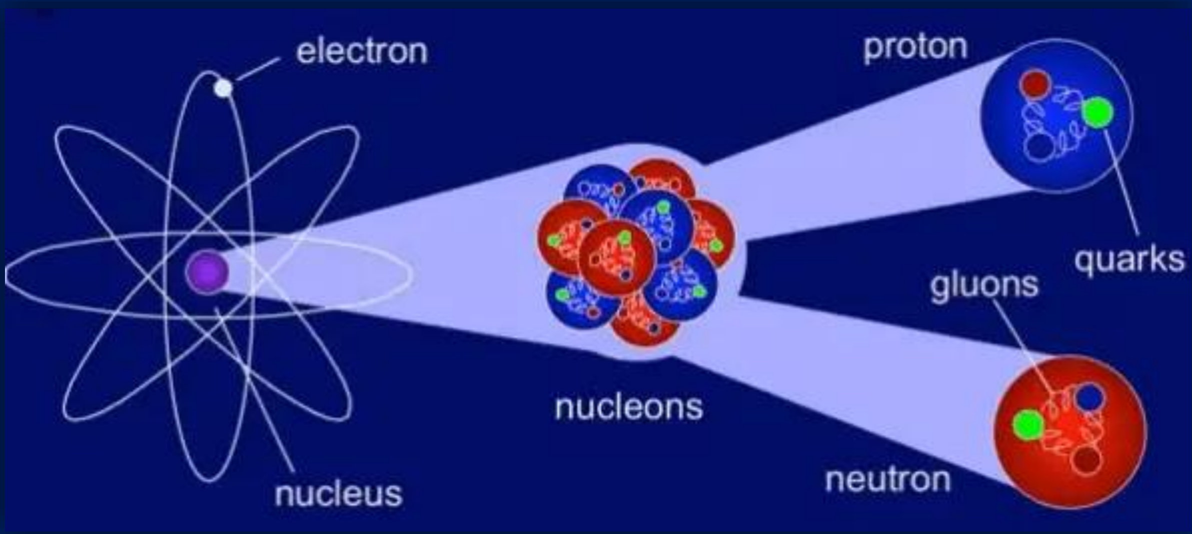
13.NUCLEI



Physics Smart Booklet

Theory + NCERT MCQs + Topic Wise Practice MCQs + NEET PYQs

Nuclear

Nuclear fission
- Splitting of a heavy nucleus into or more lighter nucler.

e.g $\Rightarrow {}_{92}U^{235} + 0^{n^1} \rightarrow {}_{56}Ba^{141} + {}_{36}kr^{92} + 30^{n^1} + 200Mev$

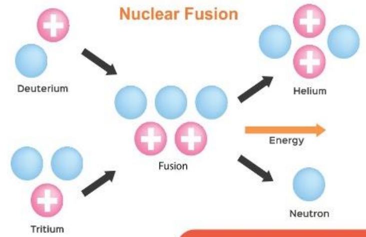
- Uncontrolled chain reaction: principle of atomic bank.
- Contralled chain reation: principle of nuclear reactors.

Nuclear fusion
- Combining two lighter nuclei to form a heavy nucle us.

$^1_1H + ^1_1H \rightarrow ^2_1H + e^+ + v + 0.42\ (energy)$

Application
Nuclear fussion is the source of energy in the sun and stars.

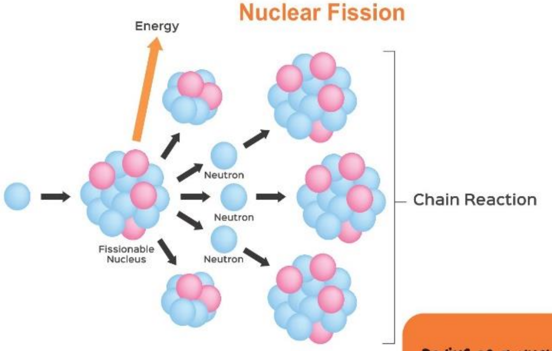
Nuclear Fusion



Nuclear of an atom onsists of proton and neutrons collectively called nucleons.

Nuclei can be
- Isotoper (Same Z but different A)
- Isobars (Same A but different Z)
- Isotores (Same N but different A)

Nuclear Fission



Representation

zXA
A = mass number
Z = Atomic number

discoverd by henri Becquerel in 1896

Radio activity

Phenomenon of Disintegrakon of heavy elements into comparatively lighter elements by emission of $\alpha, \beta, \& \gamma$ radiations.

Radius of a nucleus
R = R0 A 1/3 { R0 = 1-2fm}

- **Density of nucleus (S)**

$$\frac{Mass}{Volume} = \frac{Mass\ of\ 1\ nucleon \times A}{\frac{4}{3}\pi R^3} = \frac{1}{2}\pi R_0^3 A$$

- Nuclear density is constant its value is nearly 2.38 × 1017 kg/m3

- **Mass of nucleus** is measured in atomic mass unit (u) or (amu)
  1 amu (or u) = 1/12 (mass of C^{12}) atom = 1.6×10^{-27} kg

- **Mass defect**
The difference (Δm) between mars of constituent nucleons and nucleus is called mass defect of nucleus.
(Δm = sum of the masles of nucleons - mass of nucleus)
= $\{Zm^p + (A - Z)m_n\} - M_N$

Binding Energy of Nucleus

$\Rightarrow B.E = Dmc^2$

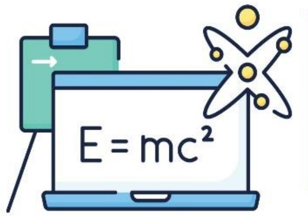
$\Rightarrow B.E = (Zm_p + (A - Z)\ m_N - m_N)c^2$

(where, c is the speed of light $c = 3 \times 10^8$ m/sec)

$\Rightarrow B.E\ per\ nucleon = \frac{B.E}{No.\ of\ nucleons}$

Nuclear binding energy is maximum for mass number 50-60.

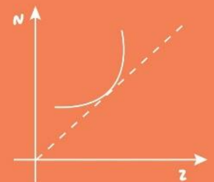
Mass and energy
- Mass m of a particle is equivalent to energy given by $E = mc^2$
- Also known as rest mass energy.



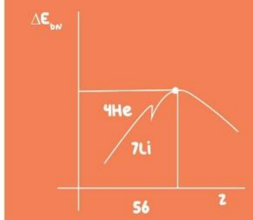
Q-value

A + B	-	C + D + Energy
MA MB	mc	md
Reactants		Product + Q- Value
Q value	=	B.E of product - B.E. Of reactants
Q-value	=	$((m_A + m_B) - (mC + mD))\ C^2$
Q-value	=	$((k.E_C + k.E_D) - (K.E_A + K.E_B))$

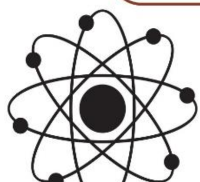
Nuclear force theory
- Nuclear force is a force which holds the nucleons together.



- For atomic number < 20, most stable nuclei have N:P ratio nearly 1:1
- For atomic number > 83, there are no stable nuclei.
- A nucleus is stable when its Binding energy per nucleus value is around 8 mev per nucleon or more.
- Following are observations from Binding energy per nucleon versus mass number cerve.



- B.E. per nucleon is more for some nuclei than their neighbours. This andicates a shell type structure of nucleus.
- B.E. per nucleon is around 8mev FOR 30 ∠A ∠120, these are stable elements.



α decay
- radiations are the helium nuclei. These are emitted as

$^A_ZX \rightarrow ^4_2He + ^{A-4}_{Z-2}Y$

α-particle, Daughter nuclei

- highest ionizing power but least penetrating power.

β- decay
two types

β+ (positron) β (Electrons)

$^A_ZX \rightarrow ^0_{-1}\beta + ^A_{Z+1}Y + \bar{v}$

(electron) (antineutrina)

(product)

$^A_ZX \rightarrow ^0_{+1}\beta + ^A_{Z-1}Y + v$

(position) (nutrino)

- less ionizing power than α -particle and moderate penetrating power.

γ decay

γ-decay office an α or - decay. nucleus vibrates with the energy shared by it and electromagnetic waves of very high frequency (α-radition) are emitted least ionizing power but highest penetrating power.

Law of radio activity

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

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

Half - life

where $N = \frac{N_0}{2}$

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

Fraction of nuclei left undcayed after n half lives is

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

where, $t = NT_{1/2}$

mean life or any life

$\tau = \frac{1}{\lambda} = \frac{T_{1/2}}{0.693} = 1.44\ T_{1/2}$

decay rate or activity

$R = -\frac{dN}{dt}$

$R = \lambda N_0 e^{-\lambda t}$ or $R = R_0 e^{-\lambda t}$

Nuclei

Atomic nucleus

All atomic nuclei are made up of fundamental particles called protons and neutrons. A proton has a positive charge of the same magnitude as that of an electron. A neutron is electrically neutral and has the mass nearly equal to that of proton. The protons and the neutrons are together called nucleons.

Terms used

- **Nucleons:** Constituents of an atomic nucleus are called nucleons. Protons and neutrons are the nucleons.
- **Chemical Symbol:** The chemical symbol for an atom (or its nucleus) is ${}_Z^AX$ or ${}_ZX^A$.

The symbol A represents the numbers of nucleons and is called the mass number. Z represents proton number in an atomic nucleus as well as the number of extra nuclear electron in the atom. The symbol n represents the number of neutrons in an atomic nucleus. Thus, A = Z + n; n = A – Z

- **Nuclide:** It is an accepted type or species of an atom characterised by its number of nucleons. A nuclide is represented by X^A. For convenience z number may also be included. For example, an oxygen nuclide is represented as ${}^{16}O$ or ${}_8^{16}O$ or ${}_8O^{16}$.

  - **Isotopes:** Nuclides with the same z are called isotopes. For example, hydrogen $({}_1^1H)$, deutron $({}_1^2D)$ and tritium $({}_1^3T)$ are the isotopes. The word isotope implies more than one species occupying the same place in the periodic table. The element like beryllium or aluminium has only one species in nature, and is said to form a single stable nuclide, rather than a single stable isotope. Unstable nuclides (natural or artificial) are called radioactive nuclides or radionuclides.
  - **Isobars:** Nuclides with the same mass numbers and different atomic numbers Z are called isobars.
    Example: ${}_6^{14}C$ and ${}_7^{14}N$ (A = 14) ${}_7^{16}N$ and ${}_8^{16}O$ (A = 16)
  - **Isotones:** Nuclides with same neutron number n are called isotones.
    Examples: ${}_{15}^{31}P$ and ${}_{16}^{32}S$; ${}_6^{14}C$, ${}_7^{15}N$, ${}_8^{16}O$
  - **Isomers:** Nuclides with the same mass number (isobaric) and the same atomic number (isotopic) but different nuclear properties (such as life times, angular momentum and magnetic moment) are called Isomers. Isomeric state or level is usually denoted by the letter m attached to the mass number.
    For example ${}^{69m}Zn$ represents an isomeric state of ${}^{69}Zn$.
  - **Mirror nuclides:** Nuclides with same mass number, but neutron number of one nuclide is equal to the proton number of the other are called mirror nuclides.

Examples:

${}_6^{11}C \to {}_5^{11}B + {}^+\beta$; $N_C = 5; Z_B = 5$

${}_8^{15}O \to {}_7^{15}N + {}^+\beta$; $N_0 = 7; Z_N = 7$

${}_9^{17}F \to {}_8^{17}O + {}^+\beta$; $N_0 = 9; Z_F = 9$

Relative abundance of isotopes of an element

Every element consists of a mixture of several isotopes. The relative abundance of different isotopes differ from one element to other.

Let the relative abundances of an element having three stable isotopes be (x) %, (y) % and (z) %. Let the atomic masses of these isotopes be M_1, M_2 and M_3. The average atomic mass of this element will be found using the following expression.

$$\text{Average atomic mass of the element} = \frac{x}{100}\times M_1 + \frac{y}{100}\times M_2 + \frac{z}{100}\times M_3$$

The sum of percentage relative abundances is 100. i.e., x + y + z = 100

General properties of a nucleus

1. **Constituents:** Protons and neutrons are the nuclear constituents.
2. **Mass:** It is the actual mass of the nucleus. It is slightly less then the sum of the masses of requisite number of nucleons in free state at rest constituting the nucleus.
3. **Size:** Experiments show that most nuclei are approximately proportional to the mass number A.

   $$V \propto A \Rightarrow \frac{4\pi R^3}{3} \propto A$$

   Thus, the nuclear radius R is approximately proportional to the cube root of the mass number

   $R \propto A^{1/3} \Rightarrow R = R_0 A^{1/3}$ where $R_0 = 1.2 \times 10^{-15}$ m = 1.2 fm
4. **Nuclear density:** It is the ratio of the nuclear mass of a nucleus to its volume. It is of the order of 10^{17} kg m^{-3}. It is nearly the same for all nuclei.
5. **Nuclear charge:** The charge of a nucleus is the total charge of its protons.

   $q_N = +Ze$, where e $\rightarrow$ magnitude of the electron charge, Z $\rightarrow$ atomic number of the nucleus
6. **Nuclear spin:** Many nuclides have an intrinsic nuclear angular momentum, or spin. Associated with the spin is the nuclear magnetic moment. The measured nuclear magnetic moments are of the order of 10^{-27} J T^{-1}. The nuclear magnetic moments are expressed in terms of a quantity called **nuclear magneton (μ_N)**

   $\mu_N = \frac{eh}{4\pi m_p} = 5.05 \times 10^{-27}\,J\,T^{-1} = 3.153 \times 10^{-8} eVT^{-1}$, where e $\rightarrow$ magnitude of the electron charge,

   h $\rightarrow$ planck's constant, $m_p \rightarrow$ mass of the proton. (Recall : Magnetic moment of an electron (I-orbit) in orbital motion $= \mu_l = \left(\frac{eh}{4\pi m_e}\right)$

   Magnetic moment of proton = 2.793 μ_N. Though the charge of the neutron is zero, it has a spin magnetic moment $\mu_n = -1.913\ \mu_N$. These results suggests that proton and neutron have complex structures.

Nuclear forces

It is clear from the stability of the nuclei, that there must be a strong attractive force which holds the nucleons together. This force which binds the neutrons and protons together in a nucleus is called nuclear force. Like gravitational and electromagnetic forces, nuclear force is also a basic force in nature.

Characteristics

- Nuclear force is the strongest force in nature ($F_{nuclear} > F_{electric} >> F_{gravitation}$)
- Nuclear force is charge independent ($F_{pp} = F_{nn} = F_{pn}$)
- Nuclear force is of short range (~ a few fermi)
- Nuclear force between nucleons within a nucleus is generally attractive
- Nuclear forces is saturated
- Nuclear forces has a non-central feature also.
- Nuclear forces is an exchange force (Exchange particle : π-meson)
- Nuclear force is spin dependent

Einstein's mass - energy relation

Einstein established from his theory of relativity, that mass and energy are equivalent. The energy equivalent of mass m is given by $E = mc^2$, where, c is the speed of light in vacuum.

Applications

1. **Mass defect and binding energy** of a nucleus are explained using mass-energy relation
2. During **nuclear reactions** such as **fission** and **fusion**, the total mass of the products is less than the total mass of the reactants. It is this difference in mass which appears as energy.
3. **Annihilation of matter:** When an electron and a positron come very close to each other, they annihilate. Their mass, appears as energy and is radiated in the form of γ-rays.

4. **Pair production:** A γ-ray photon (minimum energy $\simeq$ 1.02 mev) collides with a nucleus to create an electron position pair. In this process, energy is converted into mass.

Atomic mass unit

Atomic mass unit (u) is defined as $\left(\frac{1}{12}\right)^{th}$ the mass of a neutral carbon-12 atom.

$$1\text{ u} = \frac{1}{12}\left[\frac{12}{6.023\times 10^{26}}\right]\text{ kg} = 1.66\times 10^{-27}\text{ kg}$$

Relation between amu and eV

According to Einstein's mass energy relation $E = mc^2$. The energy equivalent of 1 u = 931.5 MeV

☞

- **The following table gives the masses of some elementary particles expressed in u and kg**

Particle	Mass (in u)	Mass in (kg)
	1	1.6605×10^{-27}
Electron	0.00055	9.1094×10^{-31}
Proton	1.007276	1.6726×10^{-27}
Hydrogen atom	1.007825	1.6735×10^{-27}
Neutron	1.008665	1.6749×10^{-27}

- **Electron Volt**

  One **electron volt** is defined as the energy gained by a particle carrying one elementary electric charge (no matter whether it is an electron or any singly charged positive or negative ion), when it is accelerated due to a potential difference of 1 volt.

  $1\text{ eV} = 1.6 \times 10^{-19}$ joule, $1\text{ MeV} = 1.6 \times 10^{-13}$ J.

Mass defect

Mass defect is the amount of mass which would be converted to energy if a nucleus were to be assembled from the requisite numbers of protons and neutrons. The same amount of energy would be required to break the nucleus into its constituent particles. Thus, the energy equivalent of the mass defect is a measure of binding energy of the nucleus.

The mass of the constituent particles is the sum of the masses of Z protons, (A – Z) neutrons. The mass defect of a nucleus can be calculated by, $\Delta m = [Zm_p + (A - Z)m_n] - M_{Z,A}$ (nuclear mass)

Binding energy

The nucleons i.e., protons and neutrons, are bound together in a nucleus. **The energy needed just to take all the nucleons in a nucleus apart, so that they are completely separated, is called the binding energy of the nucleus.**

$BE = \Delta m\,(u) \times 931.5$ MeV

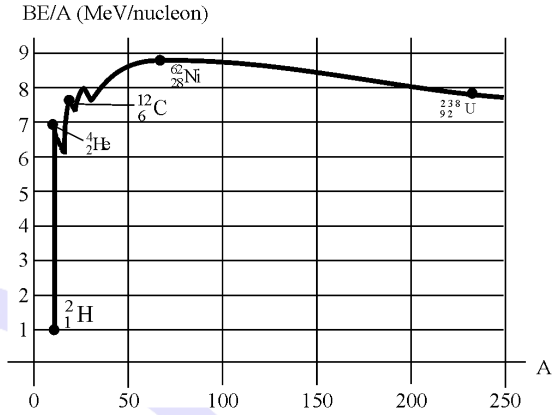
Binding energy divided by the number of nucleons in a nucleus gives its binding energy per nucleon, also called Specific binding energy (SBE).

Binding energy curve

A graph showing the variation of binding energy per nucleon with the mass number of nuclides is known as Binding energy curve (of the element).

Some of features of the BE curves are as follows:

- It is seen that specific binding energy has a low value for deuteron (nucleus of heavy hydrogen). Then it rapidly increases. For example, specific binding energy is around 7 MeV/nucleon for helium, 8 MeV/nucleon for oxygen and 8.8 MeV/nucleon in the neighborhood of around A = 60.



- It is seen that specific binding energy is about 8 MeV/nucleon for the elements with mass number between 30 and 170. For very light and very heavy elements, it is less than 8 MeV/nucleon.
- In the case of small mass numbers (approximately from 4 to 20) the curve shows characteristics peaks. For example $_2He^4$, $_6C^{12}$, $_8O^{16}$, etc have higher SBE compared to their neighbours.
- In the case of the nuclei with specific binding energy around the maximum value, it requires more energy to tear the nucleons apart. Hence, they are more stable.
- For very high mass numbers the value goes on decreasing upto to 7.6 MeV / nucleon for uranium.
- **Significance:** There is an increase in the energy when a very heavy nucleus breaks into two or more lighter nuclei (nuclear fission) and also when two or more lighter nuclei fuse together to form a single nucleus (nuclear fusion). Both the processes liberate energy. Thus, binding energy curve helps in understanding the mechanism of release of energy in nucleus fission and nucleus fusion reactions.

Nuclear fission

The process in which a heavy nucleus captures a neutron and splits into two lighter nuclei (fragments) of intermediate masses, releasing two or three neutrons and a large amount of energy is called nuclear fission. The energy is due to the conversion of a portion of atomic mass into energy. One possible process is the fission process of ^{235}U can be represented as $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n + \text{energy}$.

Other possible reactions are;

$$^{235}_{92}U + ^{1}_{0}n + ^{236}_{92}U \rightarrow \left\{\begin{array}{l} ^{135}_{52}Te + ^{98}_{40}Zr + 3\left(^{1}_{0}n\right) + \text{energy} \\ ^{140}_{56}Ba + ^{94}_{36}Kr + 2\left(^{1}_{0}n\right) + \text{energy} \\ ^{139}_{54}X_a + ^{95}_{28}Sr + 2\left(^{1}_{0}n\right) + \text{energy} \\ ^{148}_{57}L_a + ^{85}_{35}Br + 3\left(^{1}_{0}n\right) + \text{energy} \end{array}\right\} \text{Energy} \approx 200\text{ MeV}$$

In some modes of fission, 2 neutrons are released; in some other modes, 3 neutrons are released. Thus, on the average 2.5 neutrons are released per fission ^{235}U.

When 1 kg of ^{235}U undergoes fission, the energy released is about 23 × 10^6 kwh, much of the energy released appears as the kinetic energy of the fission fragments and of the neutrons.

Nuclear chain reaction

During the fission process, two or three neutrons are also released per fission. These neutrons can cause further fission thereby liberating more neutrons. This process continues. Thus, **the neutrons released during one fission can cause further fission and the process continues. Such a reaction is called a chain reaction.** There are two types of chain reactions;

In a **controlled chain reaction**, the reaction is accelerated to build up neutron population and then the rate of reaction is controlled. Thus, the energy is released at a constant rate. The controlled chain reaction is the principle of a nuclear reactor.

In an **uncontrolled chain reaction**, fission neutrons are allowed to multiply indefinitely which leads to release of enormous energy in a very short interval of time. Explosion of an atom bomb is the result of uncontrolled chain reaction.

Critical size and critical mass

The achievement of a sustained nuclear chain reaction with nuclear fuel like ^{235}U or ^{239}U uranium depends on a favourable balance among four competing processes:

1. fission of uranium nuclei, with the release of more neutrons than are captured,
2. non-fission capture of neutrons by uranium
3. non fission capture of neutrons by other materials
4. escape of neutrons without being captured.

If the loss of neutrons by the last three processes is less than or equal to the surplus produced by the first process, the chain reaction occurs; otherwise, chain reaction does not occur. There is a certain size, called the **critical size**, for which the surplus of neutrons is just equal to their non fission capture and escape, and a chain reaction is possible. If the size of the system is smaller than the critical size, a chain reaction cannot be sustained.

The amount of a particular fissionable material required to make a fission reaction self-sustaining is called the **critical mass.**

Nuclear reactor

A nuclear reactor is a device in which controlled fission of certain substances is used to produce new substances and energy.

Types of nuclear reactors

Nuclear reactors can be classified into 3 types based on the application.

1. **Research reactor:** It is used for producing radio isotopes and neutrons needed for research work.
2. **Breeder reactor:** A breeder reactor is one in which a fissionable material is produced at a greater rate than the fuel is consumed. It is used for producing fissionable material like Plutonium-239 from a fertile material like Uranium-237.
3. **Power reactor:** It is used for production of electrical energy. It is an arrangement in which the chain reaction is controlled to supply energy at a constant rate. It has an arrangement to slow down neutrons and a means of stopping the fission process when desired.

Nuclear power reactor

A nuclear reactor is a system in which the controlled nuclear fission reaction in carried out such that the reaction is self sustained. The main components of the nuclear reactor are as follows

1. **Nuclear fuel:** Nuclear fuel is the fissionable material like ^{233}U, ^{235}U, ^{239}Pu, etc.
2. **Neutron source:** Usually beryllium sand serves as the source of neutrons.
3. **Moderator**: Moderator is a material used to slow down neutrons produced during fission. The material of the moderator should be light and it should not absorb neutrons. Heavy water, graphite, paraffin are used as moderators. These moderators are rich in protons.
4. **Control rods:** Control rods have the ability to absorb slow neutrons. Cadmium and boron rods are used as control rods. By adjusting the length of these control rods in the reactor core, the rate of fission reaction is controlled.
5. **Coolant:** A substance used to remove heat from the reactor core and transfer it to the surrounding is called coolant. Liquid sodium and heavy water are the commonly used coolants
6. **Steam exchanger**: The hot coolant is circulated in steel pipes dipped in a steam exchanger. Cold water is circulated through this steam exchanger is converted into high pressure superheated steam. This steam is used to run a gas turbine which generates electrical power.
7. **Protective shield:** The whole reactor is protected with concrete walls 2 m to 2.5 m thick so that radiations emitted during nuclear reactions are prevented from reacting the surroundings.

Multiplication factor (k)

Because of the use of a moderator, it is possible that the ratio (k) of number of fission produced by a given generation of neutrons to the number of fissions of the preceding generation may be greater than unity. k is called the multiplication factor. It is a measure of growth rate of the neutrons in the reactor. When k = 1, the operation of the reactor is said to be critical.

Differences between nuclear fission and fusion

	Nuclear fission	Nuclear fusion
1.	The process of splitting of a heavy nucleus into two light nuclei of comparable masses is called fission.	The process of combining two light nuclei to produce a heavy nucleus is called fusion.
2.	Fission is initiated by a slow neutron. Hence easier to start fission.	Fusion is initiated at very high temperatures of about 10^8 K. Hence very difficult to achieve fusion.
3.	Fission can be controlled	Fusion cannot be controlled.
4.	Energy released is small. It is less than 1 MeV per nucleon.	Energy released is large. It is greater than 1 MeV per nucleon.
5.	Heavy nuclei are required for fission which are not abundantly available. Hence the source of energy is restricted.	Light nuclei are abundantly available in nature. Hence an infinite source of energy exists.
6.	Fission products are generally radioactive and harmful to the environment.	The fusion products are stable and hence they are environment, friendly.
7.	Used to construct nuclear bombs.	Used to construct hydrogen bombs (hydrogen bombs use both fission and fusion reaction).

Disposal of nuclear waste

Nuclear waste containing radioactive materials cannot be dumped anywhere as we like as radiations from it are harmful. The waste must be therefore, isolated to avoid environmental and biological contamination. Generally nuclear waste can be buried by adopting one of the following methods.

1. The waste can be packed and buried underground.
2. The waste can be stored in unused deep mines.
3. The waste can be packed in enclosures with in thick concrete thick containers and then buried under the sea.

Nuclear fusion

The process in which two or more light nuclei, combine to form a single heavy nucleus, with the release of large amount of energy, is called nuclear fusion.

The mass of a nucleus is always less than the sum of the masses of the individual nucleons that form the nucleus. The difference in mass is converted into energy in accordance with the Einstein’s mass-energy relation.

Example

Following are a few examples of fusion reactions

(i) ${}_1^2H + {}_1^2H \rightarrow {}_1^3H + {}_1^1H + Q$

where Q factor is the energy released and its value in this reaction is about 4 MeV.

(ii) ${}_1^2H + {}_1^2H \rightarrow {}_2^3He + {}_0^1n + 3.2\ \text{MeV}$

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

Fusion is very difficult to achieve because the combining nuclei have to overcome the electrostatic repulsion. Hence, the nuclei that combine should approach each other at very high velocities. This means that the temperature of the system should be very large. Fusion reactions can take place only at very high temperatures. For example, the coulomb barrier (in terms of energy) for two protons to fuse is ~ 400 k eV. The corresponding temperature to which protons shows be heated is estimated by $\frac{3}{2} = KT = KE \Rightarrow T \approx 3\times10^9 K$ (K = Boltzman constant = 1.37 × 10^{-23} JK^{-1}). Hence, reactions are called ***thermo nuclear reactions***. The working of a hydrogen bomb is based on thermonuclear reaction.

☞	• The energy released **per unit mass** during fusion is greater than that during fission. • The energy released **per fission reaction** is greater than the energy released per fusion reaction.

Stellar energy

Thermonuclear reactions are the source of energy in stars. These reactions that are taking place in the stars have supplied energy to the earth for ages. Bethe has explained how two series of reactions called the **carbon cycle** and **proton-proton cycle** account for the combination of four protons to form a helium nucleus.

Carbon cycle

$${}^{12}_{6}C + {}^{1}_{1}H \rightarrow {}^{13}_{7}N + \text{energy}$$

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

$${}^{13}_{6}C + {}^{1}_{1}H \rightarrow {}^{14}_{7}N + \text{energy}$$

$${}^{14}_{7}N + {}^{1}_{1}H \rightarrow {}^{15}_{8}O + \text{energy}$$

$${}^{15}_{8}O \rightarrow {}^{15}_{7}N + {}^{0}_{1}e + \text{energy}$$

$${}^{15}_{7}N + {}^{1}_{1}H \rightarrow {}^{12}_{6}C + {}^{4}_{2}He + \text{energy}$$

$$4({}_{1}H^{1}) \rightarrow {}^{4}_{2}He + 2({}^{0}_{1}e) + \text{energy}$$

Proton - proton cycle

$${}^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{2}_{1}H + {}^{0}_{1}e + 0.4\ \text{MeV}$$

$${}^{1}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + 5.5\ \text{MeV}$$

$${}^{3}_{2}He + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + 2({}^{1}_{1}H) + 12.9\ \text{MeV}$$

$$4({}^{1}_{1}H) \rightarrow {}^{4}_{2}He + 2({}^{0}_{1}e) + 24.7\ \text{MeV}$$

A star is able to sustain thermonuclear reaction in its core because of its strong self gravity. The thermo nuclear reactions in the core of Sun cause the high temperature, which generates a strong outward pressure known as radiation pressure. These act against Sun's own gravity, preventing it from contracting and holding it in equilibrium.

Comparison

	Nuclear fission		Nuclear fusion
1.	A heavy nucleus is split into two fragments of comparable masses	1.	Two or more light nuclei are fused to form a comparatively heavy nucleus
2.	A stray neutron can cause fission of U^{235}	2.	Very high temperature of the order of $10^7 - 10^8$ K is required for fusion to take place
3.	Energy released per fission is bout 200 MeV	3.	Energy released per fusion is around 20 MeV
4.	Energy released per unit mass is small compared to that in fusion	4.	Energy released per unit mass is around eight times more than that in fission
5.	The fission chain reaction has been controlled	5.	The fusion process is yet to be controlled

Illustrations

1. Number of electrons, protons and neutrons present in ${}_{92}U^{238}$ are respectively,

(A) 92, 92, 238 (B) 92, 92, 146 (C) 92, 146, 146 (D) 146, 146, 92

Ans (B)

$_{22}U^{238}$ is of the form $_{Z}U^{A}$ which means atomic number Z = 92 and mass number A = 238. Atomic number indicates the number of protons, which is equal to the number of electrons.

Mass number represents the total number of protons and neutrons

$\therefore$ Number of neutrons = $A - Z = 238 - 92 = 146$.

2. The ratio of the surface areas of the nuclei (assuming spherical shape) Zn^{64} and Al^{27} is

(A) 9 : 16 (B) 16 : 9 (C) 64 : 27 (D) 4 : 3

Ans (B)

Radius of a nucleus, $R = R_0 A^{\frac{1}{3}}$

$A_1(Zn) = 64,\ A_2(Al) = 27$

$$\frac{R_1}{R_2} = \left(\frac{A_1}{A_2}\right)^{\frac{1}{3}} = \left(\frac{64}{27}\right)^{\frac{1}{3}} = \frac{4}{3}$$

Surface area of a sphere $\propto$ (radius)^2

$$\therefore \frac{(\text{Surface area})_1}{(\text{Surface area})_2} = \left(\frac{4}{3}\right)^2 = \frac{16}{9}$$

3. The graph of log (R/R_0) versus log A [where A is mass number of the nucleus and R is its radius] is

(A) a circle (B) a parabola (C) a straight line (D) a hyperbola.

Ans (C)

The radius of the nucleus is given by the approximate relation $R = R_0 A^{1/3}$

$$\log R = \log R_0 + \frac{1}{3}\log A$$

$$\log R - \log R_0 = \frac{1}{3}\log A \quad \text{or} \quad \log\left(\frac{R}{R_0}\right) = \frac{1}{3}\log A \Rightarrow \log\left(\frac{R}{R_0}\right) \propto \log A$$

Therefore, the graph of $\log\left(\frac{R}{R_0}\right)$ versus log A is a straight line.

4. The rest mass of a nucleus is

(A) greater than the sum of the masses of constituent nucleons

(B) always less than the sum of the masses of the constituent nucleons

(C) equal to the sum of the masses of the constituent nucleons

(D) greater than or equal to the sum of the masses of the constituent nucleons.

Ans (B)

The difference between the sum of the masses of the nucleons and the actual mass of the nucleus, is called mass defect. $\Delta m = [z\, m_P + (A - Z)m_N - M]$, where M is the actual mass of the nucleus. According to Einstein's mass-energy relation, this mass defect appears in the form of the equivalent binding energy during the formation of the nucleus.

5. The mass number of a nucleus

(A) is always greater than its atomic number

(B) is always less than its atomic number

(C) is greater than or equal to its atomic number

(D) is less than or equal to its atomic number.

Ans (C)

For hydrogen atom $({}_1H^1)$ mass number (A) = atomic number (Z). For all other nuclei, A > Z.

6. An atomic nucleus possesses

(A) integral spin (B) half integral spin

(C) either integral or half integral spin (D) no spin motion at all.

Ans (C)

The protons and neutrons (together called nucleons) possess half integral spin. Depending on the number of nucleons present inside the nucleus, the spin of the nucleus may be either integral (for even number of nucleons) or half integral (for odd number of nucleons). However, the above principle may not always be true.

7. The magnetic moment of a free proton is approximately 2.8 μ_n (μ_n = nuclear magneton, a unit of magnetic moment; $\mu_n = 5.05 \times 10^{-27}\ JT^{-1}$). The potential energy of a proton subjected to a magnetic field 1.4 T is (assume that the magnetic moment is almost opposite to $\bar{B}$ while processing)

(A) 3.92×10^{-26} J (B) -3.92×10^{-26} J (C) 1.96×10^{-26} J (D) -1.96×10^{-26} J

Ans (C)

Potential energy, $U = -\ \bar{\mu} \cdot \bar{B}$

$= -\ \mu B \cos\theta$

$U = \ \mu B\ [\theta = 180°, \cos 180° = -1]$

$= 2.8 \times 5.05 \times 10^{-27} \times 1.4 \approx 19.6 \times 10^{-27}\ J = 1.96 \times 10^{-26}\ J$

8. Of the three basic forces, gravitational, nuclear, and electrostatic forces, the forces that can provide considerable attractive force between two neutrons is

(A) gravitation and electrostatic forces (B) gravitational and nuclear forces

(C) nuclear and electrostatic force (D) the nuclear force only

Ans (D)

Since the neutrons are electrically neutral, the electrostatic force is absent. However, the gravitational and the nuclear forces of attraction act between them. However, gravitational attraction is negligible.

9. Two protons are kept apart by 10Å. If f_N and f_E represent the nuclear and the electrostatic force between them respectively, then

(A) $f_N = f_E$ (B) $f_N << f_E$ (C) $f_N >> f_E$ (D) $f_N \geq f_E$

Ans (B)

The nuclear force exists between the nucleons within a distance of 10^{-14} m. Since the separation between the protons is 10^{-9} m, the nuclear force does not exist between them. However, the electrostatic force of repulsion acts between the two protons.

10. If F_{pp}, F_{pn}, and F_{nn} are the magnitudes of the nuclear force between proton–proton, proton–neutron and neutron – neutron respectively, then

(A) $F_{PP} = F_{nn} > F_{Pn}$ (B) $F_{PP} = F_{nn} < F_{Pn}$ (C) $F_{PP} = F_{nn} = F_{Pn}$ (D) $F_{Pn} < F_{PP} < F_{nn}$

Ans (C)

The magnitude of the nuclear force acting between any two nucleons is constant.

11. If f_{pp}, f_{pn}, and f_{nn} are the net forces acting between proton–proton, proton–neutron, neutron–neutron respectively, then

(A) $f_{PP} = f_{Pn} = f_{nn}$ (B) $f_{PP} < f_{Pn} = f_{nn}$ (C) $f_{PP} < f_{Pn} < f_{nn}$ (D) $f_{PP} < f_{Pn} < f_{nn}$

Ans (B)

The net force between two nucleons is equal to the algebraic sum of the nuclear and electrostatic forces acting between them. Between proton–neutron and neutron–neutron, only the nuclear force of attraction act. But between proton–proton, apart from the nuclear force, electrostatic force of repulsion also acts. This tends to reduce the net force between the two protons. (Contribution of gravitational force of attraction is negligible).

12. Choose the wrong statement.

(A) A nucleus is more stable if the nucleus contains more neutrons compared to the number of protons.

(B) A nucleus becomes less stable if the nucleus contains too many protons compared to the neutrons

(C) The nuclear stability is higher if the nucleus contains a large number of nucleons

(D) Nuclei with atomic number greater than 82 show a tendency to disintegrate.

Ans (C)

With large increase in the number of nucleons, the binding energy per nucleon decreases; this, in turn, leads to the instability of the nucleus.

13. According to Yukawa, the nuclear force arises as a result of exchange of certain particles between the nucleons. These particles are

(A) positrons (B) neutrinos (C) mesons (D) leptons

Ans (C)

The first theory to explain the nature of the nuclear force was proposed in 1935 by Japanese physicist Hideki Yukawa (Nobel Laureaute in Physics: 1949). Yukawa proposed the existence of a new particle, known as meson, whose exchange between the nucleons in the nucleus results in the nuclear force. Subsequent studies showed that Yukawa's meson, now called as pi-mesion (π-meson) or pion comes in three charge states π^+, π^- and π^0. The π^+ and π^- particles (π^- is the antiparticle of π^+) each have a mass of 139.6 MeV/c^2 and the mass of π^0 is 135.0 MeV/c^2.

14. Choose the wrong statement.

(A) Nuclear force is the strongest force in nature (B) Nuclear force is spin dependent

(C) Nuclear force is charge dependent (D) Nuclear force is a saturated force

Ans (C)

The nuclear force is independent of the charge on the nucleons. The same nuclear force exists between proton–proton, proton–neutron and neutron–neutron.

15. The binding energy per nucleon of a hydrogen atom is

(A) 13.6 eV (B) zero (C) infinity (D) 8.5 MeV.

Ans (B)

The hydrogen nucleus consists of only one proton (Z = 1, A = 1). Therefore, its binding energy per nucleon is zero.

16. Removing a neutron from ${}_{20}Ca^{42}$ leaves ${}_{20}Ca^{41}$. Removing a proton from ${}_{20}Ca^{42}$ leaves ${}_{19}K^{41}$. If $(BE)_n$ and $(BE)_p$ represent the binding energies of the missing neutron and the missing proton respectively, then

(A) $(BE)_n > (BE)_p$ (B) $(BE)_n < (BE)_p$ (C) $(BE)_n << (BE)_p$ (D) $(BE)_n \approx (BE)_p$

Ans (A)

- A neutron is acted upon only by attractive nuclear forces, whereas a proton is acted upon in addition by repulsive electric forces that decreases its binding energy. Hence, removing a proton is easier.
- $(BE)_n$ = 11.48 MeV; $(BE)_p$ = 10.27 MeV

17. Assume the graph of specific binding energy versus mass number is as shown in the figure. Using this graph, select the correct choice from the following:

(A) Fusion of two nuclei of mass number lying in the range of 1 < A < 50 will release energy.

(B) Fission of the nucleus of mass number lying in the range of 100 < A < 200 will release energy when broken into two fragments.

(C) Fusion of two nuclei of mass number lying in the range of 100 < A < 200 will release energy.

(D) Fusion of two nuclei of mass number lying in the range of 51 < A < 100 will release energy.

Ans (D)

Specific B.E of the products is greater than the reactants.

18. During a fission reaction, a mass difference per fission is 0.11 u. If 10^{15} fissions occur per second, the power generated is ($1\text{ u} = 1.66\times10^{-27}$ kg)

(A) 1.5 kW (B) 15 kW (C) 150 kW (D) 1.5 MW

Ans (B)

$E = mc^2$

m = (mass in u) $\times\ 1.66\times10^{-27} = 0.10\times1.66\times10^{-27}$ kg

$E = 0.10\times1.66\times10^{-27}\times\left[3\times10^{8}\right]^{2}$ joule per fission

$\text{Power} = 0.10\times1.66\times10^{-27}\times9\times10^{16}\times10^{15}$

joule per second (for 10^{15} fissions per second)

$\text{Power} = 1.5\times10^{4}\,\text{Js}^{-1} = 15\times10^{3}\,\text{Js}^{-1} = 15\ \text{kW}$

A hint for quick calculation:

$1\ \text{u} \sqcup\ 1.66\times10^{-27}\times(3\times10^{8})^{2} \cong 15\times10^{-10}\,\text{J}$

Power = $\dfrac{\text{Energy}}{\text{second}}$ = Δm (1 u) × fission energy released (J) per 1 u × No. of fissions / second

= $0.1\times15\times10^{-10}\times10^{15}$ = 15 kW

19. A large electric power generating station uses a nuclear reactor. The thermal power produced in the reactor core is 4000 MW and 1200 MW of electricity is generated by the station. The fuel is 9×10^4 kg of uranium oxide, distributed among 6×10^4 fuel rods. The uranium is enriched to 3% of U^{235}. The efficiency of the generating station and the rate of thermal energy that will be discharged to the environment are respectively.

(A) 30 %, 2800 MW (B) 15%, 2800 MW (C) 30%, 3880 MW (D) 15 %, 3880 MW

Ans (A)

$$\text{Efficiency},\ \eta = \frac{\text{useful output}}{\text{energy input}} = \frac{1200}{4000} = 0.3$$

For all power plants, the efficiency attainable is decided by the second law of thermodynamics. To run this plant, energy at the rate of 4000 MW – 1200 MW = 2800 MW must be discharged as thermal energy to the environment.

20. The binding energy per nucleon of ${}_3Li^7$ is 5.6 MeV and that of ${}_2He^4$ is 7.06 MeV. The energy released during the reaction ${}_3Li^7 + {}_1H^1 \rightarrow 2\,{}_2He^4 + \text{Energy}$, is

(A) 1.726 MeV (B) 17.26 MeV (C) 0.1726 MeV (D) 172.6 MeV

Ans (B)

${}_3Li^7 + {}_1H^1 = 2\times{}_2He^4$

Energy, E = ($2E_{He} \sim E_{Li}$)

E_{Li} = 7 × 5.6 MeV = 39.2 MeV

E_{He} = 4 × 7.06 MeV = 28.24 MeV

E = (2 × 28.24 – 39.2) MeV = 17.26 MeV

21. When two light nuclei fuse to form a relatively heavier nucleus, the specific binding energy of the product nucleus is

(A) lower than that of the reacting nuclei

(B) equal to that of the reacting nuclei

(C) greater than that of the reacting nuclei

(D) equal to exactly half of either of the reacting nuclei

Ans (C)

Greater than that of the reacting nuclei.

22. A sample of uranium containing both the isotopes U^{235} and U^{238} is bombarded with a slow neutron. Then the isotope that undergoes fission readily is

(A) U^{235} (B) U^{238} (C) both U^{235} and U^{238} (D) neither U^{235} nor U^{238}

Ans (A)

U^{238} undergoes fission only when bombarded with a fast neutron.

23. Two deutrons combine to form a stable helium nucleus. During this process, energy is released because

(A) the mass of the helium nucleus is greater than that of two deuterons

(B) the mass of the helium nucleus is less than that of two deuterons

(C) the mass of the helium nucleus is equal to that of two deuterons

(D) the total binding energy of the helium nucleus is less than that of the combination of deuterons.

Ans (B)

The difference between the masses of two deuterons and the helium nucleus is called the mass defect. The mass defect is responsible for the energy released during the fusion reaction.

24. The minimum energy required to disintegrate a deuteron into its constituent nucleons is (mass of deuteron nucleus = 2.0140 amu, mass of the proton = 1.0073 amu and mass of the neutron = 1.0087 amu)

(A) 1.862 MeV (B) 18.62 MeV (C) 0.931 MeV (D) 1.1 MeV

Ans (A)

The energy E required to split the nucleus = total binding energy (BE) of the nucleus

Mass defect,

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

$= [1 \times 1.0073 + 1 \times 1.0087] - 2.0140 = 0.002$ amu

Energy required,

$E = BE = \Delta m \times 931$ MeV $= 1.862$ MeV

25. The density of the nucleus is of the order of

(A) 10^{17} kg m^{-3} (B) 10^{14} kg cm^{-3} (C) 10^{18} kg m^{-3} (D) 10^{6} kg cm^{-3}

Ans (A)

Density, $\rho = \dfrac{A}{\frac{4}{3}\pi R^3} = \dfrac{A \times 1.66 \times 10^{-27}}{\frac{4}{3} \times \pi (R_0 \times A^{1/3})^3}$

$$= \frac{1.66 \times 10^{-27} \times 3}{4 \times \pi (1.3 \times 10^{-15})^3} \cong 1.8 \times 10^{17} \text{ kg m}^{-3}$$

Radioactivity

H.A. Becquerel, a French Physicist while investigating the fluorescence caused by X-rays, accidentally discovered that uranyl potassium sulfate emits highly penetrating radiations which affect photographic plates. A Polish scientist, Marie Curie with her husband Pierre Curie discovered two more radioactive elements namely polonium and radium. Pioneering work by Rutherford and others showed that **the emission of these radiations is spontaneous and is unaffected by external factors like temperature, pressure, electric field, magnetic field etc.** Also it was revealed that heavy elements whose atomic numbers are greater than 82, by nature, emit such radiations. These radiations are called radioactive rays (Becquerel rays) and this phenomenon exhibited by heavy elements is called natural radioactivity. Thus, natural radioactivity is defined as **the phenomenon in which heavy nuclei** (Z > 82) **undergo spontaneous disintegration with the emission of certain radiations.**

Types of Radioactive Rays

In general radioactive substances disintegrate in three ways,

(i) by emitting α-particles (α-rays)

(ii) by emitting β-particles (β-rays)

(iii) by emitting γ-radiation (γ-rays)

- α-rays are streams of positively charged particles identical with helium nuclei (^4_2He).
- β-rays are streams of negatively charged particles emitted from the nucleus of radioactive substance, identical with electrons ($_{-1}e^{\circ}$).
- γ-rays are high frequency electromagnetic radiations.

A radioactive nucleus emits either α or β particle but not both. This may be accompanied by a γ-ray.

Characteristics of α, β, and γ rays

Property	α	β	γ
Nature	helium nuclei $(2p+2n)$	Electrons	Electromagnetic radiation
Charge	+2e	–1e	no charge
Mass (in terms of mass of a proton, m_p)	~ 4 m_p	(1/1840) m	no inertial mass
Velocity (in terms of speed of light, c)	around (1/20) c	0.3 c to 0.9 c	c
Relative penetrating power	1	10^2	10^4
Relative ionising power	10^4	10^2	1
Suitable absorber	~ 0.1 mm thick Al foil	5 mm thick Al sheet	a thick block of Pb

Laws of radioactivity

Soddy's group displacement laws

When a radioactive element emits an α or a β particle, the parent atom decays into another atom called the daughter atom. During the change there is conservation of charge and energy. The process continues till a stable (non-radioactive) element is reached. The laws are stated as follows:

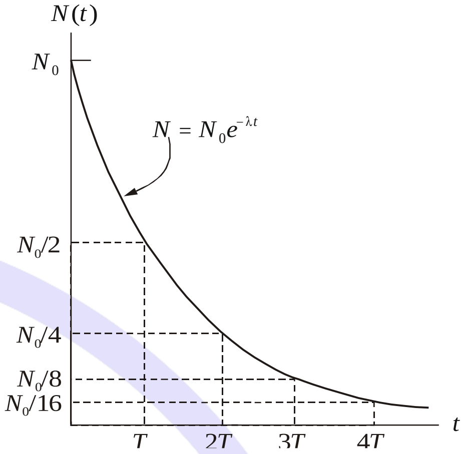
1. $^A_Z X \xrightarrow{\alpha-\text{decay}} {}^{A-4}_{Z-2}Y + {}^4_2He$
2. $^A_Z X \xrightarrow{\beta-\text{decay}} {}^{A}_{(Z+1)}Y + {}^0_{-1}e$

☞	• The emission of a β particle from a nucleus is explained as due to the conversion of neutron into a proton and an electron ($_0n^1 \rightarrow {}_1p^1 + {}_{-1}e^{\circ} + \tilde{\nu}$, where $\tilde{\nu}$ = (antinewutrino). • A gamma ray photon is emitted when the nucleus transists from an excited energy state to a lower energy state. The photon carries away the energy difference. Since no change of mass or charge is involved, no group displacement takes place.

Law of radioactive disintegration (Decay law)

At a given instant, the rate of radioactive disintegration is directly proportional to the number of radioactive atoms present in a sample at that instant of time.

Let a radioactive sample contain N atoms at an instant of time *t*. If dN number of atoms disintegrate in a time dt, then $\left(\frac{dN}{dt}\right)$ is the rate of disintegration. The quantity dN represents the decrease in the number of atoms and hence it is taken with a negative sign.



Radioactive decay curve

According to disintegration law,

$$\frac{dN}{dt} \propto N \text{ i.e., } \frac{dN}{dt} = -\lambda N$$

where λ is a constant for the given radioactive element called the *decay constant* or *disintegration constant.*

The negative sign indicates that as time increases, $\left(\frac{dN}{dt}\right)$ decreases.

It can be shown that $N = N_o e^{-\lambda t}$ and hence the decay is exponential.

$N \to 0$, only when $t \to \infty$. Thus, for all atoms in a radioactive sample to completely disintegrate, it takes an infinitely long time.

Decay constant

Decay constant of a radioactive element is equal to the reciprocal of the time required for the number of atoms in a radioactive sample to reduce to $\left(\frac{1}{e}\right)$ times the initial number.

We know that e = 2.718 and $\left(\frac{1}{e}\right) = 0.37$

The decay constant of an element is equal to the reciprocal of the time required for the number of atoms in a sample to reduce to 0.37 times (i.e., 37 %) the initial number.

Activity of a radioactive sample

The rate of decay of a radioactive substance is called the activity (A) of the substance.

Mathematically, we can write

$$\text{activity, } A = \left|\frac{dN}{dt}\right| = \lambda N$$

Since, $\therefore N = N_o e^{-\lambda t}$, we have $A = A_o e^{-\lambda t}$

Here, $A_o = \lambda N_o$ is the activity of the sample at t = 0.

☞

1. If two radioactive samples of activities A_1 and A_2 are mixed together, the activity of the sample is $A = A_1 + A_2$ or $A = \lambda_1 N_1 + \lambda_2 N_2$.
2. λ depends on the nature of the radioactive element. But activity depends on λ and mass of the radioactive substance.

Units of activity

The SI unit of activity is **becquerel** (abbreviated as Bq).

One becquerel is 1 disintegration per second. The activity of a radioactive sample is said to be 1 becquerel if the rate of disintegration is 1 disintegration per second.

Other units are

1. **Curie** (Ci) is 3.7×10^{10} disintegrations per second. Therefore, 1 Ci = 3.7×10^{10} Bq. The activity of a radioactive sample is said to be curie if 3.7×10^{10} disintegration take place in one second.
2. **Rutherford** (Rd) is 10^6 disintegrations per second. 1 Rd = 10^6 Bq.

Half-life of a radioactive element

Half-life (T) of a radioactive element is defined as the time taken for half of the number of atoms in a radioactive sample to disintegrate. It can be shown that $T = \frac{0.693}{\lambda}$

- If the time interval during which the decay takes place is equal to n number of half-lives i.e., t = nT, then the number of atoms remaining at the end of an interval t = nT is given by $N = \left(\frac{N_0}{2^n}\right)$ where N_o = number of atoms initially present.

Mean life

Radioactive disintegration is a **statistical** phenomenon. In a given radioactive sample, which atom disintegrates first and which disintegrates later is purely a matter of chance. The atom disintegrating first will have a life time equal to zero and the one disintegrating in the last will have an infinitely large life time.

The mean life or the average life of a radioactive sample is equal to the sum of the life times of all the radioactive atoms in a sample divided by their total number.

It is also defined as the average time for which the atoms of a radioactive element exist.

Mean life $T_m = \frac{1}{\lambda}$, where λ is the decay constant.

Relation between half-life and mean life

Half life of a radioactive element is given by $T = \frac{0.693}{\lambda}$

The mean life of the same element is $T_m = \frac{1}{\lambda}$

$T = 0.693\ T_m$

Artificial radioactivity (Induced radioactivity)

Natural radioactivity is a phenomenon confined to a small group of heavy elements. Even a lighter element can be rendered radioactive, when bombarded by high energy particles.

The phenomenon in which lighter elements are made radioactive by bombarding them with high energy particles is known as artificial transmutation or induced radioactivity.

Example:

- Radioactive nitrogen disintegrates into a stable carbon isotope by emitting a β-ray. Its half life is 10.1 minute. The corresponding nuclear reactions can be written as

  $^{10}_{5}B + ^{4}_{2}H_e \rightarrow ^{13}_{7}N + ^{1}_{0}n + \text{energy}$

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

- By bombarding aluminium with α-particles radioactive phosphorus can be produced.

$${}^{27}_{13}Al + {}^{4}_{2}He \rightarrow {}^{30}_{15}P + {}^{1}_{0}n + \text{energy}$$

$${}^{30}_{15}P \rightarrow {}^{30}_{14}Si + {}^{0}_{1}e \quad (T = 2.5 \text{ minute})$$

Isotopes of an element, which are radioactive are called **radioactive isotopes** or **radioisotopes.** Radio isotopes of a large number of elements are available.

Uses of radio isotopes

Radio isotopes are extensively used in various fields in two ways, viz., (1) as tracers (2) as a source of radiation. By adding small quantities of a radio isotope to a nonradioactive sample, it is possible to trace the course of the element in a system that receives it. This is called the tracer technique. Radio isotopes are used in industry, agriculture, chemistry, medicine, geology etc.

☞

Carbon dating

Plants use atmospheric carbon dioxide for their growth. Atmospheric CO_2 also contains ${}_6C^{14}$ which is radioactive isotope of carbon. Thus plants and the animals that eat the plants – are slightly radioactive throughout their lives. As soon as a tree is cut or falls down, all its metabolic processes stop and C^{14} is not absorbed. The amount of radioactive carbon in the wood decreases as time goes on

C – 14 is a β-emitter $\Rightarrow {}_6C^{14} \rightarrow {}_7N^{14} + \beta$

Since the half-life of C^{14} is 5700 years, the decay will last for many millennia. Thus, by measuring the amount of C^{14} in old samples of wood, we can estimate the estimate of age of wood using the relation,

$$t = \frac{2.303(\log a_0 - \log a)}{\lambda} \quad \text{where} \; \frac{0.7}{5700 \;\; \text{years}}$$

a_0 = activity (w.r.t. C^{14}) in the corresponding live sample

a = present activity in the old decay

λ = decay constant of $C^{14} = \frac{0.693}{T}$.

Uranium – lead dating

The decay of radioactive elements and its complete independence of physical and chemical conditions gives us a valuable method for estimating the age of old geological formations.

Age of the earth is ≈ 4.5 billion years.

Tritium dating

Tritium (${}_1H^3$ – radioisotope of hydrogen) is produced in the terrestrial atmosphere by the action of cosmic radiation and is carried to the earth's surface by rains. The half-life of tritium is only 12.5 years. $({}_1H^3 \rightarrow {}_2He^3 + \beta)$. Thus all age measurements involving this isotope can be carried out only for comparatively recent dates. By taking samples of water from different locations and from different depths, we can estimate by their tritium content how long ago this water came down in the form of rain.

Important expressions

RADIOACTIVE DECAY LAW	
In terms of number of atoms in a sample	$\frac{dN}{dt} = -\lambda t \quad N = N_0 e^{-\lambda t}$
In terms of mass of a sample	$\frac{dM}{dt} = -\lambda t \quad M = M_o e^{-\lambda t}$
In terms of activity of a sample	$\frac{dA}{dt} = -\lambda t \quad A = A_o e^{-\lambda t}$
Relation between T and λ	$T = \frac{0.693}{\lambda}$
Relation between T_m and λ	$T_m = \frac{1}{\lambda}$

Relation between T and T_m	$T = 0.693T_m$
Number of atoms present after n half lives $n = \frac{t}{T}$, t = given time, T = Half life	$N = \frac{N_o}{2^n}$
Mass of the active sample after n half lives	$M = \frac{M_o}{2^n}$
Activity of the sample after n half lives	$A = \frac{A_o}{2^n}$

Illustrations

1. A radioactive isotope may emit
   (A) α, β, and γ – rays simultaneously
   (B) both α and β rays simultaneously
   (C) α, γ or β, γ
   (D) protons, α – rays and γ – rays

Ans (C)

Each radioactive element disintegrates either by emitting an α-particle or a β-particle along with a γ-photon. But a radioactive nucleus cannot emit α and β-particles, simultaneously.

2. Choose the wrong statement out of the following.
   (A) γ – rays are the electromagnetic radiations of shorter wavelength
   (B) β – rays consist of electrons
   (C) α – particle consists of two protons and two neutrons
   (D) β – particles emitted are the electrons that revolve round the nucleus.

Ans (D) : Nucleus does not contain electrons. The β-particles (electrons) are emitted as a result of conversion of neutron into proton.

$n \rightarrow p + {}_{-1}e^0(\beta^-) + \tilde{\nu}$ (antineutrino).

A positron is emitted when a proton is converted into a neutron $p \rightarrow n + {}_{+1}e^0\ (\beta^+) + \nu$ (neutrino)

3. In a radioactive series a nucleus X disintegrates into nucleus Y by emitting two alpha and two beta particles. If m and n are the mass number and atomic number of the nucleus X, then the mass number and atomic number of the nucleus Y respectively are
   (A) (m – 4), n
   (B) (m – 8), (n – 2)
   (C) (m – 8), n
   (D) (m – 4), (n – 2)

Ans (B)

${}_nX^m \xrightarrow{2\alpha-\text{particles}} {}_{n-4}(X')^{m-8} \xrightarrow{2\beta-\text{particles}} {}_{n-2}Y^{m-8}$

(Hint: ${}_ZX^A \xrightarrow{\alpha} {}_{Z-2}Y^{A-4}$ ${}_ZX^A \xrightarrow{\beta} {}_{Z+1}Y^A$)

4. In a radioactive series, ${}_{92}U^{238}$ disintegrates such that a stable nucleus of ${}_{82}Pb^{206}$ is formed. During this process the number of alpha and beta particles emitted are
   (A) 6, 8
   (B) 8, 6
   (C) 8, 4
   (D) 4, 8

Ans (B)

Let n and n′ be the number of α and β-particles emitted respectively. Emission of β-particle does not alter the mass number but it increases the atomic number by 1 unit.

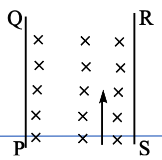
$238 - 4n = 206 \Rightarrow n = 8$

$92 - 2n + n' = 82 \Rightarrow 2n - n' = 10$ or $2 \times 8 - n' = 10$

$\therefore n' = 6$.

5. A magnetic field is applied perpendicular to the plane of the paper and directed into it in the region PQRS in space as shown in figure.

   If α, β and γ – rays are projected perpendicular to the field as shown in figure, then



(A) α – particles deflect towards RS and β – particles towards PQ.

(B) α – particles deflect towards PQ and β – particles towards RS.

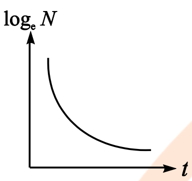
(C) both α and β particles deflect towards PQ.

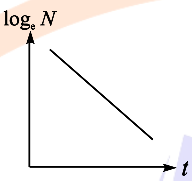
(D) all the rays deflect towards PQ.

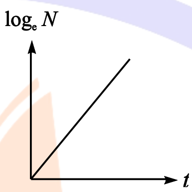
Ans (B) : **α-particles deflect towards PQ and β-particles towards RS**

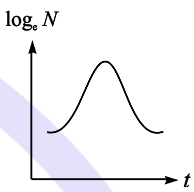
Use Fleming's left hand rule to determine the direction.

6. The correct graph of $\log_e N$ v/s t (Number of radioactive atoms v/s time) among the following is

(A) 

(B) 

(C) 

(D) 

Ans (B)

$N = N_0 e^{-\lambda t}$ $\log_e N = \log_e N_0 + (-\lambda)t$

This is of the form y = c + mx. Therefore, the graph of $\log_e N$ against t is a straight line with negative slope (slope m = −λ)

7. The decay constant of a radioactive sample is λ. The value of half life and average life of a radioactive sample are respectively given by

(A) $\lambda \log_e 2, \frac{1}{\lambda}$ (B) $\frac{\log_e 2}{\lambda}, \lambda$ (C) $\frac{\log_e 2}{\lambda}, \frac{1}{\lambda}$ (D) $\log_e 2, \frac{1}{\lambda}$

Ans (C)

8. The ratio of the initial mass of the radioactive sample to that of the mass of the sample left after n half lives is

(A) $\frac{1}{2^n}$ (B) 2^n (C) $\frac{\sqrt{2}-1}{\sqrt{2}}$ (D) $\frac{\sqrt{2}+1}{\sqrt{2}}$

Ans (B)

The mass of a radioactive sample after n half-lives is given by $m = m_0\left(\frac{1}{2}\right)^n$ where m_0 is the initial mass of the sample.

$\therefore \frac{m}{m_0} = \frac{1}{2^n}$. Hence, $\frac{m_0}{m} = 2^n$

9. The half life of a radioactive sample is T. The fraction of the initial mass of the sample that decays in an interval T/2 is

(A) $\frac{1}{\sqrt{2}}$ (B) $\sqrt{2}$ (C) $\frac{\sqrt{2}-1}{\sqrt{2}}$ (D) $\frac{\sqrt{2}+1}{\sqrt{2}}$

Ans (A)

The fraction of the sample after n half−lives is given by $\frac{N}{N_0} = \frac{1}{2^n}$. But n = $\frac{t}{T}$

$n = \frac{(T/2)}{T} = \frac{1}{2}$. Therefore, $\frac{N}{N_0} = \frac{1}{2^{1/2}}$

10. The activity of a radioactive sample is A_1 at time t_1 and A_2 at time t_2. If T_{av} is the average life time of the radioactive sample, then the number of atoms that decay during interval $(t_2 - t_1)$ is

(A) $A_1t_1 - A_2t_2$ (B) $(A_1 - A_2)T_{av}$ (C) $\frac{A_1 - A_2}{T_{av}}$ (D) $\frac{A_1 - A_2}{(t_1 - t_2)}$

Ans (B)

Activity, $A = \lambda N \Rightarrow A_1 = \lambda N_1 = \frac{1}{T_{av}} N_1$; $A_2 = \frac{N_2}{T_{av}}$ $\therefore (N_1 - N_2) = (A_1 - A_2) T_{av}$

11. The half life of a radioactive sample is 20 days. This means that
(A) the substance completely disintegrates in 40 days
(B) the substance completely disintegrates in 80 days
(C) 1/8 part of the substance disintegrates in 60 days
(D) 7/8 part of the substance disintegrates in 60 days

Ans (D)

Number of half-lives, $n = \frac{t}{T} = \frac{60}{20} = 3$;

$\frac{N}{N_0} = \frac{1}{2^3} = \frac{1}{8}$. Fraction remaining $= \frac{1}{8}$

Fraction that disintegrates in 60 days $= 1 - \frac{1}{8} = \frac{7}{8}$

12. The half life of a radioactive sample for α and β emission are T_α and T_β respectively. If the substance emits α and β particles simultaneously, the effective half life of the material is

(A) $T_\alpha + T_\beta$ (B) $\frac{T_\alpha T_\beta}{T_\alpha + T_\beta}$ (C) $T_\alpha - T_\beta$ (D) $\frac{T_\alpha + T_\beta}{T_\alpha - T_\beta}$

Ans (B)

The decay constant, $\lambda = \lambda_\alpha + \lambda_\beta$

$$\frac{0.693}{\langle T \rangle} = \frac{0.693}{T_\alpha} + \frac{0.693}{T_\beta} \Rightarrow \frac{1}{\langle T \rangle} = \frac{1}{T_\alpha} + \frac{1}{T_\beta}$$

$< T > = \frac{T_\alpha T_\beta}{T_\alpha + T_\beta}$ = effective half life

13. The daughter nucleus formed in a radioactive decay process is also radioactive. Let λ_p and λ_d be the decay constants for parent and daughter nuclei and N_p and N_d be the number of atoms of parent and daughter nuclei at an instant of time t. The condition under which the number of daughter nuclei becomes constant is

(A) $\lambda_p / N_p = \lambda_d / N_d$ (B) $\lambda_p / \lambda_d = N_d / N_p$
(C) $\lambda_p + \lambda_d = N_p + N_d$ (D) the number of daughter nuclei cannot become constant

Ans (B)

When the rate of disintegration of daughter nuclei is equal to the rate of its formation, the number of daughter nuclei, present in the samples remains constant.

Rate of disintegration of parent nuclei = Rate of formation of daughter nuclei

$$\left(\frac{dN}{dt}\right)_{parent} = \left(\frac{dN}{dt}\right)_{daughter} \Rightarrow \lambda_P N_P = \lambda_d N_d$$

$$\therefore \frac{\lambda_p}{\lambda_d} = \frac{N_d}{N_p}$$

14. The half-life of a radioactive material is 8 hours. If 20% of the sample remains active after time t, its 10% will remain active after

(A) (t + 2) hour (B) (t + 4) hour (C) (t + 6) hour (D) (t + 8) hour

Ans (D)

$\left(\frac{N}{N_0}\right)_1 = 20\% = \frac{1}{5} = \frac{1}{2^{n_1}}$ and

$$\left(\frac{N}{N_0}\right)_2 = 10\% = \frac{1}{10} = \frac{1}{2^{n_2}}; \quad \frac{(N/N_0)_1}{(N/N_0)_2} = 2 = \frac{2^{n_2}}{2^{n_1}}$$

$$\Rightarrow 2^{n_2} = 2^{n_1} \cdot 2^1 = 2^{n_1+1} \Rightarrow n_2 = n_1 + 1$$

$$\frac{t'}{T} = \frac{t}{T} + 1 \Rightarrow t' = t + T = (t+8) \text{ hours}$$

Aliter

For the sample to disintegrate from 20% of its initial value to 10 %, one more half-life is needed. For the sample to reduce to 20 % of the initial value, time required is t hour. For the sample to reduce to half of the value at t time taken $t' = (t + T)$ hour or $(t + 8)$ hour.

15. The half-life of a radioactive substance X is 2 years. This element decays into another stable element Y. The ratio of the atoms of X and Y was found to be 1: 4 after the time t. The value of t in years is between

(A) 2 and 4 (B) 3 and 6 (C) 6 and 8 (D) 4 and 6

Ans (D)

$\frac{N_x}{N_y} = \frac{1}{4}$, where N_x and N_y are the number of atoms of X and Y left after time t. The number of atoms of Y present in the mixture is equal to number of atoms of X disintegrated.

$$N_0 - N_x = N_y \; ; \; N_0 = N_x + N_y = N_x + 4N_x = 5N_x$$

$$\frac{N_x}{N_0} = \frac{1}{5} \; ; \; \frac{N_x}{N_0} = \frac{1}{5} = \frac{1}{2^n} \Rightarrow 2^n = 5.$$

This indicates that the value of n is between 2 and 3. Therefore, the value of t lies in between 4 year $(n_1 T = 2 \times 2)$ and 6 year $(n_2 T = 3 \times 2)$.

16. A radioactive sample S_1 having an activity of 5 μCi has twice the number of nuclei as another sample S_2 which has an activity of l0 μCi. The half lives of S_1 and S_2 can be

(A) 20 yr and 5 yr, respectively (B) 20 yr and 10 yr, respectively

(C) 10 yr each (D) 5 yr each

Ans (A)

Activity of $S_1 = \frac{1}{2}$ (activity of S_2)

or $\lambda_1 N_1 = \frac{1}{2}(\lambda_2 N_2)$ or $\frac{\lambda_1}{\lambda_2} = \frac{N_2}{2N_1}$ or $\frac{T_1}{T_2} = \frac{2N_1}{N_2}$

$\left(T = \text{half-life} = \frac{\log 2}{\lambda}\right)$

Given: $N_1 = 2N_2$ $\quad \therefore \frac{T_1}{T_2} = 4$

17. The ratio of average life to half life of a radioactive substance is

(A) 1 (B) 1.44 (C) 0.693 (D) 1/e

Ans (B)

$T_{av} = \frac{1}{\lambda}$ and half life,

$T = \frac{0.693}{\lambda}; \; \frac{T_{av}}{T} = \frac{1}{0.693} = 1.44.$

18. The half life of radon is 4 days. 10 gram of radon after 16 days will reduce to

(A) 2.5 gram (B) 0.625 gram (C) 1.625 gram (D) 0.25 gram

Ans (B)

Number of half lives,

$n = \frac{t}{T} = \frac{16}{4} = 4$; $m = m_0 \frac{1}{2^n}$.

$m = 10\text{ g} \times \frac{1}{2^4} = \frac{10}{16} \Rightarrow m = 0.625\text{ g}.$

19. The half lives of two radioactive samples X and Y is 20 minutes and 40 minutes respectively. Initially both the samples have equal number of atoms. After 80 minutes, the ratio of the atoms remaining in A and B is

(A) 1 : 4 (B) 4 : 1 (C) 16 : 1 (D) 1 : 16

Ans (A)

Let N_x and N_y be the number of atoms left after 80 minutes.

$N_x = N_0 \frac{1}{2^{t/T_1}} = N_0 \times \frac{1}{2^{80/20}} = \frac{N_0}{2^4}$ or $N_x = \frac{N_0}{16}$

Similarly, $N_y = N_0 \times \frac{1}{2^{t/T_2}} = N_0 \times \frac{1}{2^{80/40}} = \frac{N_0}{2^2}$ or

$N_y = \frac{N_0}{4}$; $\frac{N_x}{N_y} = \frac{4}{16} = \frac{1}{4}$

20. The fraction of the initial number of radioactive nuclei which remain undecayed after half of a half-life of the radioactive sample is

(A) $\frac{1}{2}$ (B) $\frac{1}{\sqrt{2}}$ (C) $\frac{1}{4}$ (D) $\frac{1}{2\sqrt{2}}$

Ans (B)

NCERT LINE BY LINE QUESTIONS

1. The atomic masses of various elements expressed in atomic mass unit (u) are close to being integral multiples of mass of [NCERT Pg. 439]

(1) A hydrogen atom (2) A proton
(3) A neutron (4) Both (2) and (3)

2. The density of nuclear matter [NCERT Pg. 441]

(1) Increases with mass number (2) Decreases with mass number
(3) Is independent of mass number (4) Increases up to mass number 56 then decreases

3. For thermonuclear fusion reaction, the estimated temperature of the system should be about [NCERT Pg. 456]

(1) 3×10^3K (2) 3×10^9K (3) 1×10^5K (4) 3×10^6K

4. Nuclear force is [NCERT Pg. 445]

(1) Attractive for distance, r = 0.5 fm (2) Repulsive for distance, r < 0.8 fm
(3) Attractive for distance, r < 0.8 fm (4) Repulsive for distance, r > 0.8 fm

5. The SI unit of activity is [NCERT Pg. 447]
(1) Becquerel (2) Curie (3) Rutherford (4) Both (1) and (2)

6. The mass of iron nucleus is 55.85u and A = 56. The nuclear density of iron is [NCERT Pg. 441]
(1) $2.5\times10^{15}\,kg/m^3$ (2) $2.3\times10^{16}\,kg/m^3$ (3) $2.3\times10^{17}\,kg/m^3$ (4) $3.5\times10^{16}\,kg/m^3$

7. 1 curie is equal to [NCERT Pg. 448]
(1) $3.7\times10^{7}\,Bq$ (2) $3.7\times10^{10}\,Bq$ (3) $3.7\times10^{8}\,Bq$ (4) $3.7\times10^{6}\,Bq$

8. The half life of $_{92}U^{238}$ undergoing -decay is 4.5 x 10^9 years. The activity of 4 g sample of $_{92}U^{239}$ is [NCERT Pg. 448]
(1) 1.23 x 10^4Bq (2) 1.23 x 10^5 Bq (3) 4.9 x 10^4 Bq (4) 4.9 x 10^5 Bq

9. 1 mg radium has 2.68 x 10^{18} atoms. Its half life is 1620 years. How many radium atoms will disintegrate from 1 mg of pure radium in 3240 years. [NCERT Pg. 448]
(1) 2.01×10^{9} (2) 2.01×10^{18} (3) 0.67×10^{18} (4) 1.04×10^{9}

10. In a sample of radioactive material, what fraction of the initial number of active nuclei will remain undisintegrated after half of the half life of the sample? [NCERT Pg. 448]
(1) $\frac{1}{4}$ (2) $\frac{1}{2\sqrt{2}}$ (3) $\frac{1}{\sqrt{2}}$ (4) $\sqrt{2}-1$

11. The natural boron of atomic mass 10.81 u is found to have two isotopes ^{10}B and ^{11}B. The ratio of abundance of isotopes of natural boron should be nearly [NCERT Pg. 439]
(1) 11 : 10 (2) 81 : 19 (3) 10: 11 (4) 19:81

12. The energy liberated in a single uranium fission is about [NCERT Pg. 457]
(1) 200 MeV (2) 235 MeV (3) 20 MeV (4) 100 MeV

13. Pick out the incorrect statement from the following. [NCERT Pg. 450]
(1) β^- emission from the nucleus is always accompanied with a neutrino
(2) The energy of the α -particle emitted from a given nucleus is constant
(3) γ -ray emission makes the nucleus more stable
(4) Nuclear force is charge-independent

14. The radius of a spherical nucleus as measured by electron scattering is 3.6 fm. What is the mass number of the nucleus most likely to be? [NCERT Pg.441]
(1) 27 (2) 40 (3) 56 (4) 120

15. The number of β^- —particles emitted by a radioactive substance is twice the number of α -particles emitted by it. The resulting daughter is an [NCERT Pg. 450]
(1) Isomer of parent (2) Isotone of parent
(3) Isobar of parent (4) Isotope of parent

16. In nuclear reactors, the controlling rods are made of [NCERT Pg. 454]
(1) Cadmium (2) Graphite (3) Krypton (4) Plutonium

17. A nucleus with mass number 220 initially at rest emits an α -particle. If the Q-value of reaction is 5.5 MeV, the kinetic energy of a-particle is [NCERT Pg. 449]
(1) 4.4 MeV (2) 5.4 MeV (3) 5.0 MeV (4) 4.8 MeV

18. Choose the incorrect nuclear fusion reactions among the following [NCERT Pg. 455]
1) ${}_1^1H+{}_1^1H\rightarrow{}_1^2H+e^++v+0.42\,MeV$ 2) ${}_1^2H+{}_1^2H\rightarrow{}_2^3H+n+3.27\,MeV$
3) ${}_1^2H+{}_1^2H\rightarrow{}_1^3H+{}_1^1H+4.03\,MeV$ 4) $e^++e^-\rightarrow\gamma$

19. Fission of nuclei is possible because the binding energy per nucleon in them [NCERT Pg. 444]

(1) Decreases with mass number at low mass numbers
(2) Increases with mass number at low mass numbers
(3) Increases with mass number and high mass numbers
(4) Decreases with mass number at high mass numbers

20. Consider α, β -particles and γ -rays. The increasing order of penetration power is [NCERT Pg. 451]

1) α, β, γ 2) γ, β, α 3) β, α, γ 4) β, γ, α

NCERT BASED PRACTICE QUESTIONS

1. Pick out the incorrect statement from the following:
(1) β^{-} emission from the nucleus is always accompanied by a neutrino.
(2) The energy of α particle emitted from a given nucleus is characteristic in nature
(3) γ ray emission makes the nucleus more stable
(4) Nuclear force is charge independent

2. Pick out the incorrect statement from the following:
(1) Neutron is the most effective projectile in nuclear reactions.
(2) Photon has zero spin, while a neutrino has $\frac{1}{2}\frac{h}{2\pi}$ spin
(3) Tritium nuclei do not occur naturally and are prepared artificially in laboratories.
(4) A proton can never convert into a neutron as it is lighter than neutron

3. Pick out the incorrect statement from the following
(1) Lighter elements are better moderators for nuclear reactors than heavier moderators.
(2) In a natural uranium reactor, heavy water is a preferred moderator to ordinary water
(3) Mass energy inter-conversion takes place only in nuclear reactions and never in chemical reactions.
(4) Cadmium rods are provided in reactors.

4. Pick out the incorrect statement from the following
(1) Accurate measurement of atomic masses is carried out by mass spectrometer
(2) Energy available from bombardment of beryllium nuclei with a particles is equivalent to that of photons.
(3) Isotopes have identical chemical behavior
(4) Even we round off mass of neutron and proton to 1 amu, atomic mass of an element may not be an integral multiple of amu

5.5 With regard to Geiger and Marsden experiment, pick out the incorrect statement from the following:
(1) If electrons are used, instead of α particle, size of nuclei can be accurately measured.
(2) If α particles with energy much higher than 5.5 MeV are used, significant deviations is calculations may be observed
(3) α -particles suffer inelastic scattering against gold nuclei
(4) Trajectory of a α -particle depends upon the impact parameter

6. Nuclear forces acting between two nucleons inside nucleus:
(1) Has saturation property
(2) Is short ranged which explains the constancy is BE/A in the range $30 < A < 170$.
(3) Has zero associated potential energy associated when distance between nucleons is 0.8 fm.

(4) Is the strongest force inside nucleus

7. For radioactivity, pick the incorrect statement:
(1) Radioactivity was discovered by Marie Curie
(2) In a spontaneous radioactive decay, mass of products is less than mass of initial nucleus
(3) One can never predict which nucleus will undergo decay first
(4) ${}_{92}U^{238}$ is non fissionable but radioactive while ${}_{92}U^{235}$ is fissionable but nonradioactive

8. With regard to neutrinos, pick the incorrect statement:
(1) They are generated during b-decays
(2) They have strong interactions with other particles
(3) They are neutral particles
(4) They are hard to detect

9. In a thermonuclear fusion, which statement is incorrect:
(1) Energy is provided by raising the temperature
(2) Energy must be provided to overcome columbic repulsion between approaching positively charged nuclei.
(3) Is responsible for the formation of red giant star
(4) Required temperature is of the order of 108 K.

10. Which of the following statement is incorrect for a nuclear reaction
(1) If nuclei with less total binding energy transform to nuclei with greater binding energy, there will be a net energy release.
(2) Nuclear reactions are not balanced in the same way as chemical reactions
(3) Both the number of protons and number of neutrons are conserved, but the total mass is not conserved.
(4) In β^- decay a neutrino is generated, while is β^+ decay an anti-neutrino is generated

11. Pick the incorrect statement:
(1) Fission of 1kg of Uranium generates equal energy as burning of 1kg of coal.
(2) During fission of ${}_{92}U^{235}$, different pairs of intermediate mass fragments can be obtained
(3) The peaks at nuclides like ${}_{2}He^{4}$, ${}_{8}O^{16}$ is an evidence of shell like structure inside nuclei.
(4) Decay of unstable ${}_{6}C^{14}$ isotope into stable ${}_{6}C^{12}$ isotope is the principle of carbon dating.

12. Considering the efficient functioning of a nuclear reactor, which of the following statement is incorrect?
(1) Moderators slow down fast neutrons released in a fission reaction via elastic scattering
(2) The core of a nuclear reactor is surrounded with reflectors to prevent leakage
(3) Heavy water is used as moderators in fast breed reactors that use Plutonium - 239 as fuel
(4) Averagely $2\frac{1}{2}$ neutrons are released per fission of a ${}_{92}U^{235}$ nucleus

13. For the central portion of an atom, called nuclei, pick the incorrect statement
(1) Nuclei also have discrete energy levels
(2) For stability of nuclei, number of neutron: number of proton ratio has to be around 1 : 1 for lighter nuclei and 3 : 2 for heavier nuclei
(3) Density of nuclear matter is independent of size of nucleus
(4) As mass of proton is smaller than mass of neutron, a proton can never convert into a

neutron.

14. Which of the following statement is incorrect for nuclear decays

(1) γ decay takes place when nucleus in excited state spontaneously decays into ground state

(2) After α decay and β decay, γ decay can take place

(3) When an electron and positron come together, they can annihilate each other giving energy in the form of γ rays

(4) If β^+ emission is energetically allowed, electron capture is necessarily allowed and vice versa.

15. Corresponding to nuclear decays, which of the following statements is incorrect?

(1) In α decay, more than 95% of Q-value is realized as kinetic energy of a particle

(2) Energy spectrum of α,β and γ particles are discrete line spectrums.

(3) In b decay, daughter nucleus is an isobar of parent nuclei.

(4) γ rays are electromagnetic radiations of wavelengths shorter than X-rays

16. When a nucleus in an atom undergoes a radioactive decay, the electronic energy levels of the atom

(1) do not change for any type of radioactivity.

(2) change for a and b radioactivity but not for g radioactivity.

(3) change for a radioactivity but not for others.

(4) change for b radioactivity but not for others.

17. Heavy stable nucleus has more neutrons than protons. This is because of the fact that

(1) neutrons are heavier than protons.

(2) electrostatic force between protons are repulsive.

(3) neutrons decay into protons through beta decay.

(4) nuclear forces between neutrons are weaker than that between protons.

18. Suppose we consider a large number of containers each containing initially 50,000 atoms of a radioactive material with a half-life of 1 year. After 1 year,

(1) all the containers will have 25,000 atoms of the material.

(2) all the containers will contain the same number of atoms of the material but that number will only be approximately 25,000.

(3) the containers will in general have different numbers of the atoms of the material but their average will be close to 25,000.

(4) none of the containers can have more than 25,000 atoms.

19. In a nuclear reactor, moderators slow down the neutrons which come out in a fission process. The moderator used has light nuclei. Heavy nuclei will not serve the purpose because

(1) they will break up.

(2) elastic collision of neutrons with heavy nuclei will not slow them down.

(3) the net weight of the reactor would be unbearably high.

(4) substances with heavy nuclei do not occur in liquid or gaseous state at room temperature.

20. **Assertion :** Neutrons penetrate matter more readily as compared to protons.

Reason : Neutrons are slightly more massive than protons.

(1) If both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(2) If both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(3) If Assertion is correct but Reason is incorrect.
(4) If both the Assertion and Reason are incorrect.

21. **Assertion :** It is not possible to use 35Cl as the fuel for fusion energy.
Reason : The binding energy of 35Cl is to small.
(1) If both Assertion and Reason are correct and Reason is the correct explanation of Assertion.
(2) If both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.
(3) If Assertion is correct but Reason is incorrect.
(4) If both the Assertion and Reason are incorrect.

22. **Assertion :** The binding energy per nucleon, for nuclei with atomic mass number A > 100, decrease with A.
Reason : The forces are weak for heavier nuclei.
(1) If both Assertion and Reason are correct and Reason is the correct explanation of Assertion.
(2) If both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.
(3) If Assertion is correct but Reason is incorrect.
(4) If both the Assertion and Reason are incorrect.

23. **Assertion :** Radioactivity of 10^8 undecayed radioactive nuclei of half life of 50 days is equal to that of 1.2×10^8 number of undecayed nuclei of some other material with half life of 60 days.
Reason : Radioactivity is proportional to half-life.
(1) If both Assertion and Reason are correct and Reason is the correct explanation of Assertion.
(2) If both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.
(3) If Assertion is correct but Reason is incorrect.
(4) If both the Assertion and Reason are incorrect.

24. **Assertion :** A free neutron decays to a proton but a free proton does not decay to a neutron. This is because neutron is an uncharged particle and proton is a charged particle.
Reason : Neutron has larger rest mass than the proton.
(1) If both Assertion and Reason are correct and Reason is the correct explanation of Assertion.
(2) If both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.
(3) If Assertion is correct but Reason is incorrect.
(4) If both the Assertion and Reason are incorrect.

TOPIC WISE PRACTICE QUESTIONS

Topic 1: Composition and Size of the Nucleus

1. The constituents of nucleus are

(a) electrons and protons (b) protons and neutrons

(c) neutrons and electrons (d) electrons, protons and neutrons

2. The radius of a nucleus is

(a) directly proportional to its mass number

(b) inversely proportional to its atomic weight

(c) directly proportional to the cube root of its mass number

(d) None of these

3. The radius of nucleus is of the order of

(a) 10^{-10} m (b) 10^{-6} m (c) 10^{-15} m (d) 10^{-13} m

4. The mass number of He is 4 and that for sulphur is 32. The radius of sulphur nuclei is larger than that of helium by

(a) $\sqrt{8}$ (b) 4 (c) 2 (d) 8

5. A nucleus splits into two nuclear parts which have their velocity ratio equal to 5 : 1. What will be the ratio of their nuclear radius?

(a) $5^{1/3} : 1$ (b) $1 : 5^{1/3}$ (c) $3^{1/2} : 1$ (d) $1 : 3^{1/2}$

6. The volume of a nucleus is directly proportional to

(a) A (b) A^3 (c) $\sqrt{A}$ (d) $A^{1/3}$

7. The set which represents the isotope, isobar and isotone respectively is

(a) $({}_1H^2, {}_1H^3)$, $({}_{79}Au^{197}, {}_{80}Hg^{198})$ and $({}_2He^3, {}_1H^2)$

(b) $({}_2He^3, {}_1H^1)$, $({}_{79}Au^{197}, {}_{80}Hg^{198})$ and $({}_1H^1, {}_1H^3)$

(c) $({}_2He^3, {}_1H^3)$, $({}_1H^2, {}_1H^3)$ and $({}_{79}Au^{197}, {}_{80}Hg^{198})$

(d) $({}_1H^2, {}_1H^3)$, $({}_2He^3, {}_1H^3)$ and $({}_{79}Au^{197}, {}_{80}Hg^{198})$

8. Outside a nucleus

(a) neutron is stable (b) proton and neutron both are stable

(c) neutron is unstable (d) neither neutron nor proton is stable

9. The mass of neutron is the same as that of

(a) a proton (b) a meson (c) an epsilon (d) an electron

10. The nuclei of which one of the following pairs of nuclei are isotones?

(a) ${}_{34}Se^{74}$, ${}_{31}Ga^{71}$ (b) ${}_{38}Sr^{84}$, ${}_{38}Sr^{86}$ (c) ${}_{42}Mo^{92}$, ${}_{40}Zr^{92}$ (d) ${}_{20}Ca^{40}$, ${}_{16}S^{32}$

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

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

12. The ratio of volumes of nuclei (assumed to be in spherical shape) with respective mass numbers 8 and 64 is

(a) 0.5 (b) 2 (c) 0.125 (d) 0.25

13. Atomic weight of boron is 10.81 and it has two isotopes ${}_5B^{10}$ and ${}_5B^{11}$. Then ratio of ${}_5B^{10} : {}_5B^{11}$ in nature would be

(a) 19 : 81 (b) 10 : 11 (c) 15 : 16 (d) 81 : 19

14. Nucleus of an atom whose atomic mass is 24 consists of

(a) 11 electrons, 11 protons and 13 neutrons

(b) 11 electrons, 13 protons and 11 neutrons

(c) 11 protons and 13 neutrons

(d) 11 protons and 13 electrons

Topic 2: Mass Energy and Nuclear Reaction

15. The binding energy per nucleon for $^{2}_{1}H$ and $^{4}_{2}He$ respectively are 1.1 MeV and 7.1 MeV. The energy released in MeV when two $^{2}_{1}H$ nuclei fuse to form $^{4}_{2}He$ is

(a) 4.4 (b) 8.2 (c) 24 (d) 28.4

16. In the nuclear fusion reaction

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

given that the repulsive potential energy between the two nuclei is ~ 7.7×10^{-14} J, the temperature at which the gases must be heated to initiate the reaction is nearly [Boltzmann's Constant $k = 1.38 \times 10^{-23}$ J/K]

(a) 107 K (b) 105K (c) 103K (d) 109K

17. Two nucleons are at a separation of 1 fermi. The net force between them is F_1 if both are neutrons, F_2 if both are protons and F_3 if one is proton and the other is a neutron. Then

(a) $F_1 > F_2 > F_3$ (b) $F_1 = F_3 > F_2$ (c) $F_2 > F_1 > F_3$ (d) $F_1 = F_2 > F_3$

18. Nuclear forces are

(a) spin dependent and have no non-central part

(b) spin dependent and have a non-central part

(c) spin independent and have no non-central part

(d) spin independent and have a non-central part

19. From the following equations, pick out the possible nuclear reactions.

(a) $_6C^{13} + {_1H^1} \rightarrow {_6C^{14}} + 4.3$ MeV

(b) $_6C^{12} + {_1H^1} \rightarrow {_9N^{14}} + 2$ MeV

(c) $_7N^{14} + {_1H^1} \rightarrow {_8O^{15}} + 7.3$ MeV

(d) $_{92}U^{235} + {_0n^1} \rightarrow {_{54}X^{140}} + {_{38}Si^{94}} + {_{2}0n^1} + \gamma + 200$ MeV

20. Which of the following statements is true?

(a) $_{78}Pt^{192}$ has 78 neutrons (b) $_{84}Po^{214} \rightarrow {_{82}Pb^{210}} + \beta^-$

(c) $_{92}U^{238} \rightarrow {_{90}Th^{234}} + {_2He^4}$ (d) $_{90}Th^{234} \rightarrow {_{91}Pa^{234}} + {_2He^4}$

21. The mass of an atomic nucleus is less than the sum of the masses of its constituents. This mass defect is converted into

(a) heat energy (b) light energy

(c) electrical energy (d) energy which binds nucleons together

22. When Uranium is bombarded with neutrons, it undergoes fission. The fission reaction can be written as :

$_{92}U^{235} + {_0n^1} \rightarrow {_{56}Ba^{141}} + {_{36}Kr^{92}} + 3x$ +Q(energy) where three particles named x are produced and energy Q is released. What is the name of the particle x ?

(a) electron (b) a-particle (c) neutron (d) neutrino

23. In a fission reaction

$^{236}_{92}U \rightarrow ^{117}X + ^{117}Y + n + n$, the binding energy per nucleon of X and Y is 8.5 MeV whereas of ^{236}U is 7.6 MeV. The total energy liberated will be about

(a) 2000 MeV (b) 200 MeV (c) 2 MeV (d) 200 keV

24. Complete the equation for the following fission process :

$_{92}U^{235} + _0n^1 \rightarrow _{38}Sr^{90} + ...$

(a) $_{54}X^{143} + 3\ _0n^1$ (b) $_{54}X^{145} + 3\ _0n^1$ (c) $_{57}X^{142} + 3\ _0n^1$ (d) $_{54}X^{142} + _0n^1$

25. Which of the following statements is true for nuclear forces?

(a) they obey the inverse square law of distance

(b) they obey the inverse third power law of distance

(c) they are short range forces

(d) they are equal in strength to electromagnetic forces.

26. On an average, the number of neutrons and the energy of a neutron released per fission of a uranium atom are respectively

(a) 2.5 and 2 keV (b) 3 and l keV (c) 2.5 and 2 MeV (d) 2 and 2 keV

27. Boron rods in a nuclear reactor are used to

(a) absorb excess neutrons (b) absorb alpha particle

(c) slow down the reaction (d) speed up the reaction

28. The rest energy of an electron is

(a) 510 KeV (b) 931 KeV (c) 510 MeV (d) 931 MeV

29. If M_O is the mass of an oxygen isotope $_8O^{17}$, M_P and M_N are the masses of a proton and a neutron respectively, the nuclear binding energy of the isotope is

(a) $(M_O - 17M_N)c^2$ (b) $(M_O - 8M_P)c^2$ (c) $(M_O - 8M_P - 9M_N)c^2$ (d) M_Oc^2

30. Energy released in the fission of a single $^{235}_{92}U$ nucleus is 200 MeV. The fission rate of a $^{235}_{92}U$ filled reactor operating at a power level of 5 W is

(a) $1.56 \times 10^{-10}\ s^{-1}$ (b) $1.56 \times 10^{11}\ s^{-1}$ (c) $1.56 \times 10^{-16}\ s^{-1}$ (d) $1.56 \times 10^{-17}\ s^{-1}$

31. The binding energy of deuteron is 2.2 MeV and that of ^4_2He is 28 MeV. If two deuterons are fused to form one ^4_2He , then the energy released is

(a) 23.6 MeV (b) 19.2 MeV (c) 30.2 MeV (d) 25.8 MeV

32. If M (A; Z), M_p and M_n denote the masses of the nucleus ^A_ZX , proton and neutron respectively in units of u (1u =931.5 MeV/c^2) and BE represents its bonding energy in MeV, then

(a) $M(A, Z) = ZM_p + (A - Z) M_n - BE/c^2$

(b) $M(A, Z) = ZM_p + (A - Z) M_n + BE$

(c) $M(A, Z) = ZM_p + (A - Z) M_n - BE$

(d) M (A, Z) = $ZM_p + (A - Z)M_n + BE/c^2$

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

(a) 10 microgram (b) 20 microgram (c) 40 microgram (d) 1 microgram

34. A reaction between a proton and $_8O^{18}$ that produces $_9F^{18}$ must also liberate

(a) $_0n^1$ (b) $_1e^0$ (c) $_1n^0$ (d) $_0e^1$

35. The energy released in a typical nuclear fusion reaction is approximately

(a) 25 MeV (b) 200 MeV (c) 800 MeV (d) 1050 MeV

36. Imagine that a reactor converts all given mass into energy and that it operates at a power level of 10^9 watt. The mass of the fuel consumed per hour in the reactor will be: (velocity of light, c is 3×10^8 m/s)

(a) 0.96 gm (b) 0.8 gm (c) 4×10^{-2} gm (d) 6.6×10^{-5} gm

37. When the number of nucleons in nuclei increases, the binding energy per nucleon

(a) increases continuously with mass number

(b) de creases continuously with mass number

(c) remains constant with mass number

(d) first increases and then decreases with increase of mass number

38. The curve of binding energy per nucleon as a function of atomic mass number has a sharp peak for helium nucleus. This implies that helium

(a) can easily be broken up (b) is very stable

(c) can be used as fissionable material (d) is radioactive

39. The mass defect per nucleon is called

(a) binding energy (b) packing fraction (c) ionisation energy (d) excitation energy

40. A proton and a neutron are both shot at 100 ms^{-1} towards a $^{12}_{6}C$ nucleus. Which particle, if either, is more likely to be absorbed by the nucleus?

(a) The proton

(b) The neutron

(c) Both particles are about equally likely to be absorbed

(d) Neither particle will be absorbed

41. Calculate the binding energy of a deuteron atom, which consist of a proton and a neutron, given that the atomic mass of the deutron is 2.014102 u.

(a) 0.002388 MeV (b) 2.014102 MeV (c) 2.16490 MeV (d) 2.224 MeV

Topic 3: Radioactivity

42. Half life of radioactive element depends upon

(a) amount of element present (b) temperature

(c) pressure (d) nature of element

43. Beta rays emitted by a radioactive material are

(a) electromagnetic radiations

(b) the electrons orbiting around the nucleus

(c) charged particles emitted by nucleus

(d) neutral particles

44. A radioactive substance has a half-life of four months. Three fourth of the substance will decay in

(a) three months (b) four months (c) eight months (d) twelve months

45. Neutron decay in free space is given as follows

$${}_0n^1 \rightarrow {}_1H^1 + {}_{-1}e^0 + [\ \ ]$$

Then the parenthesis [ ] represents a

(a) neutrino (b) photon (c) antineutrino (d) graviton

46. A radioactive element X converts into another stable element Y. Half-life of X is 2 hrs. Initially only X is present. After time t, the ratio of atoms of X and Y is found to be 1 : 4, then t in hours is

(a) 2 (b) 4 (c) between 4 and 6 (d) 6

47. A radioactive sample contains 10^{-3} kg each of two nuclear species A and B with half-life 4 days and 8 days respectively. The ratio of the amounts of A and B after a period of 16 days is

(a) 1 : 2 (b) 4 : 1 (c) 1 : 4 (d) 2 : 1

48. Two radioactive materials X_1 and X_2 have decay constants 10λ and λ respectively. If initially they have the same number of nuclei, then the ratio of the number of nuclei of X_1 to that of X_2 will be 1/e after a time

(a) $1/10\lambda$ (b) $1/11\lambda$ (c) $11/10\lambda$ (d) $1/9\lambda$

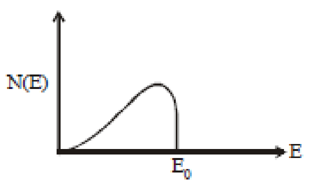
49. If N_0 is the original mass of the substance of half-life period $t_{1/2}$ = 5 years, then the amount of substance left after 15 years is

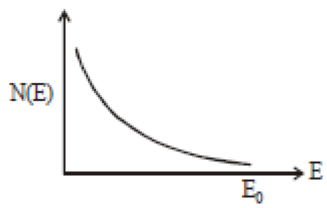
(a) $N_0/8$ (b) $N_0/16$ (c) $N_0/2$ (d) $N_0/4$

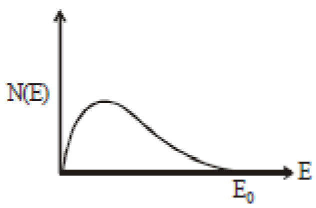
50. A radioactive sample at any instant has its disintegration rate 5000 disintegrations per minute. After 5 minutes, the rate is 1250 disintegrations per minute. Then, the decay constant (per minute) is

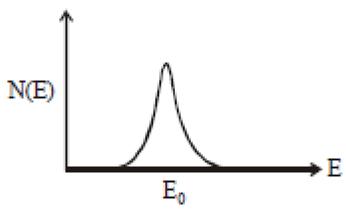
(a) 0.4 ln 2 (b) 0.2 ln 2 (c) 0.1 ln 2 (d) 0.8 ln 2

51. The energy spectrum of β-particles [number N(E) as a function of β-energy E] emitted from a radioactive source is

(a) 

(b) 

(c) 

(d) 

52. A nuclear transformation is denoted by X (n, α) ${}_3^7Li$ .Which of the following is the nucleus of element X?

(a) ${}_5^{10}B$ (b) ${}^{12}C_6$ (c) ${}_4^{11}Be$ (d) ${}_5^9B$

53. The counting rate observed from a radioactive source at t = 0 was 1600 counts s^{-1}, and t = 8 s, it was 100 counts s^{-1}. The counting rate observed as counts s^{-1} at t = 6 s will be

(a) 250 (b) 400 (c) 300 (d) 200

54. In a sample of rock, the ratio of 206 Pb to 238U nuclei is found to be 0.5. The age of the rock is (given half – life of U238 is 4.5 × 109 years)

(a) 2.25×10^9 year (b) 4.5×10^9 ln 3 year

(c) $4.5\times10^9 \dfrac{\ln\left(\frac{3}{2}\right)}{\ln 2}$ year (d) $2.25\times10^9 \ln\left(\frac{3}{2}\right)$ year

55. A radioactive sample with a half-life of 1 month has the label: 'Activity = 2 micro curies on 1–8–1991. What would be its activity two months earlier?

(a) 1.0 micro curie (b) 0.5 micro curie (c) 4 micro curie (d) 8 micro curie

56. The count rate of a Geiger Muller counter for the radiation of a radioactive material of half-life 30 minutes decreases to 5 sec^{-1} after 2 hours. The initial count rate was

(a) 20 sec^{-1} (b) 25 sec^{-1} (c) 80 sec^{-1} (d) 625 sec^{-1}

57. The half - life of At is 100 μs. The time taken for the radioactivity of a sample of At to decay to 1/16th of its initial value is

(a) 400 μs (b) 6.3 μs (c) 40 μs (d) 300 μs

58. There are n number of radioactive nuclei in a sample that undergoes beta decay. If from the sample, n' number of β-particles are emitted every 2 s, then half - life of nuclei is

(a) n'/2 (b) 0.693 × (2n/n') (c) 0.693 1n (2n/n') (d) 0.693 × n/n'

59. The half life of a radio isotope is 5 years. The fraction which will decay in 15 years, will be

(a) 1/16 (b) 3/4 (c) 7/8 (d) 5/8

60. In a given reaction

$${}_zA^A \rightarrow {}_{z+1}Y^A \rightarrow {}_{z-1}K^{A-4} \rightarrow {}_{z-1}K^{A-4}$$

Radioactive radiations are emitted in the sequence of

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

61. In gamma ray emission from a nucleus

(a) only the proton number changes

(b) both the neutron number and the proton number change

(c) there is no change in the proton number and the neutron number

(d) only the neutron number changes

62. The ratio of half-life times of two elements A and B is $\frac{T_A}{T_B}$. The ratio of respective decay constant $\frac{\lambda_A}{\lambda_B}$ is

(a) T_B / T_A (b) T_A / T_B (c) $\frac{T_A + T_B}{T_A}$ (d) $\frac{T_A - T_B}{T_A}$

63. Consider a radioactive material of half-life 1.0 minute. If one of the nuclei decays now, the next one will decay

(a) after 1 minute

(b) after $\frac{1}{\log_e 2}$ minute

(c) after $\frac{1}{N}$ minute, where N is the number of nuclei present at that moment

(d) after any time

64. One curie is equal to

(a) 3.7×10^{10} disintegration/sec

(b) 3.2×10^{8} disintegration/sec

(c) 2.8×10^{10} disintegration/sec

(d) None of these

65. The half-life of the radioactive substance is 40 days. The substance will disintegrate completely in

(a) 40 days (b) 400 days (c) 4000 days (d) infinite time

NEET PREVIOUS YEARS QUESTIONS

1. For a radioactive material, half-life is 10 minutes. If initially there are 600 number of nuclei, the time taken (in minutes) for the disintegration of 450 nuclei is **[2018]**

(a) 20 (b) 10 (c) 15 (d) 30

2. Radioactive material 'A' has decay constant '8λ' and material 'B' has decay constant 'λ'. Initially they have same number of nuclei. After what time, the ratio of number of nuclei of material 'B' to that 'A' will be $\frac{1}{e}$? **[2017]**

(a) $\frac{1}{7\lambda}$ (b) $\frac{1}{8\lambda}$ (c) $\frac{1}{9\lambda}$ (d) $\frac{1}{\lambda}$

3. If radius of the $^{27}_{12}Al$ nucleus is taken to be R_{Al}, then the radius of $^{125}_{53}Te$ nucleus is nearly: **[2015]**

(a) $\frac{5}{3}R_{Al}$ (b) $\frac{3}{5}R_{Al}$ (c) $\left(\frac{13}{53}\right)^{1/3} R_{Al}$ (d) $\left(\frac{53}{13}\right)^{1/3} R_{Al}$

4. A nucleus of uranium decays at rest into nuclei of thorium and helium. Then : **[2015]**

(a) the helium nucleus has less momentum than the thorium nucleus.

(b) the helium nucleus has more momentum than the thorium nucleus.

(c) the helium nucleus has less kinetic energy than the thorium nucleus.

(d) the helium nucleus has more kinetic energy than the thorium nucleus.

5. The Binding energy per nucleon of ${}^{7}_{3}\text{Li}$ and ${}^{4}_{2}\text{He}$ nuclei are 5.60 MeV and 7.06 MeV, respectively.

In the nuclear reaction ${}^{7}_{3}\text{Li} + {}^{1}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + \text{Q}$, the value of energy Q released is : **[2014]**

(a) 19.6 MeV (b) – 2.4 MeV (c) 8.4 MeV (d) 17.3 MeV

6. $\alpha -$ particle consists of : **[NEET – 2019]**

(1) 2 protons and 2 neutrons only (2) 2 electrons, 2 protons and 2 neutrons

(3) 2 electrons and 4 protons only (4) 2 protons only

7. The rate of radioactive disintegration at an instant for a radioactive sample of half life 2.2×10^{9} s is 10^{10} s^{-1}. The number of radioactive atoms in that sample at that instant is, **[NEET – 2019 (ODISSA)]**

(1) 3.17×10^{20} (2) 3.17×10^{17} (3) 3.17×10^{18} (4) 3.17×10^{19}

8. What happens to the mass number and atomic number of an element when it emits γ-radiation? **[NEET – 2020 (Covid-19)]**

(1) Mass number decreases by four and atomic number decreases by two.

(2) Mass number and atomic number remain unchanged.

(3) Mass number remains unchanged while atomic number decreases by one.

(4) Mass number increases by four and atomic number increases by two.

9. The half life of radioactive sample undergoing α-decay is 1.4×10^{17}s. If the number of nuclei in the sample is 2.0×10^{21}, the activity of the sample is nearly : **[NEET – 2020 (Covid-19)]**

(1) 10^{4} Bq (2) 10^{5} Bq (3) 10^{6} Bq (4) 10^{3} Bq

10. When a uranium isotope ${}^{235}_{92}U$ is bombarded with a neutron it generates ${}^{89}_{36}Kr$, three neutrons and **[NEET – 2020]**

1) ${}^{103}_{36}Kr$ 2) ${}^{144}_{56}Ba$ 3) ${}^{91}_{40}Zr$ 4) ${}^{101}_{36}Kr$

11. The energy equivalent of 0.5 g of a substance is **[NEET – 2020]**

1) $0.5 \times 10^{13} J$ 2) $4.5 \times 10^{16} J$ 3) $4.5 \times 10^{13} J$ 4) $1.5 \times 10^{13} J$

12. A nucleus with mass number 240 breaks into two fragments each of mass number 120, the binding energy per nucleon of unfragmented nuclei is 7.6 MeV while that of fragments is 8.5 MeV. The total gain in the Binding Energy in the process is **[NEET-2021]**

1) 9.4MeV 2) 804 MeV 3) 216MeV 4) 0.9MeV

13. A 9. Radioactive nucleus ${}^{A}_{Z}\text{X}$ undergoes spontaneous decay in the sequence

${}^{A}_{Z}\text{X} \rightarrow {}_{Z-1}\text{B} \rightarrow {}_{Z-3}\text{C} \rightarrow {}_{Z-2}\text{D}$, where Z is the atomic number of element X. The possible decay particles in the sequence are: **[NEET-2021]**

1) $\alpha, \beta^{+}, \beta^{-}$ 2) $\beta^{+}, \alpha, \beta^{-}$ 3) $\beta^{-}, \alpha, \beta^{+}$ 4) $\alpha, \beta^{-}, \beta^{+}$

14. The half-life of a radioactive nuclide is 100 hours. The fraction of original activity that will remain after

150 hours would be **[NEET-2021]**

1) $\frac{1}{2\sqrt{2}}$ 2) $\frac{2}{3}$ 3) $\frac{2}{3\sqrt{2}}$ 4) $1/2$

15. In the given nuclear reaction, the element X is: **[NEET-2022]**

$^{22}_{11}Na \rightarrow X + e^{+} + v$

1) $^{22}_{11}Na$ 2) $^{23}_{10}Ne$ 3) $^{22}_{10}Ne$ 4) $^{22}_{12}Mg$

16. A nucleus of mass number 189 splits into two nuclei having mass number 125 and 64. The ratio of radius of two daughter nuclei respectively is : **[NEET-2022]**

1) 1 : 1 2) 4 : 5 3) 5 : 4 4) 25 : 16

NCERT LINE BY LINE QUESTIONS – ANSWERS

1) a 2) c 3) b 4) b 5) a 6) c 7) b 8) c 9) c 10) c

11) d 12) a 13) a 14) a 15) d 16) a 17) b 18) d 19) d 20) a

NCERT BASED PRACTICE QUESTIONS - ANSWERS

1) 1 2) 4 3) 3 4) 2 5) 3 6) 3 7) 1 8) 2 9) 3 10) 4

11) 1 12) 3 13) 4 14) 4 15) 2 16) 2 17) 2 18) 3 19) 2 20) 2

21) 3 22) 3 23) 3 24) 4

TOPIC WISE PRACTICE QUESTIONS - ANSWERS

1) 2	2) 3	3) 3	4) 3	5) 2	6) 1	7) 4	8) 3	9) 1	10) 1
11) 2	12) 3	13) 1	14) 3	15) 3	16) 4	17) 2	18) 2	19) 3	20) 3
21) 4	22) 3	23) 2	24) 1	25) 3	26) 3	27) 1	28) 1	29) 3	30) 2
31) 1	32) 1	33) 3	34) 1	35) 1	36) 3	37) 4	38) 2	39) 2	40) 2
41) 4	42) 4	43) 3	44) 3	45) 3	46) 4	47) 3	48) 4	49) 1	50) 1
51) 3	52) 1	53) 4	54) 3	55) 4	56) 3	57) 1	58) 2	59) 3	60) 3
61) 3	62) 1	63) 4	64) 1	65) 4					

NEET PREVIOUS YEARS QUESTIONS-ANSWERS

1) 1	2) 1	3) 1	4) 4	5) 4	6) 1	7) 4	8) 2	9) 1
10) 2	11) 3	12) 3	13) 2	14) 1	15) 3	16) 3		

TOPIC WISE PRACTICE QUESTIONS - SOLUTIONS

1. **(b)** Protons and neutrons are the constituents of nucleus.

2. **(c)** Radius of nucleus $R = R_0 A^{1/3}$ where A is the mass number of nucleus.

$\therefore$ Volume of nucleus $=\frac{4}{3}\pi R^3=\left(\frac{4}{3}\pi R_0^3\right)A$

$\therefore$ Volume is proportional to A.

3. **(c)** Nuclear radius = 10^{-15} m.

4. **(c)** $\frac{R_s}{R_{He}}=\left(\frac{A_s}{A_{He}}\right)^{1/3}=\left(\frac{32}{4}\right)^{1/3}=2$

5. **(b)** As momentum is conserved, therefore,

$\frac{m_1}{m_2}=\frac{A_1}{A_2}=\frac{v_2}{v_1}=\frac{1}{5}$

$\therefore \frac{R_1}{R_2}=\left(\frac{A_1}{A_2}\right)^{1/3}=\left(\frac{1}{5}\right)^{1/3}=1:5^{1/3}$

6. **(a)** Radius of nucleus $R = R_0 A^{1/3}$ where A is the mass number of nucleus.

$\therefore$ Volume of nucleus $=\frac{4}{3}\pi R^3=\left(\frac{4}{3}\pi R_0^3\right)A$

$\therefore$ Volume is proportional to A.

7. **(d)** $_1H^2$ and $_1H^3$ are isotopes

$_2He^3$ and $_1H^3$ are isobars

$_{79}Au^{197}$ and $_{80}Hg^{198}$ are isotones.

8. **(c)** Outside the nucleus, neutron is unstable (life $\approx$ 932 s).

9. **(a)** a proton

10. **(a)** Isotones means equal number of neutrons i.e.,

$(A-Z) = 74 - 34 = 71 - 31 = 40$.

11. **(b)** $R=R_0(A)^{1/3}$

$\therefore \frac{R_1}{R_2}=\left(\frac{A_1}{A_2}\right)^{1/3}=\left(\frac{256}{4}\right)^{1/3}=4 \Rightarrow R_2=\frac{R_1}{4}=2$ fermi

12. **(c)** As we know $R = R_0 A^{1/3}$

$\therefore R \propto A^{1/3}$

As $V \propto R^3$ or $V \propto A$ $\therefore \frac{V_1}{V_2}=\frac{8}{64}=\frac{1}{8}=0.125$

13. **(a)** Let the percentage of B^{10} atoms be x, then average atomic weight

$=\frac{10x+11(100-x)}{100}=10.81 \Rightarrow x=19$ $\therefore \frac{N_{B^{10}}}{N_{B^{11}}}=\frac{19}{81}$

14. **(c)** Nucleus does not contain electron.

15. **(c)** The chemical reaction of process is $2\,{}_1^2H \rightarrow {}_2^4He$

Energy released = $4\times(7.1)$ - $4(1.1)$ = 24 eV

16. **(d)** The average kinetic energy per molecule $=\frac{3}{2}kT$

This kinetic energy should be able to provide the repulsive potential energy

. $\therefore \frac{3}{2}kT=7.7\times10^{-14}$

$$\Rightarrow T = \frac{2\times7.7\times10^{-14}}{3\times1.38\times10^{-23}} = 3.7\times10^{9}$$

17. **(b)** In case of Proton-Proton Electrostatic repulsive force is also present which reduces the net force.

18. **(b)** spin dependent and have a non-central part

19. (c) Only those nuclear reactions are possible in which the sum of mass number of all the reactants is equal to sum of mass number of all the products formed as well as sum of atomic number of all the reactants is equal to sum of atomic number of all the products formed.

Hence reactions shown in options B and C satisfy both the above conditions simultaneously, thus these are the possible nuclear reactions.

In option A, the condition for atomic number is not satisfied whereas option D does not satisfied the mass number condition.

20. **(c)** ${}_{92}U^{238} \rightarrow {}_{90}Th^{234} + {}_{2}He^{4}$

21. **(d)** energy which binds nucleons together

22. **(c)** Nuclear fission equation

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

Hence particle x is neutron.

23. **(b)** Binding energy

= 117 × 8.5 + 117 × 8.5 – 236 × 7.6

= 234 × 8.5 – 236 × 7.6

= 1989 – 1793.6 = 200 MeV

Thus, in per fission of Uranium nearly 200 MeV energy is liberated

24. **(a)** ${}_{92}U^{235} + {}_{0}n^{1} \longrightarrow {}_{38}Sr^{90} + {}_{54}Xe^{143} + 3\,{}_{0}n^{1} + \text{energy}$

25. **(c)** Nuclear forces are short range attractive forces which balance the repulsive forces between the protons inside the nucleus.

26. **(c)** On an average 2.5 neutrons are released per fission of the uranium atom.

And the energy of the neutron released per fission of the uranium atom is 2 MeV.

27. (a) When a neutron collides with the uranium atom, then energy is released along with three more neutrons which further collide with another uranium atom an so the chain reaction continues. Thus boron rods in nuclear reactor are used to absorb excess neutrons so that the reaction rate remains under control.

28. (a) Rest energy of an electron = mec2

Here me = 9.1 × 10^{-31} kg and C = velocity of light

$\therefore$ Rest energy = 9.1 × 10^{-31} × (3 × 10^{8})$_2$ joule

$$= \frac{9.1\times10^{-31}\times\left(3\times10^{8}\right)^{2}}{1.6\times10^{-19}}\,\text{eV} \approx 510\text{KeV}$$

29. **(c)** Binding energy

= $[ZM_P + (A – Z)M_N – M]c^2$

= $[8M_P + (17 – 8)M_N – M]c^2$

= $[8M_P + 9M_N – M]c^2$

= $[8M_P + 9M_N – Mo]c^2$

30. **(b)** Fission rate

$$= \frac{\text{total power}}{\frac{\text{energy}}{\text{fission}}} = \frac{5}{200\times1.6\times10^{-13}} = 1.56\times10^{11}\,s^{-1}$$

31. **(a)** ${}_{1}D^{2} \longrightarrow {}_{2}He^{4}$

Energy released = 28 – 2 × 2.2 = 23.6 MeV

(Binding energy is energy released on formation of Nucleus)

32. **(a)** Mass defect = $ZM_p + (A-Z)M_n - M(A,Z)$

or, $\frac{B.E}{c^2} = ZM_p + (A-Z)M_n - M(A,Z)$

$\therefore M(A,Z) = ZM_p + (A-Z)M_n - \frac{B.E}{c^2}$

33. **(c)** $E = mc^2 \qquad m = \frac{E}{c^2}$

So, mass decay per second

$\frac{dm}{dt} = \frac{1}{c^2}\frac{dE}{dt} = \frac{1}{c^2}$ (Power in watt)

$= \frac{1}{(3\times10^8)^2}\times1000\times10^3$

and mass decay per hour $= \frac{dm}{dt}\times60\times60$

$= \frac{1}{(3\times10^8)^2}\times10^6\times3600 = 4\times10^{-8}$ kg = 40 microgram

34. **(a)** ${}_{9}O^{18} + {}_{1}H^1 \rightarrow {}_{9}F^{18} + {}_{0}n^1$

35. **(a)** 25 MeV

36. **(c)** Power level of reactor, $P = \frac{E}{\Delta t} = \frac{\Delta mc^2}{\Delta t}$

mass of the fuel consumed per hour in the reactor,

$\frac{\Delta m}{\Delta t} = \frac{P}{c^2} = \frac{10^9}{(3\times10^8)^2} = 4\times10^{-2}$ gm

37. **(d)** Average BE/nucleon increases first, and then decreases, as is clear from BE curve.

38. (b) The elements high on the B.E. versus mass number plot are very tightly bound and hence, are stable. And the elements those are lower on this plot, are less tightly bound, are unstable.
Since the helium nucleus shows a peak on this plot so, it is very stable.

39. (b) Binding Energy = mass defect x c^2
The mass defect of a nucleus represents the mass that corresponds to the energy of binding of the nucleus and is the difference between the mass of a nucleus and the sum of the masses of the nucleons of which it is composed. Energy equivalent to mass defect is called binding energy.
The packing fraction is the mass defect per nucleon.

40. **(b)** Once the neutron gets sufficiently close to the nucleus, the strong nuclear force sucks it in. Same happens with proton except it is electrostatically repelled by the six protons already inside the carbon nucleus. The repulsion prevents a a100 ms^{-1} proton from getting close enough to the nucleus. Therefore, the answer is (b).

41. **(d)** Atomic mass M(H) of hydrogen and nuclear mass (M_n) are
M (H) = 1.007825 u and M_n = 1.008665 u
Mass defect,
Dm = [M (H) + Mn – M (D)]
M (D) = mass of deuteron = 2.016490 u – 2.014102 u
= 0.002388 u
As 1 u corresponds to 931.494 MeV energy, therefore, mass defect corresponds to energy,

$E_b = 0.002388 \times 931.5 = 2.224$ MeV

42. **(d)** Half life of a substance doesn't depends upon amount, temperature and pressure. It depends upon the nature of the substance.

43. **(c)** b-rays are charged particles emitted by nucleus.

44. (c) Substance left undecayed, $N_0 - \frac{3}{4}N_0 = \frac{1}{4}N_0$

$$\frac{N}{N_0} = \frac{1}{4} = \left(\frac{1}{2}\right)^n$$

$\therefore$ Number of atoms left undecided, n=2 i.e, in two half lives

$\therefore$ t=nT=2×4=8 months

45. (c) Antineutrinos are the antiparticles of neutrinos, which are neutral particles produced in nuclear beta decay. These are emitted during beta particle emissions, in which a neutron decays into a proton, electron, and antineutrino. They have a spin of , and are part of the lepton family of particles.

$$n_0 \to p^+ + e^+ e$$

46. **(d)** Radioactivity at T_1 , $R_1 = \lambda N_1$ Radioactivity at T_2, $R_2 = \lambda N_2$

$\therefore$ Number of atoms decayed in time

$(T_1 - T_2) = (N_1 - N_2)$

$$= \frac{(R_1 - R_2)}{\lambda} = \frac{(R_1 - R_2)T}{0.693} \propto (R_1 - R_2)T$$

47. **(c)** Ratio of number of half life taken is given as:

After 16 days

$T_{A1/2} = \frac{16}{4} = 4 \quad T_{B1/2} = \frac{16}{8} = 2$

$N = N_0\left(\frac{1}{2}\right)^n \quad \frac{N_A}{N_B} = \frac{1}{2^4} : \frac{1}{2^2} = 2^2 : 2^4$

$= 4:16 = 1:4$

48. **(d)** $N_1 = N_0 e^{-10\lambda t}, N_1 = N_0 e^{-\lambda t}$

$$\frac{N_1}{N_2} = e^{-9\lambda t} = e^{-1}; 9\lambda t = 1 \Rightarrow t = \frac{1}{9\lambda}$$

49. **(a)** After every half-life, the mass of the substance reduces to half its initial value.

$$N_0 \xrightarrow{5\,\text{years}} \frac{N_0}{2} \xrightarrow{5\,\text{years}} \frac{N_0/2}{2}$$

$$= \frac{N_0}{4} \xrightarrow{5\,\text{years}} \frac{N_0/4}{2} = \frac{N_0}{8}$$

50. **(a)** $\lambda = \frac{1}{t}\log_e \frac{A_0}{A} = \frac{1}{5}\log_e \frac{5000}{1250}$

$$= \frac{2}{5}\log_e 2 = 0.4 \log_e 2$$

51. **(c)** The range of energy of $\beta -$particles is from zero to some maximum value.

52. **(a)** ${}_ZX^A + {}_0n^1 \to {}_3Li^7 + {}_2He^4$

On comparison,

$A = 7 + 4 - 1 = 10$, $z = 3 + 2 - 0 = 5$

It is boron ${}_5B^{10}$

53. **(d)** $A = A_0\left(\frac{1}{2}\right)^{\frac{t}{T_{1/2}}}$

$100 = 1600\left(\frac{1}{2}\right)^{\frac{t}{T1/2}}$

$T_{1/2} = 2\,\text{sec}$, again at t = 6sec

$A = 1600\left(\frac{1}{2}\right)^{\frac{6}{2}} = 200$ counts/sec

54. **(c)** Suppose an initial radionuclide I decays to a final product F w ith a half – life $T_{1/2}$.
At any time, $N_I = N_0 e^{-\lambda t}$
Number of product nuclei = $N_F = N_0 - N_I$

$\frac{N_F}{N_I} = \frac{N_0 - N_I}{N_I} = \left(\frac{N_0}{N_I} - I\right)$

$\frac{N_0}{N_1} = \left(1 + \frac{N_F}{N_I}\right) = 1 + 0.5 = 1.5$

$\therefore \frac{T_{1/2}\ln(1.5)}{\ln 2} = 4.5\times10^9 \frac{\ln\left(\frac{3}{2}\right)}{\ln 2}$ years

55. **(d)** In two half-lives, the activity becomes one fourth.
Activity on 1–8–91 was 2 micro–curie
$\therefore$ Activity before two months,
4 × 2 micro-curie = 8 micro curie

56. **(c)** Half-life = 30 minutes; Rate of decrease (N) = 5 per second and total time = 2 hours = 120 minutes. Relation for initial and final count rate

57. **(a)** $\frac{N}{N_0} = \left(\frac{1}{2}\right)^{\text{time/half-life}} = \left(\frac{1}{2}\right)^{120/30} = \left(\frac{1}{2}\right)^4 = \frac{1}{16}$

Therefore, N_0= 16 × N = 16 × 5 = 80 s^{-1}.

58. **(b)** $t_{1/2} = \frac{0.639}{\lambda}$

59. **(c)** $T_{1/2}$ = 5 years ; 15 years = $3T_{1/2}$

$N = \frac{N_0}{2^n} = \frac{N_0}{8}$. Fraction decayed $= \frac{N_0 - N}{N_0} = \frac{7}{8}$

60. (c) As it can be mapped using the figure.
1. It is a Beta decay as a proton gets added to the element.
2. it is a Alpha decay as a helium atom is lost.
3. It is a gamma decay as Z and A values remain the same.

61. (c) In gamma decay, a nucleus changes from a higher energy state to a lower energy state through the emission of electromagnetic radiation(photons). The number of protons (and neutrons) in the nucleus does not change in this process, so the parent and daughter atoms are the same chemical element. In the gamma decay of a nucleus, the emitted photon and recoiling nucleus each have a well-defined energy after the decay. The characteristic energy is divided between only two particles.

62. **(a)** $T_{1/2} = \frac{\ln 2}{\lambda}; \therefore \lambda = \frac{\ln 2}{T_{1/2}}$

$$\Rightarrow \lambda_A = \frac{\ln 2}{T_A}, \lambda_B = \frac{\ln 2}{T_B} \Rightarrow \frac{\lambda_A}{\lambda_B} = \frac{T_B}{T_A}$$

63. **(d)** Because radioactivity is a spontaneous phenomenon.

64. (a) By definition, one curie is defined as 3.7×10^{10} atoms decay in one second. Curie is a non SI unit of radioactivity. $\therefore 1Ci=3.7\times10^{10}$ dps

65. **(d)** Time taken to disintegrate completely by a substance is infinity as $\log\frac{N_0}{N} = \lambda t \Rightarrow \log\frac{N_0}{0} = \lambda t$

$\log\infty = \lambda t$ hence when $N \to 0, t \to \infty$

NEET PREVIOUS YEARS QUESTIONS-EXPLANATIONS

1. **(a)** Number of nuclei remaining, N = 600 – 450 = 150 after time 't'

$$\frac{N}{N_0} = \frac{150}{600} = \frac{1}{4}$$

$$N = N_0 e^{-\lambda t} \Rightarrow \ell n\frac{N_0}{N} = \lambda t$$

$$\Rightarrow t = \frac{1}{\lambda}\ell n\frac{N_0}{N}$$

$$\Rightarrow t = \frac{2.303\times T_{\frac{1}{2}}}{0.693}\log_{10}\frac{N_0}{N}$$

$$= \frac{2.303\times10}{0.693}\log_{10}4 = 20$$

2. **(a)** Given, $\lambda_A = 8\lambda, \lambda_B = \lambda$

$$N_B = \frac{N_A}{e}$$

$$\Rightarrow N_0 e^{-\lambda_B t} = N_0\frac{e^{-\lambda_A t}}{e}$$

$$e^{-\lambda t} = e^{-8\lambda t}e^{-1}$$

$$e^{-\lambda t} = e^{-8\lambda t-1}$$

Comparing both side powers

$$-\lambda t = -8\lambda t - 1$$

$$-1 = 7\lambda t \Rightarrow t = -\frac{1}{7\lambda}$$

The best possible answer is $t = \frac{1}{7\lambda}$

3. **(a)** As we know, $R = R_0(A)^{1/3}$

where A = mass number

$R_{Al} = R_0(27)^{1/3} = 3R_0$

$R_{Te} = R_0(125)^{1/3} = 5R_0 = \frac{5}{3}R_{Al}$

4. **(d)** In an explosion a body breaks up into two pieces of unequal masses both part will have numerically equal momentum and lighter part will have more velocity.

$U \to Th + He$

$$KE_{Th} = \frac{P}{2m_{Th}}, KE_{He} = \frac{P^2}{2m_{He}}$$

since m_{He} is less so KE_{He} will be more.

5. **(d)** BE of $_2He^4$ = 4 × 7.06 = 28.24 MeV

BE of ^7_3Li = 7 × 5.60 = 39.20 MeV

$$^7_3Li + ^1_1H \rightarrow _2He^4 + _2He^4 + Q$$

$$39.20 \qquad 28.24 \times 2 (= 56.48\,MeV)$$

Therefore, Q = 56.48 – 39.20 = 17.28 MeV.

6. $\alpha = ^4_2He^{2+}$ = Helium Nuclei

2 protons and 2 neutrons

7. $t_{1/2} = 2.2 \times 10^9 s$

$R = 10^{10} s^{-1}$; $R = \lambda N$

$$\Rightarrow N = \frac{R}{\lambda} = \frac{R}{0.693} \times t_{1/2}$$

$$= \frac{10^{10} \times 2.2 \times 10^9}{0.693}$$

$= 3.17 \times 10^{19}$ atoms

8. $_ZX^A \xrightarrow{\gamma-decay} {_Z}Z^A$

Due to gamma emission, there is no change in massnumber ana atomic number

9. $R = \lambda N = \frac{0.693}{T} \times N$

$$\Rightarrow R = \frac{0.693}{1.4 \times 10^{17}} \times 2 \times 10^{21} = 10^4$$

10. $_{92}U^{235} + _0n^1 \rightarrow _ZX^A + _{36}Kr^{89} + 3_0n^1$

Equating mass numbers 236 = A + 92 ⇒ A = 144

Equating atomic numbers 92 = Z + 36 ⇒ Z = 56 (Ba)

The other product is $_{56}Ba^{144}$

11. $E = mc^2 = 0.5 \times 10^{-3} \times 9 \times 10^{16} = 4.5 \times 10^{13} J$

12. $\Delta E = B.E_P - B.E_R$ = 240 (8.5 – 7.6) = 216 MeV

13. $_ZX^A \xrightarrow{\beta_1} {_{Z-1}}B \xrightarrow{\alpha} {_{Z-3}}C \xrightarrow{\beta^-} {_{Z-2}}D$

14. No of half life $= \frac{150}{100} = \frac{3}{2}$

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

15. $^{22}_{11}N_a \rightarrow X + e^+ + ^0_0v$

$^{22}_{11}N_a \rightarrow ^{22}_{10}Ne + e^+ + ^0_0v$

16. $R \propto A^{1/3}$

$$\frac{R_1}{R_2} = \left(\frac{A_1}{A_2}\right)^{\frac{1}{3}} = \left(\frac{125}{64}\right)^{\frac{1}{3}} = \frac{5}{4}$$