NUCLEAR PHYSICS

Contents

Syllabus

Aotmic nucleus ; Alpha, beta and gamma radiations ; Law of radioactive decay ; Decay constant ; Half-life and mean life ; Binding energy and its calculation ; Fission and fusion processes ; Energy calculation in these processes.

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NUCLEAR PHYSICS

1. NUCLEAR DIMENSIONS :

$R = R_o A^{1/3}$ Where R_o = is an empirical constant = 1.1×10^{-15} m ; A = Mass number of the atom

2. RADIOACTIVITY :

The phenomenon of self emission of radiation is called radioactivity and the substances which emit these radiations are called **radioactive substances** . It can be natural or artificial (induced) .

3. α , β , γ RADIATION :

(i) α – particle :

(a) Helium nucleus ($_2He^4$) ; **(b)** energy varies from 4 Mev to 9 Mev ;

(c) Velocity 10^6 – 10^7 m/s ; **(d)** low penetration

(ii) β – particle : **(a)** electron or positron

(b) Have much less energy ; **(c)** more penetration ; **(d)** higher velocities than α particles

(iii) γ – radiation : Electromagnetic waves of very high energy and maximum penetration.

4. LAWS OF RADIOACTIVE DISINTEGRATION :

(A) **Displacement Law** : In all radioactive transformation either an α or β particle (never both or more than one of each simultaneously) is emitted by the nucleus of the atom.

(i) α – emission : $_zX^A \longrightarrow {}_{z-2}Y^{A-4} + {}_2\alpha^4$ + Energy

(ii) β – emission : $_zX^A \longrightarrow \beta + {}_{z+1}Y^A + \bar{\nu}$ (antinuetrino)

(iii) γ – emission : emission does not affect either the charge number or the mass number .

(B) **Stastistical Law** : The disintegration is a random phenomenon . Which atom disintegrates first is purely a matter of chance .

Number of nuclei disintegrating per second is given ;

(disintegrations /gm is called specific activity) .

(i) $\frac{dN}{dt} \alpha N \Rightarrow \frac{dN}{dt} = -\lambda N$ = activity .

Where N = Number of nuclei present at time t ; λ = decay constant

(ii) $N = N_o e^{-\lambda t}$; N_0 = number of nuclei present in the beginning .

(iii) Half life of the population $T_{1/2} = \frac{0.693}{\lambda}$;

at the end of n half–life periods the number of nuclei left $N = \frac{N_o}{2^n}$.

(iv) Mean life of an atom $= \frac{\Sigma \text{life time of all atoms}}{\text{total number of atoms}}$; $T_{av} = \frac{1}{\lambda}$

(v) **Curie :** The unit of activity of any radioactive substance in which the number of disintegration per second is 3.7×10^{10} .

5. ATOMIC MASS UNIT (a.m.u. OR U) :

$$1\text{ amu} = \frac{1}{12} \times (\text{mass of carbon} - 12\text{ atom}) = 1.6603 \times 10^{-27}\text{ kg}$$

6. MASS AND ENERGY :

The mass m of a particle is equivalent to an energy given by $E = mc^2$;
c = speed of light . 1 amu = 931 Mev

7. MASS DEFECT AND BINDING ENERGY OF A NUCLEUS :

The nucleus is less massive than its constituents . The difference of masses is called mass defect .

ΔM = mass defect = $[Zm_p + (A - Z)m_n] - M_{zA}$.

Total energy required to be given to the nucleus to tear apart the individual nucleons composing the nucleus , away from each other and beyond the range of interaction forces is called the Binding Energy of a nucleus .

B.E. = $(\Delta M)C^2$.

B.E. per nucleon = $\frac{(\Delta M)C^2}{A}$.

Greater the B.E. per nucleon, greater is the stability of the nucleus .

8. NUCLEAR FISSION :

(i) Heavy nuclei of A , above 200 , break up into two or more fragments of comparable masses.

(ii) The total B.E. increases and excess energy is released .

(iii) The man point of the fission energy is liberated in the form of the K.E. of the fission fragments . eg. ${}^{235}_{92}U + {}_{o}n^{1} \rightarrow {}^{236}_{92}U \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3\,{}_{o}n^{1}$ + energy

9. NUCLEAR FUSION (Thermo nuclear reaction) :

(i) Light nuclei of A below 20 , fuse together , the B.E. per nucleon increases and hence the excess energy is released .

(ii) These reactions take place at ultra high temperature ($\cong 10^7$K to 10^9K)

(iii) Energy released exceeds the energy liberated in the fission of heavy nuclei .

eg . $4\,{}^{1}_{1}P \rightarrow {}^{4}_{2}He + 2\,{}^{0}_{+1}e$. (Positron)

(iv) The energy released in fusion is specified by specifying Q value .
i.e. Q value of reaction = energy released in a reaction .

Note : **(i)** In emission of β^- , Atomic number (Z) increases by 1 .

(ii) In emission of β^+ , Atomic number (Z) decreases by 1 .

EXERCISE # 1

PART - I : OBJECTIVE QUESTIONS

** Marked Questions are having more than one correct option.*

SECTION (A) : PROPERTIES OF NUCLEUS , MASS DEFECT AND BINDING ENERGY

A-1. Two nucleons are at a separation of 1 fm. The net force between them is F_1 if both are neutrons , F_2 if both are protons, and F_3 if one is a proton and the other is a neutron :
(A) $F_1 > F_2 > F_3$ (B) $F_2 > F_1 > F_3$ (C) $F_1 = F_3 > F_2$ (D) $F_1 = F_2 > F_3$

A-2. Let u be denote one atomic mass unit. One atom of an element of mass number A has mass exactly equal to Au
(A) for any value of A (B) only for A = 1
(C) only for A = 12 (D) for any value of A provided the atom is stable

A-3. The binding energies of the nuclei of $^{4}_{2}$He, $^{7}_{3}$Li, $^{12}_{6}$C & $^{14}_{7}$N are 28, 52, 90, 98 Mev respectively. Which of these is most stable .
(A) $^{4}_{2}$He (B) $^{7}_{3}$Li (C) $^{12}_{6}$C (D) $^{14}_{7}$N

A-4. The surface area of a nucleus varies with mass number A as
(A) $A^{2/3}$ (B) $A^{1/3}$ (C) A (D) None

A-5. Consider the nuclear reaction

$$X^{200} \longrightarrow A^{110} + B^{90}$$

If the binding energy per nucleon for X, A and B is 7.4 MeV, 8.2. MeV and 8.2 MeV respectively, what is the energy released ?
(A) 200 MeV (B) 160 MeV (C) 110 MeV (D) 90 MeV

SECTION (B) : RADIOACTIVE DECAY & DISPLACEMENT LAW

B-1.* If a nucleus $^{A}_{Z}$x emits an α particle & a β particle in succession, then the daughter nucleus will have which of the following configurations?
(A) A – 4 nucleons (B) 4 nucleons (C) A – z – 3 neutrons (D) Z – 2 protons

B-2. A free neutron decays into a proton , an electron and :
(A) a neutrino (B) an antineutrino (C) an α-particle (D) a β-particle

B-3. When a β^--particle is emitted from a nucleus, the neutron-proton ratio :
(A) is decreased (B) is increased (C) remains the same (D) first (A) then (B)

B-4. The number of α and β^- emitted during the radioactive decay chain starting from $^{226}_{88}$Ra and ending at $^{206}_{82}$Pb is
(A) 3α & $6\beta^-$ (B) 4α & $5\beta^-$ (C) 5α & $4\beta^-$ (D) 6α & $6\beta^-$

B-5. In which of the following process the number of protons in the nucleus increases .
(A) α – decay (B) β^- – decay (C) β^+ – decay (D) k – capture

B-6. In a nuclear reaction which of the following conservation is valid?

(A) Charge conservation (B) Energy-mass conservation

(C) Momentum conservation (D) All of above

B-7. Nucleus A is converted into C through the following reactions-

$$A \rightarrow B + \alpha \quad \text{[alpha - particle]}$$

$$B \rightarrow C + 2\beta^{-} \quad \text{[electron]}$$

Then -

(A) A and C are isobars (B) A and B are isotopes

(C) A and C are isotopes (D) A and B are isobars

B-8. A certain radioactive nuclide of mass number m_x disintegrates, with the emission of an electron and an antineutrino only, to give second nuclide of mass number m_y. Which one of the following equation correctly relates m_x and m_y ?

(A) $m_y = m_x + 1$ (B) $m_y = m_x - 2$ (C) $m_y = m_x - 1$ (D) $m_y = m_x$

B-9. A radioactive nucleus emits an α-particle and a neutron simultaneously with same speed but in opposite direction in order to form a stable nuclei If the speed of emitted particles is *v* and *A* is the mass number of radioactive nucleus, then speed of stable nucleus is

(A) $\frac{3v}{A-5}$ (B) $\frac{2v}{A-5}$ (C) $\frac{4v}{A-5}$ (D) $\frac{2v}{A+5}$

B-10. Nuclei X decay into nuclei Y by emitting α particles. Energies of α particle are found to be only 1 MeV & 1.4 MeV. Disregarding the recoil of nuclei Y. The energy of γ photon emitted will be

(A) 0.8 MeV (B) 1.4 MeV (C) 1 MeV (D) 0.4 MeV

SECTION (C) : STATISTICAL LAW OF RADIOACTIVE DECAY

C-1. The half-life of a radioactive substance depends upon :

(A) its temperature

(B) the external pressure on it

(C) the mass of the substance

(D) the strength of the nuclear force between the nucleons of its atom

C-2. The radioactivity of certain radioactive element drops to $\left(\frac{1}{8}\right)^{th}$ of its initial value in 30 second, its half life is

(A)15 second (B) 5 second (C) 4 second (D) 10 second

C-3. (i) A sample of radioactive material has mass *m*, decay constant λ, and molecular weight *M*. Avogadro constant = N_A. The initial acitvity of the sample is :

(A) λm (B) $\frac{\lambda m}{M}$ (C) $\frac{\lambda m N_A}{M}$ (D) $mN_A e^{\lambda}$

(ii) In above question, the activity of the sample after time *t* will be :

(A) $\left(\frac{mN_A}{M}\right)e^{-\lambda t}$ (B) $\left(\frac{mN_A\lambda}{M}\right)e^{-\lambda t}$ (C) $\left(\frac{mN_A}{M\lambda}\right)e^{-\lambda t}$ (D) $\frac{m}{\lambda}(1-e^{-\lambda t})$

C-4. In one average-life

(A) half the active nuclei decay (B) less than half the active nuclei decay

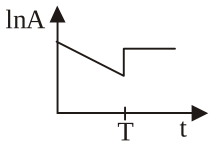
(C) more than half the active nuclei decay (D) all the nuclei decay

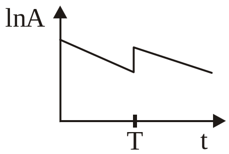
C-5. The half life of a radioactive material is T, then the fraction of radioactive nuclei remain after time $\frac{T}{2}$ is

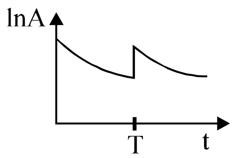
(A) $\frac{1}{2}$ (B) $\frac{3}{4}$ (C) $\frac{1}{\sqrt{2}}$ (D) $\frac{\sqrt{2}-1}{\sqrt{2}}$

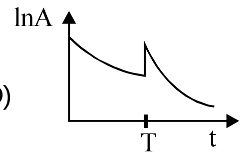
C-6. At time t = 0, some radioactive gas is injected into a sealed vessel. At time T, some more of the same gas is injected into the same vessel.

Which one of the following graphs best represents the variation of the logarithm of the activity A of the gas with time t ?

(A) 

(B) 

(C) 

(D) 

C-7. Two radioactive elements X and Y have half-life times of 50 minutes and 100 minutes, respectively. Samples X and Y initially contain equal numbers of atoms. After 200 minutes, the ratio $\frac{\text{number of undecayed atoms of } X}{\text{number of undecayed atoms of } Y}$ is :

(A) 4 (B) 2 (C) 1/2 (D) 1/4

C-8. $A \xrightarrow{\lambda} B \xrightarrow{2\lambda} C$

	A	B	C
t = 0	N_0	0	0
t	N_1	N_2	N_3

The ratio of N_1 to N_2 when N_2 is maximum is :

(A) at no time this is possible (B) 2

(C) 1/2 (D) $\frac{\ell n\, 2}{2}$

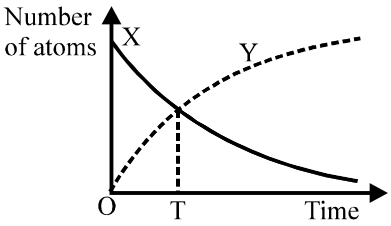
C-9. A radioactive substance is being produced at a constant rate a per second. Its decay constant is b. If N_0 are the number of nuclei at time t = 0, then the maximum number of nuclei possible are ($N_0 < a/b$)

(A) $\frac{a}{b}$ (B) $N_0 + \frac{a}{b}$ (C) N_0 (D) $N_0 + \frac{b}{a}$

C-10. A radioactive nuclide can decay simultaneously by two different processes which have decay constants λ_1 and λ_2. The effective decay constant of the nuclide is λ, then :

(A) $\lambda = \lambda_1 + \lambda_2$ (B) $\lambda = 1/2(\lambda_1 + \lambda_1)$ (C) $\frac{1}{\lambda} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}$ (D) $\lambda = \sqrt{\lambda_1 \lambda_2}$

C-11. The graph represents the decay of a newly-prepared sample of radioactive nuclide X to a stable nuclide Y. The half-life of X is t. The growth curve for Y intersects the decay curve for X after time T.



What is the time T ?

(A) t/2 (B) $\ell n(t/2)$ (C) t (D) $\ell n(2t)$

C-12. The radioactivity of an old sample of whisky due to tritium (half life 12.5 years) was found to be only about 3 % of that measured in a recently purchased bottle marked '7 years old'. The sample must have been prepared about :

(A) 70 years ago (B) 220 years ago (C) 420 years ago (D) 300 years ago

SECTION (D) : NUCLEAR FISSION AND FUSION

D-1. In the fission of U-235, the percentage of mass converted into energy is about :

(A) 0.01 % (B) 0.1 % (C) 1 % (D) 10 %

D-2. The neutrons produced in the chain reaction of U^{235} are in-

(A) Arithmetic progression (B) Harmonic progression

(C) Geometric progression (D) None of these

D-3. Choose the statement which is true.

(A) The energy released per unit mass is more in fission than in fusion

(B) The energy released per atom is more in fusion than in fission.

(C) The energy released per unit mass is more in fusion and that per atom is more in fission.

(D) Both fission and fusion produce same amount of energy per atom as well as per unit mass.

D-4. Fusion reaction is possible at high temperature because -

(A) atoms are ionised at high temperature

(B) molecules break-up at high temperature

(C) nuclei break-up at high temperature

(D) kinetic energy is high enough to overcome repulsion between nuclei.

D-5. Choose the WRONG statement . A thermonuclear fusion reactor is better than a fission reactor for the following reasons :

(A) For the same mass of substances involved , a fusion reaction releases much more energy than a fission reaction

(B) A fusion reaction can be much more easily controlled than a fission reaction

(C) A fusion reaction produces almost no radioactive waste

(D) The fuel required for fusion is readily available in abundance from sea-water

D-6. If each fission in a U^{235} nucleus releases 200 MeV, how many fissions must occurs per second to produce a power of 1 KW

(A) 1.325×10^{13} (B) 3.125×10^{13} (C) 1.235×10^{13} (D) 2.135×10^{13}

D-7. Assuming that about 20 MeV of energy is released per fusion reaction, ${}_1H^2 + {}_1H^3 \rightarrow {}_0n^1 + {}_2He^4$, the mass of ${}_1H^2$ consumed per day in a future fusion reactor of power 1 MW would be approximately

(A) 0.09 gm (B) 0.009 gm (C) 9 gm (D) 90 gm

PART - II : MISLLANEOUS QUESTIONS

1. COMPREHENSION

COMPREHENSION # 1

Rutherford's calculations used the inverse-square law of repulsive force between an α-particle (Z = 2) and a gold nucleus (Z = 79) ignoring multiple scattering. The scattering angle θ of the α-particle is related to the impact parameter b through the relation

$$b = \frac{Ze^2 \cot(\theta/2)}{4\pi\varepsilon_0 E}.$$

Where E is the kinetic energy of the incident α-particle. The impact parameter b is the perpendicular distance of the initial velocity vector of the α-particle at different angles.

1. For impact parameter (b = 0) scattering angle will be :

(A) $\theta = 0^0$ (B) $\theta = \pi$ (C) $\theta = \pi/2$ (D) None of these

2. For a given impact parameter b, with increasing energy the angle of deflection :

(A) increases (B) decreases
(C) remains constant (D) None of these

3. If scattering angle is 90º, for z = 79 and initial energy is 10 MeV, then impact parameter will be :

(A) 1.1×10^{-16} m (B) 1.1×0^{-14} m (C) 2.2×10^{-18} (D) 2.2×10^{-9} m

COMPREHENSION # 2

When radioactivity was discovered, only three kind of radioactive decays α, β and γ were known. In the later years two more kinds of radioactive decay were discovered. According to the Pauli in β -decay process along with emission of electron or positron another particle are also emitted called neutrino and antinutrino. The mass and charge on both the particles are zero and spin of both are 1/2 in the unit of $\frac{h}{2\pi}$. Spin of neutrino is antiparallel to its momentum where as spin of antinutrino is parallel to its momentum. The neutrino hypothesis saves the principles of energy conservation and angular momentum conservation in β -decay.

4. In which equation X-represent β^+

(A) ${}_6C^{14} \to {}_7N^{14} + X + \overline{v}$ (B) ${}_{29}Cu^{64} \to {}_{28}Ni^{64} + X + v$
(C) ${}_{29}Cu^{64} + \beta^- \to {}_{28}Ni^{64} + X$ (D) ${}_{92}U^{238} \to {}_{90}Th^{234} + X$

5. Which of the following decay is accompanied by x-ray

(A) β -decay (B) position - emission (C) Electron capture (D) Gamma decay

6. Choose the correct option

(A) Electron energy of β -particle vary from zero to a maximum for a particular nuclide
(B) The direction of emitted electrons and the recoiling nuclei are exactly opposite.
(C) Neutrino hypothesis violets the principle of conservation of angular momentum.
(D) none of these

2. MATCH THE COLUMN

7. In the following question x (an unstable nucleus) decays to another nucleus y. In column I different type of decay processes are mentioned. Atomic mass of element of nucleus x and element of nucleus y are M_x and M_y respectively. The atomic mass of He is M_{He}. The mass of electron is m_e. Now match the entries of column I with II.

Column I (Decay process)	Column II (Mass defect)
(A) $x \rightarrow y + \alpha$	(p) $M_x - M_y - m_e$
(B) $x \rightarrow y + {}_{-1}e^0$	(q) $M_x - M_y - M_{He}$
(C) $x \rightarrow y + {}_{+1}e^0$	(r) $M_x - M_y - 2m_e$
(D) $x + {}_{-1}e^0 \rightarrow y + \nu$ + X- rays	(s) $M_x - M_y$

8. In column-I, consider each process just before and just after it occurs. Initial system is isolated from all other bodies. Consider all product particles (even those having rest mass zero) in the system. Match the system in column-I with the result they produce in column-II.

Column I	Column II
(A) Spontaneous radioactive decay of an uranium nucleus initially at rest as given by reaction ${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He + ...$	(p) Number of protons is increased
(B) Fusion reaction of two hydrogen nuclei as given by reaction ${}^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{2}_{1}H + ...$	(q) Momentum is conserved
(C) Fission of U^{235} nucleus initiated by a thermal neutron as given by reaction ${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{144}_{56}Ba + {}^{89}_{36}Kr + 3{}^{1}_{0}n + ...$	(r) Mass is converted to energy or vice versa
(D) β^- decay (negative beta decay)	(s) Charge is conserved

3. TRUE/FALSE :

9. (i) The order of magnitude of the density of nuclear matter is 10^4 kg/m^3
(ii) Mass defect per nucleon in the nucleus is called packing fraction.
(iii) Consider α-particle, β-particles and γ-rays each having an energy of 0.5 MeV. In increasing order of penetrating powers, the radiations are α, β, γ.
(iv)In pair production a high energy gamma ray, while passing through the strong electric field of a nucleus, gives rise to a particle and its antiparticle.
(v)The energy released per nucleon in fission is less than that released in fusion.

4. FILL IN THE BLANKS :

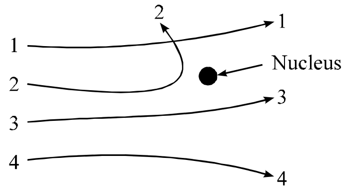
10. (i) The yield of U^{235} from any natural uranium sample is not greater than .... percent.
(ii) When nitrogen nucleus ${}_7N^{14}$ is bombarded by α-particle, proton is emitted. The resulting nucleus is of the element .... and has the mass number ....
(iii) The difference between ${}_{92}U^{235}$ and ${}_{92}U^{238}$ is that ${}_{92}U^{238}$contains three more .... and fission of ${}_{92}U^{238}$ is caused by .... neutrons while fission of ${}_{92}U^{235}$ is caused by .... neutrons.
(iv) The binding energies per nucleon for deuteron (${}_1H^2$) and helium (${}_2He^4$) are 1.1 MeV and 7.0 MeV respectively. The energy released when two deuterons fuse to form a helium nucleus (${}_2He^4$) is ....
(v) In the nuclear process, ${}_6C^{11} \rightarrow {}_5B^{11} + \beta^+ + X$, X stands for ....
(vi) A reaction between a proton and ${}_8O^{18}$ that produced ${}_9F^{18}$ must also liberate ....
(vii) The equation $4\,{}_1H^1 \rightarrow {}_2He^4 + 2e^- + 26$ MeV represents ....

PART - I : MIXED OBJECTIVE

*** Marked Questions are having more than one correct option.***

SINGLE CORRECT ANSWER TYPE

1. Alpha particles are fired at a nucleus . Which of the paths shown in figure is not possible ?



(A) 1 (B) 2 (C) 3 (D) 4

2. Masses of two isobars ${}_{29}Cu^{64}$ and ${}_{30}Zn^{64}$ are 63.9298 units and 63.9292 units respectively. It can be concluded from this data that

(A) both isobars are stable

(B) Zn^{64} is radioactive decaying to Cu^{64} through β^- -decay

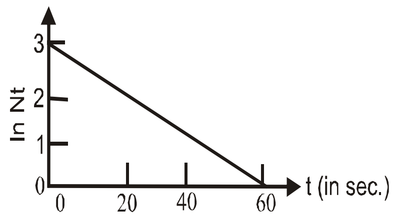
(C) Cu^{64} is radioactive decaying to Zn^{64} through γ-decay

(D) Cu^{64} is radioactive decaying to Zn^{64} through β^--decay

3. A nucleus ruptures into two nuclear parts which have their velocity ratio equal to 2 : 1. What will be the ratio of their nuclear sizes-

(A) $2^{1/3} : 1$ (B) $1 : 2^{1/3}$ (C) $3^{1/2} : 1$ (D) $1 : 3^{1/2}$

4. The graph (fig.) shows the number of particles N_t emitted per second by a radioactive source as a function of time t



(A) $N_t = 1000e^{-(20t/s)}$ (B) $N_t = 20e^{(20t/s)}$

(C) $N_t = 3e^{-(0.05t/s)}$ (D) $N_t = 20e^{-(0.05t/s)}$

5. The graph of log (R/R_0) versus A (R = radius of a nucleus and A = mass number) is

(A) a circle (B) an ellipse (C) a parabola (D) a straight line

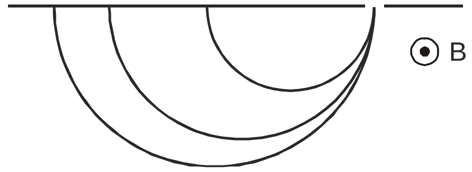
6. 90% of a radioactive sample is left undecayed after time t has elapsed. What percentage of the initialsample will decay in a total time 2t:

(A) 20% (B) 19% (C) 40% (D) 38%

7. Let a neutron hits a nucleus producing 5 neutrons. Assuming that all neutrons hit nuclei, without fail, what will be the number of neutrons produced after their n^{th} hit?

(A) 5^{n-1} (B) 5^n (C) $n \times 5$ (D) n^5

8. Protons and singly ionized atoms of U^{235} & U^{238} are passed in turn (which means one after the other and not at the same time) through a velocity selector and then enter a uniform magnetic field. The protons describe semicircles of radius 10 mm. The separation between the ions of U^{235} and U^{238} after describing semicircle is given by



(A) 60 mm (B) 30 mm (C) 2350 mm (D) 2380 mm

9. A free neutron decays to a proton but a free proton does not decay to a neutron. This is because

(A) neutron is a composite particle made of a proton and an electron whereas proton is fundamental particle
(B) neutron is an uncharged particle whereas proton is a charged particle
(C) neutron has larger rest mass than the proton
(D) weak forces can operate in a neutron but not in a proton.

10. The activity of a sample of radioactive material is A_1 at time t_1 and A_2 at time t_2 ($t_2 > t_1$). Its mean life is T then which relation is correct :

(A) $A_1t_1 = A_2t_2$ (B) $\frac{A_1 - A_2}{t_2 - t_1}$ = constant (C) $A_2 = A_1 e^{(t_1 - t_2/T)}$ (D) $A_2 = A_1 e^{(t_1/Tt_2)}$

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

(A) 13.8 days (B) 16.5 days
(C) 53 days (D) 76 days

12. A radioactive isotope is being produced at a constant rate A. The isotope has a half-life T. After a time t > > T, the number of nuclei become constant. The value of this constant is :

(A) $\frac{AT}{\ell n 2}$ (B) AT. ℓn 2 (C) $\frac{A}{T}\ell n 2$ (D) AT

13.

$$A \xrightarrow{\lambda_1} B \xrightarrow{\lambda_2} C$$

	A	B	C
t = 0	N_0	0	0
t	N_1	N_2	N_3

In the above radioactive decay C is stable nucleus. Then:

(A) rate of decay of A will first increase and then decrease
(B) number of nuclei of B will first increase and then decrease
(C) if $\lambda_2 > \lambda_1$, then activity of B will always be higher than activity of A
(D) if $\lambda_1 >> \lambda_2$, then number of nucleus of C will always be less than number of nucleus of B.

14. A fraction f_1 of a radioactive sample decays in one mean life, and a fraction f_2 decays in one half–life.
(A) $f_1 > f_2$
(B) $f_1 < f_2$
(C) $f_1 = f_2$
(D) May be (A), (B) or (C) depending on the values of the mean life and half life

15. Activity of a radioactive substance is R_1 at time t_1 and R_2 at time $t_2 (t_2 > t_1)$. Then the ratio $\frac{R_2}{R_1}$ is :

(A) $\frac{t_2}{t_1}$ (B) $e^{-\lambda(t_1+t_2)}$ (C) $e^{\left(\frac{t_1-t_2}{\lambda}\right)}$ (D) $e^{\lambda(t_1-t_2)}$

16. N atoms of a radioactive element emit n alpha particles per second at an instant. Then the half - life of the element is : (one alpha particle from one nucleus)

(A) $\frac{n}{N}$ sec. (B) 1.44 $\frac{n}{N}$ sec. (C) 0.69 $\frac{n}{N}$ sec. (D) 0.69 $\frac{N}{n}$ sec.

17. The activity of a sample reduces from A_0 to $A_0/\sqrt{3}$ in one hour. The activity after 3 more hours will be

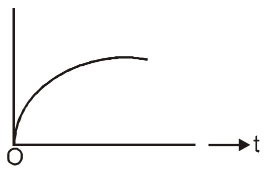
(A) $\frac{A_0}{3\sqrt{3}}$ (B) $\frac{A_0}{9}$ (C) $\frac{A_0}{9\sqrt{3}}$ (D) $\frac{A_0}{27}$

18. Radio carbon dating is done by estimating in the specimen :
(A) the amount of ordinary carbon still present
(B) the amount of radio carbon still present
(C) the ratio of the amounts of $^{14}_{6}C$ to $^{12}_{6}C$ still present
(D) none of the above

MULTIPLE CORRECT ANSWER(S) TYPE QUESTIONS

19. A nitrogen nucleus $_7N^{14}$ absorbs a neutron and can transform into lithium nucleus $_3Li^7$ under suitable conditions, after emitting :
(A) 4 protons and 3 neutrons
(B) 2 alpha particles and 2 gamma particles
(C) 1 alpha particle, 4 protons and 2 negative beta particles and 2 antineutrino
(D) 4 protons and 4 neutrons

20. For the graph shown in Figure, which of the following statements is/are possible ?



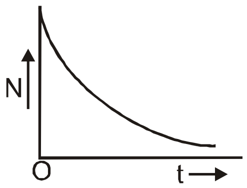
(A) y-axis shows number of nuclei of a radioactive element which is produced at a constant rate
(B) y-axis represents number of nuclei decayed in a radio nuclide
(C) y-axis represents activity of a radionuclide
(D) None of these

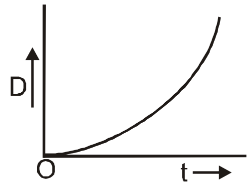
21. $_{92}U^{235}$ is α (alpha) active. Then in a large quantity of element :
(A) the probability of a nucleus disintegrating during one second is lower in the first half life and greater in the fifth half life
(B) the probability of a nucleus disintegrating during one second remains constant for all time
(C) quite an appreciable quantity of U^{235} will remain, even after the average life.
(D) the energy of the emitted 'α' particle is less than the disintegration energy of the U^{235} nucleus

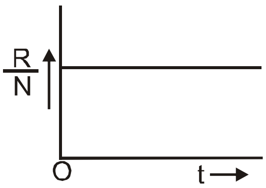
22. During radioactive decay -

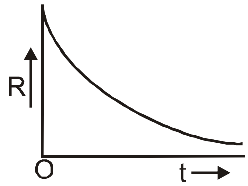
(A) atomic mass number cannot increase
(B) atomic number may increase
(C) atomic number may decrease
(D) atomic number may remain unchanged

23. A large population of radioactive nucleus starts disintegrating at t = 0. At time t, if N = number of parent nuclei present, D = the number of daughter nuclie present and R = rate at which the daughter nuclie are produced, then the correct representation will be :

(A) 

(B) 

(C) 

(D) 

24. 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 & M_2 the mass of a $^{40}_{20}$Ca nucleus. Then (B.E. per nucleons is more for Ca than Ne)

(A) $M_2 = 2\,M_1$
(B) $M_2 > 2\,M_1$
(C) $M_2 < 2\,M_1$
(D) $M_1 < 10\,(m_n + m_p)$

25. The heavier stable nuclei tend to have larger N/Z ratio because -

(A) a neutron is heavier than a proton
(B) a neutron is an unstable particle
(C) a neutron does not exert electric repulsion
(D) Coulomb forces have longer range compared to nuclear forces

PART - II : SUBJECTIVE QUESTIONS

1. A radioactive decay counter is switched on at t = 0. A β - active sample is present near the counter. The counter registers the number of β - particles emitted by the sample. The counter registers 64×10^5 β - particles at t = 36 s and 1×10^5 β - particles at t = 108 s.The $T_{1/2}$ of this sample is (10 + x) sec . Find x .

2. A wooden piece of great antiquity weighs 50 gm and shows C^{14} activity of 320 disintegrations per minute. The length of the time (in year) which has elapsed since this wood was part of living tree is 5.196×10^x find x ?, assuming that living plants show a C^{14} activity of 12 disintegrations per minute per gm. The half life of C^{14} is 5730 yrs.

3. U^{238} decays with a half life of 4.5×10^9 yrs, the decay series eventually ending at Pb^{206}, which is stable. A rock sample analysis shows that the ratio of the numbers of atoms of Pb^{206} to U^{238} is 0.5. Assuming that all the Pb^{206} has been produced by the decay of U^{238} and that all other half lives in the chain are negligible. Calculate the age of the rock sample.

4. A radioactive isotope is being produced at a constant rate dN/dt = R in an experiment .The isotope has a half-life $t_{1/2}$. Show that after a time $t >> t_{1/2}$, the number of active nuclei will become constant. Find the value of this constant. Suppose the production of the radioactive isotope starts at t = 0. Find the number of active nuclei at time t.

5. U^{238} and U^{235} occur in nature in an atomic ratio 140 : 1. Assuming that at the time of earth's formation the two isotopes were present in equal amounts. Calculate the age of the earth.
(Half life of U^{238} = 4.5×10^9 yrs & that of U^{235} = 7.13×10^8 yrs)

6. The kinetic energy of an α-particle which flies out of the nucleus of a Ra^{226} atom in radioactive disintegration is 4.78 MeV. Find the total energy evolved during the escape of the α-particle.

7. Knowing the decay constant λ of a substance, find the probability of decay of a nucleus during the time from 0 to t.

8. A neutron star has a density equal to that of the nuclear matter($\approx 3 \times 10^{17}$ kg/m^3). Assuming the star to be spherical, find the radius of a neutron star whose mass is (i) 4.0×10^{30} kg (twice the mass of the sun) (ii) 6×10^{24} Kg (around mass of the earth).

9. Find the energy required for separation of a $_{10}Ne^{20}$ nucleus into two α – particles and a $_6C^{12}$ nucleus if it is known that the binding energies per nucleon in $_{10}Ne^{20}$, $_2He^4$ and $_6C^{12}$ nuclei are equal to 8.03, 7.07 and 7.68 MeV respectively.

10. The kinetic energy of an α – particle which flies out of the nucleus of a Ra^{226} atom in radioactive disintegration is 4.78 MeV. Find the total energy evolved during the escape of the α – particle.

11. Beta decay of a free neutron takes place with a half life of 14 minutes. Then find (a) decay constant (b) energy liberated in the process.

12. Energy evolved from the fusion reaction $2\,{}_1^2H = {}_2^4He + Q$ is to be used for the production of power. Assuming the efficiency of the process to be 30 %. Find the mass of deuterium that will be consumed in a second for an output of 50 MW.

EXERCISE # 3

PART-I IIT-JEE (PREVIOUS YEARS PROBLEMS)

*** Marked Questions are having more than one correct option.**

1. The half-life period of a radioactive element X is same as the mean-life time of another radioactive element Y. Initially both of them have the same number of atoms. Then: **[JEE 1999, 2/200]**
(A) X and Y have the same decay rate initially (B) X and Y decay at the same rate always
(C) Y will decay at a faster rate than X (D) X will decay at a faster rate than Y

2. The order of magnitude of density of uranium nucleus is, ($m_p = 1.67 \times 10^{-27}$ kg) : **[JEE 1999, 2/200]**
(A) 10^{20} kg m^{-3} (B) 10^{17} kg m^{-3} (C) 10^{14} kg m^{-3} (D) 10^{11} kg m^{-3}

3. ^{22}Ne nucleus, after absorbing energy, decays into two α-particles and an unknown nucleus. The unknown nucleus is : **[JEE 1999, 2/200]**
(A) Nitrogen (B) Carbon (C) Boron (D) Oxygen

4. Two radioactive materials X_1 and X_2 have decay constants 10λ and λ respectively. If initially they have the 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. **[JEE 1999, 2/200]**

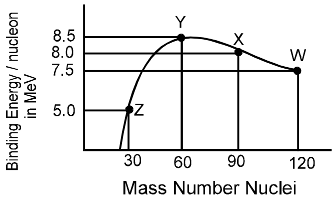
(A) $1/(10\lambda)$ (B) $1/(11\lambda)$ (C) $11/(10\lambda)$ (D) $1/(9\lambda)$

5. Which of the followings is a correct statement ?
(A) beta rays are same as cathode rays.
(B) gamma rays are high energy neutrons.
(C) alpha particles are singly-ionized helium atoms.
(D) protons and neutrons have exactly the same mass. **[JEE 1999, 2/200]**

6. The half-life of radioactive Polonium (Po) is 138.6 days. For ten lakh Polonium atoms, the number of disintegrations in 24 hours is - **[REE - 1999]**

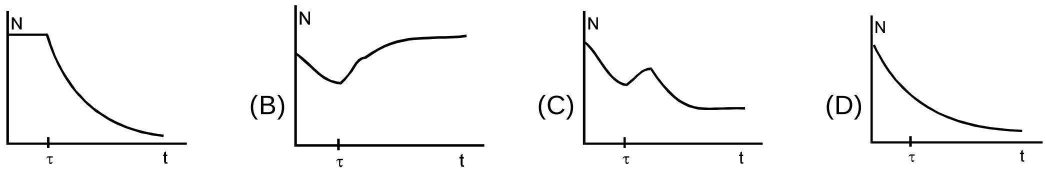
(A) 2000 (B) 3000 (C) 4000 (D) 5000

7. Binding energy per nucleon vs. mass number curve for nuclei is shown in the figure. W, X, Y and Z are four nuclei indicated on the curve. The process that would release energy is :



(A) $Y \rightarrow 2Z$ (B) $W \rightarrow X + Z$
(C) $W \rightarrow 2Y$ (D) $X \rightarrow Y + Z$ **[JEE 1999, 2/200]**

8. A radioactive sample consists of two distinct species having equal number of atoms initially. The mean life time of one species is τ and that of the other is 5τ. The decay products in both cases are stable. A plot is made of total number of radioactive nuclei as a function of time. Which of the following figures best represents the form of this plot? **[JEE 2001, 1/35]**



9. In a nuclear reactor ^{235}U undergoes fission liberating 200 MeV of energy. The reactor has a 10% efficiency and produces 1000 MW power. If the reactor is to function for 10 years, find the total mass of uranium required. **[JEE 2001, 5/100]**

10. A nucleus at rest undergoes a decay emitting an α-particle of de-Broglie wavelength, $\lambda = 5.76 \times 10^{-15}$ m. If the mass of the daughter nucleus is 223.610 a.m.u. and that of the α-particle is 4.002 a.m.u., determine the total kinetic energy in the final state. Hence, obtain the mass of the parent nucleus in a.m.u.
(1 a.m.u. = 931.470 MeV/c^2) **[JEE (Main) 2001, 5/100]**

11. A radioactive nucleus X decays to a nucleus Y with a decay constant $\lambda_X = 0.1\ \text{sec}^{-1}$. Y further decays to a stable nucleus Z with a decay constant $\lambda_Y = 1/30\ \text{sec}^{-1}$. Initially, there are only X nuclei and their number is $N_0 = 10^{20}$. Set up the rate equations for the populations of X, Y and Z. The population of the Y nucleus as a function of time is given by $N_Y(t) = \frac{N_0\lambda_X}{\lambda_X - \lambda_Y}\left[e^{-\lambda_Y t} - e^{-\lambda_X t}\right]$. Find the time at which N_Y is maximum and determine the population X and Z at that instant. **[JEE (Main) 2001, 5/100]**

12. (I) Which of the following processes represents a gamma decay?

(A) $^{A}X_{Z} + \gamma \longrightarrow {}^{A}X_{Z-1} + a + b$ (B) $^{A}X_{Z} + {}^{1}n_{0} \longrightarrow {}^{A-3}X_{Z-2} + c$

(C) $^{A}X_{Z} \longrightarrow {}^{A}X_{Z} + f$ (D) $^{A}X_{Z} + e_{-1} \longrightarrow {}^{A}X_{Z-1} + g$

(II) The half life of ^{215}At is 100 μs. The time taken for the radioactivity of a sample of ^{215}At to decay to 1/16th of its initial value is : **[JEE 2002 (Screening) 2 × 3, –1 = 6/90]**

(A) 400 μs (B) 6.3 μs (C) 40 μs (D) 300 μs

13. A nucleus with mass number 220 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 **[JEE 2003 (Screening) 3,–1/84]**

(A) 4.4 MeV (B) 5.4 MeV (C) 5.6 MeV (D) 6.5 MeV

14. For uranium nucleus how does its mass vary with volume? **[JEE 2003 (Screening) 3,–1/84]**

(A) $m \propto V$ (B) $m \propto 1/V$ (C) $m \propto \sqrt{V}$ (D) $m \propto V^2$

15. A radioactive material decays by β-particle emission. During the first 2 seconds of a measurement, *n* β-particles are emitted and the next 2 seconds 0.75 *n* β-particles are emitted. Calculate the mean-life of this material in seconds to the nearest whole number. ($\ell n\, 3 = 1.0986$ and $\ell n\, 2 = 0.6931$).**[JEE 2003 Main) 2/60]**

16. A 280 days old sample of a radioactive substance has activity of 6000 dps. In next 140 days activity falls to 3000 dps. Then initial activity of sample would have been **[JEE 2004 (Screening) 3, –1/84]**

(A) 9000 (B) 24000 (C) 12,000 (D) 18,000

17. The age of a rock containing lead and uranium is equal to 1.5×10^9 yrs. The uranium is decaying into lead with half life equal to 4.5×10^9 yrs. Find the ratio of lead to uranium present in the rock, assuming initially no lead was present in the rock. (Given $2^{1/3} = 1.259$) **[JEE 2004 (Main) 4/60]**

18. Helium nuclei combine to form an oxygen nucleus. The energy released in the reaction is if $m_O = 15.9994$ amu and $m_{He} = 4.0026$ amu **[JEE 2005 (Screening) 3/84]**

(A) 10.24 MeV (B) 0 MeV (C) 5.24 MeV (D) 4 MeV

19. Half life of a radio active substance 'A' is 4 days. The probability that a nucleus will decay in two half lives is:

(A) $\frac{1}{4}$ (B) $\frac{3}{4}$ (C) $\frac{1}{2}$ (D) 1 **[JEE 2006 3/184]**

20. **Match the following** **[JEE 2006 5/184]**

Column 1	**Column 2**
(A) Nuclear fission	(p) Converts some matter into energy
(B) Nuclear fusion	(q) Possible for nuclei with low atomic number
(C) β - decay	(r) Possible for nuclei with high atomic number
(D) Exothermic nuclear reaction	(s) Essentially proceeds by weak nuclear forces.

21. In the options given below, let E denote the rest mass energy of a nucleus and n a neutron. The correct options is : **[IIT-JEE 2007' 3/81]**

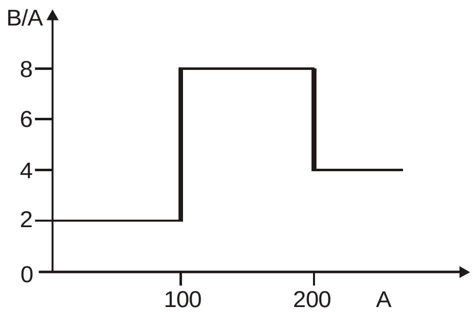
(A) $E\left({}^{236}_{92}U\right) > E\left({}^{137}_{53}I\right) + E\left({}^{97}_{39}Y\right) + 2E(n)$ (B) $E\left({}^{236}_{92}U\right) < E\left({}^{137}_{53}I\right) + E\left({}^{97}_{39}Y\right) + 2E(n)$

(C) $E\left({}^{236}_{92}U\right) < E\left({}^{140}_{56}Ba\right) + \left({}^{94}_{36}Kr\right) + 2E(n)$ (D) $E\left({}^{236}_{92}U\right) = E\left({}^{140}_{56}Ba\right) + E\left({}^{94}_{36}Kr\right) + 2E(n)$

22. Some laws / processes are given in **Column I**. Match these with the physical phenomena given in **Column II** and indicate your answer by darkening appropriate bubbles in the 4 × 4 matrix given in the ORS. **[IIT-JEE 2007' 6/81]**

	Column I		**Column II**
(A)	Transition between two atomic energy levels	(p)	Characteristic X-rays
(B)	Electron emission from a material	(q)	Photoelectric effect
(C)	Mosley's law	(r)	Hydrogen spectrum
(D)	Change of photon energy into kinetic energy of electrons	(s)	β-decay

23. Assume that the nuclear binding energy per nucleon (B/A) versus mass number (A) is as shown in the figure. Use this plot to choose the correct choice(s) given below. **[JEE 2008, 4/163]**
Figure :



(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 200 < A < 260 will release energy when broken into two equal fragments

24. A radioactive sample S_1 having an activity of 5μCi has twice the number of nuclei as another sample S_2 which has an activity of 10μCi. The half lives of S_1 and S_2 can be **[JEE 2008, 3/163]**
(A) 20 years and 5 years, respectively
(B) 20 years and 10 years, respectively
(C) 10 years each
(D) 5 years each

Paragraph for Question Nos. 25 to 27 **[JEE 2009, 4/160, –1]**

Scientists are working hard to develop nuclear fusion reactor. Nuclei of heavy hydrogen, ${}_1^2H$, known as deuteron and denoted by D, can be thought of as a candidate for fusion reactor. The D-D reaction is ${}_1^2H + {}_1^2H \rightarrow {}_2^3He + n + \text{energy}$. In the core of fusion reactor, a gas of heavy hydrogen is fully ionized into deuteron nuclei and electrons. This collection of ${}_1^2H$ nuclei and electrons is known as plasma. The nuclei move randomly in the reactor core and occasionally come close enough for nuclear fusion to take place. Usually, the temperatures in the reactor core are too high and no material wall can be used to confine the plasma. Special techniques are used which confine the plasma for a time t_0 before the particles fly away from the core. If n is the density (number/volume) of deuterons, the product nt_0 is called Lawson number. In one of the criteria, a reactor is termed successful if Lawson number is greater than 5×10^{14} s/cm^3.

It may be helpful to use the following: Boltzman constant $k = 8.6\times10^{-5}$ eV/K ; $\frac{e^2}{4\pi\varepsilon_0} = 1.44 \times 10^{-9}$ eVm.

25. In the core of nuclear fusion reactor, the gas becomes plasma because of

(A) strong nuclear force acting between the deuterons

(B) Coulomb force acting between the deuterons

(C) Coulomb force acting between deuterons-electrons pairs

(D) the high temperature maintained inside the reactor core

26. Assume that two deuteron nuclei in the core of fusion reactor at temperature T are moving towards each other, each with kinetic energy 1.5 kT, when the separation between them is large enough to neglect Coulomb potential energy. Also neglect any interaction from other particles in the core. The minimum temperature T required for them to reach a separation of 4×10^{-15} m in the range.

(A) 1.0×10^9 K < T < 2.0×10^9 K

(B) 2.0×10^9 K < T < 3.0×10^9 K

(C) 3.0×10^9 K < T < 4.0×10^9 K

(D) 4.0×10^9 K < T < 5.0×10^9 K

27. Results of calculations for four different designs of a fusion reactor using D-D reaction are given below. Which of these is most promising based on Lawson criterion ?

(A) deuteron density = 2.0×10^{12} cm^{-3}, confinement time = 5.0×10^{-3} s

(B) deuteron density = 8.0×10^{14} cm^{-3}, confinement time = 9.0×10^{-1} s

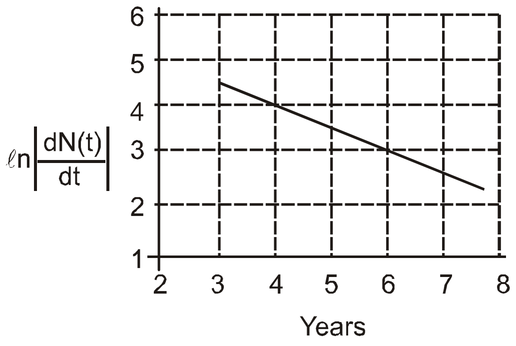
(C) deuteron density = 4.0×10^{23} cm^{-3}, confinement time = 1.0×10^{-11} s

(D) deuteron density = 1.0×10^{24} cm^{-3}, confinement time = 4.0×10^{-12} s

28. **Column II** gives certain systems undergoing a process. **Column I** suggests changes in some of the parameters related to the system. Match the statements in **Column-I** to the appropriate process(es) from **Column II**. **[JEE 2009,8/160]**

Column–I	Column–II
(A) The energy of the system is increased.	(p) System: A capacitor, initially uncharged Process: It is connected to a battery.
(B) Mechanical energy is provided to the system, which is converted into energy of random motion of its parts	(q) System: A gas in an adiabatic container fitted with an adiabatic piston Process: The gas is compressed by pushing the piston
(C) Internal energy of the system is converted into its mechanical energy	(r) System: A gas in a rigid container Process: The gas gets cooled due to colder atmosphere surrounding it
(D) Mass of the system is decreased	(s) System: A heavy nucleus, initially at rest Process: The nucleus fissions into two fragments of nearly equal masses and some neutrons are emitted
	(t) System: A resistive wire loop Process: The loop is placed in a time varying magnetic field perpendicular to its plane

29. To determine the half life of a radioactive element, a student plots a graph of $\ell n\left|\frac{dN(t)}{dt}\right|$ versus t. Here $\frac{dN(t)}{dt}$ is the rate of radioactive decay at time t. If the number of radioactive nuclei of this element decreases by a factor of p after 4.16 years, the value of p is : **[JEE 2010, 3/163]**



30. The activity of a freshly prepared radioactive sample is 10^{10} disintegrations per second, whose mean life is 10^9s. The mass of an atom of this radioisotope is 10^{-25} kg. The mass (in mg) of the radioactive sample is :

Paragraph for Questions 31 and 32

The β-decay process, discovered around 1900, is basically the decay of a neutron (n). In the laboratory, a proton (p) and an electron (e^-) are observed as the decay products of the neutron. Therefore, considering the decay of a neutron as a two-body decay process, it was predicted theoretically that the kinetic energy of the electron should be a constant. But experimentally, it was observed that the electron kinetic energy has a continuous spectrum. Considering a three-body decay process, i.e. $n \rightarrow p + e^- + \bar{v}_e$, aroung 1930, Puli explained the observed electron energy spectrum. Assuming the anti-neutrino $(\bar{v}_e)$ to be massless and possessing negligible energy, and the neutron to be rest, momentum and energy conservation principles are applied. From this calculation, the maximum kinetic energy of the electron is 0.8×10^6 eV. The kinetic energy carried by the proton is only the recoil energy.

31. What is the maximum the energy of the anti-neutrino ? **[JEE 2012 (3, –1)/136]**

(A) Zero
(B) Much less than 0.8×10^6 eV
(C) Nearly 0.8×10^6 eV
(D) Much larger than 0.8×10^6 eV

32. If the anti-neutrino had a mass of 3 eV/c^2 (where c is the speed of light) instead of zero mass, what should be the range of the kinetic energy, K, of the electron ? **[JEE 2012 (3, –1)/136]**

(A) $0 < K \leq 0.8 \times 10^6$ eV
(B) $3.0 \text{ eV} \leq K \leq 0.8 \times 10^6$ eV
(C) $3.0 \text{ eV} \leq K < 0.8 \times 10^6$ eV
(D) $0 \leq K < 0.8 \times 10^6$ eV

33. A freshly prepared sample of a radioisotope of half-life 1386 s has activity 10^3 disintegrations per second. Given that In 2 = 0.693, the fraction of the initial number of nuclei (expressed in nearest integer percentage) that will decay in the first 80 s after preparation of the sample is : **[JEE Advanced (P-1) 2013]**

Paragraph for Questions 34 and 35

The mass of a nucleus $_Z^AX$ is less than the sum of the masses of (A–Z) number of neutrons and Z number of protons in the nucleus. The energy equivalent to the corresponding mass difference is known as the binding energy of the nucleus. A heavy nucleus of mass M can break into two light nuclei of masses m_1 and m_2 only if $(m_1 + m_2) < M$. Also two light nuclei of masses m_3 and m_4 can undergo complete fusion and form a heavy nucleus of mass M' only if $(m_3 + m_4) > M'$. The masses of some neutral atoms are given in the table below : **[JEE Advanced (P-2) 2013]**

$_1^1H$	1.007825u	$_1^2H$	2.014102 u	$_1^3H$	3.016050 u	$_2^4He$	4.002603 u
$_3^6Li$	6.015123 u	$_3^7Li$	7.016004 u	$_{30}^{70}Zn$	69.925325 u	$_{34}^{82}Se$	81.916709u
$_{64}^{152}Gd$	151.919803u	$_{82}^{206}Pb$	205.974455 u	$_{83}^{209}Bi$	208.980388 u	$_{84}^{210}Po$	209.982876u

(1 u = 932 MeV/c^2)

34. The kinetic energy (in keV) of the alpha particle, when the nucleus $_{84}^{210}Po$ at rest undergoes alpha decay, is:

(A) 5319 (B) 5422 (C) 5707 (D) 5818

35. The correct statement is :

(A) The nucleus $_3^6Li$ can emit an alpha particle.

(B) The nucleus $_{84}^{210}Po$ can emit a proton.

(C) Deuteron and alpha particle can undergo complete fusion.

(D) The nuclei $_{30}^{70}Zn$ and $_{34}^{82}Se$ can undergo complete fusion.

36. Match List-I of the nuclear processes with List-II containing parent nucleus and one of the end products of each process and then select the correct answer using the codes given below the lists :

[JEE Advanced (P-2) 2013]

List-I	List-II
P. Alpha decay	**1.** $_8^{15}O \longrightarrow _7^{15}N + ...$
Q. β^+ decay	**2.** $_{92}^{238}U \longrightarrow _{90}^{234}Th + ...$
R. Fission	**3.** $_{83}^{185}Bi \longrightarrow _{82}^{184}Pb + ...$
S. Proton emission	**4.** $_{94}^{239}Pu \longrightarrow _{57}^{140}La + ...$

Codes :

	P	Q	R	S
(A)	4	2	1	3
(B)	1	3	2	4
(C)	2	1	4	3
(D)	4	3	2	1

PART-II AIEEE (PREVIOUS YEARS PROBLEMS)

*** Marked Questions are having more than one correct option.**

1. If N_0 is the original mass of the substance of half-life period $t_{1/2}$ = 5 years, then the amount of substance left after 15 years is : **[AIEEE 2002 4/300]**

(1) $N_0/8$ (2) $N_0/16$ (3) $N_0/2$ (4) $N_0/4$

2. Which of the following radiations has the least wavelength? **[AIEEE 2003 4/300]**

(1) γ-rays (2) β-rays (3) α-rays (4) X-rays

3. 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 : **[AIEEE 2003 4/300]**

(1) $\frac{4u}{238}$ (2) $-\frac{4u}{234}$ (3) $\frac{4u}{234}$ (4) $-\frac{4u}{238}$

4. A radioactive sample at any instant has its disintegration rate 5000 disintegrations per minute. After 5 minutes, the rate is 1250 disintegrations per minute. Then, the decay constant (per minute) is : **[AIEEE 2003 4/300]**

(1) 0.4 ln 2 (2) 0.2 ln 2 (3) 0.1 ln 2 (4) 0.8 ln 2

5. A nucleus with Z = 92 emits the following in a sequence : $\alpha, \alpha, \beta^-, \beta^-, \alpha, \alpha, \alpha, \alpha; \beta^-, \beta^-, \alpha, \beta^+, \beta^+, \alpha$. The Z of the resulting nucleus is : **[AIEEE 2003 4/300]**

(1) 76 (2) 78 (3) 82 (4) 74

6. Which of the following cannot be emitted by radioactive substances during their decay? **[AIEEE 2003 4/300]**

(1) Protons (2) Neutrinos (3) Helium nuclei (4) Electrons

7. In the nuclear fusion reaction, **[AIEEE 2003 4/300]**

$$^2_1H + ^3_1H \longrightarrow ^4_2He + n$$

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 = 1.38×10^{-23} J/K]:

(1) 10^7 K (2) 10^5 K (3) 10^3 K (4) 10^9 K

8. A nucleus disintegrates into two nuclear parts which have their velocities in the ratio 2 : 1. The ratio of their nuclear sizes will be : **[AIEEE 2004 4/300]**

(1) $2^{1/3} : 1$ (2) $1 : 3^{1/2}$ (3) $3^{1/2} : 1$ (4) $1 : 2^{1/3}$

9. The binding energy per nucleon of deuteron $\left(^2_1H\right)$ and helium nucleus $\left(^4_2He\right)$ is 1.1 MeV and 7 MeV respectively. If two deuteron nuclei react to form a single helium nucleus, then the energy released is : **[AIEEE 2004 4/300]**

(1) 13.9 MeV (2) 26.9 MeV (3) 23.6 MeV (4) 19.2 MeV

10. An α-particle of energy 5 MeV is scattered through 180º by a fixed uranium nucleus. The distance of the closest approach is of the order of : **[AIEEE 2004 4/300]**

(1) 1 Å (2) 10^{-10} cm (3) 10^{-12} cm (4) 10^{-15} cm

11. The intensity of gamma radiation from a given source is I. On passing through 36 mm of lead, it is reduced to 1/8. The thickness of lead, which will reduce the intensity to 1/2 will be : **[AIEEE 2005 4/300]**

(1) 6 mm (2) 9 mm (3) 18 mm (4) 12 mm

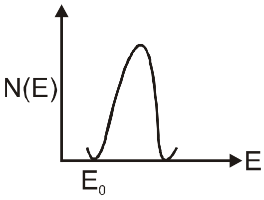
12. Starting with a sample of pure ^{66}Cu, 7/8 of it decays into Zn in 15 minutes. The corresponding half-life is : **[AIEEE 2005 4/300]**

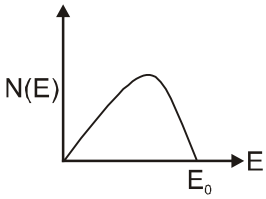
(1) 10 minute (2) 15 minute (3) 5 minute (4) $7\frac{1}{2}$ minute

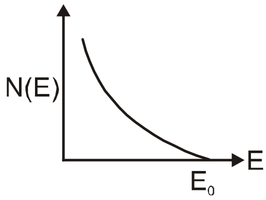
13. If radius of the $^{27}_{13}Al$ nucleus is estimated to be 3.6 Fermi, then the radius of $^{125}_{52}Te$ nucleus be nearly :
[AIEEE 2005 4/300]
(1) 6 Fermi (2) 8 Fermi (3) 4 Fermi (4) 5 Fermi

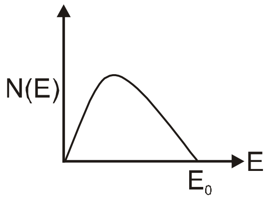
14. A nuclear transformation is denoted by $X(n, \alpha) \rightarrow {}^{7}_{3}Li$. Which of the following is the nucleus of element X?
(1) $^{12}_{6}C$ (2) $^{10}_{5}B$ (3) $^{9}_{5}B$ (4) $^{11}_{4}Be$ **[AIEEE 2005 4/300]**

15. The energy spectrum of β-particles [number N(E) as a function of β-energy E] emitted from a radioactive source is : **[AIEEE 2006 3/180, –1]**

(1) 

(2) 

(3) 

(4) 

16. When $_3Li^7$ nuclei are bombarded by protons, and the resultant nuclei are $_4Be^8$, the emitted particles will be : **[AIEEE 2006 4.5/180]**
(1) neutrons (2) alpha particles (3) beta particles (4) gamma photons

17. The 'rad' is the correct unit used to report the measurement of **[AIEEE 2006 4.5/180]**
(1) the rate of decay of radioactive source
(2) the ability of a beam of gamma ray photons to produce ions in a target
(3) the energy delivered by radiation to a target.
(4) the biological effect of radiation

18. If the binding energy per nucleon in $^{7}_{3}Li$ and $^{4}_{2}He$ nuclei are 5.60 MeV and 7.06 MeV respectively, then in the reaction

$$p + {}^{7}_{3}Li \rightarrow 2\,{}^{4}_{2}He$$

energy of proton must be : **[AIEEE 2006 4.5/180]**
(1) 39.2 MeV (2) 28.24 MeV (3) 17.28 MeV (4) 1.46 MeV

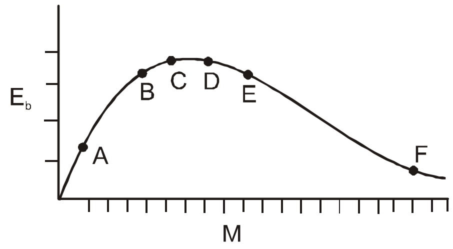
19. If M_o is the mass of an oxygen isotope $_8O^{17}$, M_p and M_N are the masses of a proton and a neutron respectively, the nuclear binding energy of the isotope is : **[AIEEE 2007]**
(1) $(M_o - 8M_P)C^2$ (2) $(M_o - 8M_P - 9M_N)C^2$ (3) M_oC^2 (4) $(M_o - 17M_N)C^2$

20. In gamma ray emission from a nucleus : **[AIEEE 2007 3/120, –1]**
(1) both the neutron number and the proton number change
(2) there is no change in the proton number and the neutron number
(3) only the neutron number changes
(4) only the proton number changes

21. The half-life period of a radio-active element X is same as the mean life time of another radio-active element Y. Initially they have the same number of atoms. Then : **[AIEEE 2007 3/120, –1]**
(1) X will decay faster than Y (2) Y will decay faster than X
(3) X and Y have same decay rate initially (4) X and Y decay at same rate always

22. This question contains Statement-1 and Statement-2. Of the four choices given after the statements, choose the one that best describes the two statements. **[AIEEE 2008 3/105, –1]**
Statement-1 : Energy is released when heavy nuclei undergo fission or light nuclei undergo fusion.
and
Statement-2 :
For heavy nuclei, binding energy per nucleon increases with increasing Z while for light nuclei it decreases with increasing Z.
(1) Statement-1 is true, Statement-2 is true; Statement-2 is a correct explanation for Statement-1
(2) Statment-1 is true, Statement-2 is true; Statement-2 is not a correct explanation for Statement-1
(3) Statement-1 is true, Statement-2 is false
(4) Statement-1 is false, Statement-2 is true

23.



The above is a plot of binding energy per nucleon E_b, agains the nuclear mass M; A, B, C, D, E, correspond to different nuclei. Consider four reactions : **[AIEEE 2009 4/144]**

(i) $A + B \rightarrow C + \varepsilon$ (ii) $C \rightarrow A + B + \varepsilon$ (iii) $D + E \rightarrow F + \varepsilon$ and (iv) $F \rightarrow D + E + \varepsilon$,

where ε is the energy released? In which reactions is ε positive?

(1) (i) and (iii) (2) (ii) and (iv) (3) (ii) and (iii) (4) (i) and (iv)

Directions : Question number 24 – 26 are based on the following paragraph.

The nucleus of mass $M + \Delta m$ is at rest and decays into two daughter nuclei of equal mass $\frac{M}{2}$ each.. Speed of light is c. **[AIEEE 2010 3/144, –1]**

24. This binding energy per nucleon for the parent nucleus is E_1 and that for the daughter nuclei is E_2. Then :

(1) $E_1 = 2E_2$ (2) $E_1 > E_2$ (3) $E_2 > E_1$ (4) $E_2 = 2E_1$

25. The speed of daughter nuclei is

(1) $c\,\frac{\Delta m}{M + \Delta m}$ (2) $c\sqrt{\frac{2\Delta m}{M}}$ (3) $c\sqrt{\frac{\Delta m}{M}}$ (4) $c\sqrt{\frac{\Delta m}{M + \Delta m}}$

26. 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

(1) $\frac{A - Z - 8}{Z - 4}$ (2) $\frac{A - Z - 4}{Z - 8}$ (3) $\frac{A - Z - 12}{Z - 4}$ (4) $\frac{A - Z - 4}{Z - 2}$

27. The half life of a radioactive substance is 20 minutes. The approximate time interval $(t_2 - t_1)$ between the time t_2 when $\frac{2}{3}$ of it has decayed an time t_1 when $\frac{1}{3}$ of it had decayed is : **[AIEEE 2011 3/144, –1]**

(1) 7 min (2) 14 min (3) 20 min (4) 28 min

28. Assume that a neutron breaks into a proton and an electron. The energy released during this process is : (mass of neutron = 1.6725×10^{-27} kg, Mass of proton = 1.6725×10^{-27} kg, mass of electron = 9×10^{-31}kg)

[AIEEE 20012 4/120, –1]

(1) 0.73 MeV (2) 7.10 MeV (3) 6.30 MeV (4) 5.4 MeV

NCERT QUESTIONS

1. Obtain the binding energy of a nitrogen nucleus ($^{14}_{7}N$) from the following data:
m_H = 1.00783 u m_n = 1.00867 u m_N = 14.00307 u
Give your answer in MeV.

2. A given coin has a mass of 3.0 g. Calculate the nuclear energy that would be required to separate all the neutrons and protons from each other. For simplicity assume that the coin is entirely made of $^{63}_{29}$Cuatoms (of mass 62.92960 u) . The masses of proton and neutron are 1.00783 u and 1.00867 u, respectively.

3. Obtain the binding energy of the nuclei $^{56}_{26}$Fe and $^{207}_{83}$Bi in units of MeV from the following data:
m_H = 1.007825 u m_n = 1.008665 u m($^{56}_{26}$Fe) = 55.934939 u
m ($^{207}_{83}$Bi) =208.980388u
Which nucleus has greater binding energy per uncleon ?

4. Write nuclear equations for:
(a) the α -decay of $^{226}_{88}$Ra (b) the β^--decay of $^{32}_{15}$P (c) the β^+–decay of $^{11}_{6}$C

5. Obtain the amount of $^{60}_{17}$Co necessary to provide a radioactive source of 8.0 mCi strength. The half-life of $^{60}_{17}$Co is 5.3 years.

6. The nucleus $^{23}_{10}$Ne decays by β^- emission. Write down the β -decay equation and determine the maximum kinetic energy of the electrons emitted. Given that : m($^{23}_{10}$Ne) = 22.994466 u ; m ($^{23}_{11}$Na) = 22.989770 u.

7. The Q value of a nuclear reaction A + b $\rightarrow$ C + d is defined by $Q = [m_A + m_b - m_C - m_d]c^2$ Where the masses refer ot nuclear rest masses. Determine from the given data whether the following reactions are exothermic or endothermic.
(i) $^{1}_{1}H + ^{3}_{1}H \rightarrow ^{2}_{1}H + ^{2}_{1}H$ (ii) $^{12}_{6}C + ^{12}_{6}C \rightarrow ^{20}_{10}Ne + ^{4}_{2}He$
Atomic masses are given to be
m ($^{1}_{1}$H) = 1.007825 u m ($^{2}_{1}$H) =2.014102 u m ($^{3}_{1}$H) = 3.016049 u
m ($^{12}_{6}$C) = 12.000000 u m ($^{20}_{10}$Ne) = 19.991439 u m($^{4}_{2}$He) = 4.002603 u

8. The fission properties of $^{239}_{94}$Pu are very simply to those $^{235}_{92}$U. The average energy released per fission is 180 MeV. How much energy, in MeV, is released if all the atoms in 1kg of pure $^{239}_{94}$Pu undergo fission ?

9. In a periodic Table the average atomic mass of mabnesium is gven as 24.312 u. The average value is based on their relative natural abundance on Earth. The three isotopes and their masses are $^{24}_{12}$Mg (23.98504), $^{25}_{12}$Mg (24.98584) and $^{26}_{12}$Mg (52.98259 u). The natural abundance of $^{24}_{12}$Mg is 78.99% by mass. Calculate the abundances of the other two isotopes.

10. The neutron separation energy is defined as the energy required to remove a neutron from the nucleus. Obtain the enutron separation energies of the nuclei $^{41}_{20}$Ca and $^{27}_{13}$Al from the following data:
m = 1.008665 u ; m ($^{40}_{20}$Ca) = 39.962591 u ; m ($^{41}_{20}$Ca) = 40.962278 u ;
m($^{26}_{13}$Al = 25.986895 u ; m ($^{27}_{13}$Al) = 26.981541 u.

11. A source contains two phosphorous radionunclides $^{32}_{15}$P ($T_{1/2}$ = 14.3 d) and $^{33}_{15}$P ($T_{1/2}$ = 25.3 d.) Initiallly, 10% of the decays come from $^{33}_{15}$P. How long one must wait until 90% do so ?

12. Consider the D-T reaction (deuterium-tritium fusion) given in Eq. (14.40).
(a) Calculate the energy released in MeV in this reaction from the data;
m ($^{2}_{1}$H) = 2.014102 u ; m ($^{3}_{1}$H) = 3.016049 u ; m ($^{4}_{2}$He) = 4.002603 u ; m_n = 1.00867 u
(b) Consider the radius of both deuterium and tritium to be approximately 1.5 fm. What is the kinetic energy needed to overcome the Coulomb repulsion? To what temperature must the gases be heated to initiate the reaction ?

ANSWERS

Exercise # 1

PART-I

A-1.	(C)	**A-2.**	(C)	**A-3.**	(B)	**A-4.**	(A)	**A-5.**	(B)	**B-1.***	(AC)	**B-2.**	(B)
B-3.	(A)	**B-4.**	(C)	**B-5.**	(B)	**B-6.**	(D)	**B-7.**	(C)	**B-8.**	(D)	**B-9.**	(A)
B-10.	(D)	**C-1.**	(D)	**C-2.**	(D)	**C-3.**	**(i)** (C),	**(ii)** (B)		**C-4.**	(C)	**C-5.**	(C)
C-6.	(B)	**C-7.**	(D)	**C-8.**	(B)	**C-9.**	(A)	**C-10.**	(A)	**C-11.**	(C)	**C-12.**	(A)
D-1.	(B)	**D-2.**	(C)	**D-3.**	(C)	**D-4.**	(D)	**D-5.**	(B)	**D-6.**	(B)	**D-7.**	(A)

PART-II

1. (B) **2.** (B) **3.** (B) **4.** (B) **5.** (C) **6.** (A)

7. A $\rightarrow$ q ; B $\rightarrow$ s ; C $\rightarrow$ r ; D $\rightarrow$ s

8. (A) $\rightarrow$ q,r,s (B) $\rightarrow$ q,r,s (C) $\rightarrow$ q,r,s (D) $\rightarrow$ p,q,r,s

9. (i) False, (ii) True, (iii) True, (iv) True, (v) True

10. (i) 0.7, (ii) $_7O^{17}$, 17, (iii) neutrons, fast, slow, (iv) 23.6 MeV,

(v) In the nuclear process, $_6C^{11} \rightarrow {_5B^{11}} + \beta^+ + X$, X stands for ....

(vi) ^1_0n neutron, (vii) nuclear fusion

Exercise # 2

PART-I

1.	(C)	**2.**	(D)	**3.**	(B)	**4.**	(D)	**5.**	(D)	**6.**	(B)	**7.**	(B)
8.	(A)	**9.**	(C)	**10.**	(C)	**11.**	(B)	**12.**	(A)	**13.**	(B)	**14.**	(A)
15.	(D)	**6.**	(D)	**17.**	(B)	**18.**	(C)	**19.**	(BCD)	**20.**	(AB)	**21.**	(BCD)
22.	(ABCD)	**23.**	(ACD)	**24.**	(CD)	**25.**	(CD)						

PART-II

1. x = 2 **2.** x = 3 **3.** 2.63×10^9 years

4. $\frac{Rt_{1/2}}{\ell n2}$; $\frac{R}{\lambda}(1-e^{-\lambda t})$ **5.** 6.04×10^9 year **6.** 4.87 MeV

7. $P = 1 - e^{-\lambda t}$

8. (i) $r_1 = \left[\frac{4\times10^{30}}{3\times10^{17}}\times\frac{3}{4\pi}\right]^{1/3}$ = 14.71 km (ii) $r_2 = \left[\frac{6\times10^{24}}{3\times10^{17}}\times\frac{3}{4\pi}\right]^{1/3}$ = 168.4 m

9. E = 20 × (8.03) – 2×4 (7.07) – 12(7.68) = 11.9 MeV **10.** $\frac{226}{222}\times 4.78$ = 4.87 MeV.

11. (a) $\frac{0.693}{14\times 60}$ = 8.25 × 10^{-4} s^{-1} (b) $(m_n - m_p - m_e)$ 931 = 782 keV

12. $\frac{2}{Q}\times\frac{100}{30}\times\frac{(50\times 10^{6})}{1.6\times 10^{-19}}\times\frac{2}{N_A}\times 10^{-3}\text{Kg}$ = 2.9 × 10^{-13} kg ;

where Q = $(2M_{_1H^2} - M_{_2He^4})$ × 931 = 23.834531 MeV

Exercise # 3

PART-I

1. (C) **2.** (B) **3.** (B) **4.** (D) **5.** (A) **6.** (D) **7.** (C)

8. (D) **9.** 3.847 × 10^4 Kg **10.** 6.25 MeV, 227.62 a.m.u.

11. (i) $\frac{dN_X}{dt} = -\lambda_X N_X$, $\frac{dN_Y}{dt} = \lambda_X N_X - \lambda_Y N_Y$, $\frac{dN_Z}{dt} = \lambda_Y N_Y$, (ii) 16.48 s, (iii) N_X = 1.92 × 10^{19}, N_Z = 1.32 × 10^{19}

12. (I) (C), (II) (A) **13.** (B) **14.** (A) **15.** 6.954 sec **16.** (B)

17. 0.259 **18.** (A) **19.** (B)

20. (A) → (p) and (r), (B) → (p) and (q), (C) → (p) , (q) , (r) and (s) (D) → (p) , (q) and (r)

21. (A) **22.** (A) → (p), (r); (B) → (q), (s); (C) → (p); (D) → (q) **23.** (B) & (D)

24. **(A)** **25.** (D) **26.** (A) **27.** (B) **28.** (A) p, q, t ; (B) q, t ; (C) s, (D) s

29. 8 **30.** 1 **31.** (C) **32.** **(D)** **33.** 4 **34.** (A) **35.** (C)

36. (C)

PART-II

1. (1) **2.** (1) **3.** (3) **4.** (1) **5.** (2) **6.** (1) **7.** (4)

8. (4) **9.** (3) **10.** (3) **11.** (4) **12.** (3) **13.** (1) **14.** (2)

15. (4) **16.** (4) **17.** (4) **18.** (3) **19.** (2) **20.** (2) **21.** (2)

22. (3) **23.** (4) **24.** **(3)** **25.** (2) **26.** (2) **27.** (3) **28.** (1)

Exercise # 4

1. 104.7 meV

2. 1.6×10^{25} MeV : 1 gram-mole of a substance contains of 6×10^{23} atoms.

3. $1\ u = 1.660565 \times 10^{-27}$ kg
$1\ u \times c^2 \cong 931.5$ MeV
Using the formula for binding energy given in Section 14.4, we get

$$\text{B.E.}\ ({}^{56}_{26}\text{Fe}) = 492.26\ \text{MeV}$$
B.E. per nucleon = 8.79 MeV
$$\text{B.E.}\ ({}^{209}_{83}\text{Bi}) = 1640.30\ \text{MeV}$$

${}^{56}_{26}\text{Fe}$ has greater binding energy per nucleon.

4. ${}^{226}_{88}\text{Ra} \to {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{He}$, ${}^{32}_{15}\text{P} \to {}^{32}_{16}\text{S} + e^- + \bar{\nu}$, ${}^{11}_{6}\text{P} \to {}^{11}_{5}\text{B} + e^+ + n$

5. 7.1 mg

6. ${}^{23}_{10}\text{Ne} \to {}^{23}_{11}\text{Na} + e^- + \bar{\nu} + Q$

$$Q = [m_N({}^{23}_{10}\text{Ne}) - m_N({}^{23}_{11}\text{Na}) - m_e]\ c^2$$
where the neutrino mass has been neglected. Thus,
$$Q = [m({}^{23}_{10}\text{Ne}) - 10m_e - m({}^{23}_{11}\text{Na}) + 11m_e - m_e]\ c^2$$
$$= [m({}^{23}_{10}\text{Ne}) - m({}^{23}_{11}\text{Na})]\ c^2$$
$$= 4.374\ \text{MeV}$$
This is the maximum energy of the β^- emitted.

7. (i) $Q = [m_N({}^{1}_{1}\text{H}) + m_N({}^{3}_{1}\text{H}) - 2m_N({}^{2}_{1}\text{H})]c^2$
$$= [m({}^{1}_{1}\text{H}) + m({}^{3}_{1}\text{H}) - 2m({}^{2}_{1}\text{H})]c^2$$
$$= -4.03\ \text{MeV}$$
(ii) $Q = [m_N({}^{12}_{6}\text{C}) - m_N({}^{20}_{10}\text{Ne}) - m_N({}^{4}_{2}\text{He})]c^2$
Reaction (i) is endothermic, while reaction (ii) is exothermic.

8. 4.5×10^{23} MeV

9. ${}^{25}\text{Mg}$: 9.303%; ${}^{26}\text{Mg}$: 11.71%

10. Neutron separation energy S_n of nucleus ${}^{A}_{Z}X$ given by
$$S_n = [m_N({}^{A-1}_{Z}X) + m_N({}^{A}_{Z}X)]\ c^2$$
From the given data, using $c^2 = 931.5$ MeV/u, we get
$$S_n = ({}^{41}_{20}\text{Ca}) = 8.36\ \text{MeV}$$
$$S_n({}^{27}_{13}\text{Al}) = 13.06\ \text{MeV}$$

11. 209 d

12. (a) For the process ${}^{2}_{1}\text{H} + {}^{3}_{1}\text{H} \to {}^{4}_{2}\text{He} + n + Q$
$$Q = [m_N({}^{2}_{1}\text{H}) + m_N({}^{3}_{1}\text{H}) - m_N({}^{4}_{2}\text{He}) - m_n]\ c^2$$
$$= [m({}^{2}_{1}\text{H}) + m({}^{3}_{1}\text{H}) - m_N({}^{4}_{2}\text{He}) - m_n]\ c^2$$
$$= 17.59\ \text{MeV}$$
(b) Repulsive potential of two nuclei when they almost touch each other
$$= \frac{q^2}{4\pi\varepsilon_0 d} \qquad = \frac{9\times10^9 \times (1.6\times10^{-19})}{2\times1.5\times10^{-15}}\ \text{J}$$
$$= 7.68\ \text{J}$$