+2 PHYSICS
STUDY MATERIAL

Unit – 8 ATOMIC AND NUCLEAR PHYSICS

It includes

- Book Back Answers
- One Marks With Hints
- Book Back Problem Solution
- Book Inside Questions
- Concept Based One Marks

Unit – 8 ATOMIC AND NUCLEAR PHYSICS

I. Multiple Choice Questions (Book Back)

1.Suppose an alpha particle accelerated by a potential of V volt is allowed to collide with a nucleus whose atomic number is Z , then the distance of approach of alpha particle to the nucleus is

(a) $14.4\frac{Z}{V}\tilde{\text{Å}}$ (b) $14.4\frac{V}{Z}\tilde{\text{Å}}$ (c) $1.44\frac{Z}{V}\tilde{\text{Å}}$ (d) $1.44\frac{V}{Z}\tilde{\text{Å}}$

Hint; $r_o = \frac{1}{4\pi\varepsilon_o}\frac{Ze}{V}$ sub value for $\frac{1}{4\pi\varepsilon_o}$ & e **(c) $1.44\frac{Z}{V}\tilde{\text{Å}}$**

2. In an hydrogen atom , the electron revolving in the fourth orbit has angular momentum equals to

(a)h (b)$\frac{h}{\pi}$ (c)$\frac{4h}{\pi}$ (d) $\frac{2h}{\pi}$

Hint : L = mvr = $\frac{nh}{2\pi}$

Here n = 4 →L = mvr = $\frac{4h}{2\pi}$ **(d) $\frac{2h}{\pi}$**

3.Atomic number of H – like atom with ionization potential 122.4 V for n =1 is

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

Hint: $V = \frac{13.6}{n^2}Z^2$

Here n = 1 V = 122.4 → $Z^2 = \frac{122.4}{13.6} = 9$ **Therefore Z = 3** **(c) 3**

4.The ratio between the first three orbits of hydrogen atom is

(a) 1:2:3 (b)2:4:6 (c)1:4:9 (d) 1:3:5

Hint; $r_n = 0.529n^2$

Here n values are 1 , 2 , 3

Ratio of first three orbit = $r_1 : r_2 : r_3 = n_1^2 : n_2^2 : n_3^2 \to 1^2 : 2^2 : 3^2$ **(c)1:4:9**

5.The charge of cathode rays is

(a) positive (b) negative (c) neutral (d) not defined

Hint :Cathode rays nothing but beam of electrons , so it is negatively charges (b) negative

6.In J.J Thomson experiment , a beam of electron is replaced by that of muons (particle with same charge as that of electrons but mass is 208 times that of electrons).No deflection condition is achieved by only if

(a). B is increased by 208 times (b) B is decreased by 208 times
(c) B is increased by 14.4 times (d) B is decreased by 14.4 times

Hint: In the condition of no deflection $\frac{e}{m} = \frac{E^2}{2VB^2}$

m is increased by 208 then be should be increased by $\sqrt{208} = 14.4$

(c) B is increased by 14.4 times

7. The ratio of the wavelengths for the transition from *n* =2 to *n* = 1 in Li^{++} , He^{+} and H is

(a) 1:2:3 (b)1:4:9 (c)3:2:1 (d) 4:9:36

Hint :Binding energy = $[Zm_p + Nm_n - M(N,Z)]c^2$

On arranging for mass we will get $M(N, Z) = NM_n + ZM_p - B/c^2$

13. A radioactive nucleus (initial mass number A and atomic number Z) emits 2α and 2 positrons. The ratio of number of neutrons to that of proton in the final nucleus will be

(a) $\frac{A-Z-4}{Z-2}$ (b) $\frac{A-Z-2}{Z-6}$ (c) $\frac{A-Z-4}{Z-6}$ (a) $\frac{A-Z-12}{Z-4}$

Hint : After two alpha particle ${}^{4}_{2}He$ emission , atomic number decreases by 4 and mass number decreases by 8 and after two positrons ${}^{0}_{1}e$, atomic number decreases by 2

Totally atomic number decreases by 6 and mass number decreases by 8

$\frac{N_n}{N_p} = \frac{A-8+Z-6}{Z-6} = \frac{A-Z-2}{Z-6}$

(b) $\boldsymbol{\frac{A-Z-2}{Z-6}}$

14. The half-life period of a radioactive element A is same as the mean life time of another radioactive element B. Initially both have the same number of atoms. Then

(a) A and B have the same decay rate initially

(b) A and B decay at the same rate always

(c) B will decay at faster rate than A

(d) A will decay at faster rate than B.

Hint: Given $(t_{1/2})A = \tau(B)$

$$\frac{0.6931}{\lambda(A)} = \frac{1}{\lambda(B)}$$

$$\lambda(A) = 0.693\lambda(B)$$

(c) B will decay at faster rate than A

15. A system consists of N_o nucleus at t=0. The number of nuclei remaining after half of a half-life (that is, at time t = $\frac{1}{2}T_{\frac{1}{2}}$

(a) $\frac{N_o}{2}$ (b) $\frac{N_o}{\sqrt{2}}$ (c) $\frac{N_o}{4}$ (d) (a) $\frac{N_o}{8}$

Hint : N = $N_o\left(\frac{1}{2}\right)^n$

t = $\frac{1}{2}T_{\frac{1}{2}}$

N = $N_o\left(\frac{1}{2}\right)^{1/2}$

(b) $\boldsymbol{\frac{N_o}{\sqrt{2}}}$

Book inside

1. The pressure at which the walls of the glass discharge tube fluoresce with green colour is
a) 0.001 mm of Hg **b)0.01mm of Hg**
c)0.1mmofHg d)1mmofHg

2. Cathode rays possess
a) momentum but not kinetic energy b) kinetic energy but not momentum
c) both momentum and kinetic energy d) neither momentum nor kinetic energy

3. The characteristics of cathode rays depend on the
a) nature of the cathode b) nature of the gas enclosed in the discharge tube
c) nature of the anode
d) neither the nature of anode, cathode nor the nature of the gas enclosed in the discharge tube

4. According to Rutherford atom model, the spectral lines emitted by an atom is
a) continuous spectrum b) line spectrum
c) band spectrum d) continuous absorption spectrum

5. The direction of the electric field in Millikan's oil drop experiment is
a) down wards **b) upwards**
c) first upwards then down words d) first downwards then upwards

6. The ascending order of specific charge of electron, proton, neutron, alpha particle will be
a) electron, proton, neutron, alpha particle b) alphaparticle, neutron, electron, proton
c) proton, electron, alphaparticle, neutron **d) neutron, alphaparticle, proton, electron**

7. Wave number is defined as the number of waves
a) produced in one second **b) in a distance of 1 metre**
c) in a distance of X metre d) in a distance of 3 x 10^8 metre

8. In Hydrogen atom which of the following transitions spectral line of maximum frequency
a) 6 → 2 **b)2→1** c)4→3 d)5→2
Hint : $\frac{1}{\lambda} = R\left[\frac{1}{n^2} - \frac{1}{m^2}\right]$

9. The first excitation potential energy or the minimum energy required to excite the atom from ground state of hydrogen atom is
a) 13.6 eV **b) 10.2 eV** c) 3.4 eV d) 1.89 eV
Hint : $E_n = -\frac{13.6}{n^2}$
$\Delta E = E_2 - E_1$
$\Delta E = 3.4 - 13.6 = 10.2$

a) Zero b) 10.2 eV c) 6.8 eV **d) 3.4 eV**

34. A nucleus with Z=92 emits the following sequence $\alpha,\alpha,\beta^-,\beta^-,\alpha,\alpha,\alpha,\alpha,\beta^-,\beta^-,\alpha,\beta^+,\beta^+,\alpha$ The Z of the resulting nucleus is

a) 76 **b) 78** c)74 d) 82

Hint : Atomic number of final nucleus

= 92 -2 (no.of α - Particle) + 1 (No. of β^- - 1(No.of β^+ Particle)

= 92 - 2 $\times$ 8 + 1 $\times$ 4 - 1 $\times$ 2

= 78

35. The ionisation Potential of hydrogen atom is 13.6 eV. An electron in the ground state absorbs Photon of energy 12.75 eV. How many different spectral lines can one expect when electron make a down ward transition

a) 1 b) 2 c) 6 **d) 4**

Hint : $\Delta E = E_n - E_1$

$E_n = \Delta E + E_1 = 12.75 - 13.6 = -0.85$

$E_n = -\frac{13.6}{n^2}$

On solving you will get n = 4

36. The binding energy Per nucleon of deuteron ${}^2_1H$ and Helium nucleus(${}^4_2He$□ is 1.1 MeV and 7.0 MeV respectively. If two deuteron nucleus react to form a single helium nucleus, the energy released is

a)23.6 MeV b) 26.9 MeV c) 13.9 MeV d) 19.2 MeV

Hint : ${}^2_1H + {}^2_1H \rightarrow {}^4_2He$

Binding energy of nucleus = 4 (7) – [2 (1.1) +2 (1.1) = 28 – 4.4 = 23.6 eV

37.In gamma decay

a)there is change in atomic number b)there is change in mass number

c)there is no changes in both atomic and mass number d)none of these

38. The binding energy Per nucleon for the Parent nucleus is E_1 and then daughter nucleus is E_2

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

39. A and B are two radioactive substance whose half lives are 1 and 2 years respectively. Initially 10 g of A and 1 g of B is taken. The time after which they will have same quantity remaining is

a)3.6 years b)6.6 years c) 5years d)3 years

Hint : $t_{1/2}A = 1$ $t_{1/2}B = 2$

$N_o(A) = 10$ $N_o(B) = 1$

Find decay constant for both substance

Equate radioactive law for both and you will get 6.6 years

40. The energy released by the fission of one uranium atom is 200 MeV. The number of fission Per second required to Produce 3.2 w of Power is

a) 10^{10} **b) 10^{11}** c) 10^{12} d) 10^{7}

Hint : Refer Exercise problem : 9

41. The innermost orbit of the hydrogen atom has a radius 0.53 A. what is radius of 2nd orbit is ?

a) 3.12 Å b) 4.12 Å c) 5.12 Å **d) 2.12 Å**

Hint : $r_n = 0.53\, n^2$ Å where n = 2 Therefore $r_n = 4 \times 0.53 = 2.12$

42. The ratio of minimum to maximum wave length in Balmer series is

a) $\frac{4}{9}$ **b) $\frac{5}{9}$** c) $\frac{7}{9}$ d) $\frac{8}{9}$

Hint : $\frac{1}{\lambda} = R\left[\frac{1}{n^2} - \frac{1}{m^2}\right]$

Maximum n = 3 Minimum n = ∞

You will get $\frac{4}{R}$ for maximum and $\frac{5R}{36}$ for minimum

By dividing min to max you will get $\frac{5}{9}$

43. A radioactive substance decays to $\frac{1}{16}$th of its initial activity in 40 days , then the half life of the radioactive substance is expressed in day is

a) 20 **b) 10** c) 30 d) 50

Hint : $\frac{N}{N_o} = \left(\frac{1}{2}\right)^{\frac{t}{T^{1}/_{2}}}$

$$\frac{1}{16} = \left(\frac{1}{2}\right)^{\frac{40}{T^{1}/_{2}}}$$

$16 = 2^{\frac{40}{T^{1}/_{2}}}$

On solving you will get 10 days

II Short answer questions (Book Back)

1. What are cathode rays?.

It is beam of electrons travelling from cathode (negatively charged) to anode (positively charged) at a pressure of 0.01 mm of Hg in discharge tube across a voltage difference between the electrodes

2. Write the properties of cathode rays.

1) When the cathode rays are allowed to fall on matter, they produce heat. They affect the photographic plates and also produce fluorescence when they fall on certain crystals and minerals.
2) When the cathode rays fall on a material of high atomic weight, x-rays are produced.
3) Cathode rays ionize the gas through which they pass.
4) The speed of cathode rays is up to $\left(\frac{1}{10}\right)^{th}$ of the speed of light.
5) Cathode rays possess energy and momentum and travel in a straight line with high speed of the order of 10^7m s^{-1}. The direction of deflection by electric field and magnetic field indicates that they are negatively charged particles.

3. Give the results of Rutherford alpha scattering experiment.

- Most of the alpha particles are un-deflected through the gold foil and went straight.
- Some of the alpha particles are deflected through a small angle.
- A few alpha particles (one in thousand) are deflected through the angle more than 90°
- Very few alpha particles returned back (back scattered) –that is, deflected back by 180°

4. Write down the postulates of Bohr atom model.

1) The electron in an atom **moves around nucleus in circular orbits** under the influence of Coulomb electrostatic force of attraction. This Coulomb force gives necessary centripetal force for the electron to undergo circular motion.

2) Electrons in an atom revolve around the nucleus only in certain discrete orbits called stationary orbits where it does not radiate electromagnetic energy. Only those discrete orbits allowed are stable orbits

3) Energy of orbits are not continuous but discrete. This is called the quantization of energy.
4) An electron can jump from one orbit to another orbit by absorbing or emitting a photon whose energy is equal to the difference in energy (ΔE) between the two orbital levels

$$\Delta E = E_{final} - E_{initial} = h\upsilon = h\frac{c}{\lambda}$$

10. Write a general notation of nucleus of element X. What each term denotes?

$^{A}_{Z}X$

A – Mass number

Z – Atomic number

11. What is isotope? Give an example.

Isotopes are atoms of the **same element** having **same atomic number *Z*,** but different mass number *A*.

Example : $^{1}_{1}H$, $^{2}_{1}H$, $^{3}_{1}H$

12. What is isotone? Give an example.

Isotones are the atoms of different elements having same number of neutrons.

Example : $^{13}_{6}C$, $^{12}_{5}B$

13. What is isobar? Give an example.

Isobars are the atoms of different elements having the same mass number *A*, but different atomic number *Z*.

Example : $^{40}_{18}Ar$, $^{40}_{17}Cl$

14. Define atomic mass unit *u*.

One atomic mass unit (*u*) is defined as the 1/12th of the mass of the isotope of carbon $^{12}_{6}C$

$$1u = 1.660 \times 10^{-27} kg$$

15. Show that nuclear density is almost constant for nuclei with *Z* > 10. (or) Calculate the density of the nucleus with mass number *A*.

$$\rho = \frac{mass\ of\ nuclei}{volume\ of\ nuclei} \ldots\ldots.(1)$$

$$mass\ of\ nuclei = A.m \ \ldots.(2)$$

Where m is mass of proton

$$volume\ of\ nuclei = \frac{4}{3}\pi R^3 \ldots\ldots.(3)$$

$R = R_o A^{1/3}$

Sub R value in 3

$$volume\ of\ nuclei = \frac{4}{3}\pi R_o^3 \left(A^{1/3}\right)^3$$

$$= \frac{4}{3}\pi R_o^3 A \ldots\ldots.(4)$$

Sub (2) & (3) in (1)

$$\rho = \frac{A.m}{\frac{4}{3}\pi R_o^3 A} = \frac{m}{\frac{4}{3}\pi R_o^3}$$

Since density of the nuclei equation does not contain any mass number (A) term therefore nuclear density is almost constant for nuclei with *Z* > 10.

24. What is half-life of nucleus? Give the expression.

It is time required for nucleus initially present to reduce one half of its initial amount .

$N = N_o/2$ $T = T_{1/2}$

$$T_{1/2} = \frac{0.6931}{\lambda} secs$$

25. What is meant by activity or decay rate? Give its unit.

Activity (R) or decay rate which is the number of nuclei decayed per second

$$R = \left|\frac{dN}{dt}\right|$$

$$R = \lambda N$$

Activity at any time t is equal to the product of the decay constant and number of undecayed nuclei at the same time t

Unit : Becquerel

26. Define curie.

- It is a unit of radioactivity corresponding to **3.7×10^{10}** disintegration per second
- One curie is defined as number od decays per second in 1g of radium and is equal to 3.7×10^{10} decays per second

27. What are the constituent particles of neutron and proton?

- Protons and neutrons are not fundamental particles; in fact they are made up of quarks.
- **Proton** is made up of **two up quarks** and **one down quark** and **neutron** is made up of **one up quark** and **two down quarks**

Book inside

1.What are the Conclusion made by Rutherford based on α scattering experiment

- An atom has a lot of empty space and contains a tiny matter known as nucleus whose size is of the order of 10^{-14} m.
- The nucleus is positively charged and most of the mass of the atom is concentrated in nucleus.
- The nucleus is surrounded by negatively charged electrons.
- Since static charge distribution cannot be in a stable equilibrium, he suggested that the electrons are not at rest and they revolve around the nucleus in circular orbits like planets revolving around the sun.

2.Write down the empirical formula for the radius of nucleus.

$$R = R_o A^{1/3}$$

A – Mass number

$R_o = 1.2$ F $= 1.2 \times 10^{-15}$

3. Drawbacks of Rutherford model

- This model fails to explain the distribution of electrons around the nucleus and also the stability of the atom.
- Rutherford model could not account for the stability of atoms.
- According to this model, emission of radiation must be continuous and must give continuous emission spectrum but experimentally we observe only line (discrete) emission spectrum for atoms.

III Long answer questions (Book Back)

1. Explain the J.J. Thomson experiment to determine the specific charge of electron.

Principle

In the presence of electric and magnetic fields, the cathode rays are deflected. By the variation of electric and magnetic fields, mass normalized charge or the specific charge (charge per unit mass) of the cathode rays is measured.

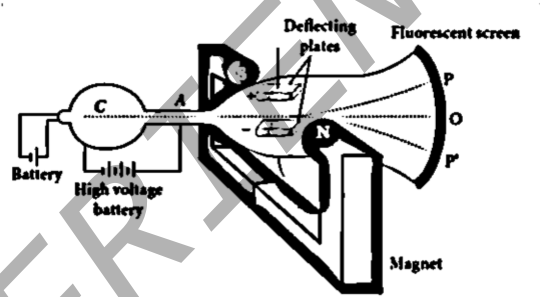

Figure 8.3 Arrangement of J.J. Thomson experiment to determine the specific charge of an electron

Construction

- A highly evacuated discharge tube is used and cathode rays (electron beam) produced at cathode are attracted towards anode disc A.
- Anode disc is made with pin hole in order to allow only a narrow beam of cathode rays.
- These cathode rays are now allowed to pass through the parallel metal plates, maintained at high voltage.
- Further, this gas discharge tube is kept in between pole pieces of magnet such that both electric and magnetic fields are perpendicular to each other.
- When the cathode rays strike the screen, they produce scintillation and hence bright spot is observed. This is achieved by coating the screen with zinc sulphide.

Working

Determination of velocity of cathode rays

- For a fixed electric field between the plates, the magnetic field is adjusted such that the cathode rays (electron beam) strike at the original position O
- This means that the magnitude of electric force is balanced by the magnitude of force due to magnetic field .

Let *e* be the charge of the cathode rays,

Force due to electric field = eE

Force due to magnetic field = Bev

$$Ee = Bev$$

$$v = \frac{E}{B}$$

Determination of specific charge

- Since the cathode rays (electron beam) are accelerated from cathode to anode, the potential energy of the electron beam at the cathode is converted into kinetic energy of the electron beam at the anode.
- Let V be the potential difference between anode and cathode, then the potential energy is eV.
- Then from law of conservation of energy,

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

$$\frac{e}{m} = \frac{v^2}{2V}$$

sub $v = \frac{E}{B}$ in above equation we get

$$\frac{e}{m} = \frac{1}{2V}\frac{E^2}{B^2}$$

Substituting the values of E, B and V, the specific charge can be determined as

$$\frac{e}{m} = 1.7 \times 10^{11} Ckg^{-1}$$

Deflection of charge only due to uniform electric field

When the magnetic field is turned off, the deflection is only due to electric field. The deflection in vertical direction is due to the electric force.

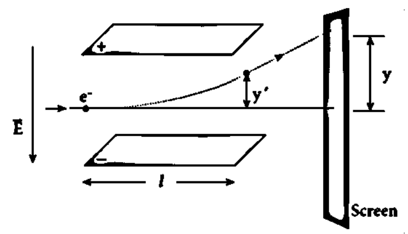

Figure 8.5 Deviation of path by applying uniform electric field

$F_e = eE$........(1)

m be the mass of the electron and by applying Newton's second law of motion, acceleration of the electron is

$a_e = \frac{1}{m}F_e$

sub (1) in above equation

$a_e = \frac{1}{m}eE$........(2)

y - deviation produced from the original position on the screen .
Let the initial upward velocity be u = 0 before entering the parallel plates.
t - Time taken to travel in electric field
l – length of the one of the plates

$t = \frac{l}{v}$

deflection $y' = ut + \frac{1}{2}at^2$

Here u = 0 $a_e = \frac{1}{m}eE$

$$y' = \frac{1}{2}\frac{1}{m}eE\left(\frac{l}{v}\right)^2$$

(d) viscous force F_v

(a) Determination of radius of the droplet

- When the electric field is switched off, the oil drop accelerates downwards.
- Due to the presence of air drag forces, the oil drops easily attain its terminal velocity and moves with constant velocity.
- This velocity can be carefully measured by noting down the time taken by the oil drop to fall through a predetermined distance.
- The free body diagram of the oil drop is shown in Figure 8.7 (a), we note that viscous force and buoyant force balance the gravitational force.
- Let the gravitational force acting on the oil drop (downward) be $F_g = mg$
- Let us assume that oil drop to be spherical in shape. Let ρ be the density of the oil drop, and r be the radius of the oil drop, then the mass of the oil drop can be expressed in terms of its density as

$$\rho = \frac{m}{v}$$

$$m = \rho\left(\frac{4}{3}\pi r^3\right) \qquad \text{(volume of the sphere, } V = \frac{4}{3}\pi r^3\text{)}$$

$$F_g = mg$$

Sub m value in above equation

$$\boldsymbol{F_g = \rho\left(\frac{4}{3}\pi r^3\right) g}$$

Let σ be the density of the air, the upthrust force experienced by the oil drop due to displaced air is

$$\boldsymbol{F_b = \sigma\left(\frac{4}{3}\pi r^3\right) g}$$

Once the oil drop attains a terminal velocity v, the net downward force acting on the oil drop is equal to the viscous force acting opposite to the direction of motion of the oil drop.

From Stokes law, the viscous force on the oil drop is

$$\boldsymbol{F_v = 6\pi r v \eta}$$

From the free body diagram

$$\boldsymbol{F_g = F_v + F_b}$$

$$\rho\left(\frac{4}{3}\pi r^3\right) g = \sigma\left(\frac{4}{3}\pi r^3\right) g + \boldsymbol{6\pi r v}\eta$$

$$\boldsymbol{6\pi r v}\eta = \frac{4}{3}\pi r^3(\rho - \sigma)g$$

$$\boldsymbol{r = \left[\frac{9\pi v\eta}{2((\rho - \sigma)g}\right]^{\frac{1}{2}}}$$

(b) Determination of electric charge

- When the electric field is switched on, charged oil drops experience an upward electric force (qE). Among many drops, one particular drop can be chosen in the field of view

From (2) & (4)

$\boldsymbol{U_n = -2K.E_n}$**.......(5)**

Total energy $\boldsymbol{E_n = K.E_n + U_n}$.......(6)

From (5)

$E_n = K.E_n - 2K.E_n = -K.E_n$

$E_n = -\frac{1}{8\varepsilon_0^2}\frac{Z^2 me^4}{h^2 n^2}$.........(7)

For hydrogen atom Z = 1

$\boldsymbol{E_n = -\frac{1}{8\varepsilon_0^2}\frac{me^4}{h^2n^2} joule}$**.........(8)**

n - principal quantum number.

The negative sign in equation (8) indicates that the electron is bound to the nucleus. Substituting the values of mass and charge of an electron (*m* and *e*), permittivity of free space ε_0 and Planck's constant *h* and expressing in terms of *eV*, we get

$$\boldsymbol{E_n = 13.6\frac{1}{n^2}}$$

4. Discuss the spectral series of hydrogen atom.

The wavelengths of the spectral lines $\boldsymbol{\frac{1}{\lambda} = R\left(\frac{1}{n^2} - \frac{1}{m^2}\right) = \bar{\upsilon}}$

R – Rydberg constant (R = 1.09737 x 10^7 m^{-1})

m and ***n*** are positive integers such that *m* > *n*.

$\bar{\upsilon}$ – wave number which is inverse of wavelength,

(i) Lyman series

When the electron jumps from any of the outer orbits (m = 2 , 3, 4…) to the first orbit(n= 1), the spectral lines emitted are in the **ultraviolet region** of the spectrum and they are said to form a series called Lyman series

m = 2 , 3, 4… n = 1 $\boldsymbol{\bar{\upsilon} = \frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{m^2}\right)}$

(ii) Balmer series

When the electron jumps from any of the outer orbits(m = 3, 4…) to the second orbit (n = 2), we get a spectral series called the Balmer series.

All the lines of this series in hydrogen have their wavelength in the **visible region.**

m = 3, 4… n = 2 $\boldsymbol{\bar{\upsilon} = \frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{m^2}\right)}$

(iii) Paschen series

This series consists of all wavelengths which are emitted when the electron jumps from outer most orbits (m = 4 , 5 , 6…..) to the third orbit (n=3)

This series is in the infrared region **(near IR)**

m = 4,5 , 6… n = 3 $\boldsymbol{\bar{\upsilon} = \frac{1}{\lambda} = R\left(\frac{1}{3^2} - \frac{1}{m^2}\right)}$

(iv) Brackett series

6. Explain in detail the nuclear force.

Strong attractive force between protons to overcome the repulsive Coulomb's force and holds the nucleus together is called strong nuclear force.

Properties of strong nuclear force are

(i) The strong nuclear force is of **very short range**, acting only up to a distance of a few Fermi.

(ii) It is the **strongest force** in nature.

(iii) The strong nuclear force is attractive and acts with an equal strength between proton-proton, proton-neutron, and neutron – neutron.**(charge independent)**

(iv) It does not act on the electrons , therefore it **does not affect the chemical properties of atom**

7. Discuss the alpha decay process with example.

When an unstable nucleus decay by an emitting alpha particle $({}_2^4He)$, it losses two proton and two neutrons.

Due to this its atomic number decreases by 2 and mass number decreases by 4

$$ {}_Z^AX \rightarrow {}_{Z-2}^{A-4}Y + {}_2^4He $$

$X - parent\ nucleus$

Y – daughter nucleus

Example : Decay of uranium to thorium with the emission of alpha particle

$ {}_{92}^{238}U \rightarrow {}_{90}^{234}Th + {}_2^4He $

Total mass of daughter nucleus and helium particle is always less than that of parent nucleus

The difference in mass is released as energy called disintegration energy Q

Q = $(m_x - m_y - m_\alpha)c^2$

For spontaneous decay (natural radioactivity) Q **>0.**

In alpha decay process, the disintegration energy is certainly positive

8. Discuss the beta decay process with examples.

In beta decay, a radioactive nucleus emits either electron or positron. If electron (e^-) is emitted, it is called β^- decay and if positron (e^+) is emitted, it is called β^+ decay.

β^+ decay

In this decay , the atomic number is decreased by one and the mass number remains the same.

$$ {}_Z^AX \rightarrow {}_{Z-1}^{A}Y + e^+ + v $$

It implies that the element X becomes Y by giving out an electron and antineutrino $\bar{v}$

$$ p \rightarrow n + e^+ + v $$

Example : $ {}_{11}^{22}Na \rightarrow {}_{10}^{22}Ne + e^+ + v $

10. Obtain the law of radioactivity.

At any instant t, the number of decays per unit time, called rate of decay $\left(\frac{dN}{dt}\right)$ proportional to the number of nuclei (N) at the same instant.

$$\frac{dN}{dt} \; \alpha \; N$$

$$\boldsymbol{\frac{dN}{dt} = -\lambda N \ldots\ldots\ldots\ldots(1)}$$

$\boldsymbol{\lambda}$ – Decay constant

Decay constant is different for different radioactive sample and the negative sign in the equation implies that the N is decreasing with time.

Here dN represents the number of nuclei decaying in the time interval dt.

$t = 0 \quad N = N_o$

By integrating the equation (1), we can calculate the number of undecayed nuclei N at any time t.

$$\int_{N_o}^{N} \frac{dN}{N} = -\int_{0}^{T} \lambda \, dt$$

$$[\ln N]_{N_o}^{N} = -\lambda t$$

$$\ln\left[\frac{N}{N_o}\right] = -\lambda t$$

Taking exponentials on both sides, we get

$$\mathbf{N = N_o e^{-\lambda t} \ldots\ldots\ldots\ldots(2)}$$

Eq(2) is called the law of radioactive decay.

Number of atoms is decreasing exponentially over the time. This implies that the time taken for all the radioactive nuclei to decay will be infinite.

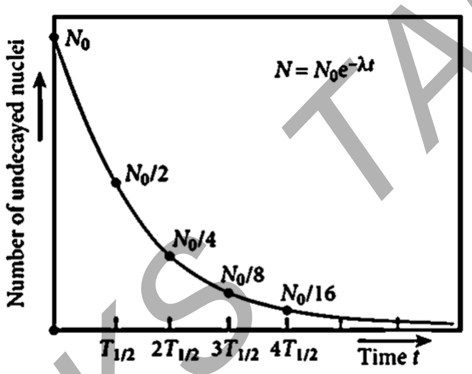

Figure 8.26 Law of radioactive decay

11.

11.Discuss the properties of neutrino and its role in beta decay.

1. It has **zero charge**
2. It has an antiparticle called anti-neutrino.
3. Recent experiments showed that the neutrino has **very tiny mass.**

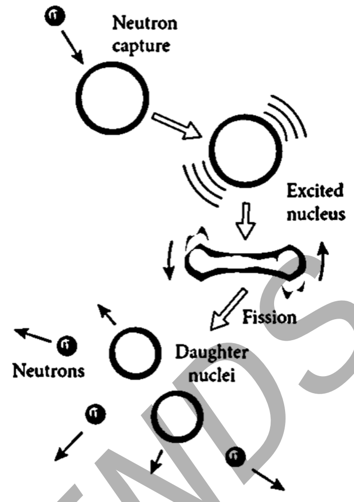

Figure 8.27 Nuclear fission

- Uranium undergoes fission reaction in 90 different ways
- The most common fission reactions of $^{235}_{92}U$

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U^{*} \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n + Q$$

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U^{*} \rightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + 2^{1}_{0}n + Q$$

Q is energy released during the decay of each uranium nuclei. When the slow neutron is absorbed by the uranium nuclei, the mass number increases by one and goes to an excited state $^{235}_{92}U^{*}$

- Excited state does not last longer than 10^{-12} s and decay into two daughter nuclei along with 2 or 3 neutrons.
- From each reaction, on an average, 2.5 neutrons are emitted.

14. Discuss the process of nuclear fusion and how energy is generated in stars?

- When two or more light nuclei (A<20) combine to form a heavier nucleus, then it is called nuclear fusion.
- The nuclear fusion never occurs at room temperature unlike nuclear fission.
- It is because when two light nuclei come closer to combine, it is strongly repelled by the coulomb repulsive force.
- To overcome this repulsion, the two light nuclei must have enough kinetic energy to move closer to each other such that the nuclear force becomes effective.
- This can be achieved if the temperature is very much greater than the value 10^7 K.
- When the surrounding temperature reaches around 10^7K, lighter nuclei start fusing to form heavier nuclei and this resulting reaction is called thermonuclear fusion reaction.

Energy generation in stars:

- The natural place where nuclear fusion occurs is the core of the stars, since its temperature is of the order of 10^7K.
- Energy generation in every star is only through thermonuclear fusion.
- Most of the stars including our Sun fuse hydrogen into helium and some stars even fuse helium into heavier elements.
- The sun's interior temperature is around 1.5×10^7 K.
- The sun is converting hydrogen into helium every second and it has enough hydrogen such that these fusion lasts for another 5 billion years
- **proton-proton cycle** of fusion reaction.
- This cycle consists of three steps
- $^{1}_{1}H + ^{1}_{1}H \rightarrow ^{2}_{1}H + e^{-} + \nu$
- $^{1}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}H + \gamma$
- A number of reactions are possible in the third step. But the dominant one is

- $_{2}^{3}H + _{2}^{3}H \rightarrow _{2}^{4}H + _{1}^{1}H + _{1}^{1}H$

15. Describe the working of nuclear reactor with a block diagram.

- Nuclear reactor is a system in which the nuclear fission takes place in a self-sustained controlled manner and the energy produced is used either for research purpose or for power generation.
- The main parts of a nuclear reactor are
- fuel, moderator and control rods. In addition to this, there is a cooling system which is connected with power generation set up.

Fuel:

- The fuel is fissionable material, usually uranium or plutonium. Naturally occurring uranium contains only 0.7% of $_{92}^{235}U$
- 99.3% are $_{92}^{238}U$.
- So the $_{92}^{238}U$ must be enriched such that it contains at least 2 to 4% of $_{92}^{235}U$
- A neutron source is required to initiate the chain reaction for the first time.
- A mixture of beryllium with plutonium or polonium is used as the neutron source.
- During fission of $_{92}^{235}U$, only fast neutrons are emitted but the probability of initiating fission by it in another nucleus is very low.
- Slow neutrons are preferred for sustained nuclear reactions.

Moderators

- The moderator is a material used to convert fast neutrons into slow neutrons.
- Usually the moderators are chosen in such a way that it must be very light nucleus having mass comparable to that of neutrons. Hence, these light nuclei undergo collision with fast neutrons and the speed of the neutron is reduced
- Most of the reactors use **water, heavy water (D_2O) and graphite** as moderators.
- The blocks of uranium stacked together with blocks of graphite (the moderator) to form a large pile

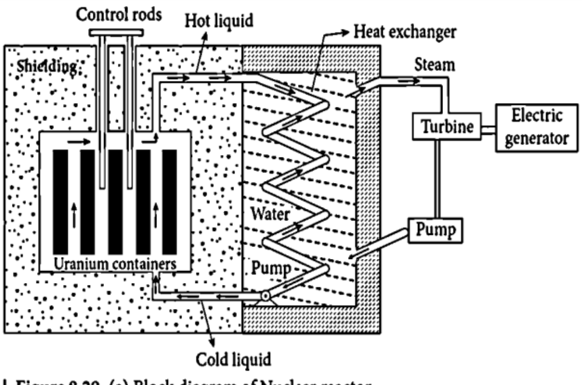

Figure 8.29 (a) Block diagram of Nuclear reactor

Control rod :

- The control rod are use to adjust the reaction rate .
- During each fission, on an average 2.5 neutrons are emitted and in order to have the controlled chain reactions, only one neutron is
- allowed to cause another fission and the remaining neutrons are absorbed by the control rod .
- **Control rods :** cadmium or boron These rods are inserted into the
- uranium blocks

- Murray Gellman and George Zweig theoretically proposed that protons and neutrons are not fundamental particles; in fact they are made up of quarks.
- These quarks are now considered elementary particles of nature.
- Electrons are fundamental or elementary particles because they are not made up of anything.
- There are six quarks namely, up, down, charm, strange, top and bottom and their antiparticles.
- All these quarks have fractional charges. For example**, charge of up quark is** $+\frac{2}{3}e$ and that of **down quark is** $-\frac{1}{3}e$
- According to quark model, proton is made up of two up quarks and one down quark and neutron is made up of one up quark and two down quarks

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Long answers

1.Explain about discovery of neutrons and its properties

- When beryllium was bombarded with α particles, highly penetrating radiation was emitted.
- This radiation was capable of penetrating the thick layer of lead and was unaffected by the electric and magnetic fields.
- James Chadwick discovered that those radiations are not EM waves but they are particles of mass little greater than the mass of the proton and had no charge.
- He called them as neutrons.
- $^{9}_{4}Be + ^{4}_{2}He \rightarrow ^{12}_{6}C + ^{1}_{0}n$
- $^{1}_{0}n - Denotes\ neutron$

Properties

- Neutrons are stable inside the nucleus. But outside the nucleus they are unstable. If the neutron comes out of the nucleus (free neutron), it decays with emission of proton,
- electron, and antineutrino with the half life of 13 minutes.

Neutrons are classified according to their kinetic energy as

(i) slow neutrons (0 to 1000 eV)

(ii) fast neutrons (0.5 MeV to 10 MeV).

The neutrons with average energy of about 0.025 eV in thermal equilibrium are called thermal neutron, because at 298K, the thermal energy $kT \sim 0.025$eV

Slow and fast neutrons play a vital role in nuclear reactors.

2.Explain about J. J. Thomson's Model and its limitations

- In this model, the atoms are visualized as homogeneous spheres which contain uniform distribution of positively charged particles .

$$\vec{F}_{coulomb} = \frac{1}{4\pi\varepsilon_0}\frac{(+Ze)(-e)}{r_n^2}\hat{r}$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r_n^2}\hat{r}$$

This force provides necessary centripetal force

$$\vec{F}_{centripetal} = \frac{mv_n^2}{r_n}\hat{r}$$

m – Mass of electron

v_n – velocity of electron in a circular orbit

$$\left|\vec{F}_{coulomb}\right| = \left|\vec{F}_{centripetal}\right|$$

$$\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r_n^2} = \frac{mv_n^2}{r_n}$$

Multiply and divide by m

$$\boldsymbol{r_n = \frac{4\pi\varepsilon_0 (mv_n r_n)^2}{Zme^2}} \quad \textbf{.........(1)}$$

From Bohr's assumption, the angular momentum quantization condition $mv_n r_n = n\hbar$

Sub $mv_n r_n = n\hbar$ in (1)

$$r_n = \frac{4\pi\varepsilon_0 (n\hbar)^2}{Zme^2}$$

$$= \left(\frac{\varepsilon_0 h^2}{\pi m e^2}\right)\frac{n^2}{Z} \qquad \left(\hbar = \frac{h}{2\pi}\right)$$

n ϵ natural number

ε_0 , h , e and π are constant

$$r_n = a_0 \frac{n^2}{Z}$$

$$r_n \alpha\, n^2$$

$$\boldsymbol{a_0 = \frac{\varepsilon_0 h^2}{\pi m e^2} = 0.529\tilde{\text{Å}}}$$

This is known as Bohr radius which is the smallest radius of the orbit in an atom. Bohr radius is also used as unit of length called Bohr. 1 Bohr = 0.53 Å

For hydrogen atom (Z = 1), the radius of n^{th} orbit is

$$\boldsymbol{r_n = a_0 n^2}$$

Bohr's angular momentum quantization condition leads to

$$mv_n r_n = m\frac{n^2}{Z}a_0\frac{n^2}{Z} = n\frac{h}{2\pi}$$

$$\boldsymbol{v_n = \frac{h}{2\pi m a_0}\frac{Z}{n}} \qquad v_n\, \alpha\, \frac{1}{n}$$

5.Explain about chain reaction

- When one $^{235}_{92}U$ nucleus undergoes fission, the energy released might be small.
- But from each fission reaction, three neutrons are released.
- These three neutrons cause further fission in another three nuclei which in turn produce nine neutrons.
- These nine neutrons initiate fission in another 27 $^{235}_{92}U$nuclei and so on.
- This is called a chain reaction and the number of neutrons goes on increasing almost in geometric progression.
- There are two kinds of chain reactions**: (i) uncontrolled chain reaction (ii) controlled chain reaction.** In an uncontrolled chain reaction, the number of neutrons multiply indefinitely and the entire amount of energy released in a fraction of second.
- The atom bomb is an example of nuclear fission in which uncontrolled chain reaction occurs.
- If the chain reaction is controllable, then we can harvest an enormous amount of energy for our needs. It is achieved in a controlled chain reaction.
- In the controlled chain reaction, the average number of neutron released in each stage is kept as one such that it is possible to store the released energy. In nuclear reactors, the controlled chain reaction is achieved and the produced energy is used for power generation or for research purpose.

Exercises

1. Consider two hydrogen atoms H_A and H_B in ground state. Assume that hydrogen atom H_A is at rest and hydrogen atom H_B is moving with a speed and make head-on collide on the stationary hydrogen atom H_A. After the strike, both of them move together. What is minimum value of the kinetic energy of the moving hydrogen atom H_B, such that any one of the hydrogen atoms reaches one of the excitation state.

Given : $u_A = 0$ velocity of B will be u_B

Since mass of both atom = m

Total kinetic energy before collision = $\frac{1}{2}mu_A^2 + \frac{1}{2}mu_B^2$

$$= 0 + \frac{1}{2}mu_B^2$$

After striking they move with the same velocity. Therefore $v_A = v_B = v$

Total kinetic energy after collision = $\frac{1}{2}mv_A^2 + \frac{1}{2}mv_B^2$

$$= \frac{1}{2}mv^2(1+1) = mv^2$$

Change in kinetic energy $\Delta E = \frac{1}{2}mu_B^2 - mv^2$ ……….(1)

By the law of conservation of linear momentum

$m(u_A + u_B) = m(v + v)$

$m(0 + u_B) = 2mv$

m u_B = 2mv

v = $\frac{u_B}{2}$ sub v value in (2)

$$\Delta E = \frac{1}{2}mu_B^2 - m\left(\frac{u_B}{2}\right)^2$$
$$= \frac{1}{4}mu_B^2$$

This loss in kinetic energy is due to excitation of one hydrogen atom .
The ground state (n =1) energy of hydrogen atom is -13.6 eV
The energy of first excited level (n = 2)is – 3.4 eV
Minimum energy required to excite a hydrogen atom from ground state to first excited state is

$$= [-3.4 - (-1.6)]eV$$
$$= 10.2\ eV$$

Loss in kinetic energy in collision is due to energy used up in exciting one of atoms

Thus $\frac{1}{4}mu_B^2 = 10.2\ eV$

$$\frac{1}{2}mu_{min}^2 = 2 \times 10.2$$
$$\frac{1}{2}mu_{min}^2 = 20.4eV$$

2. In the Bohr atom model, the frequency of transitions is given by the following expression

υ= $Rc\left(\frac{1}{n^2} - \frac{1}{m^2}\right)$ where n < m , Consider the following transitions:

Transition	m → n
1	3 → 2
2	2 → 1
3	3 → 1

υ= $Rc\left(\frac{1}{n^2} - \frac{1}{m^2}\right)$

m = 3 and n = 2

$$\upsilon_{3\to2} = Rc\left(\frac{1}{2^2} - \frac{1}{3^2}\right) = \frac{5}{36}$$

m = 2 and n = 1

$$\upsilon_{2\to1} = Rc\left(\frac{1}{1^2} - \frac{1}{2^2}\right) = \frac{3}{4}$$

m = 3 and n = 1

$$\upsilon_{3\to1} = Rc\left(\frac{1}{1^2} - \frac{1}{3^2}\right) = \frac{8}{9}$$

Atom can undergo transition from 3 to 1 either directly or in two steps from 3 to 2 and 2 to 1

$$2.3 \times 10^{17} = \frac{5.97 \times 10^{24}}{\frac{4}{3}\pi r^3}$$

$$r^3 = \frac{5.97 \times 10^{24} \times 3}{2.3 \times 10^{17} \times 4 \times 3.14}$$

$$r^3 = 0.62 \times 10^7$$

r = 183.7 m

5. Calculate the mass defect and the binding energy per nucleon of the $^{108}_{47}Ag$ nucleus. [atomic mass of Ag = 107.905949]

Given : atomic mass of Ag = 107.905949 Number of proton = 47

Number of neutrons = 108 -47 = 61

m_p = 1.00783 m_n = 1.00867

Mass of 47 protons = 47 × 1.00783 = 47.36801

Mass of 61 neutrons = 61 × 1.00867= 61.52887

$$\boldsymbol{\Delta m = [Zm_P + Nm_n - m]}$$

$$= 47.36801 + 61.52887 - 107.905949$$

$$= 108.89688 - 107.905949$$

$$= 0.990931u$$

$$\overline{\boldsymbol{BE}} = \frac{[\boldsymbol{Zm_P + Nm_n - m}]\boldsymbol{c^2}}{\boldsymbol{A}}$$

$$= \frac{0.990931u \times 931\ MeV}{108}$$

$$= \boldsymbol{8.597\ MeV}$$

6. Half lives of two radioactive elements A and B are 20 minutes and 40 minutes respectively. Initially, the samples have equal number of nuclei. Calculate the ratio of decayed numbers of A and B nuclei after 80 minutes.

Given : $t_{1/2}$(A) = 20 min and $t_{1/2}$(B) = 40 min

By given $t_{1/2}$ at the end of 80 minutes A will have Four half lives and B will have two half live

N_A after 80 minutes = $\left(\frac{1}{2}\right)^n N_o = \frac{1}{2^4} N_o = \frac{N_o}{16}$

Number of nucleus decayed = $N_o - \frac{N_o}{16} = \frac{15}{16} N_o$

N_B after 80 minutes = $\left(\frac{1}{2}\right)^n N_o = \frac{1}{2^2} N_o = \frac{N_o}{4}$

Number of nucleus decayed = $N_o - \frac{N_o}{4} = \frac{3}{4} N_o$

the ratio of decayed numbers of A and B nuclei after 80 minutes = $\frac{15}{16} N_o \times \frac{4}{3N_o}$

$$= \mathbf{5 : 4}$$

9. Assuming that energy released by the fission of a single $^{235}_{92}U$ nucleus is 200MeV, calculate the number of fissions per second required to produce 1 watt power.

Given : Energy per fission = 200 MeV

Energy released per fission = $200 \times 10^{6} \times 1.6 \times 10^{-19}$ J = 320×10^{-13}J

N – number of fissions per second producing 1W power

$320 \times 10^{-13} \times N = 1$ J/s

N = $\frac{1}{320\times10^{-13}} = \mathbf{3.125 \times 10^{10} \mathit{Fissions}}$

10.Show that the mass of radium $^{226}_{88}Ra$ with an activity of 1 curie is almost a gram. Given $T_{1/2}$ = 1600 years

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

$\frac{dN}{dt} = 1\ Curie = 3.7 \times 10^{10}\ disintegration/s$

$t_{1/2} = \frac{0.6931}{\lambda} secs$

$\lambda = \frac{0.6931}{1600 \times 365 \times 24 \times 60 \times 60}$

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

$= 3.7 \times 10^{10} \times \frac{1600 \times 365 \times 24 \times 60 \times 60}{0.6931}$

$= 2.6936 \times 10^{21}$

$6.023 \times 10^{23} atoms = 226\ g\ of\ Radium$

$For\ 2.6936 \times 10^{21}\ atom = \frac{226}{6.023 \times 10^{23}} \times 2.6936 \times 10^{21}$

= 1.0107gram

11.Charcoal pieces of tree is found from an archeological site. The carbon-14 content of this charcoal is only 17.5% that of equivalent sample of carbon from a living tree. What is the age of tree?

Given : N = 0.175 N_o $t_{1/2}$ = 5730 years

$t_{1/2} = \frac{0.6931}{\lambda} secs$

$\lambda = \frac{0.6931}{5730} = 1.2094 \times 10^{-4} years$

$\frac{N}{N_o} = e^{-\lambda t}$

t $= log\left(\frac{1}{0.175}\right)\frac{1}{1.2094 \times 10^{-4}}$

Age of tree = 14.408 years