Unit - 20

NUCLEAR PHYSICS

Learning Objectives

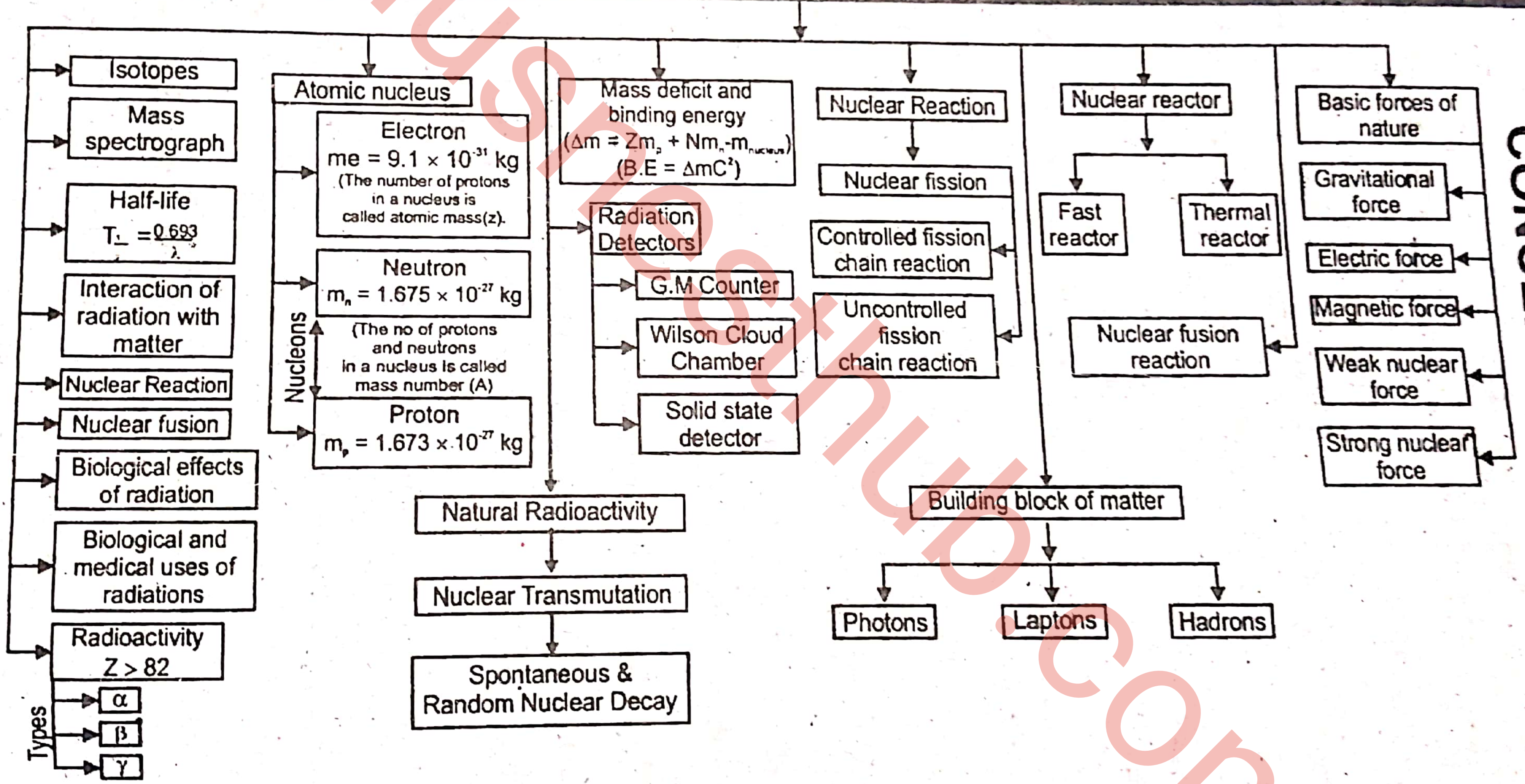
After studying this chapter the students will be able to:

- Describe a simple model for the atom to include protons, neutrons and electrons.
- Determine the number of protons, neutrons and nucleons it contains for the specification of nucleus in the form $_ZX^A$
- Explain that an element can exist in various isotopic forms each with a different number o neutrons.
- Explain the use of mass spectrograph to demonstrate the existence of isotopes and to measure thei relative abundance.
- Define the terms unified mass scale, mass defect and calculate binding energy using Einstein's equation.
- Illustrate graphically the variation of binding energy per nucleon with the mass number.
- Explain the relevance of binding energy per nucleon to nuclear fusion and to nuclear fission.
- Identify that some nuclei are unstable, give out radiation to get rid of excess energy and are said to be radioactive.
- Describe that an element may change into another element when radioactivity occurs.
- Identify the spontaneous and random nature of nuclear decay.
- Describe the term half-life and solve problems using the equation $\boxed{T_{1/2} = \frac{0.693}{\lambda}}$
- Determine the release of energy from different nuclear reactions.
- Explain that atomic number and mass number conserve in nuclear reactions.
- Describe energy and mass conservation in simple reactions and in radioactive decay.
- Describe the phenomena of nuclear fission and fusion.
- Describe the function of various components of a nuclear reactor.
- Describe the interaction of nuclear radiation with matter.
- Describe the use of Geiger Muller counter and solid state detectors to detect the radiations.
- Describe tne basis forces of nature.
- Describe the key features and components of the standard model of matter including hadrons, leptons and quarks.

CONCEPT MAP

NUCLEAR PHYSICS

The branch of Physics which deals with isolated nuclei of atoms or The branch of Physics which deals with nuclear part of an atom and various phenomenon associated with it



For your Information

The goals of Nuclear Physics is to discover, explore, and understand all forms of nuclear matter. Every star shines because of the energy provided by nuclear reactions taking place inside it. It is also nuclear reactions that drive the spectacular stellar explosions seen as supernovas, which create nearly all of the chemical elements. A supernova, which create nearly all of the chemical elements. A supernova is the explosion of a star. In an instant, a star with many times the mass of our Sun can detonate with the energy of a billion suns. And then within just a few hours or day, it dims down again.

Q.1 Explain the structure of the nucleus.

Atomic Nucleus

Atomic Nucleus

At the center of each atom, there is an extremely small nucleus. The entire positive charge of the atom and *99.9%* of its mass is concentrated in the nucleus. The radius of the atom is 10^5 *times* greater than the radius of the nucleus.

A nucleus consists of nucleons. Comprising protons and neutrons.

Proton

Proton has a positive charge. It is equal to 1.6×10^{-19} C. It is equal in magnitude to the charge on an electron and mass of proton is equal to 1.673×10^{-27} kg

Neutron

Neutron has no charge. It is a **neutral** particle and mass of neutron is equal to 1.675×10^{-27} kg

Proton and Neutron have nearly same masses. The charge on the proton is positive, while that of an electron is negative. As an atom on the whole is electrically neutral, therefore we conclude that the number of protons inside the nucleus is equal to the number of electrons outside the nucleus.

Unified Mass Scale

Mass of atomic particles is generally expressed by using unified mass scale (u) instead of kilogram.

By definition 1u is exactly $\frac{1}{12}$th of the mass of carbon atom ${}^{12}_{6}\mathrm{C}$

$$1\,\mathrm{u} = 1.6606 \times 10^{-27}\ \mathrm{kg}$$

On this scale

$$m_p = 1.007276\ \mathrm{u}$$

$$m_n = 1.008665\ \mathrm{u}$$

Charge Number or Atomic Number (Z)

The number of protons inside a nucleus is called charge number or atomic number.

It is denoted by Z.

Neutron Number (N)

The number of neutrons inside a given nucleus is called neutron number.

It is denoted by N.

Mass Number (A)

The total number of protons and neutrons in a nucleus is called mass number. It is denoted by A.

As $$\begin{pmatrix}\text{Mass}\\ \text{Number}\end{pmatrix} = \begin{pmatrix}\text{Number of}\\ \text{Protons}\end{pmatrix} + \begin{pmatrix}\text{Number of}\\ \text{Neutrons}\end{pmatrix}$$

Thus $A = N + Z$

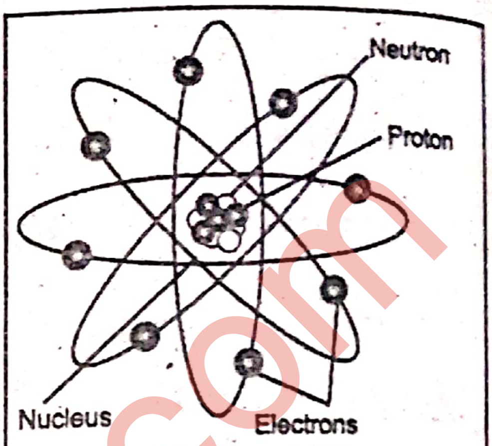
or $N = A - Z$

Now we consider different elements of the periodic table.

Hydrogen

Hydrogen is the simplest of all the atoms. Its nucleus has only one proton. So, $Z = 1$, $A = 1$

So, Hydrogen is represented by symbol $^{1}_{1}H$



Atomic nucleus

Thus the nucleus of "$_{11}Na^{23}$", a sodium atom which has atomic number 11 and mass number 23, contains 11 protons and 12 neutrons. $_6C^{12}$ has $Z = 6$ and $A = 12$.

Uranium:

Its charge number $Z = 92$

Its mass number $A = 235$

So, neutron number $N = A - Z$

$N = 235 - 92 = 143$

So, Uranium is represented by $^{235}_{92}U$

Or in general, any element can be represented by $^{A}_{Z}X$

Note:

(i) In light elements such as H, He, N, C, O the number of neutrons is same as that of number of protons.

(ii) In heavy elements such as U, Pb (lead) neutron number is greater than the number of protons.

- The nucleus is made up neutrons and protons, two particles which are about 1840 times more massive than electrons. They are spoken of collectively as nucleons Fig 20.1(a).
- The mass of the nucleus is very nearly equal to the mass of the atom; in kilograms it is the atomic weight divided by Avogadro's number, 6.03×10^{26}.
- The nucleus was first discovered in 1911 in experiment conducted by lord Rutherford and his students Geiger and Marsden on scattering of alpha particles by atom. He found that the scattering pattern could be explained of atoms consist of a small nucleus, deviation indicate that the nuclear size in of the order of 10^{-14} m.
- The mass of nucleus is of the order of 10^{-27} kg.
- In nucleus, protons and neutrons are collectively called as nucleons.

Q.2 Define and explain Isotopes.

Isotopes

Isotopes are nuclei of the same element having the same charge number (Z) but different mass number (A).

For example, natural uranium mostly consists of the isotopes $_{92}U^{238}$ and a small proportion of the isotopes $_{92}U^{235}$. Both types of atoms are uranium atoms, each nucleus containing 92 protons. However the isotope $_{92}U^{238}$ contains three more neutrons than the isotope $_{92}U^{235}$.

Others examples are $_6C^{11}$; $_6C^{12}$; $_6C^{13}$; and $_6C^{14}$ are four isotopes of carbon,

$_1H^1$; $_1H^2$ and $_1H^3$ are three isotopes of hydrogen etc.

Note that the number of electrons in an atom is equal to the number of protons in the nucleus.

- The chemical properties of an element are the same for all the isotopes of the element.
- This is because chemical reactions are determined by the electrons in an atom.

Atoms of the same element undergoes the same chemical reactions because each atom has the same electron arrangement even if the atoms are different isotopes of the same elements.

MCQ's From Past Board Papers

1. The value of 1 u mass = (Federal 2011)
(A) 933 MeV (B) 932 MeV (C) 933 MeV (D) 931 MeV

2. Both Xenon and cesium have
(A) 33 isotopes (B) 34 isotopes (C) 35 isotopes (D) 36 isotopes

3. Which of following has no change?
(A) α-rays (B) β-rays (C) γ-rays (D) Cathode rays

4. **A naturally occurring disintegration involving the emission of high energy electrons is called:**
(A) Positron Decay (B) Beta Decay (C) Gamma Decay (D) Alpha Decay

5. **By emitting β – particle and γ – Particle simultaneously the nucleus changes its charge by:**
(A) Losses by 1 (B) Increases by 1 (C) Increases by 2 (D) change will be observed

6. **The mass of β – particle is equal to mass of:**
(A) Proton (B) Electron (C) Neutron (D) Boron

7. **γ – rays emitted from radioactive element have speed:**
(A) 1×10^7 ms^{-1} (B) 1×10^9 ms^{-1} (C) 3×10^8 ms^{-1} (D) 4×9^9 ms^{-1}

8. **At higher energies more than 1.02 MeV the dominant process is:**
(A) Photo electric effect (B) Compton effect (C) Pair production (D) Nuclear fission

9. **Mass spectrograph is used for identification of:**
(A) Mass number (B) Atomic number (C) Isotopes (D) Isobars

10. **Neutron was discovered in 1932 by:**
(A) Bohr (B) Chadwick (C) Dirac (D) Fermi

11. **The isotope $_1H^1$ contains:**
(A) One neutron (B) Two neutrons (C) Three neutrons (D) No neutrons

12. **The number of protons in an atom are always equal to number of:**
(A) Electrons (B) Neutrons (C) Positron (D) Mesons

13. **The radius of atom is of the order of:**
(A) 10^{10}m (B) 10^{-10}m (C) 10^{-14} (D) 10^{14} m

14. **When a radioactive nucleus emits a β – particle, the proton – neutron ratio**
(A) remains the same (B) increases (C) decreases (D) equals 1

15. **Nuclei of an element having same charge number but different mass number are called:**
(A) Isobars (B) Isotopes (C) Mass numbers (D) Atomic numbers

16. **Materials can be identified by measuring their:**
(A) Mass (B) Half life (C) Both a, b (D) None of a, b, c

17. **The number of protons in any atom are always equal to the number of:**
(A) Neutrons (B) Electrons (C) Positrons (D) Mesons

18. **The number of neutrons in Li are**
(A) 3 (B) 7 (C) 4 (D) 2

19. **The number of Neutrons in $^{238}_{92}U$ is:-**
(A) 92 (B) 238 (C) 146 (D) 330

20. **Number of isotopes of Neon gas are:-**
(A) 2 (B) 3 (C) 4 (D) 1

21. **Mass of proton is**
(A) 1.67×10^{-27} kg (B) 1.67×10^{-19} kg (C) 1.67×10^{-31} kg (D) 9.1×10^{-31} kg

22. **The number of neutrons in the nucleus is:**
(A) $N = A - Z$ (B) $N = A + Z$ (C) $N = \frac{A+Z}{2}$ (D) $N = \frac{A-Z}{2}$

23. **As mass number increases, which of the following does not change?** **(Federal 2017)**
(A) Mass (B) Volume (C) Density (D) Binding energy

Answers Key

1. D	2. D	3. C	4. B	5. B	6. B	7. C	8. C	9. C	10. B	11. A	12. A
13. B	14. B	15. B	16. B	17. B	18. C	19. C	20. B	21. A	22. A	23. C	

Q.3 Describe principle, construction and working of mass spectrograph. **(Federal 2016)**

Mass Spectrograph

It is a device with the help of which not only the isotopes of any element can be separated from one another but their masses can also be determined quite accurately. A mass spectrograph is based upon the principle that a beam of ions moving through electric and magnetic fields suffers a deflection that depends upon the charge and masses of the ions.

Hence ions of various masses are deflected differently. A spectrometer separates a mixture of ions into a spectrum of atoms having different masses.

A simple mass spectrograph is shown in (fig 20.1b). The atoms or molecules of the elements under investigation, in vapour form, are ionized in the ion source S. As a result of ionization, one electron is removed from the particles, leaving with a net positive charge +e. the positive ions, escaping the slit S_1 are accelerated through a potential difference V applied between two slits S_1 and S_2.

The ion passes through slit S2 in the form of a narrow beam. The K.E of single charged ion at the slit S_2 will be given by

$$K\text{-}E = Vq$$

or $$\frac{1}{2}mv^2 = Vq$$

or $$mv^2 = 2Vq$$

$$v^2 = \frac{2Vq}{m}$$

$$v = \sqrt{\frac{2Vq}{m}} \qquad ......(1)$$

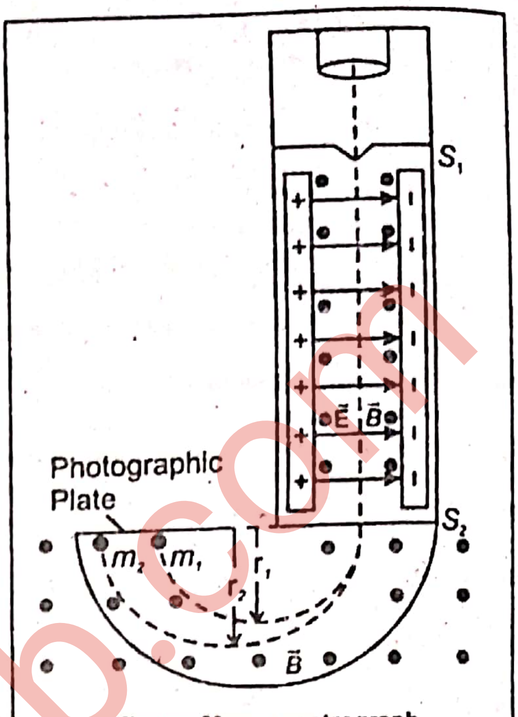


Figure: Mass spectrograph

The ions are then subjected to a perpendicular and uniform magnetic field B in a vacuum chamber, where they are deflected in semi-circular paths towards a detector. The detector records the number of ions arriving per second. The centripetal force applied by magnetic fields is given by

Magnetic Force = Centripetal Force

$$F_m = F_C$$

$$qvB = \frac{mv^2}{r}$$

$$qB = \frac{mv}{r}$$

$$m = \frac{qBr}{v} \qquad ....(2)$$

Putting the value of 'v' from equation (1) in (2) we get

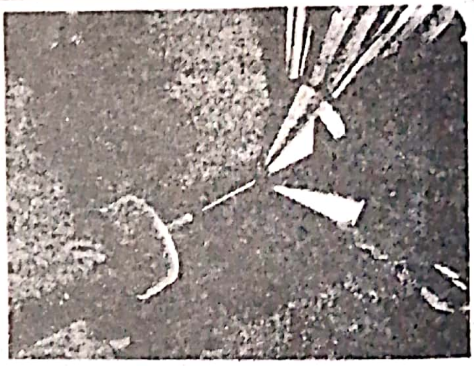
$$m = \frac{qBr}{\sqrt{\frac{2Vq}{m}}}$$

Squaring both sides, we get

$$m^2 = \frac{q^2B^2r^2}{\frac{2Vq}{m}}$$

$$m^2 = \frac{q^2B^2r^2m}{2Vq}$$

$$m = \left(\frac{qr^2}{2V}\right)B^2 \qquad ......(3)$$



Modern Mass Spectrometry Instruments are used in the Drug Discovery and Development process.

We can therefore, compute the mass m of the ion if r, B, q and V are known.

We can also write (Eq.3) in the form $r^2 = \frac{2Vm}{qB^2}$.

Taking square root of both sides

$$r = \sqrt{\frac{2Vm}{B^2q}} \qquad ... (4)$$

This relation shows that if V, B and q to be constant, r depends upon the mass m of the ion. Thus ions of different masses will strike the photographic plate at different places, so, therefore, different isotopes can be separated from one another.

Q4 What are nuclear masses? Explain

Nuclear Masses

It is known that a kilogram-mole of any element should contain Avogadro's number of atoms: 6.023×10^{26} atoms/kg mole. Thus the mass of an atom or a nucleus is of the order of 10^{-27} kg. Since it is a small number, therefore, atomic and nuclear masses are expressed in term of unified (U) mass scale. The unified mass scale is a scale based on assigning a mass exactly 12 to rest mass of an atom of C^{12}. On this scale one, mass unit, called an atomic mass unit or

a.m.u., is equal to $\frac{1}{12}$ of the mass of the carbon atom ${}_6C^{12}$. All other masses are then measured in this unit by comparison. The relation of a.m.u. or u to the kilogram is found as follows:

$$\text{Mass of } 6.23 \times 10^{26} \text{ atoms of } c^{12} = 12\text{kg}$$

$$\text{Mass of 1 atom of } C^{12} = \frac{12}{6.023 \times 10^{26}}\text{kg} = 1.660 \times 10^{-27}\text{kg}$$

It is often convenient, in nuclear physics to express certain masses in energy unit. According to Einstein mass-energy equivalence relation.

$$E = mc^2$$

$$1u = (1.660 \times 10^{-27}\text{kg})(3 \times 10^8\text{ms}^{-2})^2$$

$$= 1.49 \times 10^{-10}\text{J}$$

$$\text{Since 1eV} = 1.60 \times 10^{-19}\text{J}$$

$$1u = \frac{1.49 \times 10^{-10}}{1.60 \times 10^{-19}}\text{eV} = 9.31 \times 10^8\text{eV}$$

$$1u = 931 \times 10^6\text{eV} = 931\text{ MeV}$$

The masses of electron, proton and neutron on u-scale are

$$m_e = 9.109 \times 10^{-31}\text{kg} = 5.485 \times 10^{-4}\text{u} = 0.51\text{ MeV}$$

$$m_p = 1.673 \times 10^{-27}\text{kg} = 1.007\text{u} = 937\text{ MeV}$$

imp

$$m_n = 1.675 \times 10^{-27}\text{kg} = 1.008\text{u} = 938\text{ MeV}$$

Q.5 Define and explain terms Mass Defect and Binding Energy.

Mass defect and binding energy

The mass of a nucleus is always less than the total mass of its protons and neutrons.

Def: This difference in mass of nucleons and mass of isolated nucleus is called mass defect.

It is also called mass deficit. It is denoted by Δm and is given by the relation.

Z = The number of protons in the nucleus.

A = The number of neutrons and protons,

So A – Z is the number of neutrons in nucleus.

1. The mass defect (in atomic mass unit) of the nucleus,

$$\Delta m = Zm_p + (A - Z)m_n - M_{(A,Z)}$$

Or

$$\Delta m = Zm_p + Nm_n - M_{(A,Z)} \quad \text{.............(1)}$$

Where m_p is the mass of a proton and m_N is the mass of a neutron.

Why should a large unstable nucleus release energy when it fissions or a radioactive change takes place?

- The potential energy of a system depends on the position of the particles in the system, relative to each other.
- A stable system is one in which the potential energy of the system is at its lowest.
- When an unstable system becomes more stable, it changes to a **state of lower potential energy.**
- The protons and the neutrons in a nucleus are held together by a strong attractive force that prevents the protons pushing away from one another. To separate the protons and neutrons from one another, work would need to be done on them to overcome the strong nuclear force.

Binding Energy (B.E.)

Definition

The energy required to break the nucleus into its nucleons i.e., neutrons and protons is called binding energy (B.E.).

The missing mass i.e., mass defect Δm is converted into energy during the formation of the nucleus and is called the binding energy (B.E.).

The greater the binding energy of a nucleus, the greater the work that would be needed to separate the neutrons and the protons in the nucleus from each other.

- The mass of a nucleus is less than the mass of the same number of separate neutrons and protons.

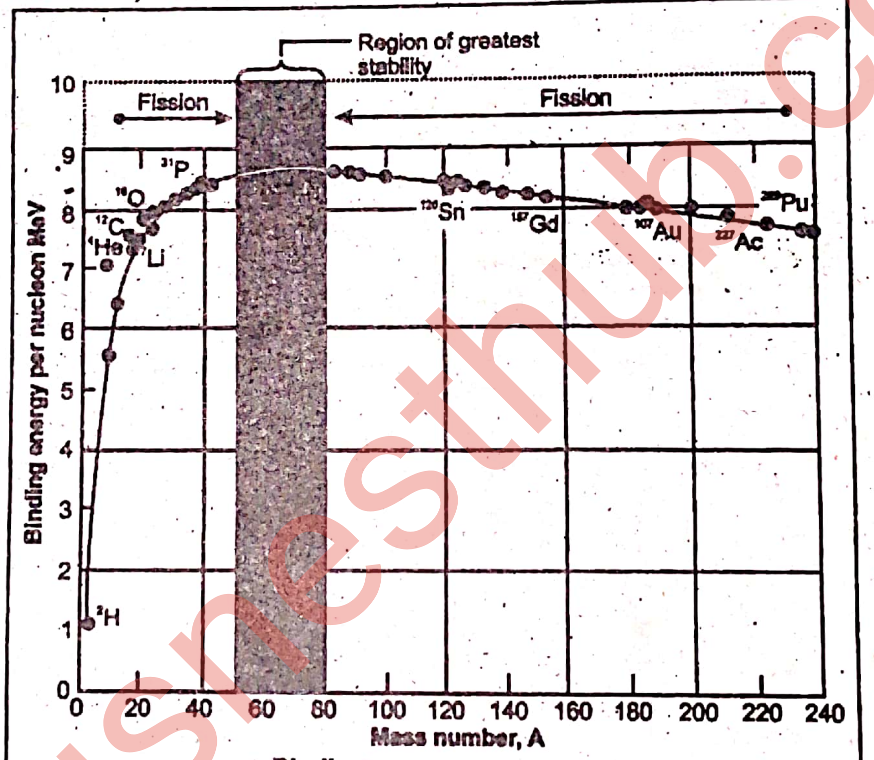
For example, the mass of a helium nucleus which consists of two protons and two neutrons is **0.8% less than the** mass of two protons and two neutrons separated from each other. This difference is called the mass defect of the nucl and is due to the protons and neutrons binding together when the nucleus was formed. The binding energy of the nucle can be calculated from the mass defect using Einstein's famous equation $E = mc^2$.

Binding energy = mass defect × c^2 ... (2)

Nuclear masses are usually expressed in atomic mass unit (u).

2. The binding energy E_b (in MeV) = in MeV) = 1 × Δm
3. The binding energy per nucleon = $\frac{E_b}{A}$ (Packing fraction)
4. The binding energy per nucleon of a nucleus is the binding energy of a nucleus divided by the number of nucleons (i.e. protons and neutrons) in the nucleus.
5. This quantity is a measure of the stability of a nucleus. It can be easily calculated for any nucleus $_ZX^A$ of known mass M by following the steps below:
6. A graph of binding energy per nucleon number A is shown in fig 20.2 Remember that greater the binding energy per nucleon of a nucleus is, the more stable the nucleus is the graph shows that

⊙ In Pre board! explain graph.
⊙ which more stable nuclei.
→ Ex. (Iron)



Binding energy curve

When a $_{92}U^{235}$ nucleus undergoes fission, the two fragment nuclei each comprise about half the number of nucleons. Therefore the binding energy per nucleon increases from about 7.5 MeV per nucleon for $_{92}U^{235}$ to about 8.8 MeV per nucleon for the fragments.

Thus the binding energy per nucleon increases by about 1 MeV for every nucleon which means that the energy released from the fission of a single fissionable nucleus is about 200 MeV. The mass of a $_{92}U^{235}$ nucleus is about 4 × 10^{-25} kg.

Note: Factors which increases the Binding energy.

- The binding energy per nucleon is maximum for iron. So iron is the most stable of all the elements.
- Mass defect of ^1_1H is zero and its binding energy is also zero.

MCQ's From Past Board Papers

1. **One amu is equal to**

(A) 931 MeV (B) 9.31 MeV (C) 93.1 MeV (D) 0.931 MeV

3. **Binding energy for deuteron nucleus is given by:**
(A) 2.8 MeV (B) 2.23 MeV (C) 2.28 MeV (D) 2.25 MeV

4. **1 Kg mass will be equivalent to Energy**
(A) 9×10^{8} J (B) 9×10^{12} J (C) 9×10^{18} J (D) 9×10^{16} J

5. **0.1 Kg is equivalent to the energy of**
(A) 5×10^{8} J (B) 6×10^{15} J (C) 9×10^{18} J (D) 9×10^{15} J

The binding energy per nucleon is maximum for:
(A) Helium (B) Iron (C) Polonium (D) Radium

Answers Key

1. A	2. B	3. C	4. D	5. B

Q.6 What do you understand by radioactivity? Give an account of three types of radiations i.e., α, β and γ emitted from radioactive substances.

Radioactivity

Radioactivity

The elements having charge number Z > 82 are unstable. They emit invisible radiation which effect the photographic plate. Such elements are called radioactive elements and the process is called radioactivity.

The radiations emitted by radioactive elements are of three types named as α, β and γ.

Radioactivity is a purely nuclear phenomenon. It is not affected by physical or chemical reaction.

Radioactivity does not depend upon physical state of the radioactive material such as **temperature, pressure, density etc.**

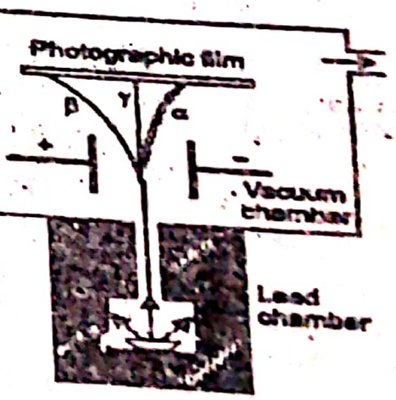
Nuclear radiations

Discovery

Radioactivity was discovered by **Henri Becquerel** in **1896**. He found that an ore containing Uranium (Z = 92) emits an invisible radiation which penetrates through a black paper wrapping a photographic plate, and affects the plate.

After Becquerel's discovery **Marie Curie and Pierre Curie** discovered two new radioactive elements **Polonium and Radium.**

Becquerel and the curies were awarded the noble prize in physics for their discoveries 1903.



Explanation

The radioactive material is placed at the center of a block of lead by drilling a hole in the block.

Radioactive radiations enter a vacuum chamber after emerging out of this hole. After passing between the two parallel charged plates, the radiations strike a photographic plate at three different points.

Conclusion

From this experiment we conclude that:

(i) All radiations from radioactive material are not alike (same).
(ii) The radiations bending towards the –ve plate are positively charged particles; called α-particles.
(iii) The radiations bending towards the +ve plate are negatively charged particles; called β-particles.
(iv) The radiations that go straight without bending have no charge on them. These are called γ-rays.

α-Particles:

They are helium nuclei. Each α-particle has 2-protons and 2-neutrons.

charge number Z = 2
mass number A = 4

a. Is easily stopped by cardboard or thin metal.

b. Has a range in air of no more than a few centimeters.

c. Ionizes air molecules much more strongly than the other two types of radioactive radiation.

β-Particles:

They are fast moving electrons (i.e.,) coming out of nucleus.

charge number $Z = -1$
mass number $A = 0$

a. Is stopped by 5 – 10 mm of metal.

b. Has a range in air of about 1m.

c. Ionizes air molecules less strongly than α-particles.

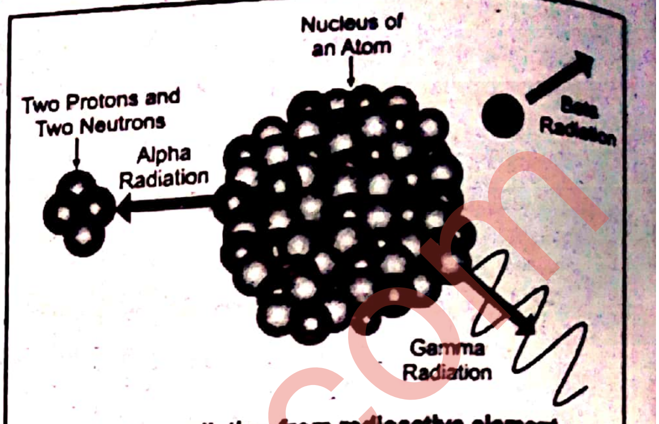
γ-Rays:

Like x-rays, γ-rays are electromagnetic rays coming out of nucleus. The wavelength of γ-rays is much shorter than the X-rays. They have very high frequency.

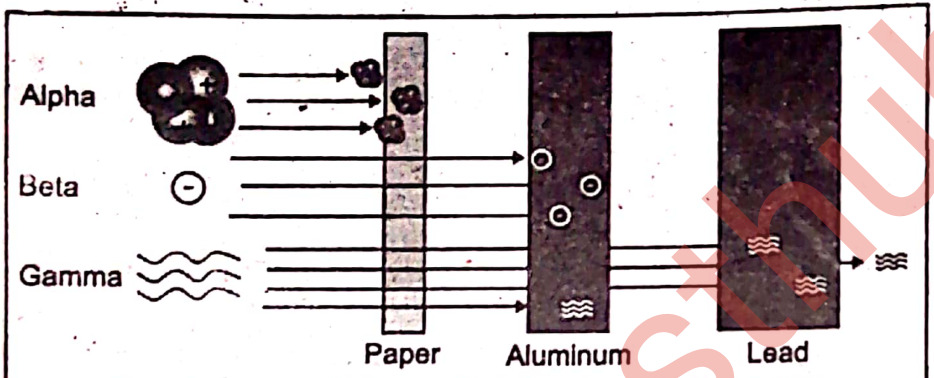
a. Is stopped only by several cm of lead.

b. Has an infinite range in air.

c. Ionizes air molecules very weakly.



Nuclear radiation from radioactive element.



Three forms of radiations with different penetration power

(ii) $_xX^A - \beta \rightarrow R^A_{z+1}$

(i) $_zX^A - \alpha \rightarrow R^{A-4}_{z-2} + Q$

Alpha Emission

Whenever an atom $_ZX^A$ disintegrates by α-emission, its atomic number reduces by 2 and the mass number reduces by 4 units. The disintegration reaction is, written as,

$$_ZX^A \longrightarrow {}_{Z-2}Y^{A-4} + {}_2He^4 + Q$$

Q is the disintegration energy. Which is always positive, as the process is spontaneous. The decay product $_{Z-2}Y^{A-4}$ is called the daughter nucleus of the parent nucleus $_ZX^A$. The α particle is often written as $_2He^4$. The daughter nucleus may also remain unstable and undergo further disintegration till it attains stability. Following are examples of α decay.

$$_{92}U^{238} \longrightarrow {}_{93}TH^{234} + {}_2He^4 + Q$$

$$_{88}Ra^{226} \longrightarrow {}_{86}Rn^{222} + {}_2He^4 + Q$$

Beta Emission

The process of β emission involve no change in mass number A. It does, however, change the atomic number Z by −1 or +1 depending upon whether the particle emitted is negative β particle (electron) or positive β-particle (positron). Thus the β disintegration may lead to either of the following disintegration.

$$_ZX^A \longrightarrow {}_{Z+1}X^A + {}_{-1}\beta^0 + \text{antineutrino} + Q_1$$

$$_ZX^A \longrightarrow {}_{Z-1}X^A + {}_{+1}\beta^0 + \text{neutrino} + Q_1$$

As an example of negative β emission is the decay of thorium into protactinium:

$$_{90}Th^{234} \longrightarrow {}_{91}Pa^{234} + {}_{-1}\beta^0 + \text{antineutrino} + Q_1$$

The prototype of β decay is the decay of neutron itself. The neutron, in free space, is unstable, decaying to proton and electron with a half life of 12 minutes.

$$_0n^1 \longrightarrow {}_1H^1 + {}_{-1}\beta^0 + \text{antineutrino}$$

The best known example of β decay is from the naturally occurring isotope of C^{14}.

$${}_6C^{14} \longrightarrow {}_7N^{14} + {}_{-1}\beta^0 + \text{antineutrino}$$

As an example of a positron emitter is carbon 11, which decay by the reaction;

$${}_6C^{11} \longrightarrow {}_5B^{11} + {}_1\beta^0 + \text{neutrino}$$

Gamma Emission

Most frequently the alpha or beta emission leaves the daughter nuclide in **an exited state. Such a nuclide may go back to a more stable configuration** and eventually to its ground state by emitting one or more γ-rays. Since γ-rays are massless photons, their emission will cause no change either in A or Z of the parent nuclide. The γ-decay process is written as follows:

$${}_ZX^A \longrightarrow ({}_ZX^A)^* \longrightarrow {}_ZX^A + \gamma$$

Where $({}_ZX^A)^*$ represents an excited state of the nucleus.

Spontaneous and Random Nuclear Decay

We know that radioactive elements disintegrates and emit α, β and γ radiations.

This process is called **transmutation by spontaneous disintegration.**

- In this process each of the nuclei of a radioactive sample has a probability of decay into a **daughter nucleus.**
- The probability of decay of all nuclei per unit time is the same and has a fixed value, characteristics of material.
- The decay probability of one nucleus is quite independent of that of another nucleus. So in the natural spontaneous disintegration of a radioactive material not all the atoms disintegrates at the same time. Contrary, different atoms decay at different times.
- The process of disintegration takes place randomly.
- When a nucleus disintegrates, nobody knows when it will decay.
- It is observed that, on the number of decaying atoms at any instant, is proportional to the number of atoms present at that time. As time passes, some nuclei disintegrates and other survive. So the activity continues but with ever decreasing intensity.

Q.7 What is meant by half life of a radioactive element? How it can be determined by the decay of radioactive element?

Half-life and rate of decay

Definition: The time during which half of the atoms radioactive element decay is called half-life.

- The half-life of a radioactive isotope is the time taken for half the number of atoms of the isotope to disintegrate. Suppose 10000 atoms of a certain radioactive isotope “X” are present initially. The number of atoms decreases.

  From 10000 to 5000 after first half life, then

  From 5000 to 2500 second a further half life, then

  From 2500 to 1250 third a further half life, etc.

The amount of the un-decay radioactive isotope therefore decreases with time as shown in fig: 20.4 which is a half-life curve. Half-life values range from a fraction of a second to billions of years.

For example, the **half-life of polonium 212 is 3×10^{-7} s and that of lead 204 is 1.4×10^{7} years.**

- This radioactive decay process is quite random. We cannot foretell about any particular atom as to when will it decay. It would decay immediately or it may remain unchanged for millions of years. Hence, we do not talk about a single atom, but we talk about the group of atoms.
- **The decay process is independent of temperature and pressure.**
- **For complete decay of an element an infinite time is required.**

Determination of half life by a graph

At $t = 0$ the number of atoms in a given sample of radioactive element is N_o.

After one half life $T_{1/2}$ the remaining number of atoms $= \dfrac{N_o}{2} = \dfrac{1}{2}N_o$

After 2nd half-life $2T_{1/2}$ the remaining number of atoms $= \frac{1}{2}\left(\frac{N_o}{2}\right) = \frac{1}{4}N_o = \left(\frac{1}{2}\right)^2 N_o$

After 3rd half-life $3T_{1/2}$ the remaining number of atoms $= \frac{1}{2}\left(\frac{N_o}{4}\right) = \frac{N_o}{8} = \left(\frac{1}{2}\right)^3 N_o$

Similarly

After n^{th} half-life the remaining number of atoms is $= \left(\frac{1}{2}\right)^n N_o$

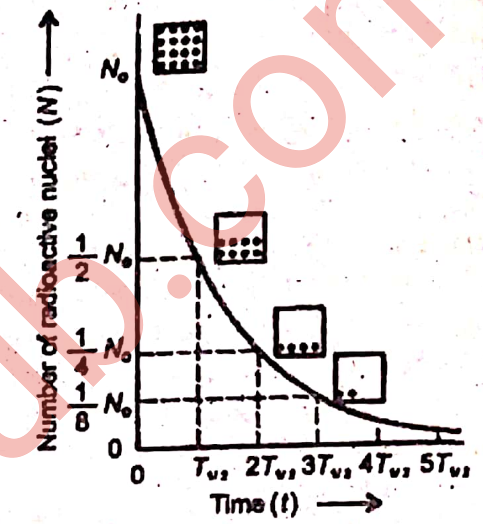
It has been found experimentally that the number of decaying nuclei ΔN is proportional to original number of atoms N and decay time Δt.

$$\frac{\Delta N}{\Delta t} \propto -N$$

$$\frac{\Delta N}{\Delta t} = -\lambda N \qquad \dots (1)$$

Where λ is a constant of proportionality which depends on the nature of the element and is called decay constant.

And the negative sign signifies that N decreases with time, that is, ΔN is negative.



The half time $T_{1/2}$ of a radioactive decay is the time in which one-half of the radioactive nuclei disintegrate

Definition of decay constant λ:

The fraction of decaying atoms per unit time is called decay constant and its unit is s^{-1}.

Dimensions of decay constant = $[T^{-1}]$

The value of λ for any isotope determines the rate of decay.

***The decay rate, or activity R, of a sample is defined as the number of* decaying atoms per second. From equation (1) the decay rate is**

$$R = -\frac{\Delta N}{\Delta t} = \lambda N \qquad \dots (2)$$

Thus we [illegible] that isotopes with a large value of λ decay at a rapid rate in those with a small λ value decay slowly. A gener [illegible] cay curve for a radioactive sample shown in figure (20.4a). One can show from equation (2) that the number of nucle [illegible] sent varies with time according to the expression.

$$N = N_o e^{-\lambda t} \qquad \dots (3)$$

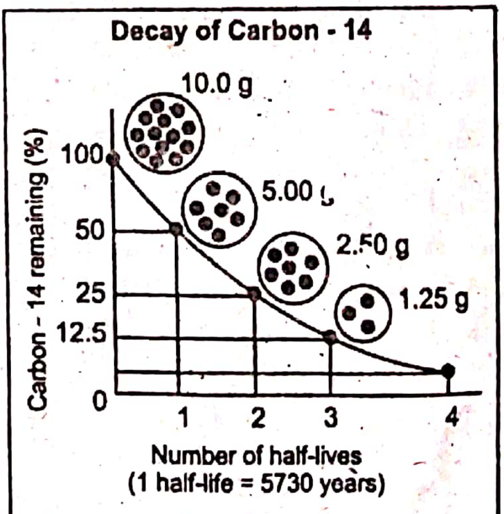
Where N is the number of radioactive nuclei present at time t, N_o is the number present at time. T = 0, and e = 2.718... is the base of the natural logarithm. Processes that obey equation (3) are sometimes said to **undergo exponential decay. This is known as decay law of radioactive element.** The unit of activity is the curie (Ci), defined as

$$1\text{Ci} = 3.70 \times 10^{10} \text{ decay/s}$$

The S.I. unit of the activity is the Becquerel (Bq):

1 Bq = 1 decay per second

$$1\text{ Ci} = 3.70 \times 10^{10} \text{ Bq}$$



Half - life curve

By substituting $N = \frac{1}{2}N_o$ and $T = T\frac{1}{2}$ in the equation (3), we find that

$$\frac{1}{2}N_o = N_o e^{-\lambda T\frac{1}{2}}$$

$$\frac{1}{2} = e^{-\lambda T\frac{1}{2}}$$

$$2 = e^{\lambda T\frac{1}{2}}$$

Take natural logarithm of both sides and note that ln e = 1. We find that

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

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

$$T_{1/2} = \frac{0.693}{\lambda} \qquad \ldots (4)$$

▶ This is the relation between the decay constant λ and the half-life T ½.

The half-life for radioactive isotope C^{14} **is 5730 years**, it means in 5730 years the 10g of carbon disintegrated to 5g and 5g remain in given sample. As the time passes, the amount of remaining substance decreases but never reached to zero. The value of half-life is constant for each radioactive element and it is possible to characterize the element by using its half-life value.

The rate of radioactive decay is directly proportional to the stability of the isotope. The half-life is a measurement of stability of radioactive elements. **The half-life of U^{238} is 4.5×10^9 years.** So C^{14} is far less stable than U^{238}.

MCQ's From Past Board Papers

1. **Half life of U-238 is:**
(A) 2.5×10^{9} years (B) 3.5×10^{9} years (C) 4.5×10^{9} years (D) 5.5×10^{9} years

2. **Half life of Uranium - 239 is:**
(A) 26.5 minutes (B) 24.5 minutes (C) 25.5 minutes (D) 23.5 minutes

3. **Half life of radon gas is**
(A) 3.8.minutes (B) 3.8 days (C) 3.8 months (D) 18 years

4. **If $^{233}U_{92}$ is decayed twice by α-emission, then the resulting isotope is:**
(A) $^{229}Y_{92}$ (B) $^{233}Y_{88}$ (C) $^{233}Y_{92}$ (D) $^{225}Y_{88}$

5. **A sample contains N radioactive nuclei. After 4 half lives number of nuclei decayed is____.**
(A) $\frac{N}{16}$ (B) $\frac{15N}{16}$ (C) $\frac{N}{8}$ (D) $\frac{7N}{8}$

6. **The half-life on n $^{91}_{38}Sr$ is 9.70 hours. What is its decay constant?** **(Fed 2011, Fed 2012)**
(A) $1.98 \times 10^{-5}\ s^{-1}$ (B) $1.6 \times 10^{-4}\ s^{-1}$ (C) $2.5 \times 10^{-5}\ s^{-1}$ (D) None of these

7. **Half life of a radioactive element T½ is given by:** **(Federal 2017, Federal 2011)**
(A) 0.693λ (B) $\frac{0.693}{\lambda}$ (C) $\frac{\lambda}{0.693}$ (D) $\frac{1}{0.693\lambda}$

8. **When γ-rays are emitted, the nuclear mass**
(A) Decreases by 4 units (B) Does not change (C) Increases by 2 units (D) Increases by 1 unit

9. **The activity of radioactive sample :**
(A) is constant (B) Increases with time
(C) Decreases linearly with time (D) Decreases exponentially with time

10. **1 a.m.u. is equal to**
(A) 1.66×10^{-19} kg (B) 1.66×10^{-24} kg (C) 1.66×10^{-27} kg (D) 1.66×10^{-34} kg

11. **The units of decay constant is**
(A) Second (B) $(\text{Second})^{-1}$ (C) m^{-1} (D) mk

12. **When a nucleus emits an alpha particle, its atomic mass decreases by**
(A) 1 (B) 2 (C) 3 (D) 4

13. **The half life of I^{131} is;**
(A) 6 days (B) 7 days (C) 8 days (D) 9 days

14. **Marie Curie and Pierre curie discovered**
(A) Uranium (B) Uranium and radium (C) Polonium and Radium (D) Radium

15. **The decay constant of a radioactive element depends upon**
(A) nature of material (B) temperature of material (C) pressure on material (D) dimensions of material

16. **Which of the following is similar to electron**
(A) α-particles (B) β-particles (C) neutron (D) protons

17. **The element formed by radioactive decay is called**
(A) Father element (B) Mother element (C) Parent element (D) Daughter element

18. After two half-lives the number of decayed nuclei of an element are

(A) N (B) $\frac{N}{2}$ (C) $\frac{N}{4}$ (D) $\frac{3N}{4}$

Answers Key

1. C	2. D	3. B	4. D	5. B	6. A	7. B	8. B	9. D	10. C	11. B	12. D
13. C	14. C	15. A	16. B	17. B	18. D						

Q.8 Discuss interaction of α, β and γ rays and neutrons with matter.

Interaction of Radiations with Matter

Interaction of α -Particles with Matter

1. The distance covered by α-particle in a medium before coming to rest is called **the range of** the α-particle.

   Range depends upon:

   (i) Charge, mass and energy of the particle and

   (ii) The density of the medium and ionization potentials of the atoms of the medium.

2. As the particle passes through a solid, liquid or gas it loses energy **due to excitation and ionization of atoms and molecules in the matter.**
3. The ionization may be due to **direct elastic collisions or through electrostatic attraction.**
4. Ionization is the main interaction with matter to detect the particle or to measure its energy.
5. Since **α-particle is about 7000 times more massive than an electron**, so it does not suffer any appreciable deflection from its straight path, provided it does not approach too closely to the nucleus of the atom. Thus α-particle continues producing intense ionization along its straight path till it loses all its energy and comes almost to rest. Thus it **captures two electrons** from the medium and becomes a **neutral helium atom.**
6. **Fluorescence** is the property of absorbing radiant energy of the high frequency and re-emitting energy of low frequency in the visible region of electromagnetic spectrum.
7. α-particles produce fluorescence or glow on striking some substance like Zinc sulphide, Sodium iodide or Barium platinocyanide coated screens.

Interaction of β-Particles with Matter

1. β-particles also lose energy by producing ionization.
2. Its ionization ability is **100 times less than that of α-particles.**
3. So **its range is 100 times more than α-particles.**
4. β-particles are more easily deflected by collisions than heavy α-particles. So, the path of β-particles in matter is not straight but it is much struggling or scattering.
5. The range of β-particles is measured by the **effective depth of penetration into the medium** not by the length of erratic path (zig zag).
6. The more dense the material through which β-particles pass, the shorter its range will be
7. β-particles produce fluorescence in some substance like **Zinc sulphide, Sodium iodide or Barium platinocyanide** coated screens.

Interaction of γ-rays with Matter

1. γ-ray photons produce very little ionization because it has no charge.
2. Photons are removed form a beam by either scattering or absorption in the medium.
3. γ-rays interact with matter in three ways, depending on their energies.

   (a)At Low Energies (**Less than about 0.5 MeV**) the dominant process is **Photoelectric Effect.**

   (b)At Intermediate Energies (**between 0.1 MeV – 1 MeV**) the dominant process is **Compton Scattering**).

   (c) At Higher Energies (**more than 1.02 MeV**) the dominant process is **pair production.**

4. In air γ-rays intensity 'I' falls off as **the inverse square** of the distance from the source.

$$\left(I \propto \frac{1}{r^2}\right)$$

5. In solids, the intensity decreases exponentially from its maximum value I_o after passing through a distance

x in the medium is reduced to intensity I given by the relation,

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

Where μ is the linear absorption coefficient of the medium (solid).

μ depends upon the energy of the particle as well as on the properties of the medium.

6. γ-particles produce fluorescence or glow on striking some substance like Zinc sulphide, Sodium iodide or Barium platinocyanide coated screens.

Interaction of Neutrons with Matter

1. Being neutral particles their range is very large. They are extremely penetrating particles.
2. To be stopped or slowed, a neutron must undergo a direct collision with a nucleus or some other particle that has a mass comparable to that of the neutron. Materials such as water or plastic, which contain more low mass nuclei per unit volume are used to stop neutrons.
3. Neutrons produce a very little indirect ionization when they interact with materials containing Hydrogen atoms and knock out protons.

Characteristics	α-particles	β-particles	γ-rays
1. Nature	Helium nuclei of charge 2e	Electrons or positrons from the nucleus of charge ±e	E.M. Waves from excited nuclei with no charge
2. Typical sources	Radon-222	Strontium-94	Cobalt-60
3. Ionization (Ion pairs mm in air)	About 10^4	About 10^2	About 1
4. Range in air	Several centimeters	Several metres	Obeys inverse square law
5. Absorbed by	A paper	1-5 mm of Al sheet	1-10 cm of lead sheet
6. Energy spectrum	Emitted with the same energy	Variable energy	Variable energy
7. Speed	$\sim 10^7$ ms^{-1}	$\sim 1 \times 10^8$ ms^{-1}	$\sim 3 \times 10^8$ ms^{-1}

MCQ's From Past Board Papers

1. Minimum energy required for pair production is
(A) 0.51 MeV (B) 0.81 MeV (C) 1.02 MeV (D) 1.05 MeV

2. When a nucleus emits an alpha particle, its atomic mass decreases by
(A) 1 (B) 2 (C) 3 (D) 4

3. Which particle has large range in air:
(A) α-particles (B) γ-particles (C) β-particles (D) Neutron

4. Cobalt 60 emits γ-rays of energy (Fed 2013)
(A) 117 MeV (B) 11.7 MeV (C) 1.17 MeV (D) 1.17 GeV

5. When α–particle is emitted from any nucleus, its mass number _____ and its charge number_____.
(A) increases by 2, increased by 2 (B) decreases by 4, increases by 2
(C) decreases by 4,decreases by 2 (D) decreases by 4, decreases by 4

6. At higher energies more than 1.02 MeV, the dominant process is:
(A) Compton scattering (B) Pair production (C) Photo electric effect (D) Annihilation

7. Which of the following have no charge?
(A) α–rays (B) β–rays (C) γ–rays (D) Cathode rays

8. Fluorescence is the property of:
(A) High frequency particles (B) moderate frequency particles (C) Low frequency particles (D) visible light

9. Extremely penetrating particles are:
(A) neutrons (B) α – particles (C) β–particles (D) γ–particles

10. The charge on β–particle is:
(A) +e (B) –e (C) +2 e (D) none of these

11. By emitting β-particle and γ-particle simultaneously the nucleus changes its charge by:
(A) Losses by 1 (B) Increases by 1 (C) Increases by 2 (D) No change will be observed

12. The emission of α-particle from $^{226}_{88}Ra$ results into the formation of new element $^{A}_{Z}Y$ in a reaction [$^{226}_{88}Ra \rightarrow ^{A}_{Z}Y + \alpha$]. (Fed 2014)
where $^{A}_{Z}Y$ stands for ________.
(A) $^{230}_{88}Y$ (B) $^{224}_{84}Y$ (C) $^{222}_{86}Y$ (D) $^{226}_{84}Y$

13. Which is true for both α–particles and γ–rays:
(A) They cause ionization in air
(B) They can be deflected by electric field
(C) They can be deflected by magnetic field
(D) They can penetrate a few millimeter of aluminum

14. The mass of β particle is equal to the mass of:
(A) Proton (B) Neutron (C) Electron (D) Photon

15. Speed of β particles is nearly equal to
(A) 1×10^8 m/s (B) 10^7 m/s (C) 3×10^8 m/s (D) 10^6 m/s

16. α – particle carries a change:
(A) –e (B) + 2e (C) –2e (D) no charge

17. Gamma rays from cobalt-60 are used for the treatment of:
(A) Circulation of blood (B) Cancer (C) Heart attack (D) Thyroid glands

18. γ-emission from the nucleus of an atom causes a
(A) Change in Z (B) Change in A (C) Change in both A and Z (D) No change in A and Z

19. In Beta decay, ___ reaction takes place.
(A) $^{1}_{0}n \rightarrow ^{1}_{1}H + ^{0}_{1}e$ (B) $^{3}_{1}H \rightarrow ^{1}_{0}H \rightarrow ^{1}_{0}n + ^{0}_{-1}e$ (C) $^{1}_{0}n \rightarrow ^{2}_{1}H + ^{0}_{-1}e$ (D) $^{1}_{0}n \rightarrow ^{1}_{1}H + ^{0}_{-1}e$

20. By emitting β-particle and γ-particle simultaneously the nucleus changes its charge by:
(A) –1 (B) +1 (C) –2 (D) +2

Answers Key

1. C	2. D	3. B	4. D	5. C	6. B	7. C	8. A	9. A	10. B	11. B	12. C
13. A	14. C	15. A	16. B	17.B	18. D	19. D	20. B				

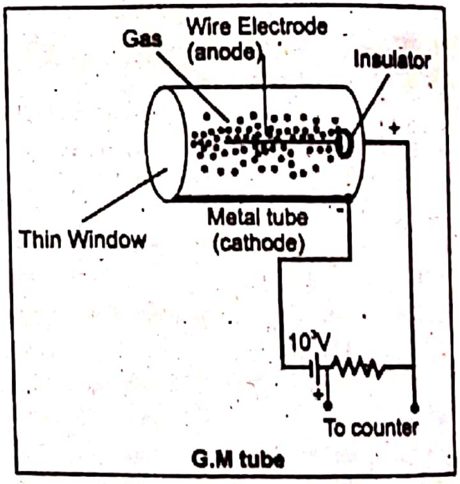
Q.9 What are radiation detectors? Describe the principle, construction and working of G.M. Counter.

Radiation Detectors

Various devices have been developed for detecting radiations. They are used for a variety of purposes including medical diagnosis, radioactive dating measurement and the measurement of background radiations.

Geiger-Muller Counter

The Geiger-Muller counter (Fig 20.5) is perhaps the most common device used to detect radiations.



Principle

The discharge in the tube is produced due to the ionization produced by the incident radiation.

Construction

It consists of a cylindrical metal tube filled with gas at low pressure and a long wire along the axis of the tube. The wire is maintained at a high positive potential (about 1000V) with respect to the tube.

Working

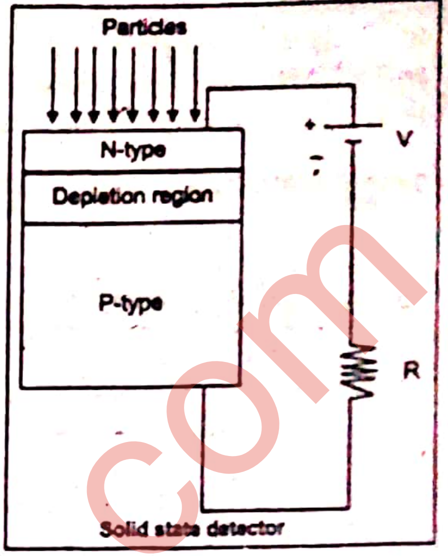
When a high energy particle or photon enters the tube through a thin window at one end, some of the atoms of the gas become ionized. The electrons removed from the atoms are attracted towards the wire, and in the process they ionize other atoms in their path. This results in an avalanche of electrons, which produces a current pulse at the output of the tube. After the pulse is amplified, it can be either used to trigger an electronic counter or delivered to a loudspeaker which clicks each time a particle enters the detector.

Dead Time:

The positive ions take several hundred times as long to reach the outer cathode, because positive ions are very massive than the electrons. During this time further incoming particles cannot be counted. This time is called the dead time (10^{-4} s) of the counter.

Q.10 Describe the principle, construction and working of solid state detector.

Solid State Detector



Solid state detector

A solid state detector or **semi-conductor diode detector is essentially a** reversed-biased P-N junction (Fig 20.6).

Principle

It is based upon the principle that when radiation is allowed to enter the depletion region, **electron hole pairs are produced.**

Construction

A solid state detector is a **specially designed pn-junction** as shown in figure.

It is **connected in reverse bias** so that no current can flow through it when radiations are not falling on it .

A P-N junction diode is a device which passes current readily when forward-biased and impedes the flow of current when reversed-biased.

Working

As an energetic particle passes through the junction, and electrons holes are simultaneously created. **The internal electric field sweeps the electrons towards the side of the junction connected to positive side of the battery and the holes are swept toward the negative side.** This creates a pulse of current that can be measured with any electronic counter. In a typical device, the duration of the pulse is about 10^{-7} s.

USES

(i) The production of a current pulse requires a small amount of energy roughly 3.0 eV to 4.0 eV. So, the device is practically useful for detecting low energy particles.

(ii) The collection time of electrons and holes is much less than gas filled counters (such as Geiger counter) and hence solid state counter can count very fast.

(iii) It is small in size than any other detector and operates at low voltage.

(iv) The solid state detectors are more useful to detecting α and β-particles where as a specially designed detector and an amplifier can also be used for high energy γ-rays.

MCQ's From Past Board Papers

1. The dead time of G.M tube is:
(A) 10^{-1} sec (B) 10^{-6} sec (C) 10^{-4} sec (D) 10^{-8} sec

2. Energy needed to produce to electron - hole pair in solid state detector is
(A) 1 to 2 eV (B) 3 to 4 eV (C) 6 to 7 eV (D) 8 to 9 eV

3. Solid state detector is basically ________. **(Fed 2012)**
(A) NPN Transistor (B) PNP Transistor (C) PN Junction (D) LED

4. A device that shows the visible path of ionizing particles is called
(A) Gm counter (B) Solid state detector (C) Scalar (D) Wilson cloud chamber

5. In nuclear radiation, track of α particles is
(A) Thin (B) Discontinuous (C) Erratic (D) Continuous

Answers Key

1. C	2. B	3. C	4. D	5. D

Q.11 Write a detailed note on Nuclear Reactions.

Nuclear Reactions

The process which changes the structure of the nucleus by the bombardment of a target nucleus with some fast moving particles such as proton, neutron, α-particles are called nuclear reactions.

When a nucleus "X" is bombarded with some light particle "*a*", nuclear reaction take place, the product nucleus "Y" and a light particle "b" will be obtained. This will be represented by the equation.

$$X + a \longrightarrow Y + b$$

Rutherford was the first to observe nuclear reaction in 1919, using naturally occurring radioactive sources for the bombarding particles. He bombarded α-particles on nitrogen. He observed that as result of this reaction, oxygen is obtained and a proton is emitted. That is

$${}_7N^{14} + {}_2He^4 \longrightarrow {}_8O^{17} + {}_1H^1 + Q \qquad (1)$$

The energy equivalent of the difference between the rest masses of elements on the L.H.S and those on the R.H.S

is called the nuclear reaction energy and is denoted by "Q". Basically, "Q" represents the energy absorbed or evolved in any reaction.

- **If "Q" is negative, energy is absorbed in the reaction (endothermic reaction)**
- **If "Q" is positive, energy is evolved in the reaction (exothermic reaction).**
- If "Q" is negative, the energy required to complete the reaction is usually provided by the K.E of the incoming particle unlike the case of chemical reaction, where the energy is usually provided by heating.

Conservation Laws in a Nuclear Reaction

In any nuclear reaction the following conservation laws must be obeyed. These laws form the guiding principles in determining which isotopes are formed during a nuclear reaction.

Conservation of atomic and mass number

Before and after any nuclear reaction the number of protons and neutrons must remain the same because protons and neutrons can neither be created nor destroyed using equation 1), we have

The number of nucleons on the L.H.S. = The number of nucleons on the R.H.S.

Number of protons = 7 + 2 = 8 + 1

Number of neutrons = 7 + 2 = 9 + 0

Number of nucleons = 18 = 18

Conservation of mass-energy

The conservation of number of nucleon does not imply the conservation of mass because the mass numbers differ from the atomic masses and the difference provides the **binding energy to nucleons in the nucleus.**

From Einstein's mass-energy relation it the principle of conservation of energy in mechanics is extended to the conservation of mass-energy in nuclear reactions.

Based on the above conservation laws one can determined the (i) energy absorbed or liberated in any nuclear reaction and (ii) the product nucleus formed etc.

Let us calculate the reaction energy for the reaction given by equation (1).

The rest mass of various particles on addition is

$$_2He^4 = 4.00263u \qquad _8O^{17} = 16.999133u$$

$$_7N^{14} = \frac{14.003074u +}{18.005677} \qquad _1H^1 = \frac{1.007825u +}{18.006958u}$$

Difference in rest masses before and after the reaction.

$$= 18.005677 - 18.006958$$
$$= -0.001281u$$
$$Q = -0.001281 \times 931$$
$$Q = -1.192 \text{ MeV}$$

Since "Q" is negative, the α-particle **must have K.E 1.192 MeV for this reaction to occur.** If the particle has less energy, this transformation will not take place. Usually the α-particles, i.e., more than 1.192 MeV, appears, as the K.E of product particles or nuclei.

Q.12 Write a detailed note on Nuclear Fission.

Nuclear Fission

Such a reaction in which a heavy nucleus like Uranium $^{235}_{92}U$ splits-up into two intermediate nuclei along with the emission of energy is called Fission Reaction.

Explanation:

In 1939 two German Scientists made a very important discovery. Their names are Otto Hahn and Frtiz Strassmann. They bombarded Uranium −235($^{235}_{92}U$) with slow neutrons. A nuclear reaction took place. As a result, Barium $^{141}_{92}Ba$ and Krypton $^{92}_{36}Kr$ were formed and on the average 3 neutrons were released along with the release of 200 MeV energy.

This nuclear reaction is different from other nuclear reactions in two way:

(i) As a result of breakage of the Uranium nucleus two nuclei of almost equal size are obtained.

(ii) A very large amount of energy is released.

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

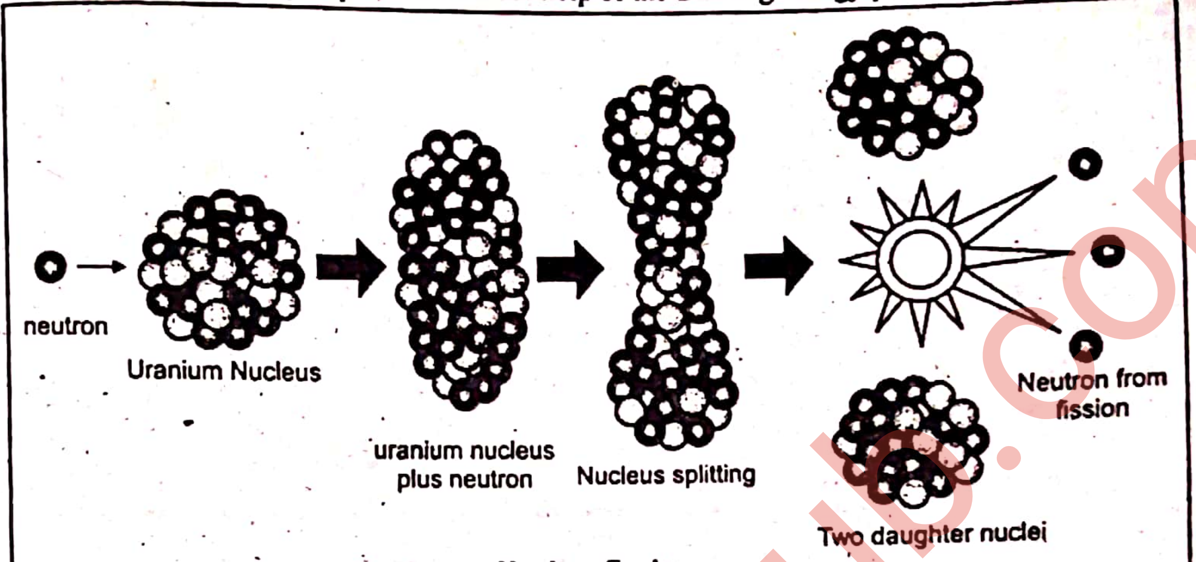
(Q = 200 MeV)

Q = 200 MeV of energy comes from the difference in the mass of reactants and mass of products.

Note: Charge number is conserved in the reaction $92 + 0 = 56 + 36$

Mass number is conserved in the reaction $235 + 1 = 141 + 92 + 3$

Fission reaction can be easily explained with the help of the Binding energy per nucleon curve as shown in figure.



Nuclear fission

Only U^{235} undergoes this process of fission-though naturally occurring uranium has 99.3% of U^{238} and 0.7% of U^{235}.

- We shall see that in this process there is a decrease in the mass of the system and hence energy is released.
- Since this process can be started automatically, it can be controlled and the energy liberated provides a good source of energy.
- Where Q, is the energy of reaction which can be calculated from the value of rest masses of different nuclei. The calculation is given below

Initial masses	Final masses
$U^{235} = 235.0439$ u ${}_0n^1 = 1.0087$u + 236.0526 u	$Ba^{141} = 140.9139$ u $Kr^{92} = 91.8973$ u $3{}_0n^1 = 3.0261$u + 235.8373 u

The decrease in mass = 236.0526 − 235.8373 = 0.215 u

$$Q = 0.215 \times 931 \text{ MeV} = 200 \text{ MeV}$$

Therefore, when one atom of U^{235} undergoes fission 200 MeV of energy is released.

- If 1g of naturally occurring uranium, which has about 10^{19} atoms of U^{235} undergoes fission the total energy released would be 200×10^{19} MeV $= 3.2 \times 10^{8}$ J.
- It is found that 1.0 kg of uranium deliver as much energy as the combustion of about 3000 tons of coal.

Fission Chain Reaction

As mentioned before when one uranium atom undergoes fission it releases 3 neutrons. If more than one of these neutrons is able to cause fission in the other U^{235} nuclei, the number of neutrons will increase rapidly. Thus, a chain reaction can be set up (Fig 20.7(b). The fission would produce at an ever-increasing rate and in a very short time the whole of U^{235} would be transformed with the release of a large amount of energy.

- During fission chain reaction the large energy can cause a violent explosion and destroy every thing that comes in its way.

- **This is the principle of the atom bomb.**
- **If the chain reaction is to start, it is necessary that the mass of uranium must be greater than some minimum mass called the critical mass or critical size.**

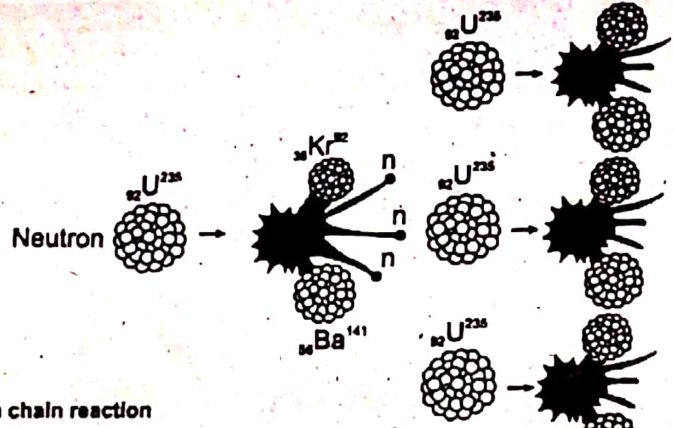


Figure: Nuclear fission chain reaction

Figure: Uranium ore rock

Q.13 What is nuclear reactor? Describe function of its main parts and types of reactor.

Nuclear Reactors

It is a device in which nuclear fission chain reaction takes place at a constant rate in a controlled manner. It is used to produce nuclear energy for industrial and other useful purposes.

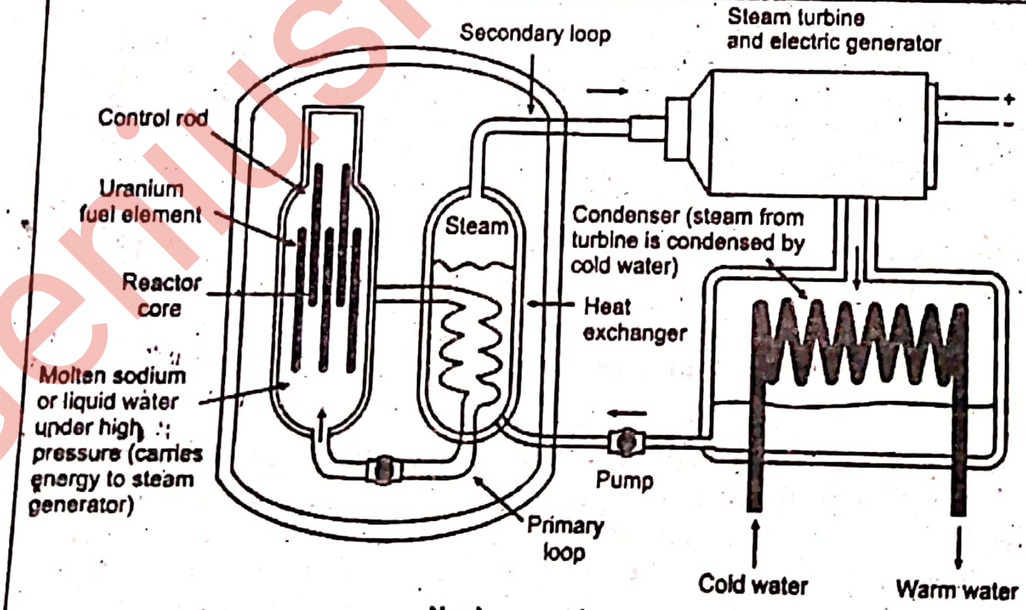
- The first reactor was installed and operated by **Fermi and his co-workers in 1942 in the USA**

Principle:

Controlled Fission Chain Reaction is the principle of a nuclear reactor.

Explanation:

The role of a reactor in a nuclear power station is the same as that of a furnace in a thermal power station. Heat energy is produced in Fission Reaction. This energy is used to rotate a turbine. The turbine rotates the generator which produces electricity. The sketch of a nuclear power station is shown in figure.



Nuclear reactor

Basically, it consists of five parts (i) a core of nuclear fuel, (ii) a moderator for slowing down neutrons, (iii) control rods, (iv) coolant or heat exchanger for removing heat in the core, and (v) radiation shielding.

1. **Core:** Nuclear fuel is a material that can be fissioned by thermal neutrons. It can be either one or all of the following isotopes. U^{233}, U^{235} and Pu^{239}. We shall see that when natural uranium is used, plutonium is produced in the nuclear reactor. Usually the fuel is put in different aluminium cans in cylindrical rods placed some distance apart. The fuel cans are separated by the moderator.
2. **Moderator:** The moderator is used to slow down the fast neutrons produced in the fission process when thermal neutrons strike the nuclear fuel. The fast neutrons have many collisions with the materials and come out with thermal energies to strike another fuel can. The material of moderator (i) should be light, and (ii) should not absorb neutrons. **Usually, graphite and heavy water** (water containing deuterium instead of hydrogen) are used as moderators.
3. **Absorbing Rods or Control Rods:**
   These are neutron absorbing rods which control the number of neutrons which produce nuclear fission reaction. For this purpose cadmium or Boron rods are used. These control rods are moved in or out of the reactor core to control neutrons that can initiate further fission. In this way speed of the chain reaction is kept under control.
   In case of emergency or for repair purposes control rods are allowed to fall back into the reactor and thus stop the chain reaction and shut down the reactor.
4. **The coolant**, or heat exchanger, is used to cool the fuel rods and the moderator, and is capable of carrying away large amount of heat generated in the fission process. If the moderator, fuel rods, etc. are not cooled, the heat generated can melt them. The heat carried by the coolant produces steam that can run a turbine, which in turn can run an electric generator as shown in (fig 20.8).

Radiation shielding: The last part of the nuclear reactor is the shielding. Since the neutrons and the fragments in a reactor undergo radioactive decay and produce radiations which are harmful to life, there must be some shielding device to absorb those radiations. For this purpose a concrete wall which in a few feet thick is used.

Types of Reactors

There are two main types of nuclear reactors. These are:

(i) Thermal reactor (ii) Fast reactors

(i) **Thermal reactors:** The thermal reactors are called **"thermal" because the neutron must be slowed down to "thermal energies"** to produce further fission. They use natural uranium or slightly enriched uranium as fuel. Enriched uranium contains a greater percentage of U^{235} than natural uranium does. There are several designs of thermal reactors. **Pressurized water reactor (PWR)**, are most widely used reactors in the world. In this type of reactor, the water is prevented from boiling, being kept under high pressure. This hot water is used to boil another circuit of water which produces steam for turbine rotation of electricity generators.

(ii) **Fast reactor:** Fast reactor are designed to make use of ${}_{92}U^{238}$ which is about 99% content of natural uranium. Each ${}_{92}U^{238}$ nucleus absorbed a fast neutron and change into ${}_{94}Pu^{239}$.

$$ {}_{92}U^{238} + {}_{0}n^{1} \longrightarrow {}_{93}N_{p}{}^{239} + {}_{-1}\beta^{0} $$

$$ {}_{93}N_{p}{}^{234} \longrightarrow {}_{94}P_{u}{}^{239} + {}_{-1}\beta^{0} $$

Plutonium can be fissioned by fast neutrons; hence, moderator is not needed in fast reactors. The core of fast reactors consists of a mixture of plutonium and uranium dioxide. Surrounded by a blanket of U^{238} Neutrons that escape from the core interact with U^{238} in the blanket, producing there by ${}_{94}P_{u}{}^{239}$. Thus more plutonium fuel is bred in this way and natural uranium is used more effectively.

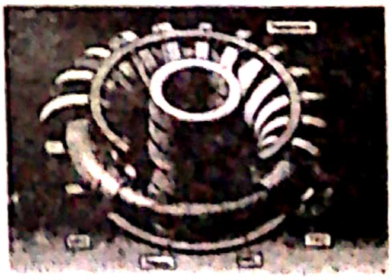
Q.14 Explain nuclear fusion reaction. What are nuclear reactions in the sun?

Nuclear Fusion

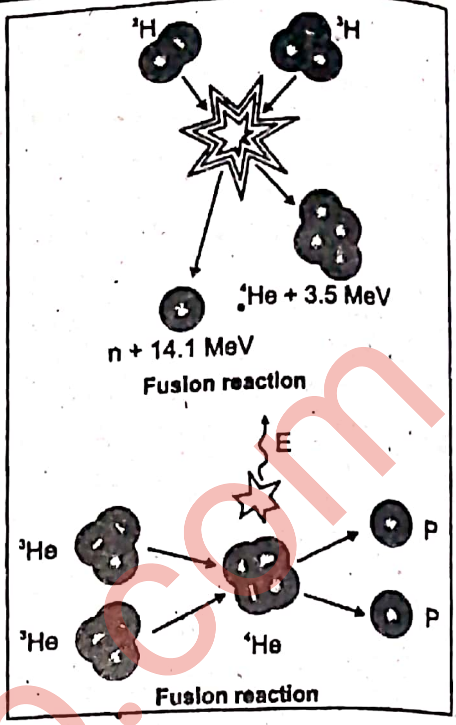
Such a nuclear reaction in which two light nuclei merge to form a heavy nucleus is called fusion reaction.

Let us now take the example of a fusion reaction. When two deuterons (${}_{1}^{2}H$) merge to form a helium nucleus, 24 MeV energy is released during this reaction.

For your Information



Experimental research reactor called tokamaks used for fusion.



$$^2_1H + ^2_1H \longrightarrow ^4_2He + 24\text{ MeV}$$

Figure 20.2 shows that the binding energy for light nuclei (those having a mass number of less than 20) is much smaller than the binding energy for heavier nuclei. This suggests a possible process that is the reverse of fission.

Because the mass of the final nucleus is less than the rest masses of the original nuclei, there is a loss of mass accompanied by a release of energy.

During a fusion reaction, mass is lost which appears in the form of energy and this energy per nucleon is more than the energy released in fission. But at the same time, it is more difficult to start this reaction, because when two light nuclei are brought close to each other then a very large amount of energy is required to overcome this repulsive Coulomb's force. Whereas in fission a neutron being neutral does not need large energy to reach a nucleus.

The basic exothermic reaction in stars, including our own sun- and hence the source of nearly all of the energy in the universe – **is the fusion of hydrogen nuclei into helium nucleus.**

This can take place under stellar conditions in two different series of processes.

- ▶ In one of them, the proton- proton cycle, direct collisions of protons result in the formation of heavier nuclei whose collision in turn yield helium nuclei.
- ▶ The other, the carbon cycle, in a series of steps in which carbon nuclei absorbed a succession of protons until they ultimately disgorge alpha particles to become carbon nuclei once more.

The initial reaction in the proton-proton cycle is

$$_1H^1 + _1H^1 \longrightarrow _1H^2 + e^+ + \nu$$

Where, e^+ is called positron and "ν" is neutrino. A deuteron may then combine with a proton to from a $_2He^3$ nucleus:

$$_1H^1 + _1H^2 \longrightarrow _2He^3 + \gamma$$

Finally two $_2He^3$ nuclei react to produce a $_2He^4$ nucleus plus two protons:

$$_2He^3 + _2He^3 \longrightarrow _2He^4 + _1H^1 + _1H^1$$

The total energy evolved is $(\Delta m)c^2$, where Δm is the difference between the mass of four protons and the mass of an alpha particles plus two positron; it turn out to be 24.7 MeV.

The carbon cycle proceeds in the following way:

$$_1H^1 + _6C^{12} \longrightarrow _7N^{19}$$
$$_7H^{13} \longrightarrow _6C^{13} + e^+ + \nu$$
$$_1H^1 + _6C^{13} \longrightarrow _7N^{14} + \gamma$$
$$_1H^1 + _7N^{14} \longrightarrow _8O^{15} + \gamma$$
$$_8O^{15} \longrightarrow _7N^{15} + e^+ + \nu$$
$$_1H^1 + _7N^{15} \longrightarrow _6C^{12} + _2He^4$$

The net result again is the formation of an alpha particle and two positrons from four protons, with the evolution of 24.7 MeV; the initial $_6C^{12}$ **acts as a catalyst for the process, since it reappears at the end.**

Self-sustaining fusion reactions can occur only under conditions of extreme temperature and pressure, to ensure that the participating nuclei have enough energy to react despite their mutual electrostatic repulsion and that reactions occurs frequently to counter balance losses of energy to the surrounding.

In sun, whose interior temperature is estimated to be 2 × 10^6 K, the carbon and proton-proton cycles have about equal probabilities for occurrence. In general, the carbon cycle is more efficient at high temperature, while the proton-proton cycle is more efficient at low temperature.

Hence stars hotter than the sun obtain their energy the former cycle, while those cooler than the sun obtain the greater part of their energy from the latter cycle.

The energy liberated in the fusion of light nuclei into heavier ones is often **called thermonuclear energy,** particularly when the fusion take place under man's control on the earth neither the proton-proton nor carbon cycle offers any hope of practical application, since their several steps required a great deal of time.

MCQ's From Past Board Papers

1. **In nuclear fission reaction, when the products are ^{140}Xe and ^{94}Sr, the number of neutrons emitted is:**
(A) 4 (B) 3 (C) 2 (D) 1

2. **Energy given out per nucleon in p-p reaction is:**
(A) 5.2 MeV (B) 6 MeV (C) 6.4 MeV (D) 7.7 MeV

3. **Which of the following statements is CORRECT?** (Fed 2013)
(A) Moderators slow down the neutrons (B) Moderators bring the neutrons to rest
(C) Moderators absorb the neutrons (D) Moderators reflect the neutrons

4. **The moderator used in a nuclear reactor is:**
(A) Sodium (B) Uranium (C) Graphite (D) Cadmium

5. **Nuclear fission chain reaction is controlled by using:**
(A) Steel rods (B) Graphite rods (C) Cadmium rods (D) Platinum rods

6. **When Nitrogen is bombarded by Alpha Particles, Nitrogen Nucleus change into:**
(A) Oxygen (O) (B) Carbon (C) (C) Berium (Be) (D) Helium (He)

7. **The amount of energy required to break the nucleus is called its:**
(A) Nuclear energy (B) Kinetic energy (C) Potential energy (D) Binding energy

8. **Energy liberated when one atom of $^{235}_{92}U$ undergoes fission reaction:**
(A) 140 MeV (B) 28 MeV (C) 200 MeV (D) 60 MeV

Answers Key

1. C	2. C	3. A	4. C	5. C	6. A	7. D	8. C

Q.15 Write a note on radiation exposure and biological effect of radiations.

Radiation Exposure

When a Geiger tube is used in any experiment, it records radiation even when a radioactive source is no-where near it. This is caused by radiation called background radiation.

It is partly due to cosmic radiation which comes to us from outer space and partly from naturally occurring radioactive substance in the Earth's crust.

The cosmic radiation consists of high energy charged particles and electromagnetic radiation.

The atmosphere acts as a shield to absorb some of these radiation as well as ultraviolet rays. In recent past, the depletion of ozone layer in upper atmosphere has been detected which particularly filter ultraviolet rays reaching us. This may result in increased eye and skin diseases. The depletion of ozone layer is suspected to be caused due to excessive release of some chemicals in the atmosphere such as **chlorofluorocarbons** (CFC) used in refrigeration, aerosol spray and plastic foam industry. Its use is now being replaced by environmentally friendly chemicals.

- Many building materials contain small amounts of radioactive isotopes, (radon) radioactive carbon gas enters buildings from the ground. It gets trapped inside the building which makes radiation levels much higher from radon inside than outside. A good ventilation can reduce radon level inside the building. All types of food also contain a little radioactive substance. The most common are K^{40} and C^{14} isotopes.
- Some radiation in environment is added by human activities. Medical practices, mostly diagnostic x-rays probably contribute the major portion to it. It is an unfortunate fact that many x-rays exposures such as routine chest x-rays and dental x-rays are made for no strong reason and may do more harm than good. Even x-rays exposure should have a definite justification that outweighs the risk. The other source include radioactive waste from nuclear facilities, hospital, research and industrial establishments, colour television, luminous watches and to tobacco leaves. A smoker not only inhales toxic smoke but also hazardous radiation. Low level background radiation from natural sources is normally considered to be harmless. However, higher levels of exposure are certainly damaging. We cannot avoid unnecessary exposure to any kind of ionizing radiation.

Biological Effects of Radiation

Excessive exposure to radiation can cause damage to living tissues, cells, or organism.

- The degree and kind of damage caused to a particular part of the body depend upon the type, energy and dose of radiation received. There is no lower limit below which radiation damage does not occur. A number of small doses received over long period of time may lead to fatal consequences.

- **Radiation damage to living organism is primarily due to ionization effects in the cells.** the cells is the basic unit of life. Its normal metabolic function may be disrupted as a result of interaction with the ionizing radiation. Excessive radiation does may cause death of individual cells, or produce chromosome abnormalities or genetic mutation.

Do You Know?

Radioactive wastes are of three types i.e., high level, medium and low level. All these wastes are dangerous for ground water and land environment.

- The biological effects are generally of two types. **Somatic and genetic.** Somatic effects affect an individual directly. **Skin burns, loss of hair, drop in the white blood cells and induction of cancer are example of somatic effects.**
- The genetic effects may become apparent after a long time. The reason is that radiation can alter chemistry of the genes and may cause mutations. Even very low radiation doses reaching the reproductive organ of the body are potentially dangerous. Genetic effects may be passed on the future generations.

Q.16 Write a note on:

(a) Biological and Medical uses of Radiation

(b) Medical Diagnostics and Therapy

Biological and Medical uses of Radiation

Although, all the isotopes of an element chemically behaves identically, but **every isotopes emits radiations due to which it is easy to identify an isotope.** It is this characteristic due to which the isotopes are being used in different fields of our life.

Biological Use

The chemical changes going on in an animal or a plant are very complex. The tracer method has been applied to study these changes. For example, the process of **photosynthesis and the incorporation of carbon atoms in the CO_2 into giant and complex protein or carbohydrate molecules have been investigated by tracer techniques.**

- Similarly information concerning the complex process of **metabolism** is obtained by means of radioisotope tracers. The distribution of various elements, such as hydrogen, sodium, iodine, phosphorous, strontium, irons etc; in the body can be obtained by tracer technique. Genetic mutations are engineered by intense radioactively.

Radiation Therapy

High energy radiations penetrate deep into the body and can be used for intentional selective destruction of tissues, such as cancerous tumor. **Radioisotopes of Co^{60} which emit β-particle and high-energy γ-rays** is employed for the treatment of various types of cancers some radioisotopes are taken internally where they are selectively absorbed by certain organs and thus concentrate the radiation where it is most needed. For example, **cancerous thyroid is treated with I^{131} radioisotope. Sometimes pellets or capsules of radioisotopes are planted** close to the tumor and can be removed after treatment.

The Co^{60} source of γ-radiation is rotated around the patient.

Medical Diagnostics

Hydrogen and sodium atoms are distributed uniformly throughout the body where iodine tends to concentrate in **thyroids, phosphorous and strontium in bones and cobalt in liver.** They can serve as tracer when injected or other wise given to patients. Radiation detectors may ascertain the passage of tracer through the body and their concentration in diseased tissues. The pattern of distribution of the radioactive tracers in a body can give a clue about normality or abnormality of the specific parts of the body.

Tracing Techniques

Radioactive particles can be used to trace chemicals participating in various reactions one of the most valuable uses of radioactive tracers is in medicine. **For example, I^{131} is an artificially produced isotope of iodine.** Iodine, which is a necessary nutrient for out bodies, is obtained largely through the intake of iodized salt and seafood. The thyroid gland *plays a major role in the distribution of iodine throughout the body* in order to evaluate the performance of the thyroid; the patient drinks a very small amount of radioactive sodium iodide. Two hours later, the amount of iodine in the thyroid gland is determined by measuring the radiation intensity at the neck area.

- A second medical application is that a salt containing radioactive sodium is injected into a vein in the leg. The time at which the radioisotope arrives at another part of the body is detected with the radiation counter. The elapsed time is a good indication of the presence or absence of constriction in the circulatory system.
- The tracer technique is also useful in agricultural research. Suppose, one wishes to determine the best method of fertilizing a plant. A certain material in the fertilizer, such as nitrogen, can be tagged with one of its radioactive isotopes. The fertilizer is then sprayed on one group of plants, sprinkled on the ground for second group and raked into soil for a third. A Geiger counter is then used to track the nitrogen through the three types of plants.

MCQ's From Past Board Papers

1. Absorbed Dose "D" is defined as:
(A) m/E (B) E/C (C) C/m (D) E/m

2. Circulation Blood can be studied by using Radioactive Isotope:
(A) Cobalt-60 (B) Phosphorus-32 (C) Sodium – 24 (D) Iodine -131

3. The background radiations that we are exposed per year on the average is
(A) 1 m Sv (B) 2 m Sv (C) 3 m Sv (D) 4 m Sv

4. Gamma rays from cobalt – 60 are used for the treatement of
(A) Thyroid glands (B) Circulation of blood (C) Cancer (D) Heart attack

5. The average of the background radiation to which we are exposed:
(A) 2 mSv (B) 1 mSv (C) 3 mSv (D) 0.01 Sv

6. Cobalt-60 is the source for:
(A) α-rays (B) γ-rays (C) β-rays (D) Neutrons

7. One gray (Gy) is equal to:
(A) 1.6×10^{-19} J (B) $1.6 \times 10^{-10} \frac{J}{kg}$ (C) $1 \frac{J}{kg}$ (D) $4 \frac{J}{kg}$

8. The most useful tracer isotope for the treatment of Thyroid gland is:
(A) Cobalt 60 (B) Carbon 14 (C) Iodine-131 (D) Strontium 90

9. Unit of radio activity is curie which is equal to:
(A) 3.74×10^9 disintegration (B) 3.74×10^{10} disintegration (C) 3.70×10^{10} disintegration (D) 3.60×10^{10} disintegration

10. Circulation of Blood can be studied by using Radioactive Isotope:
(A) cobalt-60 (B) Phosphorus-32 (C) Sodium-24 (D) Iodine-131

11. One joule of energy absorbed in a body per kg is equal to:
(A) 1 rad (B) 1 rem (C) 1 sievert (D) 1 gray

12. Iodine-131 is used for the treatment of
(A) Bones (B) Eyes (C) Thyroid gland (D) Lungs

13. When nitrogen is bombard by Alpha, particle, then nitrogen nuclei change into
(A) Oxygen (B) Carbon (C) Helium (D) Beryllium

14. Curie is unit of;
(A) Conductivity (B) Binding energy (C) Radioactivity (D) Resistivity

Answers Key

1. D	2. C	3. B	4. C	5. A	6. B	7. C	8. C	9. B	10. C	11. D	12. C
13. A	14. C										

17 (a) What are basic forces of nature? Explain.

Basic Forces of Nature

The key to understand the properties of elementary particles is to be able to describe the forces between them.

1. Gravitational force
2. Magnetic force
3. Electric force
4. Weak nuclear force
5. The strong force

Unification of electric and magnetic forces

Faraday and ***Maxwell*** unified electric and magnetic forces, leaving behind four fundamental forces i.e., gravitational force, the strong force, electromagnetic force and weak nuclear force

- **The strong force is very short-ranged and is responsible for the binding of neutrons and protons into nuclei.** This force represents the "glue" that hold the nucleons together and is the strongest of all the fundamental forces. The strong force is very short-ranged and is **negligible for separation greater than 10^{-14} m.**
- **The electromagnetic force**, which is about 10^{-2} times the strength of the strong force, is responsible for the binding of atoms and molecules. It is a long-range force that decreases in strength as the inverse square of the separation between interacting particles.

  It cause all chemical reactions, binds all atoms, molecules, crystals, tree, building and you. Friction, cohesion and adhesion are due to this force.
- **The weak nuclear force** is a short-range nuclear force that tends to produce instability in certain nuclei. It is responsible for most radioactive decay processes such as beta decay, and its strength is only about 10^{-9} time that of the strong force. Scientists now believe that the weak and electromagnetic forces are two manifestations of a single force called **the electro weak force.**
- **Finally, the gravitational force is a long-range force** that has a strength of only about 10^{-36} times that of strong force. Although this familiar interaction is the force that holds the plants, stars, and galaxies together, its effect on elementary particles is negligible. Thus the gravitational force is the weakest of all the fundamental forces.

In modern physics, one often describes the interaction between particles in terms of the exchange of field particles or quanta. In the case of the familiar electromagnetic interaction, the field particles are photon. In the language of modern physics, one can say that the electromagnetic force is mediated by photons, which are the quanta of the electrometric field. Likewise, the strong force mediated by **field particle called gluons**, the weak force is mediated by particles called the w and z bosons and the gravitational force is mediated by quanta of the gravitational field called gravitons.

Q.18 What are building blocks of matter? Explain.

Building Blocks of Matter

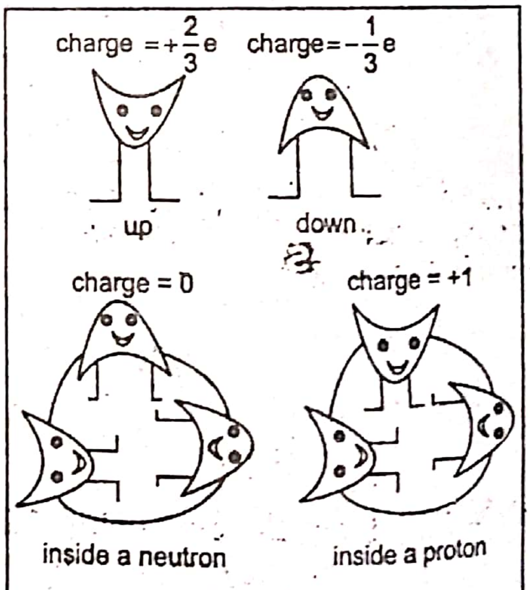
The word "atom" is from Greek word atomos, which mean indivisible. At one time atoms were thought to be the indivisible constituents of matter, that is, they were regarded to be elementary particles. Discoveries in the early part of the 20th century revealed that the atom is not elementary, but has as its constituents protons, neutrons and electrons. Up until the 1960s, physicists were bewildered by the large number and variety of elementary particles being discovered. In the last two decades, physicists have made tremendous advance in our knowledge of the structure of matter by recognizing that all particles with the exception of electrons, photons, and a few related particles are made of smaller particles called quarks. Thus, protons and neutrons, for example, are not truly elementary particles but are system of tightly bound quarks.

Classification particles

Hadrons

Particles that interact through the **strong force** are called **hadrons**. There are two class of hadrons, known as mesons and baryons. Mesons has mass between the mass of the electron and the mass of proton. All mesons are known to be decay finally into electrons, positrons, neutrinos and photons. The pion is the lightest of known mesons.

Baryons, which are the second class of hadrons, have mass equal to or greater than proton mass. Protons and neutrons are included in the baryon family, as are many other particles with the exception of the proton all baryons decay in such a way that the end products include a proton.



Up and down quarks illustration

Leptons

These are the particles which do not experience strong nuclear force.

Include in this group are electrons, muons, and neutrinos, which are all less massive than the lightest hadron. Since lepton has no internal structure, they appear to be truly elementary particles scientists believe that there are only six leptons.

Quarks

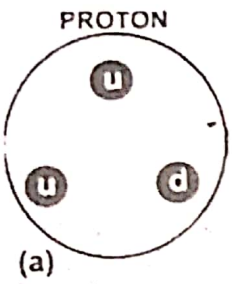
According to quark theory initiated by M.Gell-Mann and G.Zweig. the quarks are proposed as the basic building blocks of the mesons and baryons. The quark model is based on the following assumptions:

1. **There are six different types of quark**, the up quark, the down quark, the strange quark, the charmed quark, the bottom quark and the top quark referred to as u, d, s, c, b and t.
2. **For every type of quark, there is a corresponding antiquark.**
3. **Quarks combine in threes** to form particles like the protons and the neutrons. Antiquarks also combine in threes to form antiparticles like the antiproton and the antineutron.
4. A meson consists of a quark and an antiquark.

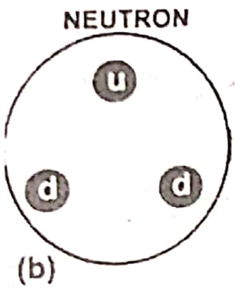
In term of the charge of the electron, the *u*, *c* and *t* quarks each carry a charge of $+\frac{2}{3}$ e and the other three quarks carry a charge of $-\frac{1}{3}$ e. An antiquark carries an equal and opposite charge to its corresponding quark. The symbol for antiquark is the same as for a quark but with a bar over the top. For example, $\bar{d}$ represents the symbol for a down antiquark.

Thus

- ▶ A proton is composed of two up quarks and a down quark.
- ▶ A neutron consists of an up quark and two down quarks, as shown in fig 20.11.



(a)
Charge
2/3 + 2/3 - 1/3 = 1



(b)
Charge
2/3 - 1/3 - 1/3 = 0

Quarks and Antiquarks

Name	Symbol	Charge
Up	*u*	$+\frac{2}{3}$ e
Down	*d*	$-\frac{1}{3}$ e
Strange	*s*	$-\frac{1}{3}$ e
Charm	*c*	$+\frac{2}{3}$ e
Top	*t*	$+\frac{2}{3}$ e
Bottom	*b*	$-\frac{1}{3}$ e

Antiquarks

Symbol	Charge
$\bar{u}$	$-\frac{2}{3}$ e
$\bar{d}$	$+\frac{1}{3}$ e
$\bar{s}$	$+\frac{1}{3}$ e
$\bar{c}$	$-\frac{2}{3}$ e
$\bar{t}$	$-\frac{2}{3}$ e
$\bar{b}$	$+\frac{1}{3}$ e

MCQ's From Past Board Papers

1. **The number of Quark are**
(A) 2 (B) 4 (C) 6 (D) 8
2. **In an electronic transition, atom can not emit:**
(A) Infrared rays (B) Visible light (C) Ultraviolet rays (D) γ- rays
3. **The particles equal in mass or greater than protons are called:**
(A) Baryons (B) Hadrons (C) Perm ions (D) Mesons
4. **Electrons are:**
(A) Hadrons (B) Leptons (C) Quarks (D) Baryons
5. **Two down and one up quarks make:**
(A) Proton (B) Neutron (C) Photon (D) Positron
6. **Leptons are particles that do not experience ________.** **(Fed 2011)**
(A) Weak nuclear force (B) Strong nuclear force (C) Electric force (D) Magnetic force
7. **Mass of meson is :**
(A) Greater than proton (B) Less than proton (C) Equal to proton (D) Equal to neutron
8. **Strong nuclear force acts on:**
(A) Meson only (B) Pions only (C) Photons only (D) Hadrons only
9. **The particles equal in mass but greater than proton are:**
(A) Mueons (B) Baryons (C) Leptons (D) Hadrons
10. **A pair of quark and antiquark makes:**
(A) Meson (B) Baryon (C) Photon (D) Proton

11. Which one belongs to Lepton's group:
(A) Electron (B) Muons (C) Neutrinos (D) All of these

12. Which of the following are elementary particles:
(A) Protons (B) Neutrons (C) Photons (D) Mesons

13. The building blocks of protons and neutrons are called:
(A) Ions (B) Electrons (C) Positrons (D) Quarks

14. Which of the followings are not hadrons?
(A) Muons (B) Mesons (C) Protons (D) Neutrons

15. Two up quarks and one down quark mates a
(A) Proton (B) Neutron (C) Photon (D) Meson

16. Subatomic Particles are divided into groups:
(A) Photon (B) Leptons (C) Hadrons (D) All these

17. A proton consists of quarks which are:
(A) two up, one down (B) one up, two down (C) all up (D) all down

18. Which pair of particles belongs to the Hadrons
(A) Photons and Electrons (B) Positrons and electrons (C) Protons and Neutrons (D) Photons and poistrons

19. The range of week nuclear force is of the order of
(A) 10^{-15} m (B) 10^{-14} m (C) 10^{-17} m (D) 10^{-22} m

Answers Key

1. C	2. D	3. A	4. B	5. B	6. B	7. B	8. D	9. D	10. A	11. D	12. C
13. D	14. A	15. A	16. D	17. A	18. C	19. C					

* * *

FORMULAE

1	Neutron number	$N = A - Z$	
2	Mass spectrograph	$m = \left(\frac{er^2}{2V}\right)B^2$	
3	Mass deficit	$\Delta m = (m_p + m_n) - m_{nucleus}$	
4	Mass defect per nucleon	$\frac{\Delta m}{A} = \frac{(m_p + m_n) - m_{nucleus}}{A}$	
5	Binding energy	$B.E = \Delta m\, c^2 = (m_p + m_n)\, c^2 - m_{nucleus}\, c^2$	
6	Binding energy per nucleon	$\frac{B.E}{A} = \frac{\Delta m\, c^2}{A} = \frac{(m_p + m_n)c^2 - m_{nucleus\, c^2}}{A}$	
7	Relation between unified mass scale and energy	l u = 931 MeV	
8	Alpha decay	${}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$	
9	Beta decay	${}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e$	
10	Gamma decay	${}^{A}_{Z}X^{*} \longrightarrow {}^{A}_{Z}X + \gamma$-radiation	
11	Decay constant	$\frac{\Delta N}{N} = -\lambda \Delta t$	

12	Half life	$T_{1/2} = \frac{0.693}{\lambda}$	$T_{1/2} = \frac{\ln 2}{\lambda}$
13	No. of undecayed atoms	$\left(\frac{1}{2}\right)^n N_o$	
14	Intensity variation of γ-rays in air	$I \propto \frac{1}{r^2}$	
15	Intensity variation of γ-rays in solids	$I = I_o e^{-\mu x}$	
16	First nuclear reaction	${}^{226}_{88}Ra \longrightarrow {}^{222}_{86}R_n + {}^{4}_{2}He$	
17	Dose	$D = \frac{E}{m}$	
18	Equivalent dose	$D_e = D \times RBE$	

UNITS

1	Decay constant	s^{-1}		
2	Half life	second		
3	Dose	J/kg	gray	rad
4	Equivalent dose		sievert	rem
5	Units of radioactivity	curie	bequrrel	

CONSTANTS

1	Mass of electron	9.11×10^{-31} kg	0.00055 u
2	Mass of proton	1.673×10^{-27} kg	1.007276 u
3	Mass of neutron	1.675×10^{-27} kg	1.008665 u
4	1 u	1.6606×10^{-27} kg	931.5 MeV
5	Charge on electron	-1.6×10^{-19} C	
6	Charge on proton	1.6×10^{-19} C	
7	Charge on neutron	zero	
8	Decay constant	Depends upon nature of material	
9	Absorption coefficient	Depends upon nature of material	
10	Radioactive biological effectiveness	Depends upon nature of material	

Key Points

- The combined number of all the protons and neutrons is known as mass number and is denoted by *A*.
- The protons and neutrons present in the nucleus are called nucleons.
- The number of neutrons present in a nucleus in called its neutrons number and is denoted by *N*.
- The number of protons inside a nucleus or the number of electrons outside of the nucleus is called the atomic number or the charge number of an atom and is denoted by *Z*.
- Isotopes are such nuclei of an element that have the same charge number Z, but have different mass number *A*.
- The mass of the nucleus is always less than the total mass of the protons and neutron that make up the nucleus. The difference of the masses is called mass defect. The missing mass is converted to energy in the formation of the nucleus and is called binding energy.
- The emission of radiations $(\alpha, \beta \text{ and } \gamma)$ from elements having charge number Z greater than 82 is called radioactivity.
- The change of an element into a new element due to emission of radiations is called radioactive decay. The original element is called parent element and the element formed due to this decay is called daughter element.
- Such a reaction in which a heavy nucleus like uranium splits up into two nuclei of equal size along with emission of energy during reaction is called fission reaction.
- Half-life of a radioactive element is that period in which half of the atoms of the parent element decay into daughter element.
- Such a nuclear reaction in which two light nuclei merge to form a heavy nucleus along with the emission of energy is called fusion reaction.
- The strength of the radiation source is indicated by its activity measured in Becquerel. One Becquerel (Bq) is one disintegration per second. A larger unit is curie (ci) which equals 3.7×10^{10} disintegration per second.
- The does D defined as the energy E absorbed from ionizing radiation per unit mass m of the absorbing body.

Solved Examples

Example 20.1:

The mass of a $_{92}U^{235}$ nucleus is 234.993333U. The mass of proton = 1.00728 u and mass of neutron = 1..00864u. Calculate the binding energy per nucleons of a $_{92}U^{235}$ nucleus.

Solution:

Z = 92 A = 235

The number of neutrons = A – Z = 143

Mass defect = (92×1.00728) + 143 × 1.00867) – (234.99333 = 1.91624 U.

Binding energy = 1.91624 × 931 = 1784 MeV

Binding energy per nucleon = $= \frac{1784}{235}$ =7.6 MeV/A

A graph of binding energy per nucleon number A is shown in fig 20.2 Remember that greater the binding energy per nucleon of nucleus is, the more stable the nucleus is. The graph shows that

1 The binding energy per nucleon increases as “*A*” increases to a maximum of about 1MeV per nucleon at

about "A" = 50 to 60 then decreases gradually.

2. The most stable nuclei are about A = 50 to 60 since this is where the binding energy per nucleons is greatest.
3. The binding energy per nucleon is increased when nuclear fission of a uranium 235 nucleus occurs.
4. The binding energy per nucleons is increased when light nuclei are fused together.

When a $_{92}U^{235}$ nucleus undergoes fission, the two fragment nuclei each comprise about half the number of nucleon. Therefore the binding energy per nucleon increases from about 7.5 MeV per nucleon for $_{92}U^{235}$ to about 8.8 MeV per nucleon for the fragments.

Thus the binding energy per nucleon increases by about 1 MeV for every nucleon which means tht the energy released from the fission of a single fissionable nucleus is about 200 MeV. Mass of $_{92}U^{235}$ nucleus is about 4×10^{-25} kg.

Example 20.2:

The half-life of radioactive nucleus $_{86}Ra^{226}$ is 1.6×10^{3} years. Determine the decay constant.

Solution:

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

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

$$T_{1/2} = 1.6\times10^{3}\ \text{years} = \left(1.6\times10^{3}\ \text{years}\right)\left(3.15\times10^{7}\ \text{s/year}\right)$$

$$= 5.0\times10^{10}\text{s}$$

Therefore $\lambda = \dfrac{0.639}{5.0\times10^{10}\text{s}} = 1.4\times10^{-11}\text{s}^{-1}$

Example 20.3:

Determine the activity of a 1 g sample of $_{38}Sr^{90}$ whose half-life against β - decay is 28 years.

Solution:

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

$$= \frac{0.693}{28\,\text{years}\times3.15\times10^{7}\text{s/years}}$$

$$= 7.83 10^{-10}\text{s}^{-1}$$

A k mole of an isotope has a mass equal to the atomic weight of that isotope expressed in kilograms. Hence 1 g of $_{38}Sr^{90}$ contains.

$$\frac{10^{-3}\text{kg}}{90\text{kg k mole}} = 1.11\times10^{-5}\ \text{k moles}$$

One k mole of any isotope contains Avogadro's number of atoms, and so 1g of $_{38}Sr^{90}$ contains 1.11×10^{-5} kmole $\times6.025\times10^{26}$ atoms

Thus the activity of the sample is,

$R = \lambda N$

$= 7.83\times10^{-10}6.690+10^{21}s^{-1}$

$= 141$ curies

Text Book Exercises

Q.1 Select the correct answer of the following questions.

(i) **The binding energy for nucleus A is 7.7 MeV and that for nucleus B is 7.8 MeV. Which nucleus has the larger mass?**

(a) Nucleus A (b) Nucleus B (c) Less than nucleus A (d) None of these

(ii) **How many neutrons are there in the nuclide Zn^{66}?**

(a) 22 (b) 30 (c) 36 (d) 66

(iii) **Mass equivalent of 931 MeV energy is:**

(a) 6.02×10^{-23} kg (b) 1.766×10^{-27} kg (c) 2.67×10^{-27} kg (d) $6.02\times10-27$kg

(iv) **The energy equivalent of 1 kg of matter is about.**

(a) 10^{-15} J (b) 1 J (c) 10^{-12} J (d) 10^{17} J

(v) **The radioactive nuclide $_{86}Ra^{228}$ decays by a series of emissions of three alpha particles and one beta particle. The nuclide X finally formed is,**

(a) $_{84}X^{220}$ (b) $_{86}X^{222}$ (c) $_{83}X^{216}$ (d) $_{88}X^{215}$

(vi) **A radioactive substance has a half life of four months. 3 –fourth of the substance will decay in.**

(a) 6 months (b) 8 months (c) 12 months (d) 16 months

(vii) **Gammas radiations are emitted due to:**

(a) De-excitation of atom (b) De-excitation of nucleus

(c) Excitation of atom (d) Excitation of nucleus

(viii) **Unit of decay constant λ is,**

(a) ms (b) m^{-1} (c) m (d)

(ix) **Which of the following basic force is able to provide an attraction between two neutrons:**

(a) Electrostatic and nuclear (b) Electrostatics and gravitational

(c) Gravitational and strong nuclear (d) only nuclear force

(x) **Bottom quark carries charge:**

(a) $\frac{2}{3}e$ (b) $\frac{-2}{3}e$ (c) $\frac{+1}{3}e$ (d) $\frac{-1}{3}e$

No.	Option	ANSWER	EXPLANATION
(i)	(b)	Nucleus B	As B.E = ΔmC^2 So the nucleus of greater mass has greater binding energy.
(ii)	(c)	36	As $^{66}_{30}Zn$, number of neutrons are N = A-Z = 66 – 30 = 36
(iii)	(b)	1.766×10^{-27} kg	$E = mC^2$ $931\times10^6\times1.6\times10^{-19} = m(3\times10^8)^2$ $m = \frac{931\times10^6\times1.6\times10^{-19}}{(3\times10^8)^2}$ $m = 1.776\times10^{-27}$ kg

(iv)	(d)	10^{17} J	$E = mC^2$ $E = (1)(3 \times 10^8)^2$ $= 9 \times 10^{16}$ J $\sim 10^{17}$ J
(v)	(c)	$_{83}X^{216}$	$^{228}_{88}Ra \xrightarrow{3\alpha} {}^{216}_{82}Y \xrightarrow{\beta} {}^{216}_{83}X$
(vi)	(b)	8 months	Fraction of undamaged nuclei $= 1 - \left(\frac{1}{2}\right)^2$ $\frac{3}{4} = 1 - \left(\frac{1}{2}\right)^2$ $\left(\frac{1}{2}\right)^n = \frac{1}{4}$ $\left(\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^2$ so $n = 2$ As time for one half life is four month. So the time for two half lives is eight months.
(vii)	(b)	De-excitation of nucleus	Nucleus can also de-exites as an atom, which results in emission of energy (γ-ray)
(viii)	(d)	s^{-1}	$\lambda = \frac{\Delta N/N}{\Delta t}$ As $\frac{\Delta N}{N}$ has no unit of s^{-1}.
(ix)	(c)	Gravitational and strong nuclear	Gravitational and strong núclear forces are both attractive.
(x)	(d)	$\frac{-1}{3}e$	Charge on bottom quark is $-\frac{1}{3}$ e.

Comprehensive Questions

Q.2 Write short answers of the following questions.

1. What is meant by natural radioactivity? How are the natural radioactive eadiations classified into three types?

Ans: See Theory Question No. 6

Explain the principle, construction, working and necessary mathematical theory of a mass spectrometer.

Ans: See Theory Question No. 3

3. What are isotopes? Explain with examples.

Ans: See Theory Question No. 2

4. Explain the term mass defect and binding energy related to a nucleus.

Ans: See Theory Question No. 5

5. Define and explain the half—life of a radioactive element?

Ans: See Theory Question No. 7

6. Define and explain nuclear reactions.

Ans: See Theory Question No. 11

7. Write a comprehensive note on nuclear fission.

Ans: See Theory Question No. 12

8. What is a nuclear reactor? Give the principle, construction working and uses of a typical nuclear reactor.

Ans: See Theory Question No. 13

9. What is meant by nuclear fusion? Discuss how can energy be released in the fusion process? Illustrate with examples.

Ans: See Theory Question No. 14

10. What is a radiation detector? Explain the principle and working of GM counter and solid state detector.

Ans: See Theory Question No. 9

11. Discuss the technique and use of radio isotopes in the different fields of human activities.

Ans: See Theory Question No. 15

12. Write a comprehensive note on hadrons, leptons and quarks.

Ans: See Theory Question No. 18

13. What are harmful effects of radiations? What measures can be adopted to safeguard us from the nuclear hazards.

Ans: See Theory Question No. 15 & 16

14. Explain tracer technique in agricultural research.

Ans: See Theory Question No. 16

15. Name the four fundamental interaction and the particles that mediate each interaction.

Ans: See Theory

16. Discuss the differences between hadrons and leptons.

Ans: See Theory Question No. 18

Conceptual Questions

1. Why does the alpha particle not make physical contact with nucleus, when an alpha particle in headed directly toward the nucleus of an atom.

Ans: At the atomic level atoms and nuclei compositely has no sharp boundary so there is no such thing as physical contact. However alpha particle as being positively charged particle also suffers an electrostatic repulsion from a positively charged nucleus therefore there is less probability for alpha particle to come into nuclear dimensions.

Explanation:

An alpha particle consists of two protons and two neutrons, so it is a positively charged particle. All the nuclei have protons in them along with neutral neutrons therefore they all carry positive charge. Now when an alpha particle is headed directly towards the nucleus it will suffer strong, electrostatic repulsion due to similar positive charges. Since nuclei have no well-defined boundary, so we cannot define physical contact. However, alpha particle will suffer repulsion due to electromagnetic force well before coming into the nuclear dimensions. Thus we can say that positively charged particle cannot make physical co[illegible] it means that they can't enter into the nucleus.

2. Why do heavier elements require more neutrons in order to maintain stability?

Ans: Binding energy per nucleon decreases with the increase of neutron to proton ratio, this represents the instability of nucleus.

Explanation:

The packing fraction is the measure of stability of a nucleus. The nucleus with large packing fraction is more stable. If A = N + Z is the mass number (number of nucleons), then the binding fraction f(binding energy per nucleon) is;

$$f = \frac{E_B}{A} = \frac{(ZM_P + NM_N - M)c^2}{A}$$

The nuclear force is a short range force limited to about 10^{-15} m, and decreases rapidly to zero when the distance increases. The nuclear force is therefore between the neighbor nucleons only. On the other hand, electromagnetic force has infinite range, and is applied on all nucleons nearly equally within the atomic nucleus.

For large nuclei, there is large number of protons; the Coulomb repulsion between the protons opposes the binding effect of nuclear force on all nuclei due to its long range. Hence the binding energy per nucleons is observed to decrease for nuclei with large number of protons. So large nuclei require an increased number of neutrons in order to increase the packing fraction and thus the stability.

3. An alpha particle has twice the charge of a beta particle. Why does the former deflect less than the later when passing between electrically charged plates, assuming they both have the same speed?

Ans: A beta particle (a high energy, fast moving electron) with its smaller mass deflects more.

Explanation:

An alpha particle is a Helium nucleus, having two protons and two neutrons, has a charge of +2. A beta particle has a charge of +1 or −1, depending on whether it is a positive or negative beta particle. The mass of alpha particle is about 8000 times the mass of beta particle.

Due to double the amount of charge the electromagnetic force on alpha particle will be two times the force on beta particle, however because of its large mass about 8000 times the mass of beta particle it will carry huge inertia and will be difficult to bend, and about 8000 times more force will be required to produce the same deflection.

4. Element X has several isotopes. What do these isotopes have in common?

Ans: Isotopes have same chemical properties but different physical properties.

Explanation:

Isotopes are atoms of a chemical element with the same atomic number and nearly identical chemical behaviour but with differing atomic mass or mass number due to difference in the number of neutrons and therefore have different physical properties.

All the isotopes of the element X will react with different elements similarly because all the isotopes will have the same number of electrons. The physical properties like boiling point, melting points, will not be affected. The isotopes of element X will have difference in the mass of the atom, the density and the half life of the element due to the difference in their neutron number.

5. How many protons are there in the nucleus $_{86}Rn^{222}$? How many neutrons? How many electrons are there in the neutral atom?

Ans: $_{86}Rn^{222}$ nucleus has 86 protons and 136 neutrons. As number of protons and electrons are equal in an atom so as a whole it is neutral .

Explanation:

In symbol $_ZX^A$, X represents the chemical symbol for the element, Z represents the number of protons and A represents the number of nucleons (i.e. number of protons and neutrons). Therefore, in $_{86}Rn^{222}$, Z = 86, thus there are 86 protons. Since A = 222, this means that Number of nucleons = 222.

So

Number of neutrons + number of protons = 222

Number of neutrons = 222 – number of protons

Therefore,

Number of neutrons = 222 – 86 = 136

Hence there are 136 neutrons in ${}_{86}Rn^{222}$. In neutral the number of electrons will be equal to the number of protons, therefore in neutral atom of ${}_{86}Rn^{222}$ there will be 86 electrons.

6. Ra^{226} has half-life of 1600 years.
(a) What fraction remains after 4800 years?
(b) How many half-lives does it have in 9600 years?

Ans: (a) as three half lives would have passed after 4800 years therefore one eighth of the total amount of original radium would be left and (b) six half lives would have passed after 9600 years.

(a)

Number of half-lives in 4800 years is

$$n = \frac{\text{time passed}}{\text{half-life}} = \frac{4800\text{ yrs}}{1600\text{ yrs}} = 3$$

The number of nuclei left N to the total nuclei present N_o is given by formula

$$N = \frac{N_o}{2^n}$$

$$N = \frac{N_o}{2^3}$$

$$N = \frac{N_o}{8}$$

$$N = 0.125N_o$$

Thus the number of nuclei left N will be 0.125 times total nuclei N_o present.

(b) Number of half-lives in 9600 years is

$$n = \frac{\text{time passed}}{\text{half-life}} = \frac{9600\text{ yrs}}{1600\text{ yrs}} = 6$$

hence 6 half lives would have passed after 9600 years.

7. Radium has a half-life of about 1600 years. If the universe was formed five billion or more years ago, why is there any radium left now?

Ans: Radium is the decay product of ${}_{92}U^{238}$ with a half life of 4.5 billion years therefore radium with a half-life of only 1600 years is still found in nature.

Explanation:

For complete decay of radioactive element an infinite time is required. As life of earth is 5 billion year but not infinity therefore Ra still exist in universe.

8. Nuclear power plants use nuclear fission reactions to generate steam to run steam-turbine generator. How does the nuclear reaction produce heat?

Ans: A heavy nucleus splits into intermediate size nuclei accompanied by free neutrons and photons (in the form of gamma rays), and with release of large amount of energy in a fission process. In this way nuclear reaction produces heat, which run steam turbine generator in a nuclear reactor.

Explanation:

When a slow moving (thermal) neutron is bombarded on U-235 nucleus and the nucleus will absorb the neutron, become unstable and split into two intermediate size fragments with the emission of 200 MeV energy is released. About 85% of this energy appears in the form of kinetic energy in the fragments produced. The remaining heat is due to gamma rays and the neutrons liberated.

The K.E of fission fragments converts into heat energy during their collision with each other and with other objects.

9. What factors make a fusion reaction difficult to achieve?

Ans: Explanation:

For the fusion of two light nuclei work has to be done against the repulsive force between them.

For this purpose, the nuclei are moved towards each other with very high velocity. This can be done by increasing their temperature up to 10 Million degree Celsius. At this temperature the nuclei get sufficient thermal K.E to over come electrostatic repulsion. But such a ***high temperature*** is difficult to achieve.

10. Discuss the similarities and differences between fission and fusion.

Ans: Similarities:

1. Both are able to give off energy as heat & radiation, as in these reactions mass is lost, and this lost mass is converted into energy.
2. Both may form chain reactions a self-sustaining series of reactions.
3. Both nuclear fusion and nuclear fission use the energy stored in atomic particles in the energy production process.
4. Both nuclear reactions can be used in the creation of nuclear weapons.

Differences:

1. Fission is the process of splitting of an atom into two or smaller atoms and fusion is the fusing or joining together of two or more smaller atoms to form a larger one.
2. Fission and fusion happen in different conditions. Fission requires large Critical Mass and a slow neutron to initiate the process. Very high temperatures (about 10^6 K) and increased density are required for a fusion reaction.
3. In case of fusion reactions, fusion reactors cannot sustain a chain reaction so they can never melt down like fission reactors. Fusion reaction produces very less or, if the right atoms are chosen, no radioactive waste. In case of nuclear fission large radioactive waste is produced.
4. The amount of mass transformed into energy is that much greater in a fusion reaction than in a fission reaction.

11. In what ways is time constant *CR* similar to and different from (a) radioactive decay constant, λ (b) radioactive half-life?

Ans: Relationship between time constant CR and radioactive decay constant

Similarities:

(i) Both capacitor and radioactive nucleus decay (change) at an exponential rate, relative high initial rate, progressively decreasing.

(ii) Neither fully completes their decay (needing an infinite time).

(iii) Both RC and λ are constant quantities.

(iv) Relation between them is $RC = \frac{1}{\lambda}$

(v) In equal time intervals, the charge on the capacitor or the number of un-decayed nuclei changes in the same ratio.

Differences:

(i) Decay constant λ determines the rate of decay while capacitive time constant RC is the time in which charge of capacitor drops to $\frac{1}{e}$ of its maximum value.

(ii) Radioactive decay is spontaneous and random process unlike the regular flow of charge off a capacitor.

(iii) Radioactive decay results in a permanent change to the particles involved (nuclear change) whereas electrons are physically unchanged in capacitor.

(iv) Radioactive decay rate of a given sample cannot be influenced by any means while the rate of decay for a capacitor (voltage drop or discharge current) is controllable by altering capacitance value or circuit resistance.

(v) Unit of capacitive time constant RC is that of time (sec) while the unit of radioactive decay constant λ is reciprocal of time (sec^{-1}).

(vi) Larger the value of λ, greater the rate of decay whereas larger the value of RC, smaller the rate of discharge.

Relationship between time constant CR and radioactive half life

Similarities:

(i) Both capacitive time constant RC and radioactive half-life $T_{1/2}$ have same dimension.

(ii) Both RC and $T_{1/2}$ represent time for a particular process.

(iii) Relation between both is $T_{1/2} = \ln(2) \times RC$.

Differences:

(i) Half-life of a radioactive substance cannot change by any means while changing the resistor or capacitance or both can change the time constant of capacitor.

(ii) RC is used when dealing with charges in electrostatics while $T_{1/2}$ is used when dealing with radioactive nuclei in nuclear physics.

(iii) Rate of discharge of a capacitor is called current while rate of decay of radioactive substance is called activity.

12. What happen to atomic number of a nucleus that emits γ - rays photons?

Ans: The atomic number and mass number of nucleus remain unchanged, when a nucleus emits gamma ray photon.

Explanation:

Gamma particle are simply high energy photon carry no charge and has no rest mass. Gamma rays are emitted by unstable nuclei which are in high energy state to attain stability. Gamma radioactive decay photons commonly have energies of a few hundred KeV, and are almost always less than 10 MeV in energy. Their emissions do not make any change in charge number Z or nucleon number A. The gamma decay process is written as:

$$({}_{Z}X^{A})^{*} \rightarrow {}_{Z}X^{A} + \gamma$$

13. What happen to the atomic number of nucleus that emits gamma ray photons? What happen to its mass?

Ans: When a nucleus emits a gamma ray photon then its charge number Z and mass number A remain the same

Explanation:

As gamma radiation is simply a photon which has neither any charge nor any rest mass. After the emission of alpha or beta particle, the daughter nucleus is in the excited state. The excited state is unstable, so the nucleus comes to a stable state by emission of one or more gamma rays photons. So their emissions do not make any change in charge number or mass number It can be expressed as,

$$({}_{Z}X^{A})^{*} \rightarrow {}_{Z}X^{A} + \gamma$$

14. Explain why neutron activated nuclides tend to decay by β-rather than β^{+}.

Ans: In neutron activated nuclides the number of neutrons increases. The nucleus in order to attain stability converts the neutron into proton by emission of β.

Explanation:

Induced radioactivity is the irradiation of stable isotopes with particles generates unstable isotopes, which decay again to stable isotopes by emitting radiation. Neutron activation is the main form of induced radioactivity, which happens when free neutrons are captured by nuclei. Neutrons are ideal projectiles for nuclear transformation, because they are electrically neutral and therefore suffer no electrical repulsion in their approach to positively charged nuclei especially at low energies.

β-decay takes place in nuclei with excess neutrons, such as to convert the neutron into proton to counter surplus neutrons. When the target nucleus absorbs (captures) a neutron, the mass number is incremented by . If the product nucleus is unstable, then it is due to increase in the neutron number, therefore it will de-excites by emission of gamma rays or by β.

An example of this kind of a nuclear reaction occurs in the production of cobalt-60 within a nuclear reactor:

$$_{27}Co^{60} + {}_0N^3 \rightarrow {}_{27}Co^{60}$$

The cobalt-60 then decays by the emission of a beta particle plus gamma rays into nickel-60 with a half-life of about 5.27 years.

β-decay take place in the neutron deficient nuclei, such as to convert the proton into neutron to overcome the deficiency.

5. Why are large nuclei unstable?

ns: Due the presence of large number of protons in the atomic nucleus the packing fraction (binding energy per nucleon) decreases, thus large nuclei are unstable.

Explanation:

The packing fraction is the measure of stability of a nucleus. The nucleus with large packing fraction is more stable. If A = N + Z is the mass number (number of nucleons), then the binding fraction f is;

$$f = \frac{E_B}{A} = \frac{(ZM_E + NM_S - M)c^2}{A}$$

The nuclear force is a short range force limited to about 10^{-15} m, and decreases rapidly to zero when the distance increases. The nuclear force is therefore between the neighbour nucleons only. On the other hand, electromagnetic force has infinite range, and is applied on all nucleons nearly equally within the atomic nucleus.

For large nuclei, there are large numbers of protons; the Coulomb repulsion between the protons opposes the binding effect of nuclear force. Hence the binding energy per nucleons is observed to decrease for nuclei with large nucleon number (A). Thus the nuclei with large A will be less stable.

Conclusion: Large nuclei are unstable due to decrease in the packing fraction, because of the presence of large number of protons.

16. What happen to the atomic number and mass number of a nucleus that (a) emits an electron? (b) Undergoes electron? (c) Emits an α-particle?

Ans: In electron emission and electron capture mass number of nucleus does not change, only the atomic number changes. However, in alpha emission both mass number and atomic number changes.

(a) Electron Emission:

- In electron emission (or beta decay β) of a radionuclide does not change its mass number A, because electron emission changes a neutron into a proton. Thus the atomic number Z is increased by one unit.

$$_ZX^A \rightarrow {}_{Z+1}Y^A + {}_{-1}e^0 + \bar{\nu} + Q$$

Example: ${}_6C^{12} \rightarrow {}_7N^{13} + {}_{-1}e^0 + \bar{\nu} + Q$

(b) Electron capture:

Electron capture is a process in which a proton-rich (unstable) nuclide absorbs an inner atomic electron, thereby changing a nuclear proton to a neutron and causing the emission of a neutrino. Thus the mass number. A does not change but the atomic number Z decreases by one unit.

$$_ZX^A + e^- \rightarrow {}_{Z+1}Y^A + \nu + Q$$

Example: ${}_{28}Ni^{59} + e^- \rightarrow {}_{27}Co^{59} + \nu + Q$

(c) Alpha Emission:

In alpha decay, the original (parent) nuclide is converted to a daughter by the emission of a helium nucleus. Balancing the reaction shows that the daughter nuclide has a mass number A reduced by four and atomic number Z reduced by two.

$${}_ZX^A \rightarrow {}_{Z+1}Y^{A-1} + \alpha + Q$$

Example: ${}_{86}Rn^{220} \rightarrow {}_{84}Ro^{216} + {}_2He^4$

17. How many α-decay occur in the decay of thorium ${}_{90}Th^{298}$ into ${}_{82}Pb^{212}$?

Ans: Four alpha decays will transform thorium-228 ${}_{90}Th^{228}$ into lead-212 ${}_{82}Pb^{212}$.

Explanation:

In alpha decay, the original (parent) nuclide is converted to a "daughter" by the emission of an α-particle. Balancing the reaction shows that the daughter nuclide has a nucleon number reduced by four and a charge number reduced by two.

$${}_{90}Th^{228} \longrightarrow {}_{88}Ra^{224} + {}_2He^4 \ (\alpha\text{-particle})$$
$${}_{88}Ra^{224} \longrightarrow {}_{86}Rn^{220} + {}_2He^4 \ (\alpha\text{-particle})$$
$${}_{86}Rn^{220} \longrightarrow {}_{84}Po^{216} + {}_2He^4 \ (\alpha\text{-particle})$$
$${}_{84}Po^{216} \longrightarrow {}_{82}Pb^{212} + {}_2He^4 \ (\alpha\text{-particle})$$

18. What is color force?

Ans: The force that holds quarks together, operating by means of the colour charge. The colour force is the source of the strong interaction, or that the strong interaction is like a residual colour force which extends beyond the proton or neutron to bind them together in a nucleus.

Colour Force: The strong force between quarks is often called the colour force. The force is carried by massless particles called gluons. According to QCD, there are eight gluons, all with colour charge, and their anti-gluons. When a quark emits or absorbs a gluon, its colour changes. For example, a blue quark that emits a gluon may become a red quark that absorbs this gluon becomes a blue quark. The colour force between quarks is analogous to the electric force between charges: like colours repel each other, but a red quark will be attracted to an anti-red quark. Although the colour force between two colour-neutral hadrons (such as a proton and a neutron) is negligible at large separations, the strong colour force between their constituent quarks does not exactly cancel at small separations of about 1 fm. This residual strong force is in fact the nuclear force that binds protons and neutrons to form nuclei.

Numerical Problems

1. Find the mass defect and binding energy for helium nucleus?

Given:

Number of proton $Z = 2$
Mass of proton $M_P = 1.00727u$
Number of neutrons $N = 2$
Mass neutron $M_n = 1.008665u$
Mass of helium nucleus $M = 4.002602u$

To Find:

Mass defect $\Delta m = ?$
Binding energy $E = ?$
Hydrogen mass not proton mass is used
$M_P = M_H = 1.007825$

Solution:

The mass detect is gives by: $\Delta m = ZM_P + NM_N - M$

Putting values: $\Delta m = 2(1.007825u) + 2(1.008665u) - 4.002602u$

$\Delta m = 2.01565u + 2.01733u - 4.002602u$

The binding energy is given by

$E_B = (ZM_P + NM_N - M)\,c^2$

$E_B - \Delta m \times c^2 - \Delta m \times 931.5MeV$

Putting values $E_B = 0.30378 \times 931.5MeV$

Therefore, $\boxed{E_B = 28.297107MeV}$

2. A certain radioactive isotope has half-life of 8 hours. A solution containing 500 million atoms of this isotope is prepared. How many atoms of this isotope have not disintegrated after?

(a) 8 hours (b) 24 hours

Given:

Number of atoms present $N_O = 500$ million

Number of half-lives n(after 8 hours) = 1

To Find:

Number of atoms left N = ?

Solution:

The number of nuclei after left to the total nuclei present is given by formula: $N = \left(\frac{1}{2}\right)^2 N_o$

Putting value: $N = \left(\frac{1}{2}\right)^1 N_o$

$$N = \frac{500\text{ million}}{2}$$

$$\boxed{N = 250\text{ million}}$$

(b) **given:**

Number of atoms present = 500 million

Number of half lives n(after 24 hours) = 3

To Find:

Number of atoms left N = ?

Solution:

The number of nuclei left to the total nuclei present is given by formula: $N = \left(\frac{1}{2}\right)^n N_o$

putting values

$$N = \left(\frac{1}{2}\right)^3 N_o$$

$$N = \frac{500\text{ million}}{8}$$

Therefore, $\boxed{N = 62.5\text{ million}}$

3. Write the nuclear equation for the beta decay of:

(a) ${}_{82}Pb^{210}$ **(b)** ${}_{83}Bi^{210}$ **(c)** ${}_{90}Th^{234}$ **(d)** ${}_{93}N_p{}^{239}$

Solution:

The general formula for the (-) beta emission

$${}^{A}_{Z}X = {}^{A}_{Z+1}Y\,\bar{\beta} + \bar{\upsilon} + Q$$

(a) Lead converts into bismuth by releasing a negative beta particle and an anti-neutrino :

$$\boxed{{}_{82}Pb^{210} \rightarrow {}_{83}Bi^{210} + {}^{\;0}_{-1}\beta + \bar{\upsilon} + Q}$$

(b) Bismuth convert into polonium by releasing a (-) beta particle and anti-neutrino

$$\boxed{{}_{83}Bi^{210} \rightarrow {}_{84}Po^{210} + {}_{-1}\beta^{0} + \bar{\upsilon} + Q}$$

(c) Thorium converts into protactinium by releasing a (-) beta particle and an anti- neutrino

$$\boxed{{}_{90}Th^{234} \rightarrow {}_{91}Pa^{237} + {}_{-1}\beta^{0} + \bar{\upsilon} + Q}$$

(d) Neptunium convert into plutonium by releasing a negative beta particle and anti-neutrino

$$\boxed{{}_{93}Np^{239} = {}_{94}Pu^{239} + {}_{-1}\beta^{0} + \bar{\upsilon} + Q}$$

4. Calculate the total energy released if 1 kg of U^{235} undergoes fission? Taking the disintegration energy per event to be Q = 208 MeV.

Given:

Number of nuclei per atom n = 235

Disintegration energy Q = 208MeV

To Find:

Total energy released E = ?

Solution:

The total released 'E' will be equal to the product of number of atoms 'N' present in the sample and the energy released per event Q.

$$E_{total} = NQ \longrightarrow (i)$$

As 1kg of any element = 6.023×10^{26}

So, $$N = \frac{\text{Mass of } 6.023 \times 10^{26} \text{ nuclei of } U^{235} \text{ per mole}}{235\text{kg per mol}}$$

$$N = 2.56 \times 106 \text{ nuclei of } {}^{U235}$$

Putting values in equation (i)

$$E_{total} = 2.56 \times 10^{26} \times 208\text{MeV}$$

$$\boxed{E_{total} = 5.3248 \times 10^{26}\ \text{MeV}}$$

5. Find the energy released in the following fission reaction.

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

Given:

Reaction

To Find:

Total energy released Q = ?

Solution:

Nuclear reaction energy Q:

The energy released in this fission can be calculated as

Reactants	Products
${}^{1}_{0}n = 1.0087u$	${}^{141}_{35}Ba = 140.9139u$
${}^{235}_{92}U = 235.0439u$	${}^{92}_{36}Kr = 91.8973u$
	$3{}^{1}_{0}n = 3.0261u$
Total = 236.0526m	Total = 235.8373u

The mass detect is $\Delta m = 236.0526u - 235.8373u = 0.2153u$

Since 1μ is equivalent to 931.5 meV, the energy released in

$$\text{Nuclear energy} = 0.2153\ \mu \times \frac{931.5\text{MeV}}{1\mu}$$

$$\text{Nuclear energy} = \boxed{200.55195\text{MeV}}$$

6. Find the energy released in the fusion reaction, $_1H^2 + _1H^3 \to _2He^4 + _0n^1$

Given:

Initial masses	**Final masses**
$^2_1H = 2.014u$	$^4_2He = 4.0026\mu$
$^3_1H = 3.016u$	$^1_0n = 1.0087\mu$
Total = 5.0302u	Total = 5.0113μ

The decrease in mass, or the mass is $\Delta m = 5.0302u - 5.0113u = 0.0189u$

Since 1u is equivalent to 931.5MeV, the energy released in

$$\text{Released energy} = 0.0189u \times \frac{931.5MeV}{1u}$$

$$\boxed{\text{Released Energy} = 17.6\,MeV}$$

---

7. Complete the following nuclear reactions,

$$_7N^{14} + _2He^4 \to _1H^1 + ?$$

$$_5B^{11} + _1H^1 \to _6C^{11} + ?$$

$$_3Li^6 + ? \to _4Be^7 + _0n^1\ (_8O^{17}, _0n^1, _1H^2)$$

Solution:

$^{14}_7N - ^4_2He \longrightarrow ^1_1H + ^{17}_8O$ symbolic represents $^{14}_7N(\alpha, \sigma)^{17}_8O$

$^{11}_5B + ^1_1H \longrightarrow ^{11}_6C + ^1_0n$ symbolic represents $^{11}_5B(P, n)^{11}_6C$

$^6_3Li + ^2_1H \longrightarrow ^7_4Be + ^1_0n$ symbolic represents $^6_3Li(d, n)^7_4Be$

---

8. $_3Li^6$ is bombarded by deuterons. The reaction gives two α-particles along with release of energy equal to 22.3 MeV. Knowing masses of deuteron and α-particles determine mass of lithium isotope of $_3Li^6$.

Given:

The relation is $^2_1H + ^6_3Li \longrightarrow 2\,^4_2He + Q$

To Find:

Mass of isotope $_3Li_6 \longrightarrow = ?$

Solution:

The masses of the given nuclei in this reaction, as well as the energy released are $^2_1H = 2.014\ \mu$, $^4_2He = 4.0026\mu$

$$Q = 22.3MeV = 0.0239\mu$$

The energy released in atomic mass units can be written as, since 1μ is equivalent to 931.5MeV,

$$1u = 931.5MeV \text{ therefore } 1MeV = \frac{1}{931.5}u$$

Or $$Q = 22.3MeV = \frac{22.3}{931.5}u$$

From the reaction $m^6_3Li = 2 \times m^4_2He + Q - m^2_1H$

$$m\,^6_3Li = 2\times4.00264 + 0.02394u - 2.0154u$$

$$\boxed{m^6_3Li = 6.01504u}$$

ind the energy released when β-decay changes $_{90}Th^{234}$ $_{91}Pa^{234}$. Mass of $_{90}Th^{234}$ = 234.0436u and $_{91}Pa^{234}$ =234.042762u.

Given: Mass of $_{90}Th^{234} = 234.0436\mu$
Mass of $_{91}Pa^{234}$ 234.0428μ

To Find:

Energy released Q = ?

Solution:

The reaction is $_{90}Th^{234} \longrightarrow {}_{91}Pa^{234} + {}_{-1}\overset{o}{\beta} = \bar{\upsilon} + Q$
The mass of beta particle is 0.000594μ
The energy released is given by the equation

$$Q - m\,{}^{234}_{90}Th - m\,{}^{234}_{91}Pa - m\beta^{-}$$

Putting values:

$$Q = 234.0436\mu - 234.042762\mu - 0.0005485$$

Since 1μ is equivalent to 931.5 MeV, the energy released is

$$\text{Released energy} = 0.0002895\,\cancel{\mu} \times \frac{931.5\text{MeV}}{\cancel{\mu}}$$

$$\boxed{\text{Released energy} \doteq 0.26967\text{MeV}}$$

10. Find out the K.E to which a proton must be accelerated to induce the following nuclear reaction. Li^{7} (p,n) Be^{7}.

Given:

The reaction is ${}^{1}_{3}H + {}^{7}_{3}Li \rightarrow {}^{7}_{4}Be + {}^{1}_{0}n + Q$

To Find:

Kinetic energy of proton Q = ?

Solution:

The masses of the given nuclei in this reaction are

${}^{2}_{1}H = 1.00814u$ ${}^{7}_{3}Li = 7.01823u$
${}^{7}_{4}Be = 7.01592u$ ${}^{1}_{0}n = 1.00866u$

∴ e energy released in given by equation

$$Q = m_{1}^{1}H + m_{3}^{1}Li - m_{4}^{7}Be - m_{0}^{1}n$$
$$Q = 1.00814u + 7.01823u - 7.01592u - 1.00866u$$
$$Q = 0.00179u$$

Since Iμ is equivalent to 931.5MeV, the energy released as

$$\text{Released energy} = 0.00179\cancel{\mu} \times \frac{931.5\text{MeV}}{1\cancel{\mu}}$$

$$\boxed{\text{Released energy} = 1.67\text{MeV}}$$

Additional Conceptual Short Questions With Answers

What is atomic mass unit (a.m.u) and show that
$1U = 1.6606 \times 10^{-27}$ Kg

s. Atomic mass unit is the unit of mass used in nuclear physics as adopted by the international union of pure and Applied Physics (IUPAP).

One amu is equal to $\left(\frac{1}{12}\right)$th of the mass of one $_{6}C^{12}$ atom

$$\text{Mass of one carbon atom} = \frac{12\text{gm}}{6.023 \times 10^{23}}$$

$$\text{Mass of one carbon atom} = \frac{12 \times 10^{-3}\ \text{Kg}}{6.023 \times 10^{23}}$$

$$1\text{amu} = \frac{1}{12}\text{(mass of one carbon atom)}$$

$$= \frac{1}{12}\left(\frac{12 \times 10^{-3}\ \text{Kg}}{6.023 \times 10^{23}}\right)$$

$$= \frac{1}{12}(1.992678 \times 10^{-26}\ \text{Kg})$$

$$1\text{amu} = 1\text{U} = 1.6606 \times 10^{-27}\ \text{Kg}$$

2. Show that 1U = 931Mev (approximately) OR

What is relation between amu and Mev

Ans. $1\text{U} = 1.660565 \times 10^{-27}\ \text{Kg}$

$E = mc^2$

$$\text{Energg of } 1\text{U} = 1.660565 \times 10^{-27}(2.998 \times 10^{8})^2$$

$$= 1.4925 \times 10^{-10}\ \text{J}$$

$$\text{IU} = \frac{1.4925 \times 10^{-10}}{1.602 \times 10^{-19}}$$

$$\text{IU} = 931.64 \times 10^{6}\text{ev}$$

IU = 931 Mev (approximately)

3. What are the drawback of a Geiger counter as a radiation detector?

Ans. It is not suitable for fast counting of the radiations, it is due to its long dead time (10^{-4} sec), some of the radiations remains unaccounted during long dead time.

4. Will a single nucleus emit α – particle, β – particle and γ – rays together?

Ans. No, one nucleus can emit either α – particle or β – particle at one time.

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

Ans. Isotopes are the different atoms of the same the element which have same atomic or charge number Z but different mass numbers A.

Similarities:

(i) Same atomic or charge number Z.
(ii) Same chemical properties.

Differences:

(i) Different mass numbers A.
(ii) Different physical properties.

6. Why are heavy nuclei unstable?

Ans. A nucleus is unstable if it is too big. i-e, Its atomic number (becomes greater) than 82

Reason:

In the heavy nuclei which have too ***many neutrons relative to protons*** (i.e. N > Z), the strong nuclear force between two nucleous falls off rapidly. Hence electrostatic repulsive force overcomes the strong nuclear force.

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

Ans. If N_o = Number of original atoms then after 2 half-lives, Number of un-decayed atoms = $\frac{N_o}{4}$

Therefore, number of decayed atoms $N_o - \frac{N_o}{4} = \frac{3N_o}{4}$

So, radioactive sample will not be completely decayed after 2 half-lives, only $\frac{3N_o}{4}$(75%) will have decayed.

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

Ans. A particle which produces more ionization loses its energy more rapidly and hence comes to rest soon after covering a smaller distance. So, it has less penetrating power.

9. What factors make a fusion reaction difficult to achieve?

Ans. Fusion reactions take place at very high temp e.g., 10^7 K because charged nuclei have great repulsive force between them. This high temperature increases their K.E. so much that it overcome the repulsive forces. This factor of very high temperature & K.E. makes the fusion reactions difficult to achieve.

10. If you swallowed an α-source and a β-particle, which would be more dangerous to you? Explain why?

Ans. α-source is more dangerous if it swallowed, became it has 100 times more ionization power than the β-particle.

* * *

Self-Assessment Paper 1

Q.No.1 Encircle the correct option.

1. Absorbed Dose "D" is defined as
(A) $\frac{m}{E}$ (B) $\frac{E}{C}$ (C) $\frac{C}{m}$ (D) $\frac{E}{m}$

2. Half life of radium is 1620 years. In how many years shall the earth loss all its radium due to radioactive decay?
(A) 1590×10^{6} years (B) 1590×10^{12} years (C) 1590×10^{24} years (D) never

3. The most useful tracer is __________
(A) Sr – 90 (B) I – 131 (C) Ca – 41 (D) C – 14

4. Which of the following will be a better shield against γ - rays?
(A) ordinary water (B) heavy water (C) lead (D) aluminum

5. The maximum safe limit dose for persons working in nuclear power station is __________
(A) 1 rem per week (B) 5 rem per week (C) 4 rem per week (D) 3 rem per week

6. When α – particle is emitted from any nucleus mass number ______ and its charge number ______
(A) increases by 2m , increases by 2 (B) decreases by 4, decreases by 2
(C) decreases by 4, increases by 2 (D) decreases by 4, decreases by 4

7. In mass spectrograph mass of each ion reaching the detector is proportional to
(A) $\sqrt{r}$ (B) B^2 (C) V^2 (D) $\sqrt{B}$

8. The radioactive element has the half life of 1600 years, after 6400 years what function will remain
(A) 1/16 (B) 1/8 (C) 1/2 (D) 1/4

9. The binding energy per nucleon is maximum for
(A) ${}_{26}Fe^{56}$ (B) ${}_{92}U^{235}$ (C) ${}_{56}Ba^{141}$ (D) ${}_{2}He^{4}$

10. The dead time of Geiger – Muller Counter is of the order of
(A) micro second (B) millisecond (C) more than millisecond (D) nanosecond

Q.No.2 Write Short Answers any SIX of the following questions.

1. Which radiation dose would deposit more energy to the body (a) 10 mGy to the hand (b) 1 mGy to the whole body?
2. State the radioactive decay laws.
3. Describe the principle of operation of solid state detector of ionizing radiation in generation and detection of charge carriers.
4. What fraction of a radioactive sample decays after two half-lives have elapsed?
5. What do you mean by critical mass?
6. How can the radioactivity help I the treatment of cancer?
7. Prove that 1 u = 931 MeV.

Q.Nc 3Extensive Question.

Q. (a) What is mass spectrograph? Explain its working.
(b) Find the mass Defect and binding energy for helium nucleus?

Self-Assessment Paper 2

Q.No.1 Encircle the correct option.

1. **The amount of the energy equivalent to 1 a.m.u. is**
   (A) 931 MeV (B) 93.15 MeV (C) 9.315 MeV (D) 2.224 MeV
2. **The energy released by fusion of two deuterons into a Helium nucleus is about**
   (A) 24 MeV (B) 200 MeV (C) 1.02 MeV (D) 7.2 MeV
3. **The particles equal in mass or greater than protons are called**
   (A) Leptons (B) Baryons (C) Mesons (D) Mouns
4. **Thyroid cancer is cured by**
   (A) iodine – 131 (B) carbon – 14 (C) sodium – 24 (D) cesium – 137
5. **By emitting $\beta-$particle and $\gamma-$particle simultaneously the nucleus changes its charge by**
   (A) losses by 1 (B) increases by 1 (C) increase by 2 (D) no change will be observed
6. **The half life on $^{91}_{38}Sr$ is 9.70 hours. What is its decay constant?**
   (A) $1.98\times10^{-5}s^{-1}$ (B) $1.6\times10^{-4}s^{-1}$ (C) $2.5\times10^{-5}s^{-1}$ (D) none of these
7. **A sample contains N radioactive nuclei. After 4 half lives number of nuclei decayed is ________**
   (A) $\frac{N}{16}$ (B) $\frac{15N}{16}$ (C) $\frac{N}{8}$ (D) $\frac{7N}{8}$
8. **Energy given out per nucleon in p – p reaction is**
   (A) 5.2 MeV (B) 6 MeV (C) 6.4 MeV (D) 7.7 MeV
9. **Leptons are particles that do not experience ________**
   (A) weak nuclear force (B) strong nuclear force (C) electric force (D) magnetic force
10. **A pair of quark and anti quark makes**
   (A) meson (B) Baryon (C) photon (D) proton

Q.No.2 Write Short Answers any SIX of the following questions.

1. A particle which produces more ionization is less penetrating. why?
2. What information is revealed by the length and shape of the tracks of an incident particle in Wilson cloud chamber?
3. What do you mean by dead time in GM counter?
4. Discuss the advantages and disadvantages of fission power compared to the use of fossil fuel generated power.
5. The half life of $^{91}_{38}Sr$ is 9.70 hours. Find its decay constant.
6. Find the binding energy of tritium. Mass of tritium nucleus=3.016049u, mass of proton=1.007276u, Mass of neutron=1.008665u.
7. Describe the brief account of interaction of various type of radiations with matter.

Q.No.3Extensive Questions.

Q. (a) What is nuclear reactor? Describe its principle and working in detail.

(b) Calculate the total energy released if 1kg of U^{235} undergoes fission? Taking the disintegration energy per event to be Q = 208MeV.

⊙⊙⊙⊙⊙⊙⊙