CHAPTER 3

RADIOACTIVITY AND NUCLEAR TRANSFORMATION

3.1 RADIOACTIVITY

Radioactivity is a process in which nuclei of certain elements undergo spontaneous disintegration without excitation by any external means.

All heavy elements from bismuth through uranium and a few of lighter elements have naturally occurring isotopes which possess the property of radioactivity. These isotopes have unstable nuclei and attain stability through the phenomenon of radioactivity. The activity results in the emission of a complex type of powerful radiations known as alpha, beta and gamma rays. **All those substances which have the tendency to emit these radiations are termed radioactive materials.** The property of disintegration of a radioactive material is independent of temperature, pressure and other external conditions. **Radioactivity is a nuclear phenomenon,** *i.e.*, the kind of intensity of the radiation emitted by any radioactive substance is absolutely the same whether the element is present as such or in any one of its compounds. $^{226}_{88}Ra$ isotope is radioactive. When this isotope is dissolved in sulphuric acid, it is converted into radium sulphate ($RaSO_4$). The property of radioactivity in radium sulphate and free radium isotope is the same, no doubt that the radium ion in radium sulphate has different number of electrons than free neutral radium isotope.

	Radium atom (Ra)	Radium ion (Ra^{2+})
No. of protons	88	88
No. of electrons	88	86
Atomic mass	226	226

This example clearly shows that the phenomenon of radioactivity does not depend on the orbital electrons but depends only on the composition of nucleus.

In the universe, there are only 81 stable elements having one or more non-radioactive isotopes. No stable isotope exists for the elements above $^{209}_{83}Bi$. Thus, **bismuth** is the heaviest stable nuclide. Two earlier elements **technetium** and **promethium** exist only as radioactive isotopes (see table at the bottom).

3.2 CHARACTERISTICS OF RADIOACTIVE RADIATIONS

The following are the main characteristics of radiations emitted by radioactive materials:

(i) Photographic effect: Radiations affect the photographic plate in a similar manner to that of light. The effect is even observed in dark. The portions of the photographic plate where radiations fall, become blackened after treatment with a developer.

This property is used for the detection of radioactivity.

(ii) Scintillations: When radiations fall on the zinc sulphide (ZnS) screen, flashes of light are produced. This is known as scintillations. The number of particles emitted in unit time can be counted by noting the scintillations produced in the apparatus having a zinc sulphide screen.

The apparatus is called spinthariscope.

(iii) Emission of heat: Radioactive materials continuously emit energy in the form of kinetic energy. Heat energy is

								H									He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Lr	Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub		Uuq		Uuh		

La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No

Shaded elements are radioactive

produced when the radiation particles collide with matter. Radium produces 134.7 cals of heat per gram per hour.

(iv) Physiological effect: Radioactive radiations have serious physiological effects, which may be cumulative over a period of time. Even a short exposure to intense source of radiations is sufficient to cause painful inflammation. **Gamma rays are most effective.** In general, abnormal cells are more affected than the healthy cells. On account of this property radiations are used to destroy cancerous tumours.

(v) Ionisation of gases: This is the most important effect observed in the case of radioactive radiations. Radiations produce ionisation in the gases through which they are passed. **This effect is used for quantitative measurement of radioactivity.** The radiations cause a number of molecules of the gas to lose electrons and pass into positive ions. The electrons immediately become attached to the neutral molecules, thus making them negative ions. **The total ions of one sign are equal to the total ions of the other type. The rate of production of these ions is proportional to the intensity of radiation.** The extent, to which a definite quantity of a gas is rendered a conductor by a radioactive substance, is a measure of the radioactive power of a radioactive substance. The apparatus used for this purpose is called **electroscope** (Fig. 3.1).

Geiger-Muller counter is based on this effect. The ionisation chamber consists of 90% argon and 10% ethyl alcohol vapour at 10 mm pressure. Due to ionisation, a flow of current occurs, which is measured after amplification.

3.3 HISTORY OF THE DISCOVERY OF RADIOACTIVITY

In 1895, **Henri Becquerel** was studying the effect of sunlight on various phosphorescent minerals, among them a uranium ore. During a period of several cloudy days, he left the uranium sample in a drawer along with some photographic paper wrapped in black paper. Much to his surprise, he discovered that the photographic paper had been fogged by exposure to some invisible radiation from uranium. He called this mysterious property of the ore 'radioactivity'. **Radioactivity means ray-emitting activity.** He further observed that the radioactive mineral emitted these mysterious radiations day after day and month after month and the emission seemed to be endless. The emission was completely unaffected by physical and chemical conditions. A year later, in 1896, **Marie Curie** found that besides uranium and its compounds, thorium was another element which possessed the property of radioactivity. In 1898, **Marie Curie** and her husband **P. Curie** observed that the uranium ore '*pitchblende*', contained more activity than was expected from the uranium which it contained. It must be obviously due to the presence of some other radioactive elements which were far more radioactive than uranium. Finally, they isolated two new radioactive elements **polonium** and **radium**.

Almost in the same period, **G. C. Schmidt** reported that thorium compounds possessed radioactivity. In 1901, **A. Debierne and F.S. Giesel** discovered another new radioactive element actinium in uranium minerals. Further systematic researches led to the discovery of many more radioactive elements. At present over forty such materials are known to exist in nature.

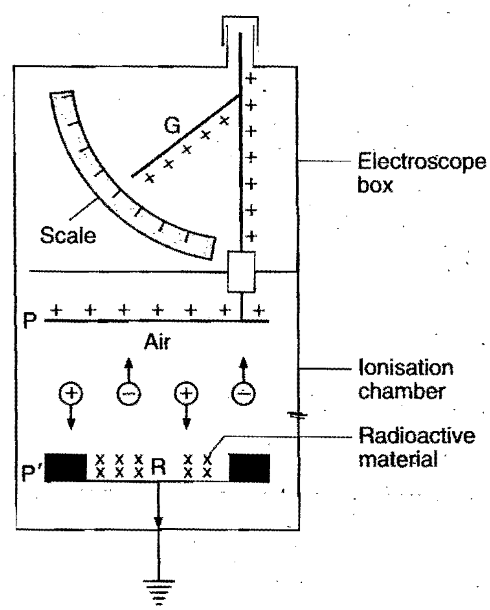


Fig. 3.1 Electroscope for measurement of radioactivity

3.4 ANALYSIS OF RADIOACTIVE RADIATIONS

In 1904, **Rutherford and his co-workers** observed that when radioactive radiations were subjected to a magnetic field or a strong electric field, these were split into three types, as shown in Fig. 3.2. The rays which are attracted towards the negative plate are positively charged and are called **alpha (α) rays.** The rays which are deflected towards the positive plate are negatively charged and are called **beta (β) rays.** The third type of rays which are not deflected on any side but move straight are known as **gamma (γ) rays.** The important properties of these radiations are tabulated on next page:

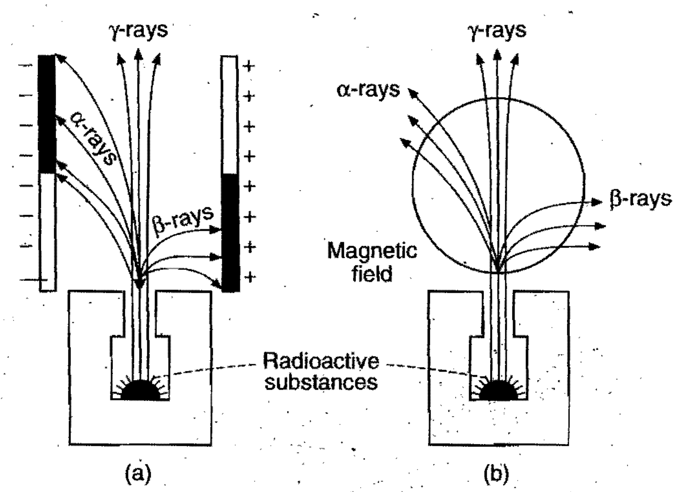


Fig. 3.2 (a) Deflection of radioactive rays in electric field and (b) Emission of radioactive rays and their deflection in a magnetic field.

Property	α-rays	β-rays	γ-rays
1. Nature	These consist of small positively charged particles which are merely nuclei of helium atoms, each consisting of 2 protons and 2 neutrons. These are represented as $_2^4He$.	These consist of negatively charged particles which have the same e/m value as the cathode rays. β-rays are merely electrons. The β-rays are represented as $_{-1}^{0}\beta$ or $_{-1}^{0}e$.	γ-rays are similar to X-rays. These are neutral in nature. They have very small wavelengths of the order of 10^{-10} to 10^{-13} m.
2. Velocity	The α-rays are ejected with high velocities ranging from 1.4×10^9 to 1.7×10^9 cm/sec. The velocity of α-rays depends upon the kind of nucleus from which they are emitted.	The β-rays are much faster than α-rays. They have generally different velocities sometimes approaching the velocity of light.	They travel with the velocity of light.
3. Penetrating power	α-particles have small penetrating power due to relatively larger size. They are stopped by a piece of aluminium foil of 0.1 mm thickness.	β-rays are more penetrating than α-particles. This is due to small size and high velocity. These are stopped by a 1 cm thick sheet of aluminium.	Due to high velocity and non-material character, γ-rays are 10^{10} times more penetrating than α-rays.

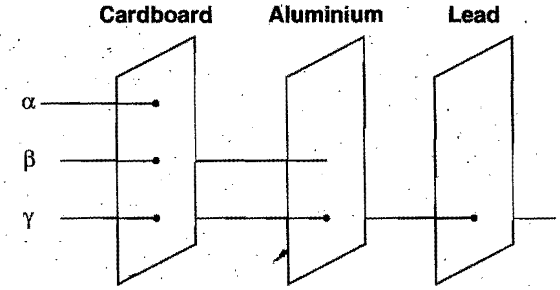


Fig. 3.2 (c) Comparison of penetrating power of α, β and γ-rays

Property	α-rays	β-rays	γ-rays
4. Ionising power	α-particles produce intense ionisation in gases. Ionising power is 100 times greater than β-rays and 10,000 times greater than γ-rays. This is due to high kinetic energy.	Due to low value of kinetic energy ionising power is less than α-particles but 100 times greater than γ-rays.	γ-rays produce minimum ionisation or no ionisation.
5. Photographic effect	α-particles affect the photographic plate.	β-rays effect on a photographic plate is greater than α-particles. Like cathode rays, β-rays produce X-rays.	γ-rays have little effect on photographic plate.
6. Effect on zinc sulphide screen	α-particles produce luminosity on ZnS screen due to high kinetic energy.	β-particles have little effect on ZnS screen due to low kinetic energy.	γ-rays have very little effect on ZnS screen.

Note :

(i) The quantum energy of γ-rays emitted by a radioactive substance can have unique and discrete values.

(ii) The energy of α-particles emitted by a radioactive substance (α-emitter) has unique value.

(iii) The energy of β-particles emitted by a radioactive substance, (β-emitter) can have any value between zero and end point energy.

3.5 CAUSE OF RADIOACTIVITY

Except in the case of ordinary hydrogen, all other nuclei contain both neutrons and protons. A look at the stable nuclei shows that the ratio n/p (neutrons/protons) in them is either equal to 1 or more than 1. The ratio is ≈ 1 in all the light-stable nuclei up to calcium ($_{20}^{40}Ca$) and thereafter the ratio is greater than 1 and increases up to 1.6 for heavy stable nuclei as shown in the following table:

Neutron-proton ratio in some stable nuclei

Isotope	$_6^{12}C$	$_7^{14}N$	$_8^{16}O$	$_{10}^{20}Ne$	$_{20}^{40}Ca$	$_{30}^{64}Zn$	$_{40}^{90}Zr$	$_{50}^{120}Sn$	$_{60}^{150}Nd$	$_{80}^{202}Hg$
n	6	7	8	10	20	34	50	70	90	122
p	6	7	8	10	20	30	40	50	60	80
n/p	1	1	1	1	1	1.13	1.25	1.40	1.50	1.53

The variation of n *versus* p for some nuclei is shown in Fig. 3.3.

The stable nuclei lie within the shaded area which is called the **region** or **zone of stability.** All the nuclei falling outside this zone are invariably radioactive and unstable in nature. **Nuclei that fall above the stability zone have an excess of neutrons while those lying below have more protons.** Both of these cause instability. These nuclei attain stability by making adjustment in the n/p ratio.

Two cases thus arise:

(i) n/p ratio is higher than required for stability. Such nuclei have a tendency to emit β-rays, *i.e.*, transforming a neutron into proton.

$$_0^1n \longrightarrow {}_1^1p + {}_{-1}^{0}e \text{ (β-particle)}$$

Thus, in β-emission n/p ratio decreases. For example, in the change of $_6^{14}C$ to $_7^{14}N$, n/p ratio decreases from 1.33 to 1.

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

Similarly, in the following examples, the n/p ratio decreases during β-emission:

	$^{32}_{15}P \longrightarrow$	$^{32}_{16}S + ^{0}_{-1}e$	
n/p ratio	17/15	16/16	
	$^{87}_{36}Kr \longrightarrow$	$^{87}_{37}Rb + ^{0}_{-1}e$	
n/p ratio	51/36	50/37	

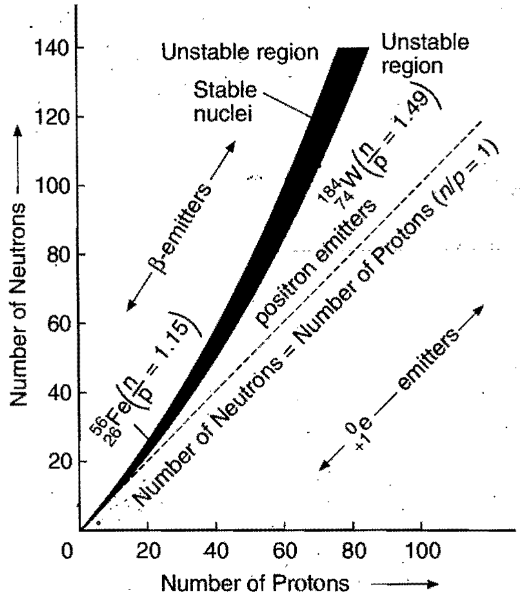


Fig. 3.3 Variation of number of neutrons with number of protons in stable non-radioactive nuclei

(ii) n/p ratio is lower than required for stability. Such nuclei can increase n/p ratio by adopting any one of the following three ways:

(a) By emission of an alpha particle (Natural radioactivity):

$$^{238}_{92}U \longrightarrow ^{234}_{90}Th + ^{4}_{2}He \ (\alpha\text{-particle})$$

n/p ratio 146/92 = 1.58 144/90 = 1.60

(b) By emission of a positron (Artificial emission):

$$^{13}_{7}N \longrightarrow ^{13}_{6}C + ^{0}_{+1}e$$

n/p ratio 6/7 7/6

(c) By K-electron capture:

$$^{194}_{79}Au + ^{0}_{-1}e \longrightarrow ^{194}_{78}Pt$$

n/p ratio 115/79 116/78

Alpha emission is usually observed in natural radioactive isotopes while emission of positron or K-electron capture is observed in artificial radioactive isotopes. The unstable nuclei continue to emit alpha or beta particles until a stable nucleus comes into existence.

Conclusion: (i) For the elements (mass number $A \le 40$), nature prefers the number of protons and neutrons in the nucleus to be same or perhaps one more neutron than protons. *e.g.*, $^{7}_{3}Li$, $^{12}_{6}C$, $^{16}_{8}O$, $^{32}_{16}S$, etc.

(ii) For the elements (mass number $A \ge 40$), there is preference for the number of neutrons to be greater than the number of protons ($n > Z$), *e.g.*, $^{11}_{5}B$ is stable but $^{11}_{6}C$ is not. There are two stable elements $^{1}_{1}H$ and $^{3}_{2}He$, in which number of neutrons is less than that of protons.

(iii) Beyond Bi ($Z = 83$), all isotopes are unstable and radioactive. These elements do not have a strong nuclear **"superglue"** to hold nucleons together.

Illustration :

Nuclide	$\frac{n}{p}$ Ratio	Nature of Emission
$^{35}_{16}S$	$\frac{19}{16} = 1.2$	β-emission $^{35}_{16}S \longrightarrow ^{35}_{17}Cl + ^{0}_{-1}e$
$^{17}_{9}F$	$\frac{8}{9}\left(\frac{n}{p} < 1\right)$	Positron emission $^{17}_{9}F \longrightarrow ^{17}_{8}O + ^{0}_{+1}e$
$^{105}_{47}Ag$	$\frac{n}{p} = \frac{58}{47} = 1.23$	Lies below stability belt, it has a heavy nucleus and it decays by K-electron capture. $^{105}_{47}Ag + ^{0}_{-1}e \longrightarrow ^{105}_{46}Pd + h\nu$
$^{238}_{92}U$	$\frac{n}{p} = \frac{146}{92} = 1.59$	It is a neutron rich species. It undergoes decay by α-emission. $^{238}_{92}U \longrightarrow ^{234}_{90}Th + ^{4}_{2}He$

Some other examples : $^{60}_{29}Cu$ (positron emission), $^{140}_{54}Xe$ (α or β-decay), $^{240}_{93}N_p$ (α-decay), $^{33}_{15}P$ (β-decay), $^{125}_{53}I$ (K-electron capture).

3.6 THEORY OF RADIOACTIVE DISINTEGRATION

Rutherford and **Soddy**, in 1903, postulated that radioactivity is a nuclear phenomenon and all the radioactive changes are taking place in the nucleus of the atom. They presented an interpretation of the radioactive processes and the origin of radiations in the form of a theory known as **theory of radioactive disintegration.** The main points of the theory are:

(i) The atomic nuclei of the radioactive elements are unstable and liable to disintegrate any moment.

(ii) The disintegration is spontaneous, *i.e.*, constantly breaking. The rate of breaking is not affected by external factors like temperature, pressure, chemical combination, etc.

(iii) During disintegration, atoms of new elements called daughter elements having different physical and chemical properties than the parent element come into existence.

(iv) During disintegration, either alpha or beta particles are emitted from the nucleus.

The disintegration process may proceed in one of the following two ways:

(a) α-particle emission: When an α-particle [$^{4}_{2}He$] is emitted from the nucleus of an atom of the parent element, the nucleus of the new element, called daughter element, possesses atomic mass or atomic mass number less by four units and nuclear charge or atomic number less by 2 units because α-particle has mass of 4 units and nuclear charge of two units.

The daughter element after α-emission is called an isodiaphere of parent element.

	Parent element $\xrightarrow{-\alpha}$	Daughter element
Atomic mass	W	$W-4$
Atomic number	Z	$Z-2$

For example, in the following transformations, each α-particle emission is accompanied by decrease of atomic mass by 4 and of atomic number by 2.

$$\underset{\text{(Radium)}}{{}^{226}_{88}\text{Ra}} \longrightarrow \underset{\text{(Radon)}}{{}^{222}_{86}\text{Rn}} + {}^{4}_{2}\text{He}$$

$$\underset{\text{(Uranium)}}{{}^{238}_{92}\text{U}} \longrightarrow \underset{\text{(Thorium)}}{{}^{234}_{90}\text{Th}} + {}^{4}_{2}\text{He}$$

$$\underset{\text{(Bismuth)}}{{}^{213}_{83}\text{Bi}} \longrightarrow \underset{\text{(Thallium)}}{{}^{209}_{81}\text{Tl}} + {}^{4}_{2}\text{He}$$

$$\underset{\text{(Polonium)}}{{}^{215}_{84}\text{Po}} \longrightarrow \underset{\text{(Lead)}}{{}^{211}_{82}\text{Pb}} + {}^{4}_{2}\text{He}$$

(b) β-particle emission: β-particle is merely an electron which has negligible mass. Whenever a beta particle is emitted from the nucleus of a radioactive atom, the nucleus of the new element formed possesses the same atomic mass but nuclear charge or atomic number is increased by 1 unit over the parent element. Beta particle emission is due to the result of decay of neutron into proton and electron.

$${}^{1}_{0}n \longrightarrow {}^{1}_{1}p + {}^{0}_{-1}e$$

The electron produced escapes as a beta particle leaving proton in the nucleus.

	Parent element $\xrightarrow{-\beta}$	Daughter element
Atomic mass	W	W
Atomic number	Z	$Z+1$

For example, in the following transformations, beta particle emission results in increase of atomic number by one without any change in atomic mass, *i.e.*, **daughter element is an isobar of parent element.** (See table 3.1)

Table 3.1 Isotopes, Isobars, Isotones, Isomers, Isoters and Isodiapheres

	Characteristics Z = at. no., A = mass no., N = neutrons, P = protons	Examples
Isotopes	Z = same, A = different	${}^{1}_{1}H$, ${}^{2}_{1}H$, ${}^{3}_{1}H$, ${}^{235}_{92}U$, ${}^{238}_{92}U$
Isobars	Z = different, A = same	${}^{228}_{88}Ra$, ${}^{228}_{89}Ac$, ${}^{228}_{90}Th$
Isotones	N = same, nucleons = different, Z = different	${}^{39}_{18}Ar$, ${}^{40}_{19}K$
Isomers	N = same, P = same, Z = same, A = same Nuclear energy levels = different	U - X_2, U - Z
Isoters	No. of atoms = same, No. of electrons = same, physical properties = same.	CO_2, N_2O
Isodiapheres	Isotopic excess mass (N—P) = same.	${}_{92}U^{235}$, ${}_{90}Th^{231}$

$$\underset{\text{(Lead)}}{{}^{214}_{82}\text{Pb}} \longrightarrow \underset{\text{(Bismuth)}}{{}^{214}_{83}\text{Bi}} + {}^{0}_{-1}e$$

$$\underset{\text{(Thorium)}}{{}^{234}_{90}\text{Th}} \longrightarrow \underset{\text{(Protoactinium)}}{{}^{234}_{91}\text{Pa}} + {}^{0}_{-1}e$$

$$\underset{\text{(Bismuth)}}{{}^{213}_{83}\text{Bi}} \longrightarrow \underset{\text{(Polonium)}}{{}^{213}_{84}\text{Po}} + {}^{0}_{-1}e$$

Special case: If in a radioactive transformation, 1 alpha and 2 beta particles are emitted, the resulting nucleus possesses the same atomic number but atomic mass is less by 4 units. A radioactive transformation of this type always produces an isotope of the parent element.

$${}^{W}_{Z}A \xrightarrow{-\alpha} {}^{W-4}_{Z-2}B \xrightarrow{-\beta} {}^{W-4}_{Z-1}C \xrightarrow{-\beta} {}^{W-4}_{Z}D$$

A and D are isotopes.

(v) Gamma rays are emitted due to secondary effects. After the emission of an alpha particle or a beta particle, the nucleus is left behind in excited state due to recoil. The excess of energy is released in the form of gamma rays. **Thus, γ-rays arise from energy rearrangements in the nucleus.** As γ-rays are short wavelength electromagnetic radiations with no charge and no mass, **their emission from a radioactive element does not produce a new element.**

On passing through an absorbing material, the intensity of γ-radiation decreases exponentially with the thickness traversed and is given by :

$$I = I_0 e^{-\mu x}$$

where μ = Absorption coefficient,
x = Thickness
I_0 = Initial intensity
I = Transmitted intensity

All radioactive nuclei have the same probability of disintegration. However, a radioactive nucleus may undergo decay next moment while some other may have to wait for billions of years to decay one cannot predict, when a particular atom will decay.

(vi) Internal conversion: An excited nucleus, in some cases, may return to its ground state by giving up its excitation energy to one of the orbital electrons around it. The emitted electron has a kinetic energy equal to the lost nuclear excitation energy minus the binding energy of the electron in the atom.

Kinetic energy of the ejected electron

= Available excitation energy

− Binding energy of the ejected electron

This process is called *internal conversion* and emitted electron is called conversion electron.

(vii) Brems strahlung (German word meaning 'Breaking Radiation'): Continuous γ-radiations emitted when β-particles are slowed down by interaction with atomic nucleus.

Note: Counting of the number of α and β-particles in a radioactive transformation:

Parent element $\longrightarrow$ Daughter element

$$_{Z_1}A^{M_1} \longrightarrow {}_{Z_2}B^{M_2}$$

$$\text{Number of } \alpha\text{-particles} = \frac{\text{Change in mass number}}{4} = \frac{M_1 - M_2}{4}$$

Let 'x' α and 'y' β-particles be emitted.

Atomic number of parent element $- 2x + y$ = Atomic number of daughter element

$$Z_1 - 2x + y = Z_2$$

3.7 GROUP DISPLACEMENT LAW

This law was presented by **Fajan, Soddy** and **Russel** in 1913 to explain the changes which occur when an alpha particle or a beta particle is emitted from a radioactive element. According to this law, **"when an α-particle is emitted, the daughter element has atomic number 2 units less than that of the parent element. It is consequently displaced two places (groups) to the left in the periodic table. When a β-particle is emitted, the daughter element has an atomic number 1 unit higher than that of the parent element. It is consequently displaced one place (group) to the right in the periodic table."**

Examples

(i) Polonium ($^{214}_{84}Po$) belongs to group 16 (VIA) of the periodic table. On losing an alpha particle, it is transformed into lead ($^{210}_{82}Pb$) which belongs to group 14 (IVA), *i.e.*, two places to the left of the parent element, polonium.

$$\underset{\substack{16 \\ (\text{VI A})}}{^{214}_{84}Po} \longrightarrow \underset{\substack{14 \\ (\text{IV A})}}{^{210}_{82}Pb}$$

(ii) Bismuth ($^{213}_{83}Bi$) belongs to group 15 (VA) of the periodic table. It emits an alpha particle resulting in the formation of thallium which belongs to group 13 (IIIA), *i.e.*, two places to the left of the parent element, bismuth.

$$\underset{\substack{15 \\ (\text{V A})}}{^{213}_{83}Bi} \longrightarrow \underset{\substack{13 \\ (\text{III A})}}{^{209}_{81}Tl}$$

(iii) Carbon ($^{14}_{6}C$) belongs to group 14 (IV A) and emits a β-particle forming nitrogen ($^{14}_{7}N$) which belongs to group 15 (V A), *i.e.*, one place to the right of the parent element.

$$\underset{(\text{IV A})}{^{14}_{6}C} \longrightarrow \underset{(\text{V A})}{^{14}_{7}N} + {}^{0}_{-1}e$$

(iv) Phosphorus ($^{32}_{15}P$) belongs to group 15 (VA) and emits a β-particle forming sulphur ($^{32}_{16}S$) which belongs to group 16 (VIA), *i.e.*, one place right to the parent element.

$$\underset{(\text{V A})}{^{32}_{15}P} \longrightarrow \underset{(\text{VI A})}{^{32}_{16}S} + {}^{0}_{-1}e$$

The above examples follow group displacement law rigidly in accordance with the statement. However, there are a number of examples where confusion arises regarding the position of the element in the periodic table if the above statement is followed rigidly.

$^{27}_{12}Mg$ is β-radioactive. It belongs to group 2 (IIA) of the periodic table. On losing a beta particle, it is transformed to aluminium ($^{27}_{13}Al$) which belongs to group 13 (IIIA), *i.e.*, 11 places right to the parent element.

$$^{27}_{12}Mg \longrightarrow {}^{27}_{13}Al + {}^{0}_{-1}e$$

$^{234}_{90}Th$ is a member of actinide series. All the fourteen members of the actinide series have been placed along with actinium in the III B group, *i.e.*, group 3. It emits a beta particle and is transformed to protactinium ($^{234}_{91}Pa$) which also belongs to actinide series, *i.e.*, group 3 of the periodic table.

$$^{234}_{90}Th \longrightarrow {}^{234}_{91}Pa + {}^{0}_{-1}e$$

Hence, group displacement law should be applied with great care especially in the case of elements of lanthanide series (57 to 71), actinide series (89 to 103), VIII group (26 to 28; 44 to 46; 76 to 78), IA and IIA groups. It is always beneficial to keep in mind the setup and skeleton of the extended form of periodic table.

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII		
1	2	3	4	5	6	7	8	9	10

IB	IIB	IIIA	IVA	VA	VIA	VIIA	Zero
11	12	13	14	15	16	17	18

SOME SOLVED EXAMPLES

Example 1. *Calculate the number of neutrons in the remaining atom after emission of an alpha particle from $^{238}_{92}U$ atom.*

Solution: On account of emission of an alpha particle, the atomic mass is decreased by 4 units and atomic number by 2 units.

So, Atomic mass of daughter element = 234

Atomic number of daughter element = 90

Number of neutrons = atomic mass − atomic number

= 234 − 90 = 144

Example 2. *Radioactive disintegration of $^{226}_{88}Ra$ takes place in the following manner into RaC,*

$$Ra \xrightarrow{-\alpha} Rn \xrightarrow{-\alpha} RaA \xrightarrow{-\alpha} RaB \xrightarrow{-\beta} RaC$$

Determine mass number and atomic number of RaC.

Solution: Parent element is $^{226}_{88}Ra$.

Atomic mass = 226

Atomic number = 88

RaC is formed after the emission of 3 alpha particles. Mass of 3 alpha particles = 3 × 4 = 12

So, Atomic mass of RaC = (226 − 12) = 214

With emission of one α-particle, atomic number is decreased by 2 and with the emission of one β-particle, atomic number is increased by 1.

So, Atomic number of $RaC = 88 - (3 \times 2) + 1 = 83$

Example 3. *A radioactive element A disintegrates in the following manner,*

$$A \xrightarrow{-\alpha} B \xrightarrow{-\beta} C \xrightarrow{-\beta} D$$

which ones of the elements A, B, C and D are isotopes and which ones are isobars?

Solution: Let the mass number and atomic number of element A be M and Z, respectively. The following changes shall occur during disintegration:

$$_Z^MA \xrightarrow{-\alpha} {}_{Z-2}^{M-4}B \xrightarrow{-\beta} {}_{Z-1}^{M-4}C \xrightarrow{-\beta} {}^{M-4}_{Z}D$$

A and D are isotopes as both have same value of Z.

B, C and D are isobars as these have same values of atomic mass.

Example 4. *$^{234}_{90}Th$ disintegrates to give $^{206}_{82}Pb$ as the final product. How many alpha and beta particles are emitted in this process?*

Solution:

$$\underset{\text{Parent}}{^{234}_{90}\text{Th}} \longrightarrow \underset{\text{End product}}{^{206}_{82}\text{Pb}}$$

Decrease in mass $= (234 - 206) = 28$

Mass of α-particle $= 4$

So, Number of α-particles emitted $= \frac{28}{4} = 7$

No. of β-particles emitted = 2 × No. of α-particles–(At. No. of parent – At. No. of end product)

$= 2 \times 7 - (90 - 82) = 6$

Example 5. *The atomic mass of thorium is 232 and its atomic number is 90. During the course of its radioactive disintegration 6α and 4β-particles are emitted. What is the atomic mass and atomic number of the final atom?*

Solution: Decrease in mass due to emission of 6α-particles $= 6 \times 4 = 24$.

So, Atomic mass of the product atom $= (232 - 24) = 208$

No. of β-particles emitted = 2 × No. of α-particles $- (Z_{\text{Thorium}} - Z_{\text{Final atom}})$

$$4 = 2 \times 6 - (90 - Z_{\text{Final atom}})$$

or $Z_{\text{Final atom}} = 82$

Example 6. *An atom has atomic mass 232 and atomic number 90. During the course of disintegration, it emits 2β-particles and few α-particles. The resultant atom has atomic mass 212 and atomic number 82. How many α-particles are emitted during this process?*

Solution: The decrease in atomic mass

$= (232 - 212) = 20$

Decrease in mass occurs due to emission of α-particles. Let x be the number of alpha particles emitted.

Mass of 'x' α-particles $= 4x$

So, $4x = 20$

or $x = \frac{20}{4} = 5$

Alternative method: This can also be determined by the application of the following equation:

No. of β-particles emitted = 2 × No. of α-particles emitted $-(Z_{\text{Parent}} - Z_{\text{End product}})$

$$2 = 2 \times x - (90 - 82)$$

or $x = 5$

Example 7. *How many moles of helium are produced when one mole of $^{238}_{92}U$ disintegrates into $^{206}_{82}Pb$?*

Solution: Radioactive change is

$$^{238}_{92}\text{U} \longrightarrow {}^{206}_{82}\text{Pb}$$

Decrease in mass $= (238 - 206) = 32$

Let the number of α-particles emitted be x.

$4x = 32$

$x = 8$

Thus, 8 moles of helium are produced when one mole of $^{238}_{92}U$ disintegrates into $^{206}_{82}Pb$.

Example 8. *How many 'α' and 'β'-particles will be emitted when $_{90}Th^{234}$ changes into $_{84}Po^{218}$?*

Solution: The change is;

$$\underset{\text{Parent}}{_{90}\text{Th}^{234}} \longrightarrow \underset{\text{End product}}{_{84}\text{Po}^{218}}$$

Decrease in mass $= (234 - 218) = 16$ amu

Mass of 1 α-particle = 4 amu

Therefore, number of α-particles emitted $= \frac{16}{4} = 4$.

Number of β-particles emitted

= 2 × No. of α-particles emitted – (At. No. of parent – At. No. of end product)

$= 2 \times 4 - (90 - 84) = (8 - 6) = 2$

Hence, number of α-particles emitted = 4

and number of β-particles emitted = 2

Example 9. *$^{238}_{92}U$ is a natural an α-emitter. After α-emission, the residual nucleus U_{X_1} in turns emits a β-particle to produce another nucleus U_{X_2}. Find out the atomic number and mass number of U_{X_1} and U_{X_2}. Also if uranium belongs to IIIrd group to which group U_{X_1} and U_{X_2} belong.*

Solution: $^{238}_{92}\text{U} - {}^4_2\text{He} \longrightarrow {}^{234}_{90}\text{U}_{X_1}$

$$^{234}_{90}\text{U}_{X_1} - ({}^{0}_{-1}e) \longrightarrow {}^{234}_{91}\text{U}_{X_2}$$

Both U_{X_1} and U_{X_2} will belong to IIIrd group because both lie in actinide series.

ILLUSTRATIONS OF OBJECTIVE QUESTIONS

1. During the transformation of ^a_cX to ^b_dY, the number of β-particles emitted are: **[PET (Kerala) 2006, 08]**

(a) $\frac{a-b}{4}$ (b) $d + \frac{a-b}{2} + c$
(c) $d + \left(\frac{a-b}{2}\right) - c$ (d) $2c - d + a - b$
[**Ans.** (c)]
[**Hint:** No. of α-particles $= \left(\frac{a-b}{4}\right)$

$$Z_1 - 2\alpha + \beta = Z_2$$
$$\beta = Z_2 - Z_1 + 2\alpha$$
$$= d - c + 2\frac{(a-b)}{4}$$
$$= d + \frac{(a-b)}{2} - c]$$

2. A radioactive nuclide emits γ-rays due to:
(a) K-electron capture
(b) nuclear transition from higher to lower energy state
(c) presence of greater number of neutrons than protons
(d) presence of greater number of protons than neutrons
[**Ans.** (b)]
[**Hint:** After α, β-emission, nucleus goes to excited state; when it returns to normal state, emission of γ-radiations takes place.]

3. In which of the following transformations, the β-particles are emitted?
(a) Proton to neutron (b) Neutron to proton
(c) Proton to proton (d) Neutron to neutron
[**Ans.** (b)]
[**Hint:** ${}_0^1n \longrightarrow {}_1^1\text{H} + {}_{-1}^{0}e$ + antineutrino]

4. In the radioactive decay:
$${}_Z^AX \longrightarrow {}_{Z+1}^{A}Y \longrightarrow {}_{Z-1}^{A-4}Z \longrightarrow {}_{Z-1}^{A-4}Z^*$$
the sequence of emission is:
(a) α, β, γ (b) β, α, γ (c) γ, α, β (d) β, γ, α
[**Ans.** (b)]
[**Hint:** ${}_Z^AX - {}_{-1}^{0}e \longrightarrow {}_{Z+1}^{A}Y;\ {}_{Z+1}^{A}Y - {}_2^4\text{He} \longrightarrow {}_{Z-1}^{A-4}Z;$
${}_{Z-1}^{A-4}Z - \gamma \longrightarrow {}_{Z-1}^{A-4}Z^*$]

5. Which of the following elements is an isodiaphere of ${}_{92}^{235}\text{U}$?
(a) ${}_{83}^{209}\text{Bi}$ (b) ${}_{82}^{212}\text{Pb}$ (c) ${}_{90}^{231}\text{Th}$ (d) ${}_{91}^{231}\text{Pa}$
[**Ans.** (c)]
[**Hint:** Isodiapheres are formed by α-emission.
${}_{92}^{235}\text{U} - {}_2^4\text{He} \longrightarrow {}_{90}^{231}\text{Th}$ (Isodiaphere)]

6. A certain radioactive material ${}_Z^AX$ starts emitting α and β particles successively such that the end product is ${}_{Z-3}^{A-8}Y$. The number of α and β particles emitted are : **(VITEEE 2008)**
(a) 4 and 3 respectively (b) 2 and 1 respectively
(c) 3 and 4 respectively (d) 3 and 8 respectively
[**Ans.** (b)]
[**Hint:** ${}_Z^AX \longrightarrow {}_{Z-3}^{A-8}Y$

Number of α-particles $= \frac{\text{Change in mass number}}{4} = \frac{8}{4} = 2$

$Z - 2 \times$ Number of α-particles + Number of β-particles $= Z - 3$

$Z - 2 \times 2 +$ Number of β-particles $= Z - 3$
Number of β- particles = 1]

3.8 RADIOACTIVE DISINTEGRATION SERIES

Elements beyond bismuth are all radioactive in nature. Most of them have several radioactive isotopes. These radioactive elements disintegrate to give new elements which again disintegrate to form other elements and so on. The process continues till a non-radioactive end product is reached.

"The whole chain of such elements starting from the parent element (radioactive) to the end element (non-radioactive) is called a radioactive series or a family".

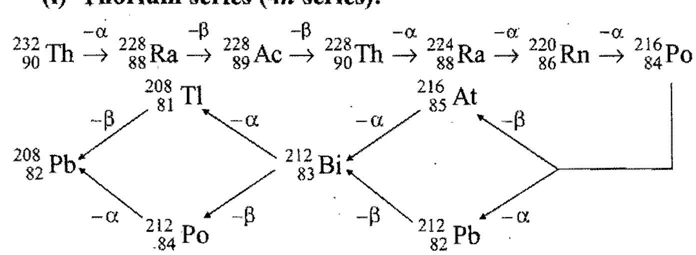
All the naturally occurring radioactive elements above atomic number 82 belong to one of the three radioactive series. These are known as:

(i) Thorium series (ii) Uranium series
(iii) Actinium series

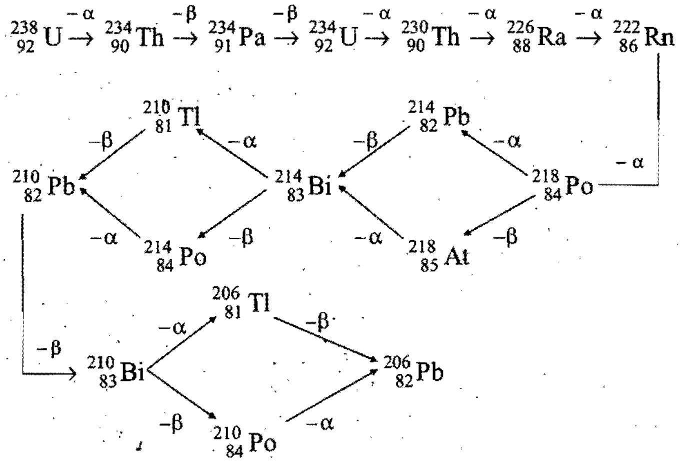
Uranium and thorium series have been named on the basis of long lived isotopes of ${}^{238}\text{U}$ and ${}^{232}\text{Th}$. The parent element of **actinium** series is ${}^{235}\text{U}$ but originally it was thought to be an isotope of actinium, ${}^{227}\text{Ac}$. The three series are also referred to $4n$ (thorium), $4n + 2$ (uranium) and $4n + 3$ (actinium) series as when the mass numbers of various members belonging to these series when divided by four, either there is no remainder (as in thorium series) or the remainder is 2 (as in uranium series) or 3 (as in actinium series). The end product in all the three series is an isotope of lead which is stable and non-radioactive in nature. The following table shows the main characteristics of three radioactive series:

Series	First member	Half life of first member in years	Last member	Atomic masses when divided by 4, the remainder	No. of α-particles emitted	No. of β-particles emitted
Thorium ($4n$)	${}_{90}^{232}\text{Th}$	1.4×10^{10}	${}_{82}^{208}\text{Pb}$	0	6	4
Uranium ($4n + 2$)	${}_{92}^{238}\text{U}$	4.51×10^{9}	${}_{82}^{206}\text{Pb}$	2	8	6
Actinium ($4n + 3$)	${}_{92}^{235}\text{U}$	7.07×10^{8}	${}_{82}^{207}\text{Pb}$	3	7	4

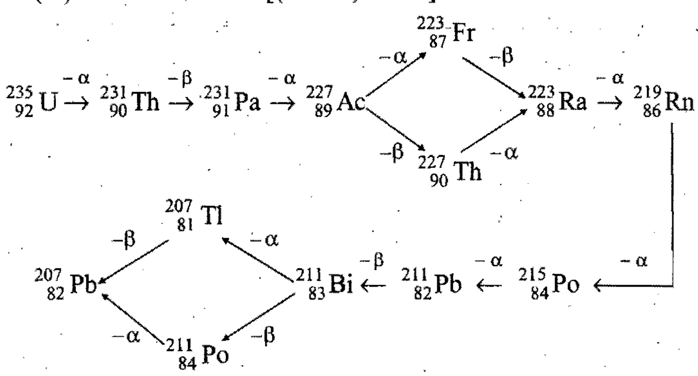
(i) Thorium series (4n series):



(ii) Uranium series [(4n + 2) series]:



(iii) Actinium series [(4n + 3) series]:



Only 18 radioactive isotopes with atomic number 82 or less are found in nature. ^{14}C is the exception because it is continuously synthesized in our atmosphere. All these natural radioactive elements have half-life longer than 10^9 yrs (age of earth). Another 45 radioactive isotopes having atomic number greater than 82 are also found in nature and fall in above three natural decay series.

Similarities between Radioactive Series

(i) In all the series, there is an element of zero group with atomic number 86. This element comes in the gaseous state and is called emanation. Different names are given to three isotopes. These are **radon** in uranium series, **thoron** in thorium series and **actinon** in actinium series.

(ii) In all the series, the last product is an isotope of lead (atomic number 82), ^{206}Pb in uranium series, ^{207}Pb in actinium series while ^{208}Pb in thorium series. Due to this reason, lead is found in nature as a mixture of these three isotopes.

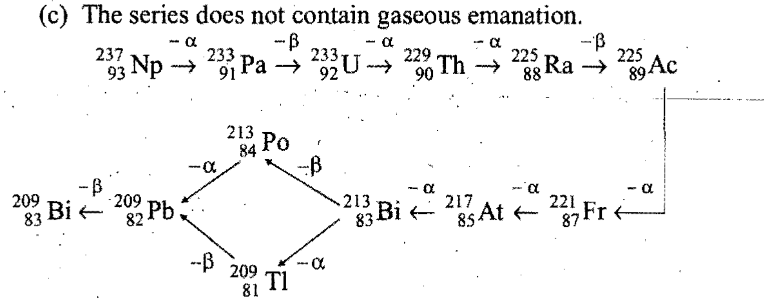
(iii) In all the series, there are certain elements which disintegrate in a branching process by emitting either α or β-particles. The species thus formed are then disintegrated in such a way as to give a common product.

Neptunium series [(4n + 1) series]: For many years scientists speculated upon the failure to find a disintegration series in nature whose isotopic masses carry a numerical relationship of 4n + 1. The most reasonable explanation for the absence of this series in nature was that no member of this series was sufficiently long lived to have survived over the years since the series might have been formed. Except the last member, all other members of this series have been obtained by artificial means. The name of this series is given on the long lived isotope of neptunium (Half life $^{237}_{93}Np = 2.25 \times 10^6$ years). This family differs from the other three naturally occurring series in the following respects:

(a) The last member of this series is an isotope of bismuth ($^{209}_{83}Bi$) and not an isotope of lead.

(b) The only member of this series which is found in nature is the last member.

(c) The series does not contain gaseous emanation.



In this series, seven alpha and four beta particles are emitted.

3.9 RATE OF DISINTEGRATION AND HALF LIFE PERIOD

The radioactive decay of the different radioactive substances differ widely. The rate of disintegration of a given substance depends upon the **nature of disintegrating substance and its total amount. The law of radioactive disintegration may be defined as "the quantity of radioactive substance which disappears in unit time is directly proportional to the amount* of radioactive substance present or yet not decayed."** The quantity of the radioactive substance which disintegrates or disappears in unit time is called rate of disintegration.

The rate of disintegration decreases with time as the amount of radioactive substance decreases with time. One of the most important characteristics of the radioactive disintegration is that a certain definite fraction of a radioactive sample undergoes disintegration in a definite period of time. This time period does not depend upon the initial amount of the radioactive substance.

For example, whatever be the amount (initial) of ^{131}I taken, it becomes half within 8 days. This has been shown in Fig. 3.4 (a).

Initial amount of ^{131}I	The amount of ^{131}I after 8 days
20 grams	10 grams
10 grams	5 grams
5 grams	2.5 grams, etc.

Rutherford introduced a constant known as **half life period.** It is defined **"as the time during which half the amount of a given sample of the radioactive substance disintegrates".**

* Amount of a radioactive substance can be taken in terms of number of atoms or moles or grams, milligrams, etc.

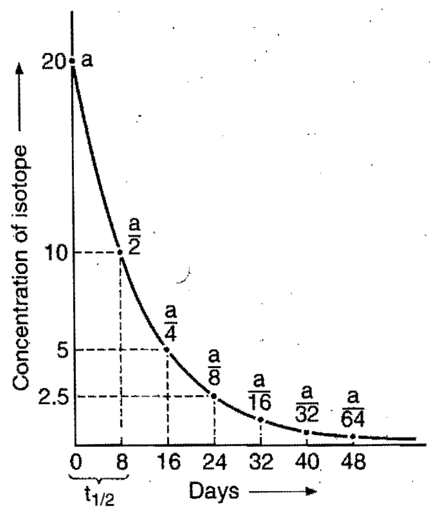


Fig. 3.4 (a)

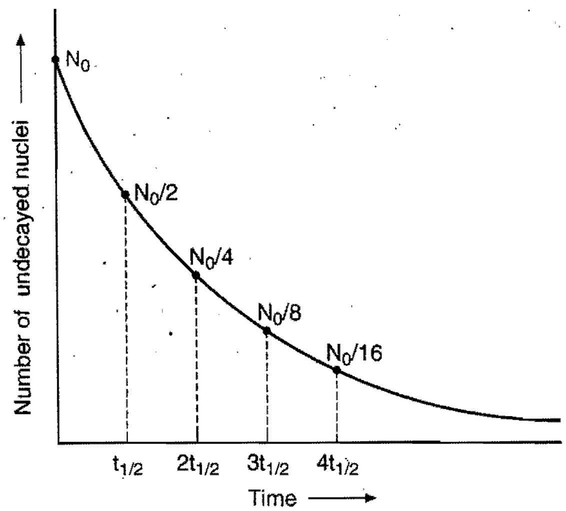


Fig. 3.4 (b)

Every radioactive element is characterised by a definite constant value of half life period. Half life period of an element is also a measure of its radioactivity, since shorter the half life period, the greater is the number of disintegrations and hence greater its radioactivity. Half life periods vary from billions of years for some radioisotopes to a fraction of a second.

Half life period is represented as $t_{1/2}$.

Let the initial amount of a radioactive substance be N_0.

After one half life period ($t_{1/2}$), it becomes $= N_0/2$

After two half life periods ($2t_{1/2}$), it becomes $= N_0/4$

After three half life periods ($3t_{1/2}$), it becomes $= N_0/8$

and After n half life periods ($nt_{1/2}$), it shall become $= \left(\frac{1}{2}\right)^n N_0$

Thus, for the total disintegration of a radioactive substance an infinite time will be required.

Time (T)	Amount of radioactive substance (N)	Amount of radioactive substance decomposed ($N_0 - N$)
0	N_0	0
$t_{1/2}$	$\frac{1}{2}N_0 = \left(\frac{1}{2}\right)^1 N_0$	$\frac{1}{2}N_0 = \left[1-\frac{1}{2}\right]N_0$
$2t_{1/2}$	$\frac{1}{4}N_0 = \left(\frac{1}{2}\right)^2 N_0$	$\frac{3}{4}N_0 = \left[1-\frac{1}{4}\right]N_0$
$3t_{1/2}$	$\frac{1}{8}N_0 = \left(\frac{1}{2}\right)^3 N_0$	$\frac{7}{8}N_0 = \left[1-\frac{1}{8}\right]N_0$
$4t_{1/2}$	$\frac{1}{16}N_0 = \left(\frac{1}{2}\right)^4 N_0$	$\frac{15}{16}N_0 = \left[1-\frac{1}{16}\right]N_0$
$nt_{1/2}$	$\left(\frac{1}{2}\right)^n N_0$	$[1-\left(\frac{1}{2}\right)^n]N_0$

Amount of radioactive substance left after n half life periods

$$N = \left(\frac{1}{2}\right)^n N_0$$

and total time $T = n \times t_{1/2}$

where, n is a whole number.

SOME SOLVED EXAMPLES

Example 10. *The half life period of radium is 1580 years. How do you interpret this statement?*

Solution: Whatever quantity of radium is taken, it shall become half after the expiry of 1580 years. The following table explains the statement:

Quantity of radium at present	Quantity of radium after 1580 years
100 atoms	50 atoms
50 gram	25 gram
5 mole	2.5 mole

Example 11. *The radioactive isotope ^{137}Cs has a half life period of 30 years. Starting with 1 mg of ^{137}Cs, how much would remain after 120 years?*

Solution: At this time, we have 1.0 mg of ^{137}Cs; after 30 years, we shall have one half of the original, or 0.50 mg; after 60 years, we shall have 0.25 mg; after 90 years, we shall have 0.125 mg and, finally, after 120 years, we shall have 0.0625 mg.

After	30 years	—	0.50 mg
	60 years	—	0.25 mg
	90 years	—	0.125 mg
	120 years	—	0.0625 mg

Alternative solution: Total time = 120 years

We know that, total time $= n \times t_{1/2}$

So, $120 = n \times 30$

$n = 4$

Thus, the quantity of the isotope left after

four half life periods $= \left(\frac{1}{2}\right)^4 N_0 = \left(\frac{1}{2}\right)^4 \times 1$

$= \frac{1}{16} = 0.0625$ mg

Example 12. *A radioactive element has half life period of 30 days. How much of it will be left after 90 days?*

Solution: Total time = 90 days

Half life $(t_{1/2}) = 30$ days

We know that, total time $= n \times t_{1/2}$

So, $90 = n \times 30$

$n = 3$

Thus, quantity left after three half life periods

$$= \left(\frac{1}{2}\right)^3 N_0 \quad [N_0 = \text{original amount}]$$

$$= \frac{1}{8} \times N_0 = \frac{1}{8} N_0$$

Example 13. *The half life period of $^{210}_{84}Po$ is 140 days. In how many days 1 g of this isotope is reduced to 0.25 g?*

Solution: Original quantity of the isotope $(N_0) = 1$ g

Final quantity of the isotope $N = 0.25$ g

We know that, $N = \left(\frac{1}{2}\right)^n N_0$

So, $\frac{1}{4} = \left(\frac{1}{2}\right)^n \times 1$

or $\left(\frac{1}{2}\right)^2 = \left(\frac{1}{2}\right)^n$

or $n = 2$

Time taken $T = n \times t_{1/2} = 2 \times 140 = 280$ days

Example 14. *The half life period of ^{234}U is 2.5×10^5 years. In how much time is the quantity of an isotope reduced to 25% of the original amount?*

Solution: Initial amount of this isotope $N_0 = 100$

Final amount of the isotope $N = 25$

We know that, $N = \left(\frac{1}{2}\right)^n N_0$

So, $25 = \left(\frac{1}{2}\right)^n \times 100$

or $\frac{25}{100} = \left(\frac{1}{2}\right)^n$

or $\frac{1}{4} = \left(\frac{1}{2}\right)^n$

or $\left(\frac{1}{2}\right)^2 = \left(\frac{1}{2}\right)^n$

or $n = 2$

Time taken $T = n \times t_{1/2}$

$= 2 \times 2.5 \times 10^5 = 5 \times 10^5$ years

$$\log \frac{N_0}{N} = \lambda t \text{ or } \log \frac{N}{N_0} = -\lambda t \text{ or } \frac{N}{N_0} = e^{-\lambda t} \text{ or } N = N_0 e^{-\lambda t}$$

Example 15. *A radioisotope has $t_{1/2} = 5$ years. After a given amount decays for 15 years, what fraction of the original isotope remains?*

Solution: Half life $(t_{1/2}) = 5$ years

Time for decay $(T) = 15$ years

We know that, $T = n \times t_{1/2}$

So, $15 = n \times 5$

or $n = 3$

Let the original amount be $= N_0$

Let the amount left after three half life periods be $= N$

fraction $= N / N_0$

We know that, $N = \left(\frac{1}{2}\right)^n N_0$

or $\frac{N}{N_0} = \left(\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^3 = \frac{1}{8}$

Thus, after 15 years $\frac{1}{8}$th of the original amount remains.

Example 16. *If in 3160 years, a radioactive substance becomes one-fourth of the original amount, find its half life period.*

Solution: $\frac{N}{N_0} = \frac{1}{4}$

So, $\frac{1}{4} = \left(\frac{1}{2}\right)^n$

or $\left(\frac{1}{2}\right)^2 = \left(\frac{1}{2}\right)^n$

or $n = 2$

We know that, total time 'T' $= n \times t_{1/2}$

So, $3160 = 2 \times t_{1/2}$

or $t_{1/2} = \frac{3160}{2} = 1580$ years

The half life period of the radioactive substance is 1580 years.

ILLUSTRATIONS OF OBJECTIVE QUESTIONS

7. Half life of a radioactive sample is $2x$ years. What fraction of this sample will remain undecayed after x years?

(a) $\frac{1}{2}$ (b) $\frac{1}{\sqrt{2}}$ (c) $\frac{1}{\sqrt{3}}$ (d) 2

[Ans. (b)]

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

$$\frac{0.693}{t_{1/2}} = \frac{2.303}{t} \log_{10}\left(\frac{N_0}{N}\right)$$

$$\frac{0.693}{2x} = \frac{2.303}{x} \log_{10}\left(\frac{N_0}{N}\right)$$

$$\frac{1}{2} \log_{10} 2 = \log\left(\frac{N_0}{N}\right)$$

$$\frac{N}{N_0} = \frac{1}{\sqrt{2}}$$

Fraction undecayed $= \frac{1}{\sqrt{2}}$]

8. Half life of a radioactive element is 10 days. What percentage of the element will remain undecayed after 100 days?
(a) 10% (b) 0.1%
(c) 0% (d) 99%
[Ans. (b)]
[Hint: In ten times of half life 99.9%, the element undergoes decay; then percentage of undecayed radioactive element will be 0.1%.]

9. Which among the following relations is correct?
(a) $t_{1/2} = 2t_{3/4}$ (b) $t_{1/2} = 3t_{3/4}$
(c) $t_{3/4} = 2t_{1/2}$ (d) $t_{3/4} = 3t_{1/2}$
[Ans. (c)]
[Hint: $\frac{0.693}{t_{1/2}} = \frac{2.303}{t}\log\left(\frac{N_0}{N}\right)$

$$\frac{0.693}{t_{1/2}} = \frac{2.303}{t_{3/4}}\log\frac{100}{75}$$

$t_{3/4} = 2t_{1/2}$]

10. Select the correct statement:
(a) Same amount will decay in every half life
(b) Amount decayed in first half life is maximum
(c) Amount decayed in first half life is minimum
(d) Amount decayed in a half life depends on the nature of element
[Ans. (b)]
[Hint: Amount decayed in first half life is maximum. Half of the initial amount is decayed in first half life.]

11. The half life period of a radioactive mineral is 15 min. What percent of radioactivity of that mineral will remain after 45 min? [UGET (Manipal Medical) 2006]
(a) 17.5% (b) 15% (c) 12.5% (d) 10%
[Ans. (c)]
[Hint: $n = \frac{45}{15} = 3$ = No. of half lives

$$N = N_0\left(\frac{1}{2}\right)^n = 100 \times \left(\frac{1}{2}\right)^3 = 12.5\%]$$

12. Half life of a radioactive element is 16 hrs. What time will it take for 75% disintegration? (DCE 2006)
(a) 32 days (b) 32 hrs (c) 48 hrs (d) 16 hrs
[Ans. (b)]
[Hint: 75% decay takes place in $t_{3/4}$ (3 / 4th life)

$$t_{3/4} = 2t_{1/2} = 2 \times 16 = 32 \text{ hrs}]$$

Disintegration constant: A chemical reaction whose rate of reaction varies directly as the concentration of one molecular species only, is termed a first order reaction. Radioactive disintegration is similar to such a chemical reaction as one radioactive species changes into other. This change can be represented by the equation:

$$A \longrightarrow B$$

Suppose the number of atoms of a radioactive substance present at the start of observation, *i.e.*, when $t = 0$, is N_0 and after time t, the number of atoms remaining unchanged is N. At this instant a very small number of atoms dN disintegrate in a small time dt; the rate of change of A into B is given by $-\frac{dN}{dt}$. The negative sign indicates that number of atoms decreases as time increases. Since, rate of disintegration or change is proportional to the total number of atoms present at that time, the relation becomes

$$-\frac{dN}{dt} = \lambda \cdot N \quad \text{... (i)}$$

'λ' is called the **disintegration constant** or **decay constant.**

Evidently $$-\frac{dN}{N} = \lambda \cdot dt \quad \text{... (ii)}$$

If $dt = 1$ second, $$\lambda = -\frac{dN}{N} \quad \text{... (iii)}$$

Thus, λ may be defined as **the fraction of the total number of atoms which disintegrate per second at any time.** This is constant for a given radioactive isotope.

Integrating eq. (ii), $-\int \frac{dN}{N} = \lambda \int dt$

$$-\log N = \lambda t + C \quad \text{... (iv)}$$

C is the integration constant.

When $t = 0$, $N = N_0$

Putting the values in eq. (iv),

$$-\log N_0 = C \quad \text{... (v)}$$

Putting the value of C in eq. (iv)

$$-\log N = \lambda t - \log N_0 \quad \text{or} \quad \log N_0 - \log N = \lambda t$$

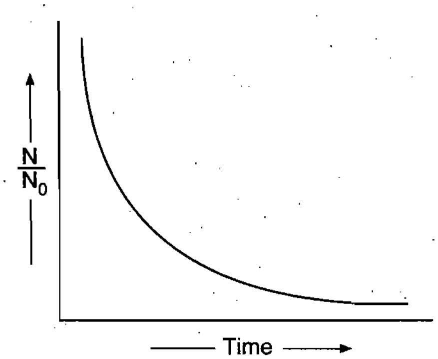


Fig. 3.5 Fraction of radioisotope remaining versus time

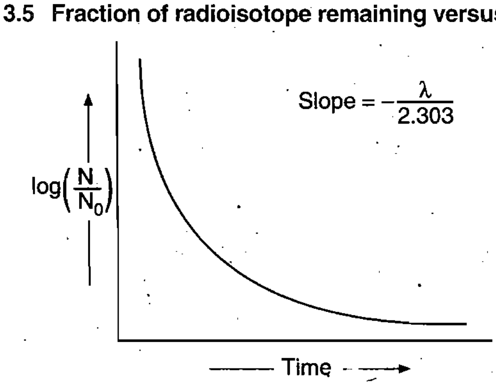


Fig. 3.6 Log of fraction remaining versus time

or $\quad \log \frac{N_0}{N} = \lambda t \qquad$ or $\quad 2.303 \log_{10} \frac{N_0}{N} = \lambda t$

or $$\lambda = \frac{2.303}{t} \log_{10} \frac{N_0}{N} \qquad \text{... (vi)}$$

This equation is called kinetic equation and is obeyed by first order reactions.

Relationship between half life period and radioactive disintegration constant.

When $\quad t = t_{1/2}, \quad N = \frac{N_0}{2}$

Putting the values in eq. (vi)

$$\lambda = \frac{2.303}{t_{1/2}} \log_{10} \frac{N_0}{N_0/2} = \frac{2.303}{t_{1/2}} \log_{10} 2$$

The value of $\log_{10} 2$ is 0.3010.

So, $\quad \lambda = \frac{0.693}{t_{1/2}} \quad$ or $\quad t_{1/2} = \frac{0.693}{\lambda}$

Thus, half life period of a given radioactive substance does not depend on the initial amount of a radioactive substance but depends only on the disintegration constant of the radioactive element.

3.10 AVERAGE LIFE

It is the sum of the periods of existence of all the atoms divided by the total number of atoms of the radioactive substance.

$$\text{Average life} = \frac{\text{Total life time of all the atoms}}{\text{Total number of atoms}}$$

$$= \frac{\int_0^\infty t\, dN}{N_0} = \frac{1}{\lambda}$$

Thus, **average life** of a radioactive element is the inverse of its disintegration or decay constant.

$$\text{Average life} = \frac{1}{\lambda} = \frac{t_{1/2}}{0.693} = 1.44 t_{1/2}$$

The **average life** of a radioactive substance is 1.44 times of its half life period.

Alternatively:

We know that, $\quad \lambda = \frac{2.303}{t} \log_{10} \left(\frac{N_0}{N}\right)$

or $\quad \lambda t = \log_e \left(\frac{N_0}{N}\right)$

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

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

Let $t = \frac{1}{\lambda}$; then $\quad \frac{N}{N_0} = e^{-1} = \frac{1}{e}$

$$\frac{N}{N_0} = \frac{1}{2.718} = 0.3679$$

$$\% \text{ remaining amount} = \frac{N}{N_0} \times 100 = 36.79$$

$$\% \text{ decayed amount} = 100 - 36.79 = 63.21$$

Time during which 63.21% substance undergoes decay is called average life.

Relation between rate of decay and mass of given element

$$\text{Rate}\left(-\frac{dN}{dt}\right) = \lambda \times N$$

$$= \lambda \times \text{No. of atoms of element undergoing decay}$$

$$= \frac{0.693}{t_{1/2}} \times \frac{\text{mass}}{\text{atomic mass}} \times \text{Avogadro's number}$$

Parallel Path Decay

Let a radioactive element 'A' decays to 'B' and 'C' in two parallel paths:

$$A \begin{matrix} \nearrow B \\ \searrow C \end{matrix}$$

Decay constant of

'A' = Decay constant of 'B' + Decay constant of 'C'

$$\lambda_A = \lambda_B + \lambda_C \qquad \text{... (i)}$$

Here, λ_B = [fractional yield of B] $\times \lambda_A$

λ_C = [fractional yield of C] $\times \lambda_A$

Maximum Yield of Daughter Element

Let a radioactive element 'A' decays to daughter element 'B'.

$$A \longrightarrow B$$

λ_A and λ_B are decay constants of 'A' and 'B'. Maximum activity time of daughter element can be calculated as:

$$t_{\max} = \frac{2.303}{(\lambda_B - \lambda_A)} \log_{10} \left[\frac{\lambda_B}{\lambda_A}\right]$$

3.11 RADIOACTIVE EQUILIBRIUM

Let us consider that a radioactive element A disintegrates to give B which is also radioactive and disintegrates into C.

$$A \longrightarrow B \longrightarrow C$$

The element B is said to be in radioactive equilibrium with A if its rate of formation from A is equal to its rate of decay into C. If λ_1 and λ_2 are the disintegration constants of A and B, N_1 and N_2 are the number of atoms of each radioactive element present at equilibrium, then we have

Rate of formation of B = Rate of decay of $A = \lambda_1 N_1$

and Rate of decay of $B = \lambda_2 N_2$

At radioactive equilibrium,

$$\lambda_1 N_1 = \lambda_2 N_2$$

or $$\frac{N_1}{N_2} = \frac{\lambda_2}{\lambda_1} = \frac{1/\lambda_1}{1/\lambda_2} = \frac{\text{Average life of A}}{\text{Average life of B}} = \frac{Z_A}{Z_B}$$

Thus, the number of atoms of A and B are in the ratio of their average life periods.

$$\frac{N_1}{N_2} = \frac{\lambda_2}{\lambda_1} = \frac{0.693/(t_{1/2})_2}{0.693/(t_{1/2})_1}$$

$$\frac{N_1}{N_2} = \frac{(t_{1/2})_1}{(t_{1/2})_2}$$

When λ_A of parent element is less than λ_B of daughter element, but both are not very small then a *transient equilibrium* is reached, when

$$\frac{N_B}{N_A} = \frac{\lambda_A}{\lambda_B - \lambda_A}$$

in fact it is steady state.

3.12 UNITS OF RADIOACTIVITY

In radioactivity, the number of atoms which disintegrate in unit time is of real importance rather than the total amount of the radioactive substance expressed by mass or number of atoms, *i.e.*, the activity of a radioactive substance is the rate of decay or number of disintegrations per second.

The unit of radioactivity called **Curie (Ci) is defined as that quantity of any radioactive substance which has a decay rate of 3.7×10^{10} disintegrations per second.**

This unit is a large one and hence smaller units like **millicurie** (mCi) and **microcurie** (μCi) are used.

$$1 \text{ millicurie} = 3.7 \times 10^7 \text{ disintegrations per sec}$$
$$1 \text{ microcurie} = 3.7 \times 10^4 \text{ disintegrations per sec}$$

There is another unit Rutherford (Rd) which is also used these days. **It is defined as the amount of a radioactive substance which undergoes 10^6 disintegrations per second.** Smaller units like milli-Rutherford and micro-Rutherford are also used.

$$1 \text{ milli-Rutherford} = 10^3 \text{ disintegrations per sec (dps)}$$

$$1 \text{ micro-Rutherford} = 1 \text{ disintegration per sec}$$

The SI unit of radioactivity is proposed as Becquerel which refers to one dps.

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

$$1 \text{ curie} = 37 \text{ GBq}$$

Here, G stands for 10^9, *i.e.*, giga

Gray (Gy) = 1 kg tissue receiving 1 J of energy

Sievert (Sv) = gray × quality number of radiation

Quality number of 1α-particle = 20

Quality number of 1β-particle = 1

Specific activity of a radionuclide is its activity per kilogram (or dm^3) of the radioactive material.

(In some cases, specific activity is taken as the activity per gram.)

Radiation counter: There are two main radiation counters in practice.

1. Geiger-Muller counter: It is used to count charged particles, *e.g.*, α and β-particles, emitted by a radioactive nucleus. This counter is simply a metal tube filled with a gas like argon.

In order to count and detect neutrons, boron trifluoride (BF_3) is added along with a gas in the G.M. counter. Neutron strikes $^{10}_{5}B$ nuclei to produce α-particle, which is then detected and counted in Geiger counter.

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

2. Scintillation counter: γ-radiations are detected by Scintillation counter. A phosphor is used in this counter which produces flash of light when it is struck by electromagnetic radiation like γ-rays, for detection of γ-rays. Sodium iodide (NaI) and thallium iodide (TlI) are used as phosphor. Rutherford first of all used zinc sulphide (ZnS) as phosphor in detection of α-particles.

SOME SOLVED EXAMPLES

Example 17. *The half life period of radium is 1600 years. Calculate the disintegration constant of radium. Mention its unit.*

Solution: Disintegration constant $\lambda = \frac{0.693}{t_{1/2}}$

Since, $t_{1/2} = 1600$ years

So, $\lambda = \frac{0.693}{1600}$

or $\lambda = 4.33 \times 10^{-4}\ \text{year}^{-1}$

Example 18. *The disintegration constant of ^{238}U is 1.54×10^{-10} year^{-1}. Calculate the half life period of ^{238}U.*

Solution: Half life period, $t_{1/2} = \frac{0.693}{\lambda}$

Since, $\lambda = 1.54 \times 10^{-10}\ \text{year}^{-1}$

So, $t_{1/2} = \frac{0.693}{1.54 \times 10^{-10}} = 4.5 \times 10^9$ years

Example 19. *The half life period of radon is 3.8 days. After how many days will only one-twentieth of radon sample be left over?*

Solution: We know that, $\lambda = \frac{0.693}{t_{1/2}} = \frac{0.693}{3.8} = 0.182\ \text{day}^{-1}$

Let the initial amount of radon be N_0 and the amount left after t days be N which is equal to $\frac{N_0}{20}$.

Applying the equation,

$$t = \frac{2.303}{\lambda} \log_{10} \frac{N_0}{N}$$
$$= \frac{2.303}{0.182} \log_{10} \frac{N_0}{N_0/20} = \frac{2.303}{0.182} \log_{10} 20$$
$$= 16.54 \text{ days}$$

Example 20. *A counter rate meter is used to measure the activity of a radioactive sample. At a certain instant, the count rate was recorded as 475 counters per minute. Five minutes later, the count rate recorded was 270 counts per minute. Calculate the decay constant and half life period of the sample.*

Solution: Let N_0 and N be the number of atoms of the radioactive substance present at the start and after 5 minutes respectively.

Rate of disintegration at the start $= \lambda N_0 = 475$

and rate of disintegration after 5 minutes $= \lambda N = 270$

Dividing both, $\frac{\lambda N_0}{\lambda N} = \frac{475}{270}$

or $\frac{N_0}{N} = 1.76$

We know that, $\lambda = \frac{2.303}{t}\log_{10}\frac{N_0}{N}$

$$\lambda = \frac{2.303}{5}\log_{10} 1.76 = 0.113 \text{ minute}^{-1}$$

$$\text{Half life period} = \frac{0.693}{\lambda} = \frac{0.693}{0.113} = 6.1 \text{ minutes}$$

Example 21. *You have* 0.1 g *atom of a radioactive isotope* $^A_Z X$ *(half life = 5 days). How many atoms will decay during the 11th day?*

Solution: Amount of radioactive substance = 0.1 g atom

So, $N_0 = 0.1 \times$ Avogadro's number

$$= 0.1 \times 6.02 \times 10^{23}$$

$$= 6.02 \times 10^{22} \text{ atoms}$$

$$\text{Number of atoms after 5 days} = \frac{6.02\times 10^{22}}{2} = 3.01\times 10^{22}$$

$$\text{Number of atoms after 10 days} = \frac{3.01\times 10^{22}}{2} = 1.505\times 10^{22}$$

Let the number of atoms left after 11 days be N.

We know that,

$$t = \frac{2.303}{\lambda}\log_{10}\frac{N_0}{N}$$

Given, $t = 11$, $\lambda = \frac{0.693}{5}$, $N_0 = 6.02\times 10^{22}$

So, $$11 = \frac{2.303\times 5}{0.693}\log_{10}\frac{6.02\times 10^{22}}{N}$$

or $$\log_{10}\frac{6.02\times 10^{22}}{N} = \frac{11\times 0.693}{2.303\times 5} = 0.6620$$

$$\frac{6.02\times 10^{22}}{N} = \text{Antilog } 0.6620 = 4.592$$

So, $$N = \frac{6.02}{4.592}\times 10^{22} = 1.3109\times 10^{22}$$

Atoms decayed during 11th day

$$= [1.5050\times 10^{22} - 1.3109\times 10^{22}]$$

$$= 0.1941\times 10^{22}$$

$$= 1.941\times 10^{21}$$

Example 22. 10 *g atoms of an* α*-active radioisotope are disintegrating in a sealed container. In one hour, the helium gas collected at STP is* 11.2 cm^3. *Calculate the half life of the radio isotope.*

Solution: Amount of radioactive isotope = 10 g atoms

or $N_0 = 10\times 6.023\times 10^{23}$ atoms

$$= 6.023\times 10^{24} \text{ atoms}$$

22400 cm^3 of helium contains $= 6.023\times 10^{23}$ atoms

$$11.2 \text{ cm}^3 \text{ of helium will contain} = \frac{6.023\times 10^{23}}{22400}\times 11.2 \text{ atoms}$$

$$= 3.01\times 10^{20} \text{ atoms}$$

As one helium atom is obtained by disintegration of one atom of radioisotope, the total number of atoms of the radioactive isotope which have disintegrated in one hour

$$= 3.01\times 10^{20} \quad \text{or} \quad 0.0003\times 10^{24}$$

The number of atoms of the radioactive isotope left after one hour,

$$N = (6.023\times 10^{24} - 0.000301\times 10^{24})$$

$$= 6.0227\times 10^{24}$$

Using, $$\lambda = \frac{2.303}{t}\log\frac{N_0}{N}$$

$$\lambda = \frac{2.303}{t}\log\frac{6.023\times 10^{24}}{6.0227\times 10^{24}}$$

$$= 2.303\times 2.1632\times 10^{-5} = 4.982\times 10^{-5}\text{ hr}^{-1}$$

$$t_{1/2} = 0.693/(4.982\times 10^{-5}\times 24\times 365) = 1.58 \text{ years}$$

Example 23. *Calculate the average life of a radioactive substance whose half life period is* 1650 *years.*

Solution: Average life $= 1.44\times t_{1/2}$

$$= 1.44\times 1650 = 2376 \text{ years}$$

Example 24. ^{90}Sr *shows* β*-activity and its half life period is* 28 *years. What is the activity of a sample containing* 1 g *of* ^{90}Sr?

Solution: Activity = No. of atoms disintegrating per second

$= \lambda\times$ total number of atoms

$$\lambda = \frac{0.693}{28\times 365\times 24\times 60\times 60}$$

$$\text{Total number of atoms in 1 g of } ^{90}\text{Sr} = \frac{6.023\times 10^{23}}{90}$$

$$\text{Activity} = \frac{0.693}{28\times 365\times 24\times 60\times 60}\times\frac{6.023\times 10^{23}}{90}$$

$$= 5.25\times 10^{12} \text{ disintegrations per second}$$

$$= \frac{5.25\times 10^{12}}{3.7\times 10^{10}} = 141.89 \text{ curie}$$

Example 25. *A chemist prepares* 1.00 g *of pure* $^{11}_{6}C$. *This isotope has half life of* 21 *minutes, decaying by the equation:*

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

(a) *What is the rate of disintegration per second (dps) at start?*

(b) *What are the activity and specific activity of* $^{11}_{6}C$ *at start?*

(c) *How much of this isotope* ($^{11}_{6}C$) *is left after 24 hours of its preparation?*

Solution: (a) Applying, $-\frac{dN}{dt} = \lambda N_0$

$$= \frac{0.693}{21\times 60}\times\frac{1\times 6.02\times 10^{23}}{11}$$

$$= 3\times 10^{19} \text{ dps}$$

(b) Activity $= \frac{3\times 10^{19}}{3.7\times 10^{10}}$ (1 curie = 3.7×10^{10} dps)

$= 8.108\times 10^8$ curie

Sp. activity $= 3\times 10^{19}\times 10^3 = 3\times 10^{22}$ dis/kg s

$= 8.108\times 10^{11}$ curie

(c) Applying, $N = N_0\left(\frac{1}{2}\right)^n \quad \left[n = \frac{t}{t_{1/2}} = \frac{24\times 60}{21} = 68.57\right]$

$$N = 1\times\left(\frac{1}{2}\right)^{68.57} = 2.29\times 10^{-21}\text{ g}$$

ILLUSTRATIONS OF OBJECTIVE QUESTIONS

13. The time of decay for the nuclear reaction is given by $t = 5t_{1/2}$. The relation between mean life τ and time of decay 't' is given by:

(a) $2\tau \ln 2$ (b) $5\tau \ln 2$ (c) $2\tau^4 \ln 2$ (d) $\frac{1}{\tau^4}\ln 2$

[**Ans.** (b)]

[**Hint:** $t = 5t_{1/2}$

$t = 5\times\frac{\ln 2}{\lambda}$

$t = 5\tau \ln 2$]

14. The activity of a sample of radioactive element ^{100}A is 6.02 curie. Its decay constant is $3.7\times 10^4\ s^{-1}$. The initial mass of the sample will be:

(a) 10^{-14} g (b) 10^{-6} g (c) 10^{-15} g (d) 10^{-3} g

[**Ans.** (c)]

[**Hint:** Activity $= \lambda\times\frac{w}{\text{At. wt.}}\times 6.023\times 10^{23}$

$6.02\times 3.7\times 10^{10} = 3.7\times 10^4\times\frac{w}{100}\times 6.023\times 10^{23}$

$w = 10^{-15}$ g]

15. A freshly prepared radio medicine has half life 2 hours. Its activity is 64 times the permissible safe value. The minimum time after which it would be possible to treat the patients with the medicine is:

(a) 3 hrs (b) 9 hrs (c) 24 hrs (d) 12 hrs

[**Ans.** (d)]

[**Hint:** $N = N_0\left(\frac{1}{2}\right)^n$

$\frac{N}{N_0} = \left(\frac{1}{2}\right)^n$

$\frac{1}{64} = \left(\frac{1}{2}\right)^n$; $n = 6$ half lives

$\therefore$ time $= 2\times 6 = 12$ hrs]

16. One gram of ^{226}Ra has an activity of nearly 1 Ci. The half life of ^{226}Ra is:

(a) 1582 yrs (b) 12.5 hrs

(c) 140 days (d) 4.5×10^9 yrs

[**Ans.** (a)]

[**Hint:** Use the following relation for calculation of activity:

Activity $= \frac{0.693}{t_{1/2}}\times\frac{w}{\text{At. wt.}}\times 6.023\times 10^{23}$

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

It will give the half life in seconds.]

17. Assuming that ^{226}Ra ($t_{1/2} = 1.6\times 10^3$ yrs) is in secular equilibrium with ^{238}U ($t_{1/2} = 4.5\times 10^9$ yrs) in a certain mineral, how many grams of radium will be present in for every gram of ^{238}U in this mineral?

(a) 3.7×10^{-7} (b) 3.4×10^7

(c) 3.4×10^{-7} (d) 3.7×10^7

[**Ans.** (c)]

[**Hint:** $\frac{N_1\ ^{226}\text{Ra}}{N_2\ ^{238}\text{U}} = \frac{t_{1/2}\ ^{226}\text{Ra}}{t_{1/2}\ ^{238}\text{U}}$

$\frac{w/226}{1/238} = \frac{1.6\times 10^3}{4.5\times 10^9}$; $w = 3.4\times 10^{-7}$ g]

18. A certain radioactive isotope decay has α-emission,

$$^{A_1}_{Z_1}X \longrightarrow\ ^{A_1-4}_{Z_1-2}Y$$

half life of X is 10 days. If 1 mol of X is taken initially in a sealed container, then what volume of helium will be collected at STP after 20 days?

(a) 22.4 L (b) 11.2 L (c) 16.8 L (d) 33.6 L

[**Ans.** (c)]

[**Hint:** After 20 days 0.75 mol helium will be formed.

$\therefore$ Volume of helium at STP $= 0.75\times 22.4$

$= 16.8$ L]

3.13 ARTIFICIAL TRANSMUTATION

Transmutation is defined as the conversion of one element into another or one type of atom into another. When this conversion is achieved by artificial means, it is termed as artificial transmutation.

The conversion of elements into one another has been the dream of the human race for many centuries. In the middle ages, it was popular under the name of '*Alchemy*'. Alchemists were unsuccessful in this attempt as they were having very little knowledge about the structure of atom. With the background of the clear picture of the structure of the atom, modern scientists have realised that to convert one element into another, the nucleus should be attacked and altered.

The first indication that a stable nucleus could be disrupted was given by Rutherford in 1919. He observed that when nitrogen was bombarded with high speed α-particles from ^{214}Po, protons were emitted. Thus, nitrogen was changed into an isotope of oxygen.

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

Later on, Rutherford and Chadwick showed that many other elements from boron to potassium with the exception of carbon and oxygen could be transmuted by bombardment with α-particles. However with heavier elements, there was only scattering of α-particles as these suffered a force of repulsion. It was, thus, concluded that to bring transmutation in heavier elements, the projectiles must have higher energies than α-particles obtained from natural sources. It was suggested by Gamow in 1928 that a proton (^1_1H) would be a much more effective projectile than an α-particle, but it was not available as a high speed particle.

The charged particles, like alpha particles, protons, deuterons can be made much more effective projectiles if they have high velocity. Out of all the instruments which have been devised for accelerating projectiles, the one which has attracted the widest interest is the cyclotron of E.O. Lawrence. The projectile can be accelerated to the speed of 25,000 miles per second.

The discovery of neutron by Chadwick, in 1932, added another projectile for transmutation. The neutron being electrically neutral can penetrate easily into the atomic nucleus. Although neutrons are the most effective and versatile of projectiles, yet they suffer the objection that they must be produced by transmutation at the time of use. High speed neutrons are obtained when beryllium-9 is bombarded with α-particles,

$$^9_4Be + {}^4_2He \longrightarrow {}^{12}_6C + {}^1_0n$$

and slow neutrons are obtained by bombarding lithium-7 with protons.

$$^7_3Li + {}^1_1H \longrightarrow {}^7_4Be + {}^1_0n$$

In general, for the transmutation of lighter elements, charged particles like alpha particles, protons, deuterons are used while for heavier elements, neutrons are used.

Nuclear Reactions

The reactions in which nuclei of atoms interact with other nuclei or elementary particles such as alpha particle, proton, deuteron, neutron, etc., resulting in the formation of a new nucleus and one or more elementary particles are called nuclear reactions. Nuclear reactions are expressed in the same fashion as chemical reactions, *i.e.*, reactants on left hand side and the products on right hand side of the sign of (=) or ($\rightarrow$). **In all nuclear reactions, the total number of protons and neutrons are conserved as in chemical reactions, the number of atoms of each element are conserved.** The symbols ^1_0n, ^1_1H, ^4_2He, ^2_1H, $^0_{-1}e$, $^0_{+1}e$ and γ are used to represent neutron, proton, α-particle, deuteron, electron, positron, γ-rays respectively. A short hand notation is often used for the representation of nuclear reactions. As for example, the nuclear reaction

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

is represented as $^{14}_7N(\alpha, p)\,^{17}_8O$. Some of the characteristics that differentiate between nuclear reactions and ordinary chemical reactions are summarised below:

Nuclear reactions	Chemical reactions
1. Elements may be converted from one to another.	No new element can be produced.
2. Particles within the nucleus are involved.	Only outermost electrons participate.
3. Often accompanied by release or absorption of tremendous amount of energy.	Accompanied by release or absorption of relatively small amount of energy.
4. Rate of reaction is independent of external factors such as temperature, pressure and catalyst.	Rate of reaction is influenced by external factors.

Example 26. *Calculate the energy in the reaction*

$$2\,^1_1H + 2\,^1_0n \rightarrow {}^4_2He$$

Given, $H = 1.00813$ amu, $n = 1.00897$ amu and $He = 4.00388$ amu

Solution: Loss of mass in the given nuclear reaction

$$= 2(1.00813 + 1.00897) - 4.00388$$
$$= 0.03032 \text{ amu}$$

Energy released $= 0.03032 \times 931 = 28.3$ MeV

Types of Nuclear Reactions

(a) Projectile capture reactions: The bombarding particle is absorbed with or without the emission of γ-radiations.

$$^{238}_{92}U + {}^1_0n \longrightarrow {}^{239}_{92}U + \gamma$$
$$^{27}_{13}Al + {}^1_0n \longrightarrow {}^{28}_{13}Al + \gamma$$

(b) Particle-particle reactions: Majority of nuclear reactions come under this category. In addition to the product nucleus, an elementary particle is also emitted.

$$^{23}_{11}Na + {}^1_1H \longrightarrow {}^{23}_{12}Mg + {}^1_0n$$
$$^{23}_{11}Na + {}^2_1H \longrightarrow {}^{24}_{11}Na + {}^1_1H$$
$$^{23}_{11}Na + {}^4_2He \longrightarrow {}^{26}_{12}Mg + {}^1_1H$$
$$^{14}_7N + {}^1_0n \longrightarrow {}^{14}_6C + {}^1_1H$$

(c) Spallation reactions: High speed projectiles with energies approximately 40 MeV may chip fragments from a heavy nucleus, leaving a smaller nucleus.

$$^{63}_{29}Cu + {}^4_2He + 400\text{ MeV} \longrightarrow {}^{37}_{17}Cl + 14\,^1_1H + 16\,^1_0n$$
$$^{75}_{33}As + {}^2_1H \longrightarrow {}^{56}_{25}Mn + 9\,^1_1H + 12\,^1_0n$$
$$^{238}_{92}U + {}^4_2He \longrightarrow {}^{187}_{74}W + 20\,^1_1H + 35\,^1_0n$$

(d) Fission reactions: A reaction in which a heavy nucleus is broken down into two or more medium heavy fragments. The process is usually accompanied with emission of neutrons and large amount of energy.

$$^{235}_{92}U + {}^1_0n \longrightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3\,^1_0n + 200\text{ MeV}$$

(e) Fusion reactions: Light nuclei fuse together to reproduce comparatively heavier nuclei.

$$^2_1H + {}^3_1H \longrightarrow {}^4_2He + {}^1_0n + 17.6\text{ MeV}$$

A fusion reaction is the source of tremendous amount of energy.

Pair production : Pair production is the most striking example of mass-energy equivalence.

We can write pair production symbolically as :

Photon + Photon $\longrightarrow$ Particle + Antiparticle

Particle + Antiparticle $\longrightarrow$ Photon + Photon

A particle and antiparticle can collide and annihilate each other, producing two high-energy gamma ray photons. Pair production must obey the law of conservation of energy and momentum.

The following are the important contributions of artificial transmutation:

(i) Discovery of neutron
(ii) Artificial radioactivity
(iii) Nuclear fission
(iv) Nuclear fusion

3.14 ARTIFICIAL RADIOACTIVITY

In 1934, Irene Curie and F. Joliot observed that when boron and aluminium were bombarded by α-particles, neutrons, protons and positrons were emitted. When bombardment was stopped, the emission of protons and neutrons ceased but that of positrons did not. The emission of positrons continued with time but decreased exponentially in a manner similar to natural radioactivity. Curie and Joliot explained this observation by saying that during bombardment, a metastable isotope is formed which behaves as a radioactive element. This process was termed as **artificial radioactivity.**

"The process in which a stable isotope is converted into a radioactive element by artificial transmutation is called artificial radioactivity."

When $^{27}_{13}Al$ is bombarded by α-particles, radioactive isotope $^{30}_{15}P$ is formed.

$$^{27}_{13}Al + ^{4}_{2}He \longrightarrow ^{30}_{14}Si + ^{1}_{1}H \text{ (95\% of total conversion)}$$

$$\longrightarrow ^{30}_{15}P + ^{1}_{0}n \text{ (5\% of total conversion)}$$

$$^{30}_{15}P \longrightarrow \underset{}{^{30}_{14}Si} + \underset{\text{Positron}}{^{0}_{+1}e}$$

In a similar manner, the artificial radioactivity was observed when $^{10}_{5}B$ was bombarded by α-particles.

$$^{10}_{5}B + ^{4}_{2}He \longrightarrow ^{13}_{6}C + ^{1}_{1}H$$

$$\longrightarrow ^{13}_{7}N^* + ^{1}_{0}n$$

$$^{13}_{7}N^* \longrightarrow ^{13}_{6}C + ^{0}_{+1}e$$

The following are some of the nuclear reactions in which radioactive isotopes are formed.

$$^{23}_{11}Na + ^{2}_{1}H \longrightarrow ^{24}_{11}Na^* + ^{1}_{1}H \quad [^{24}_{11}Na — \beta \text{ radioactive}]$$

$$^{238}_{92}U + ^{1}_{0}n \longrightarrow ^{239}_{92}U^* + \gamma \quad [^{239}_{92}U — \beta \text{ radioactive}]$$

$$^{12}_{6}C + ^{1}_{1}H \longrightarrow ^{13}_{7}N^* + \gamma \quad [^{13}_{7}N — \text{positron radioactive}]$$

$$^{25}_{12}Mg + ^{4}_{2}He \longrightarrow ^{28}_{13}Al^* + ^{1}_{1}H \quad [^{28}_{13}Al — \beta \text{ radioactive}]$$

* Half life period of $^{30}_{15}P$ is 3.2 minutes.

3.15 NUCLEAR FISSION

"The process of artificial transmutation in which heavy nucleus is broken down into two lighter nuclei of nearly comparable masses with release of large amount of energy is termed nuclear fission." The word fission is derived from its resemblance to the biological process called fission in which a living cell breaks up into two cells of roughly same size.

After the discovery of neutron, **Fermi,** in 1934, made an attempt to synthesise transuranic elements from uranium by bombarding with neutrons. This experiment was repeated in Germany by **Hahn** and **Strassmann.** In one of the chemical tests, they found that one of the products was an isotope of barium along with the formation of an isotope of the element with atomic number 93 (neptunium). In 1939, they proposed that uranium after capturing neutron undergoes two types of reactions—one with ^{238}U isotope and the other with ^{235}U isotope.

(a) $^{238}_{92}U$ is converted into $^{239}_{93}Np$ and $^{239}_{94}Pu$.

$$^{238}_{92}U + ^{1}_{0}n \longrightarrow ^{239}_{92}U \xrightarrow{-\beta} ^{239}_{93}Np \xrightarrow{-\beta} \underset{\text{(Plutonium)}}{^{239}_{94}Pu}$$

(b) $^{235}_{92}U$ captures slow neutron and splits up into fragments.

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{236}_{92}U \longrightarrow ^{144}_{56}Ba + ^{90}_{36}Kr + 2\ ^{1}_{0}n$$

It has been observed that during fission of $^{235}_{92}U$ not only isotopes of Ba and Kr are formed but isotopes of various other elements come into existence. These isotopes fall under two groups. First type—isotopes having atomic masses from 80 to 110 and atomic numbers from 35 to 43 and second type—isotopes having atomic masses from 120 to 150 and atomic numbers 51 to 57. It is believed that only two isotopes are first formed as primary fission products which then give rise to secondary products by successive disintegration.

$$\left.\begin{aligned} ^{235}_{92}U + ^{1}_{0}n &\longrightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\ ^{1}_{0}n \\ &\longrightarrow ^{139}_{54}Xe + ^{95}_{38}Sr + 2\ ^{1}_{0}n \\ &\longrightarrow ^{140}_{54}Xe + ^{95}_{38}Sr + ^{1}_{0}n \end{aligned}\right\} \text{Primary products}$$

$$\underbrace{^{140}_{54}Xe \xrightarrow{-\beta} ^{140}_{55}Cs \xrightarrow{-\beta} ^{140}_{56}Ba \xrightarrow{-\beta} ^{140}_{57}La \xrightarrow{-\beta} ^{140}_{58}Ce}_{\text{Secondary products}}$$

During fission, there is always loss of mass which is converted into energy according to Einstein equation $E = mc^2$. There is a loss of about 0.215 amu mass during one fission. Thus, energy released in one fission is equal to 0.215×931, *i.e.*, 200 MeV.

Chain reaction: Whatever are the primary products of fission of uranium, it is certain that neutrons are always set free. If the conditions are so arranged that each of these neutrons can, in turn, bring about the fission, the number of neutrons will increase at a continuously accelerating rate until whole of the material is exhausted. Such type of reaction is called **chain reaction.** It takes very small time and is uncontrolled. It ends in a terrible explosion due to release of enormous amount of energy. The chain reaction is shown in Fig. 3.7.

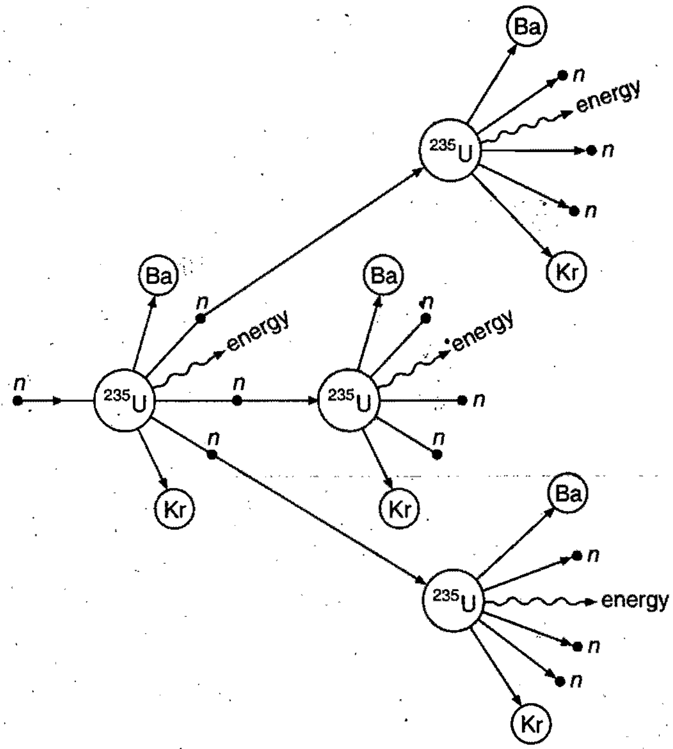


Fig. 3.7 Chain reaction in uranium-235

The chain reaction is self-propagating if the value of multiplication factor is more than 1.

Multiplication factor,

$$K = \frac{\text{No. of neutrons produced in one step}}{\text{No. of neutrons produced in preceding step}}$$

The value of K is 2.5 for ^{235}U and 0.5 for ^{238}U. This shows that if all other factors are ignored, natural uranium which is a mixture of three isotopes ($^{238}U = 99.29\%$, $^{235}U = 0.7\%$, $^{234}U = 0.0006\%$) is not suitable for a chain reaction. The following two factors hinder the self-propagation of a chain reaction:

(i) Leakage of neutrons from the system.

(ii) Presence of non-fissionable material.

If the system is such that loss of neutrons is more than their production, it is a subcritical stage. When the loss of neutrons is equal to their production, it is said to be the critical stage and when loss of neutrons is less than their production, it is the over-critical stage. Over-critical stage is required for self-propagation of chain reaction. The leakage of neutrons from the system can be reduced by suitable choice of size and shape of the fissionable material. The second source of loss of neutrons is due to absorption of neutrons by non-fissionable material. It may be reduced by careful purification of natural uranium, *i. e.*, natural uranium is submitted to the process of enrichment by which the percentage of ^{235}U in the sample is increased. The chain reaction can be carried out under two conditions: (a) uncontrolled (atom bomb) and (b) controlled (nuclear reactors).

Nuclear fuels: Nuclear fuels are of two types:

(i) Fissile materials: These, on bombardment with slow neutrons, directly produce a chain reaction leading to release of energy. Three fissile materials are in use at present. These are ^{235}U, ^{239}Pu and ^{233}U. ^{235}U is obtained from natural sources while ^{239}Pu and ^{233}U are obtained by artificial transmutation.

(ii) Fertile materials: A fertile material is one which by itself is non-fissile in nature, can be converted into a fissile material by reaction with neutrons. ^{238}U and ^{232}Th are fertile materials. ^{238}U is converted into ^{239}Pu by the following nuclear reaction:

$$^{238}_{92}U + ^{1}_{0}n \longrightarrow ^{239}_{92}U^* \xrightarrow[\text{(23 min)}]{-\beta} ^{239}_{93}Np^* \xrightarrow[\text{(2.3 days)}]{-\beta} ^{239}_{94}Pu$$

Similarly ^{232}Th is converted into ^{233}U.

$$^{232}_{90}Th + ^{1}_{0}n \longrightarrow ^{233}_{90}Th^* \xrightarrow[\text{(23 min)}]{-\beta} ^{233}_{91}Pa^* \xrightarrow[\text{(27 days)}]{-\beta} ^{233}_{92}U$$

Applications of nuclear fission: Three practical applications of nuclear fission are:

(a) Atomic bomb, (b) Nuclear reactor and (c) Power plant.

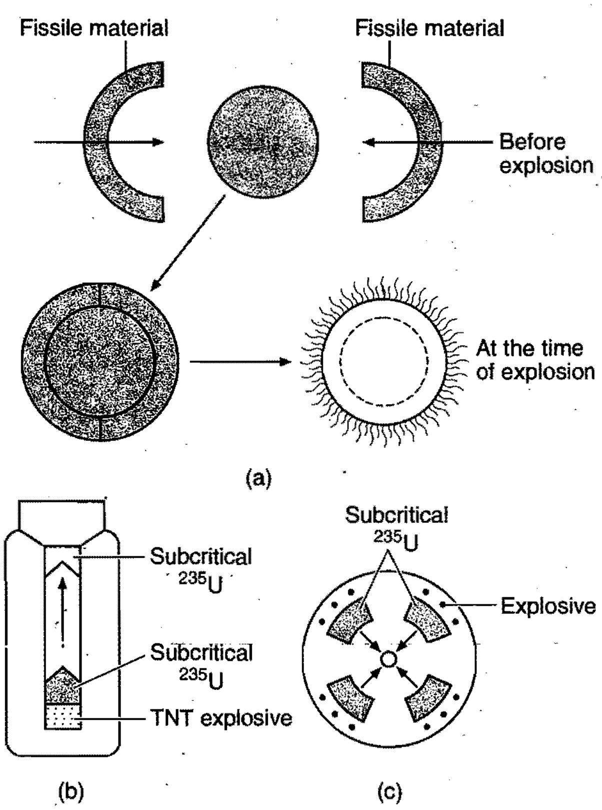


Fig. 3.8 (a), (b) and (c) various designs used in the assembly of atom bomb. (The atom bomb is made in two or more pieces of the fissile material each smaller than the critical size. The moment these pieces are forced together, the bomb explodes with terrific violence).

(a) Atomic bomb: It is based on uncontrolled chain reaction. The shape and size of the fissionable material is so adjusted at the time of explosion that it reaches the over-critical stage. In the atom bomb, a few pounds of fissionable material (^{235}U or ^{239}Pu) is taken in the form of a number of separate pieces; each piece is in subcritical stage (surface area is very large, *i.e.*, loss of neutrons is high.) At the time of explosion, these pieces are driven together rapidly by using explosives like TNT (trinitro toluene) lying behind each of ^{235}U pieces as to make one large piece of fissionable material. At this instant, the over-critical stage is achieved and a fast chain reaction is set- up. This results in a violent explosion with the release of tremendous amount of energy. Fig. 3.8 shows some of the designs of atomic bomb.

On account of explosion, the fragments fly apart with tremendous speeds. These collide with each other and kinetic energy is changed to heat energy. The amount of energy liberated in an atomic explosion is of the order of the detonation of about 20,000 or 30,000 tons of TNT raising the temperature to about 10^7°C. Air expands suddenly and a shock wave of great destructive impulse travels across. The explosion also produces a violent and intense blast of highly penetrating γ-rays which are exceedingly dangerous. The radioactive dust (fallout) scatters over wide areas causing contamination.

The first atomic bomb dropped over Hiroshima city during the second World War in 1945 utilised ^{235}U and the second atomic bomb dropped on Nagasaki made use of ^{239}Pu. India exploded their first atomic bomb at **Pokhran** in **Rajasthan** in May 1974, and used ^{239}Pu as the fissionable material.

Nuclear Power and India (Recent Developments)

Indian scientists recently repeated the history of 11th May 1974. Our great scientists successfully conducted five underground nuclear tests at **Pokhran** range in **Rajasthan,** 24 years after the nation had conducted the first such test. Three tests were conducted at 3.45 p.m. on 11th May 1998 and the two tests were made later on 13th May. These tests were up to the mark and as per our expectations.

(b) Nuclear reactor or atomic reactor or atomic pile: The reactor is the furnace of the atomic age, the place where fissionable material is burnt for useful purposes. **It is essentially an instrument designed to allow a nuclear chain to develop, under control.** All the neutrons produced are not allowed to carry out the chain reaction. A fission reactor has five main components: (i) fuel, (ii) moderator, (iii) control rods, (iv) cooling system and (v) shielding.

(i) Fuel: Either enriched uranium or natural uranium is usually used as fuel. Heterogeneous reactors employ the fuel in the form of rods, plates or hollow cylinders. Homogeneous reactors employ solution of the fuel prepared in the moderator.

(ii) Moderator: The most efficient fission reactions occur with slow neutrons. Thus, the fast neutrons ejected during fission must be slowed down by collisions with atoms of comparable mass that do not absorb them. Such materials are called **moderators.** The most commonly used moderators are ordinary water and graphite. The most efficient moderator is helium. The next most efficient one is heavy water (D_2O) but this is so expensive that it has been used only in research reactors.

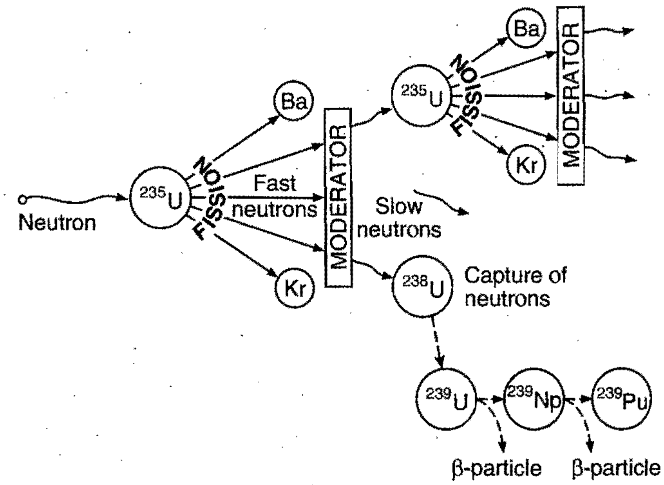


Fig. 3.9 Nuclear fission in a nuclear reactor using enriched uranium

(iii) Control rods: Boron or cadmium steel rods are used as control rods. These rods absorb neutrons and thereby control the rate of fission, *e.g.*,

$$_5B^{10} + {_0n^1} \longrightarrow {_3Li^7} + {_2He^4}$$

(iv) Cooling system: Liquid alloy of sodium and potassium is used as coolant; it takes away the heat to the exchanger. Heavy water, polyphenyls and carbon dioxide have also been used as coolants.

(v) Shielding: The reactor is enclosed in a steel containment vessel, which is housed in a thick-walled concrete building. Operating people are protected by a shield of compressed wood fibres.

Nuclear reactors are used:

1. To produce ^{239}Pu and ^{233}U: It is predicted that our limited supply of ^{235}U will last only another 50 years. However, non-fissionable ^{238}U and ^{232}Th are plentiful and can be converted into ^{239}Pu and ^{233}U. This conversion can be done in special type of reactors called **breeder reactors.** These reactors not only produce large quantities of heat from fission but also generate more fuel than they use because neutrons are absorbed in a thorium or uranium blanket to form ^{233}U and ^{239}Pu. This type of reactor requires the use of fast neutrons; no moderator is needed, but control is more difficult. Heat must be transferred very efficiently because ^{239}Pu melts at a relatively low temperature of 640°C. The process in which non fissile Nuclei $^{238}_{92}U$ and $^{232}_{90}Th$ are converted to fissile nuclei in breeder reactors is given below:

$$^{238}_{92}U + {^1_0n} \longrightarrow {^{239}_{92}U} \xrightarrow{-\beta^-} {^{239}_{93}Np} \xrightarrow{-\beta^-} {^{239}_{94}Pu}$$

$$^{232}_{90}Th + {^1_0n} \longrightarrow {^{232}_{90}Th} \xrightarrow{-\beta^-} {^{233}_{91}Pa} \xrightarrow{-\beta^-} {^{233}_{92}U}$$

2. To produce a strong beam of neutrons: These neutrons are used for making various isotopes which do not occur in nature. For example, ${}^{32}_{15}P$ and ${}^{60}_{27}Co$ are produced from the following nuclear reactions:

$$ {}^{130}_{52}Te + {}^{1}_{0}n \longrightarrow {}^{131}_{53}I + {}^{0}_{-1}e $$

$$ {}^{31}_{15}P + {}^{1}_{0}n \longrightarrow {}^{32}_{15}P $$

$$ {}^{32}_{16}S + {}^{1}_{0}n \longrightarrow {}^{32}_{15}P + {}^{1}_{1}H $$

$$ {}^{59}_{27}Co + {}^{1}_{0}n \longrightarrow {}^{60}_{27}Co $$

The non-radioactive isotope is taken in aluminium capsule which is placed inside the aluminium ball. The ball is rolled into the reactor where it is bombarded by neutrons slowed down by paraffin wax. The bombardment is continued for required period, which varies from element to element.

(c) Power plant (to generate electricity): The heat produced is utilised in generating steam which runs the steam turbines. The electric generator is connected to the turbine. The electric power is obtained from the generator. The atomic reactor when used for production of electricity is termed **power plant.**

The first nuclear reactor was assembled by **Fermi** and his co-workers at the University of Chicago in the United States of America, in 1942. In India, the first nuclear reactor was put into operation at Trombay (Mumbai), in 1956.

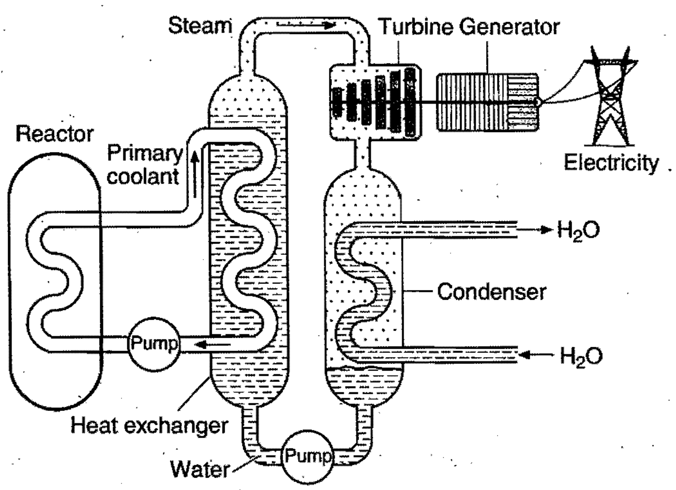


Fig. 3.10 Power plant : Application of nuclear fission for the production of electricity

3.16 NUCLEAR FUSION

A nuclear reaction in which two lighter nuclei are fused together to form a heavier nuclei is called nuclear fusion. In such a process, more stable nuclei come into existence as binding energy per nucleon increases (see sec. 2.23). A fusion reaction is difficult to occur because positively charged nuclei repel each other. At very high temperatures of the order of 10^6 to 10^7 K, the nuclei may have sufficient energy to overcome the repulsive forces and fuse. It is for this reason, fusion reactions are also called **thermonuclear reactions.** Fusion reactions are highly exothermic in nature because loss of mass occurs when heavier nuclei is formed from the two lighter nuclei. To initiate a fusion reaction is difficult, but once it is started, its continuity is maintained due to huge release of energy. Some examples of the fusion reactions are given below:

$$ {}^{2}_{1}H + {}^{2}_{1}H \longrightarrow {}^{4}_{2}He + 24.9\text{ MeV} $$

$$ {}^{3}_{1}H + {}^{3}_{1}H \longrightarrow {}^{4}_{2}He + 2\,{}^{1}_{0}n + 11.0\text{ MeV} $$

$$ {}^{1}_{1}H + {}^{3}_{1}H \longrightarrow {}^{4}_{2}He + 20.0\text{ MeV} $$

$$ {}^{2}_{1}H + {}^{3}_{1}H \longrightarrow {}^{4}_{2}He + {}^{1}_{0}n + 17.8\text{ MeV} $$

$$ {}^{7}_{3}Li + {}^{1}_{1}H \longrightarrow 2\,{}^{4}_{2}He + 17.7\text{ MeV} $$

Hydrogen bomb is based on fusion reactions. Energy released is so enormous that it is about 1000 times that of an atomic bomb. In hydrogen bomb, a mixture of deuterium oxide (D_2O) and tritium oxide (T_2O) is enclosed in a space surrounding an ordinary atomic bomb. The temperature produced by the explosion of the atomic bomb initiates the fusion reaction between ${}^{3}_{1}H$ and ${}^{2}_{1}H$ releasing huge amount of energy. The first hydrogen bomb was exploded in 1952. So far, it has not been possible to bring about fusion under controlled conditions.

It is believed that the high temperature of stars including the sun is due to fusion reactions. **Bethe** and **Weizsaeker,** in 1939, proposed that a carbon-nitrogen cycle is responsible for the production of solar energy in which hydrogen is converted into helium. The cycle is:

$$ {}^{12}_{6}C + {}^{1}_{1}H \longrightarrow {}^{13}_{7}N + \gamma $$

$$ {}^{13}_{7}N \longrightarrow {}^{13}_{6}C + {}^{0}_{+1}e $$

$$ {}^{13}_{6}C + {}^{1}_{1}H \longrightarrow {}^{14}_{7}N + \gamma $$

$$ {}^{14}_{7}N + {}^{1}_{1}H \longrightarrow {}^{15}_{8}O + \gamma $$

$$ {}^{15}_{8}O \longrightarrow {}^{15}_{7}N + {}^{0}_{+1}e $$

$$ {}^{15}_{7}N + {}^{1}_{1}H \longrightarrow {}^{12}_{6}C + {}^{4}_{2}He + \gamma $$

or

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

${}^{12}_{6}C$ acts as a kind of nuclear catalyst.

E. Saltpeter, in 1953, proposed a proton-proton chain reaction:

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

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

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

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

As a potential source of commercial electrical power, the fusion process has several advantages over the fission reaction. (i) The quantity of energy liberated in the fusion is much greater than in fission. (ii) The products of fusion are non-radioactive. Fission produces many unstable radioactive products. Fission reactors, therefore, pose a waste-disposal problem.

Difference between Nuclear Fission and Nuclear Fusion

Nuclear Fission	Nuclear Fusion
(i) This process occurs in heavy nuclei.	This process occurs in lighter nuclei.
(ii) The heavy nucleus splits into lighter nuclei of comparable masses.	The lighter nuclei fuse together to form a heavy nucleus.
(iii) The binding energy per nucleon increases.	The binding energy per nucleon increases.
(iv) This reaction occurs at ordinary temperature.	This occurs at a very high temperature.
(v) The energy liberated in one fission is about 200 MeV.	The energy liberated in one fusion is about 24 MeV.
(vi) This can be controlled.	This cannot be controlled.
(vii) Products of fission are usually unstable radioactive in nature.	Products of fusion are usually stable and non-radioactive in nature.
(viii) Percentage efficiency is less. % efficiency $=\frac{200}{236\times 931}\times 100=0.09$	Percentage efficiency is high. % efficiency $=\frac{17.8}{5\times 931}\times 100=0.38$ $[{}_1^2H+{}_1^3H\rightarrow {}_2^4He+{}_0^1n+17.8\ \text{MeV}]$
(ix) The links of fission reactions are neutrons.	The links of fusion reactions are protons.

3.17 SYNTHETIC ELEMENTS INCLUDING TRANSACTINIDES

Elements 43 (technetium), 61 (promethium), 85 (astatine) and all elements with $Z > 92$ do not exist naturally on the earth, because no isotopes of these elements are stable. The elements coming after uranium ($Z = 92$) are named **transuranic** or **transuranium** elements. The actinide series which starts with the element thorium ($Z = 90$) is complete at the element lawrencium ($Z = 103$). The elements with $Z = 104-112$ have been reported recently and are transition (d-block-fourth series) elements. These are called **transactinides** or **super heavy elements.** After the discovery of nuclear reactions early in the twentieth century, scientists between 1937 and 1945, set out to make the missing elements, *i.e.*, technetium, promethium and astatine and three members of the actinide series, neptunium ($Z = 93$), plutonium ($Z = 94$) and americium ($Z = 95$). The missing elements and all the elements above atomic number 92 are called **synthetic elements** as these have been synthesised by artificial transmutation, *i.e.*, by nuclear reactions. The credit for the discovery of most of the transuranic elements goes to **Seaborg.**

Much less is known about synthetic elements as these are radioactive and short-lived. This is also due to their limited availability. The production of synthetic elements requires binuclear reactions between two positive nuclei that must be fused together against the force of electrical repulsion. Nuclear accelerators were used for this purpose. High energy deuterons were used to increase the atomic number of target nuclei by one unit.

$${}_{42}^{98}Mo+{}_1^2H\longrightarrow {}_{43}^{99}Tc+{}_0^1n$$

$${}_{92}^{238}U+{}_1^2H\longrightarrow {}_{93}^{238}Np+2{}_0^1n$$

Elements 93 and 94 were produced using neutrons (obtained during fission) instead of accelerated positive nuclei. Neutron capture by ${}^{238}U$ followed by β-emission gives isotopes with mass number 239.

$${}_{92}^{238}U+{}_0^1n\longrightarrow {}_{92}^{239}U\xrightarrow{-\beta}{}_{93}^{239}Np\xrightarrow{-\beta}{}_{94}^{239}Pu$$

${}_{94}^{239}Pu$ is an α-emitter with half life of 2.4×10^4 years.

Americium is formed in a similar way.

$${}_{94}^{239}Pu\xrightarrow{(n,\gamma)}{}_{94}^{240}Pu\xrightarrow{(n,\gamma)}{}_{94}^{241}Pu\xrightarrow{-\beta}{}_{95}^{241}Am$$

As Z increases, the efficiency of nuclear reactions with neutron bombardment falls sharply. Instead, nuclides in the $Z = 95$ to 99 range are bombarded with beams of helium nuclei accelerated in the cyclotron to form nuclides with atomic numbers 96 to 101.

$${}_{94}^{239}Pu+{}_2^4He\longrightarrow {}_{96}^{242}Cm+{}_0^1n$$

$${}_{95}^{241}Am+{}_2^4He\longrightarrow {}_{97}^{243}Bk+2{}_0^1n$$

$${}_{96}^{242}Cm+{}_2^4He\longrightarrow {}_{98}^{245}Cf+{}_0^1n$$

$${}_{98}^{249}Cf+{}_2^4He\longrightarrow {}_{100}^{251}Fm+2{}_0^1n$$

$${}_{99}^{253}Es+{}_2^4He\longrightarrow {}_{101}^{256}Md+{}_0^1n$$

Beyond element with $Z = 101$, increasingly heavier nuclei are used as projectiles. These projectiles are accelerated by linear rather than circular accelerators. Examples of nuclear reactions of this type are the following:

$${}_{96}^{246}Cm+{}_6^{12}C\longrightarrow {}_{102}^{254}No+4{}_0^1n$$

$${}_{98}^{252}Cf+{}_5^{11}B\longrightarrow {}_{103}^{257}Lr+6{}_0^1n$$

$${}_{92}^{238}U+{}_7^{14}N\longrightarrow {}_{99}^{249}Es+3{}_0^1n$$

$${}_{92}^{238}U+{}_8^{16}O\longrightarrow {}_{100}^{250}Fm+4{}_0^1n$$

The superheavy elements have been discovered by bombardment with medium weight nuclei. For example, the elements with $Z = 107$ and $Z = 109$ have been obtained by bombardment of ${}_{83}^{209}Bi$ with accelerated ${}_{24}^{54}Cr$ and ${}_{26}^{58}Fe$ respectively.

$${}_{83}^{209}Bi+{}_{24}^{54}Cr\longrightarrow {}_{107}^{261}Uns+2{}_0^1n$$

$${}_{83}^{209}Bi+{}_{26}^{58}Fe\longrightarrow {}_{109}^{266}Une+{}_0^1n$$

The elements with $Z = 104$, 105, 106 and 108 have also been reported by the applications of the following reactions:

$${}_{98}^{249}Cf+{}_6^{12}C\longrightarrow {}_{104}^{257}Unq+4{}_0^1n$$

$${}_{98}^{249}Cf+{}_7^{15}N\longrightarrow {}_{105}^{260}Unp+4{}_0^1n$$

$$^{249}_{98}Cf + ^{18}_{8}O \longrightarrow ^{263}_{106}Unh + 4^{1}_{0}n$$

$$^{208}_{82}Pb + ^{58}_{26}Fe \longrightarrow ^{265}_{108}Uno + ^{1}_{0}n$$

The elements up to 100 (fermium) undergo radioactive decay mainly by emitting α-particles or β-particles. The elements become increasingly unstable as the atomic number increases and nobelium has a half life of only three seconds. With these heavy elements, spontaneous nuclear fission becomes the most important method of decay. ^{252}Cf could become a valuable neutron source.

The IUPAC names for the elements $Z > 100$ have been given below:

101 Unnilunium	Unu	107 Unnilseptium	Uns
102 Unnilbium	Unb	108 Unniloctium	Uno
103 Unniltrium	Unt	109 Unnilennium	Une
104 Unnilquadium	Unq	110 Ununnilium	Uun
105 Unnilpentium	Unp	111 Unununium	Uuu
106 Unnilhexium	Unh	112 Ununbium	Uub

Elements with an even number of protons in the nucleus are usually more stable than their neighbours with odd atomic numbers, *i.e.*, they are less likely to decay. Also nuclei with both an even number of protons and an even number of neutrons are more likely to be stable. A nucleus is more stable than average if the numbers of neutrons or protons are 2, 8, 20, 28, 50, 82 or 126. These are called 'magic numbers' and can be explained by the shell structure of the nucleus. This theory also requires the inclusion of numbers 114, 164 and 184 in the series of magic numbers. The stability is particularly high if number of protons and the number of neutrons are magic numbers. Thus, $^{208}_{82}Pb$ is very stable with 82 protons and (208 – 82) 126 neutrons. This suggests that nuclides as Uuq ($Z = 114$, $A = 278$), Uuq ($Z = 114$, $A = 298$) and Ubh ($Z = 126$, $A = 310$) might be stable enough to exist. Considerable efforts are being made to produce elements 114 and 126 but the present techniques have so far only succeeded in producing unstable isotopes. The elements up to $Z = 112$ have been reported so far.

ILLUSTRATIONS OF OBJECTIVE QUESTIONS

19. The radioactive isotope $^{60}_{27}Co$ which is used in the treatment of cancer can be made by (n, p) reaction. For this reaction, the target nucleus is:
(a) $^{59}_{28}Ni$ (b) $^{59}_{27}Co$ (c) $^{60}_{28}Ni$ (d) $^{60}_{27}Co$
[Manipal (Med.) 2007]

[**Ans.** (c)]

[**Hint:** $^{60}_{28}Ni + ^{1}_{0}n \longrightarrow ^{60}_{27}Co + ^{1}_{1}H$]

20. $^{14}_{7}N$ is attacked by doubly charged helium ion, it emits a proton and:
(a) $^{18}_{9}F$ (b) $^{17}_{8}O$ (c) $^{18}_{8}O$ (d) $^{19}_{9}F$
[JEE (Orissa) 2007]

[**Ans.** (b)]

[**Hint:** $^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ^{1}_{1}H$]

21. A nuclear reaction of $^{235}_{92}U$ with a neutron produces $^{90}_{36}Kr$ and two neutrons. Other element produced in this reaction is:
(a) $^{137}_{52}Te$ (b) $^{144}_{55}Cs$ (c) $^{137}_{56}Ba$ (d) $^{144}_{56}Ba$
(VITEEE 2007)

[**Ans.** (d)]

[**Hint:** $^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{90}_{36}Kr + ^{144}_{56}Ba + 2\,^{1}_{0}n$]

22. The product P of the nuclear reaction $^{235}_{92}U + ^{1}_{0}n \longrightarrow P + ^{92}_{36}Kr + 3(^{1}_{0}n)$ is :
(a) $^{141}_{56}Sr$ (b) $^{141}_{56}La$ (c) $^{141}_{56}Ba$ (d) $^{141}_{56}Cs$
[JEE (WB) 2008]

[**Ans.** (c)]
[**Hint:** Let symbol of element is $^{M}_{Z}P$.
$92 = Z + 36$
$\therefore \quad Z = 56$
$235 + 1 = M + 92 + 3$
$M = 141$
Thus, the element P will be $^{141}_{56}Ba$]

3.18 APPLICATIONS OF RADIOACTIVITY

(a) Use of γ-rays: γ-rays are used for disinfecting food grains and for preserving foodstuffs. Onions, potatoes, fruits and fish, etc., when irradiated with γ-rays, can be preserved for long periods. High yielding disease resistant varieties of wheat, rice, groundnut, jute, etc., can be developed by the application of nuclear radiations. The γ-radiations are used in the treatment of cancer. The γ-radiations emitted by cobalt-60 can burn cancerous cells. γ-radiations are used to sterilize medical instruments like syringes, blood transfusion sets, etc. These radiations make the rubber and plastics objects heat resistant.

(b) The age of the earth: The age of the earth has been estimated by uranium dating technique. The uranium ore (rock) which is found in nature is associated with non-radioactive lead which is believed to be the end product of radioactive disintegration of uranium. A sample of uranium rock is analysed for ^{238}U and ^{206}Pb contents. From this analysis, let the quantities in mole be $N = {}^{238}U$ mole, $N_0 = {}^{238}U$ mole $+ {}^{206}Pb$ mole.

Applying disintegration equation,

$$\lambda t = 2.303 \log_{10} \frac{N_0}{N}$$
$$= 2.303 \log_{10} \frac{^{238}U + ^{206}Pb}{^{238}U}$$
$$= 2.303 \log_{10} \left[1 + \frac{^{206}Pb}{^{238}U}\right]$$

The value of 't' can be calculated by putting the value of λ which is equal to $\frac{0.693}{t_{1/2}}$.

So,
$$t = \frac{2.303 \times t_{1/2}}{0.693} \log_{10} \left[1 + \frac{^{206}Pb}{^{238}U}\right]$$

Here 't' corresponds to the age of earth which has been found to be 4.5 billion years.

Example 27. *A sample of uranium mineral was found to contain ^{206}Pb and ^{238}U in the ratio of 0.008 : 1. Estimate the age of the mineral. (Half life of ^{238}U is 4.51×10^9 years)*

Solution: We know that, $t = \frac{2.303 t_{1/2}}{0.693} \log \left[1 + \frac{^{206}Pb}{^{238}U}\right]$

Given, $t_{1/2} = 4.51 \times 10^9$ years

Ratio by mass of $^{206}Pb : {^{238}U} = 0.008 : 1$

Ratio by moles of $^{206}Pb : {^{238}U} = \frac{0.008}{206} : \frac{1}{238} = 0.0092$

So, $t = \frac{2.303 \times 4.51 \times 10^9}{0.693} \log [1 + 0.0092]$

$= \frac{2.303 \times 4.51 \times 10^9}{0.693} \times 0.00397$

$= \frac{0.0412}{0.693} \times 10^9 = 0.05945 \times 10^9$ years

Hence, age of the mineral is 5.945×10^7 years.

(c) Radio carbon dating: By using the half life period of ^{14}C, it is possible to determine the age of various objects. In living material the ratio of ^{14}C to ^{12}C remains relatively constant. When a tissue in an animal or plant dies, ^{14}C decreases because the intake and utilization of ^{14}C do not occur. Therefore, in the dead tissue the ratio of ^{14}C to ^{12}C would decrease, depending on the age of the tissue. The age of the dead tissue is determined in the following way. A sample of dead tissue is burnt to carbon dioxide and the carbon dioxide is analysed for the ratio of ^{14}C to ^{12}C. From this data, the age of the dead tissue can be determined. Thus:

$$\lambda = \frac{2.303}{t} \log_{10} \left(\frac{N_0}{N}\right)$$

$$\frac{0.693}{t_{1/2} \text{ of } C^{14}} = \frac{2.303}{t} \log_{10} \left(\frac{N_0}{N}\right)$$

N_0 = Ratio of C^{14} / C^{12} in green plant or atmosphere

N = Ratio of C^{14} / C^{12} in wood

or

N_0 = Activity of green plant per unit mass

N = Activity of wood per unit mass

Although, the method is suitable to a variety of organic materials, accuracy depends on the half life to be used, variations in levels of atmospheric carbon-14 and contamination. (The half life radio carbon was redefined from 5570 ± 30 years to 5730 ± 40 years by IUPAC). The rapid disintegration of carbon-14 generally limits the dating period to approximately 50,000 years.

Example 28. *The amount of $^{14}_{6}C$ isotope in a piece of wood is found to be one-fifth of that present in a fresh piece of wood. Calculate the age of wood. (Half life of ^{14}C = 5577 years)*

Solution: We know that, $t = \frac{2.303 \times t_{1/2}}{0.693} \log \left(\frac{N_0}{N}\right)$

Given, $N = \frac{N_0}{5}$

So, $t = \frac{2.303 \times 5577}{0.693} \log 5$

or $t = \frac{2.303 \times 5577}{0.693} \times 0.6989 = 12953$ years

Example 29. *A piece of wood was found to have $^{14}C/^{12}C$ ratio 0.6 times that in a living plant. Calculate the period when the plant died. (Half life of ^{14}C = 5760 years)*

Solution: We know that, $t = \frac{2.303 \times t_{1/2}}{0.693} \log \left(\frac{N_0}{N}\right)$

So, $t = \frac{2.303 \times 5760}{0.693} \log \left(\frac{1}{0.6}\right)$

$= \frac{2.303 \times 5760}{0.693} \times 0.2201$

$= 4213$ years

(d) Potassium-Argon method: The decay of radioactive potassium isotope to argon is widely used for dating rocks. The geologists are able to date entire rock samples in this way, because potassium-40 is abundant in micas, feldspars and hornblendes. Leakage of Argon is however problem if the rock has been exposed to temperature above 125° C.

(e) Rubidium-Strontium method: This method of dating is used to date ancient igneous and metamorphic terrestrial rocks as well as lunar samples. It is based on disintegration by beta decay of ^{87}Rb to ^{87}Sr. This method is frequently used to check potassium-argon dates, because the strontium daughter element is not diffused by mild heating like argon.

ILLUSTRATIONS OF OBJECTIVE QUESTIONS

23. A wooden artifact sample gave activity of 32 β-particles per second while the freshly cut wood gave activity of 64 β-particles per second in G. M. counter. Calculate the age of the wooden artifact ($t_{1/2}$ of ^{14}C = 5760 yrs):

(a) 11520 yrs (b) 5760 yrs
(c) 2880 yrs (d) 1440 yrs

[Ans. (b)]

[Hint: $\frac{0.693}{t_{1/2}} = \frac{2.303}{t_{age}} \log_{10} \left(\frac{N_0}{N}\right)$

$\frac{0.693}{5760} = \frac{2.303}{t_{age}} \log_{10} \left(\frac{64}{32}\right)$

$t_{age} = 5760$ yrs]

24. The analysis of a rock shows that the relative number of ^{206}Pb and ^{238}U atoms is Pb/U = 0.25. If $t_{1/2}$ of ^{238}U is 4.5×10^9 yrs, then the age of the rock will be:

(a) $\frac{2.303}{0.693} (4.5 \times 10^9) \log \left(\frac{5}{4}\right)$

(b) $\frac{2.303}{0.693}(4.5\times10^9)\log\left(\frac{1}{4}\right)$

(c) $\frac{2.303}{0.693}(4.5\times10^9)\log(4)$

(d) $\frac{2.303}{0.693}(4.5\times10^9)\log\left(\frac{4}{5}\right)$

[Ans. (a)]

[Hint: $\frac{\text{Pb}}{\text{U}}=0.25;\quad\therefore\ 1+\frac{\text{Pb}}{\text{U}}=1.25$

$$\frac{\text{U}+\text{Pb}}{\text{U}}=1.25$$

$$\frac{N_0}{N}=1.25=\frac{5}{4}$$

$$\frac{0.693}{t_{1/2}}=\frac{2.303}{t}\log\left(\frac{N_0}{N}\right)$$

$$\frac{0.693}{4.5\times10^9}=\frac{2.303}{t_{\text{age}}}\log\left(\frac{5}{4}\right)$$

$$t_{\text{age}}=\frac{2.303}{0.693}(4.5\times10^9)\log\left(\frac{5}{4}\right)]$$

25. Assuming that about 200 MeV of energy is released per fission of $^{235}_{92}$U nuclei, then the mass of ^{235}U consumed per day in a fission reactor of power 1 megawatt will be approximately:

(a) 10^{-2} g (b) 1 g (c) 100 g (d) 1000 g

[Ans. (b)]

[Hint: 1 MW $=10^6\times24\times60\times60$ J

$$\text{Number of fissions}=\frac{24\times6\times6\times10^8}{200\times10^6\times1.6\times10^{-19}}=2.7\times10^{21}$$

$$\text{Mass of uranium}=2.7\times10^{21}\times235\times1.66\times10^{-24}=1.05\text{ g}]$$

26. What is the binding energy of the hydrogen nucleus?

(a) Zero (b) 13.6 eV

(c) More than 13.6 eV (d) Infinite

[Ans. (a)]

[Hint: Nucleus of hydrogen has only one proton; hence its binding energy will be zero.]

27. Which of the following is not the inverse square law force?

(a) Electric force (b) Gravitational force

(c) Nuclear force

(d) Magnetic force between two poles

[Ans. (c)]

[Hint: Nuclear forces are short range forces which do not obey inverse square law.]

28. Lead is the final product formed by a series of changes in which the rate determining stage is the radioactive decay of uranium-238. This radioactive decay is first order with half life of 4.5×10^9 years. What would be the age of a rock sample originally leadfree, in which the molar proportion of uranium to lead is now 1 : 3? [PET (Kerala) 2006]

(a) 1.5×10^9 years (b) 2.25×10^9 years

(c) 4.5×10^9 years (d) 9×10^9 years

(e) 13.5×10^9 years

[Ans. (d)]

[Hint: $\frac{0.693}{t_{1/2}\text{U}^{238}}=\frac{2.303}{t_{\text{age}}}\log\left(\frac{N_0}{N}\right)$

$$\frac{0.693}{4.5\times10^9}=\frac{2.303}{t_{\text{age}}}\log_{10}\left(\frac{4}{1}\right)$$

$$t_{\text{age}}=9\times10^9\text{ years}]$$

(f) Use of radioisotopes (tracers): Tracers have been used in the following fields:

(i) **In medicine:** Radioisotopes are used to diagnose many diseases. For example, arsenic-74 tracer is used to detect the presence of tumours; sodium-24 tracer is used to detect the presence of blood clots and iodine-131 tracer is used to study the activity of the thyroid gland. It should be noted that the radioactive isotopes used in medicine have very short half life periods.

^{90}Y: This isotope is used in the treatment of joint effusion and arthritis.

^{59}Fe: Used in the detection of anaemia.

^{32}P: This isotope is used in the treatment of polycythaemia, thrombocythaemia, skeletal metastasis, prostate SR and breast SR.

Nuclear Medicine Scan: It is an advanced nuclear technology used in diagnosis of diseases. **Magnetic Resonance Imaging** (MRI), a diagnostic medical imaging technique utilizes the principle of nuclear magnetic resonance. The first images using magnetic resonance were published in early 1970s, and medical applications have accelerated in the world during the decade of 1983 to 1993. MRI is now a most versatile, powerful and sensitive diagnostic imaging modality available. Its medical importance can be summarised briefly as having the ability to non-invasively generate thin section, functional images of any part of the body at any angle and direction in a relatively short period of time. MRI also visualizes the heart with exquisite anatomical detail at any angle and direction.

The principle of MRI is applicable in human body because we are all filled with small biological magnets, the most abundant and responsive of which is the nucleus of hydrogen atom, the proton.

Computerized Axial Tomography: Computerized Axial Tomography (CT or CAT), non-invasive diagnostic technique uses a type of X-ray device that provides a clear view of soft internal organ tissues in the body. CT is used to diagnose various conditions, in particular cancer. A CT scan is the computer analysis of a sharply limited, thin X-ray beam passed circumferentially through an area of the body, producing a cross-sectional image, or slice.

The modern CT scanner comprises five major parts. A high-speed X-ray tube cooled by oil, air and water forms the X-ray source. Its X-ray detector, normally a bank of about 1,000 solid state-crystal microprocessors coated with caesium iodide, receives the attenuated X-ray signal as it passes through the various tissues and bones of the patient being examined. The signal is electronically converted to binary data, which is read by the computer—the heart of the CT imaging system. The CT has a gantry, a framework that is mounted in such a way that it surrounds the patient in a vertical plane, and contains a rotating sub-frame onto which the X-ray source and detectors are mounted. A patient table (or couch) is positioned perpendicular and axial to the gantry so that it is able to travel along that axis.

Topographic images are produced by using an X-ray source and a detector moving in a coupled way relative to the patient. In CT a thin fan beam of radiation rotates in a circular or spiral motion around the patient. Thousands of projected X-ray signals are reconstructed by computer algorithms to produce digital CT images, displayed by a high-resolution monitor. In this way the whole body can be imaged from head to toe.

Radiation Dosage in the Radiotherapy of Cancer

Radiations and the particles emitted by radioactive nuclei are harmful for living organisms. These radiations cause genetic disorders by affecting DNA.

Effect of biological radiations can be measured in terms of the unit called RAD.

RAD = Radiation absorbed dose

1 RAD = The radiation which deposits 1×10^{-2} J of energy per kilogram of tissue.

In order to measure biological destruction by radiation, an other unit REM was introduced.

$$\text{REM} = \text{RAD} \times \text{RBE}$$

RBE = Relative biological effectiveness

RBE for α-particle = 10 unit

RBE for β and γ radiation = 1 unit

RBE for neutron = 5 unit

(ii) In agriculture: The use of radioactive phosphorus ^{32}P in fertilizers has revealed how phosphorus is absorbed by plants. This study has led to an improvement in the preparation of fertilizers. ^{14}C is used to study the kinetics of photosynthesis.

(iii) In industry: Radioisotopes are used in industry to detect the leakage in underground oil pipelines, gas pipelines and water pipes. Radioactive isotopes are used to measure the thickness of materials, to test the wear and tear inside a car engine and the effectiveness of various lubricants. Radioactive carbon has been used as a tracer in studying mechanisms involved in many reactions of industrial importance such as alkylation, polymerisation, catalytic synthesis, etc.

(iv) Analytical studies: Several analytical procedures can be used employing radioisotopes as tracers.

1. Adsorption and occlusion studies: A small amount of radioactive isotope is mixed with an inactive substance and the activity is studied before and after adsorption. Fall in activity gives the amount of substance adsorbed.

2. Solubility of sparingly soluble salts: The solubility of lead sulphate in water may be estimated by mixing a known amount of radioactive lead with ordinary lead. This is dissolved in nitric acid and precipitated as lead sulphate by adding sulphuric acid. Insoluble lead sulphate is filtered and the activity of the water is measured. From this, the amount of $PbSO_4$ still present in water can be estimated.

3. Ion-exchange technique: Ion exchange process of separation is readily followed by measuring activity of successive fractions eluted from the column.

4. Reaction mechanism: By labelling oxygen of the water, mechanism of ester hydrolysis has been studied.

$$R-\overset{\overset{\displaystyle O}{\|}}{C}-OR' + H\overset{*}{O}H \longrightarrow R-\overset{\overset{\displaystyle O}{\|}}{C}-\overset{*}{O}H + R'OH$$

5. Study of efficiency of analytical separations: The efficiency of analytical procedures may be measured by adding a known amount of radioisotope to the sample before analysis begins. After the completion, the activity is again determined. The comparison of activity tells about the efficiency of separation.

MISCELLANEOUS NUMERICAL EXAMPLES

Example 1. *One mole of A present in a closed vessel undergoes decay as:*

$$^{m}_{Z}A \longrightarrow {}^{m-8}_{Z-4}B + 2({}^{4}_{2}He)$$

What will be the volume of helium gas collected at STP after 20 *days* ($t_{1/2}$ *of* $A = 10$ *days*)?

Solution: We know that,

$$N = N_0\left(\frac{1}{2}\right)^n \text{ where, } N = \text{remaining mole of } A$$

$$N = 1\left(\frac{1}{2}\right)^2 = \frac{1}{4}$$

Number of decayed moles $= 1 - \frac{1}{4} = \frac{3}{4}$

Number of moles of helium formed

$$= 2 \times \text{number of decayed moles of } A = 2 \times \frac{3}{4} = \frac{3}{2}$$

Volume of helium at STP $= \frac{3}{2} \times 22.4 = 33.6$ litre

Example 2. ^{131}I *has half life period* 13.3 *hour. After* 79.8 *hour, what fraction of* ^{131}I *will remain?* [CBSE (PMT) 2005]

Solution: $N = N_0\left(\frac{1}{2}\right)^n$

$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^6 = \frac{1}{64}$$

Example 3. *A sample of* $^{14}CO_2$ *was to be mixed with ordinary* CO_2 *for a biological tracer experiment. In order that* 10^3 cm^3 *of the diluted gas at NTP should have* 10^4 *dis/min, how many* μCi *of radiocarbon-*14 *are needed to prepare* 60 *L of the diluted gas?*

Solution: 10 cm^3 of the diluted gas at NTP

$$= 10^4 \text{ dis/min} = \frac{10^4}{60} \text{ dps}$$

$\therefore$ 60 L (60,000 cm^3) of the dilute gas at NTP

$$= \frac{10^4 \times 60{,}000}{60 \times 10} \text{ dps}$$

Thus, no. of μCi of $^{14}CO_2$ needed

$$= \frac{10^4 \times 60{,}000}{60 \times 10 \times 3.7 \times 10^4} \quad (1\,\mu\text{Ci} = 3.7 \times 10^4 \text{ dps})$$

$$= 27.03\,\mu\text{Ci}$$

Example 4. *A radioactive nuclide is produced at a constant rate of 'α' per second. Its decay constant is λ. If N_0 be the number of nuclei at time $t = 0$, then what will be the maximum number of possible nuclei?*

(a) $\frac{\alpha}{\lambda}$ (b) $N_0 + \frac{\alpha}{\lambda}$ (c) N_0 (d) $\frac{\lambda}{\alpha} + N_0$

Solution: Maximum number of nuclei will be present when

Rate of decay = Rate of formation

$$\lambda N = \alpha$$

or

$$N = \frac{\alpha}{\lambda}$$

Example 5. *The half life of ^{212}Pb is 10.6 hour. It undergoes decay to its daughter (unstable) element ^{212}Bi of half life 60.5 minute. Calculate the time at which the daughter element will have maximum activity.*

Solution: $\lambda_{Pb} = \frac{0.693}{10.6 \times 60} = 1.0896 \times 10^{-3} \text{ min}^{-1}$

$$\lambda_{Bi} = \frac{0.693}{60.5} = 11.45 \times 10^{-3} \text{ min}^{-1}$$

$$t_{max} = \frac{2.303}{\lambda_{Bi} - \lambda_{Pb}} - \log \frac{\lambda_{Bi}}{\lambda_{Pb}}$$

$$= \frac{2.303}{(11.45 \times 10^{-3} - 1.0896 \times 10^{-3})} \times \log \frac{11.45 \times 10^{-3}}{1.0896 \times 10^{-3}}$$

$$= 227.1 \text{ min}$$

Example 6. *A radioactive isotope is being produced at a constant rate x. Half life of the radioactive substance is 'y'. After sometime, the number of radioactive nuclei becomes constant, the value of this constant is ......*

Solution: At the stage of radioactive equilibrium,

Rate of formation of nuclide = Rate of decay of nuclide

$$x = \lambda N$$

$$N = \frac{x}{\lambda} = \frac{x}{(\ln 2)/y} = \frac{xy}{\ln 2}$$

Example 7. *$^{238}_{92}U$ by successive radioactive decay changes to $^{206}_{82}Pb$. A sample of uranium ore was analysed and found to contain 1.0 g of ^{238}U and 0.1 g of ^{206}Pb. Assuming that all ^{206}Pb has accumulated due to decay of ^{238}U, find the age of the ore (half life of $^{238}U = 4.5 \times 10^9$ yrs).*

Solution: Number of moles of $^{238}U = \frac{1}{238}$

Number of moles of $^{206}Pb = \frac{0.1}{206}$

Applying the relationship,

$$t = \frac{2.303}{\lambda} \log \left[1 + \frac{^{206}Pb}{^{238}U}\right]$$

$$= \frac{2.303}{0.693} \times 4.5 \times 10^9 \log \left[1 + \frac{\frac{0.1}{206}}{\frac{1}{238}}\right]$$

$$= 7.098 \times 10^8 \text{ years}$$

Example 8. *Calculate the mass of C^{14} (half life = 5720 years) atoms which give 3.7×10^7 disintegrations per second.*

Solution: Let the mass of ^{14}C atoms be m g.

Number of atoms in m g of $^{14}C = \frac{m}{14} \times 6.02 \times 10^{23}$

$$\lambda = \frac{0.693}{\text{half life}} = \frac{0.693}{5720 \times 365 \times 24 \times 60 \times 60} = 3.84 \times 10^{-12} \text{ sec}^{-1}$$

We know that, $-\frac{dN}{dt} = \lambda \cdot N$

i.e., Rate of disintegration = λ × no. of atoms

$$3.7 \times 10^7 = \frac{0.693}{5720 \times 365 \times 24 \times 60 \times 60} \times \frac{m}{14} \times 6.02 \times 10^{23}$$

$$= \frac{3.84 \times 10^{-12} \times m \times 6.02 \times 10^{23}}{14}$$

So, $m = 2.24 \times 10^{-4}$ g

Example 9. *Prove that time required for 99.9% decay of a radioactive species is almost ten times its half life period.*

Solution: We know that, $t = \frac{2.303}{\lambda} \log \frac{N_0}{N}$

$$N_0 = 100, \quad N = (100 - 99.9) = 0.1$$

So, Time required for 99.9% decay, $t = \frac{2.303}{\lambda} \log \frac{100}{0.1}$

$$= \frac{2.303}{\lambda} \times 3$$

$$\text{Half life period} = \frac{0.693}{\lambda}$$

So, $\frac{\text{Time required for 99.9\% decay}}{\text{Half life period}} = \frac{2.303 \times 3}{\lambda} \times \frac{\lambda}{0.693}$

$$\approx 10$$

Example 10. *Half life of a radioactive substance A is two times the half life of another radioactive substance B. Initially the number of nuclei of A and B are N_A and N_B respectively. After three half lives of 'A', number of nuclei of both become equal. The ratio of $\frac{N_A}{N_B}$ will be:*

(a) $\frac{1}{2}$ (b) $\frac{1}{8}$ (c) $\frac{1}{3}$ (d) $\frac{1}{6}$

Solution: We know that, the amount remaining after n half lives can be calculated as:

$$N = N_0\left(\frac{1}{2}\right)^n$$

Remaining amount of $A = N_A\left(\frac{1}{2}\right)^3$

Remaining amount of $B = N_B\left(\frac{1}{2}\right)^6$

$$N_A\left(\frac{1}{2}\right)^3 = N_B\left(\frac{1}{2}\right)^6$$

$$\frac{N_A}{N_B} = \frac{8}{64} = \frac{1}{8}$$

Example 11. *1.0 g of $^{198}_{79}Au$ ($t_{1/2} = 65$ hours) decays by β-emission to produce mercury.*

(a) *Write the nuclear reaction for the process.*

(b) *How much mercury will be present after 260 hours?*

Solution: (a) $^{198}_{79}\text{Au} \longrightarrow {}^{198}_{80}\text{Hg} + {}^{0}_{-1}e$

(b) No. of half lives in 260 hours $= \frac{260}{65} = 4$

Amount of gold left after 4 half lives $= \left(\frac{1}{2}\right)^4 = \frac{1}{16}$ g

Amount of gold disintegrated $= 1 - \frac{1}{16} = \frac{15}{16}$ g

Amount of mercury formed $= \frac{15}{16} = 0.9375$ g

Example 12. *Calculate the probability (P) of survival of a radioactive nucleus for one mean life.*

Solution: Probability for survival $= \frac{N}{N_0} = e^{-\lambda t}$

$$t = \text{mean life} = \frac{1}{\lambda}$$

$\therefore$ Probability $= e^{-\lambda \times 1/\lambda} = \frac{1}{e}$

Example 13. *1 milligram radium has 2.68×10^{18} atoms. Its half life period is 1620 years. How many radium atoms will disintegrate from 1 milligram of pure radium in 3240 years?*

Solution: No. of half lives in 3240 years $= \frac{3240}{1620} = 2$

Amount of radium left after two half lives $= 1 \times \left(\frac{1}{2}\right)^2$

$= 0.25$ mg

Amount of radium disintegrated $= (1 - 0.25) = 0.75$ mg

No. of atoms which have disintegrated $= 0.75 \times 2.68 \times 10^{18}$

$= 2.01 \times 10^{18}$

Example 14. *A certain radioisotope ^A_ZX (Half life = 10 days) decays to $^{A-4}_{Z-2}Y$. If 1 g atom of ^A_ZX is kept in sealed vessel, how much helium will accumulate in 20 days?*

Solution: $^A_ZX \longrightarrow {}^{A-4}_{Z-2}Y + {}^4_2\text{He}$

In two half lives, $\frac{3}{4}$ of the isotope ^A_ZX has disintegrated, *i.e.*, $\frac{3}{4}$ g atom of helium has been formed from $\frac{3}{4}$ g atom of ^A_ZX.

Volume of 1 g atom of helium = 22400 mL

So, Volume of $\frac{3}{4}$ g atom of helium $= \frac{3}{4} \times 22400$ mL

= 16800 mL

Example 15. *Binding energy per nucleon of ^2_1H and ^4_2He are 1.1 MeV and 7 MeV respectively. Calculate the amount of energy released in the following process:*

$$^2_1H + {}^2_1H \longrightarrow {}^4_2He$$

Solution: Amount of energy released

= Σ Binding energy of products

− Σ Binding energy of reactants

= [4 × 7] − [4 × 1.1]

= 23.6 MeV

Example 16. *Calculate the energy associated with the following nuclear reaction:*

$$\underset{26.9815\,amu}{^{27}_{13}Al} + \underset{2.0141\,amu}{^2_1H} \longrightarrow \underset{24.9858\,amu}{^{25}_{12}Mg} + \underset{4.0026\,amu}{^4_2He}$$

Solution: Mass defect = (26.9815 + 2.0141) − (24.9858 + 4.0026)

= 0.0072 amu

Energy of the reaction = 0.0072 × 931 MeV

= 6.70 MeV

Example 17. *A radioactive isotope $_ZA^m$ ($t_{1/2} = 10$ days) decays to give $_{Z-6}B^{m-12}$ stable atom alongwith α-particles. If m g of 'A' are taken and kept in a sealed tube, how much 'He' will accumulate in 20 days at STP?*

Solution: $_ZA^m \longrightarrow {}_{Z-6}B^{m-12} + 3[{}_2\text{He}^4]$

Mole of $A = \frac{m}{m} = 1$

Number of half lives = 20 / 10 = 2

$$N = N_0\left(\frac{1}{2}\right)^n$$

$$= 1\left(\frac{1}{2}\right)^2 = \frac{1}{4}$$

Decayed moles $= 1 - 1/4 = 3/4$

Moles of 'He' formed $= 3 \times 3/4 = 9/4$

Volume of 'He' at STP $= 22.4 \times \frac{9}{4}$

$= 50.4$ litre

Example 18. *A sample of pitchblende is found to contain 50% uranium and 2.425% of lead. Of this lead only 93% was Pb^{206} isotope. If the disintegration constant is $1.52 \times 10^{-10}\ yr^{-1}$, how old could be the pitchblende deposits?*

Solution: Moles of $U^{238} = \frac{50}{100 \times 238} = 2.1 \times 10^{-3}$

Moles of $Pb^{206} = \frac{2.425}{100} \times \frac{93}{100 \times 206} = 0.109 \times 10^{-3}$

$N_0 = (x + y) = 2.1 \times 10^{-3} + 0.109 \times 10^{-3} = 2.209 \times 10^{-3}$

$N = x = 2.1 \times 10^{-3}$

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

$$1.52 \times 10^{-10} = \frac{2.303}{t} \log \frac{2.209 \times 10^{-3}}{2.1 \times 10^{-3}}$$

$$t = 3.3 \times 10^8 \text{ years}$$

Example 19. *On analysis, a sample of uranium ore was found to contain 0.277 g of $_{82}Pb^{206}$ and 1.667 g of $_{92}U^{238}$. The half life period of U^{238} is 4.51×10^9 yrs. If all the lead were assumed to have come from decay of $_{92}U^{238}$, what is the age of the earth?*

Solution: Moles of $U^{238} = \frac{1.667}{238}$

Moles of $Pb^{206} = \frac{0.277}{206}$

$$N_0 = \frac{1.667}{238} + \frac{0.277}{206}$$

and $$N = \frac{1.667}{238}$$

$$t = \frac{2.303}{\lambda} \log \frac{N_0}{N}$$

$$= \frac{2.303 \times 4.51 \times 10^9}{0.693} \log_{10} \frac{\frac{1.667}{238} + \frac{0.277}{206}}{\frac{1.667}{238}}$$

$= 1.143 \times 10^9$ years

Example 20. *$_{19}K^{40}$ consists of 0.012% potassium in nature. The human body contains 0.35% potassium by weight. Calculate the total radioactivity resulting from $_{19}K^{40}$ decay in a 75 kg human body. Half life of $_{19}K^{40}$ is 1.3×10^9 years.*

Solution:

Weight of radioactive potassium $= \frac{75000 \times 0.012}{100} \times \frac{0.35}{100}$

$= 0.0315$ g

$$\text{Activity} = \frac{0.693}{t_{1/2}} \times \frac{\text{Weight}}{\text{Atomic weight}} \times \text{Avogadro's number}$$

$$\text{Activity} = \frac{0.693}{1.3 \times 10^9 \times 365 \times 24 \times 60} \times \frac{0.0315}{40} \times 6.023 \times 10^{23}$$

$= 4.81 \times 10^5$ dpm

Example 21. *The sun radiates energy at the rate of 4×10^{26} J sec^{-1}. If the energy of fusion process is 27 MeV, calculate the amount of hydrogen that would be consumed per day for the given process.*

$$4\,{}_1^1H \longrightarrow {}_2^4He + 2\,{}_1^0e.$$

Solution: $27\text{ MeV} = 27 \times 10^6 \times 1.6 \times 10^{-19}$

$= 43.2 \times 10^{-13}$ J

Energy radiated by the sun per day

$= 4 \times 10^{26} \times 3600 \times 24$ J day^{-1}

$= 34.56 \times 10^{30}$ J day^{-1}

43.2×10^{-13} J of energy is obtained from

$= 4$ amu of H

$= 4 \times 1.66 \times 10^{-24}$ g of H

34.56×10^{30} J of energy is obtained from

$$= \frac{4 \times 1.66 \times 10^{-24}}{43.2 \times 10^{-13}} \times 34.56 \times 10^{30}$$

$= 5.31 \times 10^{19}$ g

Example 22. *A radioactive isotope X with half life of 1.37×10^9 years decays to Y, which is stable. A sample of rock from moon was found to contain both the elements X and Y in the ratio 1 : 7. What is the age of the rock?*

Solution: We know that,

$$\frac{0.693}{t_{1/2}} = \frac{2.303}{t_{age}} \log\left(\frac{N_0}{N}\right)$$

$$\frac{0.693}{1.37 \times 10^9} = \frac{2.303}{t_{age}} \log_{10}\left(\frac{1+7}{1}\right)$$

$\therefore$ $$t_{age} = 4.11 \times 10^9 \text{ years}$$

Example 23. *A sample of radioactive substance shows an intensity of 2.3 millicurie at a time 't' and an intensity of 1.62 millicurie, 600 seconds later. What is the half life period of the radioactive material?*

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

$$\frac{0.693}{t_{1/2}} = \frac{2.303}{600}\log\left(\frac{2.3}{1.62}\right)$$

$\therefore \quad t_{1/2} = 1187$ seconds

Example 24. *What mass of ^{226}Ra, whose $t_{1/2} = 1620$ yrs will give the activity of 1 millicurie?*

Solution:

$$\text{Activity} = \frac{0.693}{t_{1/2}} \times \frac{w}{\text{At. wt.}} \times 6.023 \times 10^{23}$$

$$3.7 \times 10^7 = \frac{0.693}{1620 \times 365 \times 24 \times 3600} \times \frac{w}{226} \times 6.023 \times 10^{23}$$

so $\quad w = 10^{-3}$ g

SUMMARY AND IMPORTANT POINTS TO REMEMBER

1. Radius of nucleus is calculated as:
   $$R = R_0 A^{1/3},$$
   where, $R_0 = 1.1 \times 10^{-15}$ m, A = Mass number of nucleus
   Area of cross-section of a nucleus is expressed in barns ($1 \text{ barn} = 10^{-24} \text{ cm}^2$).
2. Nucleus density $\rho = \dfrac{3 \times \text{Mass}}{4\pi R_0^3}$
   Density of all nuclei is constant, nuclear density is very large ($\approx 10^{17}$ kg/m^3) compared to atomic density ($\approx 10^3$ kg/m^3).
3. 1 amu $= 1.66 \times 10^{-27}$ kg
   In terms of energy, 1 amu ≈ 931.5 MeV
4. Rate of radioactive decay is given as:
   $$\text{Rate} = \lambda \times \frac{\text{Mass}}{\text{Atomic mass}} \times 6.023 \times 10^{23}$$
   $$= \frac{0.693}{t_{1/2}} \times \frac{w}{\text{At. wt.}} \times 6.023 \times 10^{23}$$
   (i) Radioactivity is the phenomenon of spontaneous emission of certain radiations. It was discovered by Henri Becquerel in 1895.
   (ii) Marie Curie and her husband Piere Curie isolated two radioactive elements **polonium** and **radium.** Radium is 2 million times more reactive than uranium, it is the most radioactive element.
   (iii) Radium and polonium were isolated from pitchblende (U_3O_8).
   (iv) Francium is a liquid radioactive element in natural state.
   (v) Radon is a gaseous radioactive element in natural state.
   (vi) $^{238}_{92}U$ is the heaviest known natural element and it is radioactive.
   (vii) α-particles evolved from radioactive elements possess energy up to about 10 MeV. They can penetrate an aluminium sheet of 0.02 cm thickness.
   (viii) β-rays can penetrate an aluminium sheet up to 0.2 cm thickness.
   (ix) γ-rays are high energy electromagnetic radiations of short wavelength of the order of 10 pm. These are highly penetrating rays; they can penetrate up to 100 cm thick aluminium sheet.
   (x) After γ-decay, the daughter nuclide is the nuclear isomer of parent nuclide which differs in half life.
   (xi) Potassium uranyl sulphate $K(UO_2)(SO_4)_2$ was the first compound found to be radioactive.
   (xii) Tritium ^3_1H is the lightest radioactive element.
5. Units of rate of decay:
   1 curie (Ci) $= 3.7 \times 10^{10}$ dis sec^{-1}
   1 millicurie (mCi) $= 3.7 \times 10^{7}$ dis sec^{-1}
   1 microcurie (μCi) $= 3.7 \times 10^{4}$ dis sec^{-1}
   1 rutherford (Rd) $= 10^{6}$ dis sec^{-1}
   1 millicurie (mCi) = 37 rutherford
   1 becquerel (Bq) = 1 dis sec^{-1}
6. Kinetic equation of radioactive decay:
   $$N = N_0 e^{-\lambda t} \qquad \text{(Exponential form)}$$
   $$\lambda = \frac{2.303}{t}\log_{10}\left(\frac{N_0}{N}\right) \qquad \text{(logarithmic form)}$$
   λ = Decay constant
   N_0 = Initial amount of radioactive element
   N = Amount remaining after time 't'
7. Half life $t_{1/2} = \dfrac{0.693}{\lambda}$
   $$\text{Average life } \tau = \frac{1}{\lambda} = \frac{t_{1/2}}{0.693}$$
   $$\tau = 1.44 \times t_{1/2}$$
8. Amount remaining after 'n' half lives can be calculated as:
   $$N = N_0\left(\frac{1}{2}\right)^n$$
   $$n = \frac{\text{Total time}}{\text{Half life}}$$
   (i) A radioactive element undergoes 50% decay in one half life.
   (ii) The time in which 63.2% radioactive element undergoes decay is called average life τ.
   (iii) The radioactive element undergoes 99.9% decay in 10 times of half life.
   (iv) An element undergoes 75% decay in twice of the half life.
   (v) Total life span of a radioactive element is infinite.

9. Some radioactive elements undergo α and β-decay in parallel path.

$$^{227}_{89}Ac \xrightarrow{K_1} {}^{223}_{87}Fr + {}^{4}_{2}He$$

$$^{227}_{89}Ac \xrightarrow{K_2} {}^{227}_{90}Th + {}^{0}_{-1}e$$

Overall decay constant $K = K_1 + K_2$

Fractional yield of Fr $= \dfrac{K_1}{K}$

Fractional yield of Th $= \dfrac{K_2}{K}$

10. At equilibrium,

$$A \longrightarrow B \longrightarrow C \ldots$$

$$\frac{\text{Amount of '}A\text{'}}{\text{Amount of '}B\text{'}} = \frac{\lambda_A}{\lambda_B} = \frac{t_{1/2}B}{t_{1/2}A}$$

11. If an element undergoes simultaneous α and β-decay, then

$$\lambda = \lambda_\alpha + \lambda_\beta; \quad \tau = \frac{\tau_\alpha \tau_\beta}{\tau_\alpha + \tau_\beta}$$

12. α-particles and γ-rays have line spectra, but β-particles have a continuous spectrum.

13. **Geiger-Muller counter** is used for detecting α and β-particles, **cloud chamber** is used for detecting radioactive radiations and for determining their **paths, range** and **energy.** In **scintillation counter,** the particles of radiations are detected by the flashes of light produced in the scintillator.

14. In every nuclear reaction representing transformation of one nucleus to other, the conservation of charge number, nucleons, energy and linear momentum is followed.

15. α-emission takes place when n/p ratio is lower than required for nuclear stability.

$$4\,{}^{1}_{1}H \longrightarrow {}^{4}_{2}He + 2[{}^{0}_{+1}e] + \text{energy}$$

α-particle emission shifts the daughter element two positions left in the periodic table.

$$^{M}_{Z}A - {}^{4}_{2}He \longrightarrow {}^{M-4}_{Z-2}B$$

(Here, A and B are **isodiapheres** to each other.)

16. β-emission takes place when n/p ratio is higher than the required value for nuclear stability.

$$^{1}_{0}n \longrightarrow {}^{1}_{1}H + {}^{0}_{-1}e + \text{antineutrino} + \text{energy}$$

Emission of β-particles increases the atomic number by one hence, the daughter element occupies one position right to the parent element.

$$^{M}_{Z}A - ({}^{0}_{-1}e) \longrightarrow {}_{Z+1}{}^{M}B$$

Here, A and B are **isobars;** thus β-emission is **isobaric** transformation.

17. In artificial radioactive elements, **positrons** are evolved when n/p ratio is lower than the required value for nuclear stability.

$$^{1}_{1}H \longrightarrow {}^{1}_{0}n + {}^{0}_{+1}e + \text{neutrino} + \text{energy}$$

Positron emission and K-electron capture are similar because both processes lower the number of proton by one unit.

18. $$^{M_1}_{Z_1}A \xrightarrow{(x\alpha,\, y\beta)} {}^{M_2}_{Z_2}B$$

Number of α-particles 'x' $= \dfrac{M_1 - M_2}{4}$ ... (i)

Number of β-particles can be calculated using the following relation:

$$Z_1 - 2x + y = Z_2 \quad \text{... (ii)}$$

19. There are three natural and one artificial decay series:

$$^{238}_{92}U \xrightarrow[(8\alpha,\, 6\beta)]{\text{Uranium series } (4n+2)} {}^{206}_{82}Pb$$

$$^{232}_{90}Th \xrightarrow[(6\alpha,\, 4\beta)]{\text{Thorium series } (4n)} {}^{208}_{82}Pb$$

$$^{235}_{92}U \xrightarrow[(7\alpha,\, 4\beta)]{\text{Actinium series } (4n+3)} {}^{207}_{82}Pb$$

Artificial series is also called neptunium series:

$$^{237}_{93}Np \xrightarrow[(7\alpha,\, 4\beta)]{(4n+1)} {}^{209}_{83}Bi$$

20. If both parent and daughter elements belong to actinide series (89–103) then they will belong to same group, *i.e.*, third group.

$$\underset{\text{3rd group}}{^{238}_{92}U} - {}^{4}_{2}He \longrightarrow \underset{\text{3rd group}}{^{234}_{90}Th}$$

21. $\xrightarrow{\alpha < \beta < \gamma}$ Increasing penetrating power

$\xrightarrow{\alpha > \beta > \gamma}$ Decreasing ionising power

$\xrightarrow{\alpha > \beta > \gamma}$ Decreasing luminosity on ZnS screen

22. Emission of one 'α' and two 'β' particles form an isotope of the parent element :

$$^{M}_{Z}A - {}^{4}_{2}He - 2[{}^{0}_{-1}e] \longrightarrow {}^{M-4}_{Z}A$$

23. There are only 81 stable elements having one or more non-radioactive isotopes.

24. No stable isotope exists for the elements above $^{209}_{83}Bi$. Thus, bismuth is the heaviest stable element.

25. Two elements earlier than bismuth (Tc and Pm) are radioactive.

26.

Isotope	Use
^{60}Co	Cancerous tumour detection and treatment.
^{131}I	Detection and treatment of thyroid disorders.
^{59}Fe	Anaemia.
^{32}P	Leucaemia and agriculture research.
^{24}Na	Location of blood clots and circulatory disorders.
^{74}As	Detection of presence of tumours.
^{90}Y	Treatment of joint effusion and arthritis.

^{18}O	Used in the study of mechanism of photosynthesis.
Radioactive technetium	Brain scan.

Note: Radioactive isotopes of carbon, chlorine and nitrogen are also used in the study of various reactions.

27. **Radiocarbon dating:** This method is used to determine age of wood.

$$\lambda = \frac{2.303}{t}\log_{10}\left(\frac{N_0}{N}\right)$$

$$\frac{0.693}{t_{1/2}\,{}^{14}C} = \frac{2.303}{t_{age}}\log_{10}\left(\frac{N_0}{N}\right)$$

$N_0 = {}^{14}C/{}^{12}C$ in freshly cut wood or in the atmosphere or activity of freshly cut wood.

$N = {}^{14}C/{}^{12}C$ in the given sample of wood or activity of given sample of wood.

28. **Uranium dating or rock dating:** It is used to calculate the age of a sample of rock and mineral, *i.e.*, before how many years it was separated from the fire ball of earth.

$$\lambda = \frac{2.303}{t}\log_{10}\left(\frac{N_0}{N}\right)$$

$$\frac{0.693}{t_{1/2}\,{}^{238}U} = \frac{2.303}{t_{age}}\log_{10}\left(\frac{N_0}{N}\right)$$

$$N_0 = \left(\frac{W}{238} + \frac{w}{206}\right)$$

$$N = \frac{W}{238}$$

where, W = amount of uranium in the sample
w = amount of ^{206}Pb in the sample

29. The force which binds the nucleons together in the nucleus is called nuclear force. These forces are short range forces operating over very small distances (1 fermi, 10^{-15} m). Nuclear forces are 10^{21} times stronger than electrostatic forces.

30. Hideki Yukawa of Japan discovered **mesons** in 1935. Protons and neutrons are held together by their fast mutual exchange.

$${}^1_1H + {}^{0}_{-1}\pi \longrightarrow {}^1_0n$$
$${}^1_0n + {}^{0}_{+1}\pi \longrightarrow {}^1_1H$$
$${}^1_1H + {}^{0}_{0}\pi \longrightarrow {}^1_1H$$
$${}^1_0n + {}^{0}_{0}\mu \longrightarrow {}^1_0n$$

31. **Artificial nuclear transmutation:** Conversion of one element to other by bombardment of a stable element with high speed subatomic particles. The first artificial transmutation was achieved by Rutherford in 1915 when he bombarded ${}^{14}_{7}N$ with α-particles emitted by ${}^{214}_{84}Po$.

$${}^{14}_{7}N + {}^4_2He \longrightarrow {}^{17}_{8}O + {}^1_1H$$
$${}^{27}_{13}Al + {}^1_0n \longrightarrow {}^{27}_{12}Mg + {}^1_1H$$

The nucleus bombarded is called **target;** the particles used for bombarding are called **projectiles** and the particles emitted are called **subsidiary particles.**

32. **Particle accelerator:** Various particle accelerators are used to give projectiles like protons, deuterons, α-particles and other cationic projectiles having sufficiently high kinetic energy to overcome the electrostatic repulsions of the target nuclei. Commonly used particle accelerators are linear accelerators, cyclotron and synchrotron. Synchrotron is used as proton accelerator.

33. Reactions of nuclear transformation are represented as:

$${}^9_4Be + {}^4_2He \longrightarrow {}^{12}_{6}C + {}^1_0n \quad \text{or} \quad {}^9_4Be\,(\alpha n)\,{}^{12}_{6}C$$
$${}^{23}_{11}Na + {}^1_1H \longrightarrow {}^{23}_{12}Mg + {}^1_0n \quad \text{or} \quad {}^{23}_{11}Na\,(pn)\,{}^{23}_{12}Mg$$
$${}^{27}_{13}Al + {}^1_0n \longrightarrow {}^{24}_{11}Na + {}^4_2He \quad \text{or} \quad {}^{27}_{13}Al\,(n\alpha)\,{}^{24}_{11}Na$$

34. **Artificial radioactivity** was first studied by Irene Curie. In this process, a stable nucleus is converted to radioactive isotope on bombardment of suitable particle. Radioactive isotope produced undergoes artificial decay.

$$\underset{\text{Stable}}{{}^{27}_{13}Al} + {}^4_2He \longrightarrow \underset{\text{Unstable}}{{}^{30}_{15}P} + {}^1_0n$$

$${}^{30}_{15}P \longrightarrow {}^{30}_{14}Si + {}^{0}_{+1}e \quad (t_{1/2} = 2.55 \text{ min})$$

35. **Nuclear fission** is the process in which a heavy nucleus breaks up into two smaller nuclei on bombardment with neutrons. Energy is released in the process of fission along with freshly prepared neutrons.

$${}^{235}_{92}U + {}^1_0n \longrightarrow {}^{236}_{92}U \longrightarrow \begin{cases} {}^{140}_{56}Ba + {}^{93}_{36}Kr + 3\,{}^1_0n \\ {}^{144}_{54}Xe + {}^{90}_{38}Sr + 2\,{}^1_0n \\ {}^{144}_{55}Cs + {}^{90}_{37}Rb + 2\,{}^1_0n \end{cases}$$

Mass defect of the reaction is converted to huge amount of energy.

Δm (Mass defect) = Σ Masses of reactants − Σ Masses of products

Energy released = Δmc^2

If mass defect is 1 amu then 931.5 MeV energy is released.

36. **Critical mass:** It is the minimum mass of fissionable material required that will lead to a self-sustaining chain fission reaction. For ${}^{235}_{92}U$, the critical mass is between 1 to 100 kg.

37. The material which directly undergoes fission is termed as fissile material such as ^{235}U, ^{239}Pu and ^{233}U. The material which can be converted to fissile material is termed fertile material such as ${}^{238}_{92}U$ and ${}^{232}_{90}Th$.

38. Breeder reactors not only involve the fission of ${}^{235}_{92}U$ but also converts fertile material into fissile material, *e.g.*, ^{238}U is converted to ^{239}Pu:

$${}^{238}_{92}U + {}^1_0n \longrightarrow {}^{239}_{92}U \xrightarrow{-{}^{0}_{-1}e} {}^{239}_{93}Np \xrightarrow{-\beta} {}^{239}_{94}Pu$$

39. Nuclear fission is a chain reaction. If it is uncontrolled, explosion occurs as in the atom bomb. Two or more pieces of fissile material (^{235}U or ^{239}Pu) having subcritical mass are brought together rapidly by means of conventional explosion. The subcritical masses combine to be supercritical and then chain fission starts, releasing large amount of energy.
40. The controlled chain fission reaction takes place in nuclear reactors. In these reactors the energy is used for peaceful purposes. The heat energy produced in the nuclear reactors can be used to generate electricity. A reactor consists of:
    (i) enriched fuel $^{235}_{92}U$ (2–3%).
    (ii) heavy water (D_2O) or graphite moderator. It slows down the speed of fast moving neutrons.
    (iii) control rods made of boron and cadmium. These rods absorb some neutrons and thereby control the rate of nuclear fission.
    (iv) liquid alloy of sodium and potassium is used as a coolant.
41. Nuclear fusion is the process in which two nuclei of light atoms fuse to form heavy nuclei with the liberation large amount of energy.

$$^2_1H + ^2_1H \longrightarrow ^4_2He + 23 \times 10^8 \text{ kJ/mol}$$

$$^2_1H + ^3_1H \longrightarrow ^4_2He + ^1_0n + 17.2 \times 10^8 \text{ kJ/mol}$$

42. Fusion reactions are thermonuclear reactions which require very high temperature (10^6 K or more).
43. Hydrogen bomb involves nuclear fusion.
44. Energy of a star (sun) is due to nuclear fusion; this energy is called stellar energy.
45. Hydrogen bomb is much more powerful than atom bomb and there is no restriction of critical mass in this bomb.
46. Neutron activation analysis is a technique of finding the trace amount of an element present with the other. The trace element is activated by bombarding with neutrons. It is a non-destructive method, *e.g.*, traces of silver present in lead paintings can be detected by neutron activation analysis.
47. **Spallation reactions:** It is similar to fission but differ in the fact that they are brought about by high energy bombarding particles or photons. A number of smaller particles are released along with the product, *e.g.*,

$$^{238}_{92}U + ^4_2He \longrightarrow 6\ ^1_1H + 13\ ^1_0n + ^{223}_{88}Ra$$

48. The isotope ^1_1H has $n/p = 0$ and ^3_1H has $n/p = 2$ which is maximum.
49. Only $^{12}_6C$ has zero packing fraction. Packing fraction is maximum for hydrogen and minimum for iron.

$$\text{Packing fraction} = \frac{\text{Isotopic mass} - \text{Mass number}}{\text{Mass number}} \times 10^4$$

Elements with negative packing fraction are stable because some of their mass is converted to binding energy.
50. $^{14}_6C$ is produced in upper atmosphere due to bombardment of cosmic ray neutrons on atmospheric nitrogen.

Questions

1. Match the List-I and List-II and pick the correct answer from the codes given below: [PMT (Kerala) 2006]

List-I (Atomic/Molecular species)	List-II (Corresponding pairs)
(A) Isotopes	1. $^{228}_{88}Ra$ and $^{228}_{89}Ac$
(B) Isobars	2. $^{39}_{18}Ar$ and $^{40}_{19}K$
(C) Isotones	3. $^{2}_{1}H$ and $^{3}_{1}H$
(D) Isosters	4. $^{235}_{92}U$ and $^{231}_{90}Th$
(E) Isodiapheres	5. CO_2 and N_2O

(a) A—2, B—1, C—4, D—5, E—3
(b) A—2, B—5, C—1, D—4, E—3
(c) A—3, B—1, C—2, D—5, E—4
(d) A—5, B—4, C—1, D—2, E—3
(e) A—5, B—3, C—1, D—2, E—4

2. **Matrix Matching Problems (For IIT aspirants):**

[A] Match the Column-I with Column-II:

Column-I	Column-II
(a) Stability of nucleus	(p) Depends on mass number
(b) Density of nucleus	(q) Packing fraction
(c) Spin angular momentum of proton	(r) Binding energy per nucleon
(d) Dimensionless quantity	(s) Independent of mass number

[B] Match the Column-I with Column-II:

Column-I	Column-II
(a) 2/3rd life	(p) 63.2% decay
(b) Average life	(q) 75% decay
(c) $1/\lambda$	(r) $2 \times t_{1/2}$
(d) Ten times of half life	(s) 99.9% decay

[C] Match the nuclear transformations of Column-I with the particles emitted of Column-II:

Column-I	Column-II
(a) $^{209}_{83}Bi + ^{4}_{2}He \longrightarrow ^{211}_{85}At + ...$	(p) $^{1}_{1}H$
(b) $^{9}_{4}Be + ^{4}_{2}He \longrightarrow ^{12}_{6}C + ...$	(q) $^{4}_{2}He$
(c) $^{24}_{12}Mg(^{1}_{0}n\ ...)\ ^{24}_{11}Na$	(r) $^{2}_{1}H$
(d) $^{23}_{11}Na(^{2}_{1}H\ ...)\ ^{21}_{10}Ne$	(s) $^{1}_{0}n$

[D] Match the Column-I with Column-II:

Column-I	Column-II
(a) Binding energy per nucleon increases	(p) β-decay
(b) Mass number is conserved	(q) α-decay
(c) Charge number is conserved	(r) Nuclear fusion
(d) Mass of products formed is less than the mass of reactants	(s) Nuclear fission

[E] Match the Column-I with Column-II:

Column-I	Column-II
(a) α-rays	(p) Radiations, undeviated in electric field
(b) β-rays	(q) Produced when electrons strike metal surface
(c) γ-rays	(r) Highest deflection in electromagnetic field
(d) X-rays	(s) Nucleus of helium

[F] Match the Column-I with Column-II:

Column-I	Column-II
(a) α-emission	(p) Mass number changes
(b) β-emission	(q) Atomic number and mass number are affected
(c) γ-emission	(r) Atomic number decreases
(d) β^+-emission	(s) Atomic number increases

3. Write the complete nuclear reactions:

(a) $^{9}_{4}Be + ^{4}_{2}He \longrightarrow ^{12}_{6}C + ...$
(b) $^{3}_{1}H \longrightarrow ^{3}_{2}He + ...$
(c) $^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ...$
(d) $^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{92}_{38}Sr + Xe + 3\ ^{1}_{0}n$
(e) $^{7}_{3}Li + ^{1}_{0}n \longrightarrow 2\ ^{4}_{2}He + ...$
(f) $^{238}_{92}U + ... \longrightarrow ^{239}_{92}U \longrightarrow ^{239}_{93}Np + ...$
(g) $^{14}_{7}N + ^{1}_{0}n \longrightarrow ^{3}_{1}H + ...$
(h) $^{7}_{3}Li + ... \longrightarrow ^{8}_{4}Be + \gamma$ - radiations
(i) $^{2}_{1}H + ... \longrightarrow ^{4}_{2}He + ^{1}_{0}n$
(j) $^{27}_{13}Al + ^{1}_{0}n \longrightarrow ^{24}_{11}Na + ...$
(k) $^{27}_{13}Al + ^{4}_{2}He \longrightarrow .... + ^{1}_{1}H$
(l) $^{235}_{92}U + ^{1}_{0}n \longrightarrow .... + ^{137}_{52}Te + ^{97}_{40}Zr$ (IIT 2005)
(m) $^{86}_{34}Se \longrightarrow .... + 2\ ^{0}_{-1}e$ (IIT 2005)

4. Write the particles emitted from each nuclide in the following reactions:

(a) $^{231}_{90}Th \xrightarrow[(i)]{} ^{231}_{91}Pa \xrightarrow[(ii)]{} ^{227}_{89}Ac$
(b) $^{217}_{85}At \xrightarrow[(i)]{} ^{213}_{83}Bi \xrightarrow[(ii)]{} ^{209}_{81}Tl$
(c) $^{239}_{92}U \xrightarrow[(i)]{} ^{239}_{93}Np \xrightarrow[(ii)]{} ^{239}_{94}Pu$
(d) $^{30}_{15}P \xrightarrow[(i)]{} ^{30}_{14}Si$

5. Find the atomic number and mass number of the last member in the following series:

(a) ${}^{226}_{188}\mathrm{Ra} \xrightarrow{-\alpha} \mathrm{Rn} \xrightarrow{-\alpha} \mathrm{Ra}A \xrightarrow{-\alpha} \mathrm{Ra}B \xrightarrow{-\beta} \mathrm{Ra}C$

(b) ${}^{M}_{Z}A \xrightarrow{-\alpha} B \xrightarrow{-\beta} C \xrightarrow{-\beta} D \xrightarrow{-\alpha} E$

6. Complete the following:

(a) ${}^{238}X \xrightarrow{-\alpha} Y \xrightarrow{-\beta} {}_{91}Z$

(b) ${}^{214}A \xrightarrow{-\beta} B \xrightarrow{-\beta} {}_{84}C$

7. Write the equations for the following transformations:

(a) ${}^{39}_{19}\mathrm{K}\,(p, d)$ (b) ${}^{14}_{7}\mathrm{N}\,(n, p)$ (c) ${}^{23}_{11}\mathrm{Na}\,(\alpha, p)$

(d) ${}^{9}_{4}\mathrm{Be}\,(\alpha, n)$.

8. To which radioactive families do the following nuclides belong?

${}^{222}\mathrm{Rn}$, ${}^{228}\mathrm{Ra}$, ${}^{207}\mathrm{Pb}$, ${}^{209}\mathrm{Bi}$, ${}^{233}\mathrm{Pa}$.

9. To which group of the periodic table does the last member of the following series belong?

(a) ${}^{239}_{92}\mathrm{U} \xrightarrow{-\beta} {}^{239}_{93}\mathrm{Np} \xrightarrow{-\beta} {}^{239}_{94}\mathrm{Pu}$

III Group

(b) ${}^{140}_{55}\mathrm{Cs} \xrightarrow{-\beta} {}^{140}_{56}\mathrm{Ba} \xrightarrow{-\beta} {}^{140}_{57}\mathrm{La} \xrightarrow{-\beta} {}^{140}_{58}\mathrm{Ce}$

I Group

(c) ${}^{226}_{88}\mathrm{Ra} \xrightarrow{-\alpha} {}^{222}_{86}\mathrm{Rn} \xrightarrow{-\alpha} {}^{218}_{84}\mathrm{Po}$

II Group

10. Name the process represented below:

(a) ${}^{235}_{92}\mathrm{U} + {}^{1}_{0}n \longrightarrow {}^{141}_{56}\mathrm{Ba} + {}^{92}_{36}\mathrm{Kr} + 3\,{}^{1}_{0}n + 200\text{ MeV}$

(b) ${}^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \longrightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}n + 17.6\text{ MeV}$

(c) ${}^{63}_{29}\mathrm{Cu} + {}^{4}_{2}\mathrm{He} + 400\text{ MeV} \longrightarrow {}^{37}_{17}\mathrm{Cl} + 14\,{}^{1}_{1}\mathrm{H} + 16\,{}^{1}_{0}n$

(d) ${}^{10}_{5}\mathrm{B} + {}^{4}_{2}\mathrm{He} \longrightarrow {}^{13}_{7}\mathrm{N} + {}^{1}_{0}n$

$\qquad\qquad\qquad\qquad \longrightarrow {}^{13}_{6}\mathrm{C} + {}^{0}_{+1}e$

Answers

1. (c) A–3, B–1, C–2, D–5, E–4

2. [A] (a — p, q, r); (b — s); (c — s); (d — q)
[B] (a — q, r); (b — p); (c — p); (d — s)
[C] (a — s); (b — s); (c — p); (d — q)
[D] (a–p, q, r, s); (b–p, q, r, s); (c–p, q, r, s); (d–p, q, r, s)
[E] (a — s); (b — r); (c — p); (d — p, q)
[F] (a — p, r) (b — s) (c — q) (d — q)

3. (a) ${}^{9}_{4}\mathrm{Be} + {}^{4}_{2}\mathrm{He} \longrightarrow {}^{12}_{6}\mathrm{C} + {}^{1}_{0}n$;
(b) ${}^{3}_{1}\mathrm{H} \longrightarrow {}^{3}_{2}\mathrm{He} + {}^{0}_{-1}e$;
(c) ${}^{14}_{7}\mathrm{N} + {}^{4}_{2}\mathrm{He} \longrightarrow {}^{17}_{8}\mathrm{O} + {}^{1}_{1}\mathrm{H}$;
(d) ${}^{235}_{92}\mathrm{U} + {}^{1}_{0}n \longrightarrow {}^{92}_{38}\mathrm{Sr} + {}^{141}_{54}\mathrm{Xe} + 3\,{}^{1}_{0}n$;
(e) ${}^{7}_{3}\mathrm{Li} + {}^{1}_{0}n \longrightarrow 2\,{}^{4}_{2}\mathrm{He} + {}^{0}_{-1}e$;
(f) ${}^{238}_{92}\mathrm{U} + {}^{1}_{0}n \longrightarrow {}^{239}_{92}\mathrm{U} \longrightarrow {}^{239}_{93}\mathrm{Np} + {}^{0}_{-1}e$;
(g) ${}^{14}_{7}\mathrm{N} + {}^{1}_{0}n \longrightarrow {}^{12}_{6}\mathrm{C} + {}^{3}_{1}\mathrm{H}$;
(h) ${}^{7}_{3}\mathrm{Li} + {}^{1}_{1}\mathrm{H} \longrightarrow {}^{8}_{4}\mathrm{Be} + \gamma$-radiations;
(i) ${}^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \longrightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}n$;
(j) ${}^{27}_{13}\mathrm{Al} + {}^{1}_{0}n \longrightarrow {}^{24}_{11}\mathrm{Na} + {}^{4}_{2}\mathrm{He}$;
(k) ${}^{27}_{13}\mathrm{Al} + {}^{4}_{2}\mathrm{He} \longrightarrow {}^{30}_{14}\mathrm{Si} + {}^{1}_{1}\mathrm{H}$;
(l) ${}^{235}_{92}\mathrm{U} + {}^{1}_{0}n \longrightarrow 2\,{}^{1}_{0}n + {}^{137}_{52}\mathrm{Te} + {}^{97}_{40}\mathrm{Zr}$;
(m) ${}^{86}_{34}\mathrm{Se} \longrightarrow {}^{86}_{36}\mathrm{Kr} + 2\,{}^{0}_{-1}e$

4. (a) (i) β (ii) α (b) (i) α (ii) α (c) (i) β (ii) β (d) (i) ${}^{0}_{+1}e$

5. (a) Atomic mass = 214, Atomic number = 83
(b) Atomic mass = $M - 8$, Atomic number = $Z - 2$

6. (a) ${}^{238}_{92}X \xrightarrow{-\alpha} {}^{234}_{90}Y \xrightarrow{-\beta} {}^{234}_{91}Z$
(b) ${}^{214}_{82}A \xrightarrow{-\beta} {}^{214}_{83}B \xrightarrow{-\beta} {}^{214}_{84}C$

7. (a) ${}^{39}_{19}\mathrm{K} + {}^{1}_{1}\mathrm{H} \longrightarrow {}^{38}_{19}\mathrm{K} + {}^{2}_{1}\mathrm{H}$ (b) ${}^{14}_{7}\mathrm{N} + {}^{1}_{0}n \longrightarrow {}^{14}_{6}\mathrm{C} + {}^{1}_{1}\mathrm{H}$
(c) ${}^{23}_{11}\mathrm{Na} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{26}_{12}\mathrm{Mg} + {}^{1}_{1}\mathrm{H}$ (d) ${}^{9}_{4}\mathrm{Be} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{12}_{6}\mathrm{C} + {}^{1}_{0}n$

8. ${}^{222}\mathrm{Rn}$ belongs to $(4n + 2)$ family, *i.e.*, uranium family.
${}^{228}\mathrm{Ra}$ belongs to $(4n)$ family, *i.e.*, thorium family.
${}^{207}\mathrm{Pb}$ belongs to $(4n + 3)$ family, *i.e.*, actinium family.
${}^{209}\mathrm{Bi}$ belongs to $(4n + 1)$ family, *i.e.*, neptunium series.
${}^{233}\mathrm{Pa}$ belongs to $(4n + 1)$ family, *i.e.*, neptunium series.

9. (a) ${}^{239}_{94}\mathrm{Pu}$ belongs to actinide series, hence it is present in III group.
(b) ${}^{140}_{58}\mathrm{Ce}$ belongs to lanthanide series, hence it is present in III group.
(c) ${}^{218}_{84}\mathrm{Po}$ belongs to VI group.

10. (a) Nuclear fission (b) nuclear fusion (c) spallation reaction (d) artificial radioactivity.

• PRACTICE PROBLEMS •

1. Half life of ^{24}Na is 14.8 hours. In what period of time will a sample of this element lose 90% of its activity?
[**Ans.** 49.17 hour]
2. A β-particle emitter has a half life of 60.6 min. At any instant of time, a sample of this element registers 2408 counts per second. Calculate the counting rate after 1.5 hours.
[**Ans.** 860 counts per sec]
3. A radio-isotope $^{32}_{15}P$ has half life of 15 days. Calculate the time in which the radioactivity of 1 mg quantity will fall to 10% of the initial value.
[**Ans.** 49.85 days]
4. Consider an α-particle just in contact with $^{238}_{92}U$ nucleus. Calculate the coulombic repulsion energy assuming that the distance between them is equal to the sum of their radii.
[**Ans.** 24.2 MeV]
5. The activity of a certain sample of radioactive element 'A' decreases to $1/\sqrt{2}$ of its value in 4 days. What is its half life? Assuming that,
$$^{M}_{Z}A - {}^{4}_{2}He \longrightarrow {}^{M-4}_{Z-2}B$$
what mass of the sample will be left over after 24 days if we start with one gram of 'A'? Calculate this in terms of M.
[**Ans.** $t_{1/2} = 8$ days; mass of sample left over $= \left(1 - \frac{3-5}{M}\right)$ g]
[**Hint:** $\lambda = \frac{2.303}{t}\log_{10}\left(\frac{N_0}{N}\right)$
$$\frac{0.693}{t_{1/2}} = \frac{2.303}{4}\log_{10}(\sqrt{2}) \quad \because \quad N = \frac{N_0}{\sqrt{2}}$$
$$t_{1/2} = 8 \text{ days}$$
Use $N = N_0\left(\frac{1}{2}\right)^n$ for next part.]
6. The half life of $^{238}_{92}U$ is 4.5×10^9 years. Uranium emits an α-particle to give thorium. Calculate the time required to get the product which contains equal masses of thorium and uranium.
[**Ans.** 4.55×10^9 yrs]
[**Hint:** $N_0 = \frac{1}{238} + \frac{1}{234}$; $N = \frac{1}{238}$
Use, $\frac{0.693}{t_{1/2}} = \frac{2.303}{t}\log_{10}\left(\frac{N_0}{N}\right)$]
7. 32 mg of pure $^{238}_{94}PuO_2$ has an activity of 6.4×10^7 sec^{-1}.
(i) What will be the half life of $^{238}_{94}Pu$ in years?
(ii) What amount of PuO_2 will remain if 100 mg PuO_2 is kept for 5000 years?
[**Ans.** (i) 2.45×10^4 years (ii) 86.7 mg]
[**Hint:** (i) Mass of $^{238}Pu = \frac{238}{270} \times 32 = 28.207$ mg
$$\text{Rate} = \frac{0.693}{t_{1/2}} \times \frac{w}{\text{At. wt.}} \times N$$
$$6.4 \times 10^7 = \frac{0.693}{t_{1/2}} \times \frac{28.207 \times 10^{-3}}{238} \times 6.023 \times 10^{23}$$
$$t_{1/2} = 7.729 \times 10^{11} \text{ sec} = 2.45 \times 10^4 \text{ years}$$
(ii) Use, $\frac{0.693}{t_{1/2}} = \frac{2.303}{t}\log_{10}\left(\frac{N_0}{N}\right)$
$$\frac{0.693}{2.45 \times 10^4} = \frac{2.303}{5000}\log_{10}\left(\frac{100}{N}\right)$$
$$N = 86.7 \text{ mg}]$$
8. A radioactive isotope decays as:
$$^{M}_{Z}A \longrightarrow {}^{M-4}_{Z-2}B \longrightarrow {}^{M-4}_{Z-1}C$$
The half lives of A and B are 6 and 10 months respectively. Assuming that initially only A was present, will it be possible to achieve the radioactive equilibrium for B? If so, what would be the ratio of A and B at equilibrium? What would happen if the half lives of A and B were 10 and 6 months respectively?
[**Hint:** At equilibrium, ratio of amounts of A and B will be
$$\frac{N_A}{N_B} = \frac{t_{1/2}A}{t_{1/2}B} = \frac{6}{10} = 0.6$$
If the half lives of A and B are 10 and 6 months respectively, then B will decay faster than 'A', hence equilibrium will not be achieved.]
9. Lowest level of ^{14}C activity for experimental detection is 0.03 dis per min per gram. What is the maximum age of an object that can be determined by ^{14}C method? The activity of ^{14}C in the atmosphere is 15 dis per min per gram of ^{14}C ($t_{1/2}$ for $^{14}C = 5730$ yrs).
[**Ans.** 51379.28 yrs]
10. An analysis of a rock shows that relative number of ^{87}Sr and ^{87}Rb atoms is 0.052, *i.e.*, ($^{87}Sr/^{87}Rb = 0.052$). Determine the age of the rock. Given that half life period for β-decay of Rb to Sr is 4.7×10^{10} years.
[**Ans.** 3.43×10^9 years]
[**Hint:**
$$\frac{^{87}Rb}{^{87}Sr} = \frac{x}{y} = \frac{1}{0.052}$$
$$\frac{x}{x+y} = \frac{1}{1.052}$$
$$\frac{N}{N_0} = \frac{1}{1.052}$$
$$\lambda = \frac{2.303}{t}\log_{10}\frac{N_0}{N}$$
$$\frac{0.693}{4.7 \times 10^{10}} = \frac{2.303}{t}\log_{10}1.052$$
$$t = 3.43 \times 10^9 \text{ years}]$$

11. Hydrolysis of ester was studied by isotopic labelling method. Write down the structures of products A and B in the given reaction: **(IIT 2000)**

$$CH_3-\overset{\overset{\large O}{||}}{C}-\overset{18}{O}-H + HOH \longrightarrow A + B$$

[**Ans.** $(A)\, CH_3-\overset{\overset{\large O}{||}}{C}-OH;\ (B)\, C_2H_5-\overset{18}{O}-H$]

12. Arrange the following species in decreasing order of chemical reactivity and radioactivity:

$${}_1^1H,\ {}_1^2H,\ {}_1^3H$$

[**Ans.** Reactivity ${}_1^1H > {}_1^2H > {}_1^3H$
Radioactivity ${}_1^3H > {}_1^2H > {}_1^1H$]

13. The half life of ^{212}Pb is 10.6 hours and that of its daughter element ^{212}Bi is 60.5 minutes. After how much time will the daughter element have maximum activity?

[**Ans.** 3.78 hours]

[**Hint:** $\lambda_p = \dfrac{0.693}{10.6 \times 60}$; $\lambda_d = \dfrac{0.693}{60.5} = 0.01145\ \text{min}^{-1}$

$= 0.001089\ \text{min}^{-1}$

$$t_{max} = \frac{2.303}{(\lambda_d - \lambda_p)} \log_{10} \frac{\lambda_d}{\lambda_p}$$

$$= \frac{2.303}{0.01145 - 0.001089} \log_{10} \left[\frac{0.01145}{0.001089}\right]$$

$$= 222.2758 \log_{10} \frac{0.01145}{0.001089}$$

$= 227.1$ min

$= 3.785$ hours]

14. Radioactive element is spread over a room, its half life is 30 days. Its activity is 50 times the permissible value. After how many days will it be safe?

[**Ans.** 169.30 days]

[**Hint:** $N_0 = 50N$

$$\frac{0.693}{t_{1/2}} = \frac{2.303}{t} \log_{10}\left(\frac{N_0}{N}\right)$$

$$\frac{0.693}{30} = \frac{2.303}{t} \log_{10}\left(\frac{50N}{N}\right)$$

$t = 169.3$ days]

15. Calculate the energy released in joules and MeV in the following nuclear reaction:

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

Assume that the masses of ${}_1^2H$, ${}_2^3He$ and neutron respectively are 2.0141, 3.0160 and 1.0087 amu.

[**Ans.** 5.223×10^{-13} J; 3.260 MeV]

16. A radioactive element due to an accident in research laboratory gets embedded in its floor and walls. The initial rate of decay is 64 times the safe limit. The half life of the element is 32 days. Calculate the time after which the laboratory will be safe for use.

[**Ans.** 192 days]

[**Hint:** $N_0 = 64N$

$$\frac{0.693}{t_{1/2}} = \frac{2.303}{t} \log_{10} \frac{N_0}{N}$$

$$\frac{0.693}{32} = \frac{2.303}{t} \log_{10}\left[\frac{64N}{N}\right]$$

$t = 192$ days]

17. Radium has a half life 1600 years and its daughter element radon has a half life 3.82 days. In an enclosure, the volume of radon was found constant for a week. Explain and calculate the ratio of the number of radium and radon nuclei. Will the ratio be constant after 400 years?

[**Ans.** 1.528×10^5]

[**Hint:** $\dfrac{N_1(\text{Ra})}{N_2(\text{Rn})} = \dfrac{t_{1/2}(\text{Rn})}{t_{1/2}(\text{Ra})}$

$$\frac{N_1}{N_2} = \frac{1600}{3.82} \times 365$$

$= 1.528 \times 10^5$]

18. Calculate the radius and density of ${}_{92}^{235}U$.

[**Ans.** $R = 6.8 \times 10^{-13}$ cm; $d = 2.979 \times 10^{14}$ g / cc]

[**Hint:** $R = R_0 A^{1/3} = 1.1 \times 10^{-15} (235)^{1/3} = 6.788 \times 10^{-15}$ m

$= 6.788 \times 10^{-13}$ cm

$$d = W/V = \frac{235 \times 1.66 \times 10^{-24}}{\frac{4}{3} \times \pi \times (6.788 \times 10^{-13})^3}\ \text{g / cc}$$

$= 2.979 \times 10^{14}$ g / cc]

19. ${}_{92}^{235}U$ decays with emission of α and β-particles to form ultimately ${}_{82}^{207}Pb$. How many α and β-particles are emitted per atom of Pb produced?

[**Ans.** 7 α and 4 β]

20. The half life of radium is 1600 years. After how much time, $\dfrac{1}{16}$th part of radium will remain undisintegrated in a sample?

[**Ans.** 6400 years]

21. The half life of polonium is 140 days. In what time will 15 g of polonium be disintegrated out of its initial mass of 16 g?

[**Ans.** 560 days]

[**Hint:** Polonium left is $\dfrac{1}{16}$th of the initial, *i.e.*, 4 half lives.]

22. The activity of a radioactive isotope falls to 12.5% in 90 days. Calculate the half life and decay constant of the radioactive isotope.

[**Ans.** 30 days, 0.0231 day^{-1}]

23. The radioactivity of an element was found to be one millicurie. What will be its radioactivity after 42 days if it has half life of 14 days?

[**Ans.** 0.125 millicurie]

24. There are 10^6 radioactive nuclei in a given radioactive element. Its half life is 20 seconds. How many nuclei will remain after 10 seconds? (Given, $\sqrt{2} = 1.41$)

[**Ans.** 7×10^5 (approximately)]

[**Hint:** $N = N_0\left(\frac{1}{2}\right)^n = 10^6 \times \left(\frac{1}{2}\right)^{1/2}$ as $n = \frac{10}{20} = \frac{1}{2} = \frac{10^6}{1.41}$]

25. A radioactive element decays at such a rate that after 68 minutes only one-fourth of its original amount remains. Calculate its decay constant and half life period.

[**Ans.** $\lambda = 0.0204\ \text{min}^{-1}$, $t_{1/2} = 34$ min.]

26. One gram of a radioactive element decays by β-emission to 0.125 in 200 hours. How much more time will elapse until only 0.10 g of it is left?

[**Ans.** 21.46 hours]

27. A wooden article found in a cave has only 40% as much ^{14}C activity as a fresh piece of wood. How old is the article? ($t_{1/2}$ for $^{14}C = 5760$ years)

[**Ans.** 7617 years]

28. A sample of carbon derived from one of dead sea scrolls is found to be decaying at the rate of 12.0 disintegrations per minute per gram of carbon. Estimate the age of dead sea scrolls when carbon from living plants disintegrates at the rate of 15.3 disintegrations per minute per gram. ($t_{1/2}$ for $^{14}C = 5760$ years)

[**Ans.** 2020 years]

29. One μg of a radioactive iodine contained in thyroxine is injected into the blood of a patient. How long will it take for radioactivity to fall to 50%, 25% and 10% of the initial value? ($t_{1/2}$ for $^{131}_{53}I = 8.05$ days)

[**Ans.** 8.05 days, 16.1 days, 26.75 days]

30. 1 g radium is reduced by 2.1 mg in 5 years by alpha decay, calculate the half life period.

[**Ans.** Half life = 1672 years]

[**Hint:** Mass of radium left after 5 years = (1.0 − 0.0021) g

$$= 0.9979 \text{ g}$$

Apply $\lambda = \frac{2.303}{t}\log_{10}\frac{N_0}{N} = \frac{2.303}{5}\log_{10}\frac{1}{0.9979}$]

31. The activity of a radioactive substance falls to 87.5% of the initial value in 5 years. What is the half life of the element? Calculate the time in which the activity will fall by 87.5%.

[**Ans.** Half life = 9.52 years, $t = 28.58$ years]

32. Starting with 1.0 g of a radioactive sample, 0.25 g of it is left after 5 days. Calculate the amount which was left after one day.

[**Ans.** 0.758 g]

33. A sample of wooden artifact is found to undergo 9 disintegrations per minute per gram of carbon. What is the approximate age of the artifact? The half life of $^{14}_{6}C$ is 5730 years and radioactivity of wood recently cut is 15 disintegrations per minute per gram of carbon.

34. Xenon-127 has a half life of 36.4 days. How much of a sample of xenon that originally weighed 1.0 g remains after 20 days? **(Dhanbad 1992)**

[**Ans.** 0.6835 g]

35. Calculate the ratio of $\frac{N}{N_0}$ after an hour has passed for a radioactive material of half life 47.2 seconds.

[**Ans.** $\frac{N}{N_0} = 1.12 \times 10^{-23}$]

[**Hint:**
$$\lambda t = 2.303 \log_{10}\frac{N_0}{N}$$
$$\frac{0.693}{47.2} \times \frac{60 \times 60}{2.303} = \log_{10}\frac{N_0}{N}\ ]$$

36. The activity of the hair of an Egyptian mummy is 7 disintegrations minute^{-1} of ^{14}C. Find the age of the mummy. Given, $t_{1/2}$ of ^{14}C is 5770 years and disintegration rate of fresh sample of ^{14}C is 14 disintegrations minute^{-1}.

[**Ans.** 5770 years]

37. On analysis a sample of ^{238}U ore was found to contain 20.6 g of $^{206}_{82}Pb$ and 23.8 g of $^{238}_{92}U$. The half life period of ^{238}U is 4.50×10^9 years. If all the lead were assumed to have come from decay of $^{238}_{92}U$, what is the age of the ore? **(IIT 1996)**

[**Ans.** 4.49×10^9 years]

38. It is known that 1 g of ^{226}Ra emits 11.6×10^{17} atoms of α per year. Given, the half life of ^{226}Ra to be 1600 years, compute the value of Avogadro's number.

[**Ans.** 6.052×10^{23}]

[**Hint:** Rate = λ × number of atoms in one gram

$$= \lambda \times \frac{\text{Avogadro's number}}{226}\ ]$$

39. A uranium mineral contains ^{238}U and ^{206}Pb in the ratio of 4 : 1 by weight. Calculate the age of the mineral $t_{1/2}$ ^{238}U $= 4.5 \times 10^9$ years. Assume that all the lead present in the mineral is formed from disintegration of ^{238}U.

[**Ans.** 1.648×10^9 years]

40. In a sample of pitchblende, the atomic ratio of $^{206}Pb : {}^{238}U$ is 0.23 : 1. Calculate the age of the mineral if half life of uranium is 4.5×10^9 years. Assume that all lead has originated from uranium.

[**Ans.** 1.34×10^9 years]

41. The ratio of the atoms of two elements A and B at radioactive equilibrium is $5.0 \times 10^5 : 1$ respectively. Calculate half life of B if half life of A is 245 days.

[**Ans.** 4.9×10^{-4} days]

42. Calculate the energy released in MeV during the reaction $^{7}_{3}Li + {}^{1}_{1}H \rightarrow 2[^{4}_{2}He]$ if the masses of $^{7}_{3}Li$, $^{1}_{1}H$ and $^{4}_{2}He$ are 7.018, 1.008 and 4.004 amu respectively.

[**Ans.** 16.76 MeV]

43. 1.0 g of $^{226}_{88}Ra$ is placed in a sealed vessel. How much helium will be collected in the vessel in 100 days? ($t_{1/2}$ of radium = 1600 years)

[**Ans.** 2.12×10^{-6} g]

44. The half life period of $^{141}_{58}Ce$ is 13.11 days. It is a β-particle emitter and the average energy of the β-particle emitted is 0.442 MeV. What is the total energy emitted per second in watts by 10 mg of $^{141}_{58}Ce$?

[**Ans.** 1.84 watt]

[**Hint:** Rate of disintegrations per sec = $\lambda \times$ No. of atoms

$$= \frac{0.693}{13.11 \times 24 \times 60 \times 60} \times \frac{6.023 \times 10^{23}}{141} \times 0.01$$

Total β-particles emitted = 2.61×10^{13}

Total energy emitted = $2.61 \times 10^{13} \times 0.442 = 1.1536 \times 10^{13}$ MeV

$$\text{Energy in erg} = (1.1536 \times 10^{13})(1.6 \times 10^{-6})$$

$$\text{Energy in watt} = \frac{1.1536 \times 10^{13} \times 1.6 \times 10^{-6}}{10^7} = 1.84 \text{ watt}]$$

45. A sample of $^{90}_{38}Sr$ has an activity of 0.5 mCi. What is its specific activity? ($t_{1/2}$ of $^{90}_{38}Sr$ = 19.9 years)

[**Ans.** 7.4×10^{12} dis g^{-1} s^{-1}]

[**Hint:** Rate of disintegrations = $\lambda \times$ No. of atoms

So, No. of atoms

$$= \frac{0.5 \times 3.7 \times 10^7}{0.693} \times 19.9 \times 365 \times 24 \times 60 \times 60$$

$$= 1.675 \times 10^{16}$$

$$\text{Mass} = \frac{90 \times 1.675 \times 10^{16}}{6.023 \times 10^{23}} = 2.50 \times 10^{-6} \text{ g}$$

$$\text{Specific activity} = \frac{0.5 \times 3.7 \times 10^7}{2.5 \times 10^{-6}} = 7.4 \times 10^{12} \text{ dis g}^{-1} \text{ s}^{-1}]$$

46. Calculate the Q-value of the reaction;

$$^6_3Li + ^1_0n \longrightarrow ^4_2He + ^3_1H$$

Given, $^6_3Li = 6.015126$ amu, $^4_2He = 4.002604$ amu

$^3_1H = 3.016049$ amu, $^1_0n = 1.008665$ amu

[**Ans.** +4.7835 MeV]

47. The disintegration rate of a certain radioactive sample at any instant is 4750 dpm. Five minutes later, the rate becomes 2700 dpm. Calculate half life of sample.

[**Ans.** $t_{1/2} = 6.13$ minute]

48. One of the hazards of nuclear explosion is the generation of ^{90}Sr and its subsequent incorporation in bones. This nuclide has a half life of 28.1 years. Suppose one microgram was absorbed by a new-born child, how much ^{90}Sr will remain in his bones after 20 years? (IIT 1995)

[**Ans.** 0.61 μg]

[**Hint:** $t = \frac{2.303}{\lambda} \log \frac{\text{initial}}{\text{remaining}}$

$$\lambda = \frac{2.303}{28.1} y^{-1} t = 20y, \text{ initial} = 1\,\mu g, \text{ remaining} = x\,\mu g$$

$$20 = \frac{2.303}{0.693} \times 28.1 \log \frac{1}{x}$$

$$x = 0.61\,\mu g]$$

49. It has been estimated that the carbon-14 in the atmosphere is responsible for producing 60 atoms of nitrogen-14 and 60 electrons every hour for each gram of carbon. We can quote this disintegration rate as 60 counts hour^{-1} g^{-1}. A sample of sea shell found near a sea shore was found to have a count of 4 counts hour^{-1} g^{-1}. Estimate the age of the shell. ($t_{1/2}$ for ^{14}C = 5730 years).

[**Ans.** 21000 years (approximately)]

50. Upon irradiating californium with neutrons, a scientist discovered a new nuclide having mass number of 250 and half life of 0.5 hours. Three hours after the irradiation, the observed radioactivity due to the nuclide was 10 dis/min. How many atoms of the nuclide were prepared initially?

[**Ans.** 2.8×10^4]

OBJECTIVE QUESTIONS

Set-1: Questions with single correct answer

1. Natural radioactivity was discovered by:
   (a) Rutherford (b) Becquerel
   (c) Curie (d) Schmidt
2. Radioactivity is due to:
   (a) stable electronic configuration
   (b) unstable electronic configuration
   (c) stable nucleus
   (d) unstable nucleus
3. Radioactivity is essentially:
   (a) a chemical activity (b) a physical property
   (c) a nuclear property (d) a property of non-metals
4. Radioactivity is generally found in:
   (a) light nuclei (b) stable nuclei
   (c) heavy nuclei (d) nuclei of intermediate mass
5. The activity of radioisotope changes with:
   (a) temperature (b) pressure
   (c) chemical environment (d) none of these
6. The rays are given off by a radioactive element from:
   (a) nucleus (b) valence electrons
   (c) all the orbits (d) outer orbit
7. The alpha particles are:
   (a) high energy electrons
   (b) positively charged hydrogen ions
   (c) high energy X-ray radiations
   (d) double positively charged helium nuclei
8. The emission of beta particles is from: (CBSE 1999)
   (a) the valence shell of an atom
   (b) the inner shell of an atom
   (c) the nucleus due to the nuclear conversion proton $\rightarrow$ neutron + electron
   (d) the nucleus due to the nuclear conversion neutron $\rightarrow$ proton + electron
9. Identify the nuclear reaction that differs from the rest:
   (a) Positron emission (b) K-capture
   (c) β-decay (d) α-decay
   (e) γ-decay [PET(Kerala) 2008]
   [**Hint :** Only γ-emission does not change the n/p (Neutron/Proton, ratio) of the parent element.]
10. Gamma rays are: (MLNR 1990)
    (a) high energy electrons
    (b) low energy electrons
    (c) high energy electromagnetic waves
    (d) high energy positrons
11. Radium is a radioactive substance. It dissolves in dilute H_2SO_4 and forms a compound radium sulphate. The compound is:
    (a) no longer radioactive
    (b) half as radioactive as the radium content
    (c) as radioactive as the radium content
    (d) twice as radioactive as the radium content
12. The velocity of α-rays is approximately:
    (a) equal to that of the velocity of light
    (b) $\frac{1}{10}$th of the velocity of light
    (c) 10 times more than the velocity of light
    (d) uncomparable to the velocity of light
13. α-rays have ionisation power because they possess:
    (a) lesser kinetic energy
    (b) higher kinetic energy
    (c) lesser penetration power
    (d) higher penetration power
14. The radiations from a naturally occurring radioactive substance as seen after deflection by a magnetic field in one direction are:
    (a) definitely α-rays (b) definitely β-rays
    (c) both α and β-rays (d) either α or β-rays
15. Which of the following statements about radioactivity is wrong?
    (a) It involves outer electrons activity
    (b) It is not affected by temperature or pressure
    (c) It is an exothermic process
    (d) The radioactivity of an element is not affected by any other element compounded by it
16. The radioactivity of uranium minerals is usually more in comparison to pure uranium. This is due to presence of . . . in the mineral.
    (a) actinium (b) thorium
    (c) radium (d) plutonium
17. Radioactive disintegration differs from a chemical change in being: (MLNR 1991)
    (a) an exothermic change
    (b) a spontaneous process
    (c) a nuclear process
    (d) an unimolecular first order reaction
18. The ionising power of α, β and γ-rays is in the decreasing order:
    (a) $\alpha > \beta > \gamma$ (b) $\beta > \alpha > \gamma$
    (c) $\gamma > \alpha > \beta$ (d) $\beta > \gamma > \alpha$
19. Which of the following radiations have least effect on both the photographic plate and zinc sulphide screen?
    (a) α-rays (b) β-rays
    (c) γ-rays (d) All have equal effect
20. γ-rays are emitted from a nucleus due to:
    (a) high n/p ratio
    (b) excess energy possessed by nucleus after emission of α or β-particles
    (c) fission reaction
    (d) fusion reaction
21. If a radioactive substance is placed in vacuum at 100°C, its rate of disintegration in comparison to one atmospheric pressure:

(a) is not affected
(b) increases
(c) decreases
(d) increases when the product is gas

22. In α-decay, n/p ratio:
(a) may increase or decrease
(b) remains constant
(c) decreases
(d) increases

23. In β-decay, n/p ratio:
(a) remains unchanged (b) may increase or decrease
(c) increases (d) decreases

24. A device used for the measurement of radioactivity is:
(a) mass spectrometer (b) cyclotron
(c) nuclear reactor (d) G.M. counter

25. Which of the following does not contain material particles? [CET (Pb.) 1991]
(a) α-rays (b) β-rays (c) γ-rays (d) Anode rays

26. If by mistake some radioactive substance gets into human body, then from the point of view of radiation damage, the most harmful will be one that emits:
(a) γ-rays (b) neutrons (c) β-rays (d) α-rays

27. Radioactive decay is a reaction of:
(a) zero order (b) first order
(c) second order (d) third order

28. If n/p ratio is high, the nucleus tends to stabilise by:
(a) the emission of a β-particle
(b) neutron capture
(c) losing a positron
(d) any one of the above

29. Emission of β-particles by an atom of an element results in the formations of:
(a) isobar (b) isomer (c) isotope (d) isotone

30. Which of the following process will cause the emission of X-ray?
(a) α-emission (b) β-emission
(c) K-electron capture (d) γ-emission

31. When a β-particle is emitted by the atom of a radioactive element, the new species formed possesses: [PET (MP) 1990]
(a) same atomic mass and atomic number less by one unit
(b) same atomic mass and atomic number less by two units
(c) same atomic mass and atomic number higher by one unit
(d) same atomic mass and atomic number higher by two units

32. Successive emission of an α-particle and two β-particles by an atom of a radioactive element results in the formation of its: [IIT (Screening) 1993]
(a) isobar (b) isomer (c) isotone (d) isotope

33. The isotope $^{235}_{92}U$ decays in a number of steps to an isotope of $^{207}_{82}Pb$. The groups of particles emitted in this process will be:
(a) $4\alpha, 7\beta$ (b) $6\alpha, 4\beta$ (c) $7\alpha, 4\beta$ (d) $10\alpha, 8\beta$

34. The number of α and β-particles emitted in the nuclear reaction $^{228}_{90}Th \longrightarrow {}^{212}_{83}Bi$ are: [MLNR 1992; JEE (Orissa) 2010]
(a) $8\alpha, 1\beta$ (b) $4\alpha, 7\beta$ (c) $3\alpha, 7\beta$ (d) $4\alpha, 1\beta$

35. $^{210}_{84}Po \longrightarrow {}^{206}_{82}Pb + {}^{4}_{2}He$
In above reaction, predict the position of Po in the periodic table when lead belongs to IVB group:
(a) IIA (b) VIB (c) IVB (d) VB

36. When $^{226}_{88}Ra$ emits an α-particle, the new element formed belongs to:
(a) third group (b) zero group
(c) fourth group (d) second group

37. The radius of nucleus is: **(VITEEE 2007)**
(a) proportional to its mass number
(b) inversely proportional to its mass number
(c) proportional to the cube root of its mass number
(d) not related to its mass number

38. The last product of $4n$ series is:
(a) $^{208}_{82}Pb$ (b) $^{207}_{82}Pb$ (c) $^{209}_{82}Pb$ (d) $^{210}_{83}Bi$

39. $4n+2$ series is known as:
(a) actinium series (b) thorium series
(c) uranium series (d) neptunium series

40. A radioactive element A on disintegration gives two elements B and C. If B is helium and C is the element of atomic number 90 and atomic mass 234, the element A is:
(a) $^{238}_{92}U$ (b) $^{234}_{88}Ra$ (c) $^{234}_{90}Th$ (d) $^{234}_{91}Pa$

41. Group displacement law was given by:
(a) Becquerel (b) Rutherford
(c) Mendeleeff (d) Soddy and Fajan

42. ^{234}U has 92 protons and 234 nucleons total in its nucleus. It decays by emitting an alpha particle. After the decay it becomes: **(VITEEE 2008; DUMET 2010)**
(a) ^{232}U (b) ^{232}Pa (c) ^{230}Th (d) ^{230}Ra

43. Starting from radium, the radioactive disintegration process terminates when the following is obtained:
(a) lead (b) radon (c) radium A (d) radium B

44. The only, most stable nucleus formed by bombarding either $^{27}_{13}Al$ by neutrons or $^{23}_{11}Na$ by deutrons is: [CET (J&K) 2007]
(a) $^{30}_{15}P$ (b) $^{30}_{14}Si$ (c) $^{24}_{12}Mg$ (d) $^{137}_{56}Ba$

45. Quantity of radioactive material which undergoes 10^6 disintegrations per second is called:
(a) Becquerel (b) Rutherford
(c) Curie (d) Faraday

46. The number of α-particles emitted per second by 1 g of ^{226}Ra is 3.7×10^{10}. The decay constant is:
(a) 1.39×10^{-11} sec^{-1} (b) 13.9×10^{-11} sec^{-1}
(c) 139×10^{-10} sec^{-1} (d) 13.9×10^{-10} sec^{-1}

[**Hint:** $\dfrac{\text{No. of atoms disintegrating per second}}{\text{Total number of atoms present}} = \lambda$

or $\dfrac{3.7 \times 10^{10}}{\dfrac{6.02 \times 10^{23}}{226}} = \dfrac{226 \times 3.7 \times 10^{10}}{6.02 \times 10^{23}} = \lambda$]

47. The decay constant of ^{226}Ra is 1.37×10^{-11} sec^{-1}. A sample of ^{226}Ra having an activity of 1.5 millicurie will contain ...... atoms:
(a) 4.05×10^{18} (b) 3.7×10^{17} (c) 2.05×10^{15} (d) 4.7×10^{10}

[**Hint:** 1 millicurie $= 3.7 \times 10^7$ disintegrations per sec

1.5 millicurie $= 5.55 \times 10^7$ disintegrations per sec

$$\frac{5.55 \times 10^7}{N_0} = \lambda = 1.37 \times 10^{-11}]$$

48. One curie of activity is equivalent to:
(a) 3.7×10^{17} disintegrations per sec
(b) 3.7×10^{10} disintegrations per sec
(c) 3.7×10^{14} disintegrations per sec
(d) 3.7×10^3 disintegrations per sec

49. A sample of $^{40}_{19}K$ contains invariably $^{40}_{18}Ar$. This is because $^{40}_{19}K$ has tendency to undergo: **[JEE (Orissa) 2006]**
(a) α-decay (b) positronium decay
(c) β-decay (d) γ-decay

50. The value of disintegration constant of a radioactive isotope:
(a) decreases with increasing temperature
(b) decreases with increasing pressure
(c) increases with increasing concentration
(d) is independent of temperature, pressure and concentration

51. If the amount of a radioactive substance is increased three times, the number of atoms disintegrating per unit time would:
(a) be double
(b) not be change
(c) be triple
(d) be $\frac{1}{3}$rd of the original number of atoms

52. The half life of a radioactive element depends upon:
(a) the amount of the element
(b) the temperature
(c) the pressure
(d) none of these

53. The decay constant of a radioactive sample is λ. The half life and mean life of the sample are respectively: **(MLNR 1990)**
(a) $1/\lambda$, $\ln 2/\lambda$ (b) $\ln 2/\lambda$, $1/\lambda$
(c) $\lambda \ln 2$, $1/\lambda$ (d) λ / Pn_2, $1/\lambda$

54. Average life of a radioactive substance is:
(a) 0.44 times of half life (b) 2.44 times of half life
(c) 1.44 times of half life (d) 0.693 times of half life

55. Radium has atomic mass 226 and half life of 1600 years. The number of disintegrations per second per gram are: **(BHU 1990)**
(a) 4.8×10^{10} (b) 3.7×10^8
(c) 9.2×10^6 (d) 3.7×10^{10}

[**Hint:**
$$\frac{\text{No. of disintegrations per sec}}{\text{Total no. of atoms in one gram of Ra}} = \lambda$$
$$= \frac{0.693}{1600 \times 365 \times 24 \times 60 \times 60}$$
or No of disintegrations per sec
$$= \frac{0.693 \times 6.023 \times 10^{23}}{1600 \times 365 \times 24 \times 60 \times 60 \times 226}]$$

56. A radioactive sample has a half life 1500 years. A sealed tube containing 1 g of the sample will contain after 3000 years: **(MLNR 1994)**
(a) 1 g of the sample (b) 0.5 g of the sample
(c) 0.25 g of the sample (d) 0.01 g of the sample

57. ^{14}C has a half life of 5760 years. 100 mg of the sample containing ^{14}C is reduced to 25 mg in: **[PET (Raj.) 2006]**
(a) 11520 years (b) 2880 years
(c) 1440 years (d) 17280 years

58. If $3/4$ quantity of radioactive substance disintegrates in 2 hours, its half life period will be: **(BHU 2006)**
(a) 15 minutes (b) 30 minutes
(c) 60 minutes (d) 90 minutes

59. Initial mass of a radioactive element is 40 g. How many grams of it would be left after 24 years if its half life period is of 8 years?
(a) 2 (b) 5 (c) 10 (d) 20

60. Half life of radium is 1580 years. It remains $1/16$ after the years.......: **(VMMC 2007)**
(a) 1580 yrs (b) 3160 yrs (c) 4740 yrs (d) 6320 yrs

61. If half life period of radium is 1600 years, its average life period will be:
(a) 2304 years (b) 4608 years
(c) 230.4 years (d) 23040 years

62. A radioactive isotope having a half life of 3 days was received after 12 days. It was found that there were 3 g of the isotope in the container. The initial mass of the isotope when packed was:
(a) 48 g (b) 36 g (c) 24 g (d) 12 g

63. Radioactivity of a radioactive element remains $1/10$ of the original radioactivity after 2.303 seconds. The half life period is:
(a) 2.303 (b) 0.2303 (c) 0.693 (d) 0.0693

[**Hint:**
$$\lambda = \frac{2.303}{t} \log_{10} \frac{a}{(a-x)}$$
or
$$\lambda = \frac{2.303}{2.303} \log_{10} \frac{1}{1/10} = 1, T = \frac{0.693}{\lambda} = 0.693]$$

64. A freshly prepared radioactive source of half life period 2 hours emits radiations of intensity which is 64 times the permissible safe level. The minimum time after which it would be possible to work with this source is:
(a) 6 hours (b) 12 hours
(c) 24 hours (d) 48 hours

65. A radio isotope has a half life of 10 days. If today there is 125 g of it left, what was its mass 40 days earlier? **(EAMCET 1991)**
(a) 600 g (b) 1000 g (c) 1250 g (d) 2000 g

66. The half life period of four isotopes is given below:
(i) 7.6 years (ii) 4000 years
(iii) 6000 years (iv) 3.2×10^5 years
Which of the above isotopes is most stable?
(a) (iv) (b) (iii) (c) (ii) (d) (i)

67. The first indication that a stable nucleus can be broken down was afforded by:
(a) Rutherford (b) Madam Curie
(c) Soddy (d) Schmidt

68. The first stable isotope which was transmuted by artificial means was:
(a) $^{16}_{8}O$ (b) $^{14}_{7}N$ (c) $^{12}_{6}C$ (d) $^{9}_{4}Be$

69. The instability of a nucleus is due to: **(AIIMS 1999)**
(a) high, proton : electron ratio
(b) high, proton : neutron ratio
(c) low, proton : electron ratio
(d) low, proton : neutron ratio

70. When $^{27}_{13}Al$ is bombarded with α-particles, a radioactive isotope of phosphorus $^{30}_{15}P$ with the emission of . . . is formed. **[CET (Gujarat) 2006]**
(a) neutrons (b) protons
(c) positrons (d) electrons

71. Nuclear reaction accompanied with emission of neutron(s) is: **[PMT (MP) 1991]**
(a) $^{27}_{13}Al + ^{4}_{2}He \longrightarrow ^{30}_{15}P + ^{1}_{0}n$
(b) $^{12}_{6}C + ^{1}_{1}H \longrightarrow ^{13}_{7}N$
(c) $^{30}_{15}P \longrightarrow ^{30}_{14}Si + ^{0}_{1}e$
(d) $^{240}_{96}Am + ^{4}_{2}He \longrightarrow ^{244}_{97}Bk + ^{0}_{1}e$

72. Which of the following transformations is not correct?
(a) $^{75}_{33}As + ^{4}_{2}He \longrightarrow ^{78}_{35}Br + ^{1}_{0}n$
(b) $^{7}_{3}Li + ^{1}_{1}H \longrightarrow ^{7}_{4}Be + ^{1}_{0}n$
(c) $^{45}_{21}Sc + ^{1}_{0}n \longrightarrow ^{45}_{20}Ca + ^{1}_{0}n$
(d) $^{209}_{83}Bi + ^{2}_{1}H \longrightarrow ^{210}_{84}Po + ^{1}_{0}n$

73. The reaction, $^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{140}_{56}Ba + ^{93}_{36}Kr + 3\,^{1}_{0}n$ represents:
(a) artificial radioactivity
(b) nuclear fission
(c) nuclear fusion
(d) none of these

74. $^{14}_{6}C$ in upper atmosphere is generated by the nuclear reaction: **[PET (MP) 1993]**
(a) $^{14}_{7}N + ^{1}_{1}H \longrightarrow ^{14}_{6}C + ^{0}_{+1}e + ^{1}_{1}H$
(b) $^{14}_{7}N \longrightarrow ^{14}_{6}C + ^{0}_{+1}e$
(c) $^{14}_{7}N + ^{1}_{0}n \longrightarrow ^{14}_{6}C + ^{1}_{1}H$
(d) $^{14}_{7}N + ^{1}_{1}H \longrightarrow ^{11}_{6}C + ^{4}_{2}He$

75. In the transformation of $^{238}_{92}U$ to $^{234}_{92}U$, if one emission is an α-particle, what should be the other emission(s)? **(AIEEE 2006)**
(a) two β^- (b) two β^- and one β^+
(c) one β^- and one γ (d) one β^+ and one β^-
[**Hint:** $^{238}_{92}U \longrightarrow ^{234}_{92}U + ^{4}_{2}He + 2\,^{0}_{-1}e$]

76. The reaction, $^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{3}_{2}He + ^{1}_{0}n$ is called: **(CPMT 1990)**
(a) fusion (b) fission
(c) endothermic reaction (d) spontaneous reaction

77. When the nucleus of uranium is bombarded with neutrons, it breaks up into two nuclei of nearly equal mass. This process is called:
(a) nuclear fission (b) nuclear fusion
(c) physical change (d) artificial radioactivity

78. Which one of the following is an artificial fuel for nuclear reactors?
(a) ^{238}U (b) ^{239}Pu (c) ^{235}U (d) ^{232}Th

79. A positron is emitted from $^{23}_{11}Na$. The ratio of the atomic mass and atomic number of the resulting nuclide is: **(IIT 2007)**
(a) 22/10 (b) 22/11 (c) 23/10 (d) 23/12
[**Hint:** $^{1}_{1}H \longrightarrow ^{1}_{0}n + \underset{\text{Positron}}{^{0}_{+1}e}$

On positron emission, proton is converted to neutron, therefore, atomic number decreases by one unit but atomic mass remains constant.

$\therefore \frac{n}{p}$ ratio $= \frac{23}{10}$]

80. Hydrogen bomb is based on the principle of: **(AIEEE 2005)**
(a) nuclear fission (b) natural radioactivity
(c) nuclear fusion (d) artificial radioactivity

81. In nuclear reactors, the speed of neutrons is slowed down by:
(a) heavy water (b) ordinary water
(c) zinc rods (d) molten caustic soda

82. Which of the following is not a fissile material?
(a) ^{235}U (b) ^{238}U
(c) ^{233}U (d) ^{239}Pu

83. Which one of the following statements is wrong?
(a) An atom bomb is based on nuclear fission
(b) In atomic reactor, the chain reaction is carried out under control
(c) Fission reactions are the sources of sun's energy
(d) Hydrogen bomb is always associated with atomic bomb

84. The fuel in atomic pile is:
(a) carbon (b) sodium
(c) petroleum (d) uranium

85. Large energy released in atomic bomb explosion is mainly due to:
(a) conversion of heavier to lighter atoms
(b) products having lesser mass than initial substance
(c) release of neutrons
(d) release of electrons

86. One gram of mass is equal to:
(a) 5×10^{10} erg (b) 9×10^{20} erg
(c) 7×10^{5} erg (d) 11×10^{12} erg

87. If the energy released by burning 1 g of carbon is 3×10^{11} erg, then the amount of energy released by converting 1 g of carbon completely to nuclear energy would be equivalent to energy produced by burning ...... g of carbon.
(a) 10^{6} (b) 10^{8}
(c) 9×10^{20} (d) 3×10^{10}

88. Liquid sodium is used in nuclear reactors. Its function is:
(a) to collect the reaction products
(b) to act as heat exchanger
(c) to absorb the neutrons in order to control the chain reaction
(d) to act as moderator to slow down the neutrons

89. A sample of rock from moon contains equal number of atoms of uranium and lead ($t_{1/2}$ for U = 4.5×10^{9} years). The age of the rock would be: **[UGET Manipal (Medical) 2006]**
(a) 9.0×10^{9} years (b) 4.5×10^{9} years
(c) 13.5×10^{9} years (d) 2.25×10^{9} years

[Hint: $t = \dfrac{2.303}{\lambda} \log_{10}\left[1 + \dfrac{\text{No. of Pb atoms}}{\text{No. of U atoms}}\right]$
$= \dfrac{2.303 \times 4.5 \times 10^9}{0.693} \log_{10}(1+1)$]

90. In treatment of cancer, which of the following is used?
(a) ${}^{131}_{53}I$ (b) ${}^{32}_{15}P$ (c) ${}^{60}_{27}Co$ (d) ${}^{2}_{1}H$

91. In nuclear reactor, chain reaction is controlled by introducing: (AIIMS 1991)
(a) cadmium rod (b) iron rod
(c) platinum rod (d) graphite rod

92. Wooden artifact and freshly cut tree are 7.6 and 15.2 $min^{-1} g^{-1}$ of carbon ($t_{1/2}$ = 5760 years) respectively. The age of the artifact is:
(a) 5760 years (b) $5760 \times \dfrac{15.2}{7.6}$ years
(c) $5760 \times \dfrac{7.6}{15.2}$ years (d) $5760 \times (15.2 - 7.6)$ years
[Hint: $t = \dfrac{2.303}{\lambda} \cdot \log \dfrac{15.2}{7.6}$ or $t = \dfrac{2.303 \times 5760}{0.693} \log 2$]

93. The isotope used for dating archaeological finding is:
(a) ${}^{1}_{1}H$ (b) ${}^{18}_{8}O$ (c) ${}^{14}_{6}C$ (d) ${}^{235}_{92}U$

94. Which one of the following statements is wrong?
(a) Neutron was discovered by Chadwick
(b) Nuclear fission was discovered by Hahn and Strassmann
(c) Polonium was discovered by Madam Curie
(d) Nuclear fusion was discovered by Fermi

95. Neutrons are more effective projectiles than protons because they:
(a) are attracted by nuclei (b) are not repelled by nuclei
(c) travel with high speed (d) none of these

96. The source of enormous energy of sun is:
(a) fusion of hydrogen to form helium
(b) fission of uranium
(c) fusion of deuterium and tritium
(d) fusion of tritium to form helium

97. In the neutron-induced fission of ${}^{235}_{92}U$; one of the products is ${}^{90}_{37}Rb$. In this mode, another nuclide and two neutrons are also produced. The other nuclide is: [PMT (HP) 2006]
(a) ${}^{144}_{54}Xe$ (b) ${}^{144}_{55}Co$ (c) ${}^{145}_{55}Co$ (d) ${}^{143}_{54}Xe$

98. ${}^{228}_{88}X - 3\alpha - \beta \longrightarrow Y$. The element Y is: [JEE (Orissa) 2008]
(a) ${}^{216}_{82}Pb$ (b) ${}^{217}_{82}Pb$
(c) ${}^{218}_{83}Bi$ (d) ${}^{216}_{83}Bi$

99. Which radioactive isotope is used to detect tumours?
(a) ${}^{74}As$ (b) ${}^{24}Na$ (c) ${}^{131}I$ (d) ${}^{60}Co$

100. Natural uranium consists of ${}^{235}U$:
(a) 99% (b) 50%
(c) 10% (d) 0.7%

101. In the nuclear reaction, ${}^{14}_{7}N + {}^{4}_{2}He \longrightarrow {}^{p}_{q}X + {}^{1}_{1}H$ the nucleus X is: (MLNR 1995)
(a) nitrogen of mass 16 (b) nitrogen of mass 17
(c) oxygen of mass 16 (d) oxygen of mass 17

102. The radioactive decay of ${}^{88}_{35}X$ by a beta emission produces an unstable nucleus which spontaneously emits a neutron. The final product is: (MLNR 1995)
(a) ${}^{88}_{37}X$ (b) ${}^{89}_{35}Y$
(c) ${}^{88}_{34}Z$ (d) ${}^{87}_{36}W$

103. ${}^{27}_{13}Al$ is a stable isotope. ${}^{29}_{13}Al$ is expected to disintegrate by: (IIT 1996)
(a) α-emission (b) β-emission
(c) positron emission (d) proton emission

104. The mass defect of the nuclear reaction ${}^{8}_{5}B \rightarrow {}^{8}_{4}Be + {}^{0}_{1}e$ is: (JIPMER 1999)
(a) Δm = atomic mass of $({}^{8}_{4}Be - {}^{8}_{5}B)$
(b) Δm = atomic mass of $({}^{8}_{4}Be - {}^{8}_{5}B)$ + mass of one electron
(c) Δm = atomic mass of $({}^{8}_{4}Be - {}^{8}_{5}B)$ + mass of the positron
(d) Δm = atomic mass of $({}^{8}_{4}Be - {}^{8}_{5}B)$ + mass of two electrons

105. Which of the following is the man-made radioactive disintegration series?
(a) Thorium series (b) Neptunium series
(c) Uranium series (d) Actinium series

106. The density of nucleus is of the order of:
(a) 10^5 kg m^{-3} (b) 10^{10} kg m^{-3}
(c) 10^{17} kg m^{-3} (d) 10^{25} kg m^{-3}

107. A radioactive isotope having a half life of 3 days was received after 12 days. It was found that there were 3 g of the isotope in the container. The initial weight of the isotope when packed was:
(a) 12 g (b) 24 g
(c) 36 g (d) 48 g

108. A radioactive substance is decaying with $t_{1/2}$ = 30 days. On being separated into two fractions, one of the fractions, immediately after separation, decays with $t_{1/2}$ = 2 days. The other fraction, immediately after separation would show:
(a) constant activity (b) increasing activity
(c) decay with $t_{1/2}$ = 30 days (d) decay with $t_{1/2}$ = 28 days

109. A radioactive substance has a constant activity of 2000 disintegrations per minute. The material is separated into two fractions, one of which has an initial activity of 1000 disintegrations per second while the other fraction decays with $t_{1/2}$ = 24 hours. To the total activity in both samples after 48 hours of separation is:
(a) 1500 (b) 1000 (c) 1250 (d) 2000

110. A radioactive element X has an atomic number of 100. It decays directly into an element Y which decays directly into the element Z. In both processes a charged particle is emitted. Which of the following statements would be true?
(a) Y has an atomic number of 102
(b) Y has an atomic number of 101
(c) Z has an atomic number of 100
(d) Z has an atomic number of 99

111. Three isotopes of an element have mass numbers M, $(M + 1)$ and $(M + 2)$. If the mean mass number is $(M + - 0.5)$, then which of the following ratios may be accepted for M, $(M + 1)$, $(M + 2)$ in that order?
(a) 1 : 1 : 1 (b) 4 : 1 : 1 (c) 3 : 2 : 1 (d) 2 : 1 : 1

112. Enrichment of uranium is made by:
(a) distillation (b) diffusion
(c) evaporation (d) bleaching

113. Let us consider emission of α-particle from uranium nucleus:

$$_{92}U^{235} - {}_2He^4 \rightarrow {}_{90}Th^{231}$$

$e = 92$	$e = 0$	$e = 90$
$p = 92$	$p = 2$	$p = 90$
$n = 143$	$n = 2$	$n = 141$

Shortage of two electrons in thorium is due to:
(a) conversion of electron to positron
(b) combination with positron to evolve energy
(c) annihilation
(d) absorption in the nucleus

114. Artificial radioactive elements are present in:
(a) *s*-block (b) *p*-block (c) *d*-block (d) *f*-block

115. Half life of $_6C^{14}$, if its λ is 2.13×10^{-4} yrs, is: (CBSE 1999)
(a) 3.5×10^4 years (b) 3×10^3 years
(c) 2×10^2 years (d) 4×10^3 years

116. The ^{60}Co isotope decays with a half life of 5.3 years. How long would it take for 7 / 8 of a sample of 500 mg of ^{60}Co to disintegrate? (SCRA 2007)
(a) 21.2 years (b) 15.9 years
(c) 10.6 years (d) 5.3 years

117. Isotope of uranium used in atomic bomb is : [PET (MP) 2008]
(a) $^{237}_{92}U$ (b) $^{238}_{92}U$ (c) $^{239}_{92}U$ (d) $^{235}_{92}U$

118. Which among the following is wrong about isodiapheres?
(a) They have the same difference of neutrons and protons or same isotopic number
(b) Nuclide and its decay product after α-emission are isodiapheres
(c) $_ZA^M \longrightarrow {}_{Z-2}B^{M-4} + {}_2He^4$
'*A*' and '*B*' are isodiapheres
(d) All are correct

119. At radioactive equilibrium, the ratio of two atoms *A* and *B* are $3.1 \times 10^9 : 1$. If half life of '*A*' is 2×10^{10} yrs, what is half life of '*B*'?
(a) 6.45 yrs (b) 4.65 yrs (c) 5.46 yrs (d) 5.64 yrs

120. The decay constant for an α-decay of Th^{232} is $1.58 \times 10^{-10}\ s^{-1}$. How many α-decays occur from 1 g sample in 365 days?
(a) 2.89×10^{19} (b) 1.298×10^{19}
(c) 8.219×10^{19} (d) None of these

121. What percentage of decay takes place in the average life of a substance?
(a) 63.21% (b) 36.79% (c) 90% (d) 99%

122. SI unit of radioactive decay is: [PMT (MP) 2006]
(a) curie (b) rutherford
(c) becquerel (d) all of these

123. The number of neutrons accompanying the formation of $^{139}_{54}Xe$ and $^{94}_{38}Sr$ from the absorption of a slow neutron by $^{235}_{92}U$, followed by nuclear fission is: (IIT 1999)
(a) 0 (b) 2 (c) 1 (d) 3

124. Thiosulphate ion ($S_2O_3^{2-}$) on acidification changes to SO_2 along with precipitation of sulphur,

$$^{35}S^{32}SO_3^{2-} + 2H^+ \longrightarrow H_2O + SO_2 + S$$

which is the correct statement?
(a) S^{35} is in sulphur (b) S^{35} is in SO_2
(c) S^{35} is in both (d) S^{35} is in none

125. A radioactive element decays as,

$$X \xrightarrow[t_{1/2} = 30\text{ min}]{\alpha \text{ decay}} Y \xrightarrow[t_{1/2} = 2\text{ days}]{(-2\beta)\beta \text{ decay}} Z$$

which of the following statements about this decay process is incorrect?
(a) After two hours, less than 10% of the initial *X* is left
(b) Maximum amount of *Y* present at any time before 30 min is less than 50% of the initial amount of *X*
(c) Atomic number of *X* and *Z* are same
(d) The mass number of *Y* is greater than *X*

126. Among the following nuclides, the highest tendency to decay by (β^+) emission is:
(a) ^{59}Cu (b) ^{63}Cu (c) ^{67}Cu (d) ^{68}Cu

127. Identify [*A*] and [*B*] in the following:
$^{227}_{89}Ac \xrightarrow{-\beta} [A] \xrightarrow{-\alpha} [B] \xrightarrow{-\alpha} Rn$ [JEE (WB) 2010]
(a) Po, Rn (b) Th, Po (c) Ra, Th (d) Th, Ra
[**Hint:** $^{227}_{89}Ac \xrightarrow{-\beta} {}^{227}_{90}Th \xrightarrow{-\alpha} {}^{223}_{88}Ra$]

128. β-particle is emitted in radioactivity by: (AIEEE 2002)
(a) conversion of proton to neutron
(b) from outermost orbit
(c) conversion of neutron to proton
(d) β-particle is not emitted

129. The nuclear reaction,

$$^{63}_{29}Cu + {}^4_2He \longrightarrow {}^{37}_{17}Cl + 14\ {}^1_1H + 16\ {}^1_0n$$

is referred to as: [PET (MP) 2002]
(a) spallation reaction (b) fusion reaction
(c) fission reaction (d) chain reaction

130. ^{226}Ra disintegrates at such a rate that after 3160 yrs only one fourth of its original amount remains. Half life of ^{226}Ra will be: [PET (MP) 2002]
(a) 790 years (b) 3160 years
(c) 1580 years (d) 6230 years

131. $^{235}_{92}U$ nucleus absorbs a neutron and disintegrates into $^{139}_{54}Xe$, $^{94}_{38}Sr$ and '*x*'. What will be the product *x*? [CBSE (PMT) 2002]
(a) 3-neutrons (b) 2-neutrons
(c) α-particles (d) β-particles

132. A radioisotope, tritium (^3_1H) has half life of 12.3 years. If the initial amount of tritium is 32 mg, how many milligrams of it would remain after 49.2 years? [CBSE (PMT) 2003]
(a) 1 mg (b) 2 mg
(c) 4 mg (d) 8 mg

133. The radio nuclide $^{234}_{90}Th$ undergoes two successive β-decays followed by one α-decay. The atomic number and mass number of the resulting radio nuclide are: (AIEEE 2003)

(a) 92, 234 (b) 94, 230 (c) 90, 230 (d) 92, 230

134. The half life of a radioactive isotope is three hours. If the initial mass of isotope were 256 g, the mass of it remaining undecayed after 18 hours would be: (AIEEE 2003)
(a) 4 g (b) 8 g (c) 12 g (d) 16 g

135. Consider the following nuclear reactions:

$$^{238}_{92}M \rightarrow ^{X}_{Y}N + 2\,^{4}_{2}He;\quad ^{X}_{Y}N \longrightarrow ^{A}_{B}L + 2\beta^+$$

The number of neutrons in the element L is: (AIEEE 2004)
(a) 142 (b) 144 (c) 140 (d) 146

136. A radioactive element gets spilled over the floor of a room. Its half life period is 30 days. If initial rate is ten times the permissible value, after how many days will it be safe to enter the room? (AIEEE 2007)
(a) 100 days (b) 1000 days
(c) 300 days (d) 10 days

137. A photon of hard gamma radiation knocks a proton out of $^{24}_{12}Mg$ nucleus to form: (AIEEE 2005)
(a) the isotope of parent nucleus
(b) the isobar of parent nucleus
(c) the nuclide of $^{23}_{11}Na$
(d) the isobar of $^{23}_{11}Na$

138. The element $^{232}_{90}Th$ belongs to thorium series. Which of the following will act as the end product of the series? [BHU (Pre.) 2005]
(a) $^{208}_{82}Pb$ (b) $^{209}_{82}Bi$ (c) $^{206}_{82}Pb$ (d) $^{207}_{82}Pb$

139. $^{238}_{92}U$ emits 8α-particles and 6β-particles. The neutron/proton ratio in the product nucleus is: (AIIMS 2005)
(a) 60/41 (b) 61/40 (c) 62/41 (d) 61/42

140. Calculate the mass loss in the following:

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

Given the masses: $^{2}_{1}H = 2.014$ amu, $^{3}_{1}H = 3.016$ amu; $^{4}_{2}He = 4.004$ amu, $^{1}_{0}n = 1.008$ amu. [PET (Kerala) 2005]
(a) 0.018 amu (b) 0.18 amu
(c) 0.0018 amu (d) 1.8 amu
(e) 18 amu

141. A nuclide of an alkaline earth metal undergoes radioactive decay by emission of the α-particles in succession. The group of the periodic table to which the resulting daughter element would belong is: [CBSE (PMT) 2005]
(a) 4th group (b) 6th group (c) 14th group (d) 16th group

142. In the reaction $^{2}_{1}H + ^{3}_{1}H \longrightarrow ^{4}_{2}He + ^{1}_{0}n$, if the binding energies of $^{2}_{1}H$, $^{3}_{1}H$ and $^{4}_{2}He$ are a, b and c (in MeV) respectively, then energy (in MeV) released in this reaction is: [CBSE-PMT (Physics) 2005]
(a) $a + b - c$ (b) $c + a - b$
(c) $c - a - b$ (d) $a + b + c$

143. Two radioactive elements X and Y have half lives 6 min and 15 min respectively. An experiment starts with 8 times as many atoms of X as Y. How long it takes for the number of atoms of X left to equal the number of atoms of Y left? [PET (Kerala) 2008]
(a) 6 min (b) 12 min (c) 48 min (d) 30 min
(e) 24 min

144. Which of the following has the highest value of radioactivity? (DPMT 2009)
(a) 1 g of Ra (b) 1 g of $RaSO_4$
(c) 1 g of $RaBr_2$ (d) 1 g of $Ra(HPO_4)$

145. An artificial transmutation was carried out on $^{14}_{7}N$ by an α-particle which resulted in an unstable nuclide and a proton. What is the ratio of the atomic mass to the atomic number of the unstable nuclide? (SCRA 2009)
(a) $\frac{17}{8}$ (b) $\frac{15}{7}$ (c) $\frac{17}{9}$ (d) $\frac{15}{8}$

[**Hint :** $^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ^{1}_{1}H$

$$\frac{\text{Mass Number}}{\text{Atomic Number}} = \frac{17}{8}]$$

146. If 0.4 curie be the activity of 1 gram of a radioactive sample whose atomic mass is 226, then what is the half-life period of the sample? (1 curie $= 3.7 \times 10^{10}$ dis sec^{-1}) (SCRA 2009)
(a) 1.2×10^{11} sec (b) 1.8×10^{11} sec
(c) 1.2×10^{10} sec (d) 1.8×10^{10} sec

[**Hint :** Rate of decay $= \frac{0.693}{t_{1/2}} \times \frac{w}{A_w} \times 6.023 \times 10^{23}$

$$0.4 \times 3.7 \times 10^{10} = \frac{0.693}{t_{1/2}} \times \frac{1}{226} \times 6.023 \times 10^{23}$$

$$t_{1/2} = 1.2 \times 10^{11} \text{ sec}]$$

147. The half-life period of uranium is 4.5 billion years. After 9.0 billion years, the number of moles of helium liberated from the following nuclear reaction will be :

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

Initially there was 1 mole uranium. [PET (MP) 2010]
(a) 0.75 mol (b) 1.0 mol (c) 11.2 mol (d) 22.4 mol

Set-2: The questions given below may have more than one correct answers

1. Match the following radioactive series:

(A) $4n$	(i) Uranium series
(B) $4n + 1$	(ii) Neptunium series
(C) $4n + 2$	(iii) Actinium series
(D) $4n + 3$	(iv) Thorium series

	A	B	C	D
(a)	(i)	(ii)	(iii)	(iv)
(b)	(iv)	(ii)	(i)	(iii)
(c)	(iii)	(i)	(iv)	(ii)
(d)	(ii)	(iii)	(i)	(iv)

2. Match the following reactions:

(A) $_4Be^9 + _2He^4 \rightarrow _6C^{12} + \ldots$	(i) $_2He^4$
(B) $_6C^{12} + \ldots \rightarrow _5B^{10} + _2He^4$	(ii) $_0n^1$
(C) $_7N^{14} + \ldots \rightarrow _8O^{17} + _1H^1$	(iii) $_1D^2$
(D) $_{20}Ca^{40} + \ldots \rightarrow _{19}K^{37} + _2He^4$	(iv) $_1H^1$

	A	B	C	D
(a)	(i)	(ii)	(iii)	(iv)
(b)	(ii)	(iii)	(i)	(iv)
(c)	(iv)	(ii)	(iii)	(i)
(d)	(iii)	(ii)	(i)	(iv)

3. A radioactive element is present in VIII group of the periodic table. If it emits one α-particle, the new position of the nuclide will be:

(a) VI B (b) VIII
(c) VII B (d) I B

4. Which statement is true about n/p ratio?
(a) It increases by β-emission
(b) It increases by α-emission
(c) It increases by γ-emission
(d) None of the above

5. How many α and β-particles should be eliminated so that an isodiaphere is formed?
(a) $n\alpha, n\beta$ (b) $n\alpha, (n+1)\beta$
(c) $n\alpha$ (d) $n\beta$

6. Match the following:

Series	Particles emitted
(a) Thorium	(i) $8\alpha, 5\beta$
(b) Neptunium	(ii) $8\alpha, 6\beta$
(c) Actinium	(iii) $6\alpha, 4\beta$
(d) Uranium	(iv) $7\alpha, 4\beta$

	A	B	C	D
(a)	(iv)	(iii)	(ii)	(i)
(b)	(ii)	(i)	(iv)	(iii)
(c)	(iii)	(i)	(iv)	(ii)
(d)	(i)	(ii)	(iii)	(iv)

7. Which of the following are used as control rods in a nuclear reactor?
(a) Cadmium rods (b) Graphite rods
(c) Steel rods (d) All of these

8. Which of the following notations shows the product incorrectly?
(a) ${}_{96}Cm^{242}(\alpha, 2n)\,{}_{97}Bk^{243}$ (b) ${}_{5}B^{10}(\alpha, n)\,{}_{7}N^{13}$
(c) ${}_{7}N^{14}(n, p)\,{}_{6}C^{14}$ (d) ${}_{14}Si^{28}(d, n)\,{}_{15}P^{29}$

9. Which is true about decay constant (λ)?
(a) Unit is time^{-1}
(b) Value of λ is always less than 1
(c) λ is independent of temperature
(d) λ is defined as the ratio of no. of atoms disintegrating per unit time to the total no. of atoms present at that time

10. Which of the following is not correct? (EAMCET 2006)
(a) Nuclei of atoms participate in nuclear reactions
(b) ${}^{40}_{20}Ca$ and ${}^{40}_{18}Ar$ are isotones
(c) 1 amu of mass defect is approximately equal to 931.5 MeV
(d) Uranium (U^{238}) series is known as $(4n+2)$ series

11. Correct order of radioactivity is:
(a) ${}_1H^1 > {}_1H^2 > {}_1H^3$ (b) ${}_1H^3 > {}_1H^2 > {}_1H^1$
(c) ${}_1H^3 > {}_1He^1 > {}_1H^2$ (d) ${}_1H^3 > {}_1H^1 = {}_1H^2$

12. At radioactive equilibrium, the ratio between 2 atoms of radioactive elements A and B is $3 \times 10^9 : 1$. If $t_{1/2}$ of A is 10^{10} yrs what is $t_{1/2}$ of B?
(a) 30 yrs (b) 3 yrs
(c) 3.3 yrs (d) None of these

13. In the sequence of the following nuclear reaction,

$$X^{238}_{98} \xrightarrow{-\alpha} Y \xrightarrow{-\beta} Z \xrightarrow{-\beta} L \xrightarrow{n\alpha} {}_{90}M^{218}$$

what is the value of n?
(a) 3 (b) 4
(c) 5 (d) 6

14. ${}^{60}Co$ has $t_{1/2} = 5.3$ years. The time taken for 7/8 of the original sample to disintegrate will be:
(a) 4.6 yrs (b) 9.2 yrs
(c) 10.6 yrs (d) 15.9 yrs

15. Which of the following is/are correct?
(a) α-rays are more penetrating than β-rays
(b) α-rays have greater ionizing power than β-rays
(c) β-particles are not present in the nucleus, yet they are emitted from the nucleus
(d) γ-rays are not emitted simultaneously with α and β-rays

16. Select the wrong statement:
(a) Nuclear isomers contain the same number of protons and neutrons
(b) The decay constant is independent of the amount of the substance taken
(c) One curie = 3.7×10^{10} dis/minute
(d) Actinium series starts with U^{238}

17. In a nuclear reactor, heavy water is used to:
(a) provide high speed to neutrons
(b) reduce the speed of neutrons
(c) capture neutrons produced by nuclear fission
(d) transfer the heat from the nuclear reactor

18. The correct starting material and product of different disintegration series are:
(a) ${}^{232}Th, {}^{208}Pb$ (b) ${}^{235}U, {}^{206}Pb$
(c) ${}^{238}U, {}^{207}Pb$ (d) ${}^{237}Np, {}^{209}Bi$

19. Which of the following is/are not true?
(a) The most radioactive element present in pitchblende is uranium
(b) ${}^{32}P$ is used for the treatment of leukaemia
(c) CO_2 present in the air contains ${}^{12}C$ only
(d) Omission of γ-rays changes the mass number but not atomic number

20. Which of the following is/are correct?
(a) 1 Curie = 3.7×10^{10} d/s
(b) 1 Rutherford = 10^6 d/s
(c) 1 Becquerel = 1 d/s
(d) 1 Fermi = 10^3 d/s

21. Match the List-I and List-II and select the correct answer using the codes given below the lists:

List-I Nuclear reactor component	List-II Substance used
1. Moderator	A. Uranium
2. Control rods	B. Graphite
3. Fuel rods	C. Boron
4. Coolant	D. Lead
	E. Sodium

[PET (Kerala) 2005]

Codes:
(a) 1—B, 2—A, 3—C, 4—E
(b) 1—B, 2—C, 3—A, 4—E
(c) 1—C, 2—B, 3—A, 4—E
(d) 1—C, 2—D, 3—A, 4—B
(e) 1—D, 2—C, 3—B, 4—A

22. Match the List-I and List-II and select the correct answer using the codes given below the lists:

List-I Isotope	List-II Characteristics
A. $^{40}_{20}Ca$	1. Unstable, α-emitter
B. $^{133}_{53}I$	2. Unstable, β-emitter
C. $^{121}_{53}I$	3. Unstable, positron emitter
D. $^{232}_{90}Th$	4. Stable

Codes:	A	B	C	D
(a)	1	2	3	4
(b)	1	3	2	4
(c)	4	3	2	1
(d)	4	2	3	1

23. Match the List-I with List-II and select the correct answer using the codes given below the lists:

List-I Isotope	List-II Characteristics
A. ^{32}P	1. Location of tumour in brain
B. ^{24}Na	2. Location of blood clot and circulatory disorders
C. ^{60}Co	3. Radiotherapy
D. ^{131}I	4. Agriculture research

Codes:	A	B	C	D
(a)	4	1	2	3
(b)	4	3	2	1
(c)	4	2	3	1
(d)	3	1	2	4

24. Consider the following nuclear reactions:
1. $^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ^{1}_{1}H$
2. $^{9}_{4}Be + ^{1}_{1}H \longrightarrow ^{9}_{3}Li + ^{4}_{2}He$
3. $^{24}_{12}Mg + ^{4}_{2}He \longrightarrow ^{27}_{14}Si + ^{1}_{0}n$
4. $^{10}_{5}B + ^{4}_{2}He \longrightarrow ^{13}_{7}N + ^{1}_{0}n$

Examples of induced radioactivity would include the reactions:
(a) 3 and 4 (b) 1 and 2 (c) 1, 3 and 4 (d) 1, 2, 3 and 4

25. Match the Column-I Radio-isotope with Column-II Medicinal use and select correct matching:

Column-I	Column-II
(I) ^{60}Co	(a) Leucaemia
(II) ^{131}I	(b) Anaemia
(III) ^{59}Fe	(c) Cancerous tumours
(IV) ^{32}P	(d) Disorders of thyroid gland

(a) I—c; II—d; III—a; IV—b
(b) I—a; II—b; III—c, IV—d
(c) I—c; II—d; III—b; IV—a
(d) I—d; II—c; III—b; IV—a

26.
Column-I	Column-II
(I) $^{14}_{6}C$	(a) Unstable and β-emitter
(II) $^{24}_{11}Na$	(b) Stable
(III) $^{13}_{7}N$	(c) Unstable, positron emitter
(IV) $^{13}_{6}C$	(d) Unstable, α-emitter

Correct matching is/are:
(a) I only (b) III only
(c) II and IV (d) I and III

27. Which of the following statements is/are correct?
1. A nucleus in an excited state may give up its excitation energy and return to the ground state by emission of electromagnetic γ-radiation.
2. γ-radiations are emitted as secondary effect of α and β-emission.
3. The nuclear isomers produced by γ-ray bombardment have the same atomic and mass number but differ in their life-times (whatever their ground state may be).
4. X-ray and γ-ray are both electromagnetic.

(a) 1 and 2 (b) 1, 2 and 3 (c) 2 and 3 (d) 1, 2, 3 and 4

28. Which of the following statements is/are correct?
1. When an electron is emitted by an atom and its nucleus gets de-excited as a result, the process is called internal conversion.
2. Electron capture and positron emission are identical.
3. Neutrons are emitted in the electron capture process.
4. Pair production is a process which involves the creation of positron-electron pair by a photon of energy 1.02 MeV.

(a) 1 and 2 (b) 1, 2 and 4
(c) 2, 3 and 4 (d) All are wrong

29. A nuclide has mass number (A) and atomic number (Z). During a radioactive process if:
1. both A and Z decrease, the process is called α-decay.
2. A remains unchanged and Z decreases by one, the process is called β^+ or positron decay or K-electron capture.
3. both A and Z remain unchanged, the process is called γ-decay.
4. both A and Z increase, the process is called nuclear isomerism.

The correct answer is:
(a) 1, 2 and 3 (b) 2, 3 and 4
(c) 1, 3 and 4 (d) 1, 2 and 4

30. In the decay process:
$$A \xrightarrow{-\alpha} B \xrightarrow{-\alpha} C \xrightarrow{-\beta} D$$
1. A and B are isobars
2. A and D are isotopes
3. C and D are isobars
4. A and C are isotones

The correct answer is:
(a) 1 and 2 (b) 2 and 3
(c) 3 and 4 (d) 1 and 4

31. The nuclide X undergoes α-decay and another nuclide Y, β^--decay. Which of the following statements are correct?
1. The β^--particles emitted by Y may have widely different speeds.
2. The α-particles emitted by X may have widely different speeds.
3. The α-particles emitted by X will have almost same speed.
4. The β-particles emitted by Y will have the same speed.

(a) 1 and 3 are correct (b) 2 and 3 are correct
(c) 3 and 4 are correct (d) 1 and 4 are correct

32. Fill in the blank space with a suitable answer selected from the list below. Write only the letter (A, B, C, ..., etc) of the correct answer in the blanks.

	Answer
(i) ${}^{12}_{6}C + {}^{1}_{1}H \longrightarrow {}^{13}_{7}N$	......
(ii) ${}^{27}_{13}Al + {}^{1}_{1}H \longrightarrow {}^{24}_{12}Mg + {}^{4}_{2}He$	......
(iii) ${}^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{140}_{56}Ba + {}^{93}_{36}Kr + 3\,{}^{1}_{0}n$	......
(iv) ${}^{75}_{33}As + {}^{2}_{1}H \longrightarrow {}^{56}_{25}Mn + 9\,{}^{1}_{1}H + 12\,{}^{1}_{0}n$	......
(v) ${}^{2}_{1}H + {}^{3}_{1}H \longrightarrow {}^{4}_{2}He + {}^{1}_{0}n$	......

Answers:
A: Projectile capture
B: Spallation
C: Fusion
D: Projectile capture and particle emission
E: Fission

Select the correct answers according to the given codes:

Codes:	(i)	(ii)	(iii)	(iv)	(v)
(a)	A	D	E	B	C
(b)	D	C	A	E	B
(c)	A	B	C	D	E
(d)	E	D	C	B	A

Assertion-Reason TYPE QUESTIONS

The questions given below consist of two statements each printed as **Assertion (A)** and **Reason (R).** While answering these questions you are required to choose any one of the following four:

(a) If both (A) and (R) are correct and (R) is the correct explanation for (A).
(b) If both (A) and (R) are correct and (R) is not the correct explanation for (A).
(c) If (A) is correct but (R) is incorrect.
(d) If both (A) and (R) are incorrect.
(e) If (A) is incorrect but (R) is correct.

1. (A) Mass numbers of most of the elements are fractional.
(R) Mass numbers are obtained by comparing with the mass number of carbon taken as 12.

2. (A) The activity of 1 g pure uranium-235 will be greater than the same amount present in U_3O_6.
(R) In the combined state, the activity of the radioactive element decreases.

3. (A) α-rays have greater ionising power than β.
(R) α-particles carry 2^+ charge while β-particles carry only 1^- charge.

4. (A) β-particles have greater penetrating power than α-rays but less than γ-rays.
(R) β-particles are lighter than α but heavier than γ.

5. (A) During β-decay, a new element with atomic number greater than one is obtained.
(R) Protons and neutrons keep on changing into one another through meson.

6. (A) The average life of a radioactive element is infinity.
(R) As a radioactive element disintegrates, more of it is formed in nature by itself.

7. (A) Hydrogen bomb is more powerful than atomic bomb.
(R) In hydrogen bomb, reaction is initiated.

8. (A) The archaeological studies are based on the radioactive decay of carbon-14 isotope.
(R) The ratio of C-14 to C-12 in the animals or plants is the same as that in the atmosphere.

9. (A) The reactions taking place in the sun are nuclear fusion reactions.
(R) The main reason for nuclear fusion reactions in the sun is that H_2 is present in the sun's atmosphere so that hydrogen nuclei can fuse to form helium.

10. (A) In a radioactive disintegration, an electron is emitted by the nucleus.
(R) Electrons are always present inside the nucleus.

11. (A) In radioactive disintegrations, ${}_2He^4$ nuclei can come out of the nucleus but lighter ${}_2He^3$ can't.
(R) Binding energy of ${}_2He^3$ is more than that of ${}_2He^4$.

12. (A) Protons are better projectiles than neutrons.
(R) The neutrons being neutral do not experience repulsion from positively charged nucleus.

13. (A) Enrichment of U^{235} from a mixture containing more abundant U^{238} is based on diffusion of UF_6.
(R) UF_6 is a gaseous compound under ordinary conditions.

14. (A) The nucleus emits β-particles though it doesn't contain any electron in it.
(R) The nucleus shows the transformation ${}_0n^1 \rightarrow p + \beta +$ anti-neutrino for β-emission.

15. (A) Any kind of exchange force helps the nucleus to be more destabilised.
(R) π-mesons are exchanged between nucleons incessantly.

16. (A) Nuclide ${}_{13}Al^{30}$ is less stable than ${}_{20}Ca^{40}$. (IIT 1998)
(R) Nuclides having odd number of protons and neutrons are generally unstable.

17. (A) During β-decay, a new element with atomic number greater than one is obtained.
(R) Protons and neutrons keep on changing into one another with the help of meson.

18. (A) The position of an element in periodic table after emission of one α and two β-particles remains unchanged.
(R) Emission of one α and two β-particles gives isotope of the parent element which acquires same position in the periodic table.

19. (A) Nuclear isomers have same atomic number and same mass number but with different radioactive properties.
(R) $U_{(A)}$ and $U_{(Z)}$ are nuclear isomers.

20. (A) The emission of α-particles results in the formation of isodiapheres of parent element.
(R) Isodiapheres have same isotopic number.

21. (A) $^{238}_{92}U\,(IIIB) \xrightarrow{-\alpha} A \xrightarrow{-\alpha} B \xrightarrow{-\beta} C$
(R) Element B will be of IIA group.

22. (A) β-particles are deflected more than α-particles in a given electric field.
(R) Charge on α-particles is larger than on β-particles.

23. (A) The nucleus of gold is stable even though there is a very strong coulombic repulsion among the protons.
(R) The inverse square coulomb force is exactly balanced by another inverse square force which is very powerful, *i.e.*, nuclear force.

24. (A) K-shell electron capture is detected by analysing the wavelength of X-ray emitted.
(R) The wavelength of the X-ray is characteristic of the daughter element and not the parent element.

25. (A) Half life of a radioactive isotope is the time required to decrease its mass number by half.
(R) Half life of radioactive isotopes is independent of initial amount of the isotope.

26. (A) In a nuclear fission process, the total mass of fragments is always greater than the mass of the original nucleus.
(R) Difference in the mass due to the fission of a heavy nucleus is converted into energy according to mass-energy conversion. (SCRA 2007)

Answers : OBJECTIVE QUESTIONS

- **Set–1**

1. (b)	**2.** (d)	**3.** (c)	**4.** (c)	**5.** (d)	**6.** (a)	**7.** (d)	**8.** (d)
9. (e)	**10.** (c)	**11.** (c)	**12.** (b)	**13.** (b)	**14.** (d)	**15.** (a)	**16.** (c)
17. (c)	**18.** (a)	**19.** (c)	**20.** (b)	**21.** (a)	**22.** (d)	**23.** (d)	**24.** (d)
25. (c)	**26.** (a)	**27.** (b)	**28.** (a)	**29.** (a)	**30.** (c)	**31.** (c)	**32.** (d)
33. (c)	**34.** (d)	**35.** (b)	**36.** (b)	**37.** (c)	**38.** (a)	**39.** (c)	**40.** (a)
41. (d)	**42.** (c)	**43.** (a)	**44.** (d)	**45.** (b)	**46.** (a)	**47.** (a)	**48.** (b)
49. (b)	**50.** (d)	**51.** (c)	**52.** (d)	**53.** (b)	**54.** (c)	**55.** (d)	**56.** (c)
57. (a)	**58.** (c)	**59.** (b)	**60.** (d)	**61.** (a)	**62.** (a)	**63.** (c)	**64.** (b)
65. (d)	**66.** (a)	**67.** (a)	**68.** (b)	**69.** (b)	**70.** (a)	**71.** (a)	**72.** (c)
73. (b)	**74.** (c)	**75.** (a)	**76.** (a)	**77.** (a)	**78.** (b)	**79.** (c)	**80.** (d)
81. (a)	**82.** (b)	**83.** (c)	**84.** (d)	**85.** (b)	**86.** (b)	**87.** (d)	**88.** (b)
89. (b)	**90.** (c)	**91.** (a)	**92.** (a)	**93.** (c)	**94.** (d)	**95.** (b)	**96.** (a)
97. (b)	**98.** (b)	**99.** (a)	**100.** (d)	**101.** (d)	**102.** (d)	**103.** (b)	**104.** (d)
105. (b)	**106.** (c)	**107.** (d)	**108.** (b)	**109.** (d)	**110.** (b,d)	**111.** (b)	**112.** (b)
113. (b,c)	**114.** (d)	**115.** (c)	**116.** (b)	**117.** (d)	**118.** (d)	**119.** (a)	**120.** (b)
121. (a)	**122.** (c)	**123.** (d)	**124.** (a)	**125.** (d)	**126.** (c)	**127.** (d)	**128.** (c)
129. (a)	**130.** (c)	**131.** (b)	**132.** (b)	**133.** (c)	**134.** (a)	**135.** (b)	**136.** (a)
137. (c)	**138.** (a)	**139.** (c)	**140.** (a)	**141.** (c)	**142.** (c)	**143.** (d)	**144.** (a)
145. (a)	**146.** (a)	**147.** (a)					

- **Set–2**

1. (b)	**2.** (b)	**3.** (a, b, c)	**4.** (b)	**5.** (c)	**6.** (c)	**7.** (a)	**8.** (a)
9. (c)	**10.** (b)	**11.** (b)	**12.** (c)	**13.** (b)	**14.** (d)	**15.** (b, c, d)	**16.** (c, d)
17. (b, d)	**18.** (a, d)	**19.** (a, d)	**20.** (a, b, c)	**21.** (b)	**22.** (d)	**23.** (c)	**24.** (d)
25. (c)	**26.** (d)	**27.** (d)	**28.** (b)	**29.** (a)	**30.** (b)	**31.** (a)	**32.** (a)

Answers : ASSERTION-REASON TYPE QUESTIONS

1. (d)	**2.** (d)	**3.** (b)	**4.** (a)	**5.** (b)	**6.** (c)	**7.** (b)	**8.** (a)
9. (c)	**10.** (c)	**11.** (c)	**12.** (d)	**13.** (a)	**14.** (a)	**15.** (d)	**16.** (a)
17. (b)	**18.** (a)	**19.** (a)	**20.** (c)	**21.** (b)	**22.** (a)	**23.** (c)	**24.** (b)
25. (d)	**26.** (e)						

BRAIN STORMING PROBLEMS

OBJECTIVE QUESTIONS for IIT ASPIRANTS

The following questions contain single correct option:

1. The average life of a W gm sample of ^{200}RaE is T seconds and average energy of the β-particles emitted is E MeV. At what rate in watts does the sample emit energy?

(a) $\frac{8WN_0E}{T} \times 10^{-16}$ (b) $\frac{8(\ln 2)WN_0E}{T} \times 10^{-13}$

(c) $\frac{8WN_0E}{T} \times 10^{-13}$ (d) None is correct

[Hint: Rate of β-particles emitted per second

$$= \lambda \times \frac{W}{\text{At. wt.}} \times N_0 = \frac{1}{T} \times \frac{W}{200} \times N_0$$

Energy evolved per second

$$= \frac{1}{T} \times \frac{W}{200} \times N_0 \times E \times 1.6 \times 10^{-19} \times 10^6 \text{ J sec}^{-1}$$

$$= \frac{8WN_0E}{T} \times 10^{-16} \text{ watt per second}]$$

2. In nuclear fission, 0.01% mass is converted into energy. The energy released by the fission of 100 kg mass will be:

(a) 9×10^{15} J (b) 9×10^{11} kJ (c) 9×10^{17} J (d) 9×10^{13} kJ

[Hint: $\Delta m = 100 \times \frac{0.01}{100} = 0.01$ kg

$$E = \Delta mc^2 = 0.01 \times (3 \times 10^8)^2 \text{ J}$$

$$= 9 \times 10^{14} \text{ J} = 9 \times 10^{11} \text{ kJ}]$$

3. The activity of a radioactive substance is R_1 at time t_1 and R_2 at time t_2 ($> t_1$). Its decay constant is λ. Then:

(a) $R_1t_1 = R_2t_2$ (b) $R_2 = R_1e^{\lambda(t_2 - t_1)}$

(c) $R_2 = R_1e^{\lambda(t_1 - t_2)}$ (d) $\frac{R_1 - R_2}{t_2 - t_1} = \text{constant}$

[Hint: $\frac{R_2}{R_1} = \frac{R_0 e^{-\lambda t_2}}{R_0 e^{-\lambda t_1}}$, $R_2 = R_1e^{\lambda(t_1 - t_2)}$]

4. The age of a specimen 't' is related to the daughter/parent ratio by the equation:

(a) $t = \frac{1}{\lambda} \ln\left(\frac{D}{P}\right)$ (b) $t = \frac{1}{\lambda} \ln\left(1 + \frac{P}{D}\right)$

(c) $t = \frac{1}{\lambda} \ln\left(1 + \frac{D}{P}\right)$ (d) $t = \frac{1}{\lambda} \ln\left(2 + \frac{D}{P}\right)$

5. A radioactive substance is being produced at a constant rate of 200 nuclei/sec. The decay constant of the substance is 1 sec^{-1}. After what time will the number of radioactive nuclei become 100? Initially, there are no nuclei present.

(a) 1 sec (b) 2 sec (c) ln (2) sec (d) $\frac{1}{\ln (2)}$ sec

[Hint: $N = N_0 e^{-\lambda t}$

$$100 = 200e^{-1 \times t}$$

$$\frac{1}{2} = e^{-t}$$

$$t = \ln (2) \text{ sec}]$$

6. The rate of decay of a radioactive sample is given by R_1 at time t_1 and R_2 at a later time t_2. The mean life of this radioactive sample is:

(a) $T = \frac{R_1}{R_2} \times \frac{t_2}{t_1}$ (b) $T = \frac{t_1 - t_2}{\ln (R_2 / R_1)}$

(c) $T = \frac{t_2 - t_1}{\ln (R_2 / R_1)}$ (d) $T = \frac{\ln (R_2 / R_1)}{t_1 - t_2}$

[Hint: $R_2 = R_0e^{-\lambda t_2}$

$$R_1 = R_0 e^{-\lambda t_1}$$

On dividing the above equations, we get

$$\frac{R_2}{R_1} = e^{\lambda(t_1 - t_2)}$$

$$\ln\left(\frac{R_2}{R_1}\right) = \lambda(t_1 - t_2)$$

$$\frac{1}{\lambda} = \frac{(t_1 - t_2)}{\ln (R_2 / R_1)}$$

$$T = \frac{(t_1 - t_2)}{\ln (R_2 / R_1)}]$$

7. Isodiapheres are the atoms of two elements having same values of:

(a) p / n (b) $(p - n)$ (c) $(n - p)$ (d) $n \times p$

[Hint: Isodiapheres are formed by α-decay

$${}^{M}_{Z}A - {}^{4}_{2}\text{He} \longrightarrow {}^{M-4}_{Z-2}B$$

$(n - p)$ in ${}^{M}_{Z}A = (M - Z) - Z = (M - 2Z)$

$(n - p)$ in ${}^{M-4}_{Z-2}B = \{(M - 4) - (Z - 2)\} - (Z - 2)$

$$= \{M - Z - 2\} - Z + 2$$

$$= (M - 2Z)$$

$\therefore (n - p)$ of isodiapheres are same.]

8. In a sample of radioactive material, what fraction of the initial number of active nuclei will remain undisintegrated after half of a half life of the sample?

(a) $\frac{1}{4}$ (b) $\frac{1}{2\sqrt{2}}$ (c) $\frac{1}{\sqrt{2}}$ (d) $\sqrt{2} - 1$

[Hint: $\frac{0.693}{t_{1/2}} = \frac{2.303}{t} \log\left(\frac{N_0}{N}\right)$

$$\frac{2.303 \times \log 2}{t_{1/2}} = \frac{2.303}{(t_{1/2}/2)} \log_{10}\left(\frac{N_0}{N}\right)$$

$$\log_{10}(2^{1/2}) = \log_{10}\left(\frac{N_0}{N}\right)$$

$$\left(\frac{N}{N_0}\right) = \frac{1}{\sqrt{2}}]$$

9. Let T be the mean life of a radioactive sample. 75% of the active nuclei present in the sample initially will decay in time:

(a) $2T$ (b) $\frac{1}{2}(\log_e 2)T$ (c) $4T$ (d) $2(\log_e 2)T$

10. $^{218}_{84}\text{Po}$ ($t_{1/2} = 183$ sec) decays to $^{214}_{82}\text{Pb}$ ($t_{1/2} = 161$ sec) by α-emission, while $^{214}_{82}\text{Pb}$ decays by β-emission. In how much time the number of nuclei of $^{214}_{82}\text{Pb}$ will reach to the maximum?

(a) 182 sec (b) 247.5 sec (c) 308 sec (d) 194.8 sec

[**Hint:** $^{218}_{84}\text{Po} \xrightarrow{\lambda_1 = \frac{0.693}{183} = (3.786 \times 10^{-3}\ \text{sec}^{-1})}$

$^{214}_{82}\text{Pb} \xrightarrow{\lambda_2 = \frac{0.693}{161} = 4304 \times 10^{-3}\ \text{sec}^{-1}}$

$$t_{max} = \frac{2.303}{\lambda_1 - \lambda_2} \log \frac{\lambda_1}{\lambda_2}$$

$$= \frac{2.303}{3.786 \times 10^{-3} - 4.304 \times 10^{-3}} \log \frac{3.786 \times 10^{-3}}{4.304 \times 10^{-3}}$$

$$= -\frac{2.303}{5.183 \times 10^{-4}}[-0.05569]$$

$= 247.5$ sec]

11. Fusion reaction takes place at high temperature because:

(a) atoms are ionised at high temperature

(b) molecules break up at high temperature

(c) nuclei break up at high temperature

(d) kinetic energy is high enough to overcome repulsion between nuclei

12. In the radioactive change,

$$^{A}_{Z}P \longrightarrow {}^{A}_{Z+1}Q \longrightarrow {}^{A-4}_{Z-1}R \longrightarrow {}^{A-4}_{Z-1}S$$

the radiations emitted in sequence are:

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

13. The half life of a radioactive isotope is 3 hours. If the initial mass of the isotope were 256 g, the mass of it remaining undecayed after 18 hours would be:

(a) 12 g (b) 16 g (c) 4 g (d) 8 g

[**Hint:** $N = N_0 \left(\frac{1}{2}\right)^n$ n = number of half lives $= \frac{18}{3} = 6$

$$= 256\left(\frac{1}{2}\right)^6 = 4 \text{ g}]$$

14. In an old rock, the mass ratio of $^{238}_{92}\text{U}$ to $^{206}_{82}\text{Pb}$ is found to be 595 : 103. The age of the rock is (Mean life of $^{238}_{92}\text{U}$ is T_0):

(a) $T_0 \ln 1.2$ (b) $T_0 \ln \frac{698}{595}$ (c) $T_0 \frac{\ln 1.2}{\ln 2}$ (d) $T_0 \frac{\ln \frac{698}{595}}{\ln 2}$

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

$$\frac{1}{T_0} = \frac{1}{t} \ln\left(\frac{595 + 103}{595}\right)$$

$$t = T_0 \ln\left(\frac{698}{595}\right)]$$

15. 80% of the radioactive nuclei present in a sample are found to remain undecayed after one day. The percentage of undecayed nuclei left after two days will be:

(a) 64 (b) 20 (c) 46 (d) 80

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

$$= \frac{2.303}{1} \log\left(\frac{100}{80}\right) \quad \text{...(i)}$$

$$\lambda = \frac{2.303}{2} \log\left(\frac{100}{N}\right) \quad \text{...(ii)}$$

$$\frac{2.303}{1} \log\left(\frac{100}{80}\right) = \frac{2.303}{2} \log\left(\frac{100}{N}\right)$$

$$\left(\frac{5}{4}\right)^2 = \frac{100}{N}$$

$N = 64$]

16. A sample of radioactive material has mass 'm', decay constant λ and molecular mass 'M'. If N_A is Avogadro's number, the initial activity of the sample is:

(a) λm (b) $\lambda \frac{m}{M}$ (c) $\frac{\lambda m N_A}{M}$ (d) mMe^{λ}

17. A radioactive nucleus can decay by two different processes. The mean value period for the first process is Z_1 and that for the second process is Z_2. The effective mean value period for the two processes is:

(a) $\frac{Z_1 + Z_2}{2}$ (b) $Z_1 + Z_2$ (c) $\sqrt{Z_1 Z_2}$ (d) $\frac{Z_1 Z_2}{Z_1 + Z_2}$

18. The radioactivity of a sample is R_1 at time T_1 and R_2 at time T_2. If the half life of specimen is T, the number of atoms that have disintegrated in time $(T_2 - T_1)$ is proportional to:

(a) $(R_1 T_1 - R_2 T_2)$ (b) $R_1 - R_2$

(c) $\frac{(R_1 - R_2)}{T}$ (d) $(R_2 - R_1)T$

[**Hint:** Rate = $\lambda \times$ Number of atoms of element yet not decayed.

$R_1 = \lambda \times N_1$

$R_2 = \lambda \times N_2$

Number of atoms decayed in time $(T_2 - T_1)$

$$= \frac{R_2}{\lambda} - \frac{R_1}{\lambda} = \frac{(R_2 - R_1)}{\lambda} = \frac{T(R_2 - R_1)}{0.693}$$

$\therefore$ Number of atoms decayed in time $(T_2 - T_1) \propto T(R_2 - R_1)$]

19. Half life period of lead is:

(a) zero (b) infinite (c) 1590 years (d) 1590 days

20. A freshly prepared radioactive sample of half life 2 hours emits radiation of intensity which is 64 times the permissible safe level. The minimum time after which it would be possible to work safely with this source is:

(a) 6 hrs (b) 12 hrs (c) 24 hrs (d) 128 hrs

[**Hint:** $N = N_0\left(\frac{1}{2}\right)^n$

$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^n$$

$$\frac{1}{64} = \left(\frac{1}{2}\right)^n$$

$n = 6$

$\therefore$ $t = 2 \times 6 = 12$ hours]

21. Which of the following is the best nuclear fuel?
(a) ^{238}U (b) ^{236}Th (c) ^{239}Pu (d) ^{239}Np

22. A radioactive element decays by parallel path as given below:

$$A \xrightarrow{\lambda_1} B \qquad \lambda_1 = 1.8\times 10^{-2}\ sec^{-1}$$
$$2A \xrightarrow{\lambda_2} B \qquad \lambda_2 = 10^{-3}\ sec^{-1}$$

Average life of radio-nuclide A will be:
(a) 52.63 sec (b) 500 sec (c) 50 sec (d) 120 sec
[**Hint :** $\lambda = \lambda_1 + 2\lambda_2$
$= 1.8\times10^{-2} + 2\times10^{-3}$
$= 2\times10^{-2}\ sec^{-1}$
$\tau = \frac{1}{\lambda} = \frac{1}{2\times10^{-2}} = 50$ sec]

23. Among the following, which has the longest half life?
(a) $^{232}_{90}Th$ (b) $^{237}_{93}Np$ (c) $^{238}_{92}U$ (d) $^{235}_{92}U$

24. Which of the following is likely to be least stable?
(SCRA 2007)
(a) $^{40}_{20}Ca$ (b) $^{55}_{25}Mn$ (c) $^{119}_{50}Sn$ (d) $^{30}_{13}Al$

[**Hint:**

	$^{40}_{20}Ca$	$^{55}_{25}Mn$	$^{119}_{50}Sn$	$^{30}_{13}Al$
$\frac{n}{p}$	$\frac{20}{20}=1$	$\frac{30}{25}=1.2$	$\frac{69}{50}=1.38$	$\frac{17}{13}=1.31$

All are stable according to n/p rule but experimental observations confirm that $^{30}_{13}Al$ is radioactive with half life of 3.7 sec]

25. $^{27}_{13}Al$ is a stable isotope. $^{29}_{13}Al$ is expected to disintegrate by:
(a) α-emission (b) β-emission
(c) positron emission (d) proton emission
[**Hint:** Number of neutrons will be reduced by β-decay.
$^1_0n \longrightarrow {}^1_1H + {}^{0}_{-1}e$ + Antineutrino + Energy]

26. For a radioactive element, a graph of $\log N$ against time has a slope equal to:
(a) $+2.303\lambda$ (b) $+\frac{\lambda}{2.303}$ (c) $-\frac{\lambda}{2.303}$ (d) -2.303λ
[**Hint:** $\log N_0 - \log N = \frac{\lambda t}{2.303}$
$$\log N = \left(\frac{-\lambda}{2.303}\right)t + \log N_0$$
$$Y = Mx + C$$
$\therefore$ Slope $(M) = \frac{-\lambda}{2.303}$]

27. Two elements P and Q have half lives of 10 and 15 minutes respectively. Freshly prepared samples of each isotope initially contain the same number of atoms as each other. After 30 minutes, the ratio $\frac{\text{number of } P \text{ atoms}}{\text{number of } Q \text{ atoms}}$ will be:
(a) 0.5 (b) 2 (c) 1 (d) 3
[**Hint:** In 30 minutes, there will be 3 half lives of P and 2 half lives of Q.
$\therefore$ Number of P atoms will be 1/8 th and number of Q atoms will be 1/4th of original atoms.
Then, $\frac{\text{Number of atoms of } P}{\text{Number of atoms of } Q} = \frac{1/8}{1/4} = \frac{1}{2}$, *i.e.*, 0.5]

28. Select the wrong statement among the following:
(a) Antineutrino can be detected during β-emission
(b) Neutrino was predicted to conserve the spin of a nuclear reaction
(c) Synchrotron can accelerate neutrons
(d) Area of cross-section of nucleus is about 1 barn
(1 barn $= 10^{-24}$ cm^2)
[**Hint:** Synchrotron can accelerate only charged particles, not the neutral particles like neutron.]

29. A radioactive atom 'X' emits a β-particle to produce an atom 'Y' which then emits an α-particle to give an atom 'Z':
(1) The atomic number of 'X' is less than that of 'Z'
(2) The atomic number of 'Y' is less than that of 'Z'
(3) The mass number of 'X' is same as that of 'Y'
(a) 1, 2 and 3 are correct
(b) 1 and 2 are correct
(c) 2 and 3 are correct
(d) 3 is correct

30. Which one of the following is an exact example of artificial radioactivity?
(a) $^{23}_{11}Na + {}^1_0n \longrightarrow {}^{24}_{11}Na + \gamma$
$^{24}_{11}Na + {}^1_1H \longrightarrow {}^{24}_{12}Mg + {}^1_0n$
(b) $^4_2He + {}^{14}_7N \longrightarrow {}^{17}_8O + {}^1_1H$
$^{17}_8O + {}^1_0n \longrightarrow {}^{18}_7O + \gamma$
(c) $^4_2He + {}^{27}_{13}Al \longrightarrow {}^{30}_{15}P + {}^1_0n$
$^{30}_{15}P \longrightarrow {}^{30}_{14}Si + {}^{0}_{+1}e$
(d) $^{228}_{89}Ac \longrightarrow {}^{228}_{90}Th + \beta$
$^{228}_{90}Th \longrightarrow {}^{224}_{88}Ra + \alpha$

31. Consider the following decay series:
$$A \longrightarrow B \longrightarrow C \longrightarrow D$$
Where, A, B and C are radioactive elements with half lives of 4.5 sec, 15 days and 1 sec respectively and D is non-radioactive element. Starting with 1 mole of A, the number of moles of A, B, C and D left after 30 days are:
(a) one mole of D and none of A, B or C
(b) 3/4 mol of B, 1/4 mol of D and none of A or C
(c) 1/4 mol of B, 3/4 mol of D and none of A or C
(d) 1/2 mol of B, 1/4 mol of C, 1/4 mol of D and none of A
(e) 1/4 mol of each A, B, C and D

32. Consider the following nuclear reactions:
$$^{238}_{92}M \longrightarrow {}^x_yN + 2\,{}^4_2He$$
$$^x_yN \longrightarrow {}^A_BL + 2\beta^+$$
the number of neutrons present in the element 'L' is:
(a) 142 (b) 144
(c) 140 (d) 146

33. If n_t is the number of radio-atoms present at time 't', the following expression will be a constant:
[JEE (West Bengal) 2009]
(a) $\frac{n_t}{t}$ (b) $\frac{\ln n_t}{t}$
(c) $\frac{d\ln n_t}{dt}$ (d) $t\,n_t$

[**Hint :**
$$-\frac{dn_t}{dt} = \lambda n_t$$
$$-\frac{1}{n_t}\frac{dn_t}{dt} = \lambda$$
$$\frac{d}{dt}(l_n n_t) = -\lambda \text{ (constant)}$$]

34. $^{214}_{83}Bi \xrightarrow{\alpha\text{-emission}} A \xrightarrow{\beta\text{-emission}} B \xrightarrow{\beta\text{-emission}} C \xrightarrow{\beta\text{-emission}} D \xrightarrow{\alpha\text{-emission}} E$

'E' is an element of stable nucleus. What is the element 'E'?

(a) $^{207}_{81}Tl$ (b) $^{206}_{82}Pb$ (c) $^{206}_{80}Hg$ (d) $^{206}_{79}Au$

35. A radioactive element decays to one third of its initial amount in time 't'. What fraction of the element would be left after 0.5 t time ?

(a) $\frac{1}{\sqrt{3}}$ (b) $\frac{1}{2}$ (c) $\frac{1}{3}$ (d) $\sqrt{\frac{2}{3}}$

[**Hint :**
$$\lambda = \frac{2.303}{t}\log\left(\frac{N_0}{N}\right)$$
$$\frac{N}{N_0} = \frac{1}{3} \text{ in time '}t\text{'}$$
$$\therefore \quad \lambda = \frac{2.303}{t}\log_{10} 3 \qquad \text{...(i)}$$
After 0.5 t time :
$$\lambda = \frac{2.303}{0.5t}\log\left(\frac{N_0}{N}\right) \qquad \text{...(ii)}$$
Equating (i) and (ii) we get
$$\frac{N}{N_0} = \frac{1}{\sqrt{3}}$$]

36. Two radioactive isotopes A and B of atomic mass X and Y are mixed in equal amount by mass. After 20 days, their mass ratio is found to be 1 : 4. Half life of 'A' is 1 day. What will be the half life of B ?

(a) 1.11 day (b) 0.6237 day

(c) $0.11\frac{X}{Y}$ day (d) $1.11\frac{Y}{X}$ day

[**Hint :** Let 1 g of both A and B are taken initially. W_A and W_B are the amounts left after 20 days.
$$\lambda_A = \frac{2.303}{20}\log\frac{1}{W_A}$$
$$\lambda_B = \frac{2.303}{20}\log\frac{1}{W_B}$$
$$\lambda_A - \lambda_B = \frac{2.303}{20}\log\frac{W_B}{W_A}$$
$$= \frac{2.303}{20}\log 4 = 0.0693$$
$$\lambda_B = \lambda_A - 0.0693 = \frac{0.693}{t_{1/2}} - 0.0693$$
$$= \frac{0.693}{1} - 0.0693 = 0.6237$$
$$t_{1/2}B = \frac{0.693}{0.6237} = 1.11 \text{ day}$$]

37. A sample of rock from the moon was found to contain the elements X and Y in 1:7 ratio by mole. Element X is radioactive, it decays to Y with half life of 6.93×10^9 years
$$X \longrightarrow Y$$
$$t_{1/2} = 6.93 \times 10^9 \text{ yrs}]$$
What is the age of the rock?

(a) 2.079×10^{10} years (b) 1.33×10^9 years

(c) 1.94×10^{10} years (d) 10^{10} years

[**Hint :** $N_0 = 1 + 7 = 8$ (Initial moles of X)

$N = 1$ (Remaining moles of X)

We know,
$$\frac{0.693}{t_{1/2}} = \frac{2.303}{t}\log\left(\frac{N_0}{N}\right)$$
$$\frac{0.693}{6.93 \times 10^9} = \frac{2.303}{t}\log\frac{8}{1}$$
$$t = 2.079 \times 10^{10} \text{ years}]$$

38. If the relation between time of decay (t) and half life period ($t_{1/2}$) is ($t = 4\, t_{1/2}$); the relation between t and mean life (T) is:

(a) $\frac{\ln 2}{T^2}$ (b) $2T^4 \ln 2$ (c) $4T \ln 2$ (d) $2T \ln 2$

Following questions may have more than one correct options:

1. Which of the following nuclei are doubly magic?
   (a) ^4_2He (b) $^{16}_8O$ (c) $^{208}_{82}Pb$ (d) $^{238}_{92}U$
2. Which of the following make up an isotonic triad?
   (a) $^{14}_6C$, $^{16}_8O$, $^{15}_7N$ (b) $^{76}_{32}Ge$, $^{77}_{33}As$, $^{75}_{31}Ga$
   (c) $^{40}_{18}Ar$, $^{40}_{19}K$, $^{40}_{20}Ca$ (d) $^{233}_{92}U$, $^{232}_{90}Th$, $^{239}_{94}Pu$
3. In the decay process:
   $$A \xrightarrow{-\alpha} B \xrightarrow{-\beta} C \xrightarrow{-\beta} D$$ [MU (Med.) 2010]
   (a) A and B are isodiapheres (b) A and D are isotopes
   (c) B, C and D are isobars (d) A and C are isotones
4. A nuclide X undergoes α-decay and another nuclide Y undergoes β-decay. Which of the following statements are correct?
   (a) The β-particles emitted by Y may have widely different speeds
   (b) The α-particles emitted by X may have widely different speeds
   (c) The α-particles emitted by X will have almost the same speed
   (d) The β-particles emitted by Y will have the same speed
5. Which among the following nuclides is/are likely to be stable?
   (a) $^{30}_{15}P$ (b) $^{24}_{12}Mg$ (c) $^{114}_{49}In$ (d) $^{114}_{48}Cd$
6. Which among the following is/are fissile?
   (a) $^{235}_{92}U$ (b) $^{238}_{92}U$ (c) $^{239}_{94}Pu$ (d) $^{238}_{94}Pu$
7. Select the correct statements among the following:
   (a) The decay of mass during nuclear fusion and nuclear fission are 0.1% and 0.231% respectively
   (b) Lesser is the half life, more dangerous is the radioactive element
   (c) K-electron capture emits γ-rays
   (d) Nuclear forces are about 10^{21} times stronger than coulombic forces

8. A radioactive element has atomic number 'Z' and mass number 'A'. Select the correct statements among the following:
   (a) Both 'A' and 'Z' decrease in α-decay
   (b) Both 'A' and 'Z' remain unchanged in γ-decay
   (c) 'A' remains unchanged and 'Z' decreases by one; the process is called β^+ (positron) decay or K-electron capture
   (d) Both 'A' and 'Z' increase in the nuclear isomerism
9. When nucleus of an electrically neutral atom undergoes a radioactive decay process, it will remain neutral after the decay if the process is:
   (a) an α-decay (b) a β-decay
   (c) a γ-decay (d) a K-capture process
10. Which of the following is/are characteristics of nuclear forces?
   (a) These forces operate within small distances of 2×10^{-13} cm
   (b) These forces drop to zero rapidly at a distance greater than 1.4×10^2 fermi
   (c) They follow inverse square law
   (d) They are stronger than electrostatic forces of attraction
11. The correct starting material and end product of different disintegration series are:
   (a) $^{232}Th, ^{208}Pb$ (b) $^{235}U, ^{206}Pb$
   (c) $^{238}U, ^{207}Pb$ (d) $^{237}Np, ^{209}Bi$
12. Select the wrong statement(s):
   (a) Nuclear isomers contain the same number of protons and neutrons
   (b) The decay constant is independent of the amount of the substance taken
   (c) 1 curie = 3.7×10^{10} dis
   (d) Actinium series starts with ^{238}U
13. Which of the following are synthetic elements?
   (a) Tc (b) Pu (c) Np (d) U
14. Which of the following nuclides belong to actinium (U^{235}) series?
   (a) ^{213}Po (b) ^{215}Po (c) ^{222}Rn (d) ^{207}Pb
15. In a nuclear reactor, heavy water is used to:
   (a) transfer the heat from the reactor
   (b) provide high speed neutrons for the fission reaction
   (c) reduce the speed of fast moving neutrons
   (d) increase the speed of neutrons

Answers

• Single correct option

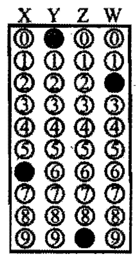
1. (a)	2. (b)	3. (c)	4. (c)	5. (b)	6. (b)	7. (c)	8. (c)
9. (d)	10. (b)	11. (d)	12. (b)	13. (c)	14. (b)	15. (a)	16. (c)
17. (d)	18. (d)	19. (b)	20. (b)	21. (c)	22. (c)	23. (a)	24. (d)
25. (b)	26. (c)	27. (a)	28. (c)	29. (d)	30. (c)	31. (d)	32. (b)
33. (c)	34. (b)	35. (a)	36. (a)	37. (a)	38. (c)		

• One or more than one correct options

1. (a, b, c)	2. (a, b)	3. (a, b, c)	4. (a, c)	5. (b, d)	6. (a, c)	7. (a, b, d)	8. (a, b, c)
9. (c, d)	10. (a, b, d)	11. (a, d)	12. (a, b)	13. (a, b, c)	14. (b, d)	15. (a, c)	

Integer Answer TYPE QUESTIONS

This section contains 7 questions. The answer to each of the questions is a single digit integer, ranging from 0 to 9. If the correct answers to question numbers X, Y, Z and W (say) are 6, 0, 9 and 2 respectively, then the correct darkening of bubbles will look like the given figure :



1. The total number of α and β particles emitted in the nuclear reaction :
   $^{238}_{92}U \longrightarrow ^{214}_{82}Pb$ is : (IIT 2009)
2. The $t_{1/2}$ of a radionuclide is 8 hours. Starting with 40 g of the isotope, the amount in gm remaining after one day will be:
3. If $\frac{3}{4}$ quantity of a radioactive nuclide disintegrates in two hours, its half-life (in hour) will be:
4. $^{7}_{4}Be$ captures a *K*-electron into its nucleus. What will be the mass number of resulting nuclide?
   [**Hint** : In *K*-electron capture, a proton of nucleus changes into neutron.
   $$^{1}_{1}H + ^{0}_{-1}e \longrightarrow ^{1}_{0}n$$
   $$^{7}_{4}Be + ^{0}_{-1}e \longrightarrow ^{7}_{3}Li$$
5. $^{232}_{90}Th$ disintegrates to $^{208}_{82}Pb$. How many of β-particles are evolved?
6. What mass in milligram of ^{226}Ra, whose ($t_{1/2} = 1620\,yr$), will be required to yield 1 millicurie of radiation?
7. The number of neutrons emitted when $^{235}_{92}U$ undergoes controlled nuclear fission to $^{142}_{54}Xe$ and $^{90}_{38}Sr$ is: (IIT 2010)
   [**Hint** : $^{235}_{92}U \longrightarrow ^{142}_{54}Xe + ^{90}_{38}Sr + 3[^{1}_{0}n]$]

Answers

1. (8) 2. (5) 3. (1) 4. (7) 5. (4) 6. (1) 7. (3)

LINKED COMPREHENSION TYPE QUESTIONS

• Passage 1

There are four radioactive decay series called thorium ($4n$); uranium ($4n+2$); actinium ($4n+3$) and neptunium ($4n+1$) series. Neptunium series is artificial while other three series are natural. End products of each radioactive decay series have stable nuclei. All natural decay series terminate at lead but neptunium or artificial series terminates at bismuth.

Answer the following questions:

1. The end product formed in the disintegration of $^{222}_{88}Ra$ is:
   (a) $^{204}_{81}Tl$ (b) $^{206}_{82}Pb$ (c) $^{222}_{86}Rn$ (d) $^{207}_{83}Bi$
2. Actinium series begins with an isotope of:
   (a) actinium (b) radium (c) uranium (d) polonium
3. $^{219}_{86}Rn$ is a member of actinium series. Another member of same series is:
   (a) $^{235}_{92}U$ (b) $^{222}_{89}Ac$ (c) $^{212}_{90}Th$ (d) $^{212}_{84}Po$
4. The end products of uranium and actinium series are respectively:
   (a) ^{206}Pb, ^{207}Pb (b) ^{206}Pb, ^{208}Pb
   (c) ^{207}Pb, ^{208}Pb (d) ^{206}Pb, ^{208}Bi
5. The starting isotope and the end product isotope of actinium series are:
   (a) $^{227}_{88}Ac$ and $^{208}_{82}Pb$ (b) $^{235}_{92}U$ and $^{207}_{82}Pb$
   (c) $^{238}_{92}U$ and $^{207}_{82}Pb$ (d) $^{235}_{92}U$ and $^{208}_{82}Pb$

• Passage 2

Initially the earth was a fire-ball; slowly it has cooled to form earth crust and its different layers. At the beginning $^{238}_{92}U$ was present and no $^{206}_{82}Pb$ was there. With the passage of time, uranium decayed to $^{206}_{82}Pb$. The decay process is:

$$^{238}_{92}U \xrightarrow[(x\alpha,\ y\beta)]{} {}^{206}_{82}Pb; \quad t_{1/2} \text{ of } ^{238}U = 4.5\times10^9 \text{ yrs}$$

Answer the following questions:

1. x and y in above decay series are:
   (a) 6, 8 (b) 8, 6 (c) 8, 8 (d) 6, 6
2. A sample of rock from South America contains equal number of atoms of ^{238}U and ^{206}Pb. The age of the rock will be:
   (a) 4.5×10^9 years (b) 9×10^9 years
   (c) 13.5×10^9 years (d) 2.25×10^9 years
   [**Hint:** $\dfrac{0.693}{t_{1/2}} = \dfrac{2.303}{t_{age}}\log\left(\dfrac{N_0}{N}\right)$
   $\dfrac{0.693}{4.5\times10^9} = \dfrac{2.303}{t_{age}}\log\left(\dfrac{2}{1}\right)$
   $t_{age} = 4.5\times10^9$ yrs.
   $N_0 = 1+1 = 2, \quad N = 1$]
3. Atomic mass of ^{238}U is 238.125 amu. Its packing fraction will be:
   (a) 5.25 (b) 0.125 (c) 12.5 (d) 1.25
4. The analysis of a rock shows the relative number of ^{238}U and ^{206}Pb atoms (Pb/U = 0.25). The age of rock will be:
   (a) $\dfrac{2.303}{0.693}\times4.5\times10^9\log1.25$ (b) $\dfrac{2.303}{0.693}\times4.5\times10^9\log0.25$
   (c) $\dfrac{2.303}{0.693}\times4.5\times10^9\log4$ (d) $\dfrac{2.303}{4.5\times10^9}\times0.693\log4$

Nathan Thomson, one of the first inhabitants of Lord Howe Island, decided to plant some European deciduous trees in his garden. Unfortunately the exact timing of planting the seeds is not known. Over the years, pollen produced by the trees accumulated at the bottom of the lake near Nathan's house. Very small quantities of radioactive ^{210}Pb ($t_{1/2} = 22.3$ years) were deposited at the same time. Note that European deciduous trees pollinate in their first year of growth.

In 1995, a team of researchers sampled a sediment core from the bottom of the lake. The examination of sediment core found that:

(a) Pollen of trees first occurs at the depth of 50 cm.

(b) The activity of ^{210}Pb at the top of sediment core is 356 Bq/kg and at 50 cm depth 1.40 Bq/kg.

Answer the following questions:

5. In what year did Nathan Thomson plant the seeds?
   (a) 1719 ± 2 (b) 1819 ± 2 (c) 1519 ± 2 (d) 1919 ± 2
   [**Hint:** $\dfrac{0.693}{t_{1/2}} = \dfrac{2.303}{t_{age}}\log\left(\dfrac{N_0}{N}\right)$
   $\dfrac{0.693}{22.3} = \dfrac{2.303}{t_{age}}\log\left(\dfrac{356}{1.40}\right)$
   $t_{age} = 176$ yrs]
6. Which step in the decay scheme explains how ^{210}Pb ends up in rain water while its parent ^{238}U is only present in earth's crust?
   (a) ^{238}U — ^{234}U (b) ^{234}U — ^{230}Th
   (c) ^{230}Th — ^{226}Ra (d) ^{226}Ra — ^{222}Rn

• Passage 3

In the atmosphere, carbon dioxide is found in two forms, i.e., $^{12}CO_2$ and $^{14}CO_2$. Plants absorb CO_2 during photosynthesis. In presence of chlorophyll, plants synthesise glucose.

$$6CO_2 + 6H_2O \xrightarrow{h\nu} C_6H_{12}O_6 + 6O_2\uparrow$$

Half life of ^{14}C is 5760 years. The analysis of wooden artifacts for ^{14}C and ^{12}C gives useful information for determination of its age.

All living organisms, because of their constant exchange of CO_2 with the surroundings have the same ratio of ^{14}C to ^{12}C, i.e., 1.3×10^{-12}. When an organism dies, the ^{14}C in it keeps on decaying as follows:

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

Thus, the ratio $^{14}C/^{12}C$ decreases with the passage of time. We can measure the proportion of ^{14}C in the remains of a dead organism and determine how long ago it died. The method of ***carbon dating*** *can be used to date anything made of organic matter, e.g., bone,* *skeleton, wood, etc. Using carbon dating, materials have been dated to about 50,000 years with accuracy.*

Answer the following questions:

1. ^{14}C exists in atmosphere due to:
   (a) conversion of ^{12}C to ^{14}C
   (b) combustion of fossil fuel
   (c) bombardment of atmospheric nitrogen by cosmic ray neutrons
   (d) none of the above
2. A wooden piece is 11520 yrs old. What is the fraction of ^{14}C activity left in the piece?
   (a) 0.12 (b) 0.25 (c) 0.50 (d) 0.75
   [**Hint:** $\frac{0.693}{t_{1/2}\ ^{14}C} = \frac{2.303}{t_{age}} \log\left(\frac{N_0}{N}\right)$
   $\frac{0.693}{5760} = \frac{2.303}{11520} \log\left(\frac{N_0}{N}\right)$
   $\frac{N}{N_0} = 0.25$]
3. In the process of photosynthesis, O_2 gas is released from:
   (a) CO_2 (b) H_2O
   (c) both H_2O and CO_2 (d) mechanism is not confirmed
4. A piece of wood from an archeological source shows a ^{14}C activity which is 60% of the activity found in fresh wood today. The age of archeological sample will be:
   (a) 4246 yrs (b) 4624 yrs (c) 4628 yrs (d) 6248 yrs
5. A sample of ancient wooden boat is found to undergo $9\,\text{dpm}\,g^{-1}$ of ^{14}C. What is the approximate age of the boat? The rate of disintegration of wood recently cut down is $15\,\text{dpm}\,g^{-1}$ of ^{14}C.
   (a) 4246.5 yrs (b) 5384 yrs (c) 4628 yrs (d) 2684 yrs

• Passage 4

The mineral monazite is a rich source of thorium, available in large quantity in Kerala. A typical monazite sample contains 9% ThO_2 and 0.35% U_3O_8. ^{208}Pb and ^{206}Pb are the stable end products in the radioactive decay series of ^{232}Th and ^{238}U respectively. All the lead in monazite is of radiogenic origin.

The isotopic ratio of $^{208}Pb/^{232}Th$ was found to be 0.104. The half lives of Th and U are 1.41×10^{10} years and 4.47×10^9 years respectively.

Answer the following questions:

1. The time elapsed since the formation of monazite sample will be:
   (a) 1.34×10^9 years (b) 2.01×10^9 years
   (c) 1.41×10^{10} years (d) 4.47×10^9 years
   [**Hint:** $\frac{0.693}{t_{1/2}\ \text{Th}} = \frac{2.303}{t_{age}} \log\left(\frac{N_0}{N}\right)$
   $\frac{0.693}{1.41 \times 10^{10}} = \frac{2.303}{t_{age}} \log(1.104)$
   $t_{age} = 2.01 \times 10^9$ years]
2. Estimated isotopic ratio of $^{206}Pb/^{238}U$ in the monazite sample will be:
   (a) 0.166 (b) 0.266 (c) 0.366 (d) 0.466
3. Select the incorrect information about ^{232}Th:
   (a) It belongs to third group of actinide series
   (b) ^{232}Th is fissile material
   (c) It is a fertile material
   (d) It belongs to $4n$ series

• Passage 5

Geiger-Nuttal proposed that the activity of a nucleus is inversely proportional to its half or average life. Thus, shorter the half life of an element, greater is its radioactivity, i.e., greater the number of atoms disintegrating per second. Half life and average life are related with each other.

$$t_{1/2} = \frac{0.693}{\lambda} = \tau \times 0.693 \quad or \quad \tau = 1.44 t_{1/2}$$

Answer the following questions:

1. The half life periods of four isotopes are given:
   I = 6.7 years; II = 8000 years; III = 5760 years; IV = 2.35×10^5 years.
   Which of these is most stable?
   (a) I (b) II (c) III (d) IV
2. Mark the incorrect relation:
   (a) $N_0 = Ne^{\lambda t}$ (b) $\tau = 1.44 t_{0.5}$
   (c) $N = N_0 \left(\frac{1}{2}\right)^n$ (d) $t_{1/2} = \lambda \ln 2$
3. Half life of a radioactive element is 10 years. What percentage of it will decay in 100 years?
   (a) 0.1% (b) 100% (c) 99.9% (d) 10%

• Passage 6

It has been estimated that the total energy radiated by the sun is 3.8×10^{26} J per second. The source of energy of stars is a thermonuclear reaction called nuclear fusion. Fusion reactions are not controlled. It is presumed that the energy of stars is due to two processes called proton-proton cycle and carbon-nitrogen cycle. Fusion cannot take place at ordinary temperature. Thus, hydrogen bomb uses a small fission bomb, which on explosion causes the temperature to rise very high, about 10^7 K. We have yet to see how a hydrogen bomb can be used for peaceful life-sustaining purpose. Energy released in the process of fusion is due to mass defect. It is also called Q-value.

$$Q = \Delta mc^2, \quad \Delta m = \text{mass defect}$$

Answer the following questions:

1. The binding energy per nucleon of ^2_1H and ^4_2He are 1.1 MeV and 7 MeV respectively. If two deuteron nuclei react to form a single helium nucleus, then the energy released is:
   (a) 13.9 MeV (b) 26.9 MeV (c) 23.6 MeV (d) 19.2 MeV
2. Mass equivalent to the energy 931 MeV is:
   (a) 6.02×10^{-27} kg (b) 1.662×10^{-27} kg
   (c) 16.66×10^{-27} kg (d) 16.02×10^{-27} kg
3. Fusion reaction takes place at about:
   (a) 3×10^2 K (b) 3×10^3 K
   (c) 3×10^4 K (d) 3×10^6 K

4. A star has 10^{40} deuterons. It produces energy via the process:

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

If the average power radiated by the star is 10^{16} W, then the deuteron supply of the star is exhausted in a time of the order of:

(a) 10^6 sec (b) 10^8 sec (c) 10^{12} sec (d) 10^{16} sec

5. In a nuclear reaction,

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

if the masses of $^{2}_{1}H$ and $^{3}_{2}He$ are 2.014741 amu and 3.016977 amu respectively, then the Q-value of the reaction is nearly:

(a) 0.00352 MeV (b) 3.27 MeV
(c) 0.82 MeV (d) 2.45 MeV

• Passage 7

Moderator is a material which is used to slow down the neutrons produced during nuclear fission. The neutrons from the source are of high speed and energy. Heavy water or graphite moderators slow down the speed of the neutrons. The energy of fast moving neutrons decreases from 2 MeV to 0.02535 eV; it corresponds to the velocity of 220 m sec^{-1}. At this velocity, the neutrons are in thermal equilibrium with the moderator. Such neutrons are called 'thermal neutrons'. Thermal neutrons cause further fission reaction. The essential characteristics of moderators are:

(i) its molar mass must be low,
(ii) it should not absorb neutrons,
(iii) it should undergo elastic collisions with neutrons.

Answer the following questions:

1. The moderator in a reactor:
(a) absorbs neutrons
(b) accelerates neutrons
(c) slows down neutrons
(d) absorbs thermal energy produced in the reactors
2. A good moderator should:
(a) not be a gas only
(b) not have appetite for neutrons only
(c) be light in mass number only
(d) be all the above three
3. Which of the following is not used as a moderator?
(a) Heavy water (b) Graphite
(c) Beryllium (d) Sodium
4. Moderator in the reactor yields:
(a) fast moving neutrons
(b) thermal neutrons
(c) magnetic neutrons
(d) electric neutrons
5. Which among the following characters make graphite a good moderator?
(a) Cross-sectional area of graphite is very high
(b) Graphite is a good conductor of electricity
(c) There is elastic collision between graphite and neutron
(d) Graphite has weak van der Waals' force between two layers

• Passage 8

Radioactive decay follows first order kinetics. The disintegration of radioactive elements does not depend on the temperature. Unlike chemical first order reactions, the nuclear reactions are also independent of catalyst. Mean life and half life of nuclear decay process are $\tau = \frac{1}{\lambda}$ and $t_{1/2} = \frac{0.693}{\lambda}$. There are a number of radioactive elements in nature; their abundance is directly proportional to half life. Amount remaining after n half lives of radioactive elements can be calculated using the relation:

$$N = N_0\left(\frac{1}{2}\right)^n$$

Answer the following questions:

1. Which is/are true about the decay constant?
(a) Unit of λ is time^{-1}
(b) λ is independent of temperature
(c) λ depends on initial amount of element taken
(d) λ depends on the nature of radioactive element
2. Amount of radioactive element (activity) decreases with passage of time as:
(a) linearly (b) exponentially
(c) parabolically (d) all of these
3. Half life of ^{60}Co is 5.3 yrs, the time taken for 99.9% decay will be:
(a) 0.53 yrs (b) 53 yrs
(c) 530 yrs (d) 5300 yrs
4. Rate of radioactive decay is:
(a) independent of time
(b) independent of temperature
(c) dependent on catalyst
(d) dependent on the amount of element not yet decayed
5. Select the correct relations:
(a) $t_{1/2} = \frac{0.693}{\lambda}$ (b) $\tau = \frac{1}{\lambda}$
(c) $\tau = 1.44 \times t_{1/2}$ (d) $\tau = \frac{t_{1/2}}{0.693}$

• Passage 9

In the disintegration of a radioactive element, α and β-particles are evolved from the nucleus.

$$^{1}_{0}n \longrightarrow ^{1}_{1}H + ^{0}_{-1}e + \text{Antineutrino} + \text{Energy}$$

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

Then, emission of these particles changes the nuclear configuration and results into a daughter nuclide. Emission of an α-particle results into a daughter element having atomic number lowered by 2 and mass number by 4; on the other hand, emission of a β-particle yields an element having atomic number raised by one. Soddy and Fajan proposed that the daughter nuclide may occupy different positions in the periodic table.

Answer the following questions:

1. Which of the following combinations give finally an isotope of the parent element?
   (a) α, α, β (b) α, γ, α (c) α, β, β (d) β, γ, α
2. A radioactive element belongs to IIIB group; it emits one 'α' and one β-particle to form a daughter nuclide. The position of daughter nuclide will be in:
   (a) IIA (b) IA (c) IIB (d) IVB
3. During β-decay, the mass of atomic nucleus:
   (a) decreases by 1 unit (b) increases by 1 unit
   (c) decreases by 2 units (d) remains unaffected
4. How many α and β-particles should be emitted from a radioactive nuclide so that an isobar is formed?
   (a) $1\alpha, 1\beta$ (b) $1\alpha, 2\beta$ (c) $2\alpha, 2\beta$ (d) $n\beta$
5. Select the correct statements among the following:
   (a) Emission of a β-particle results into isobar of parent element
   (b) Emission of a β-particle results into isodiaphere of parent element
   (c) Emission of one α and two β-particles results into isotope of the parent element
   (d) Emission of γ-radiations may yield nuclear isomer

Answers

Passage 1.	1. (b)	2. (c)	3. (a)	4. (a)	5. (b)	
Passage 2.	1. (b)	2. (a)	3. (a)	4. (a)	5. (b)	6. (d)
Passage 3.	1. (c)	2. (b)	3. (b)	4. (a)	5. (a)	
Passage 4.	1. (b)	2. (c)	3. (b)			
Passage 5.	1. (d)	2. (d)	3. (c)			
Passage 6.	1. (c)	2. (b)	3. (d)	4. (c)	5. (b)	
Passage 7.	1. (c, d)	2. (d)	3. (d)	4. (b)	5. (a, c)	
Passage 8.	1. (a, d)	2. (b)	3. (b)	4. (b, d)	5. (a, b, c, d)	
Passage 9.	1. (c)	2. (a)	3. (d)	4. (d)	5. (a, b, c, d)	

SELF ASSESSMENT

ASSIGNMENT NO. 3

SECTION-I

Straight Objective Type Questions

This section contains 10 multiple choice questions. Each question has 4 choices (a), (b), (c) and (d), out of which only one is correct.

1. If $\frac{3}{4}$ quantity of a radioactive substance decays in 2 hrs, its half life would be:
(a) 1 hour (b) 45 minutes
(c) 30 minutes (d) 15 minutes

2. Radio carbon dating is done by estimating in a specimen: **(VITEEE 2007)**
(a) the amount of ordinary carbon still present
(b) the amount of radio carbon still present
(c) the ratio of amount of ${}^{14}_{6}C$ to ${}^{12}_{6}C$ still present
(d) the ratio of amount of ${}^{12}_{6}C$ to ${}^{14}_{6}C$ still present

3. Which of the following are correct with respect to the unit of radioactivity?
(i) The SI unit of radioactivity is curie (Ci)
(ii) $1\,Ci = 3.7 \times 10^{-10}$ dis s^{-1}
(iii) $1\,Bq = 3.7 \times 10^{-10}$ Ci
(iv) The SI unit of radioactivity is becquerel (Bq)
(v) $1\,Ci = 3.7 \times 10^{10}$ Bq
(a) (i) and (iii) (b) (iv) and (v)
(c) (i) and (ii) (d) (ii) and (iv)
(e) (i) and (v)

4. A freshly cut tree and a wooden artifact have 30.4 and 15.2 counts g^{-1} min^{-1} of C^{14} of half life of 5700 years. The age of the artifact in years would be:
(a) 2850 (b) 5700 (c) 570 (d) 6930
(e) 11400

5. The radioactive isotope of cerium-137 of weight 8g was collected on 1st Feb. 2006 and kept in a sealed tube. On 1st July, 2006, it was found that only 0.25 g of it remained. The half life period of the isotope is: **[PET (Kerala) 2007]**
(a) 37.5 days (b) 30 days
(c) 25 days (d) 50 days
(e) 60 days

6. The number of α and β-particles emitted in the nuclear reaction
$${}^{228}_{90}Th \longrightarrow {}^{212}_{83}Bi \text{ are:}$$ **(DCE 2007)**
(a) 4α and 1β (b) 3α and 7β
(c) 8α and 1β (d) 4α and 7β

7. A cyclotron cannot accelerate:
(a) protons (b) deutrons
(c) neutrons (d) electrons

8. Isotope I^{128} has no medicinal importance because:
(a) it is non-radioactive (b) it is poisonous
(c) it is radioactive (d) none of these

9. The decay of mass during nuclear fission and fusion are:
(a) 0.1% and 0.231% (b) 0.231% and 0.1%
(c) 0.4% and 0.2% (d) 0.3% and 0.3%
[**Hint:** Greater mass is converted to energy in nuclear fusion as compared to that of fission.]

10. On large scale, tritium is produced by which of the following nuclear reactions? **(SCRA 2009)**
(a) ${}^{6}_{3}Li + {}^{1}_{0}n \rightarrow {}^{4}_{2}He + {}^{3}_{1}T$
(b) ${}^{2}_{1}D + {}^{2}_{1}D \rightarrow {}^{3}_{1}T + {}^{1}_{1}H$
(c) ${}^{14}_{7}N + {}^{1}_{0}n \rightarrow {}^{12}_{6}C + {}^{3}_{1}T$
(d) ${}^{14}_{7}N + {}^{1}_{1}H \rightarrow {}^{3}_{1}T$ + Other fragments

SECTION-II

Multiple Answers Type Objective Questions

11. Which of the following will emit positron?
(a) ${}^{30}_{15}P$ (b) ${}^{13}_{7}N$ (c) ${}^{3}_{1}H$ (d) ${}^{14}_{6}C$
[**Hint:** ${}^{30}_{15}P\left(\frac{n}{p}=1\right)$ and ${}^{13}_{7}N\left(\frac{n}{p}<1\right)$; these nuclei emit positron.
$${}^{30}_{15}P \longrightarrow {}^{30}_{14}Si + {}^{0}_{+1}e$$
$${}^{13}_{7}N \longrightarrow {}^{13}_{6}C + {}^{0}_{+1}e$$]

12. If $\frac{n}{p}$ ratio is less than 1, the nuclide can:
(a) *K*-capture (b) emit positron
(c) emit β-particle (d) emit α-particle

13. For radioactive decay:
(a) $t_{3/4} = 2\,t_{1/2}$ (b) $t_{7/8} = 3\,t_{1/2}$
(c) $t_{99\%} = 2\,t_{90\%}$ (d) $t_{90\%} = \frac{10}{3}\,t_{50\%}$

14. Which of the following statements is/are correct?
(a) Nuclear fusion produces more energy than nuclear fission
(b) Nuclear fusion takes place at very high temperature (10^6 K)
(c) Nuclear fusion yields radioactive product
(d) Nuclear fusion involves chain reaction

15. Decrease in atomic number is observed during:
(a) α-emission (b) β-emission
(c) positron emission (d) *K*-capture

SECTION-III

Assertion-Reason Type Questions

This section contains 4 questions. Each question contains **Statement-1** (Assertion) and **Statement-2** (Reason). Each question has following 4 choices (a), (b), (c) and (d), out of which only one is correct.
(a) Statement-1 is true; statement-2 is true; statement-2 is a correct explanation for statement-1.
(b) Statement-1 is true; statement-2 is true; statement-2 is not a correct explanation for statement-1.

(c) Statement-1 is true; statement-2 is false.
(d) Statement-1 is false; statement-2 is true.

16. Statement-1: β-particles are emitted by nucleus.

Because

Statement-2: Following transformation takes place in β-emission.

$${}_0^1n \longrightarrow {}_1^1H + {}_{-1}^{0}e$$

17. Statement-1: Nuclide ${}_{20}^{40}Ca$ is less stable than ${}_{20}^{40}Ca$.

Because

Statement-2: Nuclides having even number of nucleons are stable.

18. Statement-1: Energy is released in the nuclear fusion of hydrogen nuclei to form helium nuclei.

Because

Statement-2: Binding energy per nucleon of helium is greater than hydrogen.

19. Statement-1: ${}_{56}^{133}Ba + e^- \longrightarrow {}_{55}^{133}Cs + \text{X-ray}$
It is an example of K-electron capture.

Because

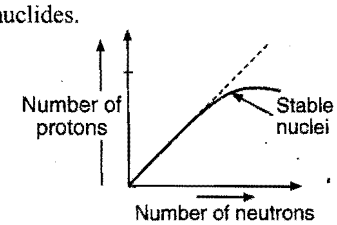
Statement-2: Atomic number of daughter nuclide decreases by one unit in K-electron capture.
[**Hint:** Nucleus may capture electron from K-shell and the vacancy is filled by electrons from higher shells; X-ray is released in this process.]

20. Statement-1: The plot of atomic number (y-axis) versus number of neutrons (x-axis) for stable nuclei shows a curvature towards x-axis from the line of 45° slope as atomic number is increased.

Because

Statement-2: Proton-proton electrostatic repulsions begin to overcome attractive forces involving protons and neutrons in heavier nuclides. **(IIT 2008)**

[**Hint:**



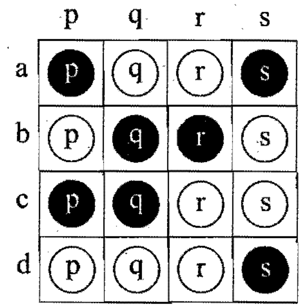
In heavier nuclei, attractive forces between proton-neutron overcome proton-proton electrostatic repulsion.]

SECTION-IV

Matrix-Matching Type Questions

This section contains 2 questions. Each question contains statements given in two columns which have to be matched. Statements (a, b, c and d) in Column-I have to be matched with statements (p, q, r and s) in Column-II. The answers to these questions have to be appropriately bubbled as illustrated in the following examples:

If the correct matches are (a-p, s), (b-q, r), (c-p, q) and (d-s), then correct bubbled 4 × 4 matrix should be as follows:



21. Match the Column-I with Column-II:

Column-I	Column-II
(a) ${}_1^2D + {}_1^3T \rightarrow {}_2^4He + {}_0^1n$ + Energy	(p) β-emission
(b) ${}_4^9Be + {}_2^4He \longrightarrow {}_6^{12}C + {}_0^1n$	(q) Artificial transmutation
(c) ${}_{12}^{24}Mg + {}_2^4He \longrightarrow {}_{14}^{27}Si + {}_0^1n$	(r) Discovery of neutrons
(d) ${}_0^1n \longrightarrow {}_1^1H + {}_{-1}^{0}e$	(s) Hydrogen bomb

22. Match the Column-I with Column-II:

Column-I	Column-II
(a) $n \longrightarrow p^+ + ...$	(p) Positron emission
(b) $p^+ \longrightarrow n + ...$	(q) β-emission
(c) X-ray emission	(r) K-electron capture
(d) $4\,[{}_1^1H] \longrightarrow ..... + 2\beta^+$ + Energy	(s) α-emission

SECTION-V

Linked Comprehension Type Questions

Nucleus of an atom resembles with a drop of liquid. Density of nucleus is very high, *i.e.*, 10^8 tonne/cc or 130 trillion tonnes m^{-3}. This density is about a trillion times greater than that of water. Density of nuclei of all elements are same, it is independent of atomic number or atomic mass. However, the radius of nucleus depends on the mass number. Surface tension of nucleus is also very high, *i.e.*, about 1.24×10^{18} times, the surface tension of water.

Answer the following questions:

23. The radius of ${}_6^{12}C$ nucleus is:
(a) 5×10^{-15} m (b) 1.4×10^{-15} m
(c) 3.5×10^{-15} m (d) 6×10^{-15} m
[**Hint:** $r = r_0 \times A^{1/3}$ where A = Mass number
$r_0 = 1.4 \times 10^{-15}$ m]

24. Ratio of volume of atom and nucleus is:
(a) $10^8 : 1$ (b) $10^{15} : 1$ (c) $10^{13} : 1$ (d) $10^{12} : 1$

25. Radius of nucleus is directly proportional to:
(a) A^2 (b) $A^{1/3}$ (c) $[A]^3$ (d) A

Answers

1. (c)	**2.** (c)	**3.** (b)	**4.** (b)	**5.** (b)	**6.** (a)	**7.** (c)	**8.** (a)
9. (a)	**10.** (b)	**11.** (a, b)	**12.** (a, b)	**13.** (a, b, c, d)	**14.** (a, b, c)	**15.** (a, c, d)	**16.** (a)
17. (d)	**18.** (a)	**19.** (b)	**20.** (c)	**21.** (a - s) (b - q, r) (c - q) (d - p)			
22. (a - q) (b - p) (c - r) (d - s)		**23.** (c)	**24.** (b)	**25.** (c)			