Atomic and Nuclear Physics

physics - 2 | unit - 9

Name :

Standard : 12 Section :

School :

Exam No :

தாமின் புறுவது உலகின் புறக்கண்டு
காமுறுவர் கற்றறிந் தார்

தமக்கு இன்பம் தருகின்ற கல்வியறிவு உலகத்தாருக்கும் இன்பம் தருவதைக் கண்டு,
அறிஞர்கள் மேலும் மேலும் பலவற்றைக் கற்றிட விரும்புவார்கள்

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2 & 3 Marks Questions and Answer

1. What are called cathode rays?

- When the pressure is about ***0.01 mm of Hg***, positive column disappears and a dark space is formed between anode and cathode which is called ***Crooke's dark space***.
- At this time the walls of the tube appear with green colour and some invisible rays emanate from cathode called ***cathode rays***, which are later found be a beam of ***electrons***.

2. Give the properties of cathode rays.

<u>**Properties of cathode rays**</u> :

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

3. Define specific charge.

- Charge per unit mass is called specific charge (or) mass-normalized charge.
- Its unit is $\boldsymbol{C\ kg^{-1}}$

4. Give the results of Rutherford alpha scattering experiment.

<u>**Results of alpha scattering experiment**</u> :

- Most of the alpha particles are undeflected 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°

5. What are the conclusion made by Rutherford from the results of alpha scattering experiments.

<u>**Conclusion made in alpha scattering experiment**</u> : <u>**(Rutherford atom model)**</u>

- Rutherford proposed that 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.

6. What is distance of closest approach? Obtain expression for it.

<u>**Definition**</u> :

- The minimum distance between the centre of the nucleus and the alpha particle just before it gets reflected back through 180° is defined as the distance of closest approach (or) contact distance r_o

<u>**Expression**</u> :

- At this closest distance, all the kinetic energy of the alpha particle will be converted into electrostatic potential energy

$$\frac{1}{2}\, m\, v_o^{\,2} = \frac{1}{4\,\pi\,\varepsilon_o}\,\frac{(2e)(Ze)}{r_o}$$

$$r_o = \frac{1}{4\,\pi\,\varepsilon_o}\,\frac{2\,Z\,e^2}{\left(\frac{1}{2}\,m\,v_o^{\,2}\right)}$$

$$\boldsymbol{r_o = \frac{1}{4\,\pi\,\varepsilon_o}\,\frac{2\,Z\,e^2}{E_K}} \qquad ----\ (1)$$

- where $\boldsymbol{E_K}$ → kinetic energy of alpha particle

7. Define impact parameter.

- The impact parameter (b) is defined as the perpendicular distance between the centre of the gold nucleus and the direction of velocity vector of alpha particle when it is at a large distance.

8. What are the drawbacks of Rutherford atom model?

(1) <u>**Stability of atom cannot be explained**</u> :

- According to classical electrodynamics, any accelerated charge emits electromagnetic radiations which results loses in its energy.
- Hence, it can no longer sustain the circular motion and the radius of the orbit becomes smaller and smaller (undergoes spiral motion) and finally the electron should fall into the nucleus and hence the atoms should disintegrate.
- But this does not happen. Hence, Rutherford model could not account for the stability of atoms.

(2) <u>**Line spectrum of atom could not explained**</u> :

- 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.

9. State the postulates of Bohr's atom model.

<u>**Postulate (1)**</u> :

- 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.

<u>**Postulate (2)**</u> :

- Electrons in an atom revolve around the nucleus only in certain discrete orbits called ***stationary orbits*** where it does not radiate electromagnetic energy.
- The angular momentum (l) of the electron in these stationary orbits are quantized (i.e.) integral multiple of $\frac{h}{2\,\pi}$

$$\boldsymbol{l = n\,\frac{h}{2\,\pi} = n\,\hbar}$$

where n → principal quantum number

- This condition is known as angular momentum quantization condition.

<u>**Postulate (3)**</u> :

- Energy of orbits are not continuous but discrete. This is called the ***quantization of energy***.

- 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

$$\Delta E = E_f - E_i = h\,\nu = h\,\frac{c}{\lambda}$$

where c → speed of light
λ → wavelength of the radiation used and
ν → frequency of the radiation

10. Define excitation energy.
- The energy required to excite an electron from lower energy state to any higher energy state is known as excitation energy.
- Its unit is ***electron volt*** (eV)

11. Define excitation potential.
- Excitation potential is defined as excitation energy per unit charge.
- Its unit is ***volt*** (V)

12. Define ionization energy.
- The minimum energy required to remove an electron from an atom in the ground state is known as binding energy or ionization energy.
- Ionization energy of hydrogen atom is

$$E_{ionizasion} = 13.6\ eV$$

13. Define ionization potential.
- Ionization potential is defined as ionization energy per unit charge.
- The ionization potential of hydrogen atom is,

$$V_{ionizasion} = 13.6\ V$$

14. What are the drawbacks in Bohr atom model?
<u>**Drawbacks of Bohr atom model**</u> :
- Bohr atom model is valid only for hydrogen atom or hydrogen like-atoms but not for complex atoms
- When the spectral lines are closely examined, individual lines of hydrogen spectrum is accompanied by a number of faint lines. These closed packed lines are called ***fine structure***. This is not explained by Bohr atom model.
- Bohr atom model fails to explain the intensity variations in the spectral lines.
- The distribution of electrons in atoms is not completely explained by Bohr atom model.

15. Define atomic mass unit.
- One atomic mass unit (u) is defined as the 1/12th of the mass of the isotope of carbon $\left({}^{12}_{6}C\right)$
- $1\,u = 1.66\ X\ 10^{-19}\ kg$

16. Give the empirical formula for nuclear radius.
- The nuclear radius is given by,

$$R = R_O\,A^{\frac{1}{3}}$$

where $R_O = 1.2\ F$ $[1\ F = 10^{-15}\ m]$

17. Difine nuclear density.
- Nuclear density is defined as the ratio of mass of the nucleus to its volume.

$$\rho = \frac{m}{\frac{4}{3}\pi R_O^3} = 2.3\ X\ 10^{17}\ kg\ m^{-3}$$

18. What is mass defect?
- The experimental mass of a nucleus is less than the total mass of its individual constituents.
- The mass difference between total mass of the nucleons and the real mass of the nucleus is called mass defect (Δm)

$$\Delta m = \left(Z\,m_p + N\,m_n\right) - M$$

19. Define binding energy.
- When Z protons and N neutrons are combine to form a nucleus, the mass diappear equivalent to mass defect (Δm) is converted in to energy which is used to bind the nucleons in the nucleus. This is known as binding energy (BE)

$$BE = \Delta m\,c^2 = \left[\left(Z\,m_p + N\,m_n\right) - M\right]c^2$$

20. Calculate the energy equivalent to one atomic mass unit (1 u). Give the answer in eV unit.
- According to Eienstein's mass - energy relation

$$E = m\,c^2 = (1\,u)\ X\ (3\ X\ 10^8)^2$$
$$E = 1.66\ X\ 10^{-27} X\ 9\ X\ 10^{16}$$
$$E = 14.94\ X\ 10^{-11}\ J$$

- But we have, $1\ eV = 1.602\ X\ 10^{-19}\ J$

∴ $E = 931\ MeV$

21. Define average binding energy per nucleon?
- The average binding energy per nucleon is the energy required to separate single nucleon from the particular nucleus. ($\overline{BE}$).
- It measures the stability of the nucleus.

22. What is nuclear force?
- It was concluded that there must be a strong attractive force between protons to overcome the repulsive Coulomb's force. This strong attractive force which holds the nucleus together is called nuclear force.

23. Give the properties of nuclear forces?
<u>**Properties of Nuclear forces**</u> :
- The strong nuclear force is of very short range, acting only up to a distance of a few Fermi.
- Nuclear force is the strongest force in nature.
- The strong nuclear force is attractive and acts with an equal strength between proton-proton, proton-neutron, and neutron – neutron.
- Strong nuclear force does not act on the electrons. So it does not alter the chemical properties of the atom.

24. Give the symbolic representation of alpha decay, beta decay and gamma decay.

(1) <u>Alpha decay :</u>
- When unstable nuclei decay by emitting an α-particle (${}^{4}_{2}He$), its atomic number (Z) decreases by 2, the mass number (A) decreases by 4.
- The α- decay process symbolically written as

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

(e.g.) ${}^{238}_{92}U \longrightarrow {}^{234}_{90}Th + {}^{4}_{2}He$

(2) <u>**Beta decay**</u> :
- In $\boldsymbol{\beta^-}$ - decay, the atomic number of the nucleus increases by one but mass number remains the same.

$${}^{A}_{Z}X \longrightarrow {}_{Z+1}{}^{A}Y + {}^{0}_{-1}e + \bar{\nu}$$

(e.g.) ${}^{14}_{6}C \longrightarrow {}^{14}_{7}N + {}_{-1}^{0}e + \bar{\nu}$

- In $\boldsymbol{\beta^+}$ - decay, the atomic number of the nucleus decreases by one but mass number remains the same.

$${}^{A}_{Z}X \longrightarrow {}_{Z-1}{}^{A}Y + {}^{0}_{1}e + \nu$$

(e.g.) ${}^{22}_{11}Na \longrightarrow {}^{22}_{10}Ne + {}^{0}_{1}e + \nu$

(3) <u>**Gamma decay**</u> :
- In α and β decay, the daughter nucleus is in the excited state most of the time.
- So this excited state nucleus immediately returns to the ground state or lower energy state by emitting highly energetic photons called γ rays.
- During gamma decay there is no change in atomic number and mass number

$${}^{A}_{Z}\boldsymbol{X}^{*} \longrightarrow {}^{A}_{Z}X + \text{gamma rays } (\gamma)$$

(e.g) ${}^{12}_{5}B \longrightarrow {}^{12}_{6}C^{*} + {}_{-1}^{0}e + \bar{\nu}$
${}^{12}_{6}C^{*} \longrightarrow {}^{12}_{6}C + \gamma$

25. Define disintegration energy.

- In decay process, the total mass of the daughter nucleus and product nucleus is always less than that of the parent nucleus. The difference in mass (Δm) is released as energy called disintegration energy Q
- If Q > 0, the decay is spontaneous (natural radioactivity) If Q < 0, the decay process cannot occur spontaneously and energy must be supplied to induce the decay.

26. In alpha decay, why the unstable nucleus emits ^4_2He nucleus? Why it does not emit four separate nucleons?

- For example, if $^{238}_{92}U$ nucleus decays into $^{234}_{90}Th$ by emitting four separate nucleons (two protons and two neutrons), then the disintegration energy Q for this process turns out to be negative.
- It implies that the total mass of products is greater than that of parent ($^{238}_{92}U$) nucleus.
- This kind of process cannot occur in nature because it would violate conservation of energy.

27. Write a note on positron?

- The positron is an anti-particle of an electron whose mass is same as that of electron and charge is opposite to that of electron (i.e.) +e.

28. State the properties of neutrino.

<u>Properties of neutrino</u> :

- It has zero charge
- It has an antiparticle called anti-neutrino.
- Recent experiments showed that the neutrino has very tiny mass.
- It interacts very weakly with the matter. Therefore, it is very difficult to detect.

29. State the law of radioactive decay.

- At any instant t, the number of decays per unit time, called rate of decay is proportional to the number of nuclei (N) at the same instant.

30. Define activity. Give its unit.

- Activity or decay rate which is the number of nuclei decayed per second and it is denoted as R

$$R = \frac{dN}{dt}$$

- Its unit is becquerel (Bq) and curie (Ci)

31. Define one bequerel.

- one Becquerel (Bq) is equal to one decay per second. $\mathbf{1\ Bq = 1\ decay/second}$

32. Define one curie.

- one curie was defined as number of decays per second in 1 g of radium

$$\mathbf{1\ Ci = 3.7\ X\ 10^{10}\ decay/second}$$

33. What is half life of nucleus. Give the expression.

- The half life ($T_{1/2}$) is the time required for the number of atoms initially present to reduce to one half of the initial amount .

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

34. What is mean life of nucleus? Give the expression.

- The mean life time (τ) of the nucleus is the ratio of sum or integration of life times of all nuclei to the total number nuclei present initially.

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

35. What is meant by nuclear fission?

- The process of breaking up of the nucleus of a heavier atom into two smaller nuclei with the release of a large amount of energy is called nuclear fission.

36. Calculate the energy released per fission.

<u>**Energy released in one fission**</u>:

- Consider the following fission reaction.

$$^{235}_{92}U + ^1_0n \longrightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\ ^1_0n + Q$$

- Total mass before fission ;

$mass\ of\ ^{235}_{92}U$ = 235.045733 u
$mass\ of\ ^1_0n$ = 1.008665 u
= 236.054398 u

- Total mass after fision ;

$mass\ of\ ^{141}_{56}Ba$ = 140.9177 u
$mass\ of\ ^{92}_{36}Kr$ = 91.8854 u
$mass\ of\ 3\ ^1_0n$ = 3.025995 u
= 235.829095 u

mass defect ; Δm = 236.054398 u
(−) 235.829095 u
= 0.225303 u

- Then energy released during this fission reaction,

$$Q = \Delta m\ X\ 931\ MeV$$
$$Q = 0.225303\ X\ 931\ MeV$$
$$\mathbf{Q = 200\ MeV}$$

37. What is called chain reaction. Give its types.

- During every fission reaction, three neutrons are released along with products. These three neutrons cause further fission produces nine neutrons and this process goes on.
- Thus the number of neutrons goes on increasing almost in geometric progression and this is called a chain reaction
- There are two kinds of chain reactions:
  (1) Uncontrolled chain reaction
  (2) Controlled chain reaction.

38. What is called nuclear reactor?

- Nuclear reactor is a system in which the nuclear fission takes place in a self-sustained controlled manner.
- The energy produced is used either for research purpose or for power generation.
- The first nuclear reactor was built in the year 1942 at Chicago, USA

39. What is nuclear fusion?

- When two or more light nuclei (A<20) combine to form a heavier nucleus, then it is called nuclear fusion.

40. What is mean by thermo nuclear reactions?

- 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 10^7 K, lighter nuclei start fusing to form heavier nuclei and this resulting reaction is called thermonuclear fusion reaction.

41. What is the source of stellar energy?

- The energy generation in every star is only through ***thermonuclear fusion*** because its temperature is of the order of 10^7 K
- Most of the stars including our Sun fuse hydrogen into helium and some stars even fuse helium into heavier elements.

42. Write a note on proton - proton cycle.

- The sun's interior temperature is around $1.5\ X\ 10^7\ K$.
- At this temperature, fusion reaction takes place and the sun is converting $6\ X\ 10^{11}\ kg$ hydrogen into helium every second.
- According to ***Hans Bethe***, the sun is powered by proton-proton cycle of fusion reaction.
- This cycle consists of three steps :

Step - 1 : $\boldsymbol{{}^1_1H + {}^1_1H \longrightarrow {}^2_1H + {}^0_1e + \nu}$

Step - 2 : $\boldsymbol{{}^1_1H + {}^2_1H \longrightarrow {}^3_2He + \gamma}$

Step - 3 : $\boldsymbol{{}^3_2He + {}^3_2He \longrightarrow {}^4_2He + {}^1_1H + {}^1_1H}$

- In general, the above three steps can be written as.

$$\boldsymbol{4\,{}^1_1H \longrightarrow {}^4_2He + 2\,{}^1_1H + 2\,{}^0_1e + 2\,\nu + 27\ MeV}$$

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

- Protons and neutrons are made up of ***quarks*** which are now considered as elementary particles
- According to quark model,

(1) Proton is made up of two up quarks $(+\frac{2}{3}e)$ and one down quark $(-\frac{1}{3}e)$ and

(2) Neutron is made up of one up quark $(+\frac{2}{3}e)$ and two down quarks $(-\frac{1}{3}e)$

44. What is radio carbon dating?

- Radioactive dating or carbon dating is the technique to estimate the age of ancient object by using radio carbon isotope $(\boldsymbol{{}^{14}_6C})$

45. Write a note on smoke detector.

<u>**Smoke detecter**</u> :

- An important application of alpha decay is smoke detector which prevent us from any hazardous fire.
- It uses around **0.2 mg** of man-made weak radioactive isotope called ***americium*** $(\boldsymbol{{}^{241}_{95}Am})$
- This radioactive source is placed between two oppositely charged metal plates and α radiations from $\boldsymbol{{}^{241}_{95}Am}$ continuously ionize the nitrogen, oxygen molecules in the air space between the plates.
- As a result, there will be a continuous flow of small steady current in the circuit.
- If smoke enters, the radiation is being absorbed by the smoke particles rather than air molecules.
- As a result, the ionization and along with it the current is reduced. This drop in current is detected by the circuit and alarm starts.
- The radiation dosage emitted by americium is very much less than safe level, so it can be considered harmless.

5 Mark Questions & Answers

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

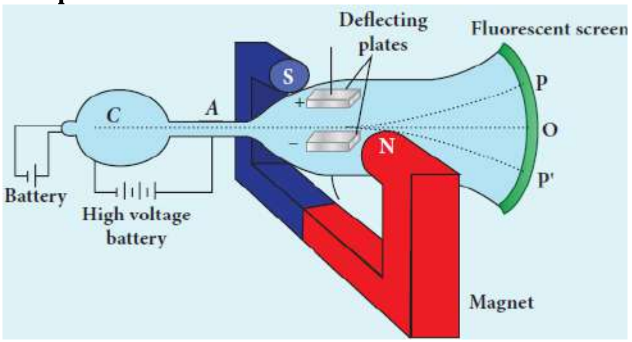
Specific charge of elctron - J J Thomson Experiment

- Charge per unit mass of an electron is called specific charge (e/m)

Principle :

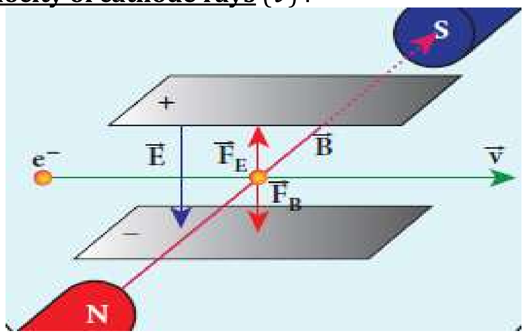
- Cathode rays (electron beam) deflects by both electric and magnetic fields is the principle involved in this method.

Set up :



- It is ahighly evacuated discharge tube
- Cathode rays (electron beam) produced at cathode 'C' are attracted towards anode disc A which allow only a narrow beam of cathode rays.
- These cathode rays are now allowed to pass through the parallel plates and strike the screen coated with ZnS, a light spot is observed at O
- The metal plates are 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.

Velocity of cathode rays (v) :



- Let 'e' be the charge of cathode ray particle.
- The upward force acting on cathode rays due to electric field 'E' is; $F_E = e\,E$
- The downward force acting on cathode rays due to magnetic field is ; $F_B = e\,B\,v$
- In undeflected equilibrium position,

$$F_E = F_B$$
$$e\,E = e\,B\,v$$
$$v = \frac{E}{B} \qquad -------(1)$$

Method (1) - To find specific charge :

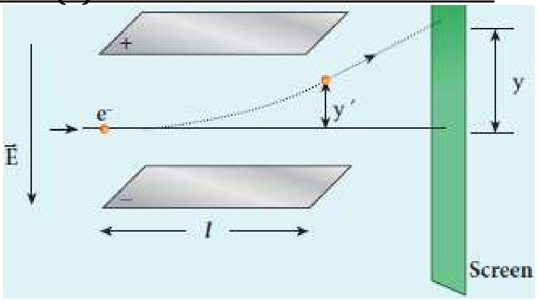
- Let 'V' be the potential difference between anode and cathode.
- Since the cathode rays (electron beam) are accelerated from cathode to anode, the potential energy 'eV' of the electron beam at the cathode is converted into kinetic energy of the electron beam at the anode. Hence,

$$eV = \frac{1}{2}\,m\,v^2$$
$$\therefore \quad \frac{e}{m} = \frac{1}{2}\frac{v^2}{V} = \frac{1}{2}\frac{E^2}{V\,B^2}$$

- The value of specific charge is ,

$$\frac{e}{m} = 1.7\ X\ 10^{11}\ C\ kg^{-1}$$

Method (2) - Deflection due to electric field :



- When the magnetic field is turned off ($B = 0$), the deflection is only due to electric field.
- Let 'm' be the mass of the electron, the upward acceleration due to electric field 'E' is

$$a_E = \frac{F_E}{m} = \frac{e\,E}{m}$$

- Upward initial velocity ; $u = 0$
- Let 'l' be the length of the deflecting plate, then time taken to travel in electric field is,

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

- Hence the deflection at the end of the electric field

$$y' = u\,t + \frac{1}{2}\,a\,t^2 = 0 + \frac{1}{2}\,a_E\,t^2$$
$$y' = \frac{1}{2}\frac{e\,E}{m}\left(\frac{l}{v}\right)^2 = \frac{1}{2}\frac{e\,E}{m}\frac{l^2}{v^2}$$
$$y' = \frac{1}{2}\frac{e\,E}{m}\frac{l^2\,B^2}{E^2}$$
$$y' = \frac{1}{2}\frac{e}{m}\frac{l^2\,B^2}{E} \qquad ---- (2)$$

- Then the deflection on the screen,

$$y \propto y' \qquad (or) \qquad y = C\,y'$$

$C \rightarrow$ Proportionality constant

- Using equation (2),

$$y = C\,\frac{1}{2}\frac{e}{m}\frac{l^2\,B^2}{E}$$
$$\frac{e}{m} = \frac{2\,y\,E}{C\,l^2\,B^2} \qquad ----- (3)$$

- By substituting the known values, we get

$$\frac{e}{m} = 1.7\ X\ 10^{11}\ C\ kg^{-1}$$

Method (3) - Deflection due to magnetic field :

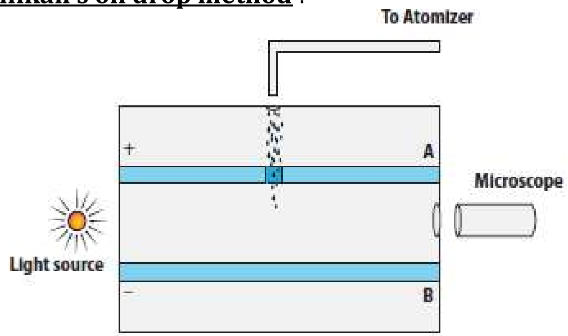
- When the electric field is turned off ($E = 0$), the deflection is only due to magnetic field.
- The magnetic force provides the centripetal force, the electron beam undergoes semi-circular path . Hence.

$$e\,v\,B = \frac{m\,v^2}{R}$$
$$e\,B = \frac{m\,v}{R}$$
$$e\,B = \frac{m\left(\frac{E}{B}\right)}{R} = \frac{m\,E}{B\,R}$$
$$\frac{e}{m} = \frac{E}{B^2\,R} \qquad ----- (4)$$

- The specific charge is independent of
  (1) Gas used
  (2) Nature of the electrodes

2. Discuss the Millikan's oil drop experiment to determine the charge of an electron.

Millikan's oil drop method :



- It consists of two horizontal circular metal plates A and B each with diameter around 20 cm and are separated by a small distance 1.5 cm.
- These two parallel plates are enclosed in a chamber with glass walls.
- A high potential difference around 10 kV applied across the metal plates, such that electric field acts vertically downward.
- A small hole is made at the centre of the upper plate A and atomizer is kept exactly above the hole to spray the liquid.
- When a fine droplet of highly viscous liquid (like glycerine) is sprayed using atomizer, it falls freely downward through the hole of the top plate only under the influence of gravity.
- Few oil drops in the chamber can acquire electric charge (negative charge) because of friction with air or passage of x-rays in between the parallel plates.
- Further the chamber is illuminated by light which is passed horizontally and oil drops can be seen clearly using microscope placed perpendicular to the light beam.
- These drops can move either upwards or downward.

(1) **Radius of oil drop** :

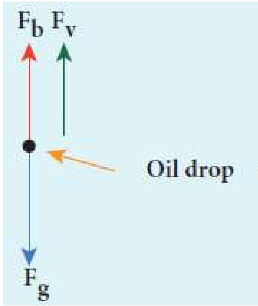
- When the electric field is switched off, the oil drop accelerates downwards.
- Due to the presence of air drag forces, the oil drops easily attain its terminal velocity and moves with constant velocity. Let it be 'v'
- Radius of the oil drop $= r$
  Density of the the oil $= \rho$
  Density of the air $= \sigma$
- The downward gravitational force acting on the oil drop is.

$$F_g = m\,g = \rho\,V\,g = \rho\left[\frac{4}{3}\pi\,r^3\right]g$$

- The upthrust force experienced by the oil drop due to displaced air is

$$F_b = m'\,g = \sigma\,V\,g = \sigma\left[\frac{4}{3}\pi\,r^3\right]g$$

- Once the oil drop attains a terminal velocity υ, 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 ; $F_v = 6\,\pi\,r\,\eta\,v$
- From the free body diagram,

$$F_g = F_b + F_v$$

$$\rho\left[\frac{4}{3}\pi\,r^3\right]g = \sigma\left[\frac{4}{3}\pi\,r^3\right]g + 6\,\pi\,r\,\eta\,v$$

$$\rho\left[\frac{4}{3}\pi\,r^3\right]g - \sigma\left[\frac{4}{3}\pi\,r^3\right]g = 6\,\pi\,r\,\eta\,v$$

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

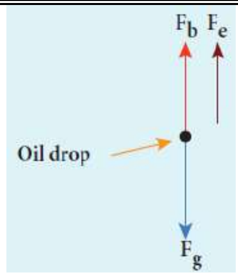
$$\frac{r^3}{r} = \frac{18}{4}\,\frac{\pi\,\eta\,v}{\pi\,(\rho - \sigma\,)g}$$

$$r^2 = \frac{9\,\eta\,v}{2\,(\rho - \sigma\,)g}$$

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

(2) **Determination of electric charge** :

- When the electric field is switched on, charged oil drops experience an upward electric force (qE).
- Strength of the electric field is adjusted to make that particular drop to be stationary.
- Under these circumstances, there will be no viscous force acting on the oil drop.



- From the free body diagram,

$$F_g = F_b + F_E$$

$$\rho\left[\frac{4}{3}\pi\,r^3\right]g = \sigma\left[\frac{4}{3}\pi\,r^3\right]g + q\,E$$

$$(or) \qquad q\,E = \rho\left[\frac{4}{3}\pi\,r^3\right]g - \sigma\left[\frac{4}{3}\pi\,r^3\right]g$$

$$q\,E = \frac{4}{3}\pi\,r^3\,(\rho - \sigma\,)g$$

$$q = \frac{4}{3\,E}\pi\,r^3\,(\rho - \sigma\,)g$$

- Put equation (1), we get

$$q = \frac{4}{3\,E}\pi\left[\frac{9\,\eta\,v}{2\,(\rho - \sigma\,)g}\right]\left[\frac{9\,\eta\,v}{2\,(\rho - \sigma\,)g}\right]^{\frac{1}{2}}(\rho - \sigma\,)g$$

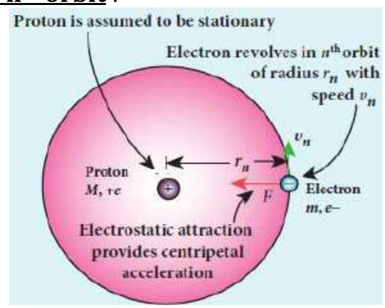
$$q = \frac{18}{E}\pi\,[\eta\,v]\left[\frac{\eta\,v}{2\,(\rho - \sigma\,)g}\right]^{\frac{1}{2}}(\rho - \sigma\,)g$$

$$\boldsymbol{q = \frac{18}{E}\pi\left[\frac{\eta^3\,v^3}{2\,(\rho - \sigma\,)g}\right]^{\frac{1}{2}}} \qquad ----(\mathbf{2})$$

- Millikan repeated this experiment several times and computed the charges on oil drops.
- He found that the charge of any oil drop can be written as integral multiple of a basic value, (-1.6 X 10^{-19} C), which is nothing but the charge of an electron. Hence, $\boldsymbol{e = -1.6\,X\,10^{-9}\,C}$

3. Derive the expression for radius and energy of the n^{th} orbit of hydrogen atom using Bohr atom model.

Radius of n^{th} orbit :



- Consider an atom which contains the nucleus at rest which is made up of of protons and neutrons.
- Let an electron revolving around the stabe nucleus
- Atomic number $= Z$
  Total charge of th nucleus $= +Z\,e$
  Charge of an electron $= -e$
  Mass of the electron $= m$
- From Coulomb's law, the force of attraction between the nucleus and the electron is

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

$$\vec{F}_{coulomb} = -\frac{1}{4\pi\varepsilon_O}\frac{Z\,e^2}{r_n^2}\hat{r}$$

- This force provides necessary centripetal force given by.

$$\vec{F}_{centripetal} = -\frac{m\,v_n^2}{r_n}\hat{r}$$

- At equilibrium,

$$\vec{F}_{coulomb} = \vec{F}_{centripetal}$$

$$-\frac{1}{4\pi\varepsilon_O}\frac{Z\,e^2}{r_n^2}\hat{r} = -\frac{m\,v_n^2}{r_n}\hat{r}$$

$$\frac{1}{4\pi\varepsilon_O}\frac{Z\,e^2}{r_n^2} = \frac{m\,v_n^2}{r_n} \qquad ------ \quad (1)$$

$$r_n = \frac{(4\pi\varepsilon_O)\,m\,v_n^2\,r_n^2}{Z\,e^2}$$

$$r_n = \frac{(4\pi\varepsilon_O)\,m^2\,v_n^2\,r_n^2}{Z\,e^2 m}$$

$$r_n = \frac{(4\pi\varepsilon_O)\,\,[m\,v_n\,r_n]^2}{Z\,e^2 m}$$

- From Bohr's postulate,

$$l_n = m\,v_n\,r_n = n\frac{h}{2\pi} = n\,\hbar$$

- Hence,

$$r_n = \frac{(4\pi\varepsilon_O)\,[l_n]^2}{Z\,e^2 m} = \frac{(4\pi\varepsilon_O)\left[\frac{nh}{2\pi}\right]^2}{Z\,e^2 m}$$

$$r_n = \frac{(4\pi\varepsilon_O)\,n^2\,h^2}{Z\,e^2 m\;X\;4\pi^2}$$

$$\boldsymbol{r_n = \left[\frac{h^2\varepsilon_O}{\pi\,m\,e^2}\right]\frac{n^2}{Z} = a_O\frac{n^2}{Z}} \qquad -- \quad (2)$$

- Here $\boldsymbol{\varepsilon_O, h, m, e}$ and $\boldsymbol{\pi}$ are constant.
  where, $a_O = \frac{h^2\varepsilon_O}{\pi\,m\,e^2} = 0.529\,A^\circ \rightarrow$ Bohr radius
- For hydrogen, (Z = 1), So radius of n^{th} orbit,

$$\boldsymbol{r_n = a_O\,n^2} \qquad --- \quad (3)$$

- For first orbit, n = 1, (ground level)

$$r_1 = a_O = 0.529\,A^\circ$$

- For second orbit, n = 2, (first excited level)

$$r_2 = 4\,a_O = 4\;X\;0.529\,A^\circ = 2.116\,A^\circ$$

- For third orbit, n = 3, (second excited level)

$$r_3 = 9\,a_O = 9\;X\;0.529\,A^\circ = 4.761\,A^\circ$$

- Thus, radius of the orbit, $\boldsymbol{r_n \propto n^2}$

<u>Velocity of electron in nth orbit</u> :

- According to Bohr's quantization condition,

$$m\,v_n\,r_n = n\frac{h}{2\pi}$$

$$m\,v_n\,a_O\frac{n^2}{Z} = n\frac{h}{2\pi}$$

$$\boldsymbol{v_n = \frac{h}{2\pi\,m\,a_O}\frac{Z}{n}} \qquad --- \quad (5)$$

- Hence, $\boldsymbol{v_n \propto \frac{1}{n}}$ (i.e.) the velocity of the electron decreases as the principal quantum number increases

<u>Total Energy of electron in nth orbit</u> :

- Electrostatic force is a conservative force.
- So potential energy of the electron in nth orbit,

$$U_n = \frac{1}{4\pi\varepsilon_O}\frac{(+Z\,e)\,(-e)}{r_n} = -\frac{1}{4\pi\varepsilon_O}\frac{Z\,e^2}{r_n}$$

- Kinetic energy of the electron in nth orbit,

$$KE_n = \frac{1}{2}\,m\,v_n^2 = \frac{1}{2}\left[\frac{1}{4\pi\varepsilon_O}\frac{Z\,e^2}{r_n}\right] \qquad [by\;eqn(1)]$$

- Thus, $\boldsymbol{U_n = -2\;KE_n}$
- Therefore, total energy of the electron in nth orbit,

$$E_n = U_n + KE_n = -2\,KE_n + KE_n = -KE_n$$

$$E_n = -\frac{1}{8\pi\varepsilon_O}\frac{Z\,e^2}{r_n}$$

- From equation (2), $r_n = \left[\frac{h^2\varepsilon_O}{\pi\,m\,e^2}\right]\frac{n^2}{Z}$ .Hence

$$E_n = -\frac{1}{8\pi\varepsilon_O}\frac{Z\,e^2}{\left[\frac{h^2\varepsilon_O}{\pi\,m\,e^2}\right]\frac{n^2}{Z}}$$

$$\boldsymbol{E_n = -\frac{m\,e^4}{8\,\varepsilon_O^2\,h^2}\frac{Z^2}{n^2}} \qquad ---- \quad \boldsymbol{(6)}$$

- For hydrogen, (Z = 1), then

$$\boldsymbol{E_n = -\frac{m\,e^4}{8\,\varepsilon_O^2\,h^2}\frac{1}{n^2}} \qquad ---- \quad \boldsymbol{(7)}$$

- The negative sign in equation (7) indicates that the electron is bound to the nucleus.
- Put the values of $\boldsymbol{\varepsilon_O, h, m, e}$ and using 'eV' unit we have,

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

- when, n = 1, $\boldsymbol{E_1 = -13.6\;eV}$
  when, n = 2, $\boldsymbol{E_2 = -\,3.4\;eV}$
  when, n = 3, $\boldsymbol{E_3 = -\,1.51\;eV}$
- Thus, as 'n' increases, energy also increases. (i.e.) the orbit which is closest to the nucleus has lowest energy. So it is often ***called ground state***
- The ground state energy of hydrogen (- 13.6 eV) is used as a unit of energy called ***Rydberg.***

1 Rydberg = − 13.6 eV

4. Explain the spectral series of hydrogen atom.

<u>Spectral series of hydrogen atom</u> :

- When an electron jumps from mth orbit to nth orbit, a spectral line was obtained whose wave number (i.e.) reciprocal of wave length is,

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

- here, R → Ryderg constant($R = 1.097\;X\;10^7 m^{-1}$)
- For m > n, various spectral series are obtained.

(1) **<u>Lyman series</u>** :
- n = 1 and m = 2, 3, 4, ...
- Hence the wave number,

$$\bar{\nu} = \frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{m^2}\right]$$

- They lie in ***ultra violet*** region

(2) **<u>Balmer series</u>** :
- $n = 2$ and $m = 3, 4, 5, ...$
- Hence the wave number,

$$\bar{\nu} = \frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{m^2}\right]$$

- They lie in ***visible*** region

(3) **<u>Paschen series</u>** :
- $n = 3$ and $m = 4, 5, 6, ...$
- Hence the wave number

$$\bar{\nu} = \frac{1}{\lambda} = R\left[\frac{1}{3^2} - \frac{1}{m^2}\right]$$

- They lie in ***infra red*** region

(4) **<u>Brackett series</u>** :
- $n = 4$ and $m = 5, 6, 7, ...$
- Hence the wave number,

$$\bar{\nu} = \frac{1}{\lambda} = R\left[\frac{1}{4^2} - \frac{1}{m^2}\right]$$

- They lie in ***middle infra red*** region,

(5) **Pfund series** :

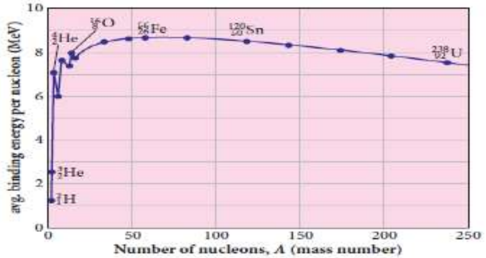
- $n = 5$ and $m = 6, 7, 8, ...$
- Hence the wave number

$$\bar{\nu} = \frac{1}{\lambda} = R\left[\frac{1}{5^2} - \frac{1}{m^2}\right]$$

- They lie in ***far infra red region***.

5. Explain the variation of average binding energy with the mass number by graph and discuss its features.

Binding energy curve :



- The average binding energy per nucleon ($\overline{BE}$) is the energy required to separate single nucleon from the particular nucleus.

$$\overline{BE} = \frac{BE}{A} = \frac{[(Z\, m_P + N\, m_n) - M_A]\, c^2}{A}$$

- $\overline{BE}$ is plotted against A of all known nuclei and the graph obtained is called binding energy curve.
- From the graph,
  (1) The value of $\overline{BE}$ rises as the mass number A increases until it reaches a maximum value of ***8.8 MeV*** for A = 56 (iron) and then it slowly decreases.
  (2) The average binding energy per nucleon is about ***8.5 MeV*** for nuclei having mass number between A = 40 and 120. These elements are comparatively more stable and not radioactive.

(3) For higher mass numbers, the curve reduces slowly and $\overline{BE}$ for uranium is about ***7.6 MeV***. They are unstable and radioactive.

(4) If two light nuclei with A<28 combine to form heavier nucleus, the binding energy per nucleon is more for final nucleus than initial nuclei. Thus, if the lighter elements combine to produce a nucleus of medium value A, a large amount of energy will be released. This is the basis of ***nuclear fusion*** and is the principle of the hydrogen bomb.

(5) If a nucleus of heavy element is split (fission) into two or more nuclei of medium value A, the energy released would again be large. The atom bomb is based on this principle.

6. Obtain the law of radioactivity (radioactive decay)

Law of radioactivity :

- At any instant t, the number of decays per unit time, called rate of decay (dN/dt) *is* proportional to the number of nuclei (N) at the same instant. This is called law of radioactive decay.

Expression :

- Let N_O be the numer of nuclei at initial time (t = 0)
- Let 'N' be the number of undecayed nuclei at any time 't'
- If 'dN' be the number of nuclei decayed in time 'dt' then, rate of decay $= \frac{dN}{dt}$
- From law of radioactivity,

$$\frac{dN}{dt} \propto N$$

$$(or) \qquad \frac{dN}{dt} = -\lambda N \qquad ------ \quad (1)$$

Here, $\lambda \rightarrow$ decay constant

- Decay constant (λ) is different for different radioactive sample and the negative sign in the equation implies that the N is decreasing with time.
- By rewriting the equation (1), we get

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

Integrating on both sides,

$$\int_{N_O}^{N} \frac{dN}{N} = -\lambda \int_0^t dt$$

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

$$[\ln N - \ln N_O] = -\lambda t$$

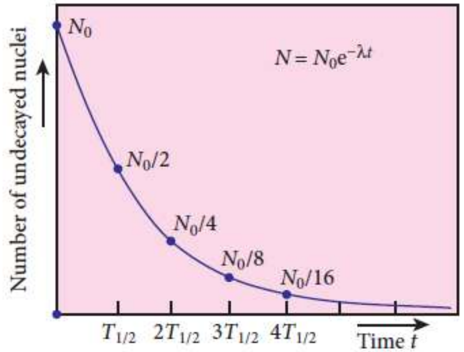
$$\ln\left[\frac{N}{N_O}\right] = -\lambda t$$

Taking exponential on both sides,

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

$$\boldsymbol{N = N_O\, e^{-\lambda t}} \qquad ---- \quad \mathbf{(2)}$$

- Equation (2) is called the law of radioactive decay.
- Here the 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.



7. Obtain an expression for half life time and mean life time.

Half life time ($T_{\frac{1}{2}}$) :

- Half-life $T_{1/2}$ is thetime required for the number of atoms initially present to reduce to one half of the initial amount.
- From the law of radioactive decay, $N = N_O\, e^{-\lambda t}$
- If $t = T_{\frac{1}{2}}$ then, $N = \frac{N_O}{2}$. Hence

$$\frac{N_O}{2} = N_O\, e^{-\lambda T_{\frac{1}{2}}}$$

$$\frac{1}{2} = e^{-\lambda T_{\frac{1}{2}}}$$

$$(or) \qquad e^{\lambda T_{\frac{1}{2}}} = 2$$

- Taking log on both sides,

$$\lambda T_{\frac{1}{2}} = \ln 2$$

$$\boldsymbol{T_{\frac{1}{2}} = \frac{\ln 2}{\lambda} = \frac{0.6931}{\lambda}}$$

- If the number of atoms present at t = 0 is N_0 , then
  (1) Number of atoms remais undecayed after 1st half life $= \frac{N_O}{2}$
  (2) Number of atoms remais undecayed after 2nd half life $= \frac{N_O}{4}$
  (3) Number of atoms remais undecayed after 3rd half life $= \frac{N_O}{8}$
- In general, after n half-lives, the number of nuclei remaining undecayed is given by

$$N = \frac{\boldsymbol{N_O}}{\boldsymbol{2^n}}$$

Mean life time (τ) :

- The mean life time of the nucleus is the ratio of sum or integration of life times of all nuclei to the total number nuclei present initially.
- Let λ be the decay constant of the radioactive substance, then ; $\boldsymbol{\tau = \frac{1}{\lambda}}$
- Thus mean life and decay constant is inversely proportional to each other.

Half life and mean life - Relation :

- Half life time is given by,

$$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda} = \frac{0.6931}{\lambda}$$

- Mean life period is given by,

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

- From the above two equations,

$$\boldsymbol{T_{\frac{1}{2}} = \tau \ \ln 2 = 0.6931\ \tau}$$

8. Explain radio carbon dating.

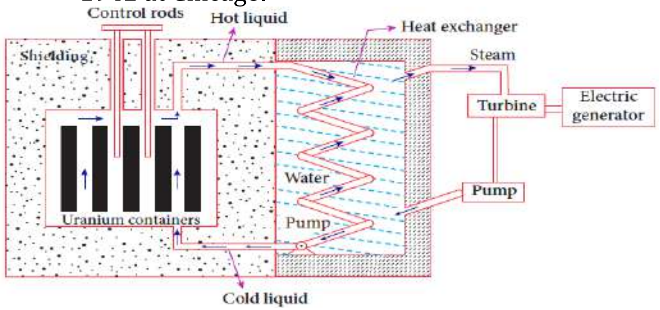
Radio carbon dating :

- The important application of ***beta ecay*** is radioactive dating or carbon dating. Using this technique, the age of an ancient object can be calculated.
- All living organisms absorb carbon dioxide (CO_2) from air to synthesize organic molecules.
- In this absorbed CO_2, the major part is ${}^{12}_{6}C$ and very small fraction ${}^{14}_{6}C$ whose half-life is ***5730 years.***
- Carbon-14 in the atmosphere is always decaying but at the same time, cosmic rays from outer space are continuously bombarding the atoms in the atmosphere which produces ${}^{14}_{6}C$. So the continuous production and decay of ${}^{14}_{6}C$ in the atmosphere keep the ratio of ${}^{14}_{6}C$ to ${}^{12}_{6}C$ always constant.
- Since our human body, tree or any living organism continuously absorb CO_2 from the atmosphere, the ratio of ${}^{14}_{6}C$ to ${}^{12}_{6}C$ in the living organism is also nearly constant.
- But when the organim dies, it stops absorbing CO_2. Since ${}^{14}_{6}C$ starts to decay, the ratio of ${}^{14}_{6}C$ to ${}^{12}_{6}C$ in a dead organism or specimen decreases over the years.
- Suppose the ratio of ${}^{14}_{6}C$ to ${}^{12}_{6}C$ in the ancient tree pieces excavated is known, then the age of the tree pieces can be calculated.

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

Nucleaar reactor :

- Nuclear reactor is a system in which the nuclear fission takes place in a self-sustained controlled manner
- The energy produced is used either for research purpose or for power generation.
- The first nuclear reactor was built in the year 1942 at Chicago.



Main parts of Nuclear reactor :

(1) Fuel :

- The commonly used fuels are ${}^{235}_{92}U$ and ${}^{239}_{94}Pu$
- Naturally occurring uranium contains only 0.7% of ${}^{235}_{92}U$ and 99.3% are only ${}^{238}_{92}U$.
- So the ${}^{238}_{92}U$ must be enriched such that it contains at least 2 to 4% of ${}^{235}_{92}U$

(2) Neutron source :

- 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

(3) Moderators :

- The probability of initiating fission by fast neutron in another nucleus is very low. Therefore, slow neutrons are preferred for sustained nuclear reactions
- The moderator is a material used to convert fast neutrons into slow neutrons.
- Usually the moderators 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.

(4) Control rods :

- The control rods are used to adjust the reaction rate.
- During each fission, on an average 2.5 neutrons are emitted
- 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 rods.
- Usually cadmium or boron acts as control rod material

(5) Coolants :

- The cooling system removes the heat generated in the reactor core.
- Ordinary water, heavy water and liquid sodium are used as coolant since they have very high specific heat capacity and have large boiling point under high pressure.
- This coolant passes through the fuel block and carries away the heat to the steam generator through heat exchanger
- The steam runs the turbines which produces electricity in power reactors.

(6) Shielding :

- For a protection against harmful radiations, the nuclear reactor is surrounded by a concrete wall of thickness of about 2 to 2.5 m.

10. Briefly explain the elementary particles of nature.

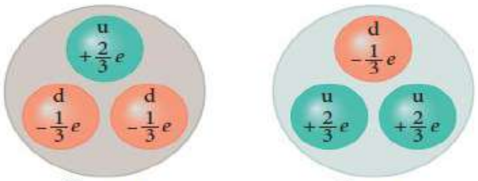
Elementary particles :

- An atom has a nucleus surrounded by electrons and nuclei is made up of protons and neutrons.
- Initially, protons, neutrons and electrons are considered as fundamental building blocks of matter.
- But in 1964, Murray Gellman and George Zweig theoretically proposed that protons and neutrons are not fundamental particles, but 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.
- In the year 1968, the quarks were discovered experimentally by Stanford.

- There are six quarks namely,
  (1) Up quark
  (2) Down quark
  (3) Charm quark
  (4) Strange quark
  (5) Top quark and
  (6) Bottom quark
- There exist their anti particle also.
- All these quarks have fractional charges. For example,

  Charge of up quark is $= +\frac{2}{3}e$

  Charge of down quark is $= -\frac{1}{3}e$
- According to quark model,
  (1) Proton is made up of two up quarks and one down quark
  (2) Neutron is made up of one up quark and two down quarks



Neutron Proton

11. Explain in detail the four fundamental forces.

Fundamental forces in nature :

- Gravitational, electromagnetic, strong and weak forces are called fundamental forces of nature.

(1) Gravitational forces :

- The attractive force between two masses is called gravitational force and it is universal in nature.
- Our planets are bound to the sun through gravitational force of the sun.
- We are in the Earth because of Earth's gravitational attraction on our body.

(2) Electromagnetic force :

- Between two charges there exists electromagnetic force and it plays major role in most of our day-today events.
- We are standing on the surface of the earth because of the electromagnetic force between atoms of the surface of the earth with atoms in our foot
- It is stronger than gravitational force.

(3) Strong Nuclear force :

- Between two nucleons, there exists a strong nuclear force and this force is responsible for stability of the nucleus.
- The atoms in our body are stable because of strong nuclear force.

(4) Weak Nuclear force :

- In addition to these three forces, there exists another fundamental force of nature called the weak force.
- This weak force is even shorter in range than nuclear force.
- This force plays an important role in beta decay and energy production of stars.
- During the fusion of hydrogen into helium in sun, neutrinos and enormous radiations are produced through weak force.
- The lives of species in the earth depend on the solar energy from the sun and it is due to weak force which plays vital role during nuclear fusion reactions going on in the core of the sun