explanation

The α- or β-decay of a radionuclide first leaves it in an excited state. This is then converted into the ground state nucleus. The excited and the ground state nuclei thus produced are called nuclear isomers. The nuclear isomers may be isotopic or isobaric.

ENERGY RELEASED IN NUCLEAR REACTIONS

Einstein's Equation Relating Mass and Energy

According to Albert Einstein, mass can be converted into energy and *vice versa.* His famous equation relating mass and energy is

$$E = mc^2 \qquad \text{...(1)}$$

where E = energy ; m = mass and c = velocity of light. In nuclear reactions, a change in mass, Δm, is accompanied by release of energy, ΔE. Thus equation (1) may be written as

$$\Delta E = \Delta mc^2 \qquad \text{...(2)}$$

If we substitute the value 3.00×10^{10} cm/sec for the velocity of light, the equation (2) directly gives the relation between the energy change in ergs and the mass change in grams.

$$\Delta E \text{ (in ergs)} = 9.00 \times 10^{20} \times \Delta m \text{ (in grams)} \qquad \text{...(3)}$$

Making use of the conversion factor 1 erg = 2.39×10^{-11} kcal, we can express the energy change in k cals.

$$\Delta E = 9.00 \times 10^{20} \text{ erg} \times \frac{2.39 \times 10^{-11}}{1 \text{ erg}} \times \Delta m$$

or $$\Delta E \text{ (in kcal)} = 2.15 \times 10^{10} \times \Delta m \text{ (in grams)} \qquad \text{...(4)}$$

Very often, in a nuclear reaction, the mass of the products is less than that of the reactants. The mass difference is converted into energy. Therefore by using equation (4), we can calculate the amount of energy released in a particular reaction. For example, in the equation

$^{7}_{3}Li$	+	$^{1}_{1}H$	$\longrightarrow$	$^{4}_{2}He$	+	$^{4}_{2}He$	+	energy
7.160 grams		1.0078 grams		4.0026 grams		4.0026 grams		

The atomic mass difference between the reactants and products is 0.0186 gram. Using equation (4)

$$\begin{aligned}\Delta E &= 2.15 \times 10^{10} \times \Delta m \\ &= 2.15 \times 10^{10} \times 0.0186 \\ &= 4.0 \times 10^{8} \text{ k calories}\end{aligned}$$

MASS DEFECT

We know that atomic nucleus consists of protons and neutrons; collectively known as nucleons. It is found that the measured mass of nucleus is always less than the sum of the masses of the individual protons and neutrons which make it up. Let us take the example of helium, $^{4}_{2}He$. It consists of two protons and two neutrons. Its mass may be calculated as :

$$\begin{aligned}\text{mass of the protons} &= 2 \times 1.00815 \\ \text{mass of the neutrons} &= 2 \times 1.00899 \\ &\quad 4.03428\end{aligned}$$

However, the experimental mass of the helium nucleus is only 4.00388. This is less by 0.03040 amu than that calculated above. This is called the mass defect of helium nucleus.

The difference between the experimental and calculated masses of the nucleus is called the Mass defect or Mass deficit.

(experimental mass of nucleus) – (mass of protons + mass of neutrons) = mass defect

NUCLEAR BINDING ENERGY

Atomic nucleus is made of protons and neutrons closely packed in a small volume. Although there exist intensive repulsive forces between the component protons, the nucleus is not split apart. This is so because the nucleons are bound to one another by very powerful forces. **The energy that binds the nucleons together in the nucleus is called the Nuclear binding energy.**

When a nucleus is formed from individual protons and neutrons, there occurs a loss of mass (mass defect). According to Einstein's theory, it is this mass defect which is converted into binding energy. **Hence binding energy is the energy equivalent of the mass defect.** The various nuclei have different binding energies.

Binding energy is a measure of the force that holds the nucleons together. Hence an energy equivalent to the binding energy is required to disrupt a nucleus into its constituent protons and neutrons. Since the nuclear energy is of an extremely high order, it is not easy to fission a nucleus.

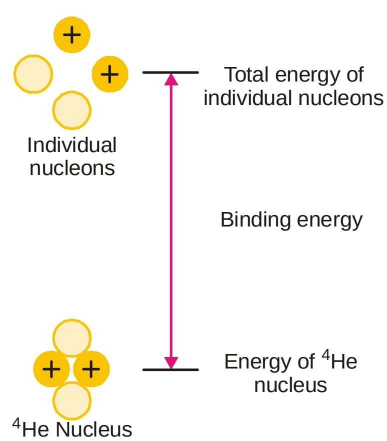


Figure 4.13
A nucleus has a lower energy and a smaller mass than free nucleons.

Calculation of Binding Energy

The binding energy of a nucleus can be calculated from its mass defect by using Einstein's equation, $\Delta E = \Delta m \times c^2$.

SOLVED PROBLEM. What is the binding energy for ${}^{11}_{5}B$ nucleus if its mass defect is 0.08181 amu ?

SOLUTION

$$\Delta E = \Delta m \times c^2 \quad \text{....Einstein's equation}$$

Here, $\Delta m = 0.08181$ g/mole

$c = 3 \times 10^{10}$ cm/sec

Substituting values in Einstein's equation,

$$\Delta E = (0.08181 \text{ g/mole})(3 \times 10^{10} \text{ cm/sec})^2$$
$$= 7.4 \times 10^{19} \text{ ergs/mole}$$

No. of nuclei in one mole is 6.02×10^{23} (Avogadro's Law).

$\therefore$ Binding energy for ${}^{11}_{5}B$ nucleus, ΔE, may be expressed as

$$\Delta E = \frac{7.4 \times 10^{19}}{6.02 \times 10^{23}} = \mathbf{1.2 \times 10^{-4} \text{ ergs/nucleus}}$$

Binding energy per nucleon

It can be calculated by dividing the total binding energy by the sum of the number of protons and neutrons present in the nucleus.

$$\text{Binding energy per nucleon} = \frac{\text{Binding energy of nucleus}}{\text{No. of protons + No. of neutrons}}$$

By plotting the binding energy per nucleon against the mass number, we get the graph shown in Fig. 4.14 This shows the relative stability of the various nuclei. **The greater the binding energy per nucleon the more stable is the nucleus.** Thus the nuclei of about 60 atomic mass having maximum energy per nucleon are most stable *e.g.*, ${}^{56}Fe$. The nuclei that are heavier or lighter than this have lower binding energies per nucleon and are less stable. Thus ${}^{235}U$ undergoes fission into lighter and more stable isotopes as ${}^{139}Ba$ and ${}^{94}Kr$ with the release of energy. Similarly two or more lighter nuclei (${}^{2}H$, ${}^{3}H$) with lower binding energy per nucleon combine or fuse together into a heavier and more stable nucleus. This is also accompanied by release of energy.

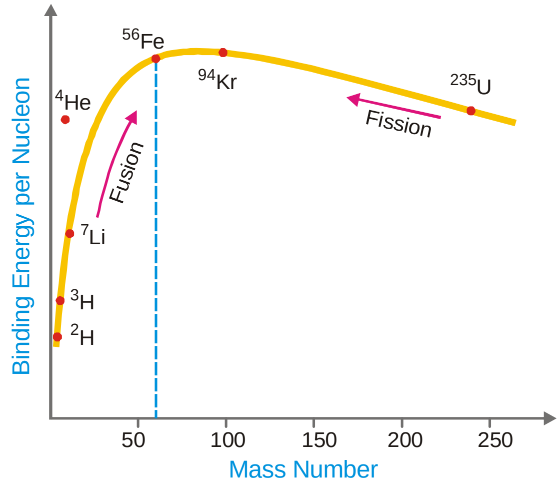


Figure 4.14
A curve of binding energy per nucleon versus mass number.

Equivalence of amu and Energy

Since 1 amu is exactly equal to $\frac{1}{12}$th of the mass of C^{12} atom, therefore

$$1 \text{ amu} = \frac{1}{12} \times \text{Mass of } C^{12} \text{ atom}$$

$$= \frac{\frac{1}{12} \times \text{gram atomic mass of } C^{12}}{\text{Avagadro's Number}}$$

$$= \frac{1}{12} \times \frac{12}{6.02 \times 10^{23}} g$$

$$= 1.66 \times 10^{-24} \text{ g}$$

Also $E = mc^2$

$\therefore$ $E = 1.66 \times 10^{-24} \text{ g} \times (3 \times 10^{10})^2$

$$= 1.494 \times 10^{-3} \text{ erg}$$

$$= \frac{1.494 \times 10^{-3}}{4.184 \times 10^{7}} \text{ cal} \qquad [\because 1 \text{ cal} = 4.184 \times 10^7 \text{ erg}]$$

$$= 0.356 \times 10^{-10} \text{ cal}$$

or $E = \frac{1.494 \times 10^{-3}}{10^{7}} \text{ joule}$ $\qquad [\because \text{ joule} = 10^7 \text{ erg}]$

$$= 1.494 \times 10^{-10} \text{ J}$$

$$= \frac{1.494 \times 10^{-10}}{1.602 \times 10^{-19}} \qquad [\because 1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}]$$

$$= 931.5 \times 10^{6} \text{ ev}$$

$$= 931.5 \text{ Mev}$$

Thus **1 amu = 931.5 Mev**

SOLVED PROBLEM. Calculate the binding energy per nucleon (in Mev) in He atom ${}^{4}_{2}\text{He}$ which has a mass of 4.00260 amu. Mass of an electron = 1.008655 amu and mass of 1 hydrogen atom = 1.007825 mass.

SOLUTION. In Helium atom there are 2 electrons, 2 protons and 2 neutrons.

$\therefore$ Mass of 2p + 2e = 2 × mass of 1 H atom

= 2 × 1.007825 amu

= 2.01565 amu

and Mass of 2 neutrons = 2 × 1.008665 amu

Mass of He atom = 2.01565 + 2.01733

= 4.03298 amu

Actual mass of the atom = 4.0026 amu (given)

$\therefore$ Mass defect = 4.0328 – 4.00260

= **0.03038 amu**

Binding Energy = 0.03038 × 931.5 Mev

= 28.298 Mev $\qquad [\because 1 \text{ amu} = 931.5 \text{ Mev}]$

Binding energy per nucleon

$$= \frac{\text{Binding Energy}}{\text{No. of Nucleons}}$$

$$= \frac{28.298}{4} = \mathbf{7.0745\ Mev}$$

NEUTRON-PROTON RATIO AND NUCLEAR STABILITY

Nuclei are composed of protons and neutrons. The protons would tend to fly apart due to repulsive forces between them. But the neutrons in some way hold the protons together within the nucleus. **The stability of a nucleus seems to depend on the neutron-to-proton ratio (*n*/*p*) in the nucleus.** Fig. 4.15 shows the neutron-to-proton ratios for all known stable elements. Each point on the graph indicates the number of protons and neutrons in a particular stable nucleus. It is clear from the graph that :

(1) **The lower elements (up to Z = 20), the stable nuclei have about equal number of protons and neutrons i.e.,** n/p = 1.

(2) **For higher elements to be stable, there must be more neutrons than protons i.e., n/p > 1.**

(3) **The shaded portion in Fig. 4.15 represents the region or belt of stability.** The element whose n/p ratios lie inside the belt are stable.

(4) **A nucleus whose n/p lies above or below the stability belt is radioactive or unstable on account** of unfavourable n/p ratio. It emits α- or β- particles so as to move into the stability range.

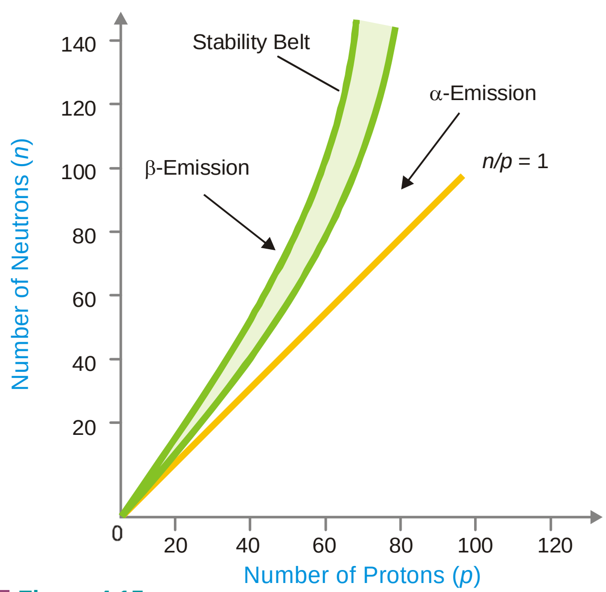


Figure 4.15
Neutron-proton ratios of stable nuclei.

(*a*) A nucleus that is above the stability belt emits a β-particle whereby a neutron is converted to proton. Thus *n*/*p* decreases and the nucleus becomes more stable or enters the stability belt. For example,

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

n/*p* 1.33 1.0

(*b*) A nucleus whose *n*/*p* lies below the stability belt emits an α-particle and loses 2 protons and 2 neutrons. This results in a net increase of *n*/*p* and the new nucleus may enter the stability belt. For example,

$$^{238}_{92}U \longrightarrow ^{234}_{90}Th + ^{4}_{2}\alpha$$

n/*p* 1.565 1.60

The radioactive nuclei continue to emit α- or β-particles, one after the other, till a stable nucleus is the end-product.

NUCLEAR FISSION PROCESS

In 1939, Hahn and Stassmann discovered that a heavy atomic nucleus as of uranium-235 upon bombardment by a neutron splits apart into two or more nuclei. U-235 first absorbs a neutron to form an unstable 'compound nucleus'. The excited 'compound nucleus' then divides into two daughter nuclei with the release of neutrons and large amount of energy.

The splitting of a heavy nucleus into two or more smaller nuclei is termed nuclear fission.

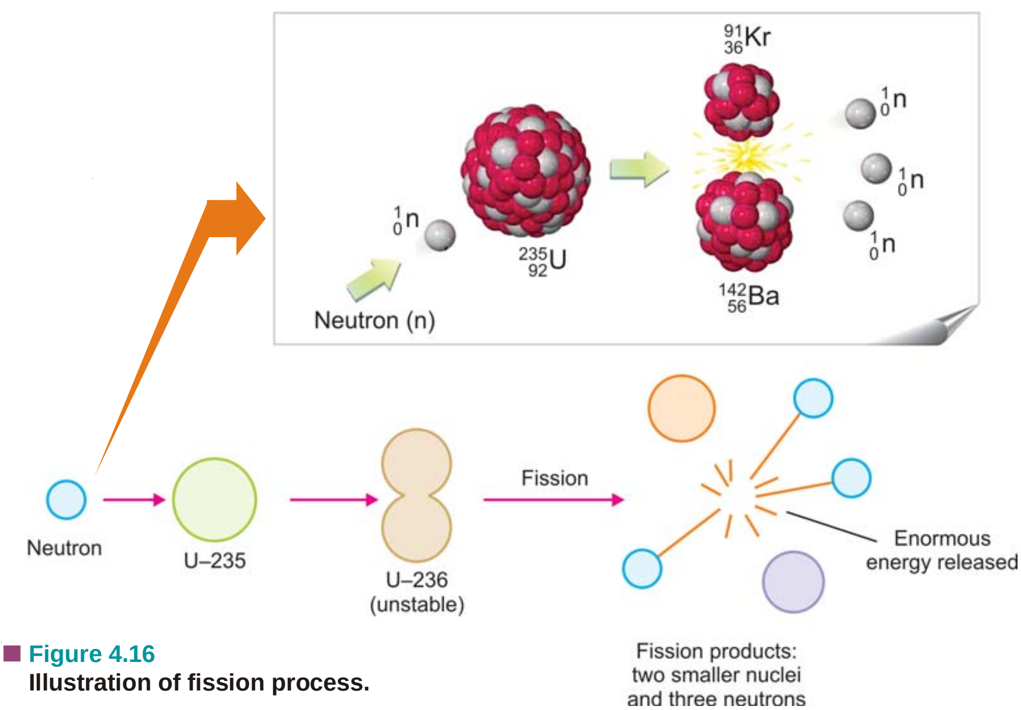
The smaller nuclei formed as a result of fission are called **fission products.** The process of fission is always accompanied by the ejection of two or more neutrons and liberation of vast energy.

A given large nucleus can fission in many ways forming a variety of products. Thus the fission of U-235 occurs in about 35 ways. Two of these are given below in the form of equations.

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{139}_{56}Ba + ^{94}_{36}Kr + 3\,^{1}_{0}n + energy$$

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{106}_{42}Mo + ^{128}_{50}Sn + 2\,^{1}_{0}n + energy$$

In these fission reactions, the mass of the products is less than the mass of the reactant. A loss of mass of about 0.2 amu per uranium atom occurs. This mass is converted into a fantastic quantity of energy which is 2.5 million times of that produced by equivalent amount of coal.



■ **Figure 4.16**
Illustration of fission process.

CHARACTERISTICS OF NUCLEAR FISSION

(1) Upon capturing a neutron, a heavy nucleus cleaves into two or more nuclei.
(2) Two or more neutrons are produced by fission of each nucleus.
(3) Vast quantities of energy are produced as a result of conversion of small mass into energy.
(4) All the fission products are radioactive, giving off beta and gamma radiations.

NUCLEAR CHAIN REACTION

We know that U-235 nucleus when hit by a neutron undergoes the reaction,

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{139}_{56}Ba + ^{94}_{36}Kr + 3\,^{1}_{0}n$$

Each of the three neutrons produced in the reaction strikes another U-235 nucleus, thus causing nine subsequent reactions. These nine reactions, in turn, further give rise to twenty seven reactions. This process of propagation of the reaction by multiplication in threes at each fission, is referred to as a **chain reaction**. Heavy unstable isotopes, in general, exhibit a chain reaction by release of two or three neutrons at each fission. It may be defined as :

a fission reaction where the neutrons from a previous step continue to propagate and repeat the reaction.

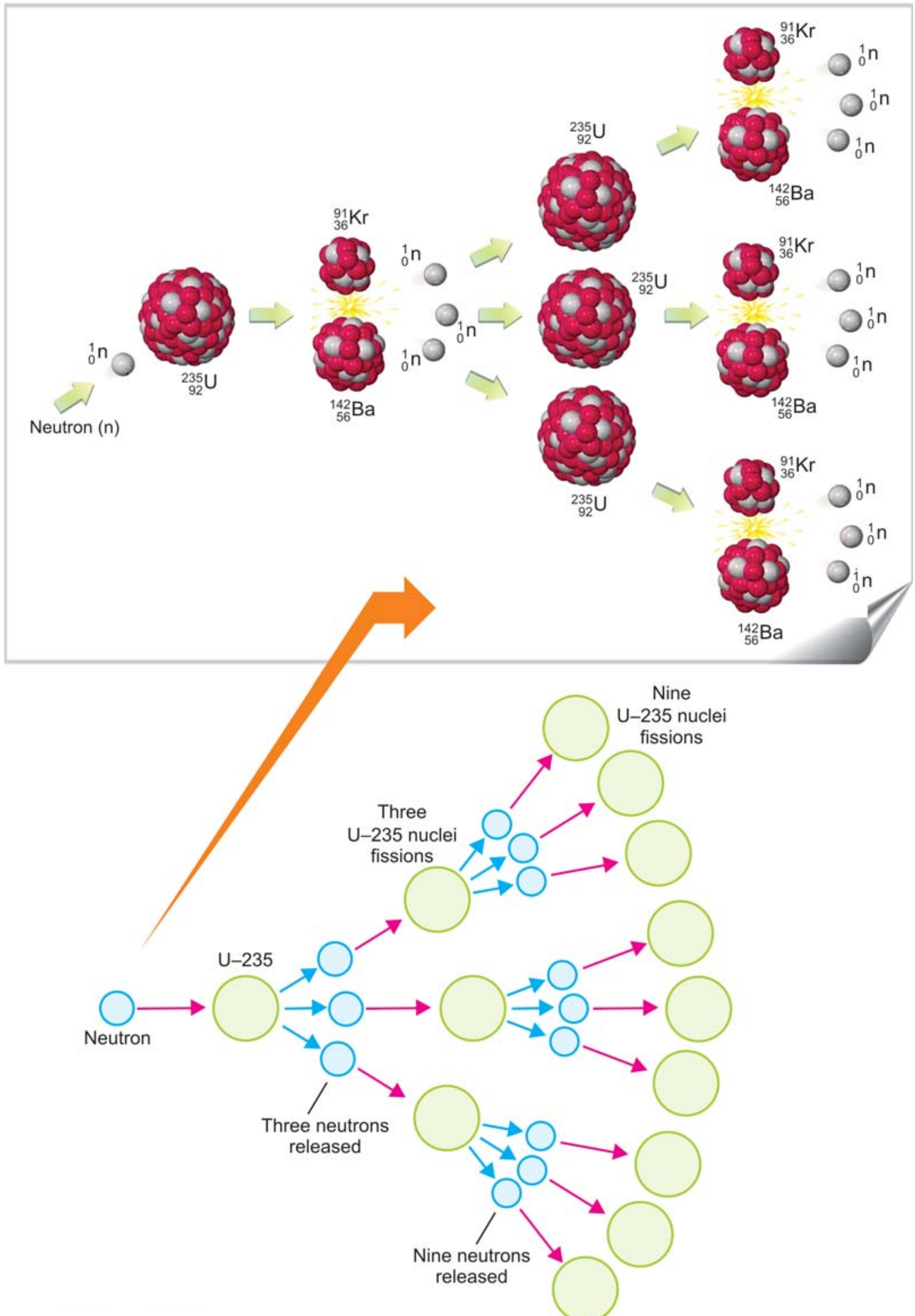
A chain reaction continues till most of the original nuclei in the given sample are fissioned. However, it may be noted that not all the neutrons released in the reaction are used up in propagating the chain reaction. Some of these are lost to the surroundings. Thus for a chain reaction to occur, the sample of the fissionable material should be large enough to capture the neutron internally. If the sample is too small, most neutrons will escape from its surface, thereby breaking the chain. **The minimum mass of fissionable material required to sustain a chain reaction is called critical mass.** The critical mass varies for each reaction. For U-235 fission reaction it is about 10 kg.

As already stated, even a single fission reaction produces a large amount of energy. A chain reaction that consists of innumerable fission reactions will, therefore, generate many times greater energy.

NUCLEAR ENERGY

A heavy isotope as uranium-235 (or plutonium-239) can undergo nuclear chain reaction yielding vast amounts of energy. **The energy released by the fission of nuclei is called nuclear fission energy or nuclear energy.** Sometimes, it is incorrectly referred to as **atomic energy.**

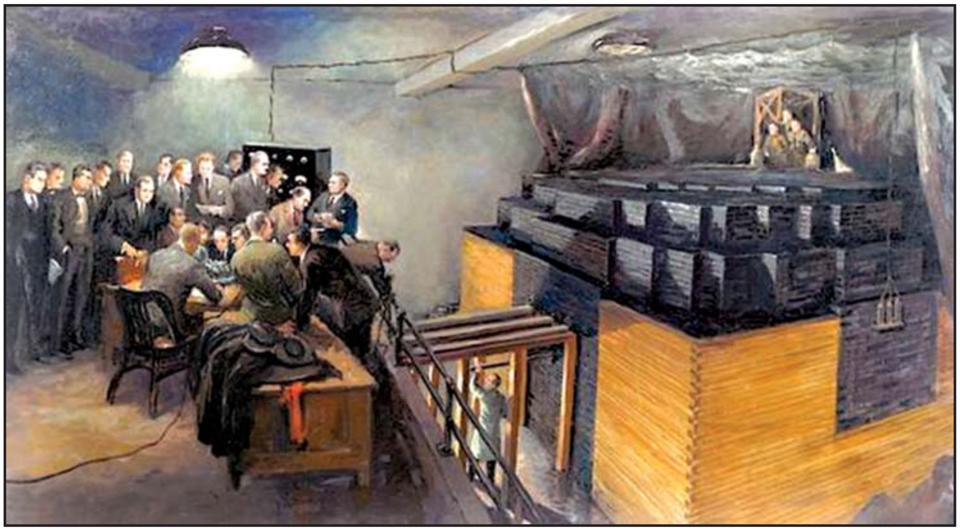
The fission of U-235 or Pu-239 occurs instantaneously, producing incomprehensible quantities of energy in the form of heat and radiation. If the reaction is uncontrolled, it is accompanied by explosive violence and can be used in atomic bombs. However, when controlled in a reactor, the fission of U-235 is harnessed to produce electricity.



■ **Figure 4.17**

Illustration showing how U-235 fission chain reaction is propagated and multiplied. The products $^{139}_{56}Ba$ and $^{94}_{36}Kr$ are not shown.

FIRST CHAIN REACTION



The first controlled nuclear fission chain reaction, directed by Italian-born American physicist Enrico Fermi, is captured here in a painting of the event, which took place under the sports stadium at the University of Chicago in December 1942. The event was the forerunner of all nuclear reactors.

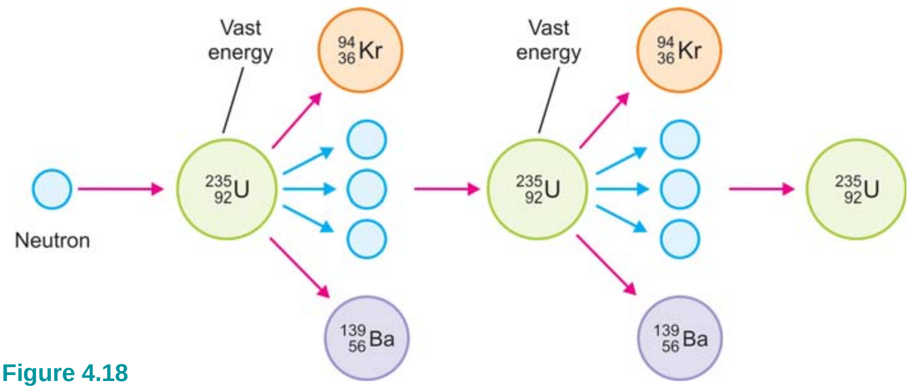


Figure 4.18
Chain reaction of Uranium-235 producing energy.

THE ATOMIC BOMB

A bomb which works on the principle of a fast nuclear chain reaction is referred to as the atomic bomb. A design of such a bomb is shown in Fig. 4.19. It contains two subcritical masses of fissionable material, ^{235}U or ^{239}Pu. It has a mass of trinitrotoluene in a separate pocket. When TNT is detonated, it drives one mass of ^{235}U into the other. A supercritical mass of the fissionable material is obtained. As a result of the instantaneous chain reaction, the bomb explodes with the release of tremendous heat energy. **Temperature developed in an atomic bomb is believed to be 10 million °C (temperature of the sun).** Besides many radionuclei and heat, deadly gamma rays are released.

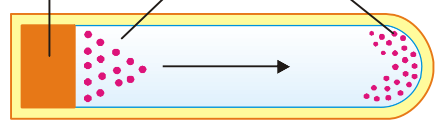
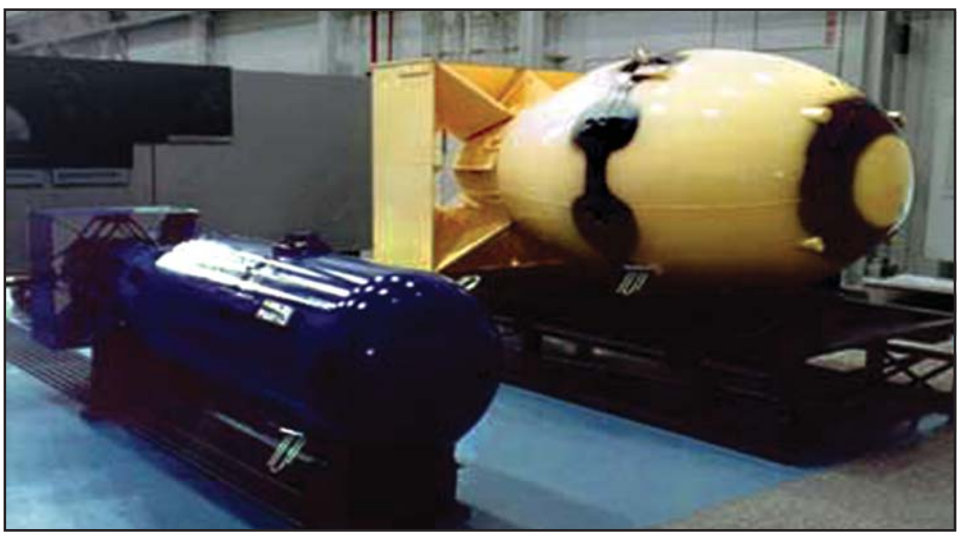


Figure 4.19
A design used in atomic bombs to bring together two subcritical masses of ^{235}U.

These play havoc with life and environment. If the bomb explodes near the ground, it raises tons of dust into the air. The radioactive material adhering to dust known as **fall out.** It spreads over wide areas and is a lingering source of radioactive hazard for long periods.

LITTLE BOY AND FAT MAN



The First Atomic Bombs

Little Boy was the first nuclear weapon used in warfare. It exploded approximately 1,800 feet over Hiroshima, Japan, on the morning of August 6, 1945, with a force equal to 13,000 tons of TNT. Immediate deaths were between 70,000 to 130,000.

Fat Man was the second nuclear weapon used in warfare. Dropped on Nagasaki, Japan, on August 9, 1945, *Fat Man* devastated more than two square miles of the city and caused approximately 45,000 immediate deaths.

While *Little Boy* was a uranium gun-type device, *Fat Man* was a more complicated and powerful plutonium implosion weapon that exploded with a force equal to 20 kilotons of TNT.

NUCLEAR REACTOR

It has been possible to control fission of U-235 so that energy is released slowly at a usable rate. **Controlled fission is carried out in a specially designed plant called a nuclear power reactor or simply nuclear reactor.** The chief components of a nuclear reactor are :

(1) **U-235 fuel rods** which constitute the 'fuel core'. The fission of U-235 produces heat energy and neutrons that start the chain reaction.

(2) **Moderator** which slows down or moderates the neutrons. The most commonly used moderator is ordinary water. Graphite rods are sometimes used. Neutrons slow down by losing energy due to collisions with atoms/molecules of the moderator.

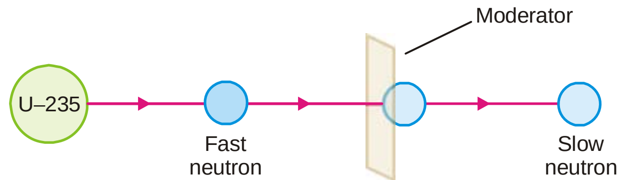


Figure 4.20
Moderator slows down a fast neutron.

(3) **Control rods** which control the rate of fission of U-235. These are made of boron-10 or cadmium, that absorbs some of the slowed neutrons.

$$^{10}_{5}B + ^{1}_{0}n \longrightarrow ^{7}_{3}Li + ^{4}_{2}He$$

Thus the chain reaction is prevented from going too fast.

(4) **Coolant** which cools the fuel core by removing heat produced by fission. Water used in the reactor serves both as moderator and coolant. Heavy water (D_2O) is even more efficient than light water.

(5) **Concrete shield** which protects the operating personnel and environments from destruction in case of leakage of radiation.

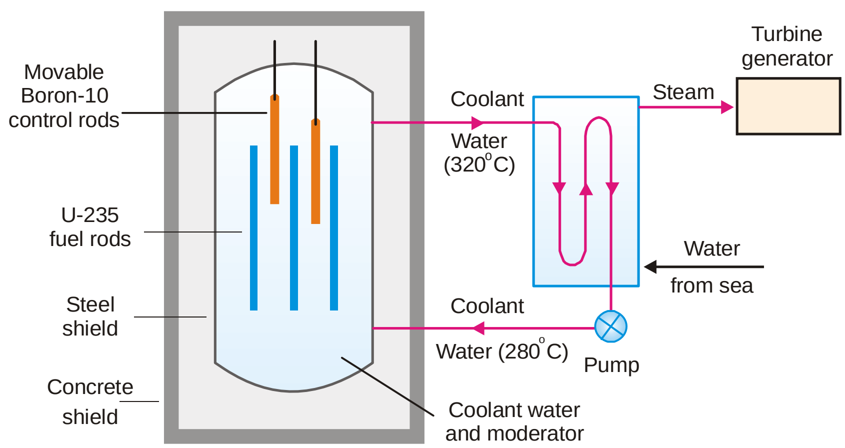


Figure 4.21
A light-water reactor producing electricity.

Light-water Nuclear power plant

Most commercial power plants today are 'light-water reactors'. In this type of reactor, U-235 fuel rods are submerged in water. Here, water acts as coolant and moderator. The control rods of boron-10 are inserted or removed automatically from spaces in between the fuel rods.

The heat emitted by fission of U-235 in the fuel core is absorbed by the coolant. The heated coolant (water at 300°C) then goes to the *exchanger*. Here the coolant transfers heat to sea water which is converted into steam. The steam then turns the turbines, generating electricity. **A reactor once started can continue to function and supply power for generations.**

About 15 per cent of consumable electricity in U.S.A. today is provided by light water reactors. India's first nuclear plant went into operation in 1960 at Tarapur near Mumbai. Another plant has been set up at Narora in Uttar Pradesh. While such nuclear power plants will be a boon for our country, they could pose a serious danger to environments. In May 1986, the leakage of radioactive material from the Chernobyl nuclear plant in USSR played havoc with life and property around.

Disposal of reactor waste poses another hazard. The products of fission *e.g.*, Ba-139 and Kr-92, are themselves radioactive. They emit dangerous radiation for several hundred years. The waste is packed in concrete barrels which are buried deep in the earth or dumped in the sea. But the fear is that any leakage and corrosion of the storage vessels may eventually contaminate the water supplies.

Breeder Reactor

We have seen that uranium-235 is used as a reactor fuel for producing electricity. But our limited supplies of uranium-235 are predicted to last only for another fifty years. However, nonfissionable uranium-238 is about 100 times more plentiful in nature. This is used as a source of energy in the so-called breeder reactors which can supply energy to the world for 5,000 years or more.

Here the uranium-235 core is covered with a layer or 'blanket' of uranium-238. The neutrons released by the core are absorbed by the blanket of uranium-238. This is then converted to fissionable plutonium-239. It undergoes a chain reaction, producing more neutrons and energy.

$$^{238}_{92}U + ^{1}_{0}n \longrightarrow ^{239}_{94}Pu + 2\,^{0}_{-1}e$$

$$^{239}_{94}Pu + ^{1}_{0}n \longrightarrow ^{90}_{38}Sr + ^{147}_{56}Ba + 3\,^{1}_{0}n$$

The above reaction sequence produces three neutrons and consumes only two. The excess neutron goes to convert more uranium to plutonium-239. **Thus the reactor produces or 'breeds' its own fuel and hence its name.** Several breeder reactors are now functioning in Europe. However, there is opposition to these reactors because the plutonium so obtained can be used in the dreaded H-bomb.

NUCLEAR FUSION PROCESS

This process is opposite of nuclear fission. Nuclear fusion may be defined as : **the process in which two light-weight nuclei combine or fuse to form a single heavier nucleus.**

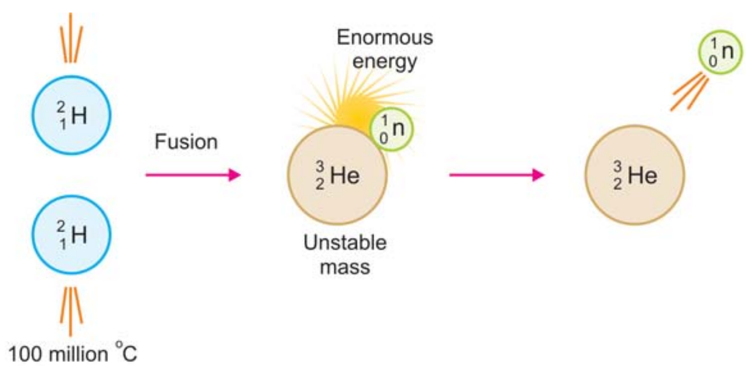


Figure 4.22
Illustration of fusion of two deuterium ($^{2}_{1}H$) nuclei to form a single nucleus of helium ($^{3}_{2}He$) with the release of a neutron and enormous energy.

For example, two nuclei of deuterium ($^{2}_{1}H$) undergo nuclear fusion to yield a heavier nucleus of helium-3. This fusion reaction takes place at a temperature of about 100 million °C. The above fusion reaction may be stated in the form of an equation as :

$$2\ ^{2}_{1}H \longrightarrow\ ^{3}_{2}He + ^{1}_{0}n + energy$$

Since fusion reactions occur at extremely high temperatures, these are also called **thermonuclear reactions.**

In a fusion reaction, the mass of the reacting nuclei is greater than that of the nucleus formed. The differential mass is manifested in the great amount of energy released in the reaction. For example,

$^{3}_{1}H$	+	$^{1}_{1}H$	$\longrightarrow$	$^{4}_{2}He$	+	*energy*
3.01495 amu		1.00782 amu		4.00260 amu		

The total mass of the reactants is 4.02277 amu which is 0.02017 amu greater than the mass of the product. The mass that lost is covered into lot of energy. A pair of reacting nuclei induces fusion of another pair of nuclei. In this way fantastic amounts of energy are generated. This is the basis of the H-bomb or **Hydrogen bomb.**

How Fusion occurs?

Let us explain the mechanism of fusion by taking the example of the fusion of deuterium ($^{2}_{1}H$) cited above. At extremely high temperatures, 100 million °C or more, atoms do not exist as such. At these temperatures, deuterium atoms are completely stripped of orbital electrons. Thus results a system containing positive nuclei and electrons, called **plasma.** In this state, the high kinetic energy of the nuclei can overcome electrostatic repulsions between them. The nuclei collide with such great force that they merge or fuse to form larger nuclei. (Fig. 4.23)

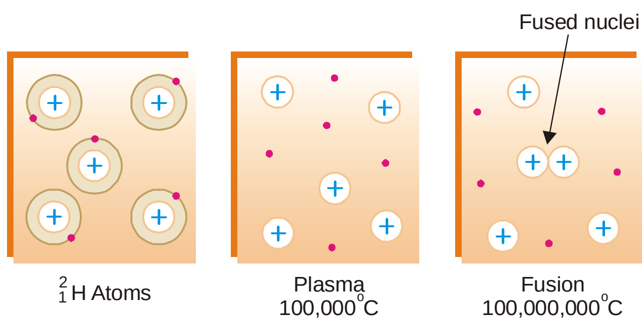


Figure 4.23
Mechanism of fusion of $^{2}_{1}H$.

SOLAR ENERGY

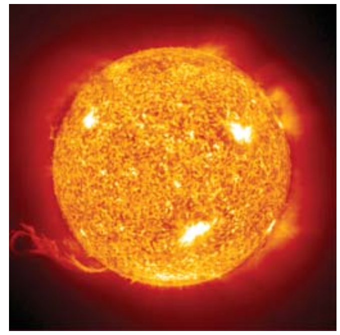
The energy released by the sun results from a series of nuclear fusion reactions. The overall reaction consists of the fusion of four hydrogen nuclei (protons) to form helium nucleus. One mechanism suggested for the process is:

$$^{1}_{1}H + ^{1}_{1}H \longrightarrow ^{2}_{1}H + ^{0}_{1}e$$

$$^{2}_{1}H + ^{1}_{1}H \longrightarrow ^{3}_{2}He$$

$$^{3}_{2}H + ^{1}_{1}H \longrightarrow ^{4}_{2}He + ^{0}_{1}e$$

Overall $$4\,^{1}_{1}H \longrightarrow ^{4}_{2}He + 2\,^{0}_{1}e \text{ (positrons)}$$



The fusion reactions in the sun take place at exceedingly high temperatures-greater than 40 million °C. Every second the sun loses 4.3×10^9 kg (4, 20,000 tons) of mass by the fusion reactions. This mass is converted to energy. But the total mass of the sun is so great that its loss of mass is imperceptible. It is hoped that the sun will continue to pour energy on the earth for billions of years.

HYDROGEN BOMB OR H-BOMB

This deadly device makes use of the nuclear fusion of the isotopes of hydrogen. It consists of a small plutonium fission bomb with a container of isotopes of hydrogen. While the exact reaction used is a strictly guarded military secret, a fusion reaction between H-2 and H-3 may be the possible source of the tremendous energy released.

$$ {}_1^2\text{H} + {}_1^3\text{H} \longrightarrow {}_2^4\text{He} + {}_0^1n + \left[\begin{matrix} \textit{tremendous} \\ \textit{energy} \end{matrix}\right] $$

The 'fusion bomb' produces the high temperature required for nuclear fusion and triggers the H-bomb. The explosion of such a bomb is much more powerful than that of a fission bomb or atomic bomb. Fortunately, the H-bombs have been tested and not used in actual warfare. If they are ever used, it may mean the end of civilisation on earth.

FUSION AS A SOURCE OF ENERGY IN 21st CENTURY

Almost likely that the world's energy source in the twenty-first century will be a fusion reactor. As indicated by the trends of research, it will be based on the reactions as:

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

$$ {}_1^2\text{H} + {}_1^3\text{H} \longrightarrow {}_2^4\text{He} + {}_0^1n + \textit{energy} $$

A fusion reactor thus developed will be any time superior to a fission reactor for generating electricity.

1. The fusion fuel, deuterium (${}_1^2\text{H}$), can be obtained in abundance from heavy water present in sea water. The supplies of U-235 needed for a fission reactor are limited.
2. A fusion reaction produces considerably greater energy per gram of fuel than a fission reaction.
3. The products of fusion (${}_2^3\text{He}$, ${}_2^4\text{He}$) are not radioactive. Thus, there will be no problem of waste disposal.

So far, it has not been possible to set up a fusion reactor. The chief difficulty is that the reactant nuclei must be heated to very high temperatures. A mixture of deuterium and tritium nuclei, for example, requires 30 million °C before they can fuse. So far no substance is known which can make a container that could with stand such high temperatures. However, scientists are making efforts to effect fusion at a lower temperature with the help of laser beams.

EXAMINATION QUESTIONS

1. Define or explain the following terms :

   (*a*) Radioactivity
   (*b*) Radioactive substances
   (*c*) Radioactive Decay
   (*d*) Half life period
   (*e*) Radioactive equilibrium
   (*f*) Group displacement law

(*g*) Nuclear reactions
(*h*) Nuclear fission reactions
(*i*) Nuclear fusion reactions
(*j*) Mass defect
(*k*) Binding energy

2. (*a*) What is group displacement law of radioactivity? How does it throw light on the idea of radioactive isotopes?

(*b*) Radium has atomic number 226 and a half-life of 1600 years. Calculate the number of disintegrations produced per second from one gram of radium.

Answer. (*b*) 3.652×10^{10} atoms

3. (*a*) Derive an expression for the decay constant for disintegration of a radioactive substance.

(*b*) The activity of a radioactive isotope reduces by 25% after 100 minutes. Calculate the decay constant and half-life period.

Answer. (*b*) 0.01386 min^{-1}; 50.007 min

4. Explain what you understand by the term Radioactive Dating. How the age of earth was determined ?

5. How many α and β particles will be emitted by an element $^{218}_{84}A$ in changing to a stable isotope of $^{206}_{82}B$?

Answer. 3 α; 4 β

6. (*a*) State and explain the group displacement law in radioactivity.

(*b*) Calculate the decay constant for ^{108}Ag, if its half-life is 2.31 minutes.

Answer. (*b*) 0.3 $minute^{-1}$

7. (*a*) Write the significance of half-life period of a radioactive substance.

(*b*) The half-life of ^{232}Th is 1.4×10^{10} years. Calculate its disintegration constant.

Answer. (*b*) 4.95×10^{-11} $year^{-1}$

8. Complete the following nuclear reactions :

(*i*) $^{15}_{8}O \rightarrow {}^{0}_{-1}e + ?$
(*ii*) $^{238}_{92}U \rightarrow {}^{234}_{90}Th + ?$

(*iii*) $^{236}_{92}U \rightarrow {}^{143}_{56}Ba + ? + {}^{1}_{0}n$
(*iv*) $^{238}_{92}U + ? \rightarrow {}^{239}_{92}U$

Answer. (*i*) $^{15}_{7}N$; (*ii*) $^{4}_{2}He$; (*iii*) $^{92}_{36}Kr$; (*iv*) $^{1}_{0}n$

9. (*a*) Define radioactivity. Discuss the liquid drop model for nuclear structure.

(*b*) Complete the following nuclear reactions :

(*i*) $^{12}_{6}C + {}^{2}_{1}M \rightarrow ? + {}^{4}_{2}He$
(*ii*) $^{27}_{13}Al + {}^{1}_{0}n \rightarrow {}^{24}_{11}Na + ?$

(*iii*) $^{14}_{7}N + ? \rightarrow {}^{11}_{6}C + {}^{4}_{2}He$

Answer. (*b*) (*i*) $^{10}_{5}B$; (*ii*) $^{4}_{2}He$; (*iii*) $^{1}_{1}H$

10. (*a*) Explain what is meant by radioactive equilibrium. How does it differ from chemical equilibrium?

(*b*) A radioactive substance having half-life of 3.8 days, emitted initially 7×10^4 alpha particles per second. In what time will its rate of emission reduces to 2×10^4 alpha particles per second?

Answer. (*b*) 6.870 days

11. Show how C–14 is used for radio-carbon dating. A freshly cut piece of plant gives 20.4 counts per minute per gram. A piece of wood antique gives 12.18 counts per minute per gram. What is the age in years of antique? It is assumed that the radioactivity is entirely due to C–14. The half life period of C–14 is 5760 years.

Answer. 4287.43 years

12. Calculate the rate of disintegration of one gram of ^{232}Th if its decay constant is 1.58×10^{-18} sec^{-1}.

Answer. 4.0998×10^3 dps

13. (*a*) Calculate the mass defect, binding energy and the binding energy per nucleon of $^{4}_{2}He$ which has an isotopic mass of 4.0026 amu ($^{1}_{1}H$ = 1.0081 amu; $^{1}_{0}H$ = 1.0089 amu)

(*b*) With the help of a diagram discuss the salient features of a nuclear power reactor.

(*c*) Explain the principle, construction and working of cyclotron.

Answer. (*a*) 0.0314 amu; 29.249 Mev; 7.312275 Mev

14. Write short notes on

(*a*) Radioactive series (*b*) Nuclear Fission

(*c*) Tracer Technique (*d*) Geiger-Muller counter

15. (*a*) What do you mean by Tracer Technique? Write different applications of Tracer-Techniques.

(*b*) The mass number and atomic number of a radioactive element Actinium are 227 and 89 respectively. Calculate the number of α and β particles emitted, if the mass number and atomic number of the new element Lead are 207 and 82 respectively.

Answer. (*b*) 5 α and 3 β

16. ${}_{84}Po^{210}$ decays with alpha to ${}_{82}Pb^{206}$ with a half life of 138.4 days. If 1.0 g of Po^{210} is placed in a sealed tube, how much helium will accumulate in 69.2 days? Express the answer in cm^3 at STP.

Answer. 31.248 cm^3

17. (*a*) What is group displacement law in radioactivity? What is binding energy and how it is related to Mass number of the nucleus?

(*b*) A radioactive isotope has half-life of 20 days. What is the amount of isotope left over after 40 days if the initial amount is 5 g?

Answer. (*b*) 1.25 g

18. (*a*) Define radioactive constant and derive the relation between decay constant and number of particles left at time *t*.

(*b*) Half-life period of thorium is 24.5 minutes. How much thorium would be left after 30 minutes if the initial amount of thorium is one gram?

Answer. (*b*) 0.429 g

19. Calculate the number of λ and β particles emitted in the conversion of Thorium, ${}_{90}Th^{232}$, to Lead, ${}_{82}Pb^{206}$.

Answer. 6 α and 4 β (*Delhi BSc, 2000*)

20. A sample of U^{238} (half life = 4.5×10^9 years) ore is found to contain 23.8 g of U^{238} and 20.6 g of Pb^{206}. Calculate the age of the ore.

Answer. 4.50×10^9 years (*Bundelkhand BSc, 2000*)

21. The half life of Cobalt-60 is 5.26 years. Calculate the percentage activity after eight years.

Answer. 34.87% (*Nagpur BSc, 2000*)

22. Calculate the time required for a radioactive sample to lose one-third of the atoms of its parent Isotope. The half life is 33 min.

Answer. 19.31 min (*Bhopal BSc, 2000*)

23. An old wooden article shows 2.0 counts per minute per gram. A fresh sample of wood shows 15.2 counts per minute per gram. Calculate the age of the wooden article. ($t_{½}$ of C^{14} = 5760 years)

Answer. 1686.6 years (*Gulbarga BSc, 2000*)

24. The mass number and atomic number of a radioactive element Actinium are 227 and 89 respectively. Calculate the number of α and β particles emitted if the mass number and atomic number of the new element Lead are 207 and 82 respectively.

Answer. 5 α and 3 β (*Calicut BSc, 2000*)

25. Calculate the age of the tooth in which C^{14} activity is 20% of the activity found at the present time (t½ for C^{14} = 5580 years)

Answer. 12961.4 years (*Delhi BSc, 2001*)

26. A piece of wood recovered in excavation has 30% as much ${}_6C^{14}$ as a fresh wood today. Calculate the age of excavated piece assuming half life period of ${}_6C^{14}$ as 5700 years.

Answer. 9908 years (*Madurai BSc, 2001*)

27. The activity of a radioactive sample falls to 85% of the initial value in four years. What is the half life of the sample? Calculate the time by which activity will fall by 85%.

Answer. 17.05 years; 46.735 years (*Mysore BSc, 2001*)

28. Write short notes on

(*a*) Carbon dating (*b*) Nuclear reaction (*Lucknow BSc, 2001*)

29. Derive an expression for the disintegration constant of a radioactive element and show that decay of the element is exponential. (*Lucknow BSc, 2001*)

30. (*a*) Write a note on Nuclear Fission and Nuclear Fusion.

(*b*) What are nuclear reactions? How are they classified? Explain with examples.

(*HS Gaur BSc, 2002*)

31. (*a*) What is Group displacement law? Explain with examples.

(*b*) How does discovery of isotopes help in explaining fractional atomic weight of elements? Mention some applications of radioactivity. (*Arunachal BSc, 2002*)

32. Write notes on

(*a*) Nuclear Fusion (*b*) Nuclear Binding Energy

(*c*) Tracers and their applications (*Mizoram BSc, 2002*)

33. Define binding energy of a nucleus. Explain with the help of binding energy curve, the stability of the nuclei. (*Nagpur BSc, 2002*)

34. (*a*) Give the details of the application of C^{14} isotope in carbon dating. How the age of an old wooden sample is determined?

(*b*) The rate of disintegration of an old wooden sample was found 25% as compared to a fresh identical sample. Find out the age of the old sample. (Half life of C^{14} = 5760 years)

Answer. (*b*) 11525 years (*Bundelkhand BSc, 2002*)

35. (*a*) How many α and β-particles are emitted for the transformation

$$^{232}_{90}Th \rightarrow \, ^{208}_{82}Pb$$

(*b*) What is a nuclide? Mention different kinds of nuclides with suitable examples.

(*c*) What is a nuclear reactor? Describe its main parts briefly. (*Sambalpur BSc, 2003*)

36. (*a*) Calculate the (*i*) Mass Defect (*ii*) Binding energy per nucleon of $_6C^{12}$. (Given C^{12} = 12.0038 amu; H^1 = 1.0081 amu; n^1 = 1.0089 amu)

(*b*) What is artificial radioactivity? Give two examples. (*Goa BSc, 2003*)

37. (*a*) Discuss the stability of nucleus under the following heads:

(*i*) binding energy per nucleon

(*ii*) neutron-proton ratio and odd-even rule

(*b*) What is the difference between Fission and Fusion reactions?

(*c*) How do two isotopes of elements differ in the number of nucleons. (*Aligarh BSc, 2003*)

38. (*a*) What is group displacement law of radioactivity? How does it throw light on the idea of radioactive isotopes?

(*b*) The half-life of radioactive isotope is 47.2 sec. Calculate N/N_o left after one hour.

Answer. (*b*) 1.12×10^{-23} (*Arunachal BSc, 2003*)

39. Give the postulates of theory of radioactive emissions. (*Arunachal BSc, 2003*)

40. Write short notes on :

(*a*) Mass defect (*b*) Packing fraction

(*c*) Nuclear Fission (*d*) Half life period (*Arunachal BSc, 2003*)

41. (*a*) What is group displacement law of radioactivity? How does it throw light on the idea of radioactive isotopes?

(*b*) Explain :

(*i*) Radioactive dating (*ii*) Average life

(*iii*) Radioactive equilibria (*Arunachal BSc, 2003*)

42. Explain :

(*a*) Why $_{13}Al^{27}$ is stable while $_{13}Al^{24}$ is radioactive in nature?

(*b*) The atomic weight of lithium is variable while in other members of group I it is fixed.

(*Delhi BSc, 2003*)

43. Calculate the half life and average life period of a radioactive element if its decay constant is 7.37×10^{-3} hour^{-1}.

Answer. 0.0261 sec; 0.0376 sec (*Sambalpur BSc, 2003*)

44. $_{92}U^{238}$ undergoes a series of changes emitting α and β particles and finally $_{82}Pb^{206}$ is formed. Calculate the number of α and β particles which must have been ejected during the series.

Answer. 8 α and 6 β (*Panjab BSc, 2004*)

45. Radioisotope $_{15}P^{32}$ has a half life of 15 days. Calculate the time in which the radioactivity of its 1 mg quantity will fall to 10% of the initial value.

Answer. 49.84 days (*Osmania BSc, 2004*)

46. An old wooden article shows 2.0 counts per minute per gram. A fresh sample of wood shows 15.2 counts per minute per gram. Calculate the age of the wooden article ($t_{1/2}$ of C^{14} = 5460 years)

Answer. 16861 years (*Banaras BSc, 2004*)

47. Explain the difference between Nuclear Fission and Nuclear Fusion. (*Agra BSc, 2005*)

48. (*a*) Write briefly on nuclear fission and nuclear fusion.

(*b*) A radioactive isotope has half-life period of 20 days. What is the amount of the isotope left over after 40 days if the initial concentration is 5 g?

Answer. (*b*) 1.25 g (*Delhi BSc, 2005*)

49. (*a*) Discuss the stability of nucleus in terms of neutron-proton ratio and binding energy.

(*b*) 2 g of radioactive element degraded to 0.5 g in 60 hours. In what time will it be reduced to 10% of its original amount?

Answer. (*b*) 4.56 hours (*Mysore BSc, 2006*)

MULTIPLE CHOICE QUESTIONS

1. Which is the correct symbol for an alpha particle?

(*a*) $^{4}_{2}He$ (*b*) $^{1}_{0}n$

(*c*) $^{0}_{-1}e$ (*d*) $^{1}_{1}p$

Answer. (*a*)

2. Of the following, which is the most damaging when ingested?

(*a*) beta emitters (*b*) alpha emitters

(*c*) gamma emitters (*d*) all of these

Answer. (*b*)

3. An alpha particle is

(*a*) an electron (*b*) one neutron and one proton

(*c*) two protons and two neutrons (*d*) an X-ray emission

Answer. (*c*)

4. By what type of decay process might ^{214}Pb convert to ^{214}Bi?

(*a*) beta decay (*b*) alpha decay

(*c*) gamma decay (*d*) electron capture

Answer. (*a*)

5. The curie is a measure of the
(*a*) lethal threshold for radiation exposure
(*b*) number of alpha particles emitted by exactly 1 g of a radioactive substance
(*c*) number of disintegrations per second of a radioactive substance
(*d*) total energy absorbed by an object exposed to a radioactive source
Answer. (*c*)

6. Of the following processes, which one does not change the atomic number?
(*a*) gamma emission (*b*) alpha emission
(*c*) positron emission (*d*) beta emission
Answer. (*a*)

7. Which of these nuclides is most likely to be radioactive?
(*a*) $^{39}_{19}K$ (*b*) $^{27}_{13}Al$
(*c*) $^{127}_{53}I$ (*d*) $^{243}_{95}Am$
Answer. (*d*)

8. The beta particle consists of
(*a*) high-energy rays (*b*) 1 neutron
(*c*) 2 neutrons and 2 protons (*d*) 1 electron
Answer. (*d*)

9. Lab coats and gloves provide shielding from
(*a*) alpha radiation (*b*) alpha and beta radiation
(*c*) alpha, beta, and gamma radiation (*d*) gamma radiation
Answer. (*b*)

10. When an alpha particle is released in nuclear decay, the mass number of the nucleus undergoing decay
(*a*) stays the same (*b*) increases by 4
(*c*) decreases by 4 (*d*) decreases by 2
Answer. (*c*)

11. Which one of the following processes could not result in the conversion of strontium to rubidium?
(*a*) gamma emission (*b*) proton emission
(*c*) electron capture (*d*) positron emission
Answer. (*a*)

12. Alpha decay of ^{226}Ra will yield which of the following nuclides?
(*a*) ^{222}Rn (*b*) ^{230}Th
(*c*) ^{222}Fr (*d*) ^{222}Th
Answer. (*a*)

13. In a Geiger-Müller counter, one "count" is directly due to
(*a*) a secondary electron (*b*) a primary electron
(*c*) many electrons and ions (*d*) a beta particle
Answer. (*c*)

14. $^{8}_{3}Li$ decays to $^{8}_{4}Be$. What type of decay is this?
(*a*) positron emission (*b*) beta
(*c*) γ-ray (*d*) alpha
Answer. (*b*)

15. _______ rays consist of He nuclei, while _______ rays are electromagnetic radiation.

(*a*) beta, alpha (*b*) alpha, beta
(*c*) alpha, gamma (*d*) gamma, beta
Answer. (*c*)

16. Which type of radioactive decay results in an increase in atomic number?
(*a*) positron emission (*b*) alpha emission
(*c*) gamma emission (*d*) beta emission
Answer. (*d*)

17. When ^{249}Cf is bombarded with ^{10}B, ^{257}Lr is formed. What other particle(s) is/are produced?
(*a*) $^{0}_{-1}e$ (*b*) $^{1}_{0}n$
(*c*) $^{0}_{1}e$ (*d*) $^{1}_{1}p$
Answer. (*b*)

18. Which combination of the number of protons and the number of neutrons is most common among the naturally occurring non-radioactive nuclides?
(*a*) even protons; even neutrons (*b*) odd protons; even neutrons
(*c*) even protons; odd neutrons (*d*) odd protons; odd neutrons
Answer. (*a*)

19. Which form of radioactivity is most penetrating?
(*a*) alpha particles (*b*) beta particles
(*c*) neutrons (*d*) gamma rays
Answer. (*d*)

20. In electron capture,
(*a*) gamma rays are emitted (*b*) a neutron is formed
(*c*) a positron is formed (*d*) an alpha particle is emitted
Answer. (*b*)

21. The spontaneous transformation of one nuclide into others occurs only if
(*a*) the process is endothermic
(*b*) the process results in a neutron/proton ratio of 1:0 in the products
(*c*) sufficient energy can be absorbed from the surroundings to drive the process
(*d*) the combined mass of the products is less than the mass of the original nuclide
Answer. (*d*)

22. What particle is released when Ga-75 decays to Ge-75?
(*a*) neutron (*b*) beta
(*c*) gamma (*d*) alpha
Answer. (*b*)

23. What particle is missing in the following bombardment reaction? $Al^{27} + ? = {}^{1}n + P^{30}$
(*a*) neutron (*b*) beta
(*c*) proton (*d*) alpha
Answer. (*d*)

24. What would be the immediate product of neutron absorption by ^{107}Ag?
(*a*) ^{107}Pd (*b*) ^{109}In
(*c*) ^{108}Cd (*d*) ^{108}Ag
Answer. (*d*)

25. When a nuclide undergoes beta decay,
(*a*) the atomic number remains unchanged and the mass number increases by one
(*b*) the mass number remains unchanged and the atomic number decreases by one

(*c*) the mass number remains unchanged and the atomic number increases by one

(*d*) the atomic number remains unchanged and the mass number decreases by one

Answer. (*c*)

26. The half-life of ^{32}P, which is used as a label on red blood cells to determine blood volume, is 14.3 days. How many days are required for the activity of a sample of ^{32}P to drop to 5.00% of its initial level?

(*a*) 26.8 days (*b*) 42.8 days

(*c*) 61.8 days (*d*) 0.209 days

Answer. (*c*)

27. The half-life of Sulfur-35 is 88 days. If 8.0 g of Sulfur-35 exists on day one, what fraction will remain after 264 days?

(*a*) 0.5 g (*b*) 4.0 g

(*c*) 0 g (*d*) 1.0 g

Answer. (*d*)

28. When Xenon-123 emits a gamma ray, what is the product?

(*a*) $^{123}_{54}Xe$ (*b*) $^{123}_{53}I$

(*c*) $^{119}_{52}Te$ (*d*) $^{123}_{55}Cs$

Answer. (*a*)

29. The cloth shroud from around a mummy is found to have a ^{14}C activity of 8.9 disintegrations per minute per gram of carbon as compared with living organisms that undergo 15.2 disintegrations per minute per gram of carbon. From the half-life for ^{14}C decay, 5.73×10^3 yr, calculate the age of the shroud.

(*a*) 9.3×10^{-5} yr (*b*) 4.4×10^3 yr

(*c*) 6.5×10^{-5} yr (*d*) 1.92×10^3 yr

Answer. (*b*)

30. ^{198}Au has a half-life of 2.70 days. Assuming you start with a 10.0 mg sample of ^{198}Au, how much will remain after 10.0 days?

(*a*) 0.246 mg (*b*) 130 mg

(*c*) 0.768 mg (*d*) 9.44 mg

Answer. (*c*)

31. The half-life for the beta decay of ^{233}Pa is 27.4 days. How many days must pass to reduce a 5.00 g sample of ^{233}Pa to 0.625 g?

(*a*) 109.6 days (*b*) 54.8 days

(*c*) 82.2 days (*d*) 27.4 days

Answer. (*c*)

32. The half-life of tritium (Hydrogen-3) is 12.3 yr. If 48.0 mg of tritium is released from a nuclear power plant during the course of an accident, what mass of this nuclide will remain after 49.2 yr?

(*a*) 6.0 mg (*b*) 3.0 mg

(*c*) 24.0 mg (*d*) 12.0 mg

Answer. (*b*)

33. How old is a fossil bone whose ^{14}C content is 15.0 percent that of living bone?

(*a*) 25400 yr (*b*) 15600 yr

(*c*) 380 yr (*d*) 6810 yr

Answer. (*b*)

34. Iodine-131 has a half-life of 8 days. How many grams of I-131 in a 4.0 g sample remain after 24 days?

(*a*) 2.0 g (*b*) 1.0 g

(*c*) 0.50 g (*d*) 0.0 g

Answer. (*c*)

35. The half-life of ^{45}Ca is 165 days. After 1.0 year, what percentage of the original sample of ^{45}Ca remains?

(*a*) 10.9 percent (*b*) 99.6 percent

(*c*) 2.16 percent (*d*) 21.6 percent

Answer. (*d*)

36. What particle is produced when Phosphorus-29 decays to silicon-29?

(*a*) positron (*b*) beta

(*c*) gamma (*d*) alpha

Answer. (*a*)

37. The bombardment of which isotope by a neutron produces ^{198}Au and proton?

(*a*) $^{199}_{81}Tl$ (*b*) $^{197}_{80}Hg$

(*c*) $^{198}_{80}Hg$ (*d*) $^{197}_{78}Pt$

Answer. (*c*)

38. Complete and balance the following nuclear equation by selecting the missing particle.

$$^{24}_{12}Mg + {}^{2}_{1}H \rightarrow {}^{4}_{2}He\ ?$$

(*a*) $^{22}_{13}Al$ (*b*) $^{22}_{11}Na$

(*c*) $^{26}_{13}Al$ (*d*) $^{20}_{10}Ne$

Answer. (*b*)

39. What is the product of beta decay of $^{159}_{64}Gd$?

(*a*) $^{159}_{65}Tb$ (*b*) $^{159}_{63}Eu$

(*c*) $^{159}_{64}Gd$ (*d*) $^{155}_{62}Sm$

Answer. (*a*)

40. Which of the following is the nuclear equation for bismuth-214 undergoing beta decay?

(*a*) $^{214}_{83}Bi \rightarrow {}^{0}_{1}e + {}^{214}_{84}Po$ (*b*) $^{214}_{83}Bi \rightarrow {}^{0}_{1}e + {}^{214}_{82}Pb$

(*c*) $^{214}_{83}Bi \rightarrow {}^{0}_{1}e + {}^{214}_{84}Po$ (*d*) $^{214}_{83}Bi \rightarrow {}^{0}_{1}e + {}^{214}_{82}Pb$

Answer. (*a*)

41. When Zinc-73 decays by beta emission, the product of decay is

(*a*) $^{74}_{29}Cu$ (*b*) $^{73}_{29}Cu$

(*c*) $^{73}_{31}Ga$ (*d*) $^{72}_{30}Zn$

Answer. (*c*)

42. When $^{27}_{13}Al$ is bombarded by an alpha particle, the products are a proton and another nuclide. What is the other nuclide?

(*a*) $^{31}_{16}S$ (*b*) $^{27}_{12}Mg$

(*c*) $^{30}_{14}Si$ (*d*) $^{31}_{13}Al$

Answer. (*c*)

43. The nucleus of an atom of radioactive I-131 used in thyroid imaging contains

(*a*) 53 protons and 75 neutrons
(*b*) 53 protons and 78 neutrons
(*c*) 53 electrons and 78 neutrons
(*d*) 53 neutrons and 78 protons

Answer. (*b*)

44. What is the product of the alpha decay of Rn-220?

(*a*) Po-216
(*b*) Rn-220
(*c*) Rn-216
(*d*) Ra-224

Answer. (*a*)

45. A short-time exposure to a radiation dose of 100 to 200 rems will result in what health effect?

(*a*) death of half the exposed population within 30 days after exposure
(*b*) there are no detectable clinical effects
(*c*) nausea and marked decrease in white blood cells
(*d*) a slight temporary decrease in white blood cell counts

Answer. (*c*)

46. When a nuclide undergoes electron capture,

(*a*) the mass number remains unchanged and the atomic number decreases by one
(*b*) the atomic number remains unchanged and the mass number increases by one
(*c*) the mass number remains unchanged the atomic number increases by one
(*d*) the atomic number remains unchanged and the mass number decreases by one

Answer. (*a*)

47. What nuclide forms as a result of the positron emission of ${}^{12}_{7}N$?

(*a*) ${}^{13}_{6}C$
(*b*) ${}^{11}_{7}N$
(*c*) ${}^{12}_{6}C$
(*d*) ${}^{12}_{8}O$

Answer. (*c*)

48. ${}^{232}_{90}Th$ undergoes a series of alpha and beta emissions resulting in the final stable product, ${}^{208}_{82}Pb$. How many alpha and beta emissions occur in this series?

(*a*) 4 alpha, 6 beta
(*b*) 8 alpha, 6 beta
(*c*) 12 alpha, 4 beta
(*d*) 6 alpha, 4 beta

Answer. (*d*)

49. What is the product formed from ${}^{207}Po$ by positron emission?

(*a*) ${}^{203}Pb$
(*b*) ${}^{207}Bi$
(*c*) ${}^{208}At$
(*d*) ${}^{206}Bi$

Answer. (*b*)

50. Which of the following statements about the biological effects of radiation is false?

(*a*) Radiation can cause leukemia
(*b*) Ionizing radiation is more dangerous than non-ionising radiation
(*c*) Radon is absorbed through the skin
(*d*) Radon is harmful because it decays to polonium

Answer. (*c*)

51. When a ${}^{235}U$ nucleus is struck by a thermal neutron, fission occurs with the release of neutrons. If the fission fragments are ${}^{90}Sr$ and ${}^{144}Xe$, how many neutrons are released?

(*a*) 3
(*b*) 4
(*c*) 1
(*d*) 2

Answer. (*d*)

52. What other product occurs when Ac-222 releases an alpha particle?

(*a*) Db-218 (*b*) Ra-218
(*c*) Fr-218 (*d*) Ac-218

Answer. (*c*)

53. Complete and balance the following nuclear equation by selecting the missing particle:

$$^{252}_{98}Cf + ^{10}_{5}B \rightarrow 3^{1}_{0}n \ ?$$

(*a*) $^{261}_{103}Lr$ (*b*) $^{259}_{103}Lr$
(*c*) $^{241}_{93}Np$ (*d*) $^{239}_{93}Np$

Answer. (*b*)

54. The nuclide Iron-56 has a mass defect of 0.52840 amu. What is the binding energy per nucleon in Mev?

(*a*) 8.81 Mev (*b*) 9.79×10^{-17} Mev
(*c*) 8.81×10^{3} Mev (*d*) 494 Mev

Answer. (*a*)

55. The mass defect for ^{12}C is 0.0990, meaning that six protons and six neutrons have a mass that is 0.0990 amu more than the mass of the ^{12}C nucleus. What is the binding energy of the ^{12}C nucleus per nucleon in kJ?

(*a*) 1.23×10^{-15} kJ (*b*) 1.23×120^{-12} kJ
(*c*) 4.11×10^{-24} kJ (*d*) 1.48×10^{-14} kJ

Answer. (*a*)

56. The combustion of one mol of graphite releases 393.5 kJ of energy. What is the mass change that accompanies the loss of this energy?

(*a*) 4.372×10^{-12} kg (*b*) 3.542×10^{22} kg
(*c*) 1.312×10^{-3} kg (*d*) none of these

Answer. (*a*)

57. Plutonium-239 is produced from ^{238}U in breeder reactor. This might involve

(*a*) neutron absorption followed by emission of two positrons
(*b*) alpha particle absorption followed by emission of three protons
(*c*) proton absorption followed by positron emission
(*d*) neutron absorption followed by emission of two beta particles

Answer. (*d*)

58. What particle is produced when Plutonium-242 decays to Uranium-238?

(*a*) gamma (*b*) alpha
(*c*) positron (*d*) beta

Answer. (*b*)

59. In a living organism, the ^{14}C concentration

(*a*) remains approximately constant
(*b*) continually increases
(*c*) continually decreases
(*d*) varies unpredictably during the lifetime of the organism

Answer. (*a*)

60. Which equation represents alpha emission from ^{196}Po?

(*a*) $^{196}_{84}Po \rightarrow ^{192}_{82}Pb + ^{4}_{2}He$ (*b*) $^{196}_{84}Po + ^{4}_{2}He \rightarrow ^{192}_{82}Pb$
(*c*) $^{196}_{84}Po \rightarrow ^{200}_{86}Rn + ^{4}_{2}He$ (*d*) $^{196}_{84}Po + ^{4}_{2}He \rightarrow ^{200}_{86}Rn$

Answer. (*a*)

61. Hydrogen burning

(*a*) is the reaction sequence that is proposed to take place in normal stars

(*b*) requires very large kinetic energy in the colliding nuclei in order to overcome huge activation energies associated with electrostatic repulsion

(*c*) results in the conversion of hydrogen nuclei to helium nuclei

(*d*) all of above

Answer. (*d*)

62. The energy produced by the Sun involves which of the following nuclei?

(*a*) Pu (*b*) Li

(*c*) U (*d*) H

Answer. (*d*)

63. From a kinetics standpoint, the radioactive decay of radium is a ________-order process, and the primary reactions in nuclear fusion in the sun are ________-order processes.

(*a*) first, first (*b*) first, third

(*d*) first, second (*d*) second, second

Answer. (*c*)

64. Radiation is used in cancer treatment to

(*a*) destroy cancer causing substances (*b*) relieve pain

(*c*) obtain images of the diseased region (*d*) destroy cancer cells

Answer. (*d*)

65. The amount of fissionable material large enough to maintain the chain reaction in nuclear fission is called the

(*a*) moderator (*b*) critical mass

(*c*) mass defect (*d*) nuclear binding energy

Answer. (*b*)

66. Food irradiation is used to

(*a*) precook food (*b*) kill insects

(*c*) kill micro-organisms (*d*) increase nutrient value

Answer. (*c*)

67. The radioisotopes used for diagnosis in nuclear medicine

(*a*) have short half lives (*b*) travel rapidly through tissue

(*c*) are usually gamma emitters (*d*) all of these

Answer. (*d*)

68. The purpose of a moderator in a nuclear reactor is

(*a*) to prevent corrosion of the core components

(*b*) to slow the fission neutrons so that they can be captured to sustain the chain reaction

(*c*) to cool the core to prevent melt down

(*d*) to dissolve the fission products for disposal

Answer. (*b*)

69. Fission reactions can be run continuously to generate electric power commercially because

(*a*) the reactors generate more readily fissionable fuel than they consume

(*b*) more neutrons are produced in the fission reactions than are consumed

(*c*) supercritical neutrons split into protons and electrons

(*d*) the different isotopes of uranium interconvert under reaction conditions to form the necessary Uranium-235

Answer. (*b*)

70. A cyclotron is used to get

(*a*) energetic ions (*b*) positrons

(*c*) magnetic fields (*d*) neutrons

Answer. (*a*)

71. The reaction of H^3 and H^2 to form He^4 and a neutron is an example of

(*a*) a fission reaction (*b*) a fusion reaction

(*c*) both fission and fusion reactions (*d*) neither a fission or fusion reaction

Answer. (*b*)

72. Nuclear fusion

(*a*) takes place in the sun (*b*) uses large nuclides

(*c*) is used in atomic bombs (*d*) takes place in a fusion reactor

Answer. (*a*)

73. Usually, the largest dose of radiation that a person gets is from

(*a*) cigarettes (*b*) natural background radiation

(*c*) medical X-rays (*d*) nuclear power plants

Answer. (*b*)

74. A moderator in a nuclear reactor serves to

(*a*) accelerate neutrons (*b*) diminish the nuclear binding energy

(*c*) provide fissionable isotopes (*d*) slow neutrons

Answer. (*d*)

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