SHORT QUESTIONS

21.1 What are isotopes? What do they have in common and what are their differences?

Ans. Isotopes are the atoms of the same element having same atomic number but different mass number. Isotopes can also be defined as those atoms of the same element which have different number of neutrons within the nucleus. e.g., hydrogen has three isotopes i.e., H^1, H^2, H^3 Isotopes have got the same chemical properties but their physical properties are different.

21.2 Why are heavy nuclei unstable?

Ans. The heavy nuclei are unstable because their binding energy per nucleon is very small therefore they are unstable and very small amount of energy is required to split a heavy nuclei.

21.3 If a nucleus has a half-life of 1 year, does this mean that it will be completely decayed after 2 years? Explain.

Ans. The half life ($T_{1/2}$) of a radioactive element is the time in which half of atoms decay. This means that if a given sample has half life of one year then 50% sample decay after one year and 50% will remain while next one year 25% will decay and 25% will remain this mean that after two years 75% sample will decays and 25% will left. Therefore an infinite time is required for complete decay of sample.

21.4 What fraction of a radioactive sample decays after two half-lives have elapsed?

Ans. Let No is the total number of atoms at any instant then

After first half-life, number of atoms decayed $= T_{1/2} = \frac{1}{2}\text{No}$

After 2^{nd} half-life, number of atoms decayed $= 2T_{1/2} = \frac{1}{2}\left(\frac{\text{No}}{2}\right)$

$$= \frac{1}{4}\text{No}$$

Total number of atoms decayed after two half lives $= \frac{\text{No}}{2} + \frac{\text{No}}{4} = \frac{3}{4}\text{No}$

Fraction of sample decayed $= \frac{3/4\ \text{No}}{\text{No}} \times 100$

$$= \frac{3}{4} \times 100$$

$$= 75\%$$

So the number of un-decayed atoms are 25%.

21.5 The radioactive element $^{226}_{88}Ra$ has a half-life of 1.6×10^3 years. Since the Earth is about 5 billion years old, how can you explain why we still can find this element in nature?

Ans. Only half of the present number of atoms $^{236}_{88}Ra$ will decay after 1.6×10^3 years and so on. It means that it will take infinite time to completely decay. So due to this fact $^{226}_{88}Ra$ is still available in nature.

21.6 Describe a brief account of interaction of various types of radiations with matter.

Ans. INTERACTION OF RADIATION WITH MATTER

(a) Interaction of α-particle with matter

(i) An α-particle travels a well defined distance in a medium before coming to rest, which is called range of α-particle.

(ii) As the α-particle passes through a solid, liquid or gas, it loses its energy due to excitation and ionization of atoms and molecules in the matter.

(iii) α-particle ionizes, by direct elastic collision with electron.

(iv) Ionization of α-particle is the main interaction with matter, which helps to detect the particle and measure its energy.

(v) α-particle is about 7000 times more massive than an electron, so it is not easy for it to change its direction from its straight path unless it passes very close to the nucleus of the atom.

(vi) The α-particle continues to ionize atoms of matter along their path straight paths till they come to rest after losing their energies.

(b) Interaction of β-particles with matter

(i) β-particle lose their energy to ionize the atoms or molecules of the matter through which they pass.

(ii) The range of β-particles is 100 times more than that of α-particles.

(iii) Path of β-particles while passing through matter is not straight.

(iv) The range of β-particle is measured by the effective depth of penetration into matter.

(v) The range of β-particle depends upon the density of matter.

(vi) β-particles when slowed down by electric field of particles radiate energy as x-ray photons.

(c) Interaction of γ-rays with matter

(i) γ-rays are unchanged (i.e., neutral), having zero rest mass, so they cannot be easily stopped.

(ii) γ-rays are electromagnetic waves having short wavelength and high frequency than that of x-rays.

(iii) Their ionizing power is very small but penetrating power is very high.

(iv) γ-rays interact with matter in three different ways depending on their energy.

21.7 Explain how α and β-particles may ionize an atom without directly hitting the electrons? What is the difference in the action of the two particles for producing ionization?

Ans. An α-particle is positively charged particle so it causes ionization in matter due to electrostatics force of attraction while as β-particle is a negatively charged particle produces ionization due to repulsion.

Difference in their action is α-particle pulls an electron from the atom but β-particle repels an electron out of the atom in ionizing the atom.

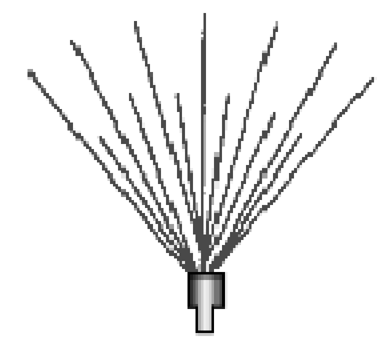
21.8 A particle which produces more ionization is less penetrating. Why?

Ans. A particle which produces more ionization loses a part of its energy during each collision with an atom. The process of ionization continuous till the particle loses all its energy and comes to rest. Therefore it has less penetrating power. As α-particle is highly ionizing therefore its penetration is less.

21.9 What information is revealed by the length and shape of the tracks of an incident particle in Wilson cloud chamber?

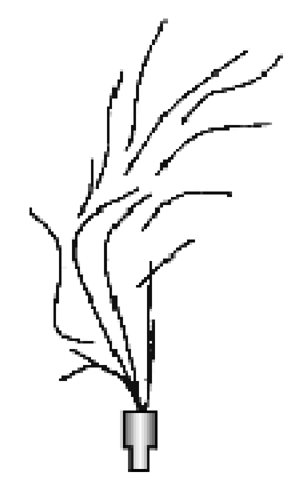
Ans. By observing the length and shape of tracks of incident particles we can study the nature and energy of that particle.

(i) α-particle: If the track is thin, straight continuous and smaller in length then it will represent α-particle because ionization power of α-particle is large but range is small.



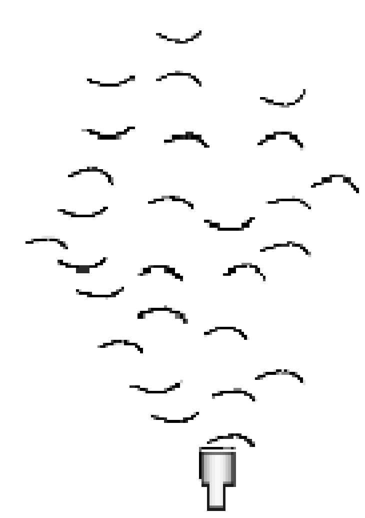
α- Particle

(ii) β-particle: If the track is thin, discontinuous and long then the track will represent β-particle whose ionization power is small.



β - Particle

(iii) γ-particle: γ-rays leave behind no definite tracks which is proportional to the energy of incident particle because ionization power of γ-rays is very small.



γ-Rays

21.10 Why must a Geiger Muller tube for detecting α-particles have a very thin end window? Why does a Geiger Muller tube for detecting γ-rays not need a window it all?

Ans. A Geiger Muller tube has a very thin end window for detecting α-particles because α-particles posses less penetrating power and very small range as compared to β and γ-rays. Therefore a window allow their entry into the tube easily. The G.M tube does not need a thin window for detecting γ-ray because of the high penetrating power.

21.11 Describe the principle of operation of a solid-state detector of ionizing radiation in terms of generation and detection of charge carriers.

Ans. Solid state detector is a specially designed P-N junction. It is always operated in reverse biased. Normally no current flows through the circuit. When an incident particle penetrates through the depletion region it produces electron hole pairs. These mobile charge carriers move towards the respective sides due to applied electric field. This gives rise to a current in the external circuit due to which a pulse of voltage is generated across the resistance R. The size of the pulse is found proportional to the energy absorbed of the incident particle.

21.12 What do we mean by the term critical mass?

Ans. Such a mass of uranium in which one neutron out of all the neutrons produced in one fission reaction produces further fission. The volume of this mass of uranium is called the critical mass.

21.13 Discuss the advantages and disadvantages of nuclear power compared to the use of fossil fuel generated power.

Ans. **Advantages of nuclear power station as compare to fossil fuel**

(1) It produces a large amount of energy.	(1) It produces a limited amount of energy.
(2) 1 kg of uranium produces 2×10^7 kwh of energy during fission process.	(2) The same amount of energy is produced by using.
(3) It does not produce smoke. So atmosphere is free of pollution.	(3) It produces smoke and causes pollution in air.
(4) The cost of electricity produced by nuclear plant power is cheep.	(4) The cost of electricity produced by it is high.
(5) Waste product can be reprocessed.	(5) Waste products cannot be used.
(6) It is permanent for a given time.	(6) It is not permanent for a given period of time.

Disadvantages

(1) Its fuel is not easily available in the market.	(1) Its fuel is easily available.
(2) Its handling is dangerous.	(2) It is not dangerous.
(3) Its waste products are dangerous to be handled.	(3) Its waste products are not dangerous.

21.14 What factors make a fusion reaction difficult to achieve?

Ans. This reaction required large amount of energy and temperature upto millions degree centigrade. So these requirements are not possible to achieve so the fusion reaction is very difficult to achieve.

21.15 Discuss the advantages and disadvantages of fusion power from the point of safety. Pollution and resources.

Ans. **Advantages**

(1) The fusion reaction is free from radioactive products so it will be safe from pollution and resources.

(2) This reaction produces more energy per nucleon.

(3) The energy produced by fusion is cheaper than other sources.

Disadvantages

(1) It is difficult to control this reaction.

(2) It is difficult to start the fusion reaction.

21.16 What do you understand by "background radiation"? State two sources of this radiation?

Ans. Back ground radiation, are the low intensity radiation resulting from the bombardment of the cosmic rays and from the presence of naturally occurring radio active nuclei in rocks, soil, air and building materials. The two sources of these radiations are K^{40} and C^{14}.

21.17 If you swallowed an α, β-source, which would be the more dangerous to you? Explain why?

Ans. α-particles are more dangerous than β-particles because α-particles have greater ionizing power as compared to β-particles. It can cause more damage to tissues.

21.18 Which radiation dose would deposit more energy to your body (a) 10 mGy to your hand, or (b) 1 mGy dose to your entire body?

Ans. We know that

$$\text{Dose} = \frac{\text{Energy}}{\text{Mass}}$$

$$D = \frac{E}{m}$$

$$\Rightarrow \quad E = m \,.\, D$$

Let m_1 be the mass of hand and E_1 be the energy.

$$E_1 = m_1 \text{ (10 mGy)} \qquad \ldots\ldots (1)$$

m_2 be the mass of entire body and E_2 be the energy.

$$E_2 = m_2 \text{ (1 mGy)} \qquad \ldots\ldots (2)$$

Since the mass of the entire body is far greater than mass of hand. Therefore 1 mGy dose will deposit more energy.

21.19 What is a radioactive tracer? Describe one application each in medicine, agriculture and industry.

Ans. A radioactive isotope behaves in just the same way as the normal isotope inside a living organism. But location and concentration of a radioactive isotope can be determined by measuring radiation it emits. Thus a radioactive isotope acts as a tracer.

Uses of Tracers

(1) In medicine: The tracers are used in medicine to detect the malignant tumors.

(2) In understanding of photosynthesis: This techniques has helped to understand more clearly the complex process of photo synthesis.

21.20 How can radioactivity help in the treatment of cancer?

Ans. Radioactivity with γ-rays from cobalt 60 is often used in the treatment of cancer. The γ-rays are carefully focused on the malignant tissue similarly radioactive iodine 131 is used to combat cancer if the thyroid gland.

PROBLEMS WITH SOLUTIONS

PROBLEM 21.1

Find the mass defect and the binding energy for tritium, if the atomic mass of tritium is 3.016049 u.

Data

Atomic mass of tritium $= m = 3.016049$ u

To Find

(i) Mass defect $= \Delta m = ?$

(ii) Binding energy for tritium $= \Delta E = ?$

SOLUTION

(i) As we know that

$$\Delta m = Zm_p + Am_n - m \qquad \ldots\ldots \text{(i)}$$

Since;

Mass of proton $= m_p = 1.007276$ u

Mass of neutron $= m_n = 1.008665$ u

Charge number of tritium $= Z = 1$

Mass number of tritium $= A = 2$

Putting in eq. (i)

$$\Delta m = 1 \times 1.007276 + 2 \times 1.008665 - 3.016049$$

$$= 1.007276 + 2.017330 - 3.016049$$

$$\Delta m = 0.00855 \text{ u}$$

(ii) For binding energy of tritium

$$\Delta E = \Delta m \times 931 \qquad \text{Since} \quad 1 \text{ u} = 931 \text{ Mev}$$

So $\Delta E = 0.00855 \times 931$

$$\Delta E = 7.97 \text{ Mev}$$

Result

(i) Mass defect $= \Delta m = 0.00855$ u

(ii) Binding energy $= \Delta E = 7.97$ Mev

PROBLEM 21.2

The half-life of $^{91}_{38}Sr$ is 9.70 hours. Find its decay constant.

Data

Half life of $^{91}_{38}Sr$ $= 9.70$ hrs

$= 9.70 \times 3600$

$= 34920$ sec.

To Find

Decay constant $= \lambda = ?$

SOLUTION

By formula

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

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

$$= \frac{0.693}{34920}$$

$$\lambda = 1.98 \times 10^{-5}\ \text{sec}^{-1}$$

Result

Decay constant $= \lambda = 1.98 \times 10^{-5}\ \text{sec}^{-1}$

PROBLEM 21.3

The element $^{234}_{91}Pa$ is unstable and decays by β-emission with a half-life 6.66 hours. State the nuclear reaction and the daughter nuclei.

Data

Half life of $^{234}_{91}Pa$ $= T_{1/2} = 6.66$ hrs.

$= 6.66 \times 3600$

$= 23976$ sec.

To Find

(i) Nuclear reaction = ?

(ii) Daughter nuclei = ?

SOLUTION

(i) For nuclear reaction

As for β-emission

$$^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}\beta$$

So $$^{234}_{91}Pa \longrightarrow {}^{234}_{92}Y + {}^{0}_{-1}\beta$$

So $$^{234}_{92}Y = {}^{234}_{92}U$$

Thus the nuclear reaction is

$$^{234}_{91}Pa \longrightarrow {}^{234}_{92}U + {}^{0}_{-1}e$$

(ii) Daughter nuclei $= {}^{234}_{92}U$

PROBLEM 21.4

Find the energy associated with the following reaction

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

What doe's negative sign indicate?

Data

The given reaction is

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

To Find

Energy associated with reaction $= \Delta E = ?$

SOLUTION

Since the given reaction is

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

So $\Delta m = (\text{Mass of } ^{14}_{7}N + \text{Mass of } ^{4}_{7}He) - (\text{Mass of } ^{17}_{7}O + \text{Mass of } ^{1}_{1}H)$

Since

Mass of $^{14}_{7}N$ = 14.0031 u

Mass of $^{4}_{2}He$ = 4.00264 u

Mass of $^{17}_{7}O$ = 16.9996 u

Mass of $^{1}_{1}H$ = 1.0073 u

Thus

$$\Delta m = (14.0031 + 4.00264) - (16.9996 + 1.0073)$$
$$= 18.00574 - 18.0069$$
$$= -0.0012 \text{ u}$$

For energy

$$\Delta E = -0.0012 \times 931$$
$$= -1.117$$
$$= -1.12 \text{ Mev}$$

Result

Energy associated with reaction

$$\Delta E = -1.12 \text{ Mev}$$

and the negative sign shows that the energy is required for this reaction.

PROBLEM 21.5

Determine the energy associated with the following reaction

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

Data

The given reaction is

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

Mass of $^{14}_{6}C$ = 14.0077 u

To Find

Energy associated with reaction = ΔE = ?

SOLUTION

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

$$\Delta m = ^{14}_{6}C - (^{14}_{7}N + ^{0}_{-1}e)$$

So Mass of $^{14}_{6}C$ = 14.0077 u

Mass of $^{14}_{7}N$ = 14.0067 u

Mass of $^{0}_{-1}e$ = 0.000548 u

Therefore;

$$\Delta m = 14.0077 - (14.0067 + 0.000548)$$
$$= 14.0077 - 14.0072$$
$$\Delta m = 0.0005$$

For energy

$$\Delta E = 0.0005 \times 931$$
$$= 0.465 \text{ Mev}$$

Result

Energy associated with reaction $= \Delta E = 0.465$ Mev

PROBLEM 21.6

If $^{233}_{92}U$ decays twice by α-emission, what is the resulting isotope?

Data

The given element is $^{233}_{92}U$.

To Find

Resulting isotope $=$?

SOLUTION

For α-emission

$$^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$$

After second emission

$$^{233}_{92}u \longrightarrow {}^{225}_{88}Y + {}^{4}_{2}He$$

Thus $^{225}_{88}Y = {}^{225}_{88}Ra$

So after 2nd emission of α-particle, the resulting isotope is $^{225}_{88}Ra$.

PROBLEM 21.7

Calculate the energy (in MeV) released in the following fusion reaction

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

Data

The given reaction is

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

To Find

Energy released $= \Delta E = $?

SOLUTION

According to reaction

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

So $\Delta m = (\text{Mass of } {}^{2}_{1}H + \text{Mass of } {}^{3}_{1}H) - (\text{Mass of } {}^{4}_{2}He + \text{Mass of } {}^{1}_{0}n)$

Since

Mass of $^{2}_{1}H = 2.014102$ u

Mass of $^{3}_{1}H = 3.016050$ u

Mass of ^4_2He = 4.002603 u

Mass of ^1_0n = 1.008665 u

Therefore;

$$\Delta m = (2.014102 + 3.016050) - (4.002603 + 1.008665)$$
$$= 5.030152 - 5.011268$$
$$= 0.018884 \text{ u}$$

Then $\Delta E = \Delta m \times 931$
$$= 0.018884 \times 931$$
$$= 17.58 \text{ Mev}$$

Result

Energy released = ΔE = 17.58 Mev/event

PROBLEM 21.8

Sheet of lead 5.0 mm thick reducing the intensity of beam of γ-rays by a factor 0.4. Find half value thickness of lead sheet which will reduce the intensity to half of its initial value.

Data

Thickness of sheet = x_1 = 5 mm
= 5×10^{-3} m

Reduction in intensity of beam = I_1 = $0.4\ I_o$

Reduction of intensity in lead sheet = I_2 = $0.5\ I_o$

To Find

Thickness of lead sheet = x_2 = ?

SOLUTION

By formula

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

For 1st case

$$I_1 = I_o e^{-\mu x_1}$$
$$0.4 I_o = I_o e^{-\mu x_1}$$
$$0.4 = e^{-\mu x_1}$$

Taking ln

$$\ln 0.4 = -\mu x_1 \ln e \qquad \text{But} \quad \ln e = 1$$
$$\ln 0.4 = -\mu x_1 \qquad \ldots\ldots \text{(i)}$$

For 2nd case

$$I_2 = I_o e^{-\mu x_2}$$
$$0.5 I_o = I_o e^{-\mu x_2}$$
$$0.5 = e^{-\mu x_2}$$

Taking ln

$$\ln 0.5 = -\mu x_2 \ln e$$
$$\ln 0.5 = -\mu x_2 \qquad \ldots\ldots \text{(ii)}$$

Divide eq. (i) by eq. (ii)

$$\frac{\ln 0.4}{\ln 0.5} = \frac{-\mu x_1}{-\mu x_2}$$

$$\frac{-0.916}{-0.693} = \frac{x_1}{x_2}$$

$$\frac{0.916}{0.693} = \frac{x_1}{x_2}$$

$$x_2 = \frac{0.693\, x_1}{0.916}$$

$$= \frac{0.693 \times 5 \times 10^{-3}}{0.916}$$

$$= 3.7827 \times 10^{-3}\ \text{m}$$

$$= 3.78\ \text{mm}$$

Result

Thickness of lead sheet $= x_2 = 3.78$ mm

PROBLEM 21.9

Radiation from a point source obeys the inverse square law. If the count rate at a distance of 1.0 m from Geiger counter is 360 counts per minute, what will be its count rate at 3.0 m from the source?

Data

1st distance $= r_1 = 1.0$ m

Count rate at 1 m $= I_1 = 360$ C/min.

To Find

Count rate at 3.0 m $= I_2 = ?$

SOLUTION

Since count rate obeys inverse square law

$$I \propto \frac{1}{r^2}$$

$$I = \frac{K}{r^2}$$

Where K is constant

So for 1st count

$$I_1 = \frac{K}{r_1^2} \qquad \ldots\ldots \text{(i)}$$

For 2nd count

$$I_2 = \frac{K}{r_2^2} \qquad \ldots\ldots \text{(ii)}$$

Divide eq. (i) by (ii)

$$\frac{I_1}{I_2} = \frac{K/r_1^2}{K/r_2^2}$$

$$\frac{I_1}{I_2} = \frac{K}{r_1^2} \times \frac{r_2^2}{K}$$

$$\frac{I_1}{I_2} = \frac{r_2^2}{r_1^2}$$

$$I_2 = \frac{I_1 \times r_1^2}{r_2^2}$$

Putting the values

$$I_2 = \frac{1}{3^2} \times 360$$

$$= \frac{360}{9} = 40 \text{ C/min.}$$

Result

Count rate at 3.0 m $= I_2 = 40$ C/min.

PROBLEM 21.10

A 75 kg person receives a whole body radiation dose radiation dose of 24 m rad, delivered by α-particles for which RBE factor is 12. Calculate (a) the absorbed energy in joules, and (b) the equivalent dose in rem.

Data

Mass $= m = 75$ kg

Dose $= D = 24$ m rad

$= 24 \times 10^{-3}$ rad

Since 1 rad $= 0.01$ Gy

$D = 24 \times 10^{-3} \times 0.01$

$= 0.24 \times 10^{-3}$ Gy

RBE $= 12$

To Find

(a) Absorbed energy in Joules $= E = ?$

(b) Equivalent dose in rem $= De = ?$

SOLUTION

(a) As we know that the absorbed energy is

$$E = m \times D$$

$$= 75 \times 0.24 \times 10^{-3}$$

$$= 18 \times 10^{-3} \text{ Joule}$$

$$= 18 \text{ m Joule}$$

(b) Since

Equivalent dose $= De = \text{Dose} \times \text{RBE}$

$= 0.24 \times 10^{-3} \times 12$

$= 2.88 \times 10^{-3}$ sec.

Now 1 rem $= 0.01$ Sv

$$De = \frac{2.88 \times 10^{-3}}{0.01}$$

$$= 0.288$$

$$= 0.29 \text{ rem}$$

Result

(a) Absorbed energy in Joule $= E = 18 \times 10^{-3}$ J

$= 18$ mJ

(b) Equivalent dose $= De = 0.29$ rem