UNIT-VIII ATOMS AND NUCLEI

FORMULA AT A GLANCE

Rate of Disintegration

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

The distance of closest approach

$$r_0 = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{\frac{1}{2}mv^2}$$

Impact Parameter (or Equivalent Distance)

$$b = \frac{Ze^2\cot(\theta/2)}{4\pi\varepsilon_0 E} = \frac{Ze^2\cot(\theta/2)}{4\pi\varepsilon_0\left(\frac{1}{2}mv^2\right)}$$

Mass no. $A = Z + N$

Radius of nucleus, $R = R_o A^{1/3}$

$R_o \rightarrow$ Range of nuclear force (or Nuclear Unit Radius)

$(= 1.1\times 10^{-15} m)$

Mass-Energy Equivalence

$$\Delta E = \Delta mc^2$$

Mass Defect

$$\Delta m = Zm_P + (A - Z)m_N - m({}_Z X^A)$$

$$\text{B.E./nucleon} = \frac{\text{Binding energy}}{A}$$

$$\text{Packing fraction} = \frac{\text{Mass defect}}{A}$$

No. of radioactive nuclei at any instant

$$N = N_0 e^{-\lambda t}$$

Radioactive decay constant

$$\lambda = \frac{dN/dt}{N} = \frac{0.693}{T_{1/2}} = \frac{1}{T_\alpha}$$

Half-Life, $T_{1/2} = \dfrac{0.693}{\lambda}$

After n half-lives, the fraction of the radioactive atoms left

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

Mean life or average life

$$T_a = \frac{1}{\lambda}$$

Relation between half life and mean life $T_{1/2} = 0.693T_a$

Activity of radioactive substance

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

$$= \lambda N_0 e^{-\lambda t} = R_o e^{-\lambda t}$$

Energy carried by α-particle during Alpha Decay

$$E_\alpha = \frac{A - A_\alpha}{A}E$$

Atom is electrically neutral, i.e., it has equal amount of positive and negative charge. There are various atom models. Some of them are as follows

Thomson's Atom Model According to Thomson, an atom is a positively charged sphere of uniform density of about 1010m in diameter in which negative charges (electrons) are embedded like plums in pudding. This model could not explain the presence of discrete spectral lines emitted by hydrogen and other atoms.

Rutherford's model of atom:-

According to this the entire positive charge and most of the mass of the atom is concentrated in a small volume called the nucleus with electrons revolving around the nucleus just as planets revolve around the sun.

Alpha particle scattering experiment (Geiger – Marsden Experiment)

Rutherford bombarded the alpha particles on a very thin foil of gold having thickness equal to 10^{-6} m. Alpha particles scattered in different directions were observed with the help of a movable detector. This experiment was conducted inside an evacuated chamber to avoid the scattering of alpha particles due to the atoms of air.

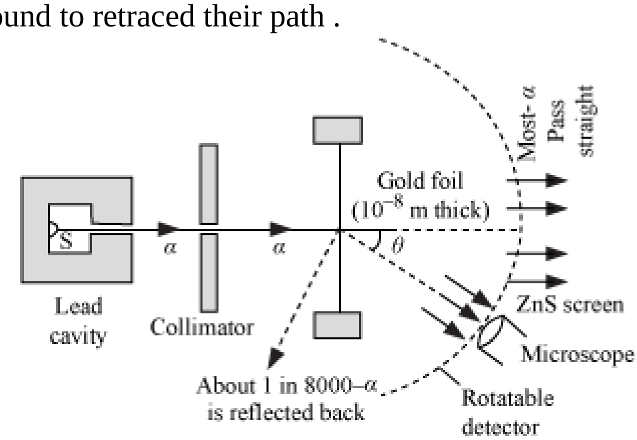
This experiment establishes Rutherford's model of atom. Highly energetic α particle are allowed to fall a thin gold foil and the following observations were recorded:

(a) A large number of α particles are found to be undeflected.

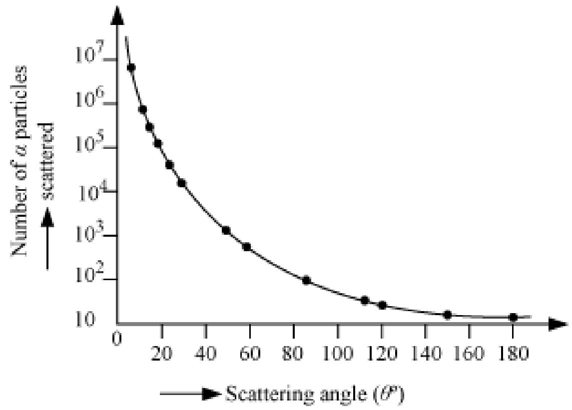
(b) Some α particles are scattered at large angles less than 90^0.

(c) Very few alpha particles got deflected at angle more than 90^0.

(d) A few particles are found to retraced their path .



Observations − A graph is plotted between the scattering angle θ and the number of α-particles $N(\theta)$, scattered at $\angle\theta$ for a very large number of α-particles.



- Most of the alpha particles pass straight through the gold foil.
- Only about 0.14% of incident α-particles scatter by more than 1.
- About one α-particle in every 8000 α-particles deflects by more than 90°.

Conclusion:-

Rutherford proposed **a** new atom model on the basis of the results of alpha-particle scattering experiment known as Nuclear model of Atom.

(i)Most of the mass and the entire positive charge of an atom is concentrated in a very small region at the center of atom called Nucleus.

(ii) The size of the nucleus is very small as compared to that of atom. So most of the space in an atom is empty.

(iii) The negatively charged particles known as electrons revolve around the nucleus in circular orbits due to the attractive force between the nucleus and them.

Distance of closest approach 'r'

It is defined as the minimum distance of an alpha -particle from the center of the nucleus upto which it can go while heading towards the nucleus. It gives the approximate measure of the size of the nucleus. It can be calculated as follows:

Let 'Z' be the atomic number of the atom

At the distance of closest approach, the K.E of an α particle gets completely converted into electrostatic potential energy PE .

KE=PE

$\frac{1}{2} mv^2 = \frac{1}{4\pi\varepsilon_0}\frac{(2e)(ze)}{r}$ Rearranging this , we get the distance of closest approach as

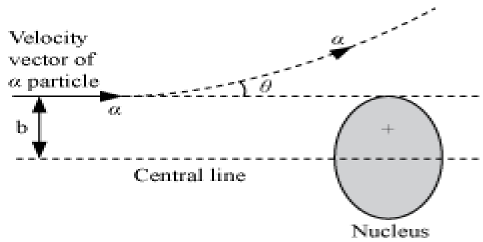
$$r = \frac{ze^2}{\pi\varepsilon_0 mv^2}$$

The value of r is found by this method approximately to be 10^{-15}m.

Impact parameter (b) is the perpendicular distance between the direction of an α particle and the axis passing through the centre of the nucleus.
It is given by

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

If b is less, deflection of the alpha-particle from it's original direction (θ) is more and vice-versa,
When b=0, θ=180



Limitation of Rutherford's model
(i) It could not explain the stability of the atom
(ii) It could not explain the spectral lines in the spectrum of atom.

Bohr atom model

To explain the stability and spectrum of an atom, Neil Bohr applied Plank's quantum theory of radiation to Rutherford's atom model and proposed a new model for an atom Most of the mass an the entire positive charge of an atom are concentrated in a very small region at the center of the atom called Nucleus.

Bohr's postulates

1) The electrons revolve in a definite orbit around the nucleus. As long as electron is in a certain orbit, it doesn't radiate any energy.
2) The electrons can revolve only in those orbits, in which its angular momentum is an integral multiple of h/2π. where h is the planck's constant (= 6.6×10^{-34} J s) Thus the angular momentum (L) of the orbiting electron is quantized. That is, **L = nh/2π.**
[$2\pi r_n = n\lambda$, But $\lambda = h/p = h/mv_n$
$2\pi r_n = n h/mv_n$ ie $mv_n r_n = nh/2\pi$,But angular momentum $L = mv_n r_n$
n is Principle quantum, v_n is Speed of moving electron in the n^{th} orbit, r_n is Radius of n^{th}orbit, L = nh/2π]
3) When an electron jumps from higher energy level (E_2) to a lower energy level (L_1), a photon is emitted having energy equal to the energy difference between the initial and final states. $\mathbf{h\nu = E_2 - E_1}$
Frequency of the emitted photon is given by $\nu = (E_2 - E_1)/h$ called Bohr frequency.

Electron orbits of Hydrogen atom

Let F_c − Centripetal force required to keep a revolving electron in orbit

F_e – Electrostatic force of attraction between the revolving electron and the nucleus

Then, for a dynamically stable orbit in a hydrogen atom,

$F_c = F_e$

$$\frac{mv^2}{r} = \frac{(e)(e)}{4\pi\varepsilon_0 r^2} \qquad \text{...(i)}$$

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

$$r = \frac{e^2}{4\pi\varepsilon_0 mv^2} \qquad \text{...(ii)}$$

K.E. of electron in the orbit,

$$K = \frac{1}{2}mv^2$$

From equation (i),

$$K = \frac{e^2}{8\pi\varepsilon_0 r}$$

Potential energy of electron in orbit,

$$\mathrm{U} = \frac{(e)(-e)}{4\pi\varepsilon_0 r} = \frac{-e^2}{4\pi\varepsilon_0 r}$$

Negative sign indicates that revolving electron is bound to the positive nucleus.

∴ Total energy of electron in hydrogen atom

$$E = k + U = \frac{e^2}{8\pi\varepsilon_0 r} - \frac{e^2}{4\pi\varepsilon_0 r}$$

$$\boxed{E = -\frac{e^2}{8\pi\varepsilon_0 r}}$$

Expression for the energy of an electron in the n^{th} orbit of a Hydrogen atom.

Total energy of an electron in an orbit is the sum of its kinetic energy and electro static potential energy in the orbit T.E= K.E + P.E

Consider an electron revolving in the n^{th} orbit of an electron in the orbit of radius r_n with speed v_n.

The centripetal force required for the revolution of the electron is provided by the electrostatic force of attraction.

So, $\frac{mv_n^2}{r_n} = \frac{1}{4\pi\varepsilon_0}\frac{(e)(e)}{r_n^2}$ Thus we get, $r_n = \frac{e^2}{4\pi\varepsilon_0 m v_n^2}$ ………………..(1)

By Bohr's second postulate, the angular momentum of the electron is given by

,$mv_n r_n = nh/2\pi$

Using equation (1), $mv_n \frac{e^2}{4\pi\varepsilon_0 m v_n^2} = nh/2\pi$ This gives the velocity of the electron as,

$$\mathbf{V_n} = \frac{e^2}{2\varepsilon_0 nh} \quad \ldots\ldots\ldots\ldots(2)$$ It implies that $\mathbf{v_n \,\alpha\, 1/n}$

Speed of an electron in an orbit is inversely proportional to the principal quantum number of its orbit.

Substituting (2) in equation (1) and solving we get ,

Radius of the orbit $$\mathbf{r_n} = \frac{\varepsilon_0 n^2 h^2}{\pi m e^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$ i.e, $\mathbf{r_n \alpha\, n^2}$

Hence kinetic energy of the electron is given by, $K.E_n = \frac{1}{2} m v_n^2$

$$= \frac{1}{2} m\left(\frac{e^2}{2\varepsilon_0 nh}\right)^2$$

$$\mathbf{K.E_n} = \frac{me^4}{8\varepsilon_0^2 n^2 h^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Potential energy of the electron is given by, $\mathbf{P.E_n} = \frac{1}{4\pi\varepsilon_0} \frac{(e)(-e)}{r_n}$

Substituting the value of radius from equation (3) we get

$$\mathbf{P.E_n} = -\frac{me^4}{4\varepsilon_0^2 n^2 h^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Finally the total energy of the electron is $E_n = K.E_n + P.E_n$

$$E_n = \frac{me^4}{8\varepsilon_0^2 n^2 h^2} + -\frac{me^4}{4\varepsilon_0^2 n^2 h^2}$$

$$E_n = -\frac{me^4}{8\varepsilon_0^2 n^2 h^2}$$

Putting the value of m, e, $_0$, and h and solving we get, $\mathbf{E_n} = -\frac{13.6}{n^2} eV$

Total energy of an electron in its orbit is negative. Negative energy tells us that electron and nucleus form a bounded system.

Note:- From the above equations it can be shown that

(i)$K.E_{n-} = -E_n$ (ii)$P.E_n = 2\,(E_n)$ and (iii)$P.E_n = -2\,(k.E_n)$

Atomic Spectra

- Each element emits a characteristic spectrum of radiation.

- In the excited state, the atoms emit radiations of a spectrum, which contains certain specific wavelengths only. This spectrum is termed as emission line spectrum and it consists of bright lines on a dark background.

Spectral Series When the electron in a hydrogen atom jumps from higher energy level to the lower energy level, the difference of energies of the two energy levels is emitted as a radiation of particular wavelength. It is called a spherical line. For transition of the electron between two different energy levels, the spectral lines of different wavelengths are obtained.

Rydberg- Balmer formula:-

According to Bohr's atom model, energy is radiated when an electron jumps from higher energy level to lower energy level. The energy of the emitted radiation, Using the third postulate we get $h\nu = E_2 - E_1 = -\frac{me^4}{8\varepsilon_0^2 n_2^2 h^2} - \frac{me^4}{8\varepsilon_0^2 n_1^2 h^2}$

$$\frac{hc}{\lambda} = \frac{me^4}{8\varepsilon_0^2 h^2}\left[\frac{1}{n^2} - \frac{1}{n^2}\right]$$

$$\frac{1}{\lambda} = R_H\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

Hence the wave number is given by $R \rightarrow$ Rydberg's constant = $1.09678 \times 10^7\ m^{-1}$

This is Rydberg-Balmer formula.The above equation can be used to explain 'Atomic spectra'

Hydrogen spectrum

When electron jumps from higher energy level to lower energy level in the hydrogen atom. The radiation of particular wavelength is emitted. This radiation is called spectral Line. The spectral lines arising from the transition of electron from higher energy levels to a particular lower energy level form a spectral series. These series in hydrogen atom are as follows

1) **Lyman series**

The spectral lines emitted due to the transition of an electron from an outer orbit (n_i=2,3,4…) to the first orbit (n_f=1) form a spectral series called lyman series.

In Lyman series, wavelength of spectral lines are given by $1/\lambda = R_H[1/1^2 - 1/n_i^2]$

This series lies in the ultra violet region. For the shortest wavelength of the series, $n_i=\infty$

$\lambda_{min}=912A^0$

For the longest wavelength of the series, $n_i=2$ $\lambda max= 1216\ A^0$

2) **Balmer series**

The spectral lines emitted due to the transition of an electron from an outer orbit (n_i=3,4,5…) to the first orbit (n_f=2) form a spectral series called balmer series.

In this series, wavelength of spectral lines are given by $1/\lambda = R_H[1/2^2 - 1/n_i^2]$

This series lies in the visible region. For the longest wavelength of the series, $n_i=3$

$\lambda_{max}=6563A^0$

For the minimum wavelength of the series, $n_i=\infty$ $\lambda_{min}=3648A^0$

3) **Paschen series**

The spectral lines emitted due to the transition of an electron from an outer orbit (n_i=4,5,6…) to the first orbit (n_f=3) form a spectral series called paschen series.

In this series, wavelength of spectral lines are given by $1/\lambda=R_H[1/3^2 - 1/n_i^2]$

This series lies in the infra red region. For the longest wavelength of the series, n_i=3

$\lambda_{max}=18761A^0$

For the minimum wavelength of the series, $n_i=\infty$, $\lambda_{min}=8208A^0$

4) **Brackett series**

The spectral lines emitted due to the transition of an electron from an outer orbit (n_i=5,6,7…) to the first orbit (n_f=4) form a spectral series called brackett series.

In this series, wavelength of spectral lines are given by $1/\lambda=R_H[1/4^2 - 1/n_i^2]$

This series lies in the infra red region.

For the minimum wavelength of the series, $n_i=\infty$, $\lambda_{min}=14592A^0$

5) **Pfund series**

The spectral lines emitted due to the transition of an electron from an outer orbit (n_i=6,7,8…) to the first orbit (n_f=5) form a spectral series called pfund series.

In this series, wavelength of spectral lines are given by $1/\lambda=R_H[1/5^2 - 1/n_i^2]$

This series lies in the infra red region. For the longest wavelength of the series, n_i=5

$\lambda_{max}=74618A^0$

For the minimum wavelength of the series, $n_i=\infty$, $\lambda_{min}=22800A^0$

This series lies in the infra red region.

De Broglie's Explanation of Bohr's Second Postulate of Quantisation

- De-Broglie's hypothesis that electron has a wavelength $\lambda = h/mv$ gave an explanation for Bohr's quantised orbits by bringing in the wave particle duality.
- Orbits correspond to circular standing waves in which the circumference of the orbits equal whole number of wavelength.

Limitations of Bohr's model

- Bohr's model is applicable only to hydrogenic (single electron) atoms.
- Unable to explain the relative intensities of the frequencies in the spectrum

Nucleus consists of Protons and Neutrons called nucleon. Total number of nucleons present in the nucleus of an atom is called its mass number. An atom (X) having atomic number Z and mass number A is symbolically denoted as $_ZX^A$

Z = Atomic number = Number of protons

N = Neutron number = Number of neutrons

A = Mass number = $Z + N$ = Total number of protons and neutrons

Isotopes :- Nuclei with the same atomic number but different mass numbers. E.g. $_2He^3$ and $_2He^4$.

Isobars:- Nuclei with the same mass number but different atomic numbers E.g. $_6C^{14}$ and $_7N^{14}$.

Isotones :- Nuclei with the same number of neutrons. E.g. $_2He^4$ and $_1H^3$.

Atomic Masses and Composition of Nucleus

One amu is defined as 1/12th of the mass of an atom of ${}_6C^{12}$ isotope.

Avogadro's number = 6.023×10^{23}

$\therefore$Mass of 6.023×10^{23} atoms of C^{12} = 12 g

$$\text{Mass of 1 atom of } C^{12} = \frac{12}{6.023\times10^{23}}\ \text{g}$$

$$1\ \text{amu} = \frac{1}{12}\times\frac{12}{6.023\times10^{23}}\ \text{g}$$

$$\boxed{\therefore \text{amu} = 1.66\times10^{-27}\ \text{kg}}$$

Conversion of a.m.u.into MeV

$E = mc^2 = (1.66 \times 10^{-27})(3 \times 10^8)^2 = 931$ MeV

Size of Nucleus

It was found experimentally that the volume of a nucleus is proportional to its mass number (A).

Let $R \rightarrow$ Radius of the nucleus

$$\therefore \text{Volume} = \frac{4}{3}\pi R^3$$

$$\therefore \frac{4}{3}\pi R^3 \propto A$$

$$\Rightarrow R \propto A^{\frac{1}{3}}$$

$$R = R_0\ A^{\frac{1}{3}}$$

Where, R_0 is a constant = 1.2×10^{-15} m is the range of nuclear force

Nuclear density is defined as the ratio of mass of nucleus to its volume.

Consider a nucleus of mass no 'A', then its mass is $M=Am_n$ where m_n=mass of one nucleon and radius of the nucleus,$R=R_0A^{1/3}$

Nuclear density,$\rho = Am_n/ (4/3\ \pi R^3)$

$= 3Am_n/ (4\ \pi R_0{}^3\ A)$

$P = 3m_n/ 4\ \pi R_0{}^3$.

Conclusion: a) The density of nucleus is independent of its mass number.

b) All nuclei have the same density.

c) The highest magnitude of density indicates that the entire matter of an atoms is concentrated in the nucleus. i.e., atoms contain lots of empty space.

Nuclear forces are the strongest the forces that hold nucleons inside the nucleus of an atom in a tiny space, overcoming the electrostatic force of repulsion between protons.

Characteristics of nuclear force

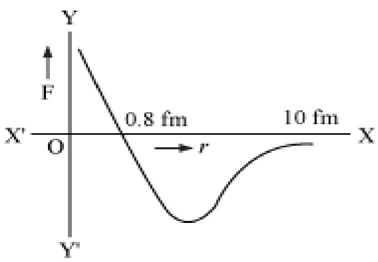
- They are the strongest force in nature. It acts between the particles(p-p,p-n,n-n) present inside the nucleus.
- It is attractive.
- They exhibit saturation property. i.e. a given nucleon influences only those nucleons close to it.
- They are charge- independent.
- They are short-ranged force and acts only up to few Fermi (10 fermi)and doesn't follow the inverse square law, i.e. It increases at a very fast rate with the decrease in the separation between the nucleons and vice-versa. It becomes repulsive if the distance between the two nucleons becomes less than 0.5 fermi.
- They are non-central forces.

Variation of potential energy with separation between nucleons.

The inter-nuclear force is the negative gradient of potential energy with the distance.

$$F = (dU/dX)$$

Negative potential energy indicates the force of attraction between nucleons. Hence the variation of force with distance can be plotted as shown:



For a separation greater than r_0, the force is attractive and for a separation less than r_0, the force is repulsive

Mass defect (Δm) of a nucleus is defined as the difference between the actual mass of a nucleus, m_N and the total individual masses of protons and neutrons inside the nucleus.

Z = Number of protons

A = Number of protons + Number of neutrons

Let m_p = Mass of a proton

m_n = Mass of a neutron

m_N = Mass of nucleus ${}_Z X^A$

∴Mass defect,

$\Delta m = [Zm_p + (A - Z)\, m_n - m_N]$

This mass defect is used to provide energy, called binding energy, to bind nucleons within the nucleus.

- Using Einstein's mass-energy equivalence,

Binding energy = $\Delta m C^2$

$$= \left[Zm_p + (A - Z)m_n - m_N \right] C^2$$

- Average binding energy per nucleon is given by the total binding energy divided by the mass number of the nucleus.

Binding energy of a nucleus is the amount of energy required to separate all its nucleons upto infinite separation from each otherand is equal to the energy corresponding to its mass defect. Using Einstein's mass-energy equivalence,

Binding energy energy of a nucleus having mass defect Δm, E = Δ*mC*²

BE $= \left[Zm_p + (A - Z)m_n - m_N \right] C^2$

Average binding energy per nucleon is given by the total binding energy divided by the mass number of the nucleusy (BE/A). It determines the stability of a nucleus.

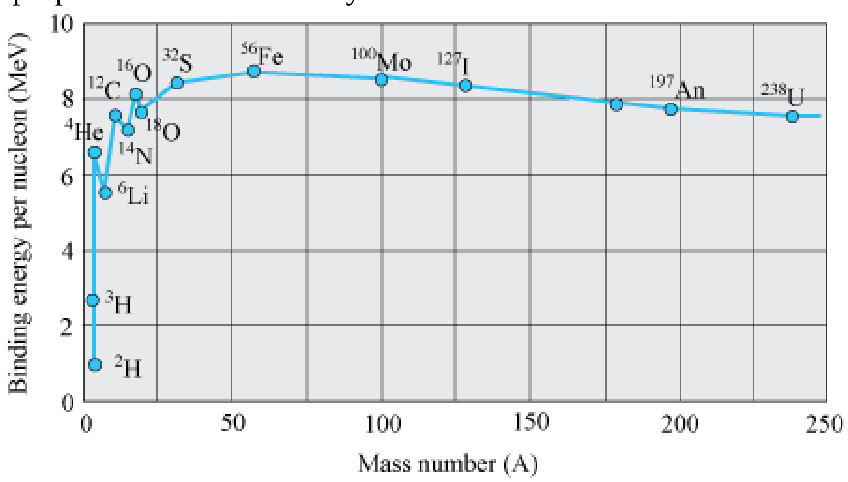
If the mass defect is 1 amu, Binding energy corresponding to a mass defect of 1 amu $E = \Delta m\, c^2$

1amu x $(3 \times 10^8)^2 = 1.66 \times 10^{-27} \times (3 \times 10^8)^2 / 1.6 \times 10^{-13} = 931$ MeV

Binding energy of a nucleus of mass defect l amu = 931 MeV.

Binding energy curve

shows the variation of B.E. per nucleon with mass number of different nuclei. BE per nucleon is directly proportional to the stability of the nucleus



Observation and Conclusion

(i) The B.E. per nucleon is not distributed uniformly over different mass numbers.

(i) Nuclei having mass number less than 20 have small BE/A and are less stable.

(ii) The nuclei with mass numbers between 30 and 170 have practically the same value of the B.E./ nucleons. Fe^{56}(8.8MeV), being with the highest B.E/nucleon is the most stable.

(iii) The constancy of the binding energy in the range 30<A<170 is a consequence of the fact that the nuclear force is short ranged.

(iv) Heavy nuclei such as Uranium possesses lower B.E./nucleon and hence they are less stable. Hence when they split to form comparatively lighter fragments, gaining higher B.E./nucleon they gain stability. This process releases energy and is called nuclear fission.
(v) Lighter nuclei such as hydrogen, also posses lower B.E./nucleon and hence they are less stable. Hence when they combine to form comparatively heavier fragments, gaining higher B.E./nucleon, they gain stability. This process also releases energy is called nuclear fusion.

Radioactivity is the phenomenon of spontaneous emission of radiations from a nucleus when it becomes unstable. The stability arises when there is a large difference in neutron and proton numbers in the nucleus. It is discovered by Henry Becquerel. Further Rutherford found that there are three types of radiations from the nucleus namely, α, β, γ with the help of the experiment depicted in the figure given alongside.

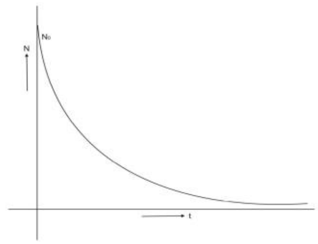
There are three types of radioactive decay Properties of α, β, and γ radiations

	Alpha	**Beta**	**Gamma**
Charge	Positive	Negative	Neutral
Mass	Equivalent to the He nucleus	Equivalent to an electron	em radiation
Max. speed	1/10th that of light	nearly equal to c	equal to c
Ionizing power	highest	lower than α	least
Penetrating power	lowest	higher	highest
Deflected	deflected in electric and magnetic fields	deflected in electric and magnetic fields	Not deflected in electric and magnetic fields
	All the three can cause change in photographic plates.		

The law of radioactive decay states that the number of radioactive atoms disintegrating per second (dN/dt) is directly proportional to the number of undecayed atoms N present in the sample at that instant.
$dN/dt \propto -N$ i.e., $dN/dt = -\lambda N$, Where λ is a constant called decay constant or disintegration constant.
The negative sign indicates that the number of undecayed atoms decreases with time.
Further, $dN/N = -\lambda dt$

On integrating, we get $\int_{N_0}^{N} \frac{dN}{N} = -\lambda \int_{t_0}^{t} dt$ $\ln N - \ln N_0 = -\lambda (t - t_0)$ At $t_0 = 0$, $\ln \frac{N}{N_0} = -\lambda t$

$\mathbf{N = N_0 e^{-\lambda t}}$



The above equation indicates that the number radioactive atoms decrease exponentially with time as shown in the graph.

Activity of the sample is defined as the total decay rate *R* of a sample.

Decay rate (R) $= -\frac{dN}{dt}$

SI unit for activity is Becquerel.

1 Becquerel = 1 Bq = 1disintegration per second, Bigger units : Rutherford (Rd) and Curie (Ci).

1Rd = 10^6 disintegration per second.

1 Ci = 3.7×10^{10} disintegration per second. In terms of activity, $\mathbf{R = R_0\, e^{-\lambda t}}$

Nuclear Energy

Energies involved in conventional energy sources are of the order of electron volts per atom, but energy involved in nuclear processes are million times larger.

Nuclear fission

It is defined as the phenomenon of splitting of a heavy unstable nucleus into two or more medium size and more stable nuclei.

Fission

- When neutrons bombard various elements, new radioactive elements are produced.
- When a neutron is bombarded on a uranium target, the uranium nucleus breaks into nearly equal fragments releasing great amount of energy.

$${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{236}_{92}U \rightarrow {}^{144}_{56}Ba + {}^{89}_{36}Kr + 3{}^{1}_{0}n$$

- Fission of uranium does not always produce Ba and Kr. It can produce any other pair also.
- Fragment nuclei produced in fission are highly neutron rich and unstable. Therefore, they emit beta particle until they reach a stable end product.
- Enormous amount of energy released in an atom bomb comes from uncontrolled nuclear fission reaction.
- Chain reactions are again of two types; (i)Controlled chain reaction (ii) Uncontrolled chain reaction Controlled nuclear fission —> nuclear reactor to generate the electricity Uncontrolled nuclear fission —> atom bomb

Nuclear Reactor

- When ${}^{235}_{92}\mathrm{U}$ undergoes fission, it produces neutron, which initiates another ${}^{235}_{92}\mathrm{U}$ nucleus to undergo fission.
- When this chain reaction is controlled suitably, we can obtain a steady energy output.
- This phenomenon is used in a nuclear reactor.
- Average energy of a neutron produced in fission of ${}^{235}_{92}\mathrm{U}$ is 2 MeV. Unless slowed down, it will escape from the reactor without interacting with the uranium nuclei.
- Light nuclei called moderator is provided in the reactor along with the nuclei for slowing down fast neutrons.
- Commonly used moderators are water, heavy water (D_2O), and graphite.
- Moderator helps to increase the ratio of number of fission produced by a given generation of neutrons to the number of the proceeding generation. This ratio is called multiplication factor (K).
- The factor K should be brought close to unity to avoid explosion.
- Reaction rate is controlled through control rods made of neutron absorbing material such as cadmium.
- Safety rods are also added to reduce K rapidly.
- Core of the reactor is the site for nuclear fission.
- Core is surrounded by reflector to reduce leakage.
- Energy released in fission is continuously removed by a suitable coolant.
- Whole assembly is shielded to check harmful radiation from coming out.
- Wastes produced by nuclear reactors are hazardous.

Nuclear Fusion

- Two light nuclei fuse to form a larger nucleus, and energy is released in the process.

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

- Two nuclei must come close enough so that attractive short range nuclear force is able to affect them.
- When fusion is achieved by raising the temperature, it is called thermonuclear fusion.
- Fusion reaction also takes place in sun in which the hydrogen is burnt into helium.
- Reaction occurring in sun is

$${}^{1}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H} \rightarrow {}^{2}_{1}\mathrm{H} + e^{-} + \nu + 0.14\ \mathrm{MeV}$$

$$e^{+} + e^{-} \rightarrow \nu + \nu + 1.12\ \mathrm{MeV}$$

$${}^{2}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{He} + \nu + 5.49\ \mathrm{MeV}$$

$${}^{3}_{2}\mathrm{H} + {}^{3}_{2}\mathrm{He} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H} + 12.86\ \mathrm{MeV}$$

Four hydrogen atoms combine to form a ${}^{4}_{2}\mathrm{He}$ atom with the release of 26.7 MeV of energy.

- After *S* billion years, the hydrogen burning will stop and the sun will begin to cool. The outer envelope of the sun will expand, turning it into the so called 'red giant'.

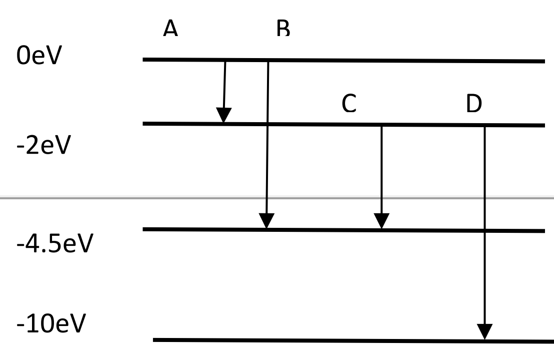
S.No:	Question Details	Marks
	MULTIPLE CHOICE QUESTIONS	
1.	Which of these statements about Bohr model hypothesis is correct? a) Velocity of electron is quantized b) Electron in a stable orbit emit quanta of light c) Angular momentum is not quantized d) Electron in a stable orbit does not radiate electromagnetic waves	**1**
2.	In the ground state of which model electrons are in stable equilibrium with zero net force? a) None of these b) Rutherford's model c) Thomson's model d) Bohr model	**1**
3.	The total energy of an electron in the first excited state of hydrogen atom is about - 3.4 eV. Its kinetic energy in this state is: a) -3.4 eV b) 3.4 eV c) -6.8 eV d) 6.8 eV	**1**
4.	When an electron jumps from the fourth orbit to the second orbit, one gets the a) Second line of Balmer series b) First line of Pfund series c) Second line of Paschen series d) Second line of Lyman series	**1**
5.	When the hydrogen atom is in first excited level, its radius is a) same b) four times c) half d) twice	**1**
6.	The angular momentum of electron in nth orbit is given by a) nh b) $nh/2\pi$ c) $n/2\pi h$ d) n h e) $n^2h/2\pi$	**1**

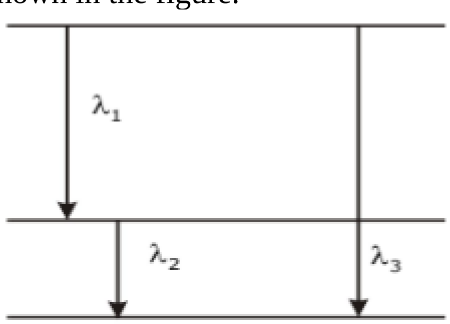
7.	Suppose you are given a chance to repeat the alpha-particle scattering experiment using a thin sheet of solid hydrogen in place of the gold foil. (Hydrogen is a solid at temperatures below 14 K.) What results do you expect? a) There would be no large-angle scattering b) There would be scattering at 90^o c) There would be scattering at all angles d) There would be no scattering	**1**
8.	What is true for the relation between angle of scattering and impact parameter of alpha particle in Rutherford scattering experiment (a) Angle of Scattering is independent of impact parameter (b) If impact parameter is large ,angle of scattering will also be large (c) If impact parameter is small ,angle of scattering will be large (d) For head on collisions impact parameter will be maximum and angle of scattering will be minimum	
9.	Taking the Bohr radius as a0 = 53pm, the radius of Li++ ion in its ground state, on the basis of Bohr's model, will be about (a) 53 pm (b) 27 pm (c) 18 pm (d) 13 pm	
10.	It is possible to understand nuclear fission on the basis of the a) liquid drop model of the nucleus b) mean theory of the nuclear forces c) proton - proton cycle d) independent particle model of the nuclear	**1**
11. 1	Of the following materials, the good moderator is a) Ordinary water b) Graphite c) Cadmium d) Helium	**1**
12.	Which of the following particles has similar mass to that of the protons? a) Neutrino b) Neutron c) Positron d) Alpha particle	**1**
13.	When a nucleus emits a photon, what happens to its atomic number and its actual mass? a) Its atomic number and its actual mass both increase b) Its atomic number remains the same but its actual mass decreases c)) Its atomic number and its actual mass both decrease d) Its atomic number and its actual mass remain unchanged	**1**

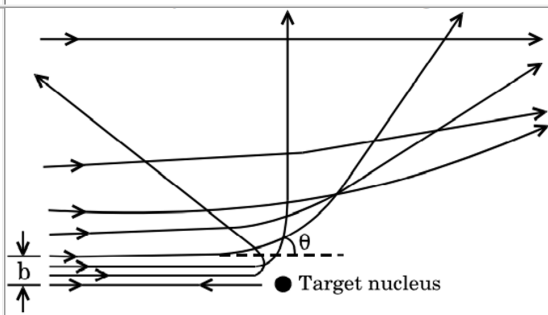
14.	In a nuclear reaction which of the following is conserved? a) Charge b) Sum of mass and energy c) Momentum d) All of these	**1**
15.	The process of fusion is used in the construction of a) a hydrogen bomb b) a neutron bomb c) an ordinary bomb d) an atom bomb	**1**
16.	Which of the following is the best nuclear fuel? a) Uranium – 236 b) Plutonium – 239 c) Thorium – 236 d) Neptunium - 239	**1**
17.	The binding energy per nucleon is almost constant for many nuclei. It shows that nuclear forces are (a) Charge independent (b) saturated in nature (c) strongest force (d) attractive in nature	
18.	The ratio of nuclear densities of 6C12 and 20Ca40 (a) 12:40 (b) 1:1 (c) 6:20 (d) 40:12	
19.	The average energy released per fission of 92U235 is approximately ……………….. MeV. a. 200 b. 235 c. 20 d. 93	
	FILL IN THE BLANKS	
1.	The series of hydrogen spectrum which lies in the visible region of electromagnetic spectrum is_________.	**1**
2.	The total energy of the electron in a stationary orbit is _________, which means the electron is bound to the nucleus and is not free to leave it.	**1**
3.	The minimum accelerating potential which would provide an electron energy sufficient just to remove it from the atom is called _________.	**1**
4.	The energy possessed by an electron for $n = \infty$ is _________.	**1**

5.	The ratio of volume of atom to the volume of nucleus is ________.	**1**
6.	Mass of a proton is ________ times the mass of an electron.	**1**
	ASSERTION AND REASON The following questions consist of two statements, each printed as Assertion and Reason. While answering these questions, you are required to choose any one of the following four responses. (a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion. (b) Both Assertion and Reason are correct, but Reason is not a correct explanation of the Assertion. (c) Assertion is correct, Reason is incorrect (d) Both Assertion and Reason are incorrect.	
1	Assertion: The alpha-particle scattering experiment is performed using a thin sheet of solid hydrogen ,there would be no large angle scattering. Reason: Hydrogen nuclei are much lighter then alpha particles .	
2	Assertion : Bohr had to postulate that the electrons in stationary orbits around the nucleus do not radiate. Reason: According to classical physics all moving electrons radiate.	
3	Assertion : In Lyman series, the ratio of minimum and maximum wavelength is 3/4 Reason : Lyman series constitute spectral lines corresponding to transition from higher energy to ground state of hydrogen atom.	
4	Assertion: The total energy of the electron is negative. Reason: This implies the fact that the electron is bound to the nucleus	
5	Assertion : Density of all the nuclei is same. Reason : Radius of nucleus is directly proportional to the cube root of mass number.	
6	Assertion : Energy is released when heavy nuclei undergo fission or light nuclei undergo fusion. Reason : For heavy nuclei, binding energy per nucleon increases with increasing Z while for light nuclei it decreases with increasing Z.	
7	Assertion : The binding energy per nucleon, for nuclei with atomic mass number A > 100, decrease with A. Reason : The nuclear forces are weak for heavier nuclei.	
8	Assertion: Energy is released in nuclear reaction Reason: In any nuclear reaction the reactant and resultant products obey law of conservation of charge and mass only	
	VERY SHORT ANSWER QUESTIONS	
1.	Can a hydrogen atom absorb a photon having energy more than 13.6 eV?	**1**
2.	Why is the classical (Rutherford) model for an atom of electron orbiting around the nucleus not able to explain the atomic structure?	**1**
3.	When is Hα - line of the Balmer series in the emission spectrum of hydrogen atom obtained?	**1**

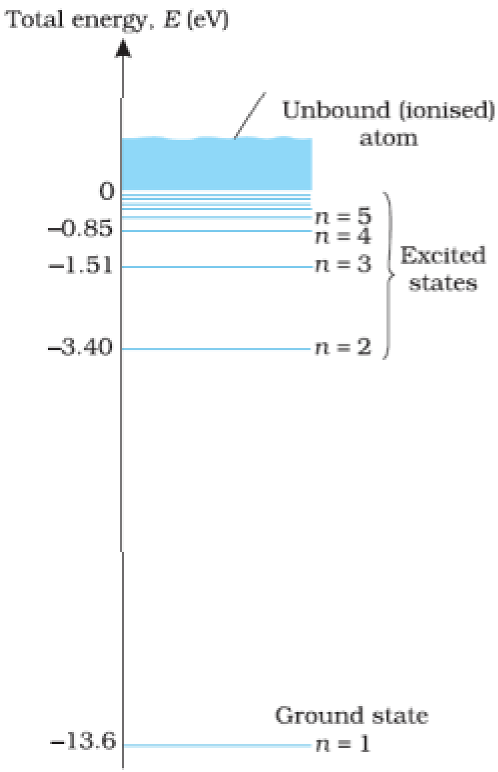
4.	When an electron falls from a higher energy level, the difference in the energies appears in the form of electromagnetic radiation. Why cannot it be emitted as other forms of energy?	**1**
5.	For a given impact parameter b, does the angle of deflection increase or decrease with increase in energy?	**1**
6.	The mass of the nucleus is less than the sum of the masses of the nucleons forming it, why?	**1**
7.	Draw a graph showing the variation of potential energy between a pair of nucleons as a function of their separation. Indicate the function in which the nuclear force is (i) attractive, (ii) repulsive.	**1**
8.	Name the series of hydrogen spectrum lying in ultraviolet and visible region?	**1**
9.	What is Bohr's quantization condition for the angular momentum of an electron in the second orbit?	**1**
10	Write the empirical relation for Paschen series lines of hydrogen atom?	**1**
11	The wavelengths of some of the spectral lines obtained in hydrogen spectrum are 9546A^o, 6463A^o and 1216A^o. Which one of these wavelengths belongs to Lyman series?	**1**
12	Consider two different hydrogen atoms. The electron in each atom is in an excited state. Is it possible for the electrons to have different energies but the same orbital angular momentum according to the Bohr model?	**1**
13	What is the distance of the closest approach of an alpha particle to the nucleus?	**1**
14.	What is the scattering angle when the impact parameter is zero?	**1**
15.	Why do we use gold in Rutherford's ά-particle scattering experiment?	**1**
16.	Calculate the radius of the smallest orbit of H-atom.	**1**
17.	Why is heavy water used as moderator in a nuclear reactor?	**1**
	2 MARKER QUESTIONS	
18,	Draw the graph showing the variation of the number (N) of scattered alpha particles with scattering angle (θ) in Geiger -Marsden experiment. Infer two conclusions from the graph .	**2**
19.	Express 16mg mass into equivalent energy in electron volt?	**2**
20.	Show that nuclear density is independent of mass number A of a nucleus?	**2**
21.	Two nuclei A and B of mass numbers are in the ratio 1: 27. What is the ratio of a) the densities and b) the radii of the 2 nuclei? [1:1 , 1/3]	**2**
22.	Draw a graph showing the variation of potential energy between a pair of nucleons as a function of their separation. Indicate the regions in which the nuclear force is (i) Attractive, (ii) Repulsive.	**2**
23.	The energy levels of an atom are as shown below. Which one of the transitions will result in the emission of a photon of wavelength 275 nm?	**2**



	[Energy of photon is $E = \frac{hc}{\lambda} = 4.5\text{eV}$ clearly transition B will be the result.]	
24.	Name the reaction which takes place when a slow neutron beam strikes $_{92}U^{235}$ nuclei. Write the nuclear reaction involved.	**2**
	3 MARKER QUESTIONS	
25.	The energy of a hydrogen atom in the first excited state is 3·4 eV. Find : (a) the radius of this orbit. (Take Bohr radius = 0·53 Å) (b) the angular momentum of the electron in the orbit. (c) the kinetic and potential energy of the electron in the orbit.	
26.	(a) In Geiger-Marsden experiment, calculate the distance of closest approach for an alpha particle with energy 2·56 10 ^{12} J. Consider that the particle approaches gold nucleus (Z = 79) in head-on position. (b) If the above experiment is repeated with a proton of the same energy, then what will be the value of the distance of closest approach ?	
27.	Plot a graph showing the variation of binding energy per nucleon as a function of mass number. Which property of nuclear force explains the approximate constancy of binding energy in the range 30 < A < 170? How does one explain the release of energy in both the processes of nuclear fission and fusion from the graph?	**3**
28.	A heavy nucleus X of mass number 240 and binding energy per nucleon 7.6 MeV splits into two fragments Y and Z of mass numbers 110 and 130. The binding energy of nucleons in Y and Z is 8.5MeV per nucleon. Calculate the energy Q released per fission in MeV.	**3**
29.	State Bohrs postulate for the permitted orbits for the electron in a hydrogen atom. Use this postulate to prove that the circumference of the *n*th permit orbit for the electron can contain exactly *n* wavelengths of the de-Broglie wavelength associated with the electron in that orbit.	**3**
30.	Find the relation between the three wavelengths λ_1, λ_2 and λ_3 from the energy level diagram shown in the figure. 	

31.	Using Bohr's atomic model derive an expression for total energy of electron in n^{th} orbit.	**3**
32.	 The trajectories, traced by different ά - particles, Geiger – Marsden experiment were observed as shown in the figure. (A) What names are given to the symbols 'b' and 'θ' shown here? (B) What can we say about the values of 'b' for (i) $\theta = 0^0$ and (ii) $\theta = \pi$ radians?	**3**
33.	Calculate the binding energy per nucleon of chlorine nucleus ($_{17}Cl^{35}$). Given mass of H –atom = 1.0081amu, mass of neutron = 1.0090amu, mass of $_{17}Cl^{35}$ atom is 34.9800amu and 1amu = 931.5 MeV.	**3**
34.	Calculate the amount of energy released during the α decay of $^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He$ Given: 1.atomic mass of U = 238.05079 u 2.atomic mass of Th= 234.04363 u 3.atomic mass of He= 4.00260 u 1 u = 931.5 MeV/c^2. Is this decay spontaneous? Give reason.	**3**
35.	Write symbolically the nuclear β^+ decay process of $^{11}_{6}C$. Is the decayed product X an isotope or isobar of $^{11}_{6}C$? Given the mass values m ($^{11}_{6}C$) = 11·011434 u and m (X) = 11·009305 u. Estimate the Q-value in this process.	**3**
	5 MARKER QUESTIONS	
36.	**CASE/SOURCE BASED QUESTIONS** (Read the passage given below and answer the following questions: 1(A) The lowest state of the atom, called the ground state, is of the lowest energy. The energy of this state (n = 1), E1 is –13.6 eV. Therefore, the minimum energy required to free the electron from the ground state of the hydrogen atom is 13.6 eV. It is called the ionisation energy of the hydrogen atom. At room temperature, most of the hydrogen atoms are in ground state. When a hydrogen atom receives energy by processes such as electron collisions, the atom may acquire sufficient energy to raise the electron to higher energy states. The atom is then said to be in an excited	

state. When the electron fall back to a state of lower energy from these excited states then, photons are emitted in this the process



The energy level diagram for the hydrogen atom.

1 Energy correspond to third excited state is

(a) - 3.4 eV

(b) -0.85 eV

(c) -1.51 eV

(d) -4.53 eV

2 Energy required to ionize a H-atom from second excited state is –

(a) 1.51 eV

(b) 3.4 eV

(c) 13.6 eV

(d) 12.1 eV

3 Energy required to excite an electron in H-atom to its first excited state is-

(a) 13.6 eV

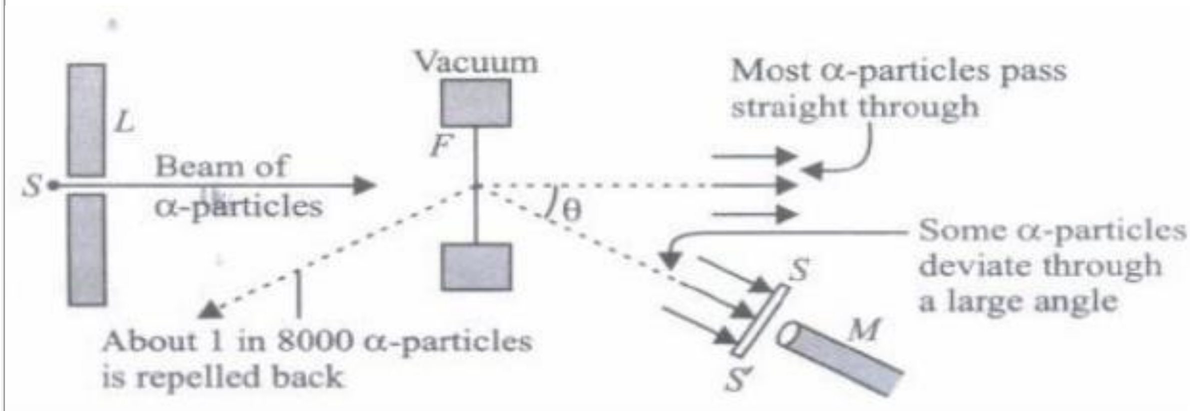
(b) – 10.2 eV

(c) 10.2 eV

(d) 12.09 eV

4 As principal quantum number ‘n’ increases value of excitation energy –

(a) increases

	(b) decreases (c) remains same (d) none of above	
37.	In 1911, Rutherford, along with his assistants, H. Geiger and E. Marsden, performed the alpha particle scattering experiment. H. Geiger and E. Marsden took radioactive source (83Bi214) for alpha-particles. A collimated beam of alpha-particles of energy 5.5 MeV was allowed to fall on 2.1 x 10-7 m thick gold foil. The alpha-particles were observed through a rotatable detector consisting of a Zinc sulphide screen and microscope. It was found that alpha-particles got scattered. These scattered alpha-particles produced scintillations on the zinc sulphide screen. Observations of this experiment are as follows. (I) Most of the alpha-particles passed through the foil without deflection. (II) Only about 0.14% of the incident alpha-particles scattered by more than 1°. (III) Only about one alpha-particle in every 8000 alpha-particles deflected by more than 90°. These observations led to many arguments and conclusions which laid down the structure of the nuclear model of an atom.  	
	a) In the Rutherford scattering experiment the distance of closest approach for an a-particle is d0 . If a-particle is replaced by a proton, how much kinetic energy in comparison to a-particle will it require to have the same distance of closest approach d0 ? b) In an experiment on alpha particle scattering by a thin foil of gold, draw a plot showing the number of particles scattered versus the scattering angle ϴ. c) Why is it that a very small fraction of the particles are scattered at an angle 180º? **OR** C) Write two important conclusions that can be drawn regarding the structure of the atom from the study of this experiment	
59	Stability of Nucleus -Neutrons and protons are identical particle in the sense that their masses are nearly the same and the force, called nuclear force. Nuclear force is the strongest force. Stability of nucleus is determined by the neutron proton ratio or mass defect or packing	

	fraction. Volume of nucleus depends on the mass number. Whole mass of the atom (nearly 99%) is present at the nucleus. (1) The correct statements about the nuclear force is/are (a) charge independent (b) short range force (c) non-conservative force (d) all of these. (2) The range of nuclear force is the order of (a) 2 x 10-10 m (b) 1.5 x 10-20 m (c) 1.2 x 10-4m (d) 1.4 x 10-15 m (3) 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 (iv) two protons are kept at a separation of 40 A0. Fn is the nuclear force and Fe is the electrostatic force between them. Then (a) Fn <<Fe (b) Fn= Fe (c) Fn >> Fe (d) Fn ≈ Fe (5) All the nucleons in an atom are held by (a) nuclear forces (b) vander waal's forces (c) tensor forces (d) coulomb forces	
60	The Nucleus of an atom consists of a tightly packed arrangement of protons and neutrons. These are the two heavy particles in an atom and hence 99.9% of the mass is concentrated in the nucleus. Of the two, the protons possess a net positive charge and hence the nucleus of an atom is positively charged on the whole and the negatively charged electrons revolve around the central nucleus. Since the mass concentration at the nucleus of an atom is immense the nuclear forces holding the protons and the neutrons together are also large. a) Two nuclei have mass numbers in the ratio 1 : 2. What is the ratio of their nuclei densities? b) Write any two characteristics of nuclear force c) Show that nuclear density in a given nucleus is independent of mass number A. OR	

	c) The mass of a nucleus in its ground state is always less than the total mass of its constituents – neutrons and protons. Explain.	

ANSWER KEY - MCQ

1	2	3	4	5	6

d	c	b	a	b	b
7	**8**	**9**	**10**	**11**	**12**
a	C	C	a	b	b
13	**14**	**15**	**16**	**17**	**18**
d	d	d	a	a	b
19	**20**				
b	a				

ANSWER KEY – FILL IN THE BLANKS

1	**2**	**3**	**4**	**5**
Balmer series	Negative	Ionisation potential	zero	Disintegration
6	**7**	**8**	**9**	**10**
t= 1.44 T	T =0.693/λ	10^{15}	Radioactivity	1836

ANSWER KEY – Assertion -Reason

1	**2**	**3**	**4**	**5**	**6**
A	B	B	A	A	C
7	**8**				
C	**C**				