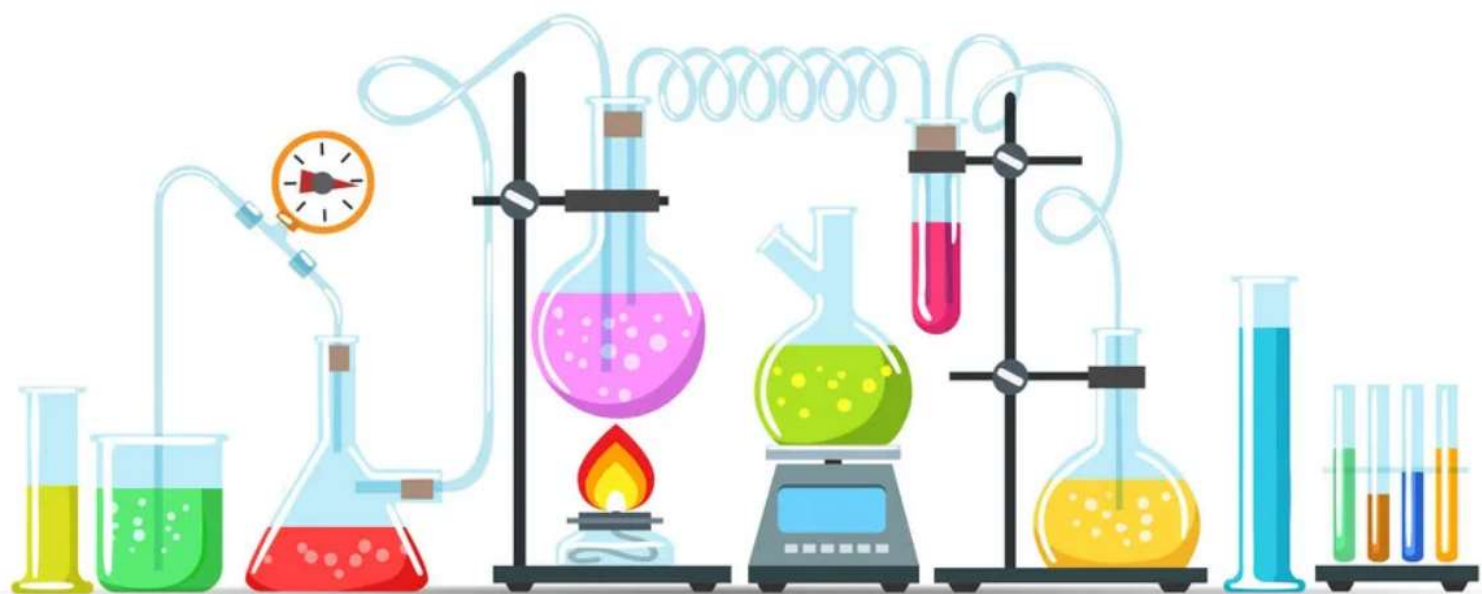


# CHEMISTRY



# STRUCTURE OF ATOM

## Introduction:

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The word "atom" has been derived from the Greek word 'atoms' which means 'indivisible'. These early ideas were mere speculation and there was no way to test them experimentally.

## Atomic Structure:

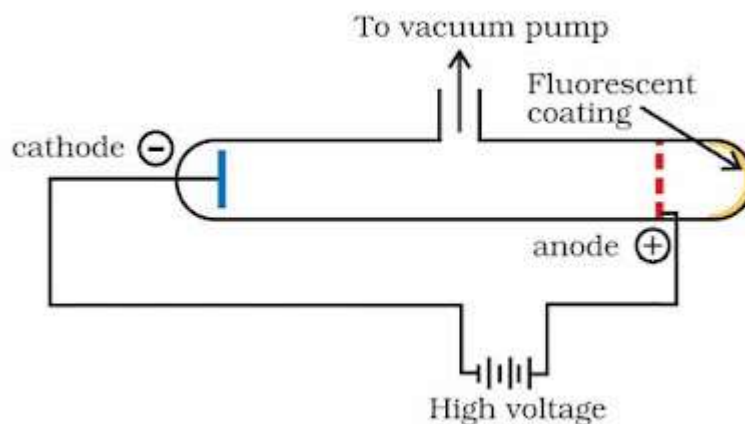
Atom is made up of smaller units like proton, neutron and electron. Some other particles like positron, neutrino, antineutrino,  $\pi$ -meson,  $\mu$ -meson, K meson etc are also present which are very short lived.

Particle	Mass	Charge	Special Remark
Electron	$9.1 \times 10^{-31}$ kg	$-1.6 \times 10^{-19}$ C	Discovered by J.J. Thomson
Proton	$1.67 \times 10^{-27}$ kg	$+1.6 \times 10^{-19}$ C	Discovered by Gold Stein
Neutron	$1.67 \times 10^{-27}$ kg		Discovered by Chadwick
Positron		$+1.6 \times 10^{-19}$	Anderson
$\pi$ meson	$\pi^0$ - 264 Me $\pi^+$ - 273 Me $\pi^-$ - 273 Me		Yukawa

## Discovery of Electron

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In 1879, **William Crooks** studied the conduction of electricity through gases at low pressure. He performed the experiment in a discharge tube which is a cylindrical hard glass tube about 60 cm in length. It is sealed at both the ends and fitted with two metal electrodes. The electrical discharge through the gases could be observed only at very low pressures and at very high voltages.



**J.J. Thomson** took a discharge tube and applied a voltage of a 10000 volt potential difference across it at a pressure of 10–2 mm of Hg. He found some glowing behind anode. It means some invisible rays produced at cathode strike behind anode and produce fluorescence. He named them cathode rays.

### Properties of Cathode Rays

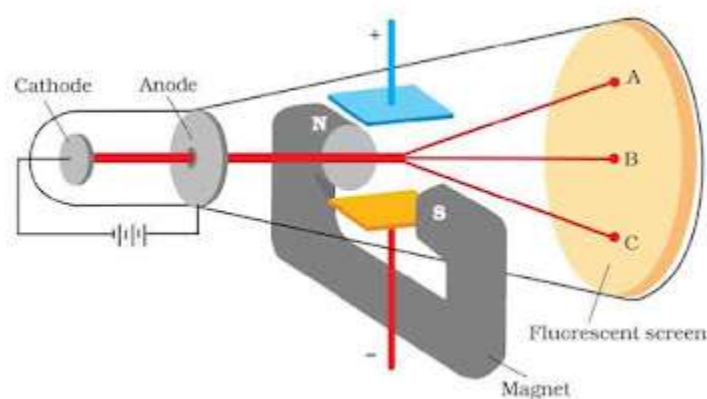
- These rays have mechanical energy and travel in straight line.
- These rays are deflected towards positive plate of electric field. It means these are made up of negatively charged particle called **electron**.
- Colour observed is independent from nature of gas.
- Mulliken determined the charge on electron which is  $1.602 \times 10^{-19}\text{C}$ .
- Specific charge on electron is calculated by J.J. Thomson.

### Charge to mass ratio

**J.J. Thomson** for the first time experimentally determined charge/mass ratio called  $e/m$  ratio for the electrons. For this, he subjected the beam of electrons released in the discharge tube as cathode rays to influence the electric and magnetic fields. These were acting perpendicular to one another as well as to the path followed by **electrons**.

According to Thomson, the amount of deviation of the particles from their path in presence of electrical and magnetic field depends on,

- Magnitude of the negative charge on particle
- Mass of particle
- Strength of magnetic field



When electric field is applied, deviation from path takes place. If only electric field is applied, cathode rays strike at A. If only magnetic field is applied, cathode rays strike at C. In absence of any field, cathode rays strike at B.

By carrying out accurate measurements on the amount of deflections observed by the electrons on the electric field strength or magnetic field strength, Thomson was able to determine the value of  $e/m_e = 1.758820 \times 10^{11} \text{ C kg}^{-1}$

where  $m_e$  = Mass of the electron in kg

$e$  = magnitude of charge on the electron in coulomb (C).

## Discovery of anode rays

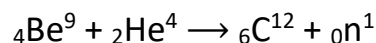
In 1886, Goldstein modified the discharge tube by using a perforated cathode. On reducing the pressure, he observed a new type of luminous rays passing through the holes or perforations of the cathode and moving in a direction opposite to the cathode rays. These rays were named as positive rays or anode rays or as canal rays. Anode rays are not emitted from the anode but from a space between anode and cathode.

## Properties of anode rays

1. These rays deflect towards negative plate of applied electric field. It means these are made up of positively charged particle.
2. Property of anode rays depends on nature of gas.
3. These rays travel in straight line and have mechanical energy.

## Discovery of Neutron

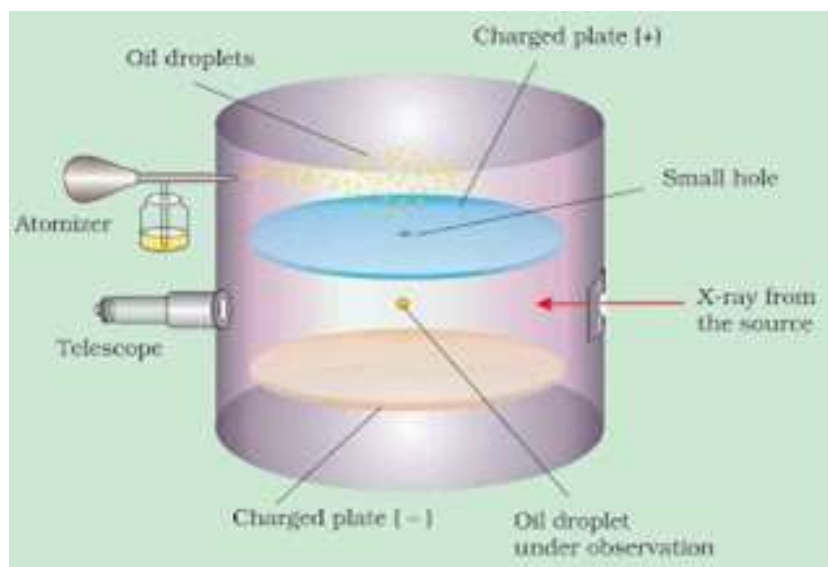
Chadwick in 1932 found the evidence for the production of neutron in given reaction.



Neutron is chargeless particle and have mass equal to proton.

## Millikan's Oil Drop Experiment

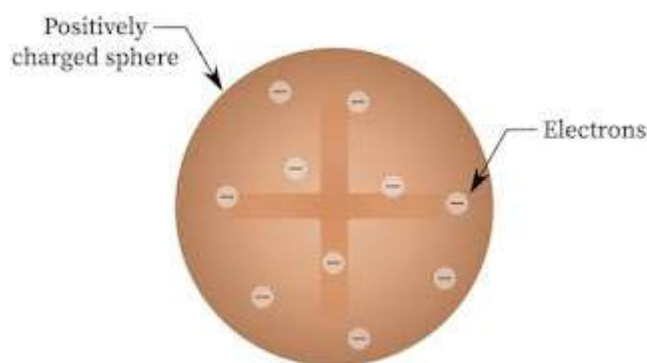
In this experiment, some fine oil droplets were allowed to enter through a tiny hole into the upper plate of electrical condenser. These oil droplets were produced by atomiser. The air in the chamber was subjected to the ionization by X-rays. The electrons produced by the ionization of air attach themselves to the oil drops.



Thus oil droplets acquire negative charge. When sufficient amount of electric field is applied, the motion of the droplets can be accelerated, retarded or made stationary. Millikan observed that the smallest charge found on them was  $-1.6 \times 10^{-19}$  coulomb and the magnitude of electrical charge,  $q$  on the droplets is always an integral multiple of the electrical charge 'e' i.e.,  $q = ne$

## Thomson's Model of Atom

J.J. Thomson in 1898, proposed a model of atom which looked more or less like plum pudding or raisin pudding. He assumed atom to be a spherical body in which electrons are unevenly distributed in a sphere having positive charge which balance the electron's charge. It is called Plum pudding model.



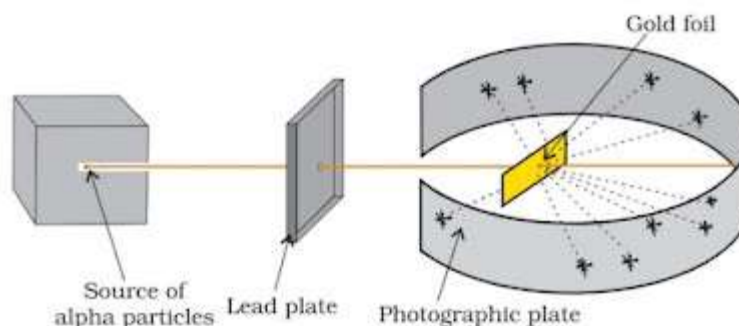
**Important Feature of This Model:** The mass of the atom is assumed to be uniformly distributed

over whole atom.

**Failure:** This model was able to explain the overall neutrality of the atom, it could not satisfactorily, explain the results of scattering experiments carried out by Rutherford in 1911.

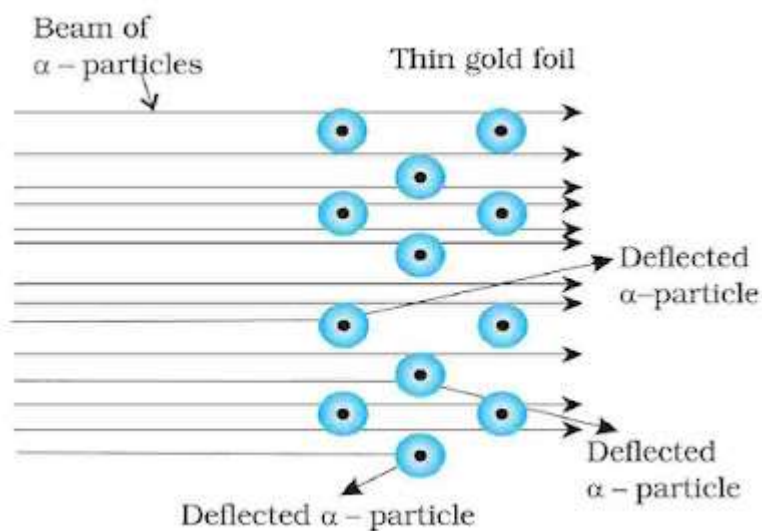
## Rutherford's Model

Rutherford in 1911, performed some scattering experiments in which he bombarded thin foils of metals like gold, silver, platinum or copper with a beam of fast moving  $\alpha$ -particles. The thin gold foil had a circular fluorescent zinc sulphide screen around it. Whenever  $\alpha$ -particles struck the screen, a tiny flash of light was produced at that point.



From these experiments, he made the following observations:

1. Most of the  $\alpha$ -particles pass without any deviation.
2. Few particles deviate with small angle.
3. Rare particles retrace its path or show deflection greater than  $90^\circ$ .



On the basis of these observation, he proposed a model.

1. Atom is of spherical shape having size of order  $10^{-10}$  meters.
2. Whole mass is concentrated in centre called nucleus having size of order  $10^{-15}$  meters.

3. Electron revolves around the nucleus in circular path like planets revolve around sun.

**Limitation:** This model could not explain stability of atom. According to Maxwell's classic theory, an accelerated charged particle liberates energy. So, during revolution, it must radiate energy and by following the spiral path it should come on nucleus.

### Atomic number

It is equal to the number of protons present in the nucleus of an atom. Atomic number is designated by the letter 'Z'. In case of neutral atom atomic number is equal to the number of protons and even equal to the number of electrons in atom.

$$Z = \text{Number of protons (p)} = \text{Number of electrons (e)}$$

### Mass number

It is equal to the sum of the positively charged protons (p) and electrically neutral neutrons (n). Mass number of an atom is designated by the letter 'A'.

$$\text{Mass number (A)} = \text{Number of protons (p or Z)} + \text{Number of neutrons (n)}$$

Note: The atom of an element X having mass number (A) and atomic number (Z) may be represented by a symbol  ${}_Z\text{X}^A$ .

### Isotopes

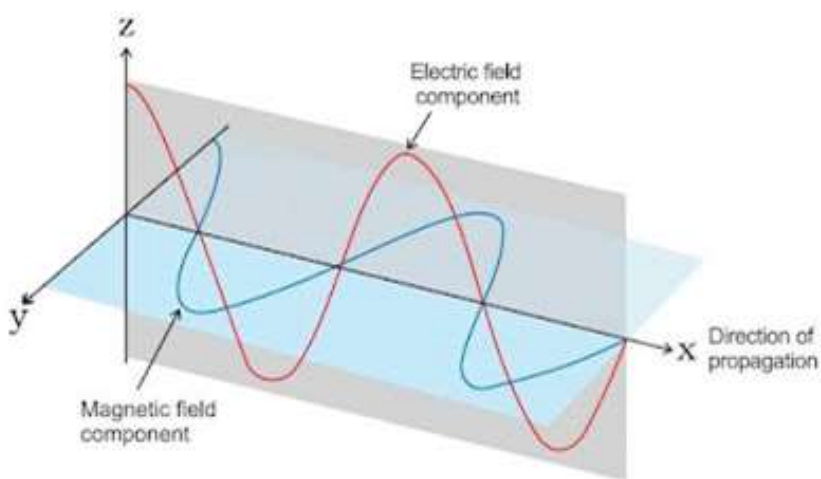
Atoms with identical atomic number but different atomic mass number are known as Isotopes. Isotopes of Hydrogen  ${}_1\text{H}^1$ ,  ${}_1\text{H}^2$  and  ${}_1\text{H}^3$

### Isobars

Isobars are the atom with the same mass number but different atomic number, for example  ${}_6\text{C}^{14}$  and  ${}_7\text{N}^{14}$

### Electromagnetic Waves Theory

This theory was put forward by James Clark Maxwell in 1864. Electromagnetic Waves are the waves which are produced by varying electric field and magnetic field which are perpendicular to each other in the direction perpendicular to both of them.



The main points of this theory are as follows:

1. The energy is emitted from any source continuously in the form of radiations and is called the radiant energy.
2. The radiations consist of electric and magnetic fields oscillating perpendicular to each other and both perpendicular to the direction of propagation of the radiation.
3. The radiations possess wave character and travel with the velocity of light  $3 \times 10^8$  m/sec.
4. These waves do not require any material medium for propagation. For example, rays from the sun reach us through space which is a non-material medium.

## Characteristics of a Wave

**Wavelength ( $\lambda$ ):** It is the distance between two consecutive crests or troughs and is denoted by  $\lambda$ .

**Frequency ( $\nu$ ):** It is the number of waves passing through a given point in one second. The unit frequency is hertz or cycle per second.

**Wave number:** It is the number of waves in a unit cycle. wave number  $= 1/\lambda = 1/\lambda$

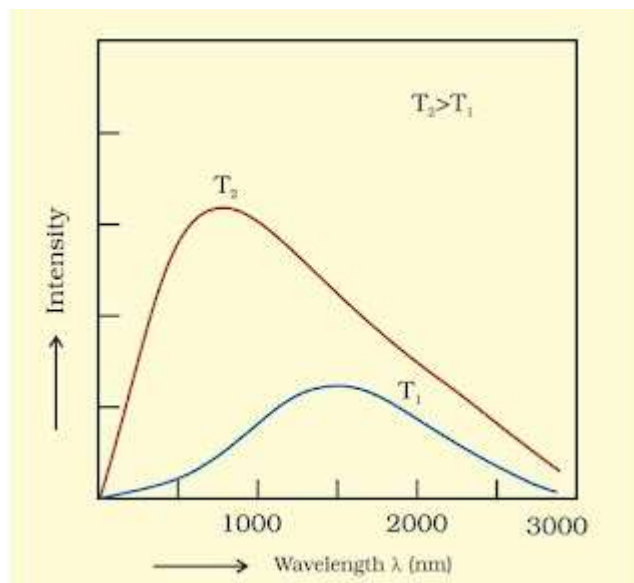
**Velocity:** Velocity of a wave is defined as the linear distance travelled by the wave in one second. It is represented by  $c$  and is expressed in m/sec.

**Amplitude:** Amplitude of a wave is the height of the crest or the depth of the trough. It is represented by  $A$  and is expressed in the units of length.

## Black Body Radiations

Black-body is an ideal body which emits and absorbs radiations of all frequencies. The radiation emitted by these bodies is called **black-body radiation**.

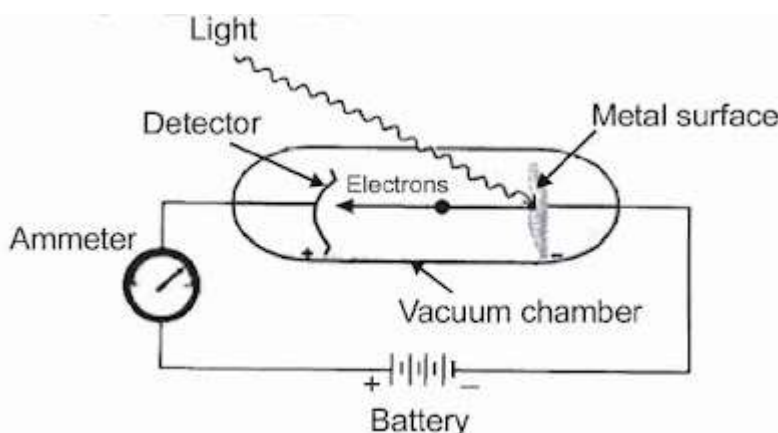




At a given temperature, the intensity and frequency of the emitted radiation depends is temperature. At a given temperature, the intensity of radiation emitted increases with decrease of wavelength.

## Photoelectric Effect

When light of a suitable frequency is allowed to incident on a metal, ejection of electrons take place. This phenomenon is known as photo electric effect.



## Observations in Photoelectric Effect

1. Only photons of light of certain minimum frequency called threshold frequency ( $\nu_0$ ) can cause the photoelectric effect. The value of  $\nu_0$  is different for different metals.
2. The kinetic energy of the electrons which are emitted is directly proportional to the frequency of the striking photons and is quite independent of their intensity.
3. The number of electrons that are ejected per second from the metal surface depends upon the intensity of the striking photons or radiations and not upon their frequency.

## Explanation of Photoelectric Effect

Einstein in (1905) was able to give an explanation of the different points of the photoelectric effect using Planck's quantum theory as under:

1. Photoelectrons are ejected only when the incident light has a certain minimum frequency (threshold frequency  $\nu_0$ ).
2. If the frequency of the incident light ( $\nu$ ) is more than the threshold frequency ( $\nu_0$ ), the excess energy ( $h\nu - h\nu_0$ ) is imparted to the electron as kinetic energy.
3. On increasing the intensity of light, more electrons are ejected but the energies of the electrons are not altered.

K.E. of the ejected electron.

$$\frac{1}{2}mv^2 = h\nu - h\nu_0$$

## Planck's Theory

According to this theory, energy cannot be absorbed or released continuously but it is emitted or released in the form of small packets called quanta. In case of light this quanta is known as photon. This photon travels with speed of light. Energy of the photon is directly proportional to frequency.

$$E \propto \nu$$
$$E = h\nu$$

$h$  is **Planck's constant**, value is  $6.62 \times 10^{-34}$  Js

## Bohr's Model

1. Niels Bohr in 1913, proposed a new model of atom on the basis of Planck's Quantum Theory. The main points of this model are as follows:
2. Atom is of spherical shape having size (of order  $10^{-10}$  metre).
3. Whole mass is concentrated in centre called nucleus (having order of size  $10^{-15}$  metre).
4. Electron revolves around nucleus only in limited circular path and he assumed that electron does not radiate energy during its revolution in permitted paths.
5. Only those orbits are allowed whose orbit angular momentum is integral multiple of  $\frac{h}{2\pi}$ .
6.  $mvr = nh/2\pi$ , where  $n = 1, 2, 3, 4, \dots$
7. When electron absorbs energy, it jumps to higher orbit and when it comes back, it radiates energy. This postulate explain spectra.

## Achievements of Bohr's Theory

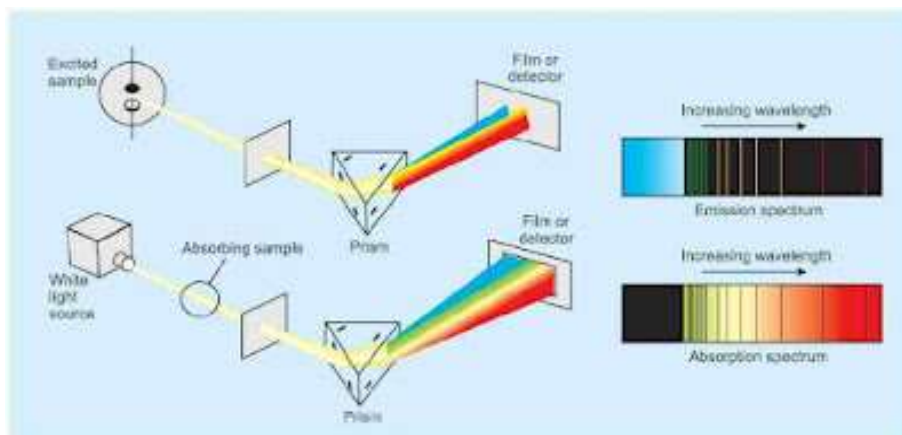
1. Bohr's theory has explained the stability of an atom.
2. Bohr's theory has helped in calculating the energy of electron in hydrogen atom and one electron species.
3. Bohr's theory has explained the atomic spectrum of hydrogen atom.

## Limitations of Bohr's Model

1. The theory could not explain the atomic spectra of the atoms containing more than one electron or multielectron atoms.
2. Bohr's theory failed to explain the fine structure of the spectral lines.
3. Bohr's theory could not offer any satisfactory explanation of Zeeman effect and Stark effect.
4. Bohr's theory failed to explain the ability of atoms to form molecule formed by chemical bonds.
5. It was not in accordance with the Heisenberg's uncertainty principle.

## Spectra

The most compelling evidence for the quantization of energy comes from spectroscopy. Spectrum word is taken from Latin word which means appearance. The record of the intensity transmitted or scattered by a molecule as a function of frequency or wavelength is called its spectrum.



Cosmic rays < gamma rays < x rays < ultraviolet rays < visible rays < infra red < micro waves < radio waves.

## Line Spectrum of Hydrogen Atom

When electric discharge is passed through hydrogen gas enclosed in discharge tube under low

pressure and the emitted light is analysed by a spectroscope, the spectrum consists of a large number of lines which are grouped into different series. The complete spectrum is known as hydrogen spectrum.

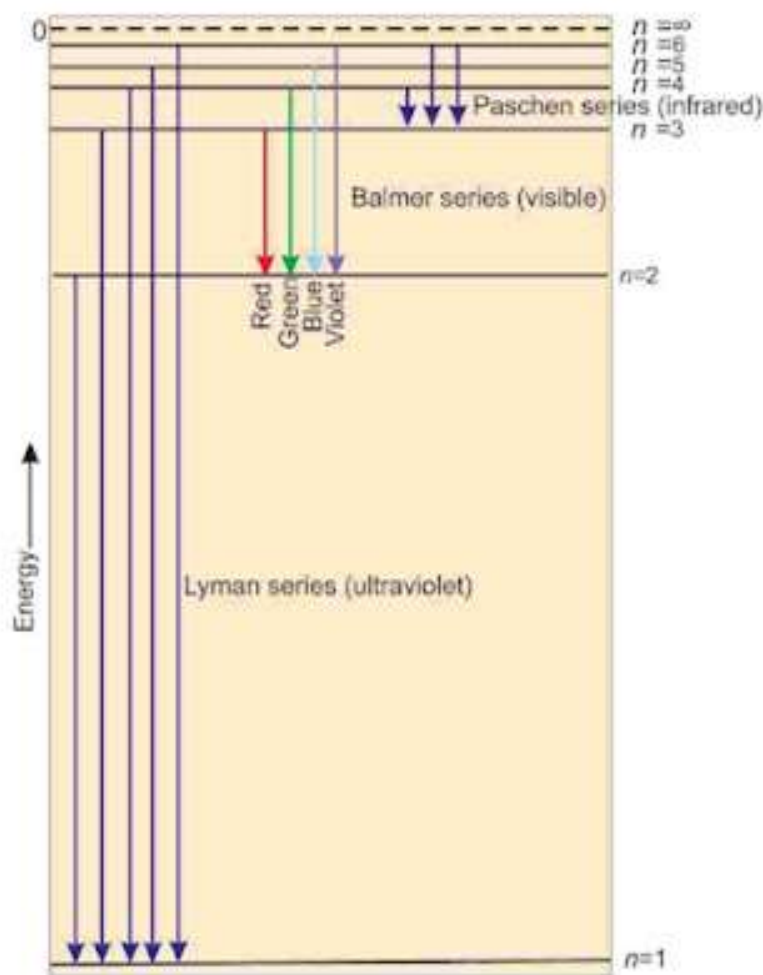
On the basis of experimental observations, Johannes Rydberg noted that all series of lines in the hydrogen spectrum could be described by the following expression:

$$\frac{1}{\lambda} = R(1/n_1^2 - 1/n_2^2)$$

R = Rydberg constant

$$R = 109678 \text{ cm}^{-1}$$

Series	$n_1$	$n_2$	Spectral Region
Lyman	1	2,3,....	Ultraviolet
Balmer	2	3,4,....	Visible
Paschen	3	4,5,....	Infrared
Brackett	4	5,6,....	Infrared
Pfund	5	6,7,....	Infrared



## Zeeman Effect

When spectral line (source) is placed in magnetic field, spectral lines split up into sublines. This is known as zeeman effect.

## Stark Effect

If splitting of spectral lines take place in electric field, then it is known as stark effect.

## Dual Behaviour of Matter (de Broglie Equation)

De Broglie in 1924, proposed that matter, like radiation, should also exhibit dual behaviour i.e., both particle like and wave like properties. This means that like photons, electrons also have momentum as well as wavelength.

Assume light have wave nature, then its energy should be given by Planck's theory

$$E = h\nu \quad \dots (i)$$

If it have particle nature, then its energy should be given by Einstein relation,

$$E = mc^2 \quad \dots (ii)$$

On comparing equation (i) and (ii),

$$h\nu = mc^2$$

$$\lambda = hmc \text{ (for light) ... (iii)}$$

For other matter,

$$\lambda = hmv \text{ ... (iv)}$$

$$\lambda = hp \text{ ... (v)}$$

where  $p$  = momentum

This equation is called de Broglie equation.

### Heisenberg's Uncertainty Principle

It states that, "It is impossible to measure simultaneously the exact position and exact momentum of a microscopic particle".

If uncertainty in position =  $\Delta x$  and

Uncertainty in momentum =  $\Delta P$

When both are measured simultaneously, According to this principle,

$$\Delta x \cdot \Delta P \geq h/4\pi$$

### Quantum Numbers

There are a set of four quantum numbers which specify the energy, size, shape and orientation of an orbital. To specify an orbital only three quantum numbers are required while to specify an electron all four quantum numbers are required.

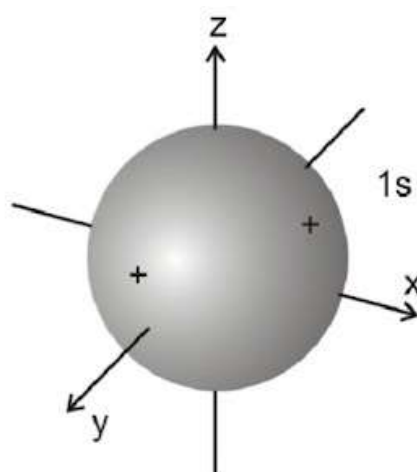
1. **Principal quantum number (n):** It identifies shell, determines sizes and energy of orbitals. It is indicated by 'n' and its values are 1, 2, 3, 4...
2. **Azimuthal quantum number (l):** Azimuthal quantum number. 'l' is also known as orbital angular momentum or subsidiary quantum number. l. It identifies sub-shell, determines the shape of orbitals, energy of orbitals in multi-electron atoms along with principal quantum number and orbital angular momentum, i.e., The number of orbitals in a sub shell =  $2l + 1$ . For a given value of n, it can have n values ranging from 0 to n-1.
3. **Magnetic quantum number (ml):** It gives information about the spatial orientation of the orbital with respect to standard set of co-ordinate axis. For any sub-shell (defined by 'l' value)  $2l+1$  values of ml are possible. For each value of l,  $ml = -l, -(l-1), -(l-2) \dots 0, 1 \dots (l-2),$

$(l-1), l$

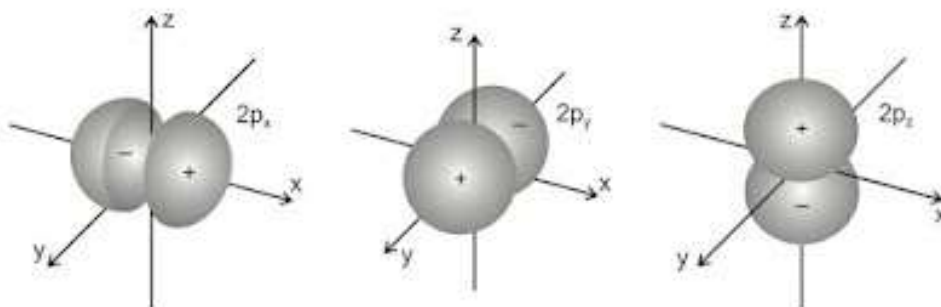
4. **Electron spin quantum number ( $m_s$ ):** It refers to orientation of the spin of the electron. It can have two values  $+1/2$  and  $-1/2$ .  $+1/2$  identifies the clockwise spin and  $-1/2$  identifies the anti-clockwise spin.

## Shape of Atomic Orbitals

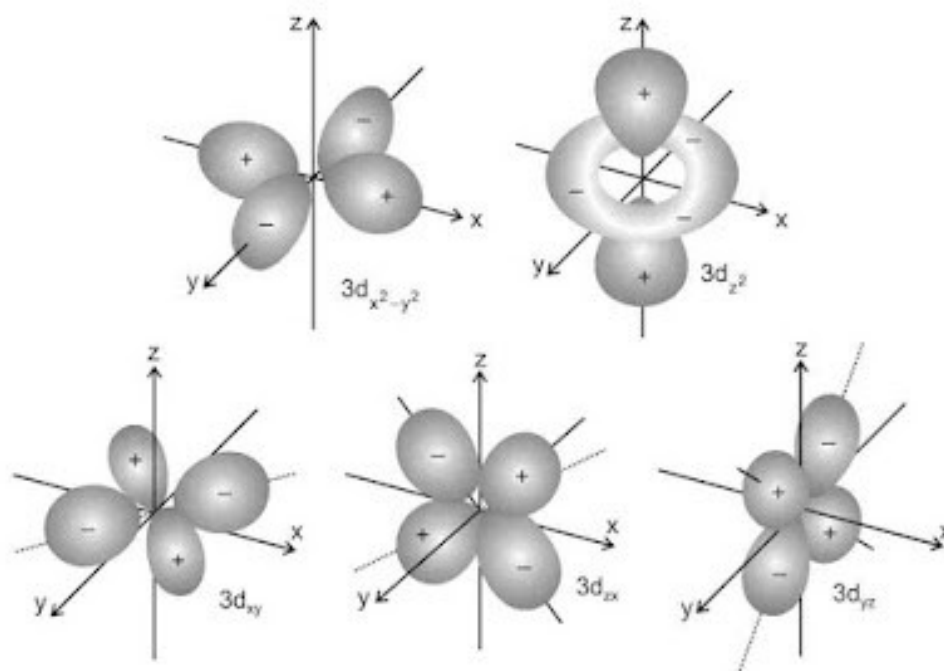
**Shapes of s-orbitals:** s-orbital is present in the s-sub shell. For this sub shell,  $l = 0$  and  $m_l = 0$ . Thus, s-orbital with only one orientation has a spherical shape with uniform electron density along all the three axes. The probability of 1s electron is found to be maximum near the nucleus and decreases with the increase in the distance from the nucleus.



**Shapes of p-orbitals:** p-orbitals are present in the p-subshell for which  $l = 1$  and  $m_l$  can have three possible orientations  $-1, 0, +1$ . Thus, there are three orbitals in the p-subshell which are designated as  $p_x, p_y$  and  $p_z$  orbitals depending upon the axis along which they are directed. The general shape of a p-orbital is dumb-bell consisting of two portions known as lobes.



**Shapes of d-orbitals:** d-orbitals are present in d-subshell for which  $l = 2$  and  $m_l = -2, -1, 0, +1$  and  $+2$ . This means that there are five orientations leading to five different orbitals. d orbitals are of five types:  $d_{xy}, d_{yz}, d_{zx}, d_{x^2-y^2}, d_{z^2}$



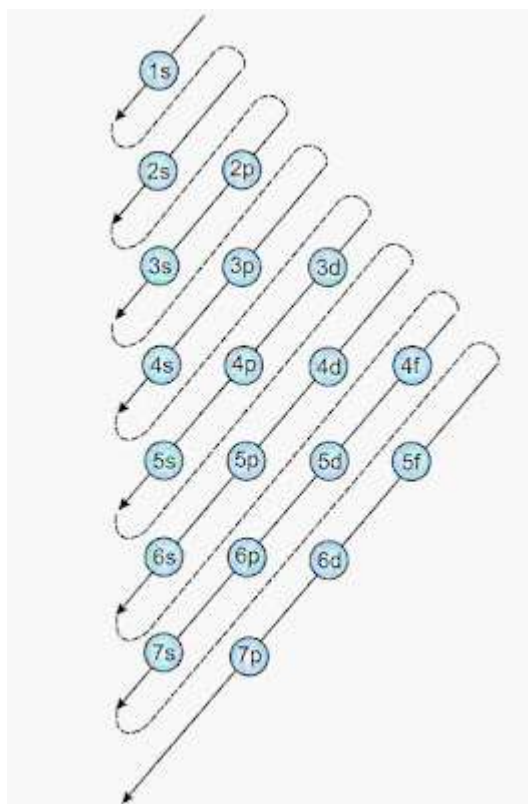
## Electronic Configuration

Distribution of electron in various orbitals is known as electronic configuration. The electrons filled in orbitals must obey the following rules-

- Aufbau's principle
- Pauli's exclusion principle
- Hund's rule of maximum multiplicity

1. **Aufbau's principle:** According to this principle, orbitals with lowest energy are filled before the orbitals having higher energy.





$$1s < 2s < 2p < 3s < 3p < 4s < 3d < 4p < 5s < 4d < 5p < 6s < 4f < 5d < 6p < 7s < 5f < 6d < 7p$$

### **(n + l) rule (Bohr Bury's Rule)**

According to this, The orbital which has lower value of (n + l) is lower in energy.

- Pauli's exclusion principle:** According to this principle, in an atom, no two electrons have same value of all the four quantum numbers. In the same orbital, electron always accommodate in opposite spins. An orbital can have a maximum of two electrons, with opposite spin.
- Hund's rule of maximum multiplicity:** According to this rule, electrons are distributed among the orbital of a subshell in such a way so as to give the maximum number of unpaired electrons with a parallel spin.

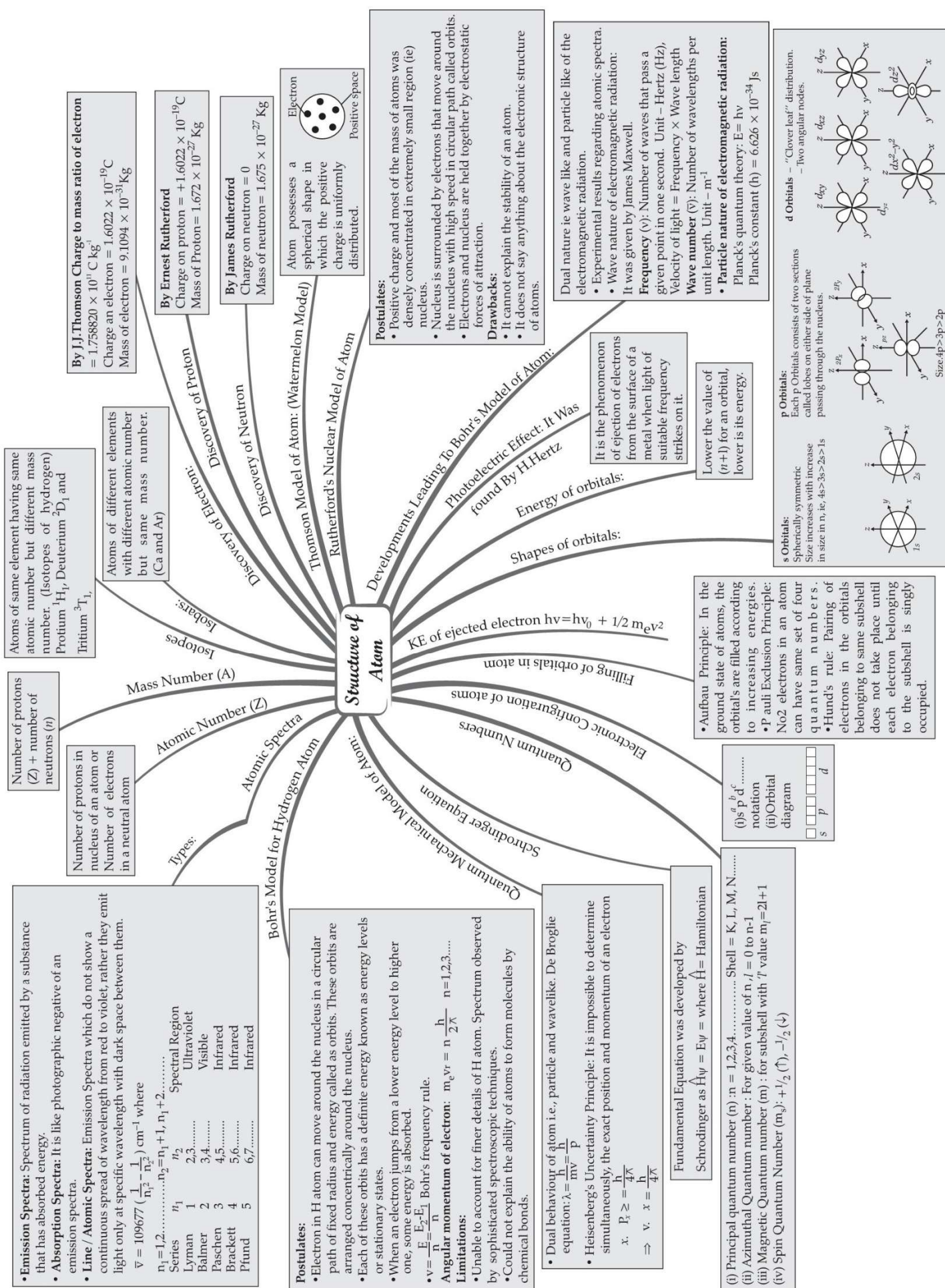
Li	$\uparrow\downarrow$	$\uparrow$			
Be	$\uparrow\downarrow$	$\uparrow\downarrow$			
B	$\uparrow\downarrow$	$\uparrow\downarrow$	$\uparrow$		
C	$\uparrow\downarrow$	$\downarrow\uparrow$	$\uparrow$	$\uparrow$	
N	$\uparrow\downarrow$	$\uparrow\downarrow$	$\uparrow$	$\uparrow$	$\uparrow$
O	$\uparrow\downarrow$	$\uparrow\downarrow$	$\uparrow\downarrow$	$\uparrow$	$\uparrow$
F	$\uparrow\downarrow$	$\uparrow\downarrow$	$\uparrow\downarrow$	$\uparrow\downarrow$	$\uparrow$
Ne	$\uparrow\downarrow$	$\uparrow\downarrow$	$\uparrow\downarrow$	$\uparrow\downarrow$	$\uparrow\downarrow$
	1s	2s	2p		

### Summary-

1. **Atomic number:** It is equal to the number of protons in the nucleus of an atom.
2. **Mass number:** It is equal to the sum of the positively charged protons (p) and electrically neutral neutrons (n).
3. **Isotopes:** Isotopes are the atoms of the same element which have the same atomic number but different mass numbers.
4. **Isobars:** Isobars are the atoms of different elements having the same mass number but different atomic numbers.
5. **Isoelectronic species:** These are those species which have same number of electrons.
6. **Radiations:** These are defined as the emission or transmission of energy through space in the form of waves.
7. **Electromagnetic waves:** The waves which consist of oscillating electric and magnetic fields are called electromagnetic waves.
8. **Electromagnetic radiations:** Those radiations which are associated with electric and magnetic field are called electromagnetic radiations.
9. **Electromagnetic spectrum:** The arrangement of the various types of electromagnetic radiations in the order of increasing or decreasing wavelengths or frequencies is known as electromagnetic spectrum.
10. **Wavelength ( $\lambda$ ):** It is the distance between successive points of equal phase of a wave.

11. **Frequency (f):** The number of waves that pass a given point in one second is known as the frequency.
12. **Time period (T):** Time taken by the wave for one complete cycle or vibration is called time period.
13. **Velocity (v):** It is the distance travelled by a wave in one second.
14. **Wave number:** It is defined as the number of wavelengths per unit length.
15. **Threshold frequency:** It is the minimum frequency of light needed to cause the photoelectric effect.
16. **Continuous spectrum:** The combination of light of different frequencies in continuous manner is called continuous spectrum.
17. **Line spectrum:** The spectrum of atoms consist of sharp well-defined lines corresponding to definite frequencies is called line spectrum.
18. **Spectroscopy:** The study of emission or absorption spectra is called spectroscopy.
19. **Quantization:** The restriction of a property to discrete values and not continuous values is called quantization.
20. **Quantum mechanics:** The branch of science that takes into account the dual behaviour of matter is called quantum mechanics.
21. **Atomic orbital:** It is the region of space where the probability of finding the electron is maximum.
22. **Quantum numbers:** may be defined as a set of four numbers with the help of which we can get complete information about electron in an atom.

# MIND MAP : LEARNING MADE SIMPLE CHAPTER - 2



## Important Questions

### Multiple Choice questions-

Question 1. Which of the following pair of ions have same paramagnetic moment?

- (a)  $\text{Cu}^{+2}$ ,  $\text{Ti}^{+3}$
- (b)  $\text{Mn}^{+2}$ ,  $\text{Cu}^{+2}$
- (c)  $\text{Ti}^{+4}$ ,  $\text{Cu}^{+2}$
- (d)  $\text{Ti}^{+3}$ ,  $\text{Ni}^{+2}$

Question 2. The charge to mass ratio of  $\alpha$  – particles is approximately ..... the charge to mass ratio of protons

- (a) Twice
- (b) Half
- (c) Four times
- (d) Six times

Question 3. The frequency of a wave of light is  $12 \times 10^{14} \text{s}^{-1}$ . The wave number associated with this light

- (a)  $5 \times 10^{-7} \text{m}$
- (b)  $4 \times 10^{-8} \text{cm}^{-1}$
- (c)  $2 \times 10^{-7} \text{m}^{-1}$
- (d)  $4 \times 10^4 \text{cm}^{-1}$

Question 4. In a multi – electron atom, which of the following orbitals described by the three quantum numbers will have the same energy in the absence of magnetic field and electric fields?

- (a)  $n = 1, l = 0, m = 0$  (b)  $n = 2, l = 0, m = 0$  (c)  $n = 2, l = 1, m = 1$  (d)  $n = 3, l = 2, m = 1$  (e)  $n = 3, l = 2, m = 0$
- (a) (a) and (b)
  - (b) (b) and (c)
  - (c) (c) and (d)
  - (d) (d) and (e)

Question 5. The electronic transitions from  $n = 2$  to  $n = 1$  will produce shortest wavelength in (where  $n$  = principal quantum state)

- (a)  $\text{Li}^{2+}$
- (b)  $\text{He}^{+}$
- (c) H

(d)  $H^+$

Question 6. In a hydrogen atom, if energy of an electron in ground state is 13.6 eV, then that in the 2nd excited state is

(a) 1.51 eV

(b) 3.4 eV

(c) 6.04 eV

(d) 13.6 eV

Question 7. The credit of discovering neutron goes to

(a) Rutherford

(b) Thomson

(c) Goldstein

(d) Chadwick

Question 8. The maximum number of electrons that can be accommodated in fifth energy level is

(a) 10

(b) 25

(c) 50

(d) 32

Question 9. According to Aufbaus principle, which of the three 4d, 5p and 5s will be filled with electrons first

(a) 4d

(b) 5p

(c) 5s

(d) 4d and 5s will be filled simultaneously

Question 10. A hydrogen atom in its ground state absorbs 10.2 eV of energy. The orbital angular momentum is increased by (Given Planck constant  $h = 6.6 \times 10^{-34}$  Jsec)

(a)  $1.05 \times 10^{-34}$  Jsec

(b)  $3.16 \times 10^{-34}$  Jsec

(c)  $2.11 \times 10^{-34}$  Jsec

(d)  $4.22 \times 10^{-34}$  Jsec

Question 11. The ionization enthalpy of hydrogen atom is  $1.312 \times 10^6$  J mol<sup>-1</sup>. The energy required to excite the electron in the atom from  $n = 1$  to  $n = 2$  is



- (a)  $8.51 \times 10^5 \text{ Jmol}^{-1}$
- (b)  $6.56 \times 10^5 \text{ Jmol}^{-1}$
- (c)  $7.56 \times 10^5 \text{ Jmol}^{-1}$
- (d)  $9.84 \times 10^5 \text{ Jmol}^{-1}$

Question 12. For principal quantum number  $n = 4$ , the total number of orbitals having  $l = 3$  is

- (a) 3
- (b) 7
- (c) 5
- (d) 9

Question 13. Maximum number of electrons in a subshell with  $l = 3$  and  $n = 4$  is

- (a) 10
- (b) 12
- (c) 14
- (d) 16

Question 14. Which hydrogen-like species will have same radius as that of Bohr orbit of hydrogen atom?

- (a)  $n = 2$ ,  $\text{Li}^{2+}$
- (b)  $n = 2$ ,  $\text{Be}^{3+}$
- (c)  $n = 2$ ,  $\text{He}^+$
- (d)  $n = 3$ ,  $\text{Li}^{2+}$

Question 15. The magnetic quantum number specifies

- (a) Size of orbitals
- (b) Shape of orbitals
- (c) Orientation of orbitals
- (d) Nuclear Stability

### Very Short:

1. How many total electrons are present in nitrate ion?
2. The nucleus of the atom of an element does not contain a neutron. Name the element and what does its nucleus consists of.
3. What are nucleons?

4. Write electronic configurations of Chromium (At. No. = 24).
5. Which of the following has the smallest de-Broglie wavelength?  $O_2$ ,  $H_2$ , a proton, an electron
6. How many unpaired electrons are there in a carbon atom in the ground state?
7. What type of spectrum is obtained when light emitted from the discharge tube containing hydrogen gas is analyzed?
8. What is the maximum number of electrons in an atom having  $n = 3$ ,  $l = 1$  and  $s = +\frac{1}{2}$ ?
9. Name the spectral line in the spectrum of H-atom obtained when an electron jumps from  $n = 4$  to  $n = 2$ .
10. Give some examples of electromagnetic radiation.

### Short Questions:

1. Enumerate the important characteristics of anode-rays (or positive rays). How this study led to the discovery of proton?
2. What are anode-rays? Illustrate their formation by a diagram.
3. Describe the important properties of cathode-rays. What is concluded about the nature of these rays?
4. What are the main features of Rutherford's model of an atom?
5. What is meant by the dual nature of radiation?
6. Describe the drawback to Rutherford's model of the atom.
7. What is the value of?
  - (i) Charge to mass ratio ( $e/m$ ) of electrons,
  - (ii) Charge of electrons,
  - (iii) Mass of an electron?

### Long Questions:

1. Describe the shape of s – and p – orbitals. What do you mean by node or nodal surface?
2. How does the Schrodinger wave equation help to understand the probability of finding the electron near the nucleus? What do you mean by an orbital?
3. How many nucleons are present in an atom of Nobelium, No? How many electrons are present in the atom? How many nucleons may be considered neutrons?
4. Complete the following table:



Particle	Atomic No.	Mass No.	No. of electrons	No. of protons	No. of neutrons
Sodium atom	11	—	—	—	12
Aluminium ion	—	27	10	—	—
Chloride ion	—	—	18	—	18
Phosphorus atom	—	31	—	15	—
Cuprous ion	—	—	28	—	35

5. Find the number of protons, electrons and neutrons in (a)  ${}_{13}^{27}\text{A}^{3+}$

### Assertion Reason Questions:

1. In the following questions, a statement of Assertion (A) followed by a statement of Reason (R) is given. Choose the correct option out of the choices given below each question.

**Assertion (A) :** All isotopes of a given element show the same type of chemical behaviour.

**Reason (R) :** The chemical properties of an atom are controlled by the number of electrons in the atom.

- (i) Both A and R are true and R is the correct explanation of A.
- (ii) Both A and R are true but R is not the correct explanation of A.
- (iii) A is true but R is false.
- (iv) Both A and R are false.

2. In the following questions, a statement of Assertion (A) followed by a statement of Reason (R) is given. Choose the correct option out of the choices given below each question.

**Assertion (A) :** Black body is an ideal body that emits and absorbs radiations of all frequencies.

**Reason (R) :** The frequency of radiation emitted by a body goes from a lower frequency to higher frequency with an increase in temperature.

- (i) Both A and R are true and R is the correct explanation of A.
- (ii) Both A and R are true but R is not the explanation of A.
- (iii) A is true and R is false.
- (iv) Both A and R are false.

### Case Study Based Question:

1. The atomic theory of matter was first proposed on a firm scientific basis by John Dalton, a British schoolteacher in 1808. His theory, called Dalton's atomic theory, regarded the atom as the ultimate particle of matter. Dalton's atomic theory was able to explain the law of conservation of mass, law of constant composition and law of multiple proportion very successfully. However, it failed to explain the results of many experiments. In mid 1850s many scientists mainly Faraday began to study electrical discharge in partially evacuated tubes, known as cathode ray discharge tubes. Electrical discharge carried out in the modified cathode ray tube led to the discovery of canal rays carrying positively charged particles. The characteristics of these positively charged particles are listed below.

- 1) Unlike cathode rays, mass of positively charged particles depends upon the nature of gas present in the cathode ray tube. These are simply the positively charged gaseous ions.
- 2) The charge to mass ratio of the particles depends on the gas from which these originate.
- 3) Some of the positively charged particles carry a multiple of the fundamental unit of electrical charge.
- 4) The behaviour of these particles in the magnetic or electrical field is opposite to that observed for electron or cathode rays.

The smallest and lightest positive ion was obtained from hydrogen and was called proton. This positively charged particle was characterised in 1919. Later, a need was felt for the presence of electrically neutral particle as one of the constituents of atom. These particles were discovered by Chadwick (1932) by bombarding a thin sheet of beryllium by  $\alpha$ -particles. When electrically neutral particles having a mass slightly greater than that of protons were emitted. He named these particles as neutrons. J. J. Thomson, in 1898, proposed that an atom possesses a spherical shape (radius approximately  $10^{-10}$  m) in which the positive charge is uniformly distributed. The electrons are embedded into it in such a manner as to give the most stable electrostatic arrangement. Many different names are given to this model, for example, plum pudding, raisin pudding or watermelon. This model can be visualised as a pudding or watermelon of positive charge with plums or seeds (electrons) embedded into it. An important feature of this model is that the mass of the atom is assumed to be uniformly distributed over the atom. Rutherford and his students (Hans Geiger and Ernest Marsden) bombarded very thin gold foil with  $\alpha$ -particles. Rutherford's famous  $\alpha$ -particle scattering experiment. The observations of Scattering experiment are as follows:-

- (i) most of the  $\alpha$ -particles passed through the gold foil undeflected.
- (ii) a small fraction of the  $\alpha$ -particles was deflected by small angles.
- (iii) a very few  $\alpha$ -particles ( $\sim 1$  in 20,000) bounced back, that is, were deflected by nearly  $180^\circ$ .

On the basis of observations and conclusions from this experiment, Rutherford proposed the nuclear model of atom. According to this model:

(i) The positive charge and most of the mass of the atom was densely concentrated in extremely small region. This very small portion of the atom was called nucleus by Rutherford.

(ii) The nucleus is surrounded by electrons that move around the nucleus with a very high speed in circular paths called orbits. Thus, Rutherford's model of atom resembles the solar system in which the nucleus plays the role of sun and the electrons that of revolving planets.

(iii) Electrons and the nucleus are held together by electrostatic forces of attraction.

1) The atomic theory of matter was first proposed on affirm scientific basis by.

- (a) John Dalton
- (b) Ernest Rutherford
- (c) J. Thomson
- (d) Henry Moseley

2) The cathode rays start from ..... and move towards the .....

- (a) Anode , Cathode
- (b) Centre , Anode
- (c) Cathode , Anode
- (d) Cathode , Centre

3) Negatively charged particles in atoms , called .....

- (a) Protons
- (b) electrons
- (c) Neutron
- (d) Positron

(4) The smallest and lightest positive ion was obtained from ..... and was called proton.

- (a) Oxygen
- (b) Nitrogen
- (c) Carbon
- (d) Hydrogen

(5) Electrically neutral particles having a mass slightly greater than that of protons, these particles termed as .....

- (a) Protons
- (b) electrons
- (c) Neutron
- (d) Positron

2. The presence of positive charge on the nucleus is due to the protons in the nucleus. As established earlier, the charge on the proton is equal but opposite to that of electron. Atomic number ( $Z$ ) = number of protons in the nucleus of an atom = number of electrons in a neutral atom. protons and neutrons present in the nucleus are collectively known as nucleons. The total number of nucleons is termed as mass number ( $A$ ) of the atom.

mass number ( $A$ ) = number of protons ( $Z$ ) + number of neutrons ( $n$ ).

Isobars are the atoms with same mass number but different atomic number for example,  $^{14}_6\text{C}$  and  $^{14}_7\text{N}$ . On the other hand, atoms with identical atomic number but different atomic mass number are known as Isotopes. For example, considering of hydrogen atom again, 99.985% of hydrogen atoms contain only one proton. This isotope is called protium ( $^1_1\text{H}$ ). Rest of the percentage of hydrogen atom contains two other isotopes, the one containing 1 proton and 1 neutron is called deuterium ( $^2_1\text{D}$ , 0.015%) and the other one possessing 1 proton and 2 neutrons is called tritium ( $^3_1\text{T}$ ). ..the studies of interactions of radiations with matter have provided immense information regarding the structure of atoms and molecules. Niels Bohr utilised these results to improve upon the model proposed by Rutherford. Two developments played a major role in the formulation of Bohr's model of atom. These were:

- (i) Dual character of the electromagnetic radiation which means that radiations possess both wave like and particle like properties, and
- (ii) Experimental results regarding atomic spectra.

James Maxwell (1870) was the first to give a comprehensive explanation about the interaction between the charged bodies and the behavior of electrical and magnetic fields on macroscopic level. He suggested that when electrically charged particle moves under calculation, alternating electrical and magnetic fields are produced and transmitted. These fields are transmitted in the forms of waves called electromagnetic waves or electromagnetic radiation. radiations are characterised by the properties, namely, frequency ( $\nu$ ) and wavelength ( $\lambda$ ). The SI unit for frequency ( $\nu$ ) is hertz ( $\text{Hz}$ ,  $\text{s}^{-1}$ ), after Heinrich Hertz. It is defined as the number of waves that pass a given point in one second. Wavelength should have the units of length and as you know that the SI units of length is meter ( $\text{m}$ ). Since electromagnetic radiation consists of different kinds of waves of much smaller wavelengths, smaller units are used. In vacuum all types of electromagnetic radiations, regardless of wavelength, travel at the same speed, i.e.,  $3.0 \times 10^8 \text{ m/s}$

$\text{s}^{-1}$  ( $2.997925 \times 10^8 \text{ ms}^{-1}$ , to be precise). This is called speed of light and is given the symbol 'c'. The frequency ( $\nu$ ), wavelength ( $\lambda$ ) and velocity of light (c) are related by the following equation .

$$c = \nu \lambda$$

The other commonly used quantity specially in spectroscopy, is the wavenumber. It is defined as the number of wavelengths per unit length. Its units are reciprocal of wavelength unit, i.e.,  $\text{m}^{-1}$ . However commonly used unit is  $\text{cm}^{-1}$

1) The presence of positive charge on the nucleus is due to the ..... in the nucleus.

- (a) Protons
- (b) Neutrons
- (c) Electron
- (d) Nucleons

2) Atomic Number is denoted by .....

- (a) A
- (b) Z
- (c) N
- (d) M

3) Atomic Mass number is denoted by .....

- (a) M
- (b) Z
- (c) N
- (d) A

4) ..... are the atoms with same mass number but different atomic number.

- (a) Isotopes
- (b) Allotropes
- (c) Isobars
- (d) None of above

5) Atoms with identical atomic number but different atomic mass number are known as ..

- (a) Isotopes

- (b) Allotropes
- (c) Isobars
- (d) None of above

### Answer Key:

#### MCQ

1. (a)  $\text{Cu}^{+2}$ ,  $\text{Ti}^{+3}$
2. (b) Half
3.  $4 \times 10^4 \text{cm}^{-1}$
4. (d) (d) and (e)
5. (a)  $\text{Li}^{2+}$
6. (a) 1.51 eV
7. (d) Chadwick
8. (c) 50
9. (9) 5s
10. (a)  $1.05 \times 10^{-34} \text{Jsec}$
11. (d)  $9.84 \times 10^5 \text{J mol}^{-1}$
12. (b) 7
13. (c) 14
14. (b)  $n = 2$ ,  $\text{Be}^{3+}$
15. (c) Orientation of orbitals

#### Very Short Answer:

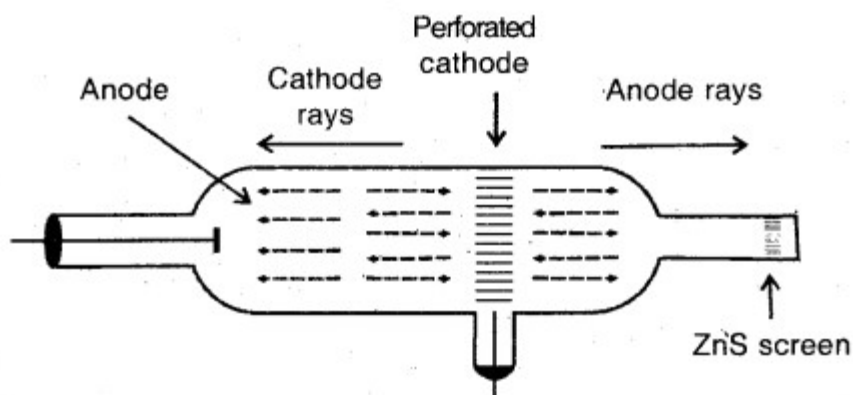
1. No. of electrons in  $\text{NO}_3^-$  ion  
= No. of electrons on N + No. of electrons on 3 oxygen atoms + one  $\bar{e}$   
=  $7 + 3 \times 8 + 1 = 32$  electrons.
2. The nucleus of hydrogen. It contains only one proton.

3. The neutrons and protons present in the nucleus of an atom are collectively called nucleons.
4.  $\text{Cr} = 24 = 1s^2, 2s^2 2p^6, 3s^2 3p^6 3d^5, 4s^1$ .
5. According to the de-Broglie equation  $\lambda = \frac{h}{m \times v}$  for same value of velocity  $\lambda \propto \frac{1}{m}$   
 $\therefore \text{O}_2$  molecule has shortest wavelength.
6.  $\text{C} = 6 = 1s^2, 2s^2, 2p^1 \times 2p^1$ . There are only two unpaired electrons.
7. Emission line spectrum.
8. Three electrons (one each in  $3p_x', 3p_y', 3p_z'$ ).
9. Balmer Series.
10. Y-rays, X-rays, UV-rays, visible rays, radio waves, etc.

### Short Answer:

**Ans: 1.** The mass of positive particles which constitute these rays depend upon the nature of the gas in the tube. The charge/mass ( $e/m$ ) ratio of anode-rays is not constant but depends upon the nature of gas in the tube. The value of  $e/m$  is greatest for the lightest gas, hydrogen the electric charge on a lightest positively charged particle from hydrogen gas was found to be exactly equal in magnitude but opposite in sign to that of the electron. This lightest positively charged particle from hydrogen gas was named the proton. The mass of a proton is almost 1836 times that of the electron.

**Ans: 2.** Anode-rays. If a perforated cathode is used in the discharge tube experiment, it is found that a certain type of radiation also travels from anode to cathode. These are called anode rays or positive rays.



Production of anode rays

**Ans: 3.** The cathode rays possess the following properties:

1. Travel in straight lines perpendicular to the surface of the cathode.
2. Consists of material particles.
3. Have got the heating effect.
4. Consists of negatively charged particles.
5. Produce X-rays when they strike against hard metals like copper, tungsten, platinum, etc.
6. Produce fluorescence when they strike glass or certain other materials like zinc sulfide.
7. Penetrate through thin aluminum foils and other metals.
8. Affect the photographic plates.

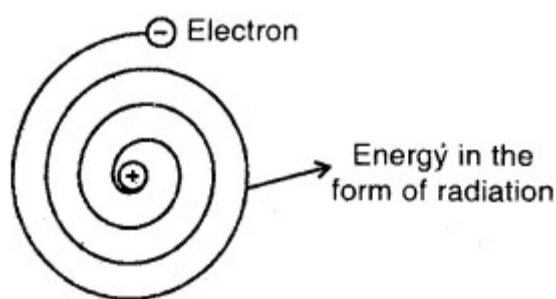
**Ans: 4.** The main features of this model are:

1. Atom is spherical and consists of two parts: Nucleus and extra-nuclear part.
2. The entire mass and entire positive charge are concentrated in a very small region at the center known as the nucleus.
3. The space surrounding the nucleus known as the extra-nuclear part is negatively charged so an atom as a whole is neutral.
4. Most of the extra-nuclear part is empty.
5. The electrons are not stationary but are revolving around the nucleus at very high speeds like planets revolving around the Sun.

**Ans: 5.** The fact that light energy is carried in terms of packets of energy (i.e., photons) as suggested by Planck's theory means that light has a particle character. At the same time, the fact light has a wave character. These experimental facts led Einstein to suggest that light has a dual character, i.e., it behaves both like a wave and like a particle.

**Ans: 6.** The main drawback is that it could not explain the stability of an atom. Maxwell has shown that when electric charge is subjected to acceleration, it emits energy in the form of radiations. In Rutherford's model of the atom, electrons are orbiting the nucleus and hence the direction of their velocity is constantly changing, i.e., electrons are accelerating. This will cause the electrons will have lesser and lesser energy and will get closer and closer to the nucleus until at last, it spirals into the nucleus and thus does not provide a stable model of the atom.





**Ans: 7.** J. Thomson determined the value of  $e/m$  for electron by the study of deflection of electron beam under the simultaneous influence of electric and magnetic field perpendicular to each other, the  $e/m$  value is  $1.76 \times 10^8$  coulomb per gram of electrons

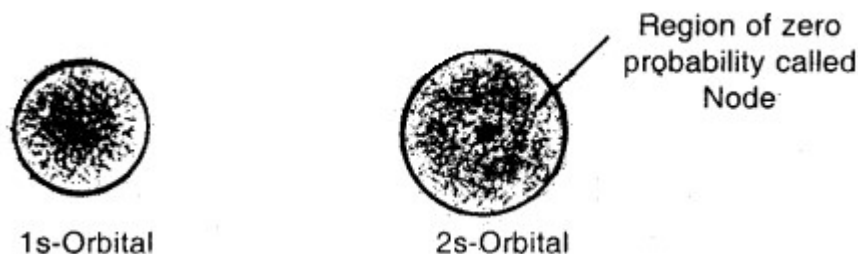
The charge of electrons was measured by Millikan in 1909 by his famous 'oil drop' experiment. It was found to be  $1.60 \times 10^{-19}$  coulombs.

The mass of electrons is  $9.1 \times 10^{-28}$  g.

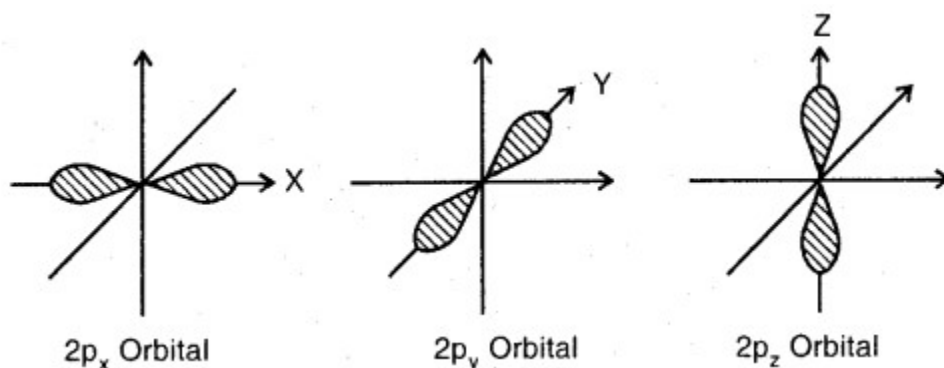
### Long Answer:

**Ans: 1.** Shapes of Orbitals:

s-orbitals: These are spherically symmetrical and non-directional. Shapes of 1s and 2s orbitals are shown in Fig. The effective volume of 2s orbital is larger than 1s orbital. Another important feature of 2s orbital is that there is a spherical shell within 2s (region without dots) where the probability of finding the electron is zero. This is called a node or a nodal surface. There are  $(n - 1)$  nodes in an s-orbital (where  $n$  is the energy level).



p-orbitals: There are three p-orbitals designated as  $p_x$ ,  $p_y$  or  $p_z$  which are oriented along the three mutually perpendicular axis x, y, and z. Each orbital consists of two lobes symmetrical about the particular axis and has a dumbbell shape. The two lobes are separated by a nodal plane.



Shapes of three 2p orbitals

The two lobes of each orbital are separated by a plane having zero electron density. This plane is known as a nodal plane.

**Ans: 2.** Probability Picture of Electrons:

Schrodinger incorporated the requirements of the uncertainty principle and de Broglie's concept of matter waves and proposed a mathematical equation to describe the behavior of an electron in an atom. The equation was known as the Schrodinger wave equation.

The Schrodinger wave equation is

$$\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} + \frac{\partial^2 \psi}{\partial z^2} + \frac{8\pi^2 m}{h^2} (E - V) \psi = 0$$

where x, y, and z are three space coordinates,

m is the mass of the electron,

h is Planck's, constant

E is the total energy and V is the potential energy of the electron,  $\psi$  (Greek letter psi) is the amplitude of the wave, called wave function,  $\frac{\partial^2 \psi}{\partial x^2}$  refers to the second derivative of  $\psi$  with respect to x only and so on.

The solution of this equation gave the mathematical expression which gives information about the various energy states and other measurable properties such as the radiation frequencies emitted or absorbed for the hydrogen atom. The solutions of the Schrodinger wave equation are called wave functions and are denoted by the symbol  $\psi$ .

The physical significance of wave function: In the physical sense  $\psi$  gives the amplitude of the wave associated with the electron. We know that in the case of light waves, the square of

the amplitude, of the wave at a point is proportional to the intensity of light. Extending the same concept of electron wave motion, the square of the wave function,  $\phi^2$  may be taken as the intensity of electrons at any point.

In other words,  $\phi^2$  determines the probability density. Thus,  $\phi^2$  has been called the probability density and  $\phi$  the probability amplitude. Thus, the solutions of the Schrodinger wave equation replace the discrete energy levels or orbits proposed by Bohr and led to the concept of the most probable regions in space in terms of  $\phi^2$ .

A large value of  $\phi^2$  means a high probability of finding the electron at that place and a small value of  $\phi^2$  means low probability. If  $\phi^2$  is almost zero at a particular point, it means that the probability of finding the electron at that point is negligible. Therefore, the wave mechanics approach gives meaningful wave functions which describe the position and energy levels of electrons in an atom.

Concept of Orbital: An orbital is a region in space around the nucleus where the probability of finding the electrons is maximum.

Ans: 3. Nucleons = 254, electrons = 102 and neutrons  $254 - 102 = 152$ .

Ans: 4.

Particle	Atomic No.	Mass No.	No. of electrons	No. of protons	No. of neutrons
Sodium atom	11	23	11	11	12
Aluminium ion	13	27	10	13	14
Chloride ion	17	35	18	17	18
Phosphorus atom	15	31	15	15	16
Cuprous ion	29	64	28	29	35

Ans: 5.

Name of the particle	Mass No.	Atomic No.	Protons	No. of Electrons	Neutrons
Oxygen	16	8	8	8	8
Sodium ion	23	11	11	10	12
Bromine	80	35	35	35	45

### Assertion Reason Answer:

- (i) Both A and R are true and R is the correct explanation of A.

2. (ii) Both A and R are true but R is not the explanation of A.

### Case Study Answer:

#### 1. Answer:

- (1) (a) John Dalton
- (2) (c) Cathode, Anode
- (3) (b) electrons
- (4) (d) Hydrogen
- (5) (c) Neutron

#### 2. Answer:

- (1) (a) Protons
- (2) (b) Z
- (3) (d) Z
- (4) (c) Isobars
- (5) (a) Isotopes