CHAPTER : 13

NUCLEI

STUDY NOTES

- **Nucleons :** The constituents of nucleus i.e, the protons and neutrons which are present in the nuclei of the atoms are collectively known as nucleons.
- **Atomic Number :** The number of protons present in the nucleus of an atom is called the atomic number. It is denoted by Z.
- **Mass number :** The number of nucleons present in a nucleus is called the mass number of the element. It is denoted by A. Number of protons in an atom = Number of electrons in an atom = Z (Since the atoms are electrically neutral). Number of nucleons in an atom = A. Number of neutrons in an atom = N = A – Z.
- **Nuclear mass :** Sum of mass of all the protons and neutrons present in a nucleus is called the nuclear mass.
- **Nuclide :** It is a specific nucleus of an atom characterized by its atomic number Z and mass number A. It is written as $^{A}_{Z}X$; where X = chemical symbol of the element, Z = atomic number, and A = mass number.
- **Isotopes :** The atoms of an element, which have the same atomic number but different mass number are called isotopes. E.g., $^{1}_{1}H$ and $^{2}_{1}H$
- **Isobars :** The atoms that have different atomic number but have the same mass number are called isobars. . E.g., $^{3}_{1}H$ and $^{3}_{2}He$
- **Isotones :** The nuclides that have the same number of neutrons are called isotones. E.g., $^{37}_{17}Cl$ and $^{39}_{19}K$.
- **Atomic mass unit (amu) :** One twelfth of the mass of one $^{12}_{6}C$ atom is defined as atomic mass unit. Its value is given by 1 amu = 1.660565×10^{-27} kg = 931 MeV.
- **Electron volt (eV) :** 1 electron volt is the amount of energy acquired by an electron when it is accelerated through a potential difference of 1 volt and is denoted by 1eV. 1eV = 1.602×10^{-19} J.
- **Relation between size of nucleus and mass number :** It is found that the radius r of a nucleus is proportional to the cube root of its mass number. $R = R_0A^{1/3}$; where $R_0 = 1.2 \times 10^{-15}$ m = 1.2 fermi.
- **Nuclear density :** The density of a nucleus is independent of the size of the nucleus.
- **Discovery of neutrons :** Chadwick in 1932 discovered neutron. When he bombarded alpha particle on beryllium nuclei, highly penetrating radiations were emitted, which consisted of neutral particles, each having mass nearly equal to the mass of the protons. These particles were called neutrons. Neutrons have more penetrating power as compared to that of protons. Free neutrons are unstable.
- **Nuclear forces :** The strong attractive forces which hold protons and neutrons together in a tiny nucleus are called as nuclear forces. These are short range forces which operate over of distances of about 2-3 fm from a nucleon. The nuclear force does not depend on the charge of the nucleus. It is an exchange force and it is a non-central force.
- **Mass defect :** The difference between the rest mass of a nucleus and the sum of the rest masses of its constituent nucleons is called its mass defect. It is given by

$$\Delta m = Zm_p + (A - Z)m_n - m$$

- **Binding energy :** It is the energy required to break up a nucleus into its constituent protons and neutrons and to separate them to such a large distance that they may not interact with each other. It may also be defined as the surplus energy which the nucleons give up by virtue of their attractions when they become bound together to form a nucleus. The binding energy of a nucleus ${}^{A}_{Z}X$ is given by

$$B.E. = [Zm_H + (A-Z)m_H - m]c^2.$$

- **Binding energy per nucleon :** It is the average amount of energy required to remove one nucleon from the nucleus. It is obtained by dividing the binding energy of a nucleus by its mass number.

$$\frac{B.E.}{A} = \frac{[Zm_H + (A-Z)m_H - m]c^2}{A}$$

- In the mass number range, A = 30 to 170, the binding energy per nucleon is nearly constant, about 8 MeV per nucleon. This suggests nuclear forces are short range forces.
- **Packing fraction :** The packing fraction of a nucleus is defined as its mass defect per nucleon.

  P.F. of a nucleus = Mass defect / Mass number

  It relates the availability of nuclear energy and the stability of the nucleus.
- **Einstein's Mass energy relation :** According to this relation a particle having mass m even at rest possesses a large amount of energy, which is given by equation,

$$E = mc^2;\ \text{where } c \text{ is the speed of light}$$

- **Pair production :** When an energetic γ-ray photon falls on a heavy substance. It is absorbed by some nucleus of the substance and an electron and a positron are produced. This phenomenon is called pair production. For pair-production it is essential that the energy of photon must be at least 2 × 0.51 = 1.02 MeV. If the energy of photon is less than this, it would cause photoelectric effect or Compton effect on striking the matter.
- **Pair-annihilation :** It is the converse phenomenon pair production. Whenever an electron and a positron come very close to each other, they annihilate each other by combining together and two photons (energy) are produced. This phenomenon is called pair annihilation
- **Radioactivity :** It is the phenomenon of spontaneous disintegration of the nucleus of an atom with the emission of one or more radiations like α–particles, β–particles or γ–rays.
- **Radioactive Substances :** The substances which spontaneously emit the above penetrating radiation.
- **Soddy-Fajan's displacement law:** It states that

  (i) When an α-particle is emitted by a radioactive nucleus, its atomic number decreases by 2 and mass decreases by 4. This process of emission is called α-decay.

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

  (ii) When a β-paritcle is emitted by a radioactive nucleus, its atomic number increases or decreases by 1 respectively depending on weather an electron or a positron is released but mass number remains the same. This process of emission is called β-decay.

$${}^{A}_{Z}X \rightarrow {}_{Z+1}^{A}Y + \beta^- + \bar{\nu} \qquad (\beta^-\text{-decay})$$

$${}^{A}_{Z}X \rightarrow {}_{Z-1}^{A}Y + \beta^+ + \nu \qquad (\beta^+\text{-decay})$$

  (iii) The emission of a γ-particle does not change the mass number or the atomic number of the radioactive nucleus. This is called γ-decay.

$$\underset{\text{(Excited state)}}{{}^{A}_{Z}X} \rightarrow \underset{\text{(Ground state)}}{{}^{A}_{Z}X} + \gamma$$

Radioactive decay law: The number of atoms of a radioactive sample disintegrating per second at any instant is directly proportional to the number of undecayed radioactive nuclei present at that instant.

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

The law may also be expressed as, $N = N_0 e^{-\lambda t}$ where N_0 is the number of nuclei at $t = 0$ and λ is decay constant.

Decay constant: It is the reciprocal of the time interval in which the number of active nuclei in a given radioactive sample reduces to $1/\lambda$ times of its initial value. Its units are s^{-1}, day^{-1}, $year^{-1}$, etc.

Half-life: It is the time in which one-half of the initial number of nuclei disintegrates.

$$T_{1/2} = \frac{0.693}{\lambda}; \; N = N_0\left(\frac{1}{2}\right)^n$$

(where N = number of half-lives in time $t = t/T_{1/2}$)

Its units are s, day, year, etc.

Mean-life: It is the ratio of the combined age of all the atoms to the total number of atoms present in the given sample.

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

Its units are s, day, year, etc.

Decay rate or activity of a sample: It is the rate of radioactive disintegrations taking place in a given sample.

$$R = \left|\frac{dN}{dt}\right| = \lambda N = \lambda N_0 e^{-\lambda t} \;\; or \;\; R = R_0 e^{-\lambda t}$$

Its SI unit becquerel, curie, rutherford.

- 1 becquerel = 1 bq = 1 decay per second.
- 1 Ci(curie)= 3.7×10^{10} disintegrations per second.
- 1 rd (rutherford) = 10^6 disintegrations per second.

Natural radioactivity: It is the phenomenon of the spontaneous emission of α –, β – or γ-radiations from the nuclei of naturally occurring isotopes.

Artificial or induced radioactivity: It is the phenomenon of inducing radioactivity in certain stable nuclei by bombarding them suitable high energy particles.

- **Nuclear reaction:** It is a reaction that involves the change of stable nucleus of one element into the nucleus of another element, by bombarding the former with suitable high energy particles.

  The general expression for the nuclear reaction is as follows:

  X(parent nucleus)+A(incident particle) → Y(compound nucleus)+ B(product particles)+ Q(energy)

- **Q value or energy of nuclear reaction :**

  The energy absorbed or released during a nuclear reaction is known as Q-value of nuclear reaction.

  Q-value = (Mass of reactants – mass of products)c^2 joules = (Mass of reactants – mass of products) amu

  If $Q < 0$, The nuclear reaction is known as endothermic. (The energy is absorbed in the reaction.)

  If $Q > 0$, The nuclear reaction is known as exothermic. (The energy is released in the reaction.)

- **Nuclear fission :** It is the process in which a heavy nucleus (A>230) when excited gets split up into two smaller nuclei of nearly comparable masses. For example,

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

- **Thermal neutrons :** These are the slow-moving neutrons of energy 0.0253 eV, corresponding to the velocities of 2200 m/s
- **Multiplication factor :** The multiplication factor of a fissionable mass is defined as the ratio of the number of neutrons present at the beginning of a particular generation to the number of neutrons present at the beginning of the previous generation.

If $k > 1$, the chain reaction grows.

If $k = 1$, the chain reaction remains steady.

If $k < 1$, the chain reaction gradually dies out.

- **Critical size and critical mass :** The size of the fissionable material for which multiplication factor is unity is called critical size and its mass is called critical mass of the material. The chain reaction in this case remains steady or sustained.
- **Nuclear reactor :** It is a device in which a nuclear chain reaction is initiated, maintained and controlled. The reaction is controlled by using neutron-absorbing materials like cadmium rods.
- **Moderator :** Any substance which is used to slow down fast-moving neutrons to thermal energies is called a moderator. The commonly used moderators are water, heavy water (D_2O) and graphite.
- **Nuclear fusion :** It is the process of fusion of two smaller nuclei into a heavier nucleus with the liberation of a large amount of energy. For example,

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{4}_{2}He + 24 MeV.$$

These reactions require the extreme conditions of temperature and pressure so that the reacting nuclei can overcome their electrostatic repulsion. For this reason, these reactions are called thermonuclear reactions.

QUESTION BANK

MULTIPLE CHOICE QUESTIONS

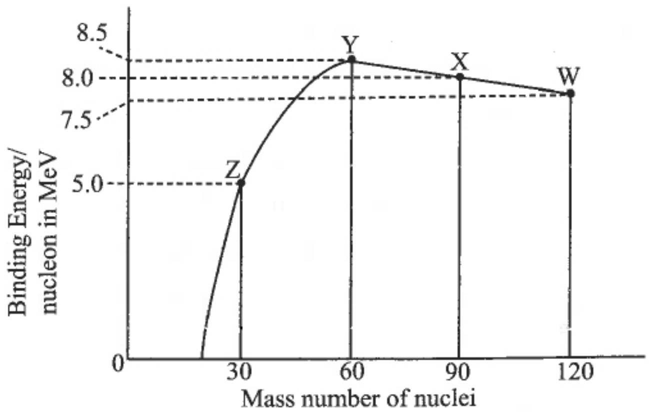
1. Two radioactive nuclei namely X and Y were kept out of their safety boxes by students during an experiment. They noticed that the number of atoms of X reduces to half of its initial value in 1 hr whereas the number of atoms Y reduces to half of its initial value in 2 hr. What is the ratio of their rates of disintegration after two hours?(Assume both X and Y have equal number of atoms initially)

   (a) 1:2 (b) 3:4 (c) 1:1 (d) 1:3

2. In a hypothetical world elements with principal quantum number n> 4 are not allowed in nature. Then how many elements are available in the world?

   (a) 64 (b) 60 (c) 20 (d) 4

3. Study graph given below.



   Among the processes, identify the process that would release energy.

   (a) Y → 2Z (b) W → X+Z (c) W → 2Y (d) X → Y + Z

4. The electrons emitted in beta radiation results from

   (a) inner orbits of atoms (b) decay of a neutron in a nuclei

   (c) free electrons existing in nuclei (d) photon escaping from the nucleus

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

(a) $\frac{1}{10\lambda}$ (b) $\frac{1}{11\lambda}$ (c) $\frac{11}{10\lambda}$ (d) $\frac{1}{9\lambda}$

6. A nucleus $_nX^m$ emits one α particle and two β^- particles. What is the resulting nucleus?

(a) $_{n-4}Z^{m-6}$ (b) $_nZ^{m-6}$ (c) $_nX^{m-4}$ (d) $_{n-2}Y^{m-4}$

7. Which of the following statements is true for nuclear forces?
   (a) they obey the inverse square law of distance
   (b) they obey the inverse third power law of distance
   (c) they are short range forces
   (d) they are equal in strength to electromagnetic clear radius of about forces

8. Light energy emitted by stars is due to
   (a) burning of nuclei
   (b) joining of nuclei
   (c) breaking of nuclei
   (d) reflection of solar light.

9. Which of the following is a correct statement?
   (a) beta rays are same as cathode rays
   (b) gamma rays are high energy neutrons
   (c) alpha particles are singly ionised helium atoms
   (d) protons and neutrons have exactly the same

10. During an experiment, α and β particles and γ– rays are emitted. The energy of each of them was found to be 0.5 MeV. Arrange the particles in the increasing order of their penetrating power.

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

11. The half life of a radioactive sample is 3.8 days. Find the time at the end of which (1/20)th of the sample will remain undecayed is (hint: $\log_{10}{}^{e} = 0.4343$)

(a) 33 days (b) 3.8 days (c) 16.5 days (d) 76 days

12. Fast neutrons can easily be slowed down by
   (a) the use of lead shielding
   (b) passing them through water
   (c) elastic collisions with heavy nuclei
   (d) applying a strong electric field.

13. ^{22}Ne nucleus, after absorbing energy, decays into two α-particles and an unknown nucleus. What is the resulting nucleus?

(a) Nitrogen (b) Carbon (c) Boron (d) Oxygen

14. Identify the correct statement.
   (a) The rest mass of a stable nucleus is less than the sum of the rest masses of its separated nucleons
   (b) The rest mass of a stable nucleus is greater than the sum of the rest masses of its separated nucleons
   (c) In nuclear fission, energy is released by fusing two nuclei of medium mass (approximately 100 amu)
   (d) In nuclear fusion, energy is released by fragmentation of a very heavy nucleus.

15. During a nuclear fusion reaction
   (a) a heavy nucleus breaks into two fragments by itself
   (b) a light nucleus bombarded by thermal neutrons breaks up
   (c) a heavy nucleus bombarded by thermal neutrons breaks up
   (d) two light nuclei combine to give a heavier nucleus and possibly other products.

16. The half life time of a radioactive sample is $T_{1/2}$. What will be the decay constant and mean life of the sample respectively?
   (a) $1/T_{1/2}$ and $(\ln 2)/T_{1/2}$
   (b) $(\ln 2)/T_{1/2}$ and $T_{1/2}$
   (c) $(\ln 2)/T_{1/2}$ and $T_{1/2}/(\ln 2)$
   (d) $T_{1/2}/(\ln 2)$ and $(\ln 2)/T_{1/2}$

17. The half-life of ^{131}t is 8 days. Given a sample of ^{131}t at time t = 0, we can say that
   (a) no nucleus will decay before t = 4 days
   (b) no nucleus will decay before t = 8 days
   (c) all nuclei will decay before t = 16 days
   (d) a given nucleus may decay at any time after t = 0

18. Name the quantity that is not conserved in a nuclear reaction
(a) momentum (b) charge (c) mass (d) none of these

19. During a chemical process, the following reaction took place

$$^{11}_{6}C \rightarrow ^{11}_{5}B + \beta^{+} + X$$

Identify X.
(a) Electron (b) Proton (c) Photon (d) Neutrino

20. The binding energies of ^{2}H, ^{4}He and ^{6}Li are B_2, B_4, and B_6 respectively, the Q of the reaction ^{2}H + ^{6}Li —> 2 ^{4}He
(a) $2B_2 + 6B_6 - 8B_4$ (b) $B_2 + B_6 - 2B_4$
(c) $2B_4 - B_6 - B_2$ (d) $8B_4 - 6B_6 - 2B_2$

21. You had a sample of 27 g of radioactive material and you found only 1 g after 60 minutes. If you had done the measurement 20 minutes earlier, how much material would you have found?
(a) 3 g (b) 9 g (c) 6 g (d) 18 g

22. ^{238}U decays via α-particle emission to
(a) ^{236}U (b) ^{234}U (c) ^{236}Th (d) ^{234}Th

23. Given that the binding energy per nucleon of an α-particle is 7 MeV, and that the energy release in the reaction $d + d \rightarrow \alpha$ is 23.6 MeV, total binding energy of a deuteron is
(a) 1.1 MeV (b) 2.2 MeV (c) 3.3 MeV (d) 4.4 MeV

24. When a nuclide undergoes β decay, which of these is unchanged?
(a) proton number (b) neutron number
(c) proton number + neutron number (d) proton number – neutron number

25. What is the maximum electron energy in neutron β-decay?
(a) 783 keV (b) 783 eV (c) 783 GeV (d) 783 TeV

26. The radioactivity of a sample of Co^{55} decreases by 4% every hour. (The decay product is not radioactive.) The half-life of Co^{55} is approximately
(a) 15 hr (b) 17 hr (c) 166 hr (d) 1 year

27. A proton is accelerated to a high energy E and shot at a nucleus of Oxygen whose radius is 3.023 fm. In order to penetrate the Coulomb barrier and reach the surface of the Oxygen nucleus, E must be at least
(a) 180 eV (b) 30.5 MeV (c) 1.8 MeV (d) 45 keV

28. The probability of electrons being captured by the nucleus is highest for
(a) K shell electrons (b) L shell electrons
(c) M shell electrons (d) Electrons in the outermost orbits

29. 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?
(a) 27 (b) 40 (c) 56 (d) 120

30. The mean momentum of a nucleon in a nucleus with mass number A varies as
(a) A (b) A^2 (c) $A^{-1/3}$ (d) $A^{-2/3}$

31. Which of the following statements is incorrect for the nuclear force between two nucleons?
(a) it is charge independent (b) it is velocity dependent
(c) it is spin independent (d) it has a non central component

32. If the nuclear radius of ^{27}Al is 3.6 fermi, the ratio of volume of ^{64}Cu and ^{27}Al is
(a) 4:3 (b) 64:27 (c) 16:9 (d) 3:4

33. Given that the binding energy per nucleon of an α-particle is 7MeV, and that the proton mass is 938 MeV/c^2 and the neutron mass is 939MeV/c^2, the mass of the α-particle is
(a) 3726 MeV/c^2 (b) 3748MeV/c^2 (c) 1870 MeV/c^2 (d) 931 MeV/c^2

34. The activity of a radioactive sample is decreased to 75% of the initial value after 30 days. The half-life (in days) of the sample is approximately [you may use *ln* 3=1.1 , *ln* 4=1.4]

(a) 38 (b) 45 (c) 59 (d) 69

35. A student was given 10 g of ^{60}Co whose decay constant is $0.5 \times 10^{-8}\ s^{-1}$. He was asked to calculate its activity in terms of disintegration per second. The number of disintegrations per second of the sample is:

(a) 0.5×10^{10} (b) 5×10^{10} (c) 5×10^{14} (d) 0.5×10^{14}

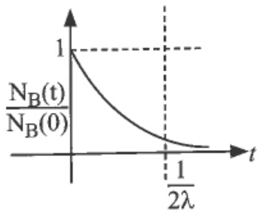
36. Binding energy per nucleon for the nuclei ^4He, ^{56}Fe, ^{197}Au and ^{235}U are given by B_1 , B_2 , B_3 and B_4 respectively. These binding energies satisfy the order

(a) $B_1 < B_2 < B_3 < B_4$ (b) $B_1 > B_2 > B_3 > B_4$

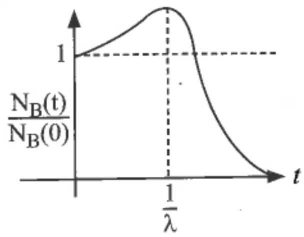
(c) $B_2 < B_3 < B_4 < B_1$ (d) $B_2 > B_3 > B_4 > B_1$

37. At time t = 0, a material is composed of two radioactive atoms A and B, where $N_A(0) = 2N_B(0)$. The decay constant of both kind of radioactive atoms is λ. However, A disintegrates to B and B disintegrates to C. Which of the following figures represents the evolution of $N_B(t) / N_B(0)$ with respect to time t? [N_A (0) = No. of A atoms at t = 0, N_B (0) = No. of B atoms at t = 0]

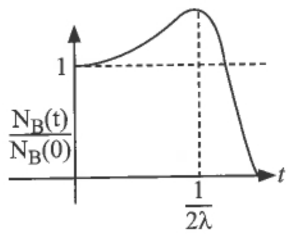
(a)



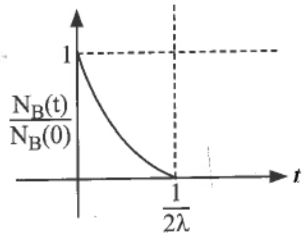
(b)



(c)



(d)



38. A nucleus with mass number 184 initially at rest emits an α-particle. If the Q value of the reaction is 5.5 MeV, calculate the kinetic energy of the α-particle.

(a) 5.5 MeV (b) 5.0 MeV (c) 0.23 MeV (d) 5.38 MeV

39. After a radioactive reaction an excited nucleus of mass M was obtained. It emitted a gamma photon of frequency 'v' to come to a stable state. The loss of internal energy of the nucleus is:

(a) hv (b) $hv\left(1+\frac{hv}{2Mc^2}\right)$ (c) $hv\left(1-\frac{hv}{2Mc^2}\right)$ (d) 0

40. The decay of a proton to neutron is

(a) always possible as it is associated only with β^+ decay

(b) possible only inside the nucleus

(c) not possible as proton mass is less than the neutron mass

(d) not possible but neutron to proton convesion is possible

41. A radioactive sample disintegrates via two independent decay processes having half lives $T^{(1)}_{1/2}$ and $T^{(1)}_{1/2} + T^{(2)}_{1/2}$ respectively. The effective half-life $T_{1/2}$ of the nuclei is :

(a) $T_{1/2} = T^{(1)}_{1/2} + T^{(2)}_{1/2}$ (b) $T_{1/2} = \frac{T^{(2)}_{1/2} T^{(1)}_{1/2}}{T^{(1)}_{1/2} + T^{(2)}_{1/2}}$

(c) $T_{1/2} = \frac{T^{(2)}_{1/2} + T^{(1)}_{1/2}}{T^{(1)}_{1/2} - T^{(2)}_{1/2}}$ (d) none of these

42. There are 10^{10} radioactive nuclei in a given radioactive element, its half-life time is 1 minute. How many nuclei will remain after 30 seconds?

(a) 2×10^{10} (b) 7×10^9 (c) 10^5 (d) 4×10^{10}

43. A radioactive material decays by simultaneous emissions of two particles with half lives of 1400 years and 700 years respectively. What will be the time after which one third of the material remains? (Take ln 3 = 1.1)
(a) 740 years (b) 1110 years (c) 700 years (d) 340 years

44. The radiation emitted by a radioactive source of half life 3 hrs is 32 times higher than the safety limit. Minimum time for the radiation to be under the safety limit is
(a) 9 hrs (b) 15 hrs (c) 12 hrs (d) 18 hrs

45. The ratio of binding energy of an alpha particle to that of a deuteron is (m_pc^2 = 938.3 MeV, m_nc^2 = 939.6 MeV, $m_\alpha c^2$ = 3727.2 MeV, m_dc^2 = 1875.7 MeV)
(a) 11 (b) 12 (c) 13 (d) 14

46. Two spherical nuclei have mass number 216 and 64 with their radii R_1 and R_2 respectively. The ratio of R_1/R_2 is
(a) 1 (b) 1.5 (c) 2 (d) 2.5

47. Two radioactive substances *X* and *Y* originally have N_1 and N_2 nuclei respectively. Half life of *X* is half of the half life of *Y*. After three half lives of *Y*, number of nuclei of both are equal. The ratio $\frac{N_1}{N_2}$ will be equal to :
(a) 1/8 (b) 3/1 (c) 1/3 (d) 8/1

48. Given the masses of various atomic particles m_p = 1.0072 u, m_n = 1.0087 u, m_e = 0.000548 u, $m_{\bar{\nu}}$ = 0, m_d = 2.0141 u, where $p \equiv$ proton, $n \equiv$ neutron, $e \equiv$ electron, $\bar{\nu} \equiv$ antineutrino and $d \equiv$ deuteron. Which of the following process is allowed by momentum and energy conservation?
(a) n + n $\rightarrow$ deuterium atom
(b) $n + p \rightarrow d + \gamma$
(c) $p \rightarrow n + e^+ + \bar{\nu}$
(d) $e^+ + e^- \rightarrow \gamma$

(Information for question 49 and 50)
In a reactor, 2 kg of ${}_{92}U^{235}$ fuel is fully used up in 30 days. The energy released per fission is 200 MeV. Given that the Avogadro number, N = 6.023×10^{26} per kilo mole and 1 eV = 1.6×10^{-19} J.

49. Net energy obtained from 2 kg of ${}_{92}U^{235}$ fuel (in MeV)
(a) 1.02×10^7 (b) 1.02×10^{27} (c) 1.02×10^{20} (d) 1.02×10^{25}

50. The power output of the reactor is close to
(a) 125 MW (b) 60 MW (c) 54 MW (d) 35 MW

51. Two radioactive substances A and B have decay constants 5λ and λ respectively. At $t = 0$, a sample has the same number of the two nuclei. The time taken for the ratio of the number of nuclei to become $(1/e)^2$ will be :
(a) $\frac{2}{\lambda}$ (b) $\frac{1}{4\lambda}$ (c) $\frac{1}{2\lambda}$ (d) $\frac{1}{\lambda}$

52. In a radioactive decay chain, the initial nucleus is ${}_{90}Th^{232}$. At the end there are 6 α-particles and 4 β-particles which are emitted. If the end nucleus is ${}_ZX^A$, A and Z are given by :
(a) A= 208; Z=80 (b) A= 208; Z=82 (c) A= 200; Z=81 (d) A= 202; Z=80

53. A radioactive nucleus (initial mass number A and atomic number Z) emits 3 α-particles and 2 positrons. The ratio of number of neutrons to that of protons in the final nucleus will be
(a) (A – Z – 4)/(Z – 2)
(b) (A – Z – 4)/(Z – 8)
(c) (A – Z – 8)/(Z – 4)
(d) (A – Z – 12)/(Z – 4)

54. In gamma ray emission from a nucleus
(a) only the proton number changes
(b) both the proton number and neutron number change
(c) there is no change in the proton number and the neutron number
(d) only the neutron number changes.

55. When U^{238} nucleus, originally at rest, decays by emitting an alpha particle having a speed *u*, the recoil speed of the residual nucleus is
(a) 4u/238 (b) – 4u/234 (c) 4u/234 (d) – 4u/238

56. Let N be the number of β particles emitted by 1 gram of ^{24}Na radioactive nuclei (half life = 15 hrs) in 7.5 hours, N_β is close to

(a) 6.2×10^{21} (b) 7.5×10^{21} (c) 1.25×10^{22} (d) 1.75×10^{22}

57. In the nuclear fusion reaction:

$$_1H^2 + {_1H^3} \rightarrow {_2He^4} + n$$

given that the repulsive potential energy between the two nuclei is 7.7×10^{-14} J. The temperature at which the gases must be heated to initiate the reaction is nearly

[Boltzmann's constant, $K_B = 1.38 \times 10^{-23}$]

(a) 10^7 K (b) 10^5 K (c) 10^3 K (d) 10^9 K

Direction for Question Nos. 58 and 59

A nucleus of mass M + Δm is at rest and decays into two daughter nuclei of equal mass M/2 each. Speed of light is c.

58. The speed of daughter nuclei is

(a) $c\sqrt{\frac{\Delta m}{M+\Delta m}}$ (b) $c\frac{\Delta m}{M+\Delta m}$ (c) $c\sqrt{\frac{2\Delta m}{M}}$ (d) $c\sqrt{\frac{\Delta m}{M}}$

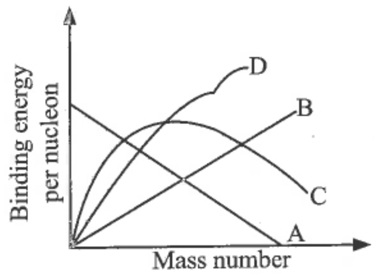
59. The binding energy per nucleon for the parent nucleus is E_1 and that of daughter nuclei is E_2

(a) $E_1 = 2E_2$ (b) $E_2 = 2E_1$ (c) $E_1 > E_2$ (d) $E_2 > E_1$

60. If an H- nucleus is completely converted into energy, the energy produced will be around

(a) 1 MeV (b) 939 MeV (c) 9.39 MeV (d) 238 MeV

61. Binding energy per nucleon plot against the mass number for stable nuclei is shown in the figure. Which curve is correct?



(a) A (b) B (c) C (d) D

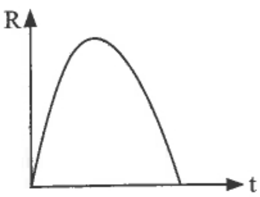
62. The curve of binding energy per nucleon as a function of a atomic mass number has a sharp peak for helium nucleus. This implies that helium

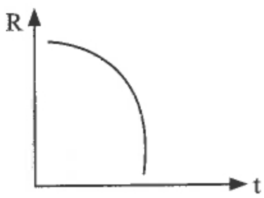
(a) can easily be broken up
(b) is very stable
(c) can be used as fissionable material
(d) is radioactive.

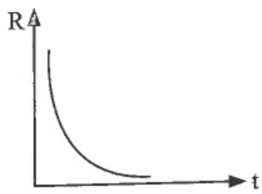
63. A nucleus is bombarded with a high speed neutron so that resulting nucleus is a radioactive one. The phenomenon is called

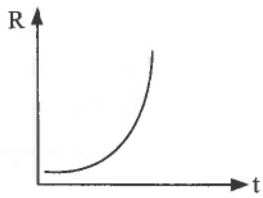
(a) artificial radioactivity (b) fusion (c) fission (d) radioactivity

64. Radioactive element decays to form a stable nuclide, then the rate of decay is

(a)


(b)


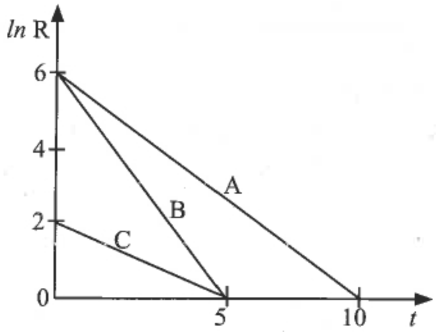
(c)


(d)


65. If the nuclear force between two protons, two neutrons and between proton and neutron is denoted by F_{pp}, F_{nn} and F_{pn} respectively, then

(a) $F_{pp} \approx F_{nn} \approx F_{pn}$
(b) $F_{pp} \neq F_{nn}$ and $F_{pp} = F_{pn}$
(c) $F_{pp} = F_{nn} = F_{pn}$
(d) $F_{pp} \neq F_{nn} \neq F_{pn}$

66. Activities of three radioactive substances A, B and C are represented by the curves A, B and C, in the figure. Then their half-lives $T_{1/2}(A):T_{1/2}(B):T_{1/2}(C)$ are in the ratio:



(a) 3:2:1 (b) 2:1:1 (c) 4:3:1 (d) 2:1:3

67. Nuclear fission is best explained by
(a) liquid droplet theory
(b) Yukawa -meson theory
(c) independent particle model of the nucleus
(d) proton-proton cycle

68. The binding energy of deuteron is 2.2 MeV and that of ${}_2He^4$ is 28 MeV. If two deuterons are fused to form one ${}_2He^4$ then the energy released is
(a) 30.2 MeV (b) 25.8 MeV (c) 23.6 MeV (d) 19.2 MeV.

69. Solar energy is mainly caused due to
(a) burning of hydrogen in the oxygen
(b) fission of uranium present in the sun
(c) fusion of protons during synthesis of heavier elements
(d) gravitational contraction.

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

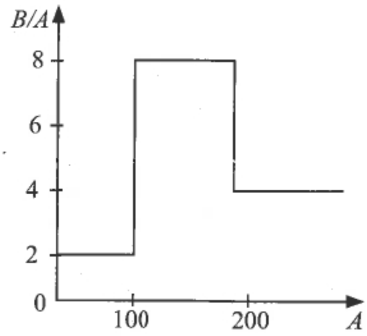
71. A certain mass of Hydrogen is changed to Helium by the process of fusion. The mass defect in fusion reaction is 0.02866 u. The energy liberated per nucleon. (given 1u=931 MeV) is
(a) 2.67 MeV (b) 6.675 MeV (c) 26.7 MeV (d) 13.35 MeV

72. The process of fusion at ordinary temperatures and pressure is impossible because
(a) nuclear forces have short range
(b) nuclei is neutral
(c) the original nuclei must be completely ionized before fusion can take place
(d) the original nuclei must first break up before combining with each other

73. In a nuclear reactor, moderators slow down the neutrons which come out in a fission process. The moderators contain light nuclei and not heavy nuclei because
(a) they will break up
(b) elastic collision of neutrons with heavy nuclei will not slow them down
(c) the net weight of the reactor would be unbearably high
(d) substances with heavy nuclei do not occur in liquid or gaseous state at room temperature

74. In the options given below, let E denote the rest mass energy of a nucleus and a neutron. The correct option is
(a) $E({}_{92}U^{236}) > E({}_{53}I^{137}) + E({}_{39}Y^{97}) + 2E(n)$
(b) $E({}_{92}U^{236}) < E({}_{53}I^{137}) + E({}_{39}Y^{97}) + 2E(n)$
(c) $E({}_{92}U^{236}) < E({}_{56}Ba^{140}) + E({}_{36}Kr^{94}) + 2E(n)$
(d) $E({}_{92}U^{236}) = E({}_{56}Ba^{140}) + E({}_{36}Kr^{94}) + 2E(n)$

75. Assume that the nuclear binding energy per nucleon (B/A) versus mass number (A) is as shown in figure. Use this plot to choose the correct choice's given below.



(a) Fusion of two nuclei with mass numbers lying in the range of 1 <A <50 will release energy

(b) Fusion of two nuclei with mass numbers lying in the range of 51 <A < 100 will release energy

(c) Fission of a nucleus lying in the mass range of 100 <A <200 will release energy when broken into two equal fragments

(d) Fission of a nucleus lying in the mass range of 51<A <100 will release energy when broken into two fragments

76. A star initially has 10^{40} deuterons. It produces energy via the processes $_1H^2 + {}_1H^2 \rightarrow {}_1H^3 + p$, and $_1H^2 + {}_1H^3 \rightarrow {}_2He^4 + n$. If the average power radiated by the star is 10^{16} W, the deuteron supply of the star is exhausted in a time of the order

(The masses of the nuclei are as follows:

$M(H^2) = 2.014$ amu; $M(p)=1.007$ amu; $M(n) = 1.008$ amu; $M(He)=4.001$ amu.)

(a) 10^6s (b) 10^8s (c) 10^{12}s (d) 10^{16}s

77. A radioactive substance X decays into another radioactive substance Y. Initially only X was present, λ_x and λ_y are the disintegration constants of X and Y. N_x and N_y are the number of nuclei of X and Y at any time t. Number of nuclei N_y, will be maximum when

(a) $\dfrac{N_y}{N_x - N_y} = \dfrac{\lambda_y}{\lambda_x - \lambda_y}$ (b) $\dfrac{N_x}{N_x - N_y} = \dfrac{\lambda_x}{\lambda_x - \lambda_y}$ (c) $\lambda_y N_y = \lambda_x N_x$ (d) $\lambda_x N_y = \lambda_y N_x$

78. How are the electronic energy levels of the atom affected during a radioactive decay?

(a) It does not change for any type of radioactivity.

(b) It changes for α and β-radioactivity but not for γ-radioactivity.

(c) It changes for α-radioactivity but not for others.

(d) It changes for β-radioactivity but not for others.

79. Among three isotopes of hydrogen, tritium is one whose nucleus is triton. It contains 2 neutrons and 1 proton. Free neutrons decay into $p + \bar{e} + \bar{n}$. If one of the neutrons in Triton decays, it would transform into He^3 nucleus. But this does not happen because

(a) Triton energy is less than that of a He^3 nucleus.

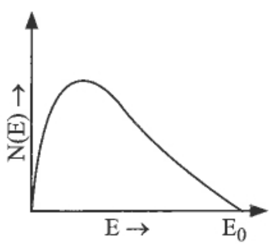
(b) The electron created in the beta decay process cannot remain in the nucleus

(c) both the neutrons in the triton have to decay simultaneously resulting in a nucleus with 3 protons, which is not a He nucleus.

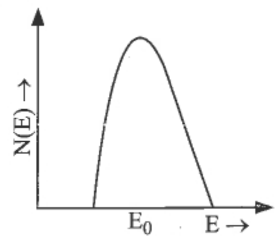
(d) free neutrons decay due to external perturbations which is absent in triton nucleus.

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

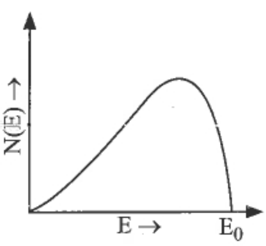
(a)



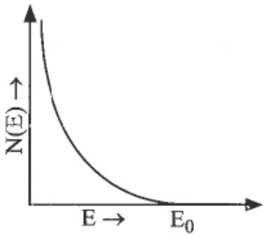
(b)



(c)



(d)



81. When a radioactive substance emits an β-particle, its position in the periodic table is increased by

(a) one place (b) three places (c) two places (d) four places.

82. Radioactive nuclei that are injected into a patient, collect at certain sites within its body, undergoing radioactive decay and emitting electromagnetic radiation. These radiations can then be recorded by a detector. This procedure provides an important diagnostic tool called

(a) gamma camera (b) CAT scan
(c) radiotracer technique (d) Gamma ray spectroscopy

83. Which of the following is used to slow down the neutrons that originate due to the fission process in a nuclear reactor?
(a) cadmium (b) plutonium (c) uranium (d) heavy water

84. In nuclear reactors, there are rods present to absorb neutrons in order to control the reaction. What are these rods made up of?
(a) cadmium (b) graphite (c) stainless steel (d) plutonium

85. There are more neutrons than protons in a stable nuclei. What is the reason behind this?
(a) neutrons are heavier than protons
(b) electrostatic force between protons are repulsive
(c) neutrons decay into protons through beta decay
(d) nuclear forces between neutrons are weaker than that between protons

86. During collison between a stream of electrons collides with a stream of photons, which of the following is not conserved?
(a) Linear momentum (b) Total energy (c) No. of photons (d) No, of electrons

87. Energy released in the fission of a single ${}_{92}U^{235}$ nucleus is 200 MeV. The fission rate of ${}_{92}U^{235}$ filled reactor operating at a power level of 5 kW is
(a) $1.56 \times 10^{10}\ s^{-1}$ (b) $1.56 \times 10^{11}\ s^{-1}$ (c) $1.56 \times 10^{16}\ s^{-1}$ (d) $1.56 \times 10^{17}\ s^{-1}$

88. A sample contains N_A, atoms of a radioactive element A and N_B atoms of a stable element B. A decays into B with decay constant λ. If at $t = 0$ the ratio N_A/N_B is R, then at time t it is
(a) $\dfrac{Re^{-\lambda t}}{1-R(1-e^{-\lambda t})}$ (b) $\dfrac{Re^{-\lambda t}}{1+R(1-e^{-\lambda t})}$ (c) $\dfrac{Re^{-\lambda t}}{1-Re^{-\lambda t}}$ (d) $\dfrac{Re^{-\lambda t}}{1+Re^{-\lambda t}}$

89. In order to determine the age of ancient wooden tools, a radiocarbon dating method is used. This is done by measuring the fraction of radioactive isotope ${}^{14}C$ of carbon compared to the normal (non-radioactive) isotope ${}^{12}C$ in a sample. An old sample is found to contain 1/10 times the fraction of ${}^{14}C$ as compared to a fresh piece of wood. Given that the half-life of ${}^{14}C$ is 5570 years, the approximate age of the old sample is
(a) 557 years (b) 18500 years (c) 12800 years (d) 55700 years

90. In a nuclear reactor, Plutonium (Pu) is used as fuel, releasing energy by its fission into isotopes of Barium (Ba) and Strontium (Sr) through the reaction

$$ {}_{94}Pu^{239} + {}_{0}n^{1} \rightarrow {}_{56}Ba^{146} + {}_{38}Sr^{91} + 3\,{}_{0}n^{1} $$

The binding energy (B.E.) per nucleon of ${}_{94}Pu^{239}$, ${}_{56}Ba^{146}$ and ${}_{38}Sr^{91}$ nuclides respectively are 7.6 MeV, 8.2 MeV and 8.6 MeV. Using this information estimate the number of such fission reactions per second in a 100 MW reactor as
(a) 8.9×10^{17} (b) 5.2×10^{18} (c) 5.2×10^{19} (d) 3.9×10^{18}

91. As one moves along the line of stability from ${}^{56}Fe$ to ${}^{235}U$ nucleus, the nuclear binding energy per particle decreases from about 8.8 MeV to 7.6 MeV, This trend is mainly due to the
(a) short range nature of the nuclear forces
(b) long range nature of the Coulomb forces
(c) tensor nature of the nuclear forces
(d) spin dependence of the nuclear forces

92. The disintegration energy is defined to be the difference in the rest energy between the initial and final states. Consider the following reaction ${}_{94}Pu^{240} \rightarrow {}_{92}U^{236} + {}_{2}He^{4}$
The emitted α particle has a kinetic energy 5.17 MeV. The value of the disintegration energy is
(a) 5.26 MeV (b) 5.08 MeV (c) 5.17 MeV (d) 2.59 MeV

93. Among the following reactions, which is not a possible nuclear fusion reaction?

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

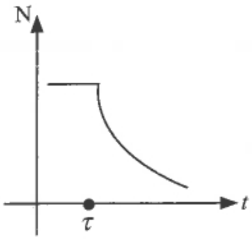
(b) ${}_6C^{12} + {}_1H^1 \rightarrow {}_7N^{13} + 2$MeV

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

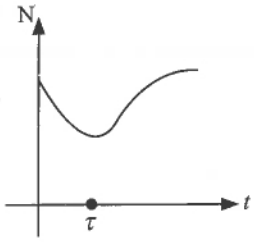
(d) ${}_{92}U^{235} + {}_0n^1 \rightarrow {}_{54}Xe^{140} + {}_{36}Sr^{94} + {}_0n^1 + {}_0n^1 + Y + 200$MeV

94. A radioactive sample consists of two distinct species having equal number of atoms initially. The mean life of one species is t and that of the other is 5π. The decay products in both cases are stable. A plot is made of the total number of radioactive nuclei as a function of time. Which of the following figures best represents the form of this plot?

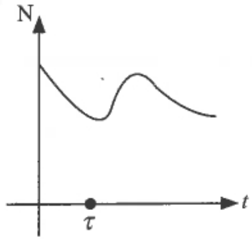
(a)



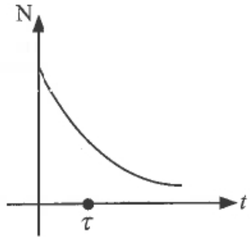
(b)



(c)



(d)



95. Half lives of two radioactive nuclei A and B are 10 minutes and 20 minutes, respectively, If initially a sample has equal number of nuclei, then after 60 minutes, the ratio of decayed numbers of nuclei A and B will be :

(a) 1:8 (b) 9:8 (c) 8:1 (d) 3:8

96. A radioactive nucleus decays by two different processes. The half life for the first process is 10 s and that for the second is 100 s. The effective half life of the nucleus is close to :

(a) 12 sec (b) 9 sec (c) 55 sec (d) 6 sec

INPUT TEXT BASED QUESTIONS

1. *By performing scattering experiments in which fast electrons are projectiles that bombard targets made up of various elements, the sizes of nuclei of various elements have been accurately measured. It has been found that a nucleus of mass number A has a radius* $R = R_0A^{1/3}$ *Where* $R_0 = 1.2 \times 10^{-15}$m *(=1.2 fm; 1 fm =* 10^{-15}m*). This means the volume of the nucleus, which is proportional to* R^3 *is proportional to A.*

(i) The nuclear radius of ${}^{16}_{8}O$ is 3×10^{-15} m. Then density of nuclear matter is

(a) 2.9×10^{34} kg m^{-3} (b) 1.2×10^{17} kg m^{-3}

(c) 16×10^{27} kg m^{-3} (d) 2.4×10^{17} kg m^{-3}

(ii) What is the density of hydrogen nucleus in SI units? Given R_0 = 1.1 fermi and m_p = 1.007825 amu.

(a) 2.98×10^{17} kg m^{-3} (b) 3.0×10^{34} kg m^{-3}

(c) 1.99×10^{11} kg m^{-3} (d) 7.85×10^{17} kg m^{-3}

(iii) Density of a nucleus is

(a) more for lighter elements and less for heavier elements

(b) more for heavier elements and less for lighter elements

(c) very less compared to ordinary matter

(d) a constant

(iv) The nuclear mass of ${}^{56}_{26}Fe$ is 55.85 amu. Then its nuclear density is

(a) 5.0×10^{19} kg m^{-3} (b) 1.5×10^{19} kg m^{-3}

(c) 2.9×10^{17} kg m^{-3} (d) 9.2×10^{26} kg m^{-3}

(v) If the nucleus of ${}^{27}_{13}Al$ has a nuclear radius of about 3.6 fm, then ${}^{125}_{52}Te$ would have its radius approximately as

(a) 9.6 fm (b) 12 fm (c) 4.8 fm (d) 6 fm

2. *A most important neutron-induced nuclear reaction is fission. An example of fission is when a uranium isotope* $_{92}U^{235}$ *bombarded with a neutron breaks into two intermediate mass nuclear fragments*

$$^1_0n + ^{235}_{92}U \rightarrow ^{236}_{92}U \rightarrow ^{144}_{56}Ba + ^{89}_{36}Kr + 3^1_0n$$

The fragment products are radioactive nuclei; they emit particles in succession to achieve stable end products. The energy released (the Q value) in the fission reaction of nuclei like uranium is of the order of 200 MeV per fissioning nucleus.

(i) It 200 MeV energy is released in the fission of a single nucleus of $^{235}_{92}U$ the fission which are required to produce a power of 1 kW is

(a) 3.125×10^{13} (b) 1.52×10^{6}
(c) 3.125×10^{12} (d) 3.125×10^{14}

(ii) The release in energy in nuclear fission is consistent with the fact that uranium has

(a) more mass per nucleon than either of the two fragments
(b) more mass per nucleon as the two fragment
(c) exactly the same mass per nucleon as the two fragments
(d) less mass per nucleon than either of two fragments

(iii) When $^{235}_{92}U$ undergoes fission about 0.1% of the orignal mass is converted into energy. The energy released when 1 kg of $^{235}_{92}U$ undergoes fission is

(a) 9×10^{11} J (b) 9×10^{13} J (c) 9×10^{15} J (d) 9×10^{18} J

(iv) A nuclear fission is said to be critical when multiplication factor or K.

(a) K = 1 (b) K > 1 (c) K < 1 (d) K = 0

(v) Einstein's mass energy conversion relation $E = mc^2$ is illustrated by

(a) nuclear fission (b) β-decay
(c) rocket propulsion (d) steam enegine

ANSWERS

1. (c)	**2.** (b)	**3.** (c)	**4.** (b)	**5.** (d)	**6.** (c)	**7.** (c)	**8.** (b)	**9.** (a)	**10.** (a)
11. (c)	**12.** (b)	**13.** (b)	**14.** (a)	**15.** (d)	**16.** (c)	**17.** (d)	**18.** (c)	**19.** (d)	**20.** (c)
21. (a)	**22.** (d)	**23.** (b)	**24.** (c)	**25.** (a)	**26.** (b)	**27.** (b)	**28.** (a)	**29.** (a)	**30.** (c)
31. (c)	**32.** (b)	**33.** (a)	**34.** (d)	**35.** (c)	**36.** (c)	**37.** (c)	**38.** (d)	**39.** (b)	**40.** (b)
41. (b)	**42.** (b)	**43.** (a)	**44.** (b)	**45.** (c)	**46.** (b)	**47.** (d)	**48.** (b)	**49.** (b)	**50.** (b)
51. (c)	**52.** (b)	**53.** (b)	**54.** (c)	**55.** (b)	**56.** (b)	**57.** (d)	**58.** (c)	**59.** (d)	**60.** (b)
61. (c)	**62.** (b)	**63.** (a)	**64.** (c)	**65.** (c)	**66.** (d)	**67.** (a)	**68.** (c)	**69.** (c)	**70.** (c)
71. (b)	**72.** (a)	**73.** (b)	**74.** (a)	**75.** (b)	**76.** (c)	**77.** (c)	**78.** (b)	**79.** (a)	**80.** (a)
81. (a)	**82.** (c)	**83.** (d)	**84.** (a)	**85.** (b)	**86.** (c)	**87.** (b)	**88.** (b)	**89.** (b)	**90.** (d)
91. (a)	**92.** (a)	**93.** (d)	**94.** (d)	**95.** (b)	**96.** (b)				

Input Text Based MCQs

1. (i) (d), (ii) (a), (iii) (d), (iv) (c), (v) (d) **2.** (i) (a), (ii) (a), (iii) (b), (iv) (a), (v) (a)