Nuclei

13 Chapter

1 ATOMIC MASSES AND COMPOSITION OF NUCLEUS

- Before discovery of neutron, nucleus was assumed to be made up of protons and electrons but later this was ruled out using argument of quantum theory.

2 DISCOVERY OF NEUTRON

- In 1932 James Chadwick observed emission of neutral radiation, when beryllium nuclei was bombarded with α-particle on the basis of energy and momentum conservation.
  Chadwick concluded that it was a new type of neutral particle called neutron.
  $^{9}_{4}Be + ^{4}_{2}He \rightarrow ^{12}_{6}C + ^{1}_{0}n$
- All nuclides with same atomic number but having different mass are called isotopes.
- All nuclides with same mass number are called isobars.
- Nuclides with same neutron but different atomic number are called isotones.
- $A = Z + N$

3 SIZE OF NUCLEUS

- The radius of nucleus with mass number 'A' is $R = R_0 A^{1/3}$ where, $R_0 = 1.2 \times 10^{-15}$ m.
- Density of nucleus is approximately 2.3×10^{17} kg/m^3 and is independent of mass number.

4 MASS ENERGY AND NUCLEAR BINDING ENERGY

- **Mass energy :** Einstein showed that mass is another form of energy and one can convert into other form. Einstein gave the famous mass energy equivalence relation $E = mC^2$.
- $1u = 931.5\ MeV/C^2$

5 NUCLEAR BINDING ENERGY

- The difference in mass of a nucleus ($_ZX^A$) and its constituents, ΔM, is called the mass defect.
  $\Delta M = [Zm_p + (A-Z)m_n] - M$
- If one wants to break the nucleus into protons and neutrons. This extra energy $(\Delta M)c^2$, has to be supplied. This energy called binding energy.
  $E_b = \Delta Mc^2$
- Binding energy per nucleon is the measure of stability of nucleus.
- The binding energy per nucleon is practically constant for nuclei of middle mass number ($30 < A < 170$), with maximum of 8.75 MeV for $A = 56$ and has a value of 7.6 MeV for $A = 238$.
- Binding energy per nucleon is lower for both light nuclei ($A < 30$) and heavy nuclei ($A > 170$)

7 LAW OF RADIOACTIVE DECAY

- Rate of disintegration, $\frac{dN}{dt} = -\lambda N$
- $N = N_0 e^{-\lambda t}$
- Half life : $T_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.6931}{\lambda}$
- λ = Decay constant.
- Mean life, $\tau = \frac{1}{\lambda} = 1.44 T_{1/2}$

α-Decay : During α-decay, atomic number decreases by two and mass number by four.

- It is nuclei of helium
  $^{A}_{Z}X \rightarrow ^{A-4}_{Z-2}Y + ^{4}_{2}He + Q$
  $Q = (m_x - m_y - m_{He})C^2$

β-Decay :

(i) β^- decay: $^{A}_{Z}X \rightarrow ^{A}_{Z+1}Y + e^- + \bar{\nu}$

$$Q = \left[m\left(_ZX^A\right) - m\left(_{Z+1}Y^A\right)\right]C^2$$

(ii) β^+ decay: $^{A}_{Z}X \rightarrow ^{A}_{Z-1}Y + e^+ + \nu$

$$Q = \left[m\left(_ZX^A\right) - m\left(_{Z-1}Y^A\right) - 2m_e\right]C^2$$

γ-Decay :

- Like an atom, a nucleus also has discrete energy levels, the ground state and excited states. When a nucleus in an excited state spontaneously decays to ground state (or to lower energy state), a photon is emitted. This is called γ-decay.
- The difference in nuclear energy levels is of the order of MeV.

6 NUCLEAR FORCE

- Inside the nucleus, a large attractive force is required to bind the nucleons against repulsion. The force is called nuclear force.
- It is strongest attractive force. $F_{P-P} = F_{n-n} = F_{P-n}$
- It is charge independent force i.e.
- It is short range force.
- It has property of saturation.
- For a distance ($r < 0.8$ fm) it is repulsive force.

8 NUCLEAR FISSION

- When a slow moving neutron strikes a heavy nucleus, which breaks into two intermediate mass nuclear fragments. This is called nuclear fission.
  $^{1}_{0}n + ^{236}_{92}U \rightarrow ^{236}_{92}U \rightarrow ^{144}_{56}Ba + ^{89}_{36}Kr + 3^{1}_{0}n$
- The energy released (the Q-value) in the fission of single uranium is of the order of 200 MeV.
- Multiplication factor (K) = $\frac{\text{Rate of production of neutrons}}{\text{Rate of loss of neutrons}}$
- Uncontrolled chain reaction is the principle of atom bomb.
- Controlled chain reaction is the principle of nuclear reactors.

9 NUCLEAR REACTOR

- U^{235} or Pu^{239} is used as fuel in a nuclear reactor.
- D_2O, graphite and beryllium oxide are used as moderator to slow down the fast neutrons.
- Rate of reaction is controlled by control rods made of cadmium or boron
- Air, ice cold water, molten sodium or CO_2 are used as coolant.

10 NUCLEAR FUSION

It is the phenomenon in which two or more lighter nuclei combine to form a single middle weight nucleus.

Some examples of nuclear fusion.

$^{1}_{1}H + ^{3}_{1}H \rightarrow ^{2}_{1}H + e^+ + \nu + 0.42\ MeV$

$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + n + 3.27\ MeV$

$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{1}H + ^{1}_{1}H + 4.03\ MeV$

Sharpen Your Understanding

1. The atomic masses of various elements expressed in atomic mass unit (u) are close to being integral multiples of mass of [NCERT Pg. 439]
   (1) A hydrogen atom
   (2) A proton
   (3) A neutron
   (4) Both (2) and (3)
2. The density of nuclear matter [NCERT Pg. 441]
   (1) Increases with mass number
   (2) Decreases with mass number
   (3) Is independent of mass number
   (4) Increases up to mass number 56 then decreases
3. For thermonuclear fusion reaction, the estimated temperature of the system should be about [NCERT Pg. 456]
   (1) 3×10^3 K (2) 3×10^9 K
   (3) 1×10^5 K (4) 3×10^6 K
4. Nuclear force is [NCERT Pg. 445]
   (1) Attractive for distance, $r = 0.5$ fm
   (2) Repulsive for distance, $r < 0.8$ fm
   (3) Attractive for distance, $r < 0.8$ fm
   (4) Repulsive for distance, $r > 0.8$ fm

NCERT Based MCQs

5. The SI unit of activity is [NCERT Pg. 447]
   (1) Becquerel (2) Curie
   (3) Rutherford (4) Both (1) and (2)
6. The mass of iron nucleus is $55.85u$ and $A = 56$. The nuclear density of iron is [NCERT Pg. 441]
   (1) 2.5×10^{15} kg/m^3 (2) 2.3×10^{16} kg/m^3
   (3) 2.3×10^{17} kg/m^3 (4) 3.5×10^{16} kg/m^3
7. 1 curie is equal to [NCERT Pg. 448]
   (1) 3.7×10^7 Bq (2) 3.7×10^{10} Bq
   (3) 3.7×10^8 Bq (4) 3.7×10^6 Bq
8. The half life of $_{92}U^{238}$ undergoing α-decay is 4.5×10^9 years. The activity of 4 g sample of $_{92}U^{239}$ is [NCERT Pg. 448]
   (1) 1.23×10^4 Bq
   (2) 1.23×10^5 Bq
   (3) 4.9×10^4 Bq
   (4) 4.9×10^5 Bq
9. 1 mg radium has 2.68×10^{18} atoms. Its half life is 1620 years. How many radium atoms will disintegrate from 1 mg of pure radium in 3240 years. [NCERT Pg. 448]
   (1) 2.01×10^9 (2) 2.01×10^{18}
   (3) 0.67×10^{18} (4) 1.01×10^9
10. In a sample of radioactive material, what fraction of the initial number of active nuclei will remain undisintegrated after half of the half life of the sample? [NCERT Pg. 448]
    (1) $\frac{1}{4}$ (2) $\frac{1}{2\sqrt{2}}$
    (3) $\frac{1}{\sqrt{2}}$ (4) $\sqrt{2}-1$
11. The natural boron of atomic mass 10.81 u is found to have two isotopes ^{10}B and ^{11}B. The ratio of abundance of isotopes of natural boron should be nearly [NCERT Pg. 439]
    (1) 11 : 10 (2) 81 : 19
    (3) 10 : 11 (4) 19 : 81
12. The energy liberated in a single uranium fission is about [NCERT Pg. 457]
    (1) 200 MeV
    (2) 235 MeV
    (3) 20 MeV
    (4) 100 MeV
13. Pick out the incorrect statement from the following. [NCERT Pg. 450]
    (1) β^- emission from the nucleus is always accompanied with a neutrino
    (2) The energy of the α-particle emitted from a given nucleus is constant
    (3) γ-ray emission makes the nucleus more stable
    (4) Nuclear force is charge-independent

14. The radius of a spherical nucleus as measured by electron scattering is 3.6 fm. What is the mass number of the nucleus most likely to be? [NCERT Pg.441]

(1) 27 (2) 40

(3) 56 (4) 120

15. The number of β^--particles emitted by a radioactive substance is twice the number of α-particles emitted by it. The resulting daughter is an [NCERT Pg. 450]

(1) Isomer of parent (2) Isotone of parent

(3) Isobar of parent (4) Isotope of parent

16. In nuclear reactors, the controlling rods are made of [NCERT Pg. 454]

(1) Cadmium (2) Graphite

(3) Krypton (4) Plutonium

17. A nucleus with mass number 220 initially at rest emits an α-particle. If the Q-value of reaction is 5.5 MeV, the kinetic energy of α-particle is [NCERT Pg. 449]

(1) 4.4 MeV

(2) 5.4 MeV

(3) 5.0 MeV

(4) 4.8 MeV

18. Choose the incorrect nuclear fusion reactions among the following [NCERT Pg. 455]

(1) ${}_1^1H + {}_1^1H \rightarrow {}_1^2H + e^+ + \nu + 0.42$ MeV

(2) ${}_1^2H + {}_1^2H \rightarrow {}_2^3He + n + 3.27$ MeV

(3) ${}_1^2H + {}_1^2H \rightarrow {}_1^3H + {}_1^1H + 4.03$ MeV

(4) $e^+ + e^- \rightarrow \gamma$

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

(1) Decreases with mass number at low mass numbers

(2) Increases with mass number at low mass numbers

(3) Increases with mass number and high mass numbers

(4) Decreases with mass number at high mass numbers

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

(1) α, β, γ (2) γ, β, α

(3) β, α, γ (4) β, γ, α

Thinking in Context

1. The radius of nucleus is smaller than the radius of atom by a factor of about _____ [NCERT Pg. 438]

2. Nucleus of an atom contains more than _____ of the mass of an atom [NCERT Pg. 438]

3. The fractional atomic masses of elements in atomic mass unit shows that most of elements have _____ [NCERT Pg. 439]

4. α-particles are the _____ of helium [NCERT Pg. 449]

5. A free neutron, unlike a free proton is _____ and has a mean life of about _____ [NCERT Pg. 440]

6. If a certain number of neutrons and protons are brought together to form a nucleus, then energy is _____ [NCERT Pg. 443]

7. The constancy of binding energy in the range $30 < A < 170$ is a consequence of the fact that nuclear force is _____ force [NCERT Pg. 444]

8. The property that a given nucleon influences only nucleons close to it, is also referred as _____ property of nuclear force. [NCERT Pg. 445]

9. Like an atom, nucleus has _____ energy levels [NCERT Pg. 451]

10. The difference in nuclear energy levels is of order of _____ [NCERT Pg. 451]

11. If nuclei with less total binding energy transform to nuclei with greater binding energy, there will be a net energy _____ [NCERT Pg. 451]

12. In nuclear fusion two lighter nuclei combine to form a comparatively _____ nucleus [NCERT Pg. 445]

13. Energy associated with nuclear processes is about a _____ times larger than in a chemical process. [NCERT Pg. 452]

14. The mass density of the nuclei is _____ of mass number [NCERT Pg. 441]

15. The energy equivalent to 1 amu is_____ [NCERT Pg. 443]

16. Isobars are atom of different elements which have same _____ number but different _____ number [NCERT Pg. 441]

❑ ❑ ❑

17. The Apsara reactor at Bhabha Atomic Research Centre, Mumbai uses _____ as moderator [NCERT Pg. 454]

18. Isotones are the nuclides which contains same number of _____ [NCERT Pg. 441]

19. Radioactivity is an indication of the _____ of nuclei. [NCERT Pg. 461]

20. The mass of the nucleus is ____ the sum of the masses of nucleons forming it [NCERT Pg. 443]