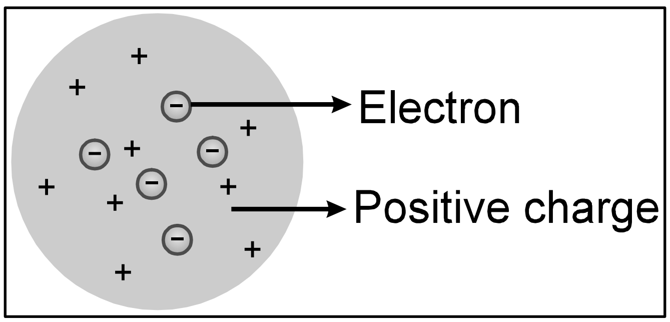
STRUCTURE OF ATOM
ATOMIC MODELS

❖ **ATOMIC MODELS**

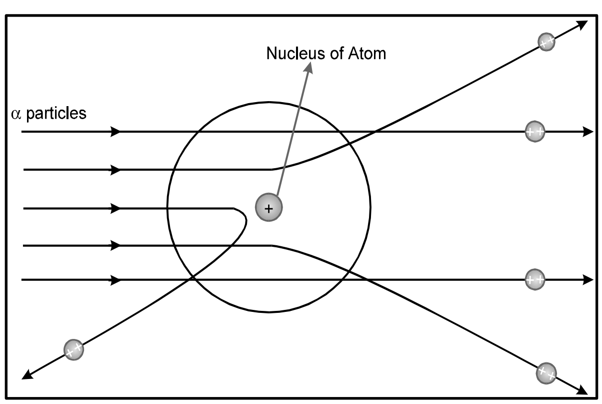
THOMSON'S MODEL OF ATOM [1904]

- Thomson was the first to propose a detailed model of the atom.
- Thomson proposed that an atom consists of a uniform sphere of positive charge in which the electrons are present at some places.
- This model of atom is known as 'Plum-Pudding model'.



Drawbacks

- An important drawback of this model is that the mass of the atoms is considered to be evenly spread over that atom.
- It is a static model. It does not reflect the movement of electron.
- RUTHERFORD'S α- SCATTERING EXPERIMENT
- α-Scattering Experiment

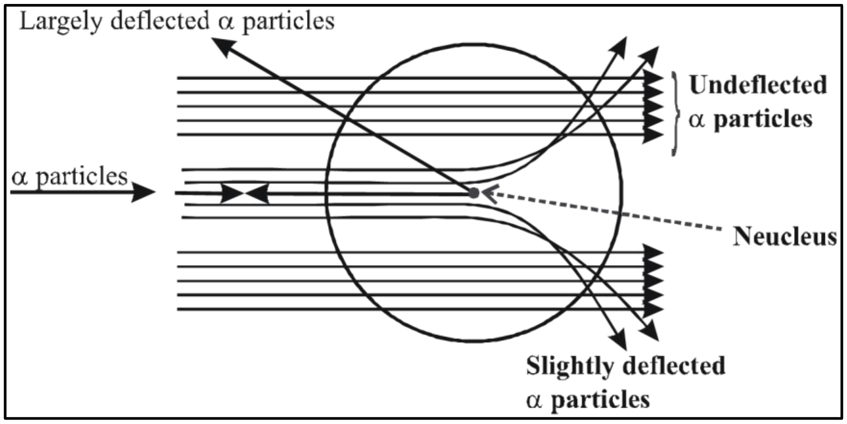


Rutherford Observed That

(i) Most of the α-particles (nearly 99.9%) went straight without suffering any deflection.

(ii) A few of them got deflected through small angles.

(iii) A very few α-particles (about one in 20,000)



did not pass through the foil at all but suffered large deflections (more than 90°) or even come back in the direction from which they have come i.e. a deflection of 180°.

Following Conclusions were Drawn from the Above Observations

(1) Since most of the α-particle went straight through the metal foil undeflected, it means that there must be very large empty space within the atom.

(2) Since few of the α-particles were deflected from their original path through moderate angles; it was concluded that whole of the +ve charge is concentrated and the space occupied by this positive charge is very small in the atom.

- Whenever α-particles come closer to this point, they suffer a force of repulsion and deviate from their paths.
- The positively charged heavy mass which occupies only a small volume in an atom is called nucleus. It is supposed to be present at the centre of the atom.

(3) A very few of the α-particles suffered strong deflections on even returned on their path indicating that the nucleus is rigid and α-particles recoil due to direct collision with the heavy positively charged mass.

(4) The relation between number of deflected particles and deflection angle θ is

$$\mu = \frac{1}{\sin^4\frac{\theta}{2}} \text{ [θ increases μ decreases]}$$

where μ = deflected particles θ = deflection angle

◆ As atomic number increases, the number of protons increases which increases the repulstion and so deflection angle θ increases.

APPLICATIONS OF RUTHERFORD MODEL

On the basis of scattering experiments, Rutherford proposed the model of an atom, which is known as nuclear atomic model. According to this model -

(i) An atom consists of a heavy positively charged nucleus where all the protons are present.

(ii) The volume of the nucleus is very small and is only a minute fraction of the total volume of the atom. Nucleus has a radius of the order of 10^{-13} cm and the atom has a radius of the order of 10^{-8} cm

$$\frac{r_A}{r_N} = \frac{\text{radius ofthe atom}}{\text{radius of the nucleus}} = \frac{10^{-8}}{10^{-13}} = 10^5, r_A = 10^5 r_N$$

Thus radius (size) of the atom is 10^5 times the radius of the nucleus.

◆ The radius of a nucleus is proportional to the cube root of the mass no. of the nucleus.

$$R \propto A^{1/3} \Rightarrow R = R_0 A^{1/3} \text{ cm}$$

Where $R_0 = 1.33 \times 10^{-13}$(a constant) and, A = mass number (p + n)

R = radius of the nucleus.

$$R = 1.33 \times 10^{-13} A^{1/3} \text{ cm}$$

(iii) There is an empty space around the nucleus called extra nuclear part. In this part electrons are present. The no. of electrons in an atom is always equal to no. of protons present in the nucleus. As the nuclear part of atom is responsible for the mass of the atom, the extra nuclear part is responsible for its volume. The volume of the atom is about 10^{15} times the volume of the nucleus.

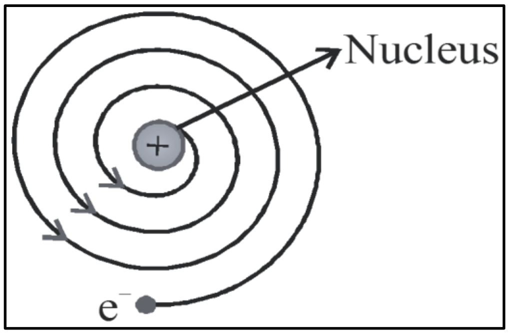
$$\frac{\text{Volume of the atom}}{\text{Volume of the nucleus}} = \frac{(10^{-8})^3}{(10^{-13})^3} = \frac{10^{-24}}{10^{-39}} = 10^{15}$$

(iv) Electrons revolve round the nucleus in closed orbits with high speeds.

◆ This model was similar to the solar system, the nucleus representing the sun and revolving electrons as planets.

Drawbacks of Rutherford Model

(1) This theory could not explain the stability of an atom. According to Maxwell electron loses it's energy continuously in the form of electromagnetic radiations. As a result of this, the e^- should loss energy at every turn and move closer and closer to the nucleus following a spiral path. The ultimate result will be that it will fall into the nucleus, thereby making the atom unstable.



(2) If the electrons loose energy continuously, the observed spectrum should be continuous but the actual observed spectrum consists of welldefined lines of definite frequencies (discontinuous). Hence, the loss of energy by electron is not continuous in an atom.

Electromagnetic Waves (EM waves) or Radiant Energy/Electromagnetic Radiation

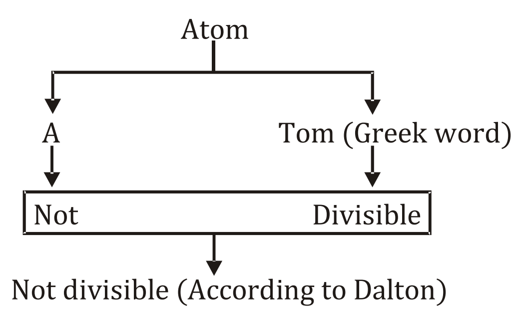
- It is the energy transmitted from one body to another in the form of waves and these waves travel in the space with the same speed as light (3×10^8 m/s) and these waves are known as Electromagnetic waves or radiant energy.
- The radiant Energy do not need any medium for propagation.

Ex: Radio waves, micro waves, Infra-red rays, visible rays, ultraviolet rays, x–rays, gama rays and cosmic rays.

S.No.	Name	Wavelength (Å)	Frequency (Hz)	Source
1.	Radio wave	$3 \times 10^{14} - 3 \times 10^{7}$	$1 \times 10^{5} - 1 \times 10^{9}$	Alternating current of high frequency
2.	Micro wave	$3 \times 10^{7} - 6 \times 10^{6}$	$1 \times 10^{9} - 5 \times 10^{11}$	Klystron tube
3.	Infrared (IR)	$6 \times 10^{6} - 7600$	$5 \times 10^{11} - 3.95 \times 10^{16}$	incandescent objects
4.	Visible	$7600 - 3800$	$3.95 \times 10^{16} - 7.9 \times 10^{14}$	Electric bulbs, sun rays

5.	Ultraviolet (UV)	$3800 - 150$	$7.9 \times 10^{14} - 2 \times 10^{16}$	Sun rays, are lamps with mercury vapours
6.	X-Rays	$150 - 0.1$	$2 \times 10^{16} - 3 \times 10^{19}$	Cathode rays striking metal plate
7.	Υ-Rays	$0.1 - 0.01$	$3 \times 10^{19} - 3 \times 10^{20}$	Secondary effect of radioactive decay
8.	Cosmic rays	$0.01 -$ Zero	3×10^{20}-Infinity	Outer space

INTRODUCTION



- Atom is a Greek Word and its meaning Indivisible i.e., an ultimate particle which cannot be further subdivided.

John Dalton (1803 - 1808) considered that " all matter was composed of small particle called atom.

ACCORDING TO DALTON'S THEORY

(1) Atom is the smallest indivisible part of matter which takes part in chemical reaction.

(2) Atom is neither created nor destroyed.

(3) Representation of atom: $_{Z}X^{A}$.

Where: A $\rightarrow$ Mass number, Z $\rightarrow$ Atomic number, X $\rightarrow$ Symbol of atom.

- **Mass Number**

It is represented by capital A. The sum of number of neutrons and protons is called the mass number. of the element. It is also known as number of nucleons because neutron & proton are present in nucleus.

$$A = \text{number of protons} + \text{number of neutrons}$$

Note: It is always a whole number.

- **Atomic Number**

It is represented by Z. The number of protons present in the Nucleus is called atomic number of an element. It is also known as nuclear charge.

For Neutral Atom: Number of protons = Number of electrons

For Charged Atom: Number of e^- = Z – (charge on atom)

Z= number of protons only

For Ex.

$$_{17}Cl^{35}$$

$$n = 18$$

$$p = 17$$

$$e = 17$$

Two different elements cannot have the same Atomic Number

$$\text{Number of Neutrons} = \text{Mass number} - \text{Atomic number}$$
$$= A - Z$$
$$= (p + n) - p$$
$$= n$$

- **Method for Analysis of Atomic Weight**

Ex.

$$_{6}C^{12}$$

$P^+ \rightarrow 6$ Weight of Proton $= 6 \times 1.00750$

$n^0 \rightarrow 6$ Weight of Neutron $= 6 \times 1.00850$

$e^- \rightarrow 6$ Weight of Electron $= 6 \times 0.000549$

Weight of C atom = 12.011 a.m.u.

Mass no. of C atom = 12 [P and n]

Note: Mass no. of atom is always a whole no. but atomic weight may be in decimal.

Ex. If no. of protons in X^{-2} is 16. then no. of e^- in X^{+2} will be–

(1) 14 (2) 16

(3) 18 (4) None

Sol. $\because$ No. of proton in X^{-2} is = 16

$\therefore$ No. of electron in X^{+2} is = 14

Ex. In C^{12} atom if mass of e^- is doubled and mass of proton is halved, then calculate the percentage change in mass no. of C^{12}.

Sol. ${}_6C^{12}$

$P^+ \rightarrow 3$

$e^- \rightarrow 12$

e^-	P^+	n°	
6	6	6	$A \rightarrow 12$
12	3	6	$A \rightarrow 9$

% change = × 100 = 25%

Ex. Assuming that atomic weight of C^{12} is 150 unit from atomic table, then according to this assumption, the weight of O^{16} will be :-

Sol. $\because$ 12 amu = 150

$\therefore$ 1 amu =

$\therefore$ 16 amu = × 16 = 200 Unit

Isotopes: Given by Soddy They are the atoms of a given element which have the same atomic number (Z) but different mass number (A) i.e. They have same Nuclear charge (Z) but different number of Neutrons (A–Z).

Ex.

${}_{17}Cl^{35}$	${}_{17}Cl^{37}$
n = 18	n = 20
e = 17	e = 17
p = 17	p = 17

- Isotopes have same chemical property but different physical property.
- Isotopes do not have the same value of $\frac{e}{m}$ $(\frac{\text{Number of electron}}{\text{mass}})$ because mass varies.

(No. of electron are same but mass varies).

Ex.

(Proteium	Deuterium	Tritium)
$_1H^1$	$_1H^2$	$_1H^3$
e = 1	e = 1	e = 1
p = 1	p = 1	p = 1
n = 0	n = 1	n = 2 e/m
1/1	1/2	1/3

$_1H^1$ is the only normal hydrogen which have n = 0 i.e., no nuetrons

Deuterium is also called as heavy hydrogen. It represents by D

Ex.

$_6C^{12}$	$_6C^{13}$	$_6C^{14}$
e = 6	e = 6	e = 6
p = 6	p = 6	p = 6
n = 6	n = 7	n = 8

Isobars: Given by Aston They are the atoms of different element which have the same mass number (A) but different atomic number (Z) i.e. They have different number of Electron, Protons & Neutrons But sum of number of neutrons & Protons i.e., number of nucleons remains same.

Ex.

$_1H^3$	$_2He^3$
p = 1	p = 2
e = 1	e = 2
n = 2	n = 1
p + n = 3	p + n = 3

- Isobars do not have the same chemical & physical property
- They do not have the same value of e/m

Ex.

$_{19}K^{40}$	$_{20}Ca^{40}$
p = 19	p = 20
n = 21	n +p = 40
n = 20	n +p = 40

$e = 19$ $e = 20$

$19 + 21 = 40$ $20 + 20 = 40$

$n + p = 40$

Number of Nucleons same

Isodiaphers

They are the atoms of different element which have the same difference of the number of Neutrons & protons.

Ex. ${}_5B^{11}$ ${}_6C^{13}$

$p = 5$ $p = 6$

$n = 6$ $n - p = 1$

$n = 7$ $n - p = 1$

$e = 5$ $e = 6$

Ex. ${}_7N^{15}$ ${}_9F^{19}$

$p = 7$ $p = 9$

$n = 8$ $n - p = 1$

$n = 10$ $n - p = 1$

$e = 7$ $e = 9$

Isotones/ Isoneutronic Species / Isotonic

They are the atoms of different element which have the same number of neutrons.

Ex. ${}_1H^3$ ${}_2He^4$

$p = 1$ $p = 2$

$n = 2$ $n = 2$

$e = 1$ $e = 2$

Ex. ${}_{19}K^{39}$ ${}_{20}Ca^{40}$

$e = 19$ $e = 20$

$p = 19$ $p = 20$

$n = 20$ $n = 20$

Isosters

They are the molecules which have the same number of atoms & electrons.

Ex.		CO_2		N_2O
	Atoms	$= 1 + 2$	Atoms	$= 2 + 1$
		$= 3$		$= 3$
	Electrons	$= 6 + 8 \times 2$	Electrons	$= 7 \times 2 + 8$
		$= 22\ e^-$		$= 22e^-$

Ex.		CaO	KF
	Atoms	2	2
	Electrons	$20 + 8$	$19 + 9$
		$28\ e^-$	$28\ e^-$

Ex.		OF_2	$HClO$
	Atoms	$= 3$	3
	Electrons	$= 8 + 18$	$1 + 17 + 8$
		$= 26\ e^-$	$26\ e^-$

Isoelectronic Species

They are the atoms, molecules or ions which have the same number of electrons.

Ex.		Cl^-	Ar
	Electron	$18\ e^-$	$18\ e^-$

Ex.	H_2O	NH_3
	$e = 2 + 8$	$e = 7 + 3$
	$10\ e^-$	$10\ e^-$

Ex.	BF_3	SO_2
	$e = 5 + 9 \times 3$	$16 + 8 \times 2$
	$5 + 27$	$16 + 16$
	$32\ e^-$	$32\ e^-$

Nuclear Isomer

Nuclear isomers (isomeric nuclei) are the atoms with the same atomic number and same mass number but with different radioactive properties.

Example of nuclear isomers is

Uranium–X (half–life 1.4 min) and

Uranium–Z (half–life 6.7 hours)

The reason for nuclear isomerism is the different energy states of the two isomeric nuclei.

Other examples are

$_{30}{}^{69}Zn\ _{30}{}^{69}Zn$ $(T_{1/2} = 13.8\text{ hr})$ $(T_{1/2} = 57\text{ min})$

$_{35}{}^{80}Br\ _{35}{}^{80}Br$ $(T_{1/2} = 4.4\text{ hour})$ $(T_{1/2} = 18\text{ min})$

EXAMPLE BASED ON NUCLEAR STRUCTURE

Ex. If the mass of neutrons is doubled & mass of electron is halved then find out the atomic mass of $_6C^{12}$ and the percent by which it is increased.

Sol. **Step-1** $_6C^{12}$

$e = 6$

$p = 6 = 6$ amu

$n = 6 = 6$ amu $= 12$ amu

If the mass of neutrons is doubled and mass of e^- is halved then.

$n = 12$ amu

$p = 6$ amu $= 18$ amu

Imp. Note: mass of e^- is negligible, so it is not considered in calculation of atomic mass.

Step-2

$$\%\text{ Increment} = \frac{\text{Final mass - Initial mass}}{\text{Initial mass}} \times 100$$

$$= \frac{18-12}{12} \times 100 \Rightarrow 50\%$$

Ex. If mass of neutron is doubled, mass of proton is halved and mass of electron is doubled then find out the change in At. wt of ${}_6C^{12}$

1. Remain same
2. Increased by 25%
3. Increased by 37.5%
4. None of them

Sol. **Step-1** ${}_6C^{12}$

$e = 6$

$p = 6 \quad = 12 \text{ amu}$

$n = 6$

If mass of neutron is doubled, mass of proton is halved and mass of electron is doubled, then new atomic mass will be:

$n = 12 \text{ amu}$

$p = 3 \text{ amu} \qquad = 15\text{amu}$

Step-2 $$\% \text{ Increment} = \frac{\text{Final mass - Initial mass}}{\text{Initial mass}} \times 100 = \frac{15-12}{12} \times 100 \Rightarrow 25\%$$

◆ **Planck's Quantum Theory: [Particle nature of light]:**

He stated that a body radiates energy in the form of discontinuous energy packets or bundles. Each bundle of energy is known as quantum and quantum of light is known as photons. Energy of each quantum is directly proportions to frequency of radiation.

$$E \propto v$$

$$E = h\nu \qquad h = \underset{\text{Plank's constant}}{\underbrace{6.62 \times 10^{-34}}} \text{ Js.}$$

Total energy absorbed or emitted by a body will be whole no. integral multiple of energy of quantum

$$E_{abs} \text{ or Eemitted } = nh\nu$$

Ex. Calculate the no. of photons emitted by 60-watt bulb in 10 hrs. When light of wavelength 6000 Å is emitted by it.

Sol. $$E = \frac{nhc}{\lambda} = 6.5 \times 10^{24}$$

Energies in Electron Volts

Room temperature thermal energy of a molecule..................................0.04 eV

Visible light photons...1.5-3.5 eV

Energy for the dissociation of an NaCl molecule into Na^+ and Cl^- ions:................4.2 eV

Ionization energy of atomic hydrogen ....13.6 eV

Approximate energy of an electron striking a color television screen
(CRT display) ....20,000 eV

High energy diagnostic medical x-ray photons..................200,000 eV (=0.2 MeV)

Typical energies from nuclear decay:

(1) gamma...0-3 MeV

(2) beta...0-3 MeV

(3) alpha...2-10 MeV

Cosmic ray energies ....1 MeV - 1000 TeV

1 MeV = 10^6 eV, 1 GeV = 10^9 eV, 1 TeV = 10^{12} eV

- **Explanation of black body radiations using Planck's quantum theory:**

When a solid substance like iron piece is heated it emits radiations. As heating is continued, more and more energy is being absorbed by the atom and hence, more energy will be emitted and therefore energy of e.m.w. increases and frequency of e.m.w. increases and therefore body first becomes red then yellow and finally white.

Therefore, it can be concluded that light posse's particle nature and energy of electromagnetic radiation depends upon frequency.

- **Explanation of Photo electric Effect using Planck's Quantum Theory:**

When a metal sheet is subjected to electromagnetic radiation of suitable frequency then some electrons are ejected from metal surface and these electrons are known as photoelectron and the effect is known as photoelectric effect.If electromagnetic radiation of low frequency are used then there is no ejection of electron inspite of continuous increasing intensity. This observation was contradicting to maxwell theory according to which energy electromagnetic radiation $\propto$ I but can be explained using Planck's quantum theory i.e.

$$E \propto \nu.$$

DUAL NATURE OF LIGHT

Since, wave nature of light explains diffraction interference phenomenon while particle nature explains black body radiation and photo electric effect

∴ light was considered to have dual nature particle nature as well as wave nature.

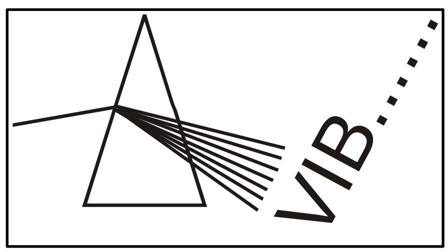
- **Electromagnetic spectrum:**

The arrangement of all the electromagnetic radiation in a definite order (decreasing or increasing of wavelength or frequency is known as electron magnetic spectrum

SPECTRUM

When light coming from a source is passed through a prism, the radiation of different wavelength deviated through different angles and get separated.

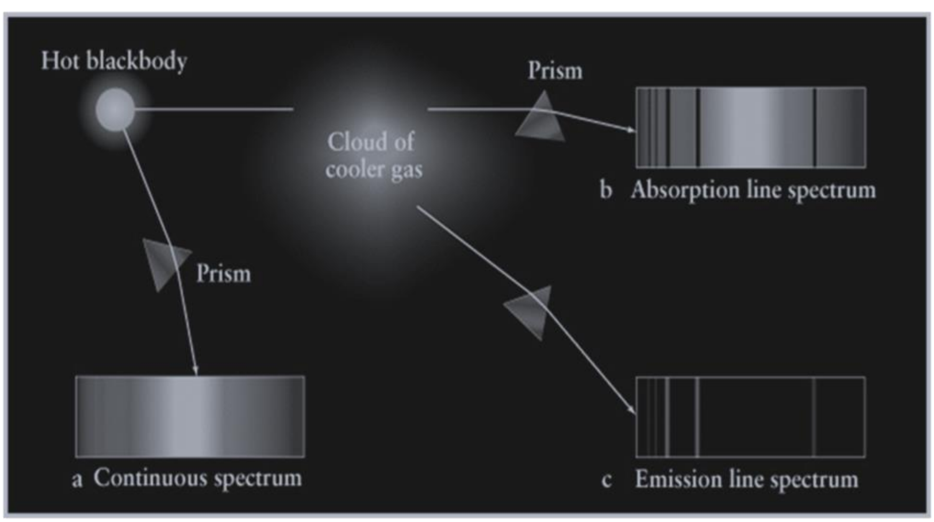
Angle of deviation $\propto \nu \propto \frac{1}{\lambda}$



this process is called dispersion.

And such a collection or dispersed light giving its wavelength composition is known as spectrum.

- **Spectrum are of two types.**



(1) Emission → Continuous, Discontinuous

(2) Absorption:

❖ **EMISSION SPECTRUM**

This is the spectrum of radiations emitted by any source or atom or molecule of any substance (Which is excited by heating or electric discharge).

(i) Continuous Spectrum:

When white light from a source is dispersed, a bright spectrum continuously distributed on the dark background is obtained. The colours are continuously changing from violet to red and there is no Sharp boundaries between various colour. These colours appear to be merge into each other and therefore spectrum is known as continuous spectrum.

(ii) Discontinuous Spectrum:

When an atom is subjected to electromagnetic radiation, it causes excitation of electron to higher energy level. When electrons return back to lower energy level, it emits certain radiations corresponding to difference in energy level and therefore spectrum obtained in case of atom is discontinuous spectrum having specific wavelength is known as atomic spectrum or line spectrum.

◆ **Absorption Spectrum:**

When an atom is subjected to white light it absorbs some specific radiation corresponding to the difference in energy level

∴ the remaining radiations (transmitted radiations) are devoid of certain specific frequencies which is observed in the form of missing line and this spectrum is known as absorption spectrum.

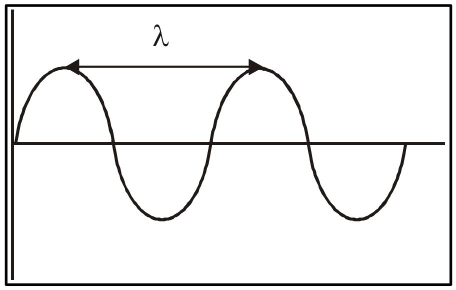
It is photographic negative of emission spectrum i.e.,

those bright lines which are present in emission spectrum of an atom are missing.

In the absorption spectrum and observed in the form of dark lines.

WAVES AND ITS CHARACTERISTICS

It is a periodical disturbance causing transfer of energy without transfer of matter.



- **Characteristics of waves:**

Amplitude: Maximum displacement from mean position it remains constant with distance except stationary or standing waves.

Wavelength: It is the distance between two adjacent crest or troughs.

Frequency (μ or ν) : The no of waves passing through a point in 1second, unit-sec^{-1} or Hz

Wave number ($\bar{\mu}$ or $\dddot{v}$) **:** No. of waves present in unit distance.

$$\bar{\mu} = \frac{1}{\lambda} = \text{ metre}^{-1}, \ \text{cm}^{-1} \qquad \text{etc.}$$

Velocity: linear distance travelled by wave in one second.

$$v = \mu\lambda$$

NATURE OF LIGHT

- **Maxwell electromagnetic wave theory (wave nature of light) :**

An accelerated electrically charged particle produces and transmits electrical and magnetic field. These are transmitted in the form of waves known as electromagnetic waves or electromagnetic radiations.

He stated that light also possess electrical and magnetic field and

$\therefore$ it is also known as electromagnetic radiations or e.m.w.

- **Characteristics of Electromagnetic Radiations:**

1. In these electromagnetic radiation electrical and magnetic field oscillates to each other and it also propagates to both fields.

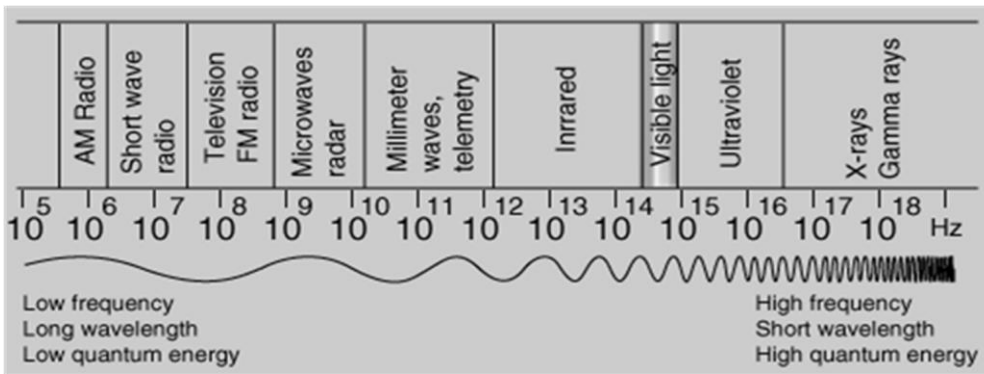
2. All these electromagnetic radiations do not require any medium and can travel in vacuum.

3. Velocity of all electromagnetic radiation is 3×10^8 m/s in vacuum.

4. Energy of an electromagnetic wave is directly proportional to intensity and it is independent of frequency.
5. There are also showing diffraction and interference And therefore. Maxwell concluded light to be wave nature.

But Maxwell theory couldn't explain the results of photoelectric effect and black body radiations.

Photon Energies for EM Spectrum



A Blackbody

A blackbody is an object that emits a well-defined spectrum of radiation solely based on its temperature. We see from figure at right that the hotter the blackbody, the more intense it is, and the shorter the peak wavelength.

The picture does not say anything about what the object is made of, or how heavy it is, etc. It doesn't matter! The only property that determines the spectrum of a blackbody is its temperature. Brick, iron or a dense gas will emit the same spectrum as long as they are at the same temperature. That spectrum will have a peak that lies at a particular wavelength.