# Nuclei

## OBJECTIVE TYPE QUESTIONS

### Multiple Choice Questions (MCQs)

**1.** If 200 MeV energy is released in the fission of a single nucleus of $^{235}_{92}U$, the fissions which are required to produce a power of 1 kW is
(a) $3.125 \times 10^{13}$ (b) $1.52 \times 10^{6}$
(c) $3.125 \times 10^{12}$ (d) $3.125 \times 10^{14}$

**2.** The equation $4\,^{1}_{1}H^{+} \rightarrow \,^{4}_{2}He^{2+} + 2e^{-} + 26$ MeV represents
(a) both fusion and fission
(b) neither fusion nor fission
(c) only fusion
(d) only fission

**3.** In nuclear reaction, there is conservation of
(a) mass only
(b) energy only
(c) momentum only
(d) mass, energy and momentum

**4.** The fission properties of $^{239}_{94}$Pu are very similar to those of $^{235}_{92}U$. The average energy released per fission is 180 MeV. If all the atoms in 1 kg of pure $^{239}_{94}Pu$ undergo fission, then the total energy released in MeV is
(a) $4.53 \times 10^{26}$ MeV (b) $2.21 \times 10^{14}$ MeV
(c) $1 \times 10^{13}$ MeV (d) $6.33 \times 10^{24}$ MeV

**5.** 1 MeV positron encounters a 1 MeV electron travelling in opposite direction. What is the wavelength of photons produced? (Given rest mass energy of electron or positron = 0.512 MeV and $h = 6.62 \times 10^{-34}$ Js)
(a) $8.2 \times 10^{-11}$ m (b) $8.2 \times 10^{-13}$ m
(c) $8.2 \times 10^{-12}$ m (d) $8.2 \times 10^{-9}$ m

**6.** In nuclear reactors, the control rods are made of
(a) cadmium (b) graphite
(c) krypton (d) plutonium

**7.** The equivalent energy of 1 g of substance is
(a) $9 \times 10^{13}$ J (b) $6 \times 10^{12}$ J
(c) $3 \times 10^{13}$ J (d) $6 \times 10^{13}$ J

**8.** The mass number of iron nucleus is 55.854 and $A = 56$, the nuclear density is
(a) $2.29 \times 10^{16}$ kg m$^{-3}$ (b) $2.29 \times 10^{17}$ kg m$^{-3}$
(c) $2.29 \times 10^{18}$ kg m$^{-3}$ (d) $2.29 \times 10^{15}$ kg m$^{-3}$

**9.** Order of magnitude of density of uranium nucleus is
(a) $10^{20}$ kg m$^{-3}$ (b) $10^{17}$ kg m$^{-3}$
(c) $10^{14}$ kg m$^{-3}$ (d) $10^{11}$ kgm$^{-3}$

**10.** How much mass has to be converted into energy to produce electric power of 500 MW for one hour?
(a) $2 \times 10^{-5}$ kg (b) $1 \times 10^{-5}$ kg
(c) $3 \times 10^{-5}$ kg (d) $4 \times 10^{-5}$ kg

**11.** Two stable isotopes $^{6}_{3}Li$ and $^{7}_{3}Li$ have respective abundances of 7.5% and 92.5%. These isotopes have masses 6.01512 u and 7.01600 u respectively. The atomic weight of lithium is
(a) 6.941 u (b) 3.321 u
(c) 2.561 u (d) 0.621 u

**12.** The ratio of the nuclear radii of the gold isotope $^{197}_{79}Au$ and silver isotope $^{107}_{47}Ag$ is
(a) 1.23 (b) 0.216
(c) 2.13 (d) 3.46

**13.** Let $m_p$ be the mass of a proton, $m_n$ the mass of a neutron, $M_1$ the mass of a $^{20}_{10}$Ne nucleus and $M_2$ the mass of a $^{40}_{20}$Ca nucleus. Then
(a) $M_2 = M_1$ (b) $M_2 > 2M_1$
(c) $M_2 = 2M_1$ (d) $M_1 < 10\,(m_n + m_p)$

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

**15.** The mass of proton is 1.0073 u and that of neutron is 1.0087 u (u = atomic mass unit). The binding energy of $^{4}_{2}He$, if mass of $^{4}_{2}He$ is 4.0015 u

(a) 0.0305 erg (b) 0.0305 J
(c) 28.4 MeV (d) 0.061 u

**16.** The set which represents the isotope, isobar and isotone respectively is

(a) $({}_1^2H, {}_1^3H)$, $({}_{79}^{197}Au, {}_{80}^{198}Hg)$ and $({}_2^3He, {}_1^2H)$

(b) $({}_2^3He, {}_1^1H)$, $({}_{79}^{197}Au, {}_{80}^{198}Hg)$ and $({}_1^1H, {}_1^3H)$

(c) $({}_2^3He, {}_1^3H)$, $({}_1^2H, {}_1^3H)$ and $({}_{79}^{197}Au, {}_{80}^{198}Hg)$

(d) $({}_1^2H, {}_1^3H)$, $({}_2^3He, {}_1^3H)$ and $({}_{79}^{197}Au, {}_{80}^{198}Hg)$

**17.** 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

**18.** If in a nuclear fusion reaction, mass defect is 0.3%, then energy released in fusion of 1 kg mass is

(a) $27 \times 10^{10}$ J (b) $27 \times 10^{11}$ J
(c) $27 \times 10^{10}$ J (d) $27 \times 10^{13}$ J

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

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

**20.** Boron has two stable isotopes, ${}_5^{10}B$ and ${}_5^{11}B$. Their respective masses are 10.01294 u and 11.00931 u, and the atomic mass of boron is 10.811 u. Find the abundances of ${}_5^{11}B$.

(a) 90.1% (b) 80.1%
(c) 85.5% (d) 95%

## Case Based MCQs

**Case I :** Read the passage given below and answer the following questions from 21 to 25.

**Discovery of Nucleus**

The nucleus was first discovered in 1911 by Lord Rutherford and his associates by experiments on scattering of $\alpha$-particles by atoms. He found that the scattering results could be explained, if atoms consist of a small, central, massive and positive core surrounded by orbiting electrons. The experimental results indicated that the size of the nucleus is of the order of $10^{-14}$ m and is thus 10000 times smaller than the size of atom.

**21.** Ratio of mass of nucleus with mass of atom is approximately

(a) 1 (b) 10
(c) $10^3$ (d) $10^{10}$

**22.** Masses of nuclei of hydrogen, deuterium and tritium are in ratio

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

**23.** Nuclides with same neutron number but different atomic number are

(a) isobars (b) isotopes
(c) isotones (d) none of these

**24.** If $R$ is the radius and $A$ is the mass number, then log $R$ versus log $A$ graph will be

(a) a straight line (b) a parabola
(c) an ellipse (d) none of these.

**25.** The ratio of the nuclear radii of the mercury isotope ${}_{80}^{198}Hg$ and silver isotope ${}_{47}^{107}Ag$ is

(a) 1.23 (b) 0.216
(c) 2.13 (d) 3.46

**Case II :** Read the passage given below and answer the following questions from 26 to 30.

**Nuclear Fission**

In the year 1939, German scientist Otto Hahn and Strassmann discovered that when an uranium isotope was bombarded with a neutron, it breaks into two intermediate mass fragments. It was observed that, the sum of the masses of new fragments formed were less than the mass of the original nuclei. This difference in the mass appeared as the energy released in the process. Thus, the phenomenon of splitting of a heavy nucleus (usually $A > 230$) into two or more lighter nuclei by the bombardment of proton, neutron, $\alpha$-particle, etc with liberation of energy is called nuclear fission.

$$ {}_{92}U^{235} + {}_0n^1 \rightarrow \underset{\text{Unstable nucleus}}{{}_{92}U^{236}} \rightarrow {}_{56}Ba^{144} + {}_{36}Kr^{89} + 3\,{}_0n^1 + Q $$

**26.** Nuclear fission can be explained on the basis of

(a) Millikan's oil drop method
(b) Liquid drop model
(c) Shell model
(d) Bohr's model.

**27.** For sustaining the nuclear fission chain reaction in a sample (of small size) of $^{235}_{92}U$, it is desirable to slow down fast neutrons by

(a) friction
(b) elastic damping/scattering
(c) absorption
(d) cooling

**28.** Which of the following is/are fission reaction(s)?

(I) $^1_0n + {}^{235}_{92}U \rightarrow {}^{236}_{92}U \rightarrow {}^{133}_{51}Sb + {}^{99}_{41}Nb + 4\,{}^1_0n$

(II) $^1_0n + {}^{235}_{92}U \rightarrow {}^{1.40}_{54}Xe + {}^{94}_{38}Sr + 2\,{}^1_0n$

(III) $^2_1H + {}^2_1H \rightarrow {}^3_2He + {}^1_0n$

(a) Both II and III (b) Both I and III
(c) Only II (d) Both I and II

**29.** On an average, the number of neutrons and the energy of a neutron released per fission of a uranium atom are respectively

(a) 2.5 and 2 keV (b) 3 and 1 keV
(c) 2.5 and 2 MeV (d) 2 and 2 keV

**30.** In any fission process, ratio of mass of daughter nucleus to mass of parent nucleus is

(a) less than 1
(b) greater than 1
(c) equal to 1
(d) depends on the mass of parent nucleus.

**Case III :** Read the passage given below and answer the following questions from 31 to 35.

**Nuclear Energy**

A heavy nucleus breaks into comparatively lighter nuclei which are more stable compared to the original heavy nucleus. When a heavy nucleus like uranium is bombarded by slow moving neutrons, it splits into two parts releasing large amount of energy. The typical fission reaction of $_{92}U^{235}$.

$$_{92}U^{235} + {}_0n^1 \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\,{}_0n^1 + 200\text{ MeV}$$

The fission of $_{92}U^{235}$ approximately released 200 MeV of energy.

**31.** If 200 MeV energy is released in the fission of a single nucleus of $^{235}_{92}U$, the fissions which are required to produce a power of 10 kW is

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

**32.** 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.

**33.** When $_{92}U^{235}$ undergoes fission, about 0.1% of the original mass is converted into energy. The energy released when 1 kg of $_{92}U^{235}$ undergoes fission is

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

**34.** A nuclear fission is said to be critical when multiplication factor or $K$

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

**35.** Einstein's mass-energy conversion relation $E = mc^2$ is illustrated by

(a) nuclear fission (b) atomic transition
(c) rocket propulsion (d) steam engine

**Case IV :** Read the passage given below and answer the following questions from 36 to 40.

**Nuclear Force**

Neutrons and protons are identical particle in the sense that their masses are nearly the same and the force, called nuclear force, does into distinguish them. Nuclear force is the strongest force. Stability of nucleus is determined by the neutron proton ratio or mass defect or packing fraction. Shape of nucleus is calculated by quadrupole moment and spin of nucleus depends on even or odd mass number. Volume of nucleus depends on the mass number. Whole mass of the atom (nearly 99%) is centred at the nucleus.

**36.** The correct statements about the nuclear force is/are

(a) charge independent
(b) short range force
(c) non-conservative force
(d) all of these.

**37.** The range of nuclear force is the order of

(a) $2 \times 10^{-10}$ m (b) $1.5 \times 10^{-20}$ m
(c) $1.2 \times 10^{-4}$ m (d) $1.4 \times 10^{-15}$ m

**38.** A force between two protons is same as the force between proton and neutron. The nature of the force is

(a) electrical force (b) weak nuclear force
(c) gravitational force (d) strong nuclear force.

**39.** Two protons are kept at a separation of 40 Å. $F_n$ is the nuclear force and $F_e$ is the electrostatic force between them. Then
(a) $F_n << F_e$ (b) $F_n = F_e$
(c) $F_n >> F_e$ (d) $F_n \approx F_e$

**40.** All the nucleons in an atom are held by
(a) nuclear forces
(b) Van der Waal's forces
(c) tensor forces
(d) coulomb forces

## Assertion & Reasoning Based MCQs

**For question numbers 41-49,** two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.
*(a) Both A and R are true and R is the correct explanation of A*
*(b) Both A and R are true but R is NOT the correct explanation of A*
*(c) A is true but R is false*
*(d) A is false and R is also false*

**41. Assertion (A) :** Two protons can attract each other.
**Reason (R) :** The distance between the protons within the nucleus is about $10^{-15}$ m.

**42. Assertion (A) :** The nuclear force becomes weak if the nucleus contains too many protons compared to neutrons.
**Reason (R) :** The electrostatic forces weaken the nuclear force.

**43. Assertion (A) :** For the fission of heavy nuclei, neutrons are more effective than protons.
**Reason (R) :** Neutrons are heavier than protons.

**44. Assertion (A) :** Energy is released in a nuclear reaction.
**Reason (R) :** In any nuclear reaction the reactants and resultant products obey the law of conservation of charge and mass only.

**45. Assertion (A) :** Density of all the nuclei is same.
**Reason (R) :** Radius of nucleus is directly proportional to the cube root of mass number.

**46. Assertion (A) :** There is a chain reaction when uranium is bombarded with slow neutrons.
**Reason (R) :** When uranium is bombarded with slow neutrons more neutrons are produced.

**47. Assertion (A) :** Cadmium rods used in a nuclear reactor, control the rate of fission.
**Reason (R) :** Cadmium rods speed up the slow neutrons.

**48. Assertion (A) :** A fission reaction can be more easily controlled than a fusion reaction.
**Reason (R) :** The percentage of mass converted to energy in a fission reaction is 0.1% whereas in a fusion reaction it is 0.4%.

**49. Assertion (A) :** Thermonuclear fusion reactions may become the source of unlimited power for the mankind.
**Reason (R) :** A single fusion event involving isotopes of hydrogen produces more energy than energy from nuclear fission of a single uranium.

# SUBJECTIVE TYPE QUESTIONS

## Very Short Answer Type Questions (VSA)

**1.** What is the radius of the nucleus of $^{64}_{29}\text{Cu}$?

**2.** Find the ratio of nuclear radius of $^{64}_{29}\text{Cu}$ and $^{27}_{13}\text{Al}$.

**3.** Define the nuclear force?

**4.** The nuclear radius of a nucleus with nucleon number 16 is $3 \times 10^{-15}$ m. Then, find the nuclear radius of a nucleus with nucleon number 128?

**5.** Assume that a neutron breaks into a proton and an electron. Find the energy required during this process ?

(Mass of neutron = $1.6725 \times 10^{-27}$ kg, Mass of proton = $1.6725 \times 10^{-27}$ kg, mass of electron = $9 \times 10^{-31}$ kg)

**6.** A neutron is absorbed by a $_{3}^{6}\text{Li}$ nucleus with the subsequent emission of an alpha particle. Calculate the energy released, in MeV, in this reaction.

[Given : mass $_{3}^{6}\text{Li}$ = 6.015126 u;

mass (neutron) = 1.0086654 u;

mass (alpha particle) = 4.0026044 u;

and mass (triton) = 3.0100000 u.

Take 1 u = 931 MeV/$c^2$]

**7.** From the relation $R = R_0 A^{1/3}$, where $R_0$ is a constant and $A$ is the mass number of a nucleus, show that the nuclear matter density is nearly constant (*i.e.,* independent of $A$).

**8.** The three stable isotopes of neon : $_{10}^{20}\text{Ne}$, $_{10}^{21}\text{Ne}$ and $_{10}^{22}\text{Ne}$ have respective abundances of 90.51%, 0.27% and 9.22%. The atomic masses of the three isotopes are 19.99 u, 20.99 u and 21.99 u, respectively. Obtain the average atomic mass of neon.

## Short Answer Type Questions (SA-I)

**9.** Find the disintegration energy $Q$ for the fission event represented by equation

$$_{92}\text{U}^{235} + {_0}n^1 \rightarrow {_{92}}\text{U}^{236} \rightarrow {_{58}^{140}}\text{Ce} + {_{40}^{94}}\text{Zr} + 2{_0}n^1$$

If mass of $_{92}\text{U}^{235}$ = 235.0439 u, $_0n^1$ = 1.00867 u, $_{58}^{140}\text{Ce}$ = 139.9054 u and $_{40}^{94}\text{Zr}$ = 93.9063 u, find energy released in the process.

**10.** $_{92}\text{U}^{235}$ absorbs a slow neutron (thermal neutron) and undergoes a fission represented by

$$_{92}\text{U}^{235} + {_0}n^1 \rightarrow {_{92}}\text{U}^{236} \rightarrow {_{56}}\text{Ba}^{141} + {_{36}}\text{Kr}^{92} + 3\,{_0}n^1 + E.$$

Calculate :

(i) The energy released $E$ per fission.

(ii) The energy released when 1 g of $_{92}\text{U}^{235}$ undergoes complete fission.

Given : $_{92}\text{U}^{235}$ = 235.1175 amu (atom),

$_{56}\text{Ba}^{141}$ = 140.9577 amu (atom)

$_{36}\text{Kr}^{92}$ = 91.9264 amu (atom), $_0n^1$ = 1.00868 amu,

1 amu = 931 MeV/$c^2$

**11.** If both the number of protons and neutrons in a nuclear reaction is conserved, in what way is mass converted into energy (or vice versa)? Explain giving one example.

**12.** Calculate the energy released in fusion reaction : $_1^2\text{H} + {_1^2}\text{H} \rightarrow {_2^3}\text{He} + n$, where B.E. of $_1^2\text{H}$ = 2.23 MeV and of $_2^3\text{He}$ = 7.73 MeV.

**13.** Which is more, the density of lead nuclei or the density of oxygen nuclei?

**14.** Consider a particle or nucleus, which contains 2 protons and 2 neutrons. Find its binding energy.

$m_p$ = 1.007276 u, $m_n$ = 1.008665 u

$m_{\text{He}}$ = 4.001508 u

**15.** A nuclide 1 is said to be the mirror isobar of nuclide 2 if $Z_1 = N_2$ and $Z_2 = N_1$. (a) Which nuclide is a mirror isobar of $_{11}^{23}\text{Na}$ ? (b) Which nuclide out of the two mirror isobars have greater binding energy and why?

**16.** Why do stable nuclei never have more protons than neutrons?

## Short Answer Type Questions (SA-II)

**17.** Calculate for how many years will the fusion of 2.0 kg deuterium keep 800 W electric lamp glowing. Take the fusion reaction as

$$_1^2\text{H} + {_1^2}\text{H} \rightarrow {_2^3}\text{He} + {_0^1}n + 3.27 \text{ MeV}$$

**18.** Consider the fusion reaction:

$$^4\text{He} + {^4}\text{He} \rightarrow {^8}\text{Be}$$

For the reaction, find (i) mass defect (ii) $Q$-value (iii) Is such a fusion energetically favourable?

Atomic mass of $^8$Be is 8.0053 u and that of $^4$He is 4.0026 u.

**19.** A nuclear reactor using $^{235}$U generates 250 MW of electrical power. The efficiency of the reactor (*i.e.*, efficiency of conversion of thermal energy into electrical energy) is 25%. What is the amount of $^{235}$U used in the reactor per year? The thermal energy released per fission of $^{235}$U is 200 MeV.

**20.** The deuteron is bound by nuclear forces just as H-atom is made up of $p$ and $e$ bound by electrostatic forces. If we consider the force between neutron and proton in deuteron as given in the form of a Coulomb potential but with an effective charge $e'$:

$$F = \frac{1}{4\pi\varepsilon_0}\frac{e'^2}{r}$$

Estimate the value of $(e'/e)$ given that the binding energy of a deuteron is 2.2 MeV.

**21.** Distinguish between the phenomena of nuclear fission and fusion.

**22.** When four hydrogen nuclei combine to form a helium nucleus estimate the amount of energy in MeV released in this process of fusion (Neglect the masses of electrons and neutrons). Given:

(i) Mass of ${}_1^1\text{H}$ = 1.007825 u

(ii) mass of helium nucleus = 4.002603 u,

1u = 931 MeV/c$^2$

**23.** In a typical nuclear reaction, *e.g.*

$${}_1^2\text{H} + {}_1^2\text{H} \rightarrow {}_2^3\text{He} + {}_0^1n + 3.27 \text{ MeV},$$

although number of nucleons is conserved, yet energy is released. How? Explain.

## Long Answer Type Questions (LA)

**24.** Deuteron is a bound state of a neutron and a proton with a binding energy $B$ = 2.2 MeV. A γ-ray of energy $E$ is aimed at a deuteron nucleus to try to break it into a (neutron + proton) such that the $n$ and $p$ move in the direction of the incident γ-ray. If $E = B$, show that this cannot happen. Hence, calculate how much $E$ should be bigger than $B$ for such a process to happen.

# ANSWERS

### OBJECTIVE TYPE QUESTIONS

**1. (a) :** Let the number of fissions per second be $n$.

Energy released = $n \times 200$ MeV = $n \times 200 \times 1.6 \times 10^{-13}$ J

Energy required = power × time = 1 kW × 1 s = 1000 J

$\therefore \quad n \times 200 \times 1.6 \times 10^{-13} = 1000$

or $\quad n = \frac{1000}{3.2\times10^{-11}} = \frac{10}{3.2}\times10^{13} = 3.125\times10^{13}$

**2. (c) :** During nuclear fusion, two or more lighter nuclei combine to form a heavier nucleus.

**3. (d) :** In any nuclear reaction mass, energy and momentum all are conserved.

**4. (a) :** Number of atoms in 1 kg of pure $^{239}$Pu

$$= \frac{6.023\times10^{23}}{239}\times1000 = 2.52\times10^{24}$$

As average energy released per fission is 180 MeV

$\therefore$ Total energy released = $2.52 \times 10^{24} \times 180$ MeV

$= 4.53 \times 10^{26}$ MeV

**5. (b) :** ${}_{-1}^{0}e + {}_{+1}^{0}e \rightarrow 2\gamma$

The total energy of the positron = 1 + 0.512 MeV

The total energy of the electron = 1 + 0.512 MeV

Energy of each photon

$$= \frac{2(1+0.512)}{2} = 1.512 \text{ MeV} = 1.512\times1.6\times10^{-13} \text{ J}$$

$$E = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E} = \frac{6.62\times10^{-34}\times3\times10^{8}}{1.512\times1.6\times10^{-13}}$$

$= 8.2 \times 10^{-13}$ m

**6. (a) :** In nuclear reactors, cadmium rods are used as control rods.

**7. (a) :** Using, $E = mc^2$

Here, $m = 1 \text{ g} = 1 \times 10^{-3}$ kg,

$c = 3 \times 10^8 \text{ m s}^{-1}$

$\therefore \quad E = 10^{-3} \times 9 \times 10^{16} = 9 \times 10^{13}$ J

**8. (b)**

**9. (b) :** Order of magnitude of nuclear density = $10^{17}$ kg m$^{-3}$

**10. (a) :** Here, $P$ = 500 MW = $5 \times 10^8$ W, $t$ = 1 h = 3600 s

Energy produced, $E = P \times t = 5 \times 10^8 \times 3600 = 18 \times 10^{11}$ J

As $\quad E = mc^2$

$$\therefore \quad m = \frac{E}{c^2} = \frac{18\times10^{11}}{(3\times10^{8})^2} = \frac{18\times10^{11}}{9\times10^{16}} = 2\times10^{-5} \text{ kg}$$

**11. (a) :** Atomic weight = Weighted average of the isotopes

$$= \frac{6.01512\times7.5+7.01600\times92.5}{(7.5+92.5)}$$

$$= \frac{45.1134+648.98}{100} = 6.941 \text{u}$$

**12. (a) :** Here, $A_1$ = 197 and $A_2$ = 107

$$\therefore \quad \frac{R_1}{R_2} = \left(\frac{A_1}{A_2}\right)^{1/3} = \left(\frac{197}{107}\right)^{1/3} = 1.225 \simeq 1.23$$

**13. (d) :** Due to mass defect, the rest mass of a nucleus is always less than the sum of the rest masses of its constituent nucleons.

$^{20}_{10}Ne$ nucleus consists of 10 protons and 10 neutrons.

$\therefore \quad M_1 < 10\ (m_p + m_n)$

**14. (b) :** Light energy emitted by stars is due to fusion of light nuclei.

**15. (c) :** $\Delta m = 2m_p + 2m_n - m(^4_2He)$

$= 2 \times 1.0073 + 2 \times 1.0087 - 4.0015 = 0.0305$ u

Binding energy = $0.0305 \times 931$ MeV = 28.4 MeV

**16. (d) :** Nuclides with same atomic number $Z$ but different mass number $A$ are known as isotopes.

Nuclides with same mass number $A$ but different atomic number $Z$ are known as isobars.

Nuclides with same neutron number $N = (A - Z)$ but different atomic number $Z$ are known as isotones.

$_1H^2$ and $_1H^3$ are isotopes

$_2He^3$ and $_1H^3$ are isobars

$_{79}Au^{197}$ and $_{80}Hg^{198}$ are isotones.

**17. (a) :** Nuclear radius, $R = R_0(A)^{1/3}$

where $A$ is the mass number of a nucleus.

Given, $R = 3.6$ fm

$$\therefore \quad 3.6 \text{ fm} = (1.2 \text{ fm})(A^{1/3}) \qquad [\because R_0 = 1.2 \text{ fm}]$$

or $\quad A = (3)^3 = 27$

**18. (d) :** Here, $\Delta m = 0.3\%$ of 1 kg $= \dfrac{0.3}{100}$ kg $= 3 \times 10^{-3}$ kg

$\therefore \quad E = (\Delta m)\ c^2 = 3 \times 10^{-3} \times (3 \times 10^8)^2 = 27 \times 10^{13}$ J

**19. (d) :** Here, $A_1 = 27$, $A_2 = 125$

$R_1 = 3.6$ fm

$$\text{As,} \quad \frac{R_2}{R_1} = \left(\frac{A_2}{A_1}\right)^{1/3} = \left(\frac{125}{27}\right)^{1/3} = \frac{5}{3}$$

$$\therefore \quad R_2 = \frac{5}{3}R_1 = \frac{5}{3} \times 3.6 = 6 \text{ fm}$$

**20. (b) :** Let abundance of $^{10}_5B$ is $x$ % than abundance of $^{11}_5B$ will be $(100 - x)$%.

Atomic mass of boron

$$= \frac{x[10.01294 \text{ u}] + (100 - x)[11.00931 \text{ u}]}{100}$$

$\Rightarrow \quad 100 \times 10811$ u = 1100.931 u – 0.99637$x$ u

Solving we get, $x = \dfrac{19.831}{0.99637} = 19.9\%$

So, relative abundance of $^{10}_5B$ isotope = 19.9%

Relative abundance of $^{11}_5B$ isotope = 80.1%

**21. (a) :** As nearly 99.9% mass of atom is in nucleus

$$\therefore \quad \frac{\text{Mass of nucleus}}{\text{Mass of atom}} = \frac{99.9}{100} = 0.99 \approx 1$$

**22. (a) :** Since, the nuclei of deuterium and tritium are isotopes of hydrogen, they must contain only one proton each. But the masses of the nuclei of hydrogen, deuterium and tritium are in the ratio of 1 : 2 : 3, because of presence of neutral matter in deuterium and tritium nuclei.

**23. (c)**

**24. (a) :** $R = R_0A^{1/3}$

$$\log R = \log R_0 + \frac{1}{3} \log A$$

Which is of form, $y = mx + c$. So, the graph between log $A$ and log $R$ is a straight line.

**25. (a) :** Here, $A_1 = 198$ and $A_2 = 107$

$$\therefore \quad \frac{R_1}{R_2} = \left(\frac{A_1}{A_2}\right)^{1/3} = \left(\frac{198}{107}\right)^{1/3} = 1.23$$

**26. (b)**

**27. (b) :** Fast neutrons are slowed down by elastic scattering with light nuclei as each collision takes away nearly 50% of energy.

**28. (d) :** Reactions I and II represent fission of uranium isotope $^{235}_{92}U$, when bombarded with neutrons that breaks it into two intermediate mass nuclear fragments. However, reaction III represents two deuterons fuses together to from the light isotope of helium.

**29. (c) :** On an average 2.5 neutrons are released per fission of the uranium atom.

The energy of the neutron released per fission of the uranium atom is 2 MeV.

**30. (a) :** In fission process, when a parent nucleus breaks into daughter products, then some mass is lost in the form of energy. Thus,

mass of fission products < mass of parent nucleus.

$$\Rightarrow \quad \frac{\text{Mass of fission products}}{\text{Mass of parent nucleus}} < 1$$

**31. (d) :** Let the number of fissions per second be $n$.

Energy released = $n \times 200$ MeV = $n \times 200 \times 1.6 \times 10^{-13}$ J

Energy required = power × time = 10 kW × 1 s = 10000 J

$\therefore \quad n \times 200 \times 1.6 \times 10^{-13} = 10000$

$$\text{or} \quad n = \frac{10000}{3.2 \times 10^{-11}} = 3.125 \times 10^{14}$$

**32. (a)**

**33. (b) :** As only 0.1% of the original mass is converted into energy, hence out of 1 kg mass 1 g is converted into energy.

$\therefore \quad$ Energy released during fission, $E = \Delta mc^2$

$= 1 \text{ g} \times (3 \times 10^8 \text{ m s}^{-1})^2 = 10^{-3} \times 9 \times 10^{16} \text{ J} = 9 \times 10^{13}$ J

**34. (a)** **35. (a)**

**36. (d) :** All options are basic properties of nuclear forces. So, all options are correct.

**37. (d) :** The nuclear force is of short range and the range of nuclear force is the order of $1.4 \times 10^{-15}$ m.

Now, volume $\propto R^3 \propto A$

**38. (d)**

**39. (a) :** Nuclear force is much stronger than the electrostatic force inside the nucleus *i.e.*, at distances of the order of fermi. At 40 Å, nuclear force is ineffective and only electrostatic force of repulsion is present. This is very high at this distance because nuclear force is not acting now and the gravitational force is very feeble. $F_{nuclear} << F_{electrostatic}$ in this case.

**40. (a)**

**41. (a) :** Due to electrostatic forces between two protons (like charges) there is a force of repulsion. However, when the distance between them is ~ $10^{-15}$ m they come under the influence of the short range, strong nuclear forces. (The range of the nuclear forces is ~ $10^{-15}$ m). These forces are attractive forces and charge independent. The net force on the protons is attractive as nuclear forces are much stronger than electrostatic forces. The protons attract each other.

**42. (c) :** Nuclear forces are strongest when the number of protons equals the number of neutrons. An excess of protons compared to neutrons weakens the nuclear force. Also too many neutrons compared to protons inside the nucleus weaken the nuclear forces. The electrostatic force which is a hundred times less than the nuclear force is not the cause.

**43. (b) :** A neutron is slightly heavier than a proton. As neutrons are chargeless particles they penetrate matter more than protons. Therefore, they are more effective than protons in fission reactions.

**44. (c) :** In both fission and fusion large amount of energy is released. Assertion is correct. Charge, mass, momentum and energy, all are conserved.

**45. (a) :** Experimentally, it is found that the average radius of a nucleus is given by

$R = R_0A^{1/3}$ where $R_0 = 1.1 \times 10^{-15}$ m = 1.1 fm

and $A$ = mass number

The volume of a nucleus is $V = \frac{4}{3}\pi R^3 = \frac{4}{3}\pi R_0{}^3 A$.

Now as the masses of a proton and a neutron are roughly equal, say $m$, the mass of a nucleus is also roughly proportional to the mass number $A$, $M = mA$. Hence density within a nucleus, $\rho = \frac{M}{V} = \frac{mA}{\frac{4}{3}\pi R_0^3 A} = \frac{m}{\frac{4}{3}\pi R_0^3}$ is independent of the mass number $A$.

**46. (a) :** When uranium is bombarded by slow neutrons the reaction is represented as

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

As more neutrons are produced, the reason is correct. These additional neutrons strike other uranium nuclei to produce even more neutrons. Thus a chain reaction is established.

**47. (c) :** Cadmium rods are used in a nuclear reactor to control the rate of fission. The cadmium rods do not slow down or speed up the neutrons produced in a fission reaction of $^{235}$U. Instead they absorb the neutrons thereby regulating the power level of the reactor.

**48. (b) :** Percentage of mass converted to energy in a fission reaction is 0.1% whereas in a fusion reaction it is 0.4%. Consequently the amount of energy released is more in a fusion than in a fission reaction.

It is not easy to control a fusion reaction.

**49. (c) :** When fusion is achieved by raising the temperature of the system so that particles have enough kinetic energy to overcome the coulomb repulsive behaviour, it is called thermonuclear fusion. It is clean source of energy but energy released in one fusion is much less than a single uranium fission.

## SUBJECTIVE TYPE QUESTIONS

**1.** As, $R = R_0A^{1/3} = (1.2 \times 10^{-15})(64)^{1/3} = 4.8 \times 10^{-15}$ m

$(\because R_0 = 1.2 \times 10^{-15}\text{ m})$

**2.** As, $R = R_0 A^{\frac{1}{3}}$

$$\Rightarrow \frac{R_{Cu}}{R_{Al}} = \left(\frac{A_{Cu}}{A_{Al}}\right)^{\frac{1}{3}} = \left(\frac{64}{27}\right)^{\frac{1}{3}} = \frac{4}{3}$$

**3.** Nuclear force is the strongest attractive force which binds the protons and neutrons together inside a tiny nucleus.

**4.** Radius $R$ of a nucleus changes with the nucleon number $A$ of the nucleus as

Hence, $\frac{R_2}{R_1} = \left(\frac{A_2}{A_1}\right)^{1/3} = \left(\frac{128}{16}\right)^{1/3} = (8)^{1/3} = 2$

$\therefore \quad R_2 = 2R_1 = 2(3 \times 10^{-15})\text{m} = 6 \times 10^{-15}$ m

**5.** ${}_0n^1 \rightarrow {}_1\mathrm{H}^1 + {}_{-1}e^0 + \bar{\nu} + Q$

$\Delta m = m_n - m_\alpha - m_e$

$= (1.6725\times10^{-27} - 1.6725\times10^{-27} - 9\times10^{-31})\text{ kg} = -9\times10^{-31}$ kg

Energy $= \Delta mc^2 = 9 \times 10^{-31} \times (3 \times 10^8)^2 = 0.511$ MeV

**6.** ${}_3\mathrm{Li}^6 + {}_0n^1 \rightarrow {}_2\mathrm{He}^4 + {}_1\mathrm{H}^3 + Q$

Total initial mass = 6.015126 + 1.0086654 = 7.0237914 amu

Total final mass = 4.0026044 + 3.01 = 7.0126044 amu

Mass defect, $\Delta m$ = 7.0237914 – 7.0126044 = 0.0111870 amu

Energy released, $Q$ = 0.0111870 × 931 = 10.415 MeV.

**7.** Density of nuclear matter $= \frac{\text{Mass of nucleus}}{\text{Volume}}$

$\rho = \frac{A \times 1\text{amu}}{\frac{4}{3}\pi R^3}$, where $R = R_0 A^{1/3}$ $(\because R_0 = 1.2 \times 10^{-15}\text{ m})$

$$\text{Density, } \rho = \frac{A \times 1\text{amu}}{\frac{4}{3}\pi R_0^3 A} = \frac{1\text{amu}}{\frac{4}{3}\pi R_0^3} = \frac{3\text{ amu}}{4\pi R_0^3}$$

$$= \frac{3 \times 1.66 \times 10^{-27}}{4 \times 3.14 \times (1.2 \times 10^{-15})^3}$$

$= 2.27 \times 10^{17}$ kg m$^{-3}$

As $R_0$ is constant, $\rho$ is constant

So, nuclear density is constant irrespective of mass number or size.

**8.** Average atomic mass of neon with the given abundances,

$$A = \frac{90.51(19.99\text{ u}) + 0.27\,(20.99\text{ u}) + 9.22\,(21.99\text{ u})}{100}$$

$$A = \frac{2017.7}{100}\text{ u} = 20.18\text{ u}$$

**9.** The mass lost in the process,

$\Delta m = 235.0439 + 1.00867 - (139.9054 + 93.9063 + 2.01734)$
$= 0.22353$ u

The corresponding energy released

$= \Delta mc^2 = 0.22353 \times 931$ MeV $= 208$ MeV

**10.** (i) $E = [M_U + m_n - M_{Ba} - M_{Kr} - 3m_n] \times 931 = 200.57$ MeV

(ii) Energy released $= \dfrac{N_A}{235} \times E$

$$= \frac{200.57 \times 10^6 \times 1.6 \times 10^{-19} \times 6.023 \times 10^{23}}{235 \times 3.6 \times 10^6} = 22.84\text{ MWh}$$

**11.** A certain number of neutrons and protons are brought together to form a nucleus of a certain charge and mass, an energy $\Delta E_b$ will be released in this process.

The energy $\Delta E_b$ is called the binding energy of the nucleus. If we separate a nucleus into its nucleons we would have to transfer a total energy equal to $\Delta E_b$, to the nucleons.

Example : ${}_{92}U^{235} + {}_0 n^1 \rightarrow {}^{141}_{56}\text{Ba} + {}^{92}_{36}\text{Kr} + 3{}^1_0 n + Q$

The energy ($Q$) released was estimated to be 200 MeV per fission and is equivalent to the difference in masses of the nuclei before and after the fission.

**12.** Given fusion reaction,

${}^2_1\text{H} + {}^2_1\text{H} \longrightarrow {}^3_2\text{He} + n$

Energy released = final $B.E.$ – initial $B.E.$

= 7.73 – (2.23 + 2.23) = 3.27 MeV.

**13.** We know that the density of solid lead is much greater than the density of gaseous oxygen. But here we are checking about the densities of their nuclei.

If the mass of a neutron is $m$, then mass of nuclei

$M = Am$.

Now, volume $V = \dfrac{4}{3}\pi R^3$

But $R = R_0 A^{1/3}$ or $V = \dfrac{4}{3}\pi (R_0 A^{1/3})^3$

$V = \dfrac{4}{3}\pi R_0^{\,3} A$

The density of the nucleus $\rho = \dfrac{M}{V}$

$$= \frac{Am}{\frac{4}{3}\pi R_0^3 A} = \frac{3m}{4\pi R_0^3} = \text{constant.}$$

Nuclear density is almost a constant, whether it is lead or oxygen.

**14.** B.E. $= (2m_p + 2m_n - m_{He})$u $\times$ 931 MeV

= [2(1.007276 u + 1.008665 u) – 4.001508 u] × 931 MeV

= [4.031882 u – 4.001508 u] × 931 MeV

= 0.030374 × 931 MeV

B.E. = 28.3 MeV

**15.** (a) For ${}^{23}_{11}\text{Na}$, $Z_1 = 11$, $N_1 = 12$

For mirror isobar of ${}^{23}_{11}\text{Na}$, $Z_2 = N_1 = 12$ and $N_2 = Z_1 = 11$.

Thus mirror isobar of ${}^{23}_{11}\text{Na}$ is ${}^{23}_{12}\text{Mg}$.

(b) As ${}^{23}_{12}\text{Mg}$ contains even number of protons (12) against ${}^{23}_{11}\text{Na}$ which contains odd number of protons (11), hence ${}^{23}_{12}\text{Mg}$ has greater binding energy comparatively.

**16.** The stability of a nucleus depends on its neutron to proton ratio. More is the number of protons in the nucleus, greater is the electrical forces between them. Therefore more neutrons are needed to provide the strong attractive force necessary to keep the nucleus stable.

**17.** Given $m = 2$ kg, $P = 800$ W.

Here two deuterium nuclei produce 3.27 MeV energy

$= 3.27 \times 10^6 \times 1.6 \times 10^{-19} = 5.232 \times 10^{-13}$ J

$\therefore$ Energy per nuclei $= \dfrac{5.232 \times 10^{-13}}{2} = 2.616 \times 10^{-13}$ J

No. of deuterium atom in 2 kg

$= \dfrac{6.023 \times 10^{23} \times 2000}{2} = 6.023 \times 10^{26}$ atom

$\therefore$ Total energy $= 6.023 \times 10^{26} \times 2.616 \times 10^{-13}$

$= 15.75 \times 10^{13}$ J

$$\text{Power} = \frac{\text{Energy}}{\text{Time}} \Rightarrow t = \frac{\text{Total energy}}{\text{Power}}$$

$$\Rightarrow t = \frac{15.75 \times 10^{13}}{800} = 1.96 \times 10^{11}\text{s}$$

$$= \frac{1.96 \times 10^{11}}{365 \times 24 \times 60 \times 60} = 6.2 \times 10^3 \text{ years}$$

**18.** ${}^4\text{He} + {}^4\text{He} \rightarrow {}^8\text{Be} + Q$

(i) $\Delta m = 2 \times 4.0026 - 8.0053 = 8.0052 - 8.0053$
$= -\,0.0001$ amu

(ii) $Q = (2m_{He} - m_{Be})\,c^2$

$= (2 \times 4.0026 - 8.0053)c^2 \times 931\ \dfrac{\text{MeV}}{c^2}$

$= -0.0931$ MeV $= -93.1$ keV

(iii) Since $Q$ is negative, the fusion is not energetically favourable.

**19.** Rate of electrical energy generation is 250 MW

$= 250 \times 10^6$ W (or J s$^{-1}$).

So, electrical energy generation is 250 MW = $250 \times 10^6$ W (or J $s^{-1}$).

Therefore, electrical energy generated in 1 year is

$(250 \times 10^6 \text{ J s}^{-1}) \times (365 \times 24 \times 60 \times 60 \text{ s}) = 7.884 \times 10^{15}$ J

Thermal energy from fission of one $^{235}$U nucleus is 200 MeV = $200 \times 1.6 \times 10^{-13} = 3.2 \times 10^{-11}$ J

Since the efficiency is 25%, the electrical energy obtained from the fission one $^{235}$U nucleus,

$$E_1 = 3.2\times10^{-11}\times\frac{25}{100} = 8.0\times10^{-12} \text{ J}$$

$\therefore$ The number of fissions of $^{235}$U required in one year,

$$N = \frac{7.884\times10^{15}}{8.0\times10^{-12}} = 9.855\times10^{26}$$

Number of moles of $^{235}$U required per year,

$$N = \frac{9.855\times10^{26}}{6.02\times10^{23}} = 1.636\times10^{3}$$

Therefore, mass of $^{235}$U required per year,

$m = 1.636 \times 10^3 \times 235 = 3.844 \times 10^5$ g = 384.4 kg

**20.** We know that binding energy of hydrogen atom in ground state,

$$E = \frac{me^4}{8\epsilon_0^2 h^2} = 13.6 \text{ eV} \qquad \ldots(\text{i})$$

Replacing $e$ by $e'$ and $m$ by $m'$, reduced mass of neutron – proton,

$$m' = \frac{M\times M}{M+M} = \frac{M}{2} = \frac{1836m}{2} = 918\,m$$

($M$ = mass of neutron/proton)

$\therefore$ Binding energy, $E' = \dfrac{918\, me'^4}{8\epsilon_0^2 h^2} = 2.2\,\text{MeV}$ ...(ii)

Dividing eq. (ii) by (i), we get

$$918\left(\frac{e'}{e}\right)^4 = \frac{2.2\times10^6}{13.6}$$

$$\frac{e'}{e} = (176.21)^{1/4} = 3.64$$

**21.**

| | Nuclear Fission | | Nuclear Fusion |
|---|---|---|---|
| 1. | The process of splitting of a heavy nucleus into two nuclei of nearly comparable masses with liberation of energy is called nuclear fission.<br>Example:<br>$^{235}_{92}\text{U} + ^{1}_{0}n \rightarrow ^{141}_{56}\text{Ba} + ^{92}_{36}\text{Kr} + 3^{1}_{0}n + Q$ | 1. | When two or more than two light nuclei fuse together to form heavy nucleus with the liberation of energy, the process is called nuclear fusion.<br>Example:<br>$^{2}_{1}\text{H} + ^{2}_{1}\text{H} \rightarrow ^{4}_{2}\text{He} + 24\,\text{MeV}$ |
| 2. | A suitable bullet or projectile like neutron is needed. | 2. | The lighter nuclei have to be brought very close to each other against electrostatic repulsion. |
| 3. | The products of nuclear fission reaction are radioactive. | 3. | The products of nuclear fusion are not radioactive. |

**22.** Energy released = $\Delta m \times 931$ MeV

$\Delta m = 4m\,(^1_1\text{H}) - m\,(^4_2\text{He})$

Energy released

$Q = [4m\,(^1_1\text{H}) - m\,(^4_2\text{He})] \times 931\text{MeV}$

= [4 × 1.007825 – 4.002603] × 931 MeV = 26.72 MeV.

**23.** In a given nuclear reaction, the sum of the masses of the target nucleus (21H) and the bombarding particle (21H) may be greater than the product nucleus $\left(^3_2\text{He}\right)$ and the outgoing neutron $_0{}^1n$. So from the law of conservation of mass-energy some energy (3.27 MeV) is released due to mass defect in the nuclear reaction. This energy is called $Q$-value of the nuclear reaction.

**24.** Applying principle of conservation of energy,

$$E - B = K_n + K_p = \frac{p_n^2}{2m} + \frac{p_p^2}{2m} \qquad \ldots(\text{i})$$

From law of conservation of momentum,

$$p_n + p_p = E/c$$

when $E = B$,

from equation (i), $p_n = p_p = 0$

$\therefore$ Process cannot take place.

For process to take place, let $E$ be very slightly bigger than $B$ so that $E = B + \lambda$, ($\lambda << B$.)

$$\lambda = \frac{p_n^2}{2m} + \frac{p_p^2}{2m}$$

$$\lambda = \frac{1}{2m}[p_p^2 + (p_p - E/c)^2]$$

$$p_p = \frac{E}{2c} \pm \sqrt{\frac{E}{4c^2} - \left(\frac{E^2}{2c^2} - m\lambda\right)}$$

For $p_p$ (momentum of proton) to be real, the determinant must be positive.

$$\frac{E^2}{4c^2} - \left(\frac{E^2}{2c^2} - m\lambda\right) \geq 0 \quad \text{or} \quad \lambda = \frac{E^2}{4mc^2} \simeq \frac{B^2}{4mc^2}$$

Therefore, for the given process to occur the value of energy $E$ must be greater than binding energy $B$ by a factor $\lambda$ which is equal to $\dfrac{B^2}{4mc^2}$.