35 Nuclear Physics

BRIEF REVIEW

Mass of Proton $m_p = 1.672622 \times 10^{-24}$ kg $= 1.007276\ u$
$= 938.2732$ MeV/c^2

Mass of neutron $m_n = 1.674927 \times 10^{-27}$ kg $= 1.008665\ u$
$= 939.5696$ MeV/c^2

Mass of electron $m_e = 9.10938 \times 10^{-31}$ kg $= 0.00054858\ u$
$= 510.99$ KeV/c^2

$$1 \text{ amu} = 1\ u = \left(\frac{1}{12} \text{ of carbon}\right)$$

$$= 1.66053873 \times 10^{-27} \text{ kg}$$

Number of neutrons $= N$, Number of protons $= Z$ (atomic number)

Nucleon number = Mass number $A = N + Z$

Nuclide A single nuclear species having specific value of N and Z.

Isotopes Nuclides having same atomic number (Z) but different number of neutrons N or different mass number A are termed as **isotopes**. For example, ${}^{12}_{6}\text{C}$, ${}^{14}_{6}\text{C}$; ${}^{35}_{17}\text{Cl}$, ${}^{37}_{17}\text{Cl}$ and ${}^{1}_{1}H$, ${}^{1}_{2}H$, ${}^{1}_{3}H$ are isotopes of carbon, chlorine and hydrogen, respectively.

Isotones The nuclides having same number of neutrons (N) are called isotones. They have different Z or A. Examples of isotones are ${}^{3}_{1}H$, ${}^{4}_{2}He$; ${}^{14}_{6}C$, ${}^{16}_{8}O$.

Isobars The nuclides having same mass number (A) but different atomic number (Z) are called isobars. For instance, ${}^{14}_{6}C$, ${}^{14}_{7}N$; ${}^{40}_{18}Ar$, ${}^{40}_{20}Ca$. Neutrons and protons together are called nucleons.

Nuclear radius $R = R_o A^{1/3}$ where $R_o = 1.1\ fm = 1.1 \times 10^{-15}$ m and is determined experimentally.

Note that nuclear density is independent of mass number, i.e., all nuclei have the same nuclear density.

Nuclear spin like electrons, protons and neutrons are also $\frac{1}{2}$ spin particles. They can have spin odd half multiple of $\hbar$. The magneitude of spin angular momentum of a neucleon is $S = \sqrt{\frac{1}{2}\left(\frac{1}{2}+1\right)} = \sqrt{S(S+1)} = \sqrt{3/4}\ \hbar$. They follow Fermi-Dirac statistics or Pauli's exclusion principle. Hence they are called Fermions. Like electronic magnetic moments the nuleons also show magnetic moments. The unit like **Bohr magneton** in atoms is **nuclear magneton** (μ_n) for nucleons.

Nuclear magneton $\mu_n = \dfrac{e\hbar}{2m_p} = 5.05079 \times 10^{-27}$ J/T $= 3.15245 \times 10^{-8}$ eV/T.

The Z-component of the spin magnetic moment of the proton $|\mu_{SZ}|_{\text{proton}} = 2.7928\ \mu_n$.

The neutron has a corresponding magnitude $|\mu_{SZ}|_{\text{neutron}} = 1.9130\ \mu_n$.

Magnetic moment of proton and neutron is supposed to come from quarks. Protons and neutrons are not fundamental particles but made of quarks. Resonant signal can flip proton spin. Spin flip experiments are called **Nuclear Magnetic Resonance** (NMR). An elaboration of this basic idea leads to **Magnetic Resonance Imaging** (MRI).

Nuclear Force The force that binds protons and neutrons together in the nucleus, despite the electrical repulsion of protons. This is an exmaple of **strong interaction** and is termed as **Nuclear force**. Some of the characteristics of nuclear force are 1. It does not depend on charge. Binding is equal for proton and neutron. 2. It is a short range force extending upto 10 *fm* at the most. 3. Nuclear force is 50–60 times stronger than electromagnetic force. 4. Binding force favour binding of pairs of protons and neutrons of opposite spin and pairs of pairs, that is, a pair of proton and a pair of neutron, each pair having opposite spins. Hence, α-particle is an extremely stable nucleus.

Heisenberg in 1932 proposed exchange force theory. Yukawa extended this theory and found even mass of π-mesons. According to this theory proton does not remain proton forever and neutron does not remain neutron for ever. They go on changing. For instance,

$${}^1_0n \rightarrow {}^1_0n + \pi^0 ; \qquad {}^1_1p \rightarrow {}^1_0n + \pi^+ ;$$

$${}^1_1p \rightarrow {}^1_0p + \pi^0 ; \qquad {}^1_0n \rightarrow {}^1_1p + \pi^- .$$

Where π^0, π^+ and π^- are π-mesons having mass = 270 m_e. Later on, π-mesons were confirmed in cosmic rays. The heavy nuclides require more neutrons so that coulomb repulsion can be balanced. **Shell model** and **liquid drop model** represent the structure of nucleus.

Binding Energy $E_B = \left(Zm_H + Nm_n - {}^A_Z M\right)c^2$. The term in the bracket or E_B / C^2 is called **mass defect.** Binding energy per neuteon $\frac{E_B}{A}$ is defined as

$$\frac{E_B}{A} = \left(\frac{Zm_H}{A} + \frac{Nm_n}{A} - \frac{M}{A}\right) c^2$$

Mass excess Let A be the mass number of a nucleus. Let *Mu* (atomic mass units) be the mass of neutral atom, *Au* be the mass of nuclide in *amu* then excess mass

$$\text{Excess mass} = (Mu - Au) = (M - A)\ \frac{931.5}{c^2} \text{ in MeV/c}^2$$

Packing fraction $P = (M - A)/A$.

Magic numbers The nuclides having number of protons or number of neutrons 2, 8, 20, 28, 50, 82 or 126 are unusually stable. Nuclides with Z = 126 have not been observed in nature. There are nuclides in which Z and N are magic numbers including ${}^{4}_{2}He$, ${}^{16}_{8}O$, ${}^{40}_{20}Ca$, ${}^{48}_{20}Ca$.

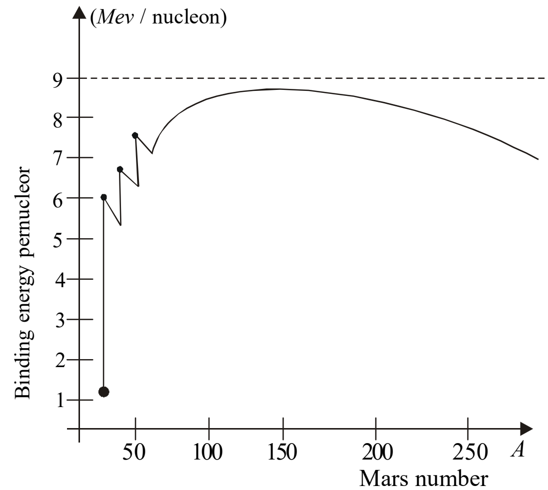


Fig. 35.1 **Binding energy per nucleon Vs. Mass number.**

Only four odd-odd nuclides are known to be stable ${}^{2}_{1}H$, ${}^{6}_{3}Li$, ${}^{10}_{5}B$ and ${}^{14}_{7}N$. The absence of other odd-odd nuclides show the influence of pairing.

Fig. 35.1 shows an approximate binding energy curve. Spikes show extra stable nuclides. Nuclides with binding energy > 7.6 MeV per nucleon are stable.

According to liquid drop model

1. Nuclear forces show saturation, i.e., an individual nucleon can interact with a few of its nearest neighbours. The effect gives a binding energy term as $C_1 A$.
2. The nucleons on the surface of the nucleus are less lightly bound. This effect leads to $-C_2 A^{2/3}$ (proportional to surface area).
3. Each proton repels the remaining (Z – 1) protons leading to an energy $-C_3 Z (Z - 1) A^{-1/3}$
4. To make nucleus stable we shall have more neutrons therefore, a term $-C_4 (N - Z)^2/A$ or $-C^1 (A - 2Z)^2/A$ be added as correction term.
5. Finally, the nuclear force favours pairing. If both Z and N are even then this term be positive, if both Z and N are odd then this term be negative and zero other wise. The form of the term is $\pm C_5 A^{-4/3}$. Thus estimated binding energy E_B is sum of these five terms.

$$E_B = C_1 A - C_2 A^{2/3} - C_3 \frac{Z(Z-1)}{A^{1/3}} - C_4 \frac{(A - 2Z)^2}{A} \pm C_5 A^{-4/3}.$$

The formula best fits if C_1 = 15.75 MeV, C_2 = 17.8 MeV, C_3 = 0.71 MeV C_4 = 23.69 MeV and C_5 = 39 MeV.

The semi emperical mass formula is

$$ {}_{Z}^{A}M = Zm_H + Nm_n - \frac{E_B}{c^2} $$

Stability Criterion According to a survey of periodic table, nuclides having $\frac{N}{Z}$ = 1 or $\frac{N}{Z}$ = 1.6 are stable. Amongst these, nuclides having even N or even Z are most stable. Nearly 90% of 2500 known nuclides are radioactive.

The heaviest stable nuclide is ${}_{83}^{209}Bi$. Lead $\left({}_{82}^{208}Pb\right)$ is the most stable heavy nuclide. All transuranic elements end into lead. The elements or nuclides which decay with time are called **radioactive nuclides**.

Radioactive decay Stable nuclides have definite atomic number and number of neutrons. Unstable nuclides decay by α or β emission. When the **recoiling nucleus** gets **de-excited γ-rays** are also produced.

Q-value of the reaction $Q = U_{\text{initial}} - U_{\text{final}} = (M_R - M_P)\,c^2$ where M_R is the mass of reactants and M_P is the mass of products. For the α-decay

$$ Q = \left[m\left({}_{Z}^{A}X\right) - m\left({}_{Z-2}^{A-4}Y\right) - m\left({}_{2}^{4}He\right)\right] c^2. $$

α-rays A stream of α-particles coming out of a radioactive source is called α-rays.

α-decay: Gamow theory based on tunneling explains α-decay. In α-decay proton number decreases by 2 and mass number decreases by 4. The residual nucleus is, thus, different and is called daughter nucleus.

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

Conditions for α-decay

Mass number $A > 210$ and $\frac{N}{Z} > 1.6$

Three types of β-decays

(a) β^- (or electron emission)

(b) β^+ (positron emission) and,

(c) K-electron capture.

β-decays kept scientist puzzled for about 20 years. We consider radioactivity as a collison process. Momentum could not be conserved as emitted β-particles have different energies as illustrated in Fig. 35.2. It was then suggested, consider β-emission as a two particle emission. The second particle was soon detected as neutrino (ν). Neutrino is a fermion as it has spin quantum number $\pm\frac{1}{2}\hbar$. It is a mass-less particle or has **rest mass zero**.

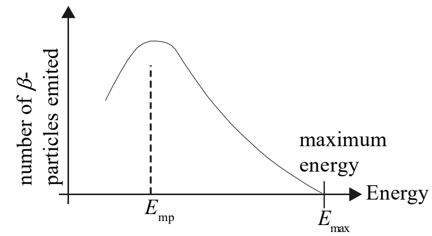


Fig. 35.2 **Energy distribution of β-emission.**

To understand β-emission we must have an idea of conservation rules.

Conservation Rules

1. Momentum is conserved.
2. Mass number is conserved.
3. Charge number is conserved.
4. Particle number is conserved.
5. Parity is conserved.

Particles and Antiparticles It is believed that particles live in positive sea and antiparticles live in negative sea separated by $2\,m_oc^2$ where m_0 is rest mass of the particle. See Fig 35.3. When particle and anti particle unite, an energy = 2 mc^2 is produced. It is believed that each particle has its antiparticle. For example, when electron

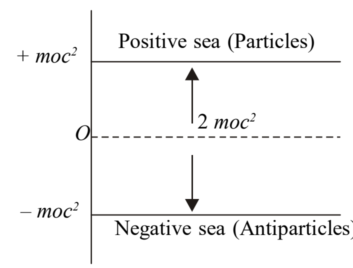


Fig. 35.3 **Particle/Antiparticle illustration**

and positron unite. γ-ray of energy 1.02 MeV is produced and the process is called **Pair annihilation.**

$$ \underset{\text{electron}}{e^-} + \underset{\text{positron}}{e^+} \rightarrow \underset{\text{rays}}{\gamma} \;(E_\gamma = 1.02\text{ MeV}). $$

Each particle is assigned a particle number +1 and each antiparticle is assigned particle number –1.

β-decay

$$ {}_{Z}^{A}X \rightarrow {}_{Z+1}^{A}Y + {}_{-1}^{0}\beta + \bar{\upsilon}. $$

Antinutrino ($\bar{\upsilon}$) is assumed to be emitted during β^- decay to conserve particle number

$$ A = A + 1 - 1 $$

Note that daughter nucleus has atomic number one larger than parent nucleus while mass number A remains unchanged. It is assumed that a neutron in the nucleus decays to a proton by the following process to facilitate β -emission.

$$ {}_{0}^{1}n \rightarrow {}_{1}^{1}p + {}_{-1}^{0}\beta + \underset{\text{antinutrino}}{\bar{\upsilon}} $$

Remember the elelctrons emitted from nucleus are called β^--particles.

Condition for β^- decay to occur $\frac{N}{Z} > 1$ for low Z-nuclides. Or $\frac{N}{Z} > 1.6$ for high Z-nuclides.

Note that **positron** is an **antiparticle** of **electron.**

β^+ (positron) emission

$$^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + \underset{\text{positron}}{{}^{0}_{+1}\beta} + \underset{\text{nutrino}}{\upsilon}.$$

See carefully that during β^+-emission charge number decreases by 1 and mass number remains unchanged. It is assumed that a proton changes to a neutron in order to achieve $\frac{N}{Z} = 1$ for light nuclides or $\frac{N}{Z} = 1.6$ for heavy nuclides.

$$^{1}_{1}p \rightarrow {}^{1}_{0}n + \underset{\text{positron}}{{}^{1}_{0}e} + \underset{\text{nutrino}}{v}$$

Condition for β^+-decay $\frac{N}{Z} < 1$ or 1.6 for light and heavy nuclides respectively.

K-electron capture If electron from K-shell is captured by the nuclide, the process is called K-electron capture. The resulting daughter nuclide will have atomic number one less than the parent like β^+-emission. The only difference in **β^+-emission** and **K-electron** capture is that in latter case X-ray is emitted (atomic process) while in β^+-emission γ-ray is emitted (nuclear process).

$$^{A}_{Z}X + \underset{\text{K-electron capture}}{{}^{1}_{0}e} \rightarrow + {}^{A}_{Z-1}Y + \underset{\text{nutrino}}{v} \ (+\text{ X-ray})$$

γ-emission The daughter nucleus after α-decay or after β^-- or β^+-decay gets excited. It de-excites after a fraction of second and emits γ-rays. Neither mass number nor atomic number changes during γ-emission. In naturally occuring radioactive substances γ-emission follows α- or β-emission.

However, artificial radioactive samples can decay only by γ-emission also.

Law of Radioactivity $\frac{dN}{dt} = -\lambda N$ where λ is decay constant or distintegration constant.

$$\int_{N_0}^{N} \frac{dN}{N} = \int_0^t -\lambda dt \Rightarrow N = N_0 e^{-\lambda t}$$

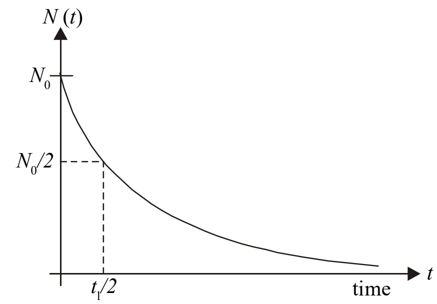


Fig. 35.4 **Rodioactive decay process**

Fig. 35.4 shows how number of nuclides left undecayed vary with time. The quantity $\frac{-dN}{dt}$ gives the number of decay per second and is called **activity.** Thus,

$$\frac{-dN}{dt} = \lambda N = A \text{ (Activity) and } A = A_0 e^{-\lambda t}$$

The SI unit of activity is Becquerel (Bq). 1 Bq = 1 dps (decay per second). The practical unit of activity are Curie and Rutherford.

1 Curie (Ci) = 3.7×10^{10} dps

1 Rutherford (R) = 10^6 dps

Activity per unit mass is called specific activity. α-, β-, γ-, neutrons and X-rays break molecular bonds and create ions, hence, the term **ionizing radiations** is used for them. They can destroy tissue cells, cause alteration in genetic material and destruction of the components in bone marrow that produce red blood cells.

Radiation dose SI unit of absorbed dose is Joule/kg and is called Gray (Gy)

1 Gy = 1 J/kg Another unit is rad. 1 rad = 0.01 J/kg = 0.01 Gy

Equal amounts of different radiation cause different effects. Therefore, **relative biological effectiveness** (RBE), also called quality factor (QF) of each specific radiation is defined by a numerical factor. X-rays with 200 keV of energy are defined to have an RBE unity. SI unit of biological equivalent dose is called Sievert (Sv)

1 Sv = (RBE) × [absorbed dose (Gy)]

The permitted dose is 50 μ Sv per annum.

A dose of 5 Sv or more causes a death in few days. Table 35.1 lists RBE for various radiations. Another common unit is Roentgen equivalent for Man (rem), 1 rem = .01Sv.

Table. 35.1

Radiation	RBE (Sv/Gy)
X-ray and γ-ray	1
electrons	1 – 1.5
Slow neutrons	3 – 5
Protons	10
α-particles	20
Heavy ions	20

half-life $t_{1/2} = \dfrac{0.693}{\lambda}$. The time in which activity reduces to the half the present value is called half life.

Average life $t_{av} = \dfrac{1}{\lambda} = 1.44\, t_{1/2}$

Properties of α-rays

1. It is a stream of He nuclides.
2. Since they have two unit positive charge. They are defelcted by electric and magnetic fields.
3. Their ionizing power is very large (maximum amongst α, β, and γ).
4. Their penetrating power is minimum. They can travel few cm in air.
5. They produce scintillation on striking with floroscent material like barium platinocyanide.
6. They affect photographic plates.

Properties of β^--rays

1. It is a stream of electrons.
2. They are deflected by electric and magnetic fields.
3. Their ionizing power is less than that of α- but greater than that of γ-particles.
4. Their penetrating power is more than that of α- but less than that of γ-rays.
5. They produce scientillation on striking a fluorescent screen.
6. They affect photographic plates.

Note: β^+ rays possess same properties as β^- rays except they are positively charged and will deflect in a direction opposite to β^- in the applied magnetic or electric field.

Properties of γ-rays

1. They are an *em* radiations (no charge, rest mass zero), move with speed of light.
2. They are not deflected by electric or magnetic fields.
3. γ-rays have maximum penetrating power amongst α, β and γ.
4. The iozining power of γ-rays is minimum amongst α, β and γ.
5. They affect photographic plates.

Nuclear fission is a decay process in which an unstable nucleus splits into two fragments of comparable mass.

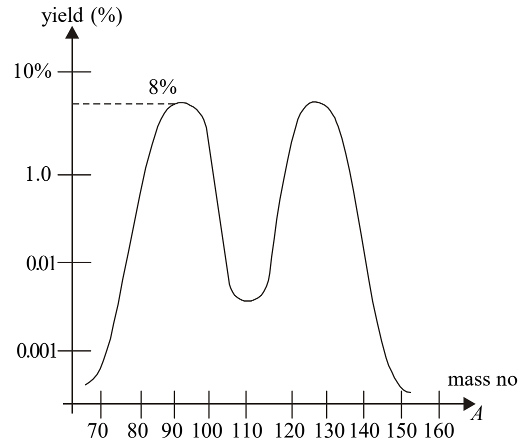


Fig. 35.5 **Yield of fragments in a nuclear fission**

$$^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{236}_{92}U$$

$$^{236}_{92}U \rightarrow {}^{137}_{53}I + {}^{97}_{39}Y + 2\,{}^{1}_{0}n$$

$$^{97}_{39}Y \xrightarrow{\beta^-} {}^{97}_{40}Zr \xrightarrow{\beta^-} {}^{97}_{41}Nb \xrightarrow{\beta^-} {}^{97}_{42}Mo$$

$$^{137}_{53}I \xrightarrow{\beta^-} {}^{137}_{54}Xe \xrightarrow[\text{delayed neutron}]{^{1}_{0}n} {}^{136}_{54}Xe;$$

$$^{236}_{92}U \rightarrow {}^{144}_{56}Ba + {}^{89}_{36}Kr + 3\,{}^{1}_{0}n$$

$$^{236}_{92}U \rightarrow {}^{140}_{56}Ba + {}^{94}_{36}Kr + 2\,{}^{1}_{0}n;$$

$$^{236}_{92}U \rightarrow {}^{140}_{54}Xe + {}^{94}_{38}Sr + 2\,{}^{1}_{0}n$$

Large number of reactions are feasible. Some of the most prominent are listed. Fig. 35.5 shows percentage yield Vs mass number of fission products of $^{236}_{92}U$. Note that some reactions give 2 neutrons and others emit 3 neutrons per reaction. Thus, on an average 2.47 neutrons per reaction are emitted. Most of the fragments have mass number 90 to 100 and 135 to 145. The delayed neutron helps a lot in controlling fission rate.

About 200 MeV energy per reaction is released in each fission. Neutrons take away about 5 MeV energy in each reaction. As the fragments further decay an additional 15–20 MeV energy is released.

Nuclear fission may be explained with liquid drop model as illustrated in Fig. 35.6.

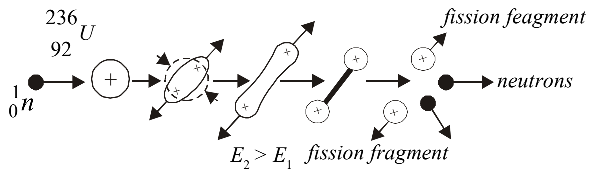


Fig. 35.6 **Liquid drop model for nuclear fission**

Initially assume the nuclide $^{236}_{92}U$ in the state E_1. It gains energy by itself for a short interval according to Hiesenberg's uncertainty principle $\Delta E \,.\, \Delta t \approx \hbar$ and reaches a higher energy state E_2. The shape gets distorted due to internal vibrations and becomes like a dumb bell and finally breaks up into two nuclides releasing energy $E_1 - E_3$ as illustrated in Fig. 35.6 and 35.7.

Table 35.2 shows fission probabilities of various substances. Note ^{240}Pu is 1.5 times more efficient than ^{236}U. This is why it is the most desirable fissionable material.

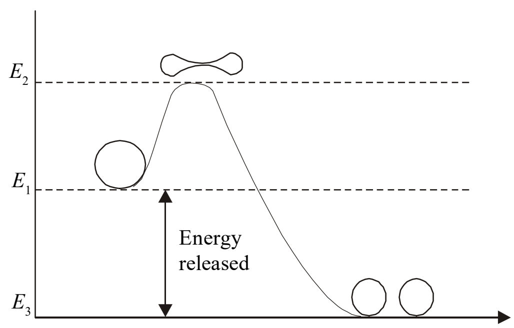


Fig. 35.7 **Energy transfer depiction during fission**

Nuclide	Fission Probability ralative to $^{236}U_{92}$
^{236}U	1 (assumed arbitrarily)
^{238}U	$< 10^{-3}$
^{240}Pu	1.5
^{244}Am	$< 2 \times 10^{-4}$

Table. 35.2 **Fission Probability**

Critical mass The minimum mass of fissionable material required to carry out fission reaction. It is 10 kg for ^{236}U.

Critical Reaction One neutron per reaction used to carry out further chain reaction while other neutrons are absorbed.

Moderator slows down the neutrons.

Thermal/Slow neutrons Neutrons having energy of the order of room temperature (0.02 eV) are termed as slow or thermal neutrons. The normal nuclear reactors use ^{236}U or ^{235}U while **breeder** reactors use ^{238}U and produce nuclear fuel which is more efficient than consumed.

$$^{238}_{92}U + ^{1}_{0}n \rightarrow ^{239}_{92}U \xrightarrow{\beta^-} ^{239}_{93}Np \xrightarrow{\beta^-} ^{239}_{94}Pu$$

Since Pu is 1.5 times more efficient than ^{235}U. Thus, a breeder reactor converts a non-fissionable material to a one which is rather more efficient.

Enriched Uranium Increasing the proportion of ^{235}U from its natural value of 0.7% to 3% or more by isotope separation processing using p^2 centrifuge is termed as enriched uranium. The fission of ^{235}U is triggered by the absorption of slow neutrons.

Nuclear fusion occurs when two light nuclide unite or fuse together to form a heavy nucleus.

To carry out fusion, the temperature should be of the order of 10^7 K

$$\left.\begin{array}{l} ^{1}_{1}H + ^{1}_{1}H \rightarrow ^{2}_{1}H + ^{0}_{+1}e + \upsilon \\ ^{2}_{1}H + ^{1}_{1}H \rightarrow ^{3}_{1}H + ^{0}_{+1}e + \upsilon \text{ or } ^{3}_{2}He \\ ^{3}_{1}H + ^{1}_{1}H \rightarrow ^{4}_{2}He \\ \text{or } ^{3}_{2}He + ^{1}_{1}H \rightarrow ^{4}_{2}He + ^{0}_{+1}e + \upsilon \end{array}\right] \begin{array}{l}\text{The overall energy}\\ \text{released is nearly}\\ \text{27 MeV}\end{array}$$

The overall reaction is

$$4\,^{1}_{1}H + ^{4}_{2}He + 2\,^{0}_{+1}e + 2\upsilon$$

Such a reaction is called thermal nuclear fusion reaction. In stars where the temperature is 10^8 K, another cycle called proton carbon cycle takes place.

$$4\,^{1}_{1}H + 2\,^{4}_{2}He \rightarrow ^{12}_{6}C + 2\,^{0}_{+1}e + 2\upsilon$$

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

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

The process continues until A = 56 (Iron). The element heavier than iron can be produced by neutron absorption and subsequent β decay.

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

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

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

$$^{1}_{1}H + ^{15}_{7}N \rightarrow ^{16}_{8}O \text{ or } ^{12}_{6}C + ^{4}_{2}He.$$

Nuclear fusion in laboratory Lawson criterion $n\,\tau \geq 10^{14}$ s cm^{-3} where n is density of fusing particles and τ is time of confinement. The quantity $n\tau$ is called Lawson number. Lawson showed that in order to achieve energy output > energy input $n\tau \geq 10^{14}$ cm$^{-3} - s$.

Four forces and their mediating particles are listed in table 35.3.

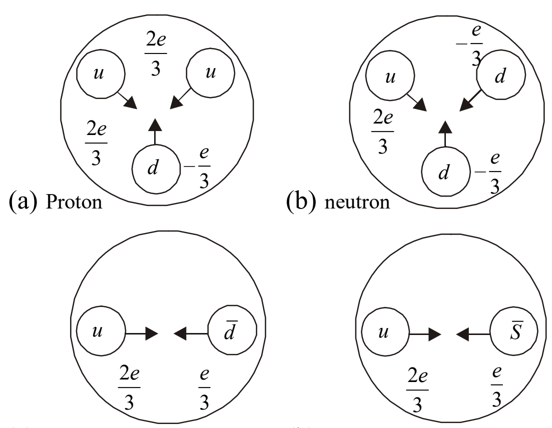
Table 35.3 Four fundamental forces

Interaction	Relative Strength	Range m	mediating particle Name	mass	Charge	Spin
Strong	1	Short $(\square 10^{-15} m)$	Gluon	0	0	1
Electromagnatic	$\frac{1}{137}$	Long $\left(\propto \frac{1}{r^2}\right)$	Photon	0	0	1
Weak	10^{-9}	Short $(\square 10^{-3} fm)$	$w\pm$	80.4 Gev/c^2	$\pm e$	0
			$z°$	91.2 Gev/c^2	0	1
Gravitational	10^{-38}	long $\left(\propto \frac{1}{r^2}\right)$	graviton	0	0	2

Leptons: The leptons do not show strong interaction. They include 6 particles and their antiparticles electrons, positronsand their neutrinos v_e and $\overline{v}_e$, muons and their neutrinos, tau and their neutrinos.

Hardons are the strong interacting particles. Each hardon has its antiparticle. There are two subclasses of hardons: **mesons** and **baryons.** Baryons include nucleons and hyperons like λ, Σ, Ξ and Ω. Hardons are made from quarks.

Quarks quark are of 6 types, *u, d, s, c, b* and *t*. Fig. 36.8 illustrates how hardons are made with quarks.



(a) Proton (b) neutron

(c) Positive pion (π^+) (b) Positive Kaon (K^+)

Fig. 35.8 **Illustration of Hardons formation using quarks**

The standard model includes 3 families of particles.

1. Six Leptons which have no strong interaction.
2. The six quarks from which all hardons are made.
3. The particles which mediate the various interactions. These mediators are gluons for strong interaction among quarks, photons for electromagnetic interaction; $W^{\pm}$, Z^0 for weak interaction (during β-decay), and the gravitons for gravitational interaction.

SHORT CUTS AND POINTS TO NOTE

1. The particles inside the nucleus are called nucleons. They are mesons and baryon. Baryons are made of quarks.
2. The radius of the nucleus is given by $R = R_0\ A^{1/3}$ where $R_0 = 1.1\ fm$ $(1\ fm = 10^{-15}\ m)$.
3. The nucleus density is independent of mass number A.
4. For nuclides to be stable $\frac{N}{Z} = 1$ for light nuclides and $\frac{N}{Z} = 1.6$ for heavy nuclides. Nuclides having number of protons or number of neutrons 2, 8, 20, 28, 50, 82 or 126 are unusually stable and termed as magic numbers. If binding energy per nucleon is greater than 7.6 MeV/nucleon, the nuclides are stable.
5. Binding energy $E_B = \left(Zm_H + Nm_n - \frac{A}{Z}M\right)c^2$. The term in the bracket is called mass defect

$$\frac{E_B}{A} = \left[\frac{Zm_H + Nm_n - \frac{A}{Z}M}{A}\right]c^2$$ is binding energy per nucleon.

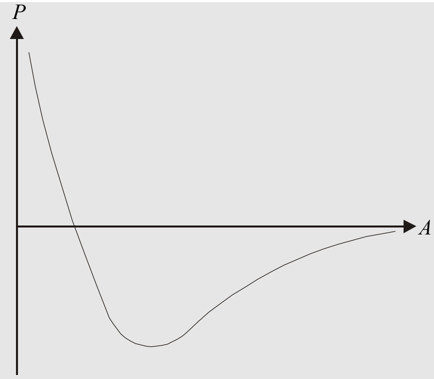


Fig. 35.9

6. Packing fraction $P = \left({}^{A}_{Z}M - A\right)\Big/A$ where ${}^{A}_{Z}M$ is atomic mass and A is mass number. More negative value of P indicates more stable the nuclide is. Fig. 36.9 shows the variation of Packing fraction with mass number A.

7. Protons and neutrons both possess spin which is half integral multiple of $\hbar$. Thus, making them fermions. They show magnetic moments

$$|\mu_{SZ}|_{\text{proton}} = 2.7928\ \mu_n \text{ and}$$

$|\mu_{SZ}|_{\text{neutron}} = 1.9130\ \mu_n$. Where μ_n is nuclear magneton $\mu_n = \dfrac{e\hbar}{2m_p}$. Interaction energy $= \vec{\mu}\,.\,\vec{B}$ when placed in a magnetic field.

8. Nuclear force binds neutrons and protons both in the nucleus. It is independent of charge. This is short range force. It depends upon distance and spin. Binding force favours binding of pairs of protons and pairs of neutrons of opposite spin and pairs of pairs. That is, a pair of proton and a pair of neutron each having opposite spins. Hence α-particle $\left({}^{4}_{2}He\right)$ is an extremely stable nuclide.

9. Nuclear fission is modelled as liquid drop model. Nuclear fission of ${}^{235}_{92}U$ generates 200 MeV per reaction. 5 MeV is the energy taken by neutrons. 2.47 neutrons per fission reaction are emitted on an average. To carry out controlled reaction 1 neutron per reaction or nearly 40% of neutrons emitted are required.

Critical mass of the fuel is 10 kg for ${}^{235}U$. Enriched uranium means increasing the % of ${}^{235}U$ from 0.7% (naturally occuring) to 3% or more by isotope separation process. Uncontrolled chain reaction is used in nuclear bombs.

10. In breeder reactor, more efficient fuel is produced than consumed. These reactors convert a nonfissionable material ${}^{238}_{92}U$ into ${}^{239}_{94}Pu$.

11. Slow neutrons or thermal neutrons are used to carry out chain reaction.

12. Neutron reproduction factor =

$$\frac{\text{rate of production of neutrons}}{\text{rate of loss of neutrons}} = \frac{\text{number of neutrons produced}}{\text{neutrons absorbed + neutron leakage}}$$

Heavy water (D_2 O) is used as a moderator.

13. A fusion reaction $4\,{}^{1}_{1}H \to {}^{4}_{2}He + 2\,{}^{0}_{+1}e + 2\,\nu$ generates 27 MeV energy per reaction. Such thermal nuclear fission reaction are possible at a temperature 10^7 K. If temperature is 10^8 K carbon cycle is feasible. Such fusion reactions can occur upto Fe (A = 56). After that higher Z elements are formed due to neutron absorption and subsequent β-emission.

14. $\dfrac{-dN}{dt} = \lambda N$ or $N = N_o\, e^{-\lambda t}$.

$$\lambda N = A = \frac{-dN}{dt} \text{ is called activity.}$$

15. $t_{1/2}$ (half life) $= \dfrac{0.693}{\lambda}$, $t_{av} = \dfrac{1}{\lambda} = 1.44\ t_{1/2}$.

16. Law of successive transformation

$$\frac{dN_2}{dt} = \lambda_1 N_1 - \lambda_2 N_2$$

$$N_2 = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_1(o)\left[e^{-\lambda_1 t} - e^{-\lambda_2 t}\right] + N_2(o)\ e^{-\lambda_2 t}$$

$$= \frac{\lambda_1}{\lambda_2 - \lambda_1} N_1(o)\ e^{-\lambda_1 t} + \left[N_2(o) - \frac{N_1(o)\lambda_1}{\lambda_2 - \lambda_1}\right] e^{-\lambda_2 t}$$

Special cases for radioactive equilibrium

a) Extremely long lived parent ($\lambda_1 << \lambda_2$)

$$N_2 = N_1(o)\ \frac{\lambda_1}{\lambda_2}\left(1 - e^{-\lambda_2 t}\right) \text{ or } N_2(eq) = \frac{\lambda_1}{\lambda_2} N_1(o)$$

b) Relatively long lived parent ($\lambda_1 < \lambda_2$)

$$N_2 = N_1(o)\ e^{-\lambda_1 t}\ \frac{\lambda_1}{\lambda_2 - \lambda_1} - N_1\ \frac{\lambda_1}{\lambda_2 - \lambda_1}$$

$$\frac{A_1}{A_2} = \frac{\lambda_1 N_1}{\lambda_2 N_2} = \frac{\lambda_2 - \lambda_1}{\lambda_2} = \frac{T_1 - T_2}{T_1}$$ where T_1 and T_2 are average life times.

c) Relatively shortlived parent ($\lambda_1 > \lambda_2$)

$$\frac{A_2}{A_1} = \frac{\lambda_2 N_2}{\lambda_1 N_1} = \frac{\lambda_2}{\lambda_1 - \lambda_2}\left[e^{(\lambda_1-\lambda_2)t} - 1\right]$$

If $t >> T_1$ then $N_2 = N_1(o)\ e^{-\lambda_2 t}$

d) Daughter and parent of nearly equal half life

$$\frac{A_2}{A_1} = \frac{t}{T_2}$$ i.e. linearly proportional to time

17. Number of nuclides left after n half lives $N = \frac{N_o}{2^n}$.

Similarly, mass of parent left after n half lives is $m = \frac{m_o}{2^n}$.

18. α-decay is explained using Gamow's theory of tunneling while β-decay is explained using neutrino hypothesis.

19. Relation between range and energy of α-particles

$R = 0.318\ E^{3/2}$

Geiger Nuttal law $\log \lambda = A + B \log R$

Range of α-particles is 2.6 cm to 8.6 cm in air.

20. α-particles are detected using scintillation counter. β and γ radiations are detected using GM (Geiger-Muller) counter.

21. Radioactivity is a nuclear process as it is not associated with atomic electrons.

22. If E_γ > 1.02 MeV then pair production may occur.

$\gamma \to e^- +$ and e^+. $e^+ + e^- \to \gamma$

electron and positron unite to form γ-ray (E_γ = 1.02 MeV), this process is called pair annihilation.

23. Absorption of α, β and γ result in ionization. γ-ray may also be absorbed causing photoelectric effect, compton scattering or pair production.

24. Leptons do not show strong interactions. e^-, e^+, v_e, $\overline{v}_e$; μ^-, μ^+, v_μ, $\overline{v}_\mu$ and $\tau, \overline{\tau}, \upsilon_\tau, \overline{\upsilon}_\tau$ are 6 pairs of leptons (particle + antiparticle).

25. Lambda (λ), Sigma (Σ), ksi (Ξ) and Omega (Ω) along with nucleons (neutron and proton) are Baryons. λ, Σ, Ξ, Ω are called hyperons.

Hardons can be divided into two types mesons and Baryons. K-meson, π-meson are examples of mesons. All Hardons are formed from quarks.

26. Gluons, photons, $W^\pm$, Z^0 and gravitons are respective mediatory particles for strong interaction, electromagnetic interaction, weak interaction and gravitational interaction respectively.

27. Fermions are spin half particles. Examples of fermions include electron, proton, neutron, neutrino etc. They follow Fermi Dirac statistics. They follow Pauli's exclusion principle.

28. Bosons are integral spin particles. Examples of Bosons are photon, graviton, pion, kaon phonons, excitons, magnons, η-meson, cooper pair etc. Bosons follow Bose–Einstein statistics.

CAUTION

1. Difficulty in remembering which type of neutrons cause fission.

$\Rightarrow$ Only thermal or slow neutrons having energy ~ 0.02 eV cause fission in ^{235}U. For ^{238}U, we use fast neutrons to make a fuel (developed in Breeder reactor).

2. Confusion between Fermions and bosons.

$\Rightarrow$ Fermions are spin half particles and follow Pauli's exclusion principle. They follow Fermi Dirac statistics.

Bosons are integral spin particles. They follow Bose–Einstein statistics.

3. Confusion between half life and average life.

$\Rightarrow$ Half life $t_{\frac{1}{2}} = \frac{0.693}{\lambda}$ (the time in which particles reduce to half the amount)

$$t_{av} = \frac{1}{\lambda}$$

4. Confusion between Curie and Rutherford and radiation dose.

$$\Rightarrow \left.\begin{array}{l} 1\text{ Ci} = 3.7\times10^{10}\text{ dps} \\ 1\text{ R} = 10^6\text{ dps} \end{array}\right\}\text{Practical units of activity}$$

$1\text{ Bq} = 1\text{dps} \longrightarrow$ SI unit of activity

$$\left.\begin{array}{l} 1\text{ Gy} = 1\text{ J/kg} \\ 1\text{ rad} = 0.01\text{ J/kg} = 0.01\text{ Gy} \end{array}\right\}\text{Radiation dose}$$

$$\left.\begin{array}{l} 1\text{ Sv} = (\text{RBE})\times\text{absorbed dose (Gy)} \\ 1\text{ rem} = 0.01\text{ Sv} \end{array}\right\}\text{Relative biological effectiveness}$$

For a normal man permitted radiation dose is 50 μ Sv per annum.

5. Not recalling the formula between time/activity.

$\Rightarrow$ $N = N_o e^{-\lambda t}$ After n half lines $N = \frac{N_o}{2^n}$

6. Non clarity on concepts of radioactive equilibrium.

$\Rightarrow$ When rate of decay of daughter is equal to rate of decay of parent, radioactive equilibrium occurs, i.e., $\lambda_1 N_1 = \lambda_2 N_2$.

7. Assuming that all β-particles emitted from a source have constant energy.

$\Rightarrow$ their energies are different. This effect is explained by neutrino hypothesis of two particle emission.

8. Considering that nuclear force is a central force.

$\Rightarrow$ Nuclear force is a short range attractive force. It is independent of charge. It depends upon spin and distance.

9. Considering neutrinos as particles having mass.

$\Rightarrow$ neutrinos are massless, chargeless particles. They have spin $\frac{\hbar}{2}$, i.e., they are Fermions. The linear momentum and spin vectors are mutually opposite for antineutrino as illustrated in Fig. 35.10.

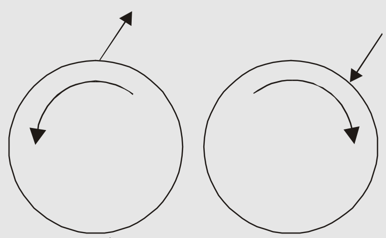


Fig. 35.10

10. Non clarity on the process of absorption of γ-rays.

$\Rightarrow$ The γ-radiation is absorbed by ionization, photo electric effect, compton scattering and by pair production. The absorption coefficient $\alpha \propto \lambda^3$ and $\alpha \propto Z^4$. $I = I_o e^{-\alpha x}$ is the absorption law.

11. Considering that nuclear density depends upon mass number.

$\Rightarrow$ Nuclear density is independent of mass number as

$$\frac{A}{\frac{4}{3}\pi R^3} = \frac{A}{\frac{4}{3}\pi R_0^3 A} = \frac{3}{4\pi R_0^3}.$$

12. Considering that a neutron cannot be a Fermion as it has no charge.

$\Rightarrow$ Chargeless particles like neutron and neutrino are Fermions as they are half spin particles.

13. Considering neutron can not have magnetic dipole moment as it is chargeless.

$\Rightarrow$ Neutron has magnetic moment. It is attributed to the fact that neutrons are composed of quarks.

14. Assuming that electrons are also present inside the nucleus as during β-emission electrons are emitted.

$\Rightarrow$ Electrons cannot live inside the nucleus otherwise their speed will exceed speed of light. It is a neutron which decays to proton and electron through a complicated process that electrons are emitted during β-decay.

15. Considering that a radioactive element can emit any particle electron, proton, neutron or alpha.

$\Rightarrow$ Naturally occuring radioactive elements emit α, β and γ. Elements with $Z > 83$ are all radioactive.

Artificially prepared radioactive samples can decay even by γ-emission or neutron or proton emission.

16. Assuming neutron as the most stable particle as it has no charge.

$\Rightarrow$ The neutron can not exist independently. Its life is hardly 7 minute. When it is outside the nucleus.

17. During positron emission taking into account mass of one electron as in β^--emission.

$\Rightarrow$ In positron emission $Q = [M_{\text{Reactant}} - M_{\text{Product}} - 2\, m_e]\, c^2$

SOLVED PROBLEMS

1. In the reaction ${}^2_1H + {}^3_1H \rightarrow {}^4_2He + {}^1_0n$, if the binding energies of ${}^2_1H$, ${}^3_1H$ and ${}^4_2He$ are respectively a, b and c (in MeV) then the energy (in MeV) released is

(a) $a + b + c$ (b) $a + b - c$

(c) $c - a - b$ (d) $c + a - b$

(CBSE PMT 2005)

Solution (b) $Q = (M_R - M_P)\, C^2 = a + b - c$

2. Fission of nuclei is possible because the binding energy per nucleon in them

(a) increases with mass number of low mass.

(b) decreases with mass number at low mass number.

(c) increases with mass number at high mass number.

(d) decreases with mass number at high mass number.

(CBSE PMT 2005)

Solution (d)

3. A star converts all its He in Oxygen. Find the amount of energy released per nucleus of oxygen. $He = 4.0026$ amu $O = 15.9994$ amu

(a) 7.26 MeV (b) 7 MeV

(c) 10.24 MeV (d) 5.12 MeV

(IIT Screening 2005)

Solution (c) $E = \Delta mc^2$

$= [4 \times 4.0026 - 15.9994]\, 931.5 = 10.24$ MeV.

4. The intensity of gamma radiation from a given source is I. On passing through 36 mm of lead it is reduced to $\frac{I}{8}$. The thickness of lead which reduces the intensity to $\frac{I}{2}$ is

(a) 6 mm (b) 9 mm

(c) 18 mm (d) 12 mm

(AIEEE 2005)

Solution (d) $\frac{I/2}{I/8} = \frac{e^{-\mu x}}{e^{-\mu 36}}$ or $\frac{8}{2} = \frac{e^{36\mu}}{e^{\mu x}}$ or $\frac{2^3}{2} = \frac{(e^{\mu x})^3}{e^{\mu x}}$

$(e^{\mu x})^3 = e^{36\mu} \therefore x = 12$

5. Starting with a sample of pure ^{66}Cu, $\frac{7}{8}$ of it decays into Zn in 15 minuts the corresponding half life is

(a) 10 min (b) 15 min

(c) 5 min (d) 7 ½ min

(AIEEE 2005)

Solution (c) Sample left $= \frac{1}{8} = \frac{1}{2^n}$

$n = 3$ i.e. 3 half lines have passed

$3\, t_{1/2} = 15$ or $t_{1/2} = 5$ min.

6. The radius of $^{27}_{13}$Al is 3.6 Fermi. Find the radius of $^{125}_{52}$Te nucleus.

(a) 6 Fermi (b) 8 Fermi

(c) 4 Fermi (d) 5 Fermi

(AIEEE 2005)

Solution (a) $\frac{R_1}{R_2} = \frac{A_1^{1/3}}{A_2^{1/3}}$

$$R_2 = \left(\frac{125}{27}\right)^{1/3} \times 3.6 = 6 \text{ Fermi.}$$

7. A. It is not possible to use ^{35}Cl as the fuel for fusion energy

R. The binding energy ^{35}Cl is too small

(AIIMS 2005)

(a) Both A and R are correct and R is correct explanation of A.

(b) A and R are correct but R is not correct explanation of A.

(c) A is true but R is false.

(d) both A & R are false.

Solution (c)

8. $^{222}_{86}A \to {}^{210}_{84}B$ in this reaction how many α and β emissions have occured

(a) $6\alpha, 3\beta$ (b) $3\alpha, 4\beta$

(c) $4\alpha, 3\beta$ (d) $3\alpha, 6\beta$

(BHU 2005)

Solution (b) Since the mass number has decreased by 12 $\therefore$ 3α emissions have occured. The charge number will decrease by 6 with 3α emission. 4β emission will make charge 84 units.

9. The phenomenon of radioactivity

(a) is an exothermic change which increases or decreases with temperature.

(b) increases on applied pressure.

(c) is a nuclear process does not depend upon external factors.

(d) none of these.

Solution (c)

10. Mean life of a radioactive sample is 100 s. Find its half life in minutes.

(a) 0.693 (b) 1

(c) 10^{-4} (d) 1.155

(CET Karnataka 2005)

Solution (d) $t_{av} = \frac{1}{\lambda}$ 100 s

$$t_{1/2} = \frac{.693}{\lambda} = 69.3\, s$$

11. Consider two nuclei of same radioactive nuclide. One of the nuclei was created in a supernova explosion 5 billion years ago. The other was created in a nuclear reactor 5 minutes ago. The probability of decay during the next time is

(a) different of each nuclei.

(b) nuclei created in explosion decays first.

(c) nuclei created in the reactor decays first.

(d) independent of time of creation.

Solution (d) It depends only on the number of nuclei present at that time.

12. Protons are placed in a magnetic field in the Z direction (magnitude = 2.3 T). The energy difference between a state with Z component of proton spin angular momentum parallel to the field and antiparallel to the field is.

(a) 4.05×10^{7} eV (b) 4.05×10^{-7} eV

(c) 2.025×10^{7} eV (d) 2.025×10^{-7} eV

Solution (b) $U_1 = |S_Z| B$

$= -2.7928 \times (2.3\ T) \times 3.152 \times 10^{-8} \left(\frac{eV}{T}\right)$

$= -2.025 \times 10^{-7}$ eV (When B and $|S_Z|$ are parallel.

$U_2 = +2.025 \times 10^{-7}$ eV when B and $|S_Z|$ are antiparallel.

$\therefore \Delta U = U_2 - U_1 = 4.05 \times 10^{-7}$ eV

13. The hyperfine lines in the spectrum is related to

(a) Zeeman effect. (b) Stark effect.

(c) Lande's splitting. (d) nuclear magnetic spin.

Solution (d)

14. Find the binding energy of ${}^{62}_{28}Ni$. Given $m_H = 1.008\ u$, $m_n = 1.0087\ u$, ${}^{62}_{28}m = 61.9238\ u$

(a) 545.3 MeV (b) 595.3 MeV

(c) 645.3 MeV (d) 695.3 MeV

Solution (a) $E_B = (28\ m_H + 34\ m_n - 61.9238)\ 931.5$

$= 545.3$ MeV

15. ${}^{57}_{27}\text{Co}$ will emit _________ radiation.

(a) β^- (b) β^+

(c) α (d) electron capture

Solution (d) ${}^{57}_{27}\text{Co}$ decays to ${}^{57}_{26}\text{Fe}$. The mass ${}^{57}_{26}\text{Fe}$ is 0.000897υ less than ${}^{57}_{27}\text{Co}$ makes it suitable for electron capture.

16. ^{57}Co decays by electron capture. Its half life is 272 days. Find the activity left after a year if present activity is 2 μ Ci.

(a) 0.788 μ Ci (b) 0.431 μ Ci

(c) 0.39 μ Ci (d) none of these

Solution (a) $\lambda = \frac{0.693}{t_{1/2}} = 2.95 \times 10^{-8} s^{-1}$

$$N_o = \frac{-dN/dt}{\lambda} = \frac{7.4 \times 10^4}{2.95 \times 10^{-8}} = 2.51 \times 10^{12} \text{ nuclei.}$$

$N_{(t)} = N_o e^{-\lambda t} = 2.51 \times 10^{12}\ e^{-2.95 \times 10^{-8} \times 3.156 \times 10^7}$

$= 0.394\,(2.51 \times 10^{12})$.

Activity = $\lambda N(t) = .394\,(2.5 \times 10^{12}) \times 2.95 \times 10^{-8} = 0.788$ μCi

Alternative method $\frac{dN(t)}{dt} = \frac{dN(o)}{dt} e^{-\lambda t}$

$= (2\,\mu\text{Ci})\,(e^{-2.95 \times 10^{-8} \times 3.156 \times 10^7})$

$= 2\,(.394) = 0.788\,\mu$Ci.

17. During a diagnostic X-ray examination a 1.2 kg portion of the broken leg receives an equivalent dose of 0.4 m Sv. Find the absorbed dose in m Gy and number of X-ray photons received if energy of X-ray is 50 KeV.

(a) 0.4 m Gy, 3×10^{15} (b) 0.32 m Gy, 3×10^{10}

(c) 0.4 m Gy, 6×10^{10} (d) 0.32 m Gy, 3×10^{15}

Solution (c) X-ray RBE = 1 $\therefore$ absorbed dose = $\frac{0.4 mSv}{1 Sv/Gy}$

$D = 0.4\,m\,Gy$.

Total energy absorbed = $0.4 \times 10^{-3} \times 1.2$

$= 4.8 \times 10^{-4}$ J $= 3 \times 10^{15}$ eV

Number of photons of X-ray absorbed

$$= \frac{3 \times 10^{15}}{50 \times 10^3} = 6 \times 10^{10}.$$

18. When ${}^{7}_{3}\text{Li}$ ($M_{Li} = 7.016004\ u$) is bombarded by a proton two α-particles result $(MHe = 4.002603u)$. Find the reaction energy.

(a) 13.35 MeV (b) 14.85 MeV

(c) 16.08 MeV (d) 17.35 MeV

Solution (d) Q = [7.016004 + 1.007825 − 2 (4.002603)] × 931.5

= .018623 × 931.5 = 17.35 MeV

19. What mass of ${}^{235}_{92}U$ has to undergo fission each day to provide 3000 MsW of power each day.

(a) 3.2 g (b) 320 g

(c) 3.2 kg (d) 32 kg

Solution (c) 1 fission or 235 u gives 200 MeV.

Mass of uranium = $\dfrac{m \times 200 \times 1.6 \times 10^{-13}}{235 \times 1.66 \times 10^{-27}}$

$= 10^6 \times 3000 \times 86400$ or $m = 3.2$ kg

20. A bone fragment found in a cave contains 0.21 times as much $^{14}_{6}C$ as an equal amount of carbon in air when the organism containing bone died. Find the approximate age of fragment $t_{1/2}$ of ^{14}C = 5730 years.

(a) $1.15 \times 10^4\, y$ (b) $1.3 \times 10^4\, y$
(c) $1.24 \times 10^4\, y$ (d) $1.4 \times 10^4\, y$

Solution (b) $\lambda = \dfrac{0.693}{t_{1/2}} = \dfrac{0.693}{5730} = 1.209 \times 10^{-4}\, y^{-1}$

$\dfrac{N}{N_o} = e^{-\lambda t} = 0.21$ or $t = \dfrac{2.303 \log \dfrac{1}{0.21}}{\lambda}$

$t = \dfrac{2.303(.6794)}{1.209 \times 10^{-4}} = \dfrac{1.564 \times 10^4}{1.2} = 1.3 \times 10^4\, y.$

21. Two Nucleons are at a separation of 1 fermi. Proton have a charge 1.6×10^{-19} C, the nuclear force between them is F_1 both are neutrons, F_2 if both are protons, F_3 if one neutron and one proton then

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

Solution (b) nuclear force is independent of charge.

22. In which of the following decays atomic number increases.

(a) α (b) β^+
(c) β^- (d) γ

Solution (c) $^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e + \overline{\nu}$

23. As the mass number A varies which of the quantity related to nucleus does not change

(a) mass. (b) volume.
(c) binding energy. (d) density.

Solution (d)

24. For the nuclie with mass number > 100

(a) binding energy of the nucleus decreases on an average as A increases.
(b) binding energy of the nucleus increases on an average as A increases.
(c) The two nuclei fuse to form a bigger nuclide releasing energy.
(d) The nucleus essentially breaks up into two nuclides of equal mass releasing energy.

Solution (a) See Binding Energy Curve.

25. The half life of ^{226}Ra is 1602 year. Calculate the activity of 0.1 g of $Ra\,Cl_2$ assuming all the Ra atoms are ^{226}Ra and mass of Cl atom is 35.5 g/mol.

(a) 1.8×10^8 dps (b) 2.8×10^8 dps
(c) 1.8×10^9 dps (d) 2.8×10^9 dps

Solution (d) Number of ^{226}Ra atoms present

$= \dfrac{.1}{297} \times 6.02 \times 10^{23}.$

Activity $= \lambda N = \dfrac{.693}{.602 \times 3.156 \times 10^7} \times \dfrac{1}{297}\, 6.02 \times 10^{22}$

$= 2.8 \times 10^9$ dps

TYPICAL PROBLEMS

26. A radioactive sample decays in two modes. In one mode its half life is t_1 and in the other mode its half life is t_2. Find the overall half life

(a) $t_1 + t_2$ (b) $\dfrac{t_1 + t_2}{2}$
(c) $\dfrac{t_1 t_2}{t_1 + t_2}$ (d) $\dfrac{t_1 t_2}{t_1 - t_2}$

Solution (c) $\lambda_{eff} = \lambda_1 + \lambda_2$ or $\dfrac{1}{t_{eff}} = \dfrac{1}{t_1} + \dfrac{1}{t_2}$.

27. Consider $^{25}_{13}Al \rightarrow {}^{25}_{12}Mg + {}^{0}_{+1}e + \nu$

$m_{AL} = 24.990423\, u$; $m_{Mg} = 24.485839\, u$. Find the Q value of reaction.

(a) 3.3 MeV (b) 1.3 MeV
(c) 2.3 MeV (d) 5.3 MeV

Solution (a) $Q = \left[24.990432u - 24.985839u - 2m_e\right] c^2$

$= .004593\,(931.5) - 1.102 = 3.3$ MeV

28. A vessel of 125 cc contains $^{3}_{1}H$ $(t_{1/2} = 12.3y)$ at 500 kPa and 300 K. Find the activity of the gas.

(a) .754 Ci (b) 7.24 Ci
(c) 72.4 Ci (d) 724 Ci

Solution (d) $PV = n\,RT$ or number of moles $n = \dfrac{PV}{RT}$

$$n = \frac{500\times10^{3}\times125\times10^{-6}}{8.31\times300} = 25\times10^{-3}$$

$$\text{Activity } A = \lambda N = \frac{0.693\times25\times10^{-3}\times6.02\times10^{23}}{12.3\times3.156\times10^{7}\times3.7\times10^{10}} = 724$$

29. Consider fusion of He plasma. At what temperature fusion at a distance 2 fm is possible?

(a) $2.23\times10^{9}\,K$ (b) $22.3\times10^{9}\,K$

(c) $2.23\times10^{8}\,K$ (d) none of these

Solution (b) $\frac{3}{2}kT = \frac{(2e)^2}{4\pi\varepsilon_o r}$

$$\Rightarrow T = \frac{8\times(1.6\times10^{-19})^2\times9\times10^{9}}{3\times1.38\times10^{-23}\times2\times10^{-15}}$$

$$= 2.23\times10^{10}\,K$$

30. Calculate the energy which can be obtained from 1 kg of H_2O through the fusion reaction ${}_{1}^{2}H + {}_{1}^{2}H \rightarrow {}_{1}^{3}H + p$ Assume 1.5×10^{-2} % of the water contains deuterium. The whole deuterium is consumed in the fusion reaction.

(a) 2820 J (b) 2820×10^{4} J

(c) 2820×10^{6} J (d) 2820×10^{8} J

Solution (c) $D_2O = 1\times1.5\times10^{-4}\text{ kg} = 0.15\text{ g}$

$$\text{Number of } {}_{1}^{2}H = \frac{0.15\times6.023\times10^{23}}{20} = 4.5\times10^{21}$$

$Q = (2\times2.014102 - 3.016049 - 1.008)\,931.5\times4.5\times10^{21}\times1.6\times10^{-13}$ J

$= 0.004155\times931.5\times7.2\times10^{8} = 2820$ M J

31. A human body excretes certain material by a law similar to radioactivity. The body excretes half the amount injected in 24 h. Find the time in which activity falls to 3 μCi. If a person is injected technitium ($t_{1/2} = 6h$) and its activity just after the injection is 6 μCi.

(a) 4.8 h (b) 6 h

(c) 6.3 h (d) none of these

Solution (a) $\frac{1}{t} = \frac{1}{t_1} + \frac{1}{t_2}$ or

$$t = \frac{t_1 t_2}{t_1+t_2} = \frac{24\times6}{24+6} = 4.8\,h$$

PASSAGE 1

Read the following passage and answer the questions given at the end.

If two deuterium nuclei get close enough together, the attraction of the strong nuclear force will fuse them to make an isotope of helium. The process will release a vast amount of energy. The range of nuclear force is 10^{-15} m. This is the principle behind the nuclear fusion reactor. The deuterium nuclei move much too fast to contain them by physical walls. Hence, they are confined magnetically.

1. How fast two nuclei shall come to have a head on collision to fuse?

(a) 1.2×10^{6} ms^{-1} (b) 1.2×10^{7} ms^{-1}

(c) 3.8×10^{6} ms^{-1} (d) 8.72×10^{6} ms^{-1}

2. What is the strength of magnetic field required to make deuterium nuclei with this speed in a circle of diameter 2.5 m.

(a) 0.2 T (b) 0.29 T

(c) 0.33 T (d) 0.16 T

Solution **1.** (b) $r = \frac{q_1q_2}{4\pi\varepsilon_0(KE)}$

$$v^2 = \frac{2q_1q_2}{4\pi\varepsilon_0 mr}$$

$$v^2 = \frac{1.6\times10^{-19}\times1.6\times10^{-19}\times9\times10^{9}\times2}{10^{-15}\times2\times1.67\times10^{-27}}$$

$$v = 12\times10^{6}\text{ ms}^{-1}$$

Solution **2.** (a) $R = \frac{mv}{eB}$

or $$B = \frac{2\times1.67\times10^{-27}\times1.2\times10^{7}}{1.6\times10^{-19}\times1.25} = 0.2\,T$$

PASSAGE 2

Read the following passage and answer the questions given at the end.

While visiting Santa Barbara county fair, you decide to impress your date by winning a stuffed animal at the magnetic shooting gallery. The object of the game is to hit a target with a light weight (250 g) electrically charged particle. The particle has charge + 0.64 C. The particle is fired horizontally from an air rifle with a muzzle speed of 14 ms^{1}. The centre of the target is at the same height as the Muzzle of the rifle. What makes the game challenging is that there exists a uniform downward magnetic field of 0.5 T at all points in the shooting gallery. Quickly sizing up the situation you quickly calculate that if there is a particular strength of uniform electric field and direction, you could hit the target. The gallery operator is so impressed with your correct calculation of electric field that he gives you the biggest stuffed animal without you having to fire a shot.

1. What should be the magnitude and direction of electric field?

(a) 7 Nc^{-1}, Vertically up $\perp$ to velocity.

(b) 7 Nc^{-1}, horizontally and $\perp$ to velocity.

(c) 14 Nc^{-1}, horizontally parallel to velocity.

(d) none of these.

2. What effect did you ignore in your calculation?

(a) effect of gravity. (b) effect of magnetic force.

(c) effect of electric force. (d) KE of the particle.

3. Which of the sketch fits the situation?

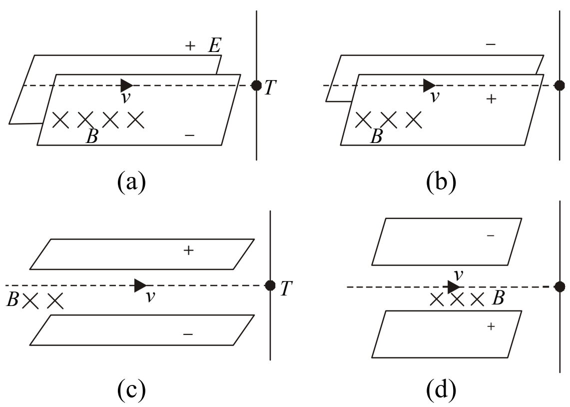


Fig. 35.11

Solution **1.** (b) $v = \frac{E}{B}$ or $E = vB = 14\,(.5) = 7\text{ NC}^{-1}$

Solution **2.** (a)

Solution **3.** (a)

PASSAGE 3

Read the following passage and answer the questions given at the end.

A particle of mass m moves in a potential $U(x) = A|x|$, where A is a positive constant. In a simplified picture quarks (the constituents of protons, neutrons and other particles) have a potential energy of interaction of approximately this form, where x represents the separation between a pair of quarks. because $U(x) \to \infty$ as $x \to \infty$. It is not possible to separate quarks from each other. This phenomenon is called quark confinement.

1. What is the force acting on the particle classically?

(a) A (b) $-A$

(c) $\frac{A|x|}{x}$ (d) $\frac{-A|x|}{x}$

2. Using uncertainty principle determine the zero point energy of the particle.

(a) $\frac{3}{2}\left(\frac{h^2A^2}{m}\right)^{1/3}$ (b) $\frac{2}{3}\,(h^2 A\, m)^{1/3}$

(c) $\frac{3}{2}\left(\frac{hA^2}{m}\right)^{1/3}$ (d) $\frac{2}{3}\left(\frac{h^2A}{m}\right)^{1/3}$

Solution **1.** (d) $F = \frac{-dU(x)}{dx} = \frac{-A|x|}{x}$

Solution **2.** (a) $E = \frac{p^2}{2m} + A|x|,\ p.x = \text{h}$

$$p = \frac{\hbar}{x}$$

$$E = \frac{\hbar^2}{x^2 2m}x^{-3} + A = |x|$$

$$\frac{dE}{dx} = \frac{2\hbar^2}{2m}x^{-3} + A = 0$$

or $$x = \left(\frac{-\hbar^2}{mA}\right)^{1/3}$$

$$E_{\min} = \frac{\hbar^2}{2m\left(\frac{-\hbar^2}{mA}\right)^{2/3}} + A\left(\frac{\hbar^2}{mA}\right)^{1/3}$$

$$= \frac{-3}{2}\left(\frac{\hbar^2A^2}{m}\right)^{1/3}$$

PASSAGE 4

Read the following passage and answer the questions given at the end.

The neutral pion π is an unstable particle produced in high energy particle collisions. Its mass is about 264 times the mass of electron. Note that its average life time is 8.4×10^{-17} s before decaying into two gamma ray photons. Using the energy mass relationship between rest mass and energy, one can find uncertainty in the mass.

1. Find the uncertainty in mass.

(a) 1.4×10^{-35} kg (b) 2.16×10^{-11} kg

(c) 2.16×10^{-13} kg (d) 8×10^{-14} kg

(e) none

2. Find the fraction of the mass.

(a) $5.8 \times 10^{-6}\ m_{pion}$ (b) $5.8 \times 10^{-7}\ m_{pion}$

(c) $5.8 \times 10^{-8}\ m_{pion}$ (d) $5.8 \times 10^{-9}\ m_{pion}$

Solution **1.** (a) $\Delta E.\Delta t$ □ $\hbar$

$$\Delta E = \frac{h}{\Delta t} = \frac{6.62\times10^{-34}}{2\pi\times8.4\times10^{-17}} = 1.24\times10^{-18}$$

$$\Delta mc^2 = \Delta E \text{ or } \Delta m = \frac{1.24\times10^{-18}}{9\times10^{16}}$$

$$= 1.38\times10^{-35}\text{ kg}$$

Solution **2.** (c) $\frac{\Delta m}{m} = \frac{1.38\times10^{-35}}{264\times9\times10^{-31}} = 5.8\times10^{-8}$

PASSAGE 5

Read the following passage and answer the questions given at the end.

In the 1986 disaster at the Chernobyl reactor in the soviet union (now Ukraine) about $\frac{1}{8}$ of ^{137}Cs present in the reactor was released. The isotope ^{137}Cs has a half life for β decay 30.07 years and decays with the emission of 1.17 MeV of energy per decay. Of this 0.51 MeV goes to emitted electron and the remaining 0.66 MeV to a γ-ray. The radio active ^{137}Cs is absorbed by plants which are eaten by livestock and humans.

1. How many ^{137}Cs need to be present in each kg of body tissue if an equivalent dose for one week is 3.55 Sv?

(a) 1.25×10^{-9} (b) 1.25×10^{11}

(c) 1.25×10^{13} (d) none

2. If the whole energy from the decay is deposited in 1 kg of tissue and that the RBE of the electrons is 1.5. What is the energy stored?

(a) 2.33 J (b) 3.5 J

(c) 5.25 J (d) none of these

Solution **1.** (d) 3.5 Sv = RBE × absorbed dose (Gy)

absorbed dose $= \frac{3.5}{1.5}\ Gy = 2.33\ J/\text{kg}$

number of ^{137}Cs atoms present

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

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

$$N = \frac{2.33}{1.17\times1.6\times10^{-13}}$$

$$= \frac{2.33\times10^{13}}{1.17\times1.6} = 1.25\times10^{13}$$

Solution **2.** (a)

PASSAGE 6

Read the following passage and answer the questions given at the end.

In an experiment, the isotope ^{128}I is created by the irradiation of ^{127}I with nuclear activation technique, i.e., a beam of neutron is bombarded that creates 1.5×10^6 ^{128}I nuclei per second. Initially no ^{128}I nuclei are present. The half life of ^{128}I is 25 minutes

1. The activity present after 50 minutes.

(a) 4.1×10^4 Bq (b) 3.6×10^5 Bq

(c) 7.5×10^5 Bq (d) 1.4×10^6 Bq

(e) none

2. What is steady state number of I after a long time?

(a) 3.2×10^9 (b) 1.5×10^8

(c) 2.3×10^9 (d) none

3. The maximum activity that can be produced reduce is

(a) 1.5×10^8 Bq (b) 1.5×10^6 Bq

(c) 1.5×10^4 Bq (d) 1.5×10^5 Bq

Solution **1.** (d) $\lambda(N_0 - N) = \lambda N_0(1 - e^{-\lambda t})$

$$= \frac{.693\times45\times10^9}{25\times60}(1-.26) = 1.4\times10^6$$

Solution **2.** (a) $\frac{dN}{dt} = N\lambda \qquad N = \frac{dN/dt}{\lambda}$

$$N = \frac{1.5\times10^6\times1500}{.693} = 3.2\times10^9$$

Solution **3.** (b)

QUESTIONS FOR PRACTICE

1. As the mass number A increases, the binding energy per nucleon in a nucleus

(a) increases. (b) decreases.

(c) remains the same.

(d) varies in a way that depends on the actual value of A.

2. Which of the following is a wrong description of binding energy of a nucleus ?

(a) It is the energy required to break a nucleus into its constituent nucleons.

(b) It is the energy made available when free nucleons combine to form a nucleus.

(c) It is the sum of the rest mass energies of its nucleons minus the rest mass energy of the nucleus.

(d) It is the sum of the kinetic energy of all the nucleons in the nucleus.

3. In one average-life,

(a) half the active nuclei decay.

(b) less than half the active nuclei decay.

(c) more than half the active nuclei decay.

(d) all the nuclei decay.

4. In a radioactive decay, neither the atomic number nor the mass number changes. Which of the following particles is emitted in the decay ?

(a) proton. (b) neutron.

(c) electron. (d) photon.

5. During a negative beta decay,

(a) an atomic electron is ejected.

(b) an electron which is already present within the nucleus is ejected.

(c) a neutron in the nucleus decays emitting an electron.

(d) a proton in the nucleus decays emitting an electron.

6. A freshly prepared radioactive source of half-life 2 *h* emits radiation of intensity which is 64 times the permissible safe level. The minimum time after which it would be possible to work safely with this source is

(a) 6 *h*. (b) 12 *h*.

(c) 24 *h*. (d) 128 *h*.

7. The decay constant of a radioactive sample is λ. The half-life and the average-life of the sample are respectively

(a) $\frac{1}{\lambda}$ and $\left(\frac{\log_e^2}{\lambda}\right)$ (b) $\left(\frac{\log_e^2}{\lambda}\right)$ and $\frac{1}{\lambda}$

(c) $\lambda(\log_e^2)$ and $\frac{1}{\lambda}$ (d) $\frac{\lambda}{\log_e^2}$ and $\frac{1}{\lambda}$.

8. Consider a sample of a pure beta-active material.

(a) All the beta particles emitted have the same energy.

(b) The beta particles originally exist inside the nucleus and are ejected at the time of beta decay.

(c) The antineutrino emitted in a beta decay has zero mass and hence, zero momentum.

(d) The active nucleus changes to one of its isobars after the beta decay.

9. In which of the following decays the atomic number decreases ?

(a) α-decay (b) β^+-decay

(c) β^--decay (d) γ-decay.

10. Free ^{238}U nuclei kept in a train emit alpha particles. When the train is stationary and a uranium nucleus decays, a passenger measures that the seperation between the alpha particle and the recoiling nucleus becomes *x,* time *t* after the decay. If a decay takes place when the train is moving at a uniform speed υ, the distance between the alpha particle and the recoiling nucleus at a time *t* after the decay, as measured by the passenger will be

(a) $x+\upsilon t$ (b) $x-\upsilon t$

(c) x

(d) depends on the directions of the train.

11. During a nuclear fission reaction

(a) a heavy nucleus breaks into two fragments by itself.

(b) a light nucleus bombarded by thermal neutrons breaks up.

(c) a heavy nucleus bombarded by thermal neutrons breaks up.

(d) two light nuclei combine to give a heavier nucleus and possibly other products.

12. The heavier nuclei tend to have larger *N*/*Z* ratio because

(a) a neutron is heavier than a proton.

(b) a neutron is an unstable particle.

(c) a neutron does not exert electric repulsion.

(d) coulomb forces have longer range compared to the nuclear forces.

13. A free neutron decays to a proton but a free proton does not decay to a neutron. This is because

(a) neutron is a composite particle made of a proton and an electron whereas proton is a fundamental particle.

(b) neutron is an uncharged particle whereas proton is a charged particle.

(c) neutron has larger rest mass than the proton.

(d) weak forces can operate in a neutron but not in a proton.

14. As the mass number *A* increases, which of the following quantities related to a nucleus do not change?

(a) mass. (b) volume.

(c) density. (d) binding energy.

15. In which of the following decays the element reduce does not change ?

(a) α-decay (b) β^+-decay

(c) β^--decay (d) γ-decay.

16. Two lithium nuclei in a lithium vapour at room temperature do not combine to form a carbon nucleus because

(a) a lithium nucleus is more tightly bound than a carbon nucleus.

(b) carbon nucleus is unstable particle.

(c) it is not energetically favourable.

(d) coulomb repulsion does not allow the nuclei to come very close.

17. Magnetic field does not cause deflection in

(a) α-rays. (b) beta-plus rays.

(c) beta-minus rays. (d) gamma rays.

18. An α-particle is bombarded on ^{14}N. As a result, a ^{17}O nucleus is formed and a particle is emitted. This particle is a

(a) neutron. (b) proton.

(c) electron. (d) positron.

19. Ten grams of ^{57}Co kept in an open container beta-decays with a half-life of 270 days. The weight of the material inside the container after 540 days will be very nearly

(a) 10 g. (b) 5 g.

(c) 2.5 g. (d) 1.25 g.

20. Which of the following are electromagnetic waves ?

(a) α-rays. (b) beta-plus rays.

(c) beta-minus rays. (d) gamma rays.

21. When a nucleus with atomic number Z and mass number A undergoes a radioactive decay process,

(a) both Z and A will decrease, if the process is α^- decay.

(b) Z will decrease but A will not change, if the process is β^+ decay.

(c) Z will increase but A will not change, if the process is β^- decay.

(d) Z and A will remain unchanged, if the process is γ decay.

22. Which of the following assertions are correct ?

(a) A neutron can decay to a proton only inside a nucleus.

(b) A proton can change to a neutron only inside a nucleus.

(c) An isolated neutron can change into a proton.

(d) An isolated proton can change into a neutron.

23. Before 1900 the activity per mass of atmospheric carbon due to the presence of 14C averaged about 0.255 Bq per gram of C 14C.?

(a) 1 ^{14}C in every 10^{14} ^{12}C.

(b) 3 ^{14}C in every 10^{12} ^{12}C.

(c) 4 ^{14}C in every 10^{10} ^{12}C.

(d) 2 ^{14}C in every 10^{11} ^{12}C.

24. The fusion of two nuclider will require a temp of the order of

(a) 10^6 K (b) 10^7 K

(c) 10^8 K (d) 10^9 K

25. If F_{NN}, F_{NP}, F_{PP} denotes net force between neutron and neutron, neutron and proton, proton and proton them

(a) $F_{NN} = F_{NP} = F_{PP}$ (b) $F_{NN} = F_{NP} > F_{PP}$

(c) $F_{NN} = F_{NP} < F_{PP}$ (d) $F_{NN} > F_{NP} > F_{PP}$

26. $^{221}_{87}Ra$ under goes radioactive decay with $t_{1/2} = 4$ days. What is the probability that a neucleus under goes a decay in two half lives (8 days)? IIT 2006

(a) 1 (b) 1/2

(c) 3/4 (d) 1/4

27. Match the following

(a) Nuclear fusion	(P) Converts some matter in to energy
(b) Nuclear fission	(Q) For atoms with high atomic number
(c) β -decay	(R) For atoms with low atomic number
(d) Exothermic nuclear reaction	(S) Weak nuclear force

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28. A γ -ray of energy 1900 MeV is absorbed by

(a) electron - positron pair

(b) photo electric effect

(c) proton-antiproton pair

(d) producing heat in the substance

29. $^2_1H + ^9_4Be \rightarrow X + ^4_2He$ Identify X.

(a) ^7_3Li (b) ^6_3Li

(c) ^7_4Be (d) $2\,^3_2He$

30. A nuclide A undergoes α decay and another nuclide B undergoes β^- decay.

(a) All the α-particles emitted by A will have almost the same speed.

(b) The α-particles emitted by A may have widely different speeds.

(c) All the β-particles emitted by B will have almost the same speed.

(d) The β-particles emitted by B may have widely different speeds.

31. Two identical nuclei A and B of the same radioactive element undergo β decay. A emits a β-particle and changes to A'. B emits a β-particle and then a γ-ray photon immediately afterwards, and changes to B'.

(a) A' and B' have the same atomic number and mass number.

(b) A' and B' have the same atomic number but different mass numbers.

(c) A' and B' have different atomic number but the same mass number.

(d) A' and B' are isotopes.

32. When the nucleus of an electrically neutral atom undergoes a radioactive decay process, it will remain neutral after the decay if the process is

(a) an α decay. (b) a β^- decay.

(c) a γ decay. (d) a K-capture process.

33. A and B are isotopes. B and C are isobars. All three are radioactive.

(a) A, B and C must belong to the same element.

(b) A, B and C may belong to the same element.

(c) It is possible that A will change to B through a radio-active-decay process.

(d) It is possible that B will change to C through a radio-active-decay process.

34. The decay constant of a radioactive sample is λ. Its half-life is $T_{1/2}$ and mean life is T.

(a) $T_{1/2} = \dfrac{1}{\lambda},\ T = \dfrac{\text{In } 2}{\lambda}$ (b) $T_{1/2} = \dfrac{\text{In } 2}{\lambda},\ T = \dfrac{1}{\lambda}$

(c) $T_{1/2} = \lambda \text{ In } 2,\ T = \dfrac{1}{\lambda}$ (d) $T_{1/2} = \dfrac{\lambda}{\text{In } 2},\ T = \dfrac{\text{In } 2}{\lambda}$.

35. The count rate from 100 cm^3 of a radioactive liquid is c. Some of this liquid is now discarded. The count rate of the remaining liquid is found to be $c/10$ after three half-lives. The volume of the remaining liquid, in cm^3, is

(a) 20 (b) 40

(c) 60 (d) 80

36. The value of A in the following reaction is

$_4Be^9 + {}_2He^4 = {}_6C^A + {}_0n^1$

(a) 14 (b) 10

(c) 12 (d) 16

37. In the fusion process there are

(a) isotopes of hydrogen. (b) isotopes of helium.

(c) isotopes of carbon. (d) isotopes.

38. For fast chain reaction, the size of U^{235} block, as compared to its critical size, must be

(a) greater. (b) smaller.

(c) same. (d) anything.

39. One of the characteristics of nuclear reactions is that in their decayed or fused parts

(a) total mass number keeps on changing.

(b) total charge number keeps on changing.

(c) total charge number remains constant.

(d) all of the above.

40. Out of atom bomb and hydrogen bomb of same capacity which one is more harmful?

(a) atom bomb.

(b) hydrogen bomb.

(c) sometimes atom bomb sometimes hydrogen bomb.

(d) nothing can be said.

41. When beryllium is bombarded by á-particles, then we obtain

(a) electron. (b) proton.

(c) positron. (d) neutron.

42. The fissionable material used in a breeder reactor is—

(a) $_{92}U^{235}$ (b) $_{94}Pu^{239}$

(c) $_{90}Th^{234}$ (d) $_6C^{12}$

43. Hydrogen bomb is based on

(a) controlled chain reaction.

(b) uncontrolled chain reaction.

(c) nuclear fusion. (d) nuclear fission.

44. Atomic reactor is based on

(a) controlled chain reaction.

(b) uncontrolled chain reaction.

(c) nuclear fission. (d) nuclear fusion.

45. The ratio of the volume of atom to volume of nucleus is

(a) 10^5 (b) 10

(c) 10^{15} (d) 10^{10}

46. The fission of U^{238} is possible by

(a) only fast neutrons.

(b) only slow neutrons.

(c) fast as well as slow neutrons.

(d) fast protons.

47. The first atomic reactor was made by

(a) Fermi. (b) Bohr.

(c) Taylor. (d) Rutherford.

48. When the number of nucleons in the nucleus increased then the binding energy per nucleon

(a) decreases continuously with A.

(b) increases continuously with A.

(c) remains constant with A.

(d) first increases with A and then decreases.

49. The necessary condition for nuclear fusion is

(a) high temperature and high pressure.

(b) low temperature and low pressure.

(c) high temperature and low pressure.

(d) low temperature and high pressure.

50. In stable nuclei the number of protons (Z) and number of neutrons (N) are related as

(a) $N > Z$. (b) $N < Z$.

(c) $N = Z$. (d) $N = Z = 0$.

51. Which of the following is the best nuclear fuel ?

(a) U^{236} (b) Pu^{239}

(c) Np^{239} (d) Th^{236}

52. The critical mass of fissionable material is

(a) 75 Kg (b) 1 Kg

(c) 20 Kg (d) 10 Kg

53. The energy of neutrons obtained during fission is approximately

(a) 2KeV (b) 4GeV

(c) 1MeV (d) Zero

54. The energy emitted per second by sun is approximately

(a) 3.8×10^{26} Joule. (b) 3.8×10^{14} Joule.

(c) 3.8×10^{12} Joule. (d) 3.8×10^{-26} Joule.

55. $_{92}U^{235} + {_0n_1} = {_{54}Xe^{139}} + ...Y + {_{20}n^1}$ Here Y is

(a) $_{38}Sr^{95}$ (b) $_{38}Si^{95}$

(c) $_{38}Ge^{95}$ (d) $_{38}Ni^{95}$

56. The energy released in the explosion of atom bomb is mainly due to

(a) nuclear fission. (b) nuclear fusion.

(c) chemical reaction.

(d) radioactive distintegratrion.

57. The difference between the atom U^{235} and U^{238} is that

(a) U^{238} contains 3 neutrons more.

(b) U^{238} contains 3 neutrons and 3 electrons more.

(c) U^{238} contains 3 protons more.

(d) U^{238} contains 3 proton and 3 electron more.

58. The mass number (A) of a nucleus as compared to its charge number (Z) is

(a) always greater. (b) always less.

(c) some times equal.

(d) sometimes equal and sometimes more.

59. The fissionable materials used in the bomb dropped on the city Nagasaki of Japan in 1945 was

(a) *Pu.* (b) *U.*

(c) *Th.* (d) *Np.*

60. The energy equivalent to 1kg of matter is (in Joule)

(a) $10^{17.}$ (b) $10^{20.}$

(c) $10^{11.}$ (d) $10^{14.}$

61. 1 a.m.u. is equivalent to

(a) 931MeV. (b) 139MeV.

(c) 93MeV. (d) 39MeV.

62. The binding energy of a nucleus is equivalent to

(a) the mass of nucleus. (b) the mass of proton.

(c) the mass of neutron.

(d) the mass defect of nucleus.

63. The atomic weight of uranium isotope, which is easily fissionable, is

(a) 235. (b) 238.

(c) 234. (d) 236.

64. The critical mass of U^{235} can be reduced by

(a) putting a neutron reflector around it.

(b) heating it.

(c) mixing impurity in it.

(d) putting neutron absorber around it.

65. The fusion process is possible at high temperatures because at high temperatures

(a) the nucleus disintegraes.

(b) molecules disintegrate.

(c) atoms become ionised.

(d) the nuclei get sufficient energy so as to overcome the Coulomb repulsive force.

66. For making atom bomb, what else is needed except U^{235}?

(a) neutron. (b) proton.

(c) electron. (c) meson.

67. The mass defect for helium nucleus is 0.0304 a.m.u. The binding energy per nucleon of helium nucleus is—

(a) 28.3 MeV (b) 7.075 MeV

(c) 9.31 MeV (d) 200 MeV

68. The most suitable material for moderator in a nuclear reactor is

(a) D_2O (b) *Cd*

(c) *B* (d) $_{92}U^{235}$

69. Which of the following reactions is impossible?

(a) $_2He^4 + {_4Be^9} = {_0n^1} + {_6c^{12}}$

(b) $_2He^4 + {_7N^{14}} = {_1H^1} + {_8O^{17}}$

(c) $4({_1H^1}) = {_2He^4} + 2({_{-1}e^0})$

(d) $_3Li^7 + {_1H^1} = {_4Be^8}$

70. In nuclear reactor which of the following quantities is conserved ?

(a) only energy. (b) only mass.

(c) only momentum.

(d) mass, energy and momentum.

71. For maintaining sustained chain reaction, the following is required

(a) protons. (b) electron.

(c) neutrons. (d) positrons.

72. Two deutrons fuse to form a helium nucleus and energy is released, because the mass of helium nucleus is

(a) equal to that of two deutrons.

(b) less than that of two deutrons.

(c) more than that of two deutrons.

(d) all of the above.

73. The energy of thermal neutrons is nearly

(a) 0.25eV. (b) 0.025eV.

(c) 200MeV. (d) 0.025 Joule.

74. The correct relation between the packing fraction P and mass number A is

(a) $P = \frac{M - A}{A}$ (b) $P = \frac{M + A}{A}$

(c) $P = \frac{A}{M - A}$ (d) $P = \frac{A}{M + A}$

75. The curve between binding energy per nucleon (E) and mass number A is

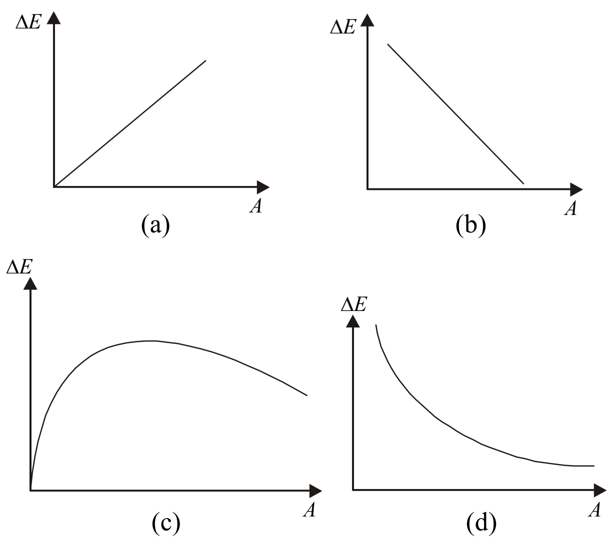

Fig. 35.12

76. Sun maintains its shining because of

(a) the fission of helium.

(b) chemical reaction.

(c) fusion of hydrogen nuclei.

(d) burning of carbon.

77. Critical mass is minimum mass necessary for

(a) chain reaction (b) fusion

(c) hydrogen bomb (d) all of the above

78. The ratio r of the rate of production of neutrons from uranium nucleus to the rate of leakage of neutrons for sustained chain reaction is

(a) $r > 1$ (b) $1 > r$

(d) $1 > r^2$ (c) $r^2 = 1$

79. The temperature necessary for fusion reactions is

(a) $3 \times 10^3 K$ (b) $3 \times 10^6 K$

(c) $3 \times 10^2 K$ (d) $3 \times 10^4 K$

80. Which of the following is a neutron absorber ?

(a) Pb (b) Ag

(c) Cd (d) Cu

81. A neutron decays to

(a) one p, one v one β^{+}.

(b) one β^+, one β^- and v.

(c) one p, one β^- and one $\overline{u}$.

(d) all of the above.

82. The nucleus ${}_{48}Cd^{115}$, after the emission two successive negative β-particles, changes to

(a) ${}_{49}Sn^{114}$. (b) ${}_{50}Sn^{113}$.

(c) ${}_{46}Pa^{115}$. (d) ${}_{50}Sn^{115}$.

83. The particle which is deflected by an electric field is

(a) α-particle. (b) neutron.

(c) x rays. (d) γ rays.

84. The maximum frequency is of

(a) blue light. (b) γ-rays.

(c) ultraviolet rays. (d) infra red rays.

85. The half life of a radioactive substance, as compared to its mean life, is

(a) 30% (b) 60%

(c) 70% (d) 100%

86. The nucleus ${}_{92}X^{234}$ emits 3α-particle and then one β-particle. The end product will be

(a) ${}_{84}Y^{222}$ (b) ${}_{87}Y^{228}$

(c) ${}_{84}Y^{228}$ (d) ${}_{87}Y^{222}$

87. The half life of radium is 1600 years. The fraction of radium atoms that remain undecayed after 4800 years will be

(a) $\frac{1}{4}$ (b) $\frac{1}{16}$

(c) $\frac{1}{8}$ (d) $\frac{1}{8}$

88. The half life of radioactive substance is 6 years. The time taken by 12 gms of this substance to decay completely will be

(a) ∞ (b) 48 years

(c) 18 years (d) 72 years

89. The ionising power is

(a) same in all the three.

(b) maximum in α- particles.

(c) maximum in β-particles.

(d) maximum in γ-rays.

90. The uranium nucleus ${}_{92}U^{238}$ emits an α-particle and resulting nucleus emits one β-particle. The atomic number and mass number of the final nucleus will respectively be

(a) 91,234 (b) 90,234

(c) 91,238 (d) 92,234

91. If the decay constant of radium is 4.28×10^{-4} per year, then its half life will approximately be

(a) 1240 years. (b) 1620 years.

(c) 2000 years. (d) 2260 years.

92. The particle emitted in the nuclear reaction

${}_{Z}X^{A} = {}_{Z+1}Y^{A} +$ .... will be

(a) α particle (b) β^- particle

(c) β^+ particle (d) Photon

93. The fraction of atoms of radioactive element that decays in 6 days is 7/8. The fraction that decays in 10 days will be

(a) $\frac{77}{80}$ (b) $\frac{71}{80}$

(c) $\frac{31}{32}$ (d) $\frac{15}{16}$

94. The two elements, with same number of electrons but different mass number, are known as

(a) isotopes. (b) isomers.

(c) isotones. (d) isobars.

95. The decay constant of a radioactive sample is λ. The values of its half life and mean life will respectively be

(a) $\frac{1}{\lambda}, \log_e 2$. (b) $\frac{\log_e 2}{\lambda}, \frac{1}{\lambda}$.

(c) $\frac{1}{\lambda}, \frac{1}{\lambda^2}$. (d) $\lambda \log_e 2, \frac{1}{\lambda}$.

96. According to Geiger–Nuttal law the curve between $\log \lambda$ and $\log R$ will be

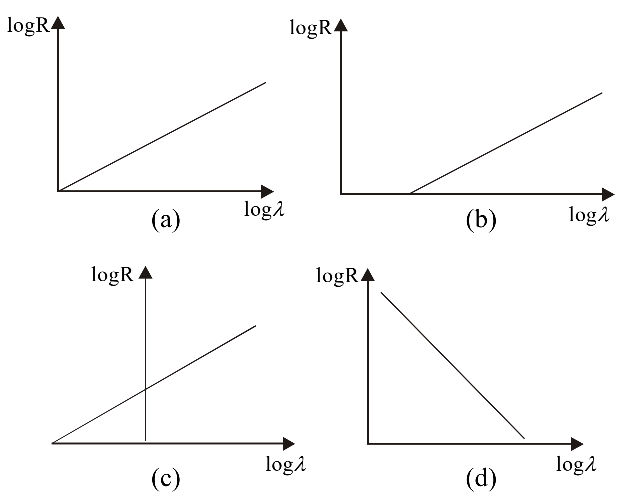

Fig. 35.13

97. The S.I. unit of radioactivity is

(a) Becquerl. (b) Curie.

(c) Rutherford. (d) Roentgen.

98. The activity of a radioactivity substances is

(a) $\frac{\lambda dN}{dt}$ (b) $\frac{dN}{dt}$

(c) $\frac{Nd\lambda}{dt}$ (d) $\frac{1}{\lambda}\frac{dN}{dt}$

99. The nucleus obtained after α-emission from the nucleus ${}_{y}A^{x}$ is

(a) ${}_{y-2}B^{x-2}$ (b) ${}_{y+2}B^{x+4}$

(c) ${}_{y}B^{x}$ (d) ${}_{y-2}B^{x-4}$

100. An α-particle and a proton enter a perpendicular uniform magnetic field. The period of revolution of α-particles as compared to that of proton is

(a) 2 (b) 3

(c) 4 (d) 1

101. The particles emitted by a radioactive element are

(a) neutral.

(b) emitted from the nucleus.

(c) elelctromagnetic radiations.

(d) electrons revolving round the nucleus.

102. In majority of radioactive elements, the ratio of the number of neutrons to that of protons

(a) decreases. (b) increases.

(c) remains constant.

(d) sometimes decreases sometimes increases.

103. The mass of α-particle is

(a) $4\,M_p$ (b) $4M_n$

(c) $2\,M_p + 2\,M_n$ (d) $2\,M_c + 2\,M_p$

104. If ${}_5B^{11}$ converts into ${}_6C^{11}$, then the particle emitted in this process will be

(a) electron. (b) proton.

(c) neutron. (d) positron.

105. Carbon dating is

(a) a process to determine the age of archaeological samples.

(b) a medicine for treatment of cancer.

(c) a process to determine the age of a meteorite.

(d) a process of treatment of diseases in animals.

106. If the half life of a radioactive material is 100 days, then its half life after 10 days will become

(a) 50 days. (b) 200 days.

(c) 400 days. (d) 100 days.

107. If 10% of a radioactive substance decays in every 5 years, then the percentage of the substance that will have decayed in 20 years will be

(a) 40%. (b) 50%.

(c) 65.6%. (d) 34.4%.

108. If the half lives of a radioactive element for α and β decay are 4 years and 12 years respectively, then the percentage of the element that remains after 12 years will be

(a) 6.25%. (b) 12.5%.

(c) 25%. (d) 50%.

109. The masses of two radioactive substances are same and their half lives are 1 year and 2 years respectively. The ratio of their activities after six years will be

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

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

110. An atom with mass number A_1 converts into another atom with mass number A_2 after radioactive decay. The correct statement is

(a) A_2 can never be equal to $A_{1.}$

(b) the value of A_1 will be less than $A_{2.}$

(c) the value of A_2 will not be more than that of $A_{1.}$

(d) the value of A_1 will not be more than that of $A_{2.}$

111. If there are N nuclear particles in a nucleus of radius R, then the number of nuclear particles in radius 3R will be

(a) N (b) $2N$

(c) $27N$ (d) $\frac{21}{3}N$

112. The intensity of γ-rays from a source (I_0) reduces to $\frac{I_0}{8}$ after passing through 48 mm thick sheet of lead. The thickness of the sheet for obtaining intensity equal to $\frac{I_0}{2}$ will be

(a) 48 mm (b) 24 mm

(c) 16 mm (d) 8 mm

113. The specific activity of Cobalt-57, whose half life is 270 days, will be

(a) 8478 Curie/gm. (b) 847.8 Curie/gm.

(c) 84.78 Curie/gm. (d) 1 Curie/gm.

114. The mass of radon-222 corresponding to 1 Curie will be, if its half is 3.8 days

(a) 6.46×10^{-8} gm. (b) 64.60×10^{-7} gm.

(c) 6.46×10^{-10} gm. (d) 64.60×10^{-10} gm.

115. The particle X in the following nuclear reaction is

${}_7N^{13} = {}_6C^{13} + {}_1e^0 + X$

(a) P (b) v

(c) e^- (d) P

116. The particle X in the following nuclear reaction is

${}_5B^{10} + {}_2He^4 = {}_7N^{13} + X$

(a) P (b) α

(c) e (d) n

117. The particle X in the following nuclear reaction is

${}_3Li + {}_1H^1 = {}_2He^4 + X$

(a) α (b) n

(c) e (d) p

118. The fraction of a radioactive material which remains active after time t is 9/16. The fraction which remains active after time t/2 will be

(a) $\frac{4}{5}$ (b) $\frac{7}{8}$

(c) $\frac{3}{5}$ (d) $\frac{3}{4}$

119. The half life of a radioactive substance is 34.65 minute If 10^{22} atoms are active at any inslant of time, then it; activity will be

(a) 1×10^{18} disintegrations/sec.

(b) 2×10^{18} disintegrations/sec.

(c) 3.33×10^{18} disintegrations/sec.

(d) 4×10^{18} disintegrations/sec.

120. The half life of Sr is 28 years. The fraction of the specimen that remains undecayed after 40 years will be

(a) 21%. (b) 37%.

(c) 45%. (d) 63%.

121. The weight based ratio of U^{238} and Pb^{226} in a sample of rock is 4 : 3. If the half life of U^{238} is 4.5×10^9 years then the age of rock is

(a) 9.0×10^9 years. (b) 6.3×10^9 years.

(c) 4.5×10^9 years. (d) 3.78×10^9 years.

122. Which of the following reactions is correct ?

(a) There are 78 neutrons in ${}_{78}Pt^{192}$

(b) ${}_{84}Po^{214} \longrightarrow {}_{82}Pb^{210} + \beta$

(c) ${}_{92}U^{238} \longrightarrow {}_{90}Th^{234} + {}_2He^4$

(d) ${}_{90}Th^{234} \longrightarrow {}_{91}Pa^{234} + {}_2He^4$

123. The initial number of atoms of a radioactive element with half life 100 days, is 9.6×10^{20}. The number of atoms remaining undecayed after 500 days, will be

(a) $9.6 \times 10^{20.}$ (b) $3.84 \times 10^{20.}$

(c) $3 \times 10^{20.}$ (d) $19.2 \times 10^{20.}$

124. Initially 480 α-particles per minute are being emitted by a radioactive substance. This number reduces to 240 after 2 hours, The number of α-particles being emitted per minute after next 4 hour will be

(a) 0 (b) 60

(c) 80 (d) 120

125. The fraction of Cs^{137} atoms decaying in one year is 1/27 Its mean life will be

(a) 27 years. (b) 18.2 years.

(c) 13.5 years. (d) 0.037 years.

126. The mass of U^{234}, with half life 2.5×10^5 years, corresponding to its activity of 1 Curie will be

(a) 163.62 gm. (b) 1.438×10^{-11} gm.

(c) 3.7×10^{-10} gm. (d) 3.7×10^{10} gm.

127. If a radioactive substance decays for time interval equal to its mean life, then its fraction that remains undecayed will be

(a) 0.6322. (b) 0.3678.

(c) 0.50. (d) 0.75.

128. The half life of radioactive nuclei is 3 minute What fraction of 1 gm of this element will remain after 9 minute?

(a) $\frac{1}{2}$ (b) $\frac{1}{4}$

(c) $\frac{1}{8}$ (d) $\frac{1}{16}$

129. The half lives of radioactive elements X and Y are 3 minute and 27 minute respectively. If the activities of both are same, then the ratio of number of atoms of X and Y will be

(a) 1 : 9 (b) 1 : 10

(c) 1 : 1 (d) 9 : 1

130. If the half life of a radioactive substance is T, then the fraction of its initial mass that remains after time $T/2$ will be

(a) $\frac{\sqrt{2}-1}{\sqrt{2}}$ (b) $\frac{3}{4}$

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

131. In the radioactive decay process of uranium the initial nuclide is $_{92}U^{238}$ and the final nuclide is $_{82}Pb^{206.}$ When uranium nucleus decays to lead, then the number of α- and β-patticles emitted will respectively be

(a) 8, 6 (b) 8, 4

(c) 6, 8 (d) 4, 8

132. The rate of decay of radioactive element at a given instant of time is 10^3 disintegration/second. If the half life of this element is I second, then the rate of decay after 3 second will be

(a) 12 per sec. (b) 50 per sec.

(c) 500 per sec. (d) 125 per sec.

133. The $\log_e N$-$\log_e t$ curve for radioactive material is

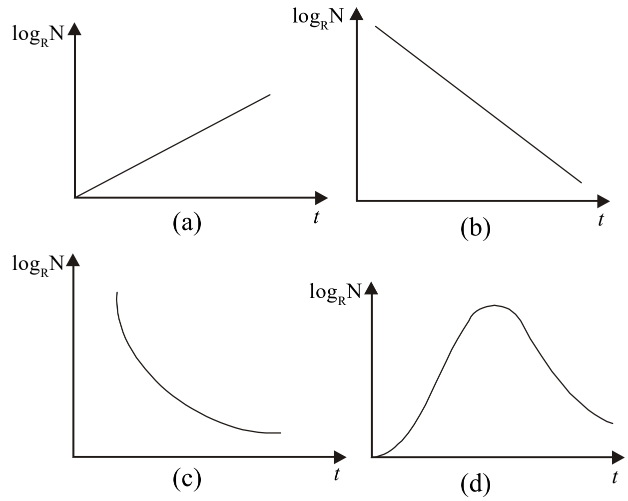

Fig. 35.14

134. An archaeologist analyses a wooden sample of prehistorical structure and finds that the ratio of C^{14} to ordinary carbon in it is only on fourth of that in the calls of living plants. If the half life of C^{14} is 5700 years, then the age of the wood will be

(a) 22,800 years. (b) 5700 years.

(c) 2450 years. (d) 11,400 years.

135. As a result of radioactive disintegration the nucleus $_{92}U^{238}$ converts into $_{91}Pa^{234}$. The particles emitted during the process are

(a) 2 β particle, 2p.

(b) 1 α particle, 1 β particle.

(c) 2 β particle, 1n (neutron).

(d) 1p, 2n.

136. A nucleus, with mass number m and atomic number n, emits one α-particle and one β-particle. The mass number and atomic number of the resulting nucleus will respectively be

(a) $(m-2), n$. (b) $(m-4), (n-1)$.

(c) $(m-4), (n-2)$. (d) $(m+4), (n-1)$.

137. The half life of C^{14} is 5730 years. What fraction of C^{14} will remain unchanged after 5 half lives ?

(a) $\frac{1}{16}$ (b) $\frac{1}{8}$

(c) $\frac{1}{64}$ (d) $\frac{1}{32}$

138. The half life of radioactive radon is 3.8 days. The time in which 1/20 fraction of radon remains undecayed, is

(a) 16.5 days. (b) 76 days.

(c) 3.8 days. (d) 33 days.

139. A given sample contains 16 gms of radioactive material whose half life is two days. The quantity of radioactive material that remains in that sample after 32 days will be

(a) $\frac{1}{2}$ g (b) $\frac{1}{8}$ g

(c) $\frac{1}{4}$ g (d) less then 1 mg

140. The rate of decay of a radioactive element at any instant is 10 disintegrations per second. If the half life of the element is 1 second then the rate of decay after one second will be

(a) 500 per sec. (b) 1000 per sec.

(c) 250 per sec. (d) 2000 per sec.

141. The particles emitted by a radioactive substance are deflected in a magnetic field. The particle may be

(a) neutrons. (b) electrons.

(c) protons. (d) hydrogen atoms.

142. Which of the following radiations can penetrate 20 cm thickness of steel ?

(a) β-particals. (b) α-particles.

(c) γ-particles. (d) ultraviolet rays.

143. The particles not emitted by a radioactive substance are

(a) γ-rays. (b) electrons.

(c) protons. (d) helium nuclei.

144. The isotope used in carbon dating is

(a) C^{14} (b) C^{12}

(c) C^{13} (d) N^{14}

145. The phenomenon explained by tunnel effect is

(a) β-decay. (b) α-decay.

(c) γ-decay. (d) All of above.

PASSAGE 1

Read the following passage and answer the questions given at the end.

A Geiger counter detects radiation such as Beta particles by using the fact that the radiation ionizes the air along its path. A thin wire lies on the axis of a hollow metal cylinder and is insulated from it (Fig 35.14). A large potential difference is established between the wire and outer cylinder, with the wire at higher potential, this sets up a strong electric field directed radially outward. When ionizing radiation enters the device, it ionizes a few air molecules. The free electrons produced are accelerated by the electric field toward the wire and, on the way there, ionize many more air molecules. Thus, a current pulse is produced that can be detected by appropriate electronic circuitry and converted to an audible "click". Suppose the radius of the central wire is 145 μm and the radius of the hollow cylinder is 1.80 cm.

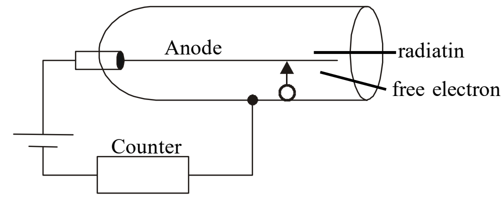

Fig. 35.14

1. The potential difference between the wire and the cylinder that produces an electric field of $2 \times 10^4 Vm^{-1}$ at a distance of 1.2 cm from the wire

(a) 360 V (b) 180 V

(c) 200 V (d) 240 V

2. Which ray/radiation can be detected by GM counter?

(a) Alpha (b) Beta

(c) γ-ray (d) all

Solution **1.** (d) $E = \frac{V}{d}$ or

$V = Ed = 2 \times 10^4 \times 1.2 \times 10^{-2}$

$= 240$ V

Solution **2.** (b), (c) α-rays cannot be detected as they cannot pass through the Aluminium window.

PASSAGE 2

Read the following passage and answer the questions given at the end.

Certain substances are unstable and emit radiations in the form of α-, β- and γ-rays and change into new substances. Such substances are called radioactive substances and the phenomenon is called radioactivity. The number of atoms of the substance at time t is given by $N_t = N_0 e^{-\lambda t}$ where N_0 is the number at time $t = 0$ and λ is a constant. Half-life of a substance is defined as the time in which the number of atoms of the substance decays to one half of its value at any given time.

1. Which of the following are neutral ?

(a) α-rays. (b) β-rays.

(c) both α- and β-rays. (d) γ-rays.

Solution (d)

2. The half-life, T, of a substance is related to the decay constant by the equation.

(a) $T = \frac{1}{\lambda}$ (b) $\frac{1}{0.693\lambda}$

(c) $\frac{0.693}{\lambda}$ (d) $\frac{2.303}{\lambda}$

Solution (c)

3. The isotope of carbon used in radiocarbon dating

(a) C^{10} (b) C^{12}

(c) C^{13} (d) C^{14}

Solution (d)

PASSAGE 3

Read the following passage and answer the questions given at the end.

In 1932, the British scientist Chadwick conducted a series of experiments with various projectiles striking different target substances to produce different nuclear reactions. One of them consisted of an experiment in which α-particles struck beryllium metal. Penetrating rays which were found to be without charge were being emitted from the Be metal. The mass of these chargeless particles was approximately equal to the proton mass.

The reaction could be symbolically represented as

$$2He^4 +_4 Be^9 \longrightarrow_0 R^1 + X$$

where R represents the rays being emitted and X was a substance whose nature was to be chemically determined.

In another experiment, protons were used to bombard Li metal and it was found that α-particles were produced along with release of energy in the form of radiation. In all such reactions, it was seen that there is always conservation of momentum, charge and energy. These conservation principles can be used to determine the nature of the unknown particles as Chadwick's experiment clearly demonstrated.

Another experiment which led to the discovery of artificial radioactivity (AR) was to bombard Al metal with α-rays. It was found that positions were emanating from theAl target and they obeyed the exponential law of decay.

1. The substance X in the experiment performed by Chadwick should consist of atoms of

(a) ${}_7N^{13}$ (b) ${}_7N^{14}$
(c) ${}_6C^{12}$ (d) ${}_6C^{13}$

Solution (c)

2. The rays produced in the above experiment consist of

(a) protons. (b) neutrons.
(c) positrons. (d) neutrinos.

Solution (b)

3. One of the methods of producing He nuclear is to bombard Li with the following projectile

(a) α-particles. (b) electrons.
(c) protons. (d) neutrons.

Solution (c)

4. The discovery of neutron was made on the basis of the conservation principle of

(a) momentum. (b) momentum and energy.
(c) charge. (d) charge and energy.

Solution (d)

5. The conclusion that may be drawn from the experiment which demonstrated artificial radioactivity (A.R.) is

(a) Al is artificial radioactive substance.
(b) positrons are essential for the production of A.R.
(c) Exponential decay led to the discovery of A.R.
(d) In A.R., only positrons are produced.

Solution (c)

PASSAGE 4

Read the following passage and answer the questions given at the end.

The sun is an average star of diameter of about 1.4 × 10^5 km and is about 1.5 × 10^8 km distance away from earth. The average density of the Sun, which consists 70% H and 28% He, is about 1.4 times density of water. The pressure and temperatures inside the sun is very large, the temperature being around 14 million K. At these high temperatures thermonuclear reactions take place, converting lighter gases into heavier ones.

1. The fusion of light elecments take place at about the temperatures of about

(a) 30°C. (b) 100°C.
(c) 10,000°C. (d) 2×10^6 °C.

Solution (d)

2. The diameter of the Sun subtends on the earth an angle (in radians) of about.

(a) 0.5. (b) 0.25.
(c) 0.0093. (d) 0.0046.

Solution (c)

3. The Sun's mean density is

(a) 1.4 kg/m^3. (b) 1.4×10^3 kg/m^3.
(c) 1.4×10^3 kg/cc. (d) 1.4 kg/cc.

Solution (b)

PASSAGE 5

Read the following passage and answer the questions given at the end.

The phenomenon of radioactivity was discovered in the year 1892 by a French physicist H. Bequerrel when he discovered that the element uranium continuously emitted radiation which affected a photographic plate and could penetrate matter. Marie and Pierre Curie discovered another radioactive element Radium in the year 1898; the emitted radiation in radium being much stronger than in Uranium.

The radiation emitted by radioactive substances consists of alpha, beta and gamma rays. Rutherford's work on the penetration of matter by alpha rays led to the discovery that the entire mass of an atom must be concentrated in a very small region, called the nucleus which is positively charged. Electrons, which constitute the negative charge of the atom revolve round the nucleus in closed orbits. Gamma rays emitted by the radioactive substances are electromagnetic in nature and can penetrate through matter through large distances.

4. The beta-particles emitted by the radioactive substances are

(a) positively charged.
(b) negatively charged.
(c) charge less.
(d) positively charged in some substances and negatively charged in others.

Solution (b)

5. The nucleus of most of the substances consist of

(a) protons only.
(b) protons and electrons.
(c) protons, neutrons and electrons.
(d) protons and nentrons.

Solution (d)

6. When radiation emitted by a radioactive substance is subjected to a magnetic field, alpha-particles describe a circle in the clockwise direction.

(a) beta and gamma particles will also be deflected in the same direction.
(b) gamma rays will be deflected to describe a circle in the counter clockwise direction but beta particles will not be deflected.
(c) gamma rays will not be deflected and beta rays will move in a circular path in the counter clockwise sense.
(d) beta and gamma rays will describe a circle in the counter clockwise sense.

Solution (c)

7. The charge on alpha particles is

(a) 1.6×10^{-19} C (b) 3.2×10^{-19} C
(c) -3.2×10^{-19} C (d) -1.6×10^{-19} C

Solution (b)

Answers to Questions for Practice

1.	(d)	**2.**	(d)	**3.**	(c)	**4.**	(d)	**5.**	(c)	**6.**	(b)	**7.**	(b)
8.	(d)	**9.**	(a,b)	**10.**	(c)	**11.**	(c)	**12.**	(c,d)	**13.**	(c)	**14.**	(c)
15.	(d)	**16.**	(d)	**17.**	(d)	**18.**	(b)	**19.**	(a)	**20.**	(d)	**21.**	(a,b,c,d)
22.	(b,c)	**23.**	(b)	**24.**	(d)	**25.**	(c)	**26.**	(c)	**27.**	a $\rightarrow$ P, R; b $\rightarrow$ P, Q		
c $\rightarrow$ S; d $\rightarrow$ P, Q, R				**28.**	(c)	**29.**	(a)	**30.**	(a,d)	**31.**	(a)	**32.**	(a,d)
33.	(d)	**34.**	(b)	**35.**	(d)	**36.**	(c)	**37.**	(a)	**38.**	(a)	**39.**	(c)
40.	(b)	**41.**	(b)	**42.**	(b)	**43.**	(c)	**44.**	(a)	**45.**	(c)	**46.**	(a)
47.	(a)	**48.**	(d)	**49.**	(a)	**50.**	(c)	**51.**	(b)	**52.**	(d)	**53.**	(c)
54.	(a)	**55.**	(a)	**56.**	(a)	**57.**	(a)	**58.**	(d)	**59.**	(a)	**60.**	(a)
61.	(a)	**62.**	(d)	**63.**	(a)	**64.**	(a)	**65.**	(d)	**66.**	(a)	**67.**	(b)
68.	(a)	**69.**	(c)	**70.**	(d)	**71.**	(c)	**72.**	(b)	**73.**	(b)	**74.**	(a)
75.	(c)	**76.**	(c)	**77.**	(a)	**78.**	(a)	**79.**	(b)	**80.**	(c)	**81.**	(c)
82.	(d)	**83.**	(a)	**84.**	(b)	**85.**	(c)	**86.**	(d)	**87.**	(c)	**88.**	(a)
89.	(b)	**90.**	(a)	**91.**	(b)	**92.**	(b)	**93.**	(c)	**94.**	(a)	**95.**	(a)
96.	(b)	**97.**	(a)	**98.**	(b)	**99.**	(d)	**100.**	(a)	**101.**	(b)	**102.**	(a)
103.	(c)	**104.**	(a)	**105.**	(a)	**106.**	(d)	**107.**	(d)	**108.**	(a)	**109.**	(a)
110.	(c)	**111.**	(c)	**112.**	(c)	**113.**	(a)	**114.**	(b)	**115.**	(b)	**116.**	(d)
117.	(a)	**118.**	(d)	**119.**	(c)	**120.**	(b)	**121.**	(d)	**122.**	(c)	**123.**	(c)
124.	(b)	**125.**	(a)	**126.**	(a)	**127.**	(b)	**128.**	(c)	**129.**	(a)	**130.**	(d)
131.	(a)	**132.**	(d)	**133.**	(b)	**134.**	(d)	**135.**	(b)	**136.**	(b)	**137.**	(d)
138.	(a)	**139.**	(d)	**140.**	(a)	**141.**	(b)	**142.**	(c)	**143.**	(c)	**144.**	(a)
145.	(b)												

EXPLANATION

26. (c) required probability $= 1 - e^{-dt} = 1 - e^{-\lambda(2T)} = 1^{(2T)}$
$$1 - e^{-\frac{\log e^{2}}{\pi}(2T)} = 1 - \frac{1}{4} = \frac{3}{4}.$$

30. (a, d) In α decay, the entire energy is carried away by the α-particle as its kinetic energy.

In β^{-} decay, the energy is shared between the β-particle and the antineutrino. Hence, the speed of the β–particle will vary, depending on the energy of the antineutrino.

35. (d) Initial count rate (CR) for 1 cm^3 of liquid $= \frac{C}{100}$ 2

after 3 half-lives, CR for 1 cm^3 of liquid $= \frac{1}{8} \times \frac{C}{100}$

Let the volume of the remaining liquid $= V$ cm^3.

$\therefore$ CR of this liquid $= V \times \frac{C}{800} = \frac{C}{10}$

or $V = 80$.