Structure of atom

John Dalton 1808, believed that matter is made up of extremely minute indivisible particles, called *atom* which can takes part in chemical reactions. These can neither be created nor be destroyed. However, modern researches have conclusively proved that atom is no longer an indivisible particle. Modern structure of atom is based on Rutherford's scattering experiment on atoms and on the concepts of quantization of energy.

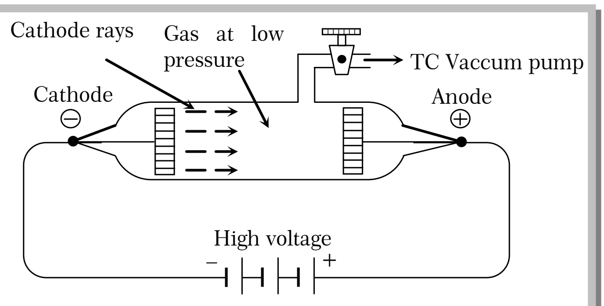
Composition of atom

The works of J.J. Thomson and Ernst Rutherford actually laid the foundation of the modern picture of the atom. It is now believed that the atom consists of several *sub-atomic particles* like electron, proton, neutron, positron, neutrino, meson etc. Out of these particles, the electron, proton and the neutron are called *fundamental subatomic particles* and others are *non-fundamental particles*.

Electron ($_{-1}e^o$)

(1) It was discovered by ***J.J. Thomson*** (1897) and is *negatively charged particle*. Electron is a component particle of cathode rays.

(2) Cathode rays were discovered by ***William Crooke's*** & ***J.J. Thomson*** (1880) using a cylindrical hard glass tube fitted with two metallic electrodes. The tube has a side tube with a stop cock. This tube was known as ***discharge tube***. They passed electricity (10,000*V*) through a discharge tube at very low pressure (10^{-2} to 10^{-3} $mm\ Hg$). Blue rays were emerged from the cathode. These rays were termed as ***Cathode rays***.



Discharge tube experiment for production of cathode rays

(3) **Properties of Cathode rays**

(i) Cathode rays travel in straight line.

(ii) Cathode rays produce mechanical effect, as they can rotate the wheel placed in their path.

(iii) Cathode rays consist of negatively charged particles known as *electron*.

(iv) Cathode rays travel with high speed approaching that of light (ranging between 10^{-9} to 10^{-11} cm/sec)

(v) Cathode rays can cause fluorescence.

(vi) Cathode rays heat the object on which they fall due to transfer of kinetic energy to the object.

(vii) When cathode rays fall on solids such as $Cu, X-$rays are produced.

(viii) Cathode rays possess ionizing power i.e., they ionize the gas through which they pass.

(ix) The cathode rays produce scintillation the photographic plates.

(x) They can penetrate through thin metallic sheets.

(xi) The nature of these rays does not depend upon the nature of gas or the cathode material used in discharge tube.

(xii) The *e/m* (charge to mass ratio) for cathode rays was found to be the same as that for an e^- (-1.76×10^8 coloumb per *gm*). Thus, *the cathode rays are a stream of electrons*.

Note: ❑ When the gas pressure in the discharge tube is 1 atmosphere no electric current flows through the tube. This is because the gases are poor conductor of electricity.

❑ The television picture tube is a cathode ray tube in which a picture is produced due to fluorescence on the television screen coated with suitable material. Similarly, fluorescent light tubes are also cathode rays tubes coated inside with suitable materials which produce visible light on being hit with cathode rays.

(4) ***R.S. Mullikan*** measured the charge on an electron by oil drop experiment. The charge on each electron is $-1.602 \times 10^{-19}\, C$.

(5) Name of electron was suggested by ***J.S. Stoney***. The specific charge (e/m) on electron was first determined by ***J.J. Thomson***.

(6) Rest mass of electron is $9.1 \times 10^{-28}\, gm = 0.000549\, amu = 1/1837$ of the mass of hydrogen atom.

(7) According to *Einstein's theory of relativity, mass* of electron in motion is, m'

$$= \frac{\text{Rest mass of electron(m)}}{\sqrt{[1-(u/c)^2]}}$$

Where u = velocity of electron, c= velocity of light.

When $u=c$ than mass of moving electron $=\infty$.

(8) Molar mass of electron = Mass of electron × Avogadro number $= 5.483 \times 10^{-4}$.

(9) 1.1×10^{27} electrons $=1$gram.

(10) 1 mole electron = 0.5483 *milligram*.

(11) Energy of free electron is ≈ 0. The minus sign on the electron in an orbit, represents attraction between the positively charged nucleus and negatively charged electron.

(12) Electron is universal component of matter and takes part in chemical combinations.

(13) The physical and chemical properties of an element depend upon the distribution of electrons in outer shells.

(14) The radius of electron is $4.28 \times 10^{-12}\, cm$.

(15) The density of the electron is $= 2.17 \times 10^{-17}\, g/mL$.

Example: 1 The momentum of electron moving with $1/3^{rd}$ velocity of light is (in $g\ cm\ sec^{-1}$)

(a) 9.69×10^{-8} (b) 8.01×10^{10} (c) 9.652×10^{-18} (d) None

Solution: (c) Momentum of electron, 'p' $= m' \times u$

Where m' is mass of electron in motion $= \frac{m}{\sqrt{1-(u/c)^2}}$; Also $u = c/3$

$$\therefore \text{ Momentum} = \frac{9.108 \times 10^{-28}}{\sqrt{1-\left(\frac{c}{3\times c}\right)^2}} \times \frac{3\times 10^{10}}{3} = \frac{9.108 \times 10^{-28} \times 3 \times 10^{10}}{0.94 \times 3} = 9.652 \times 10^{-18}\ g\ cm\ \sec^{-1}$$

Example: 2 An electron has a total energy of 2 *MeV*. Calculate the effective mass of the electron in *kg* and its speed. Assume rest mass of electron 0.511 *MeV*.

(a) 2.9×10^8 (b) 8.01×10^8 (c) 9.652×10^8 (d) None

Solution: (a) Mass of electron in motion $= \frac{2}{931} amu$ (1 *amu* = 931 *MeV*)

$$= \frac{2}{931} \times 1.66 \times 10^{-27}\, kg = 3.56 \times 10^{-30}\, kg \quad (1\, amu = 1.66 \times 10^{-27}\, kg)$$

Let the speed of the electron be u.

$$m' = \frac{m}{\sqrt{1-(u/c)^2}} \text{ or } 3.56\times10^{-30} = \frac{\frac{0.511}{931}\times1.66\times10^{-27}}{\sqrt{1-\left(\frac{u}{3\times10^8}\right)^2}} = \frac{0.911\times10^{-30}}{\sqrt{1-\left(\frac{u}{3\times10^8}\right)^2}}$$

$$\text{or } 1-\left(\frac{u}{3\times10^8}\right)^2 = 0.06548 \quad \text{or } u^2 = 9\times10^{16}\times0.93452 \text{ or } u = 2.9\times10^8 m$$

Example: 3 A electron of rest mass 1.67×10^{-27} kg is moving with a velocity of 0.9c (c = velocity of light). Find its mass and momentum.

(a) 10.34×10^{-19} (b) 8.01×10^{10} (c) 9.652×10^{-18} (d) None

Solution: (a) Mass of a moving object can be calculated using Einsten's theory of relativity:

$$m' = \frac{m}{\sqrt{1-(u/c)^2}}$$ m = rest mass (given), u = velocity (given), c = velocity of light

$$m' = \frac{1.67\times10^{-27}}{\sqrt{1-\left(\frac{0.9c}{c}\right)^2}} = 3.83\times10^{-27}\ kg$$

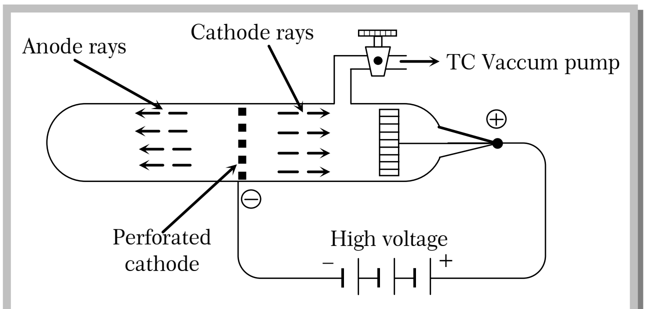
Momentum $'p' = m'\times u$

$$p = 3.83\times10^{-27}\times0.9c = 10.34\times10^{-19}\ kg\ ms^{-1}$$

Proton ($_1H^1$, H^+, P)

(1) Proton was discovered by ***Goldstein*** and is positively charged particle. It is a component particle of anode rays.

(2) **Goldstein (1886)** used perforated cathode in the discharge tube and repeated Thomson's experiment and observed the formation of anode rays. These rays also termed as *positive* or *canal rays*.



Perforated tube experiment for production of anode rays

(3) **Properties of anode rays**

(i) Anode rays travel in straight line.

(ii) Anode rays are material particles.

(iii) Anode rays are positively charged.

(iv) Anode rays may get deflected by external magnetic field.

(v) Anode rays also affect the photographic plate.

(vi) The *e/m* ratio of these rays is smaller than that of electrons.

(vii) Unlike cathode rays, their e/m value is dependent upon the nature of the gas taken in them tube. It is maximum when gas present in the tube is hydrogen.

(viii) These rays produce flashes of light on ZnS screen.

(4) Charge on proton $= 1.602 \times 10^{-19}$ *coulombs* $= 4.80 \times 10^{-10}$ *e.s.u.*

(5) Mass of proton = Mass of hydrogen atom= 1.00728 *amu* $= 1.673 \times 10^{-24}$ *gram* $= 1837$ of the mass of electron.

(6) Molar mass of proton = mass of proton × Avogadro number $= 1.008$ (approx).

(7) Proton is ionized hydrogen atom (H^+) i.e., hydrogen atom minus electron is proton.

(8) Proton is present in the nucleus of the atom and it's number is equal to the number of electron.

(9) Mass of 1 mole of protons is ≈ 1.007 *gram*.

(10) Charge on 1 mole of protons is $\approx$ 96500 *coulombs*.

(11) The volume of a proton (volume $= \frac{4}{3}\pi r^3$) is $\approx 1.5 \times 10^{-38}\ cm^3$.

(12) Specific charge of a proton is 9.58×10^4 Coulomb/gram.

Neutron ($_o n^1$, N)

(1) Neutron was discovered by ***James Chadwick*** (1932) according to the following nuclear reaction,

$$_4Be^9 + {}_2He^4 \rightarrow {}_6C^{12} + {}_o n^1 \text{ or } {}_5B^{11} + {}_2He^4 \rightarrow {}_7N^{14} + {}_o n^1$$

(2) The reason for the late discovery of neutron was its neutral nature.

(3) Neutron is slightly heavier (0.18%) than proton.

(4) Mass of neutron $= 1.675 \times 10^{-24}$ *gram* $= 1.675 \times 10^{-27}$ *kg* $= 1.00899$ *amu* $\approx$ mass of hydrogen atom.

(5) Specific charge of a neutron is zero.

(6) Density $= 1.5 \times 10^{-14}$ *gram / c.c.*

(7) 1 mole of neutrons is $\approx$ 1.008 *gram*.

(8) Neutron is heaviest among all the fundamental particles present in an atom.

(9) Neutron is an unstable particle. It decays as follows:

$$\underset{\text{neutron}}{_0n^1} \longrightarrow \underset{\text{proton}}{_1H^1} + \underset{\text{electron}}{_{-1}e^0} + \underset{\text{anti nutrino}}{_0\nu^0}$$

(10) Neutron is fundamental particle of all the atomic nucleus, except hydrogen or protium.

Comparison of mass, charge and specific charge of electron, proton and neutron

Name of constant	Unit	Electron(e^-)	Proton(p^+)	Neutron(n)
Mass (m)	amu	0.000546	1.00728	1.00899
	kg	9.109×10^{-31}	1.673×10^{-27}	1.675×10^{-24}
	Relative	1/1837	1	1
Charge(e)	Coulomb (C)	-1.602×10^{-19}	$+1.602 \times 10^{-19}$	Zero
	esu	-4.8×10^{-10}	$+4.8 \times 10^{-10}$	Zero
	Relative	-1	$+1$	Zero
Specific charge (e/m)	C/g	1.76×10^8	9.58×10^4	Zero

- The atomic mass unit (amu) is 1/12 of the mass of an individual atom of $_6C^{12}$, *i.e.* 1.660×10^{-27} *kg*.

Other non fundamental particles

Particle	Symbol	Nature	Charge esu $\times 10^{-10}$	Mass (amu)	Discovered by
Positron	$e^+, 1e^0, \beta^+$	+	+ 4.8029	0.0005486	Anderson (1932)
Neutrino	ν	0	0	< 0.00002	Pauli (1933) and Fermi (1934)

Anti-proton	p^-	–	– 4.8029	1.00787	Chamberlain Sugri (1956) and Weighland (1955)
Positive mu meson	μ^+	+	+ 4.8029	0.1152	Yukawa (1935)
Negative mu meson	μ^-	–	– 4.8029	0.1152	Anderson (1937)
Positive pi meson	π^+	+	+ 4.8029	0.1514	Powell (1947)
Negative pi meson	π^-	–	– 4.8029	0.1514	
Neutral pi meson	π^0	0	0	0.1454	

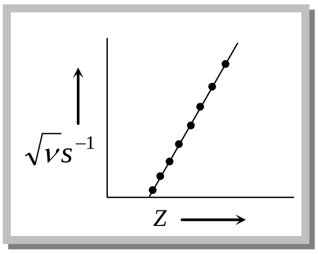
Atomic number, Mass number and Atomic species

(1) **Atomic number or nuclear charge**

(i) The number of protons present in the nucleus of the atom is called *atomic number* (Z).

(ii) It was determined by **Moseley** as,

$$\boxed{\sqrt{\nu} = a(Z-b) \text{ Or } aZ - ab}$$



Where, $\nu = X$ –rays frequency

Z= atomic number of the metal

$a \& b$ are constant.

(iii) Atomic number = Number of positive charge on nucleus = Number of protons in nucleus = Number of electrons in neutral atom.

(iv) *Two different elements can never have identical atomic number*.

(2) **Mass number**

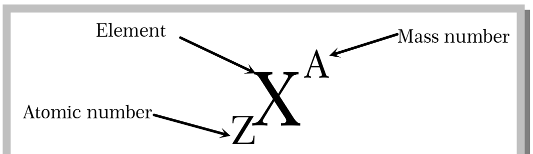
(i) The sum of proton and neutrons present in the nucleus is called mass number.

Mass number (A) = Number of protons + Number of neutrons or Atomic number (Z)

or Number of neutrons = $A - Z$.

(ii) Since mass of a proton or a neutron is not a whole number (on atomic weight scale), weight is not necessarily a whole number.

(iii) The atom of an element X having mass number (A) and atomic number (Z) may be represented by a symbol,



e.g. $_9F^{19}$, $_8O^{16}$, $_7N^{14}$ etc.

Note : ❑A part of an atom up to penultimate shell is a kernel or atomic core.

❑ Negative ion is formed by gaining electrons and positive ion by the loss of electrons.

❑ Number of lost or gained electrons in positive or negative ion =Number of protons $\pm$ charge on ion.

(3) **Different Types of Atomic Species**

Atomic species	Similarities	Differences	Examples
Isotopes (Soddy)	(i) Atomic No. (Z) (ii) No. of protons (iii) No. of electrons (iv) Electronic configuration	(i) Mass No. (A) (ii) No. of neutrons (iii) Physical properties	(i) $^1_1H, ^2_1H, ^3_1H$ (ii) $^{16}_8O, ^{17}_8O, ^{18}_8O$ (iii) $^{35}_{17}Cl, ^{37}_{17}Cl$

	(v) Chemical properties (vi) Position in the periodic table		
Isobars	(i) Mass No. (A) (ii) No. of nucleons	(i) Atomic No. (Z) (ii) No. of protons, electrons and neutrons (iii) Electronic configuration (iv) Chemical properties (v) Position in the perodic table.	(i) ${}^{40}_{18}Ar, {}^{40}_{19}K, {}^{40}_{20}Ca$ (ii) ${}^{130}_{52}Te, {}^{130}_{54}Xe, {}^{130}_{56}Ba$
Isotones	No. of neutrons	(i) Atomic No. (ii) Mass No., protons and electrons. (iii) Electronic configuration (iv) Physical and chemical properties (v) Position in the periodic table.	(i) ${}^{30}_{14}Si, {}^{31}_{15}P, {}^{32}_{16}S$ (ii) ${}^{39}_{19}K, {}^{40}_{20}Ca$ (iii) ${}^{3}_{1}H, {}^{4}_{2}He$ (iv) ${}^{13}_{6}C, {}^{14}_{7}N$
Isodiaphers	Isotopic No. (N – Z) or (A – 2Z)	(i) At No., mass No., electrons, protons, neutrons. (ii) Physical and chemical properties.	(i) ${}_{92}U^{235}, {}_{90}Th^{231}$ (ii) ${}_{19}K^{39}, {}_{9}F^{19}$ (iii) ${}_{29}Cu^{65}, {}_{24}Cr^{55}$
Isoelectronic species	(i) No. of electrons (ii) Electronic configuration	At. No., mass No.	(i) $N_2O, CO_2, CNO^-(22e^-)$ (ii) $CO, CN^-, N_2(14e^-)$ (iii) $H^-, He, Li^+, Be^{2+}(2e^-)$ (iv) $P^{3-}, S^{2-}, Cl^-, Ar, K^+ and\ Ca^{2+}(18e^-)$
Isosters	(i) No. of atoms (ii) No. of electrons (iii) Same physical and chemical properties.		(i) N_2 and CO (ii) CO_2 and N_2O (iii) HCl and F_2 (iv) CaO and MgS (v) C_6H_6 and $B_3N_3H_6$

Note : ❑ In all the elements, tin has maximum number of stable isotopes (ten).

❑ Average atomic weight/ The average isotopic weight

$$= \frac{\%\text{ of 1st isotope} \times \text{relative mass of 1st isotope} + \%\text{ of 2nd isotope} \times \text{relative mass of 2nd isotope}}{100}$$

Example: 4 The characteristics X- ray wavelength for the lines of the k_α series in elements X and Y are 9.87Å and 2.29Å respectively. If Moseley's equation $\sqrt{\nu} = 4.9\times 10^7(Z-0.75)$ is followed, the atomic numbers of X and Y are

(a) 12, 24 (b) 10, 12 (c) 6, 12 (d) 8, 10

Solution : (a) $\nu = \dfrac{c}{\lambda}$

$$\sqrt{\nu_x} = \sqrt{\frac{3\times 10^8}{9.87\times 10^{-10}}} = 5.5132\times 10^8$$

$$\sqrt{\nu_y} = \sqrt{\frac{3\times 10^8}{2.29\times 10^{-10}}} = 11.4457\times 10^8$$

using Moseley's equation we get

$\therefore\ 5.5132\times 10^8 = 4.9\times 10^7(Z_x - 0.75)$ .....(i)

and $11.4457\times 10^8 = 4.90\times 10^7(Z_y - 0.75)$ ..... (ii)

On solving equation (i) and (ii) $Z_x = 12,\ Z_y = 24$.

Example : 5 If the straight line is at an angle 45° with intercept, 1 on $\sqrt{\nu}-$axis, calculate frequency ν when atomic number Z is 50.

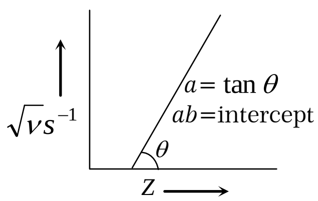
(a) $2000\,s^{-1}$ (b) $2010\,s^{-1}$ (c) $2401\,s^{-1}$ (d) None

Solution : (c) $\sqrt{\nu} = \tan 45° = 1 = a$

$ab = 1$

$\therefore\ \sqrt{\nu} = 50 - 1 = 49$

$\nu = 2401\ s^{-1}$.



Example : 6 What is atomic number Z when $\nu = 2500\ s^{-1}$?

(a) 50 (b) 40 (c) 51 (d) 53

Solution : (c) $\sqrt{\nu} = \sqrt{2500} = Z - 1,\quad Z = 51$.

Example : 7 Atomic weight of Ne is 20.2. Ne is a mixture of Ne^{20} and Ne^{22}. Relative abundance of heavier isotope is

(a) 90 (b) 20 (c) 40 (d) 10

Solution:(d) Average atomic weight/ The average isotopic weight

$$= \frac{\%\text{ of 1st isotope} \times \text{relative mass of 1st isotope} + \%\text{ of 2nd isotope} \times \text{relative mass of 2nd isotope}}{100}$$

$\therefore\ 20.2 = \dfrac{a\times 20 + (100-a)\times 22}{100}$; $\therefore\ a = 90$; per cent of heavier isotope $= 100 - 90 = 10$

Example : 8 The relative abundance of two isotopes of atomic weight 85 and 87 is 75% and 25% respectively. The average atomic weight of element is

(a) 75.5 (b) 85.5 (c) 87.5 (d) 86.0

Solution:(b) Average atomic weight/ The average isotopic weight

$$= \frac{\%\text{ of 1st isotope} \times \text{relative mass of 1st isotope} + \%\text{ of 2nd isotope} \times \text{relative mass of 2nd isotope}}{100}$$

$$= \frac{85\times 75 + 87\times 25}{100} = 85.5$$

Example : 9 Nitrogen atom has an atomic number of 7 and oxygen has an atomic number of 8. The total number of electrons in a nitrate ion is

(a) 30 (b) 35 (c) 32 (d) None

Solution : (c) Number of electrons in an element = Its atomic number

So number of electrons in $N=7$ and number of electrons in $O=8$.

Formula of nitrate ion is NO_3^-

So, in it number of electrons

$=1\times$ number of electrons of nitrogen $+3\times$ number of electrons of oxygen $+1$ (due to negative charge)

$=1\times 7+3\times 8+1=32$

Example :10 An atom of an element contains 11 electrons. Its nucleus has 13 neutrons. Find out the atomic number and approximate atomic weight.

(a) 11, 25 (b) 12, 34 (c) 10, 25 (d) 11, 24

Solution : (d) Number of electrons $=11$

$\therefore$ Number of protons $=$ Number of electron $=11$

Number of neutrons $=13$

Atomic number of element $=$ Number of proton $=$ Number of electrons $=11$

Further, Atomic weight $=$ Number of protons $+$ Number of neutrons $=11+13=24$

Example : 11 How many protons, neutrons and electrons are present in $(a)\ {}^{31}_{15}P$ $(b)\ {}^{40}_{18}Ar$ $(c)\ {}^{108}_{47}Ag$?

Solution : The atomic number subscript gives the number of positive nuclear charges or protons. The neutral atom contains an equal number of negative electrons. The remainder of the mass is supplied by neutrons.

Atom	Protons	Electrons	Neutrons
${}^{31}_{15}P$	15	15	$31-15=16$
${}^{40}_{18}Ar$	18	18	$40-18=22$
${}^{108}_{47}Ag$	47	47	$108-47=61$

Example :12 State the number of protons, neutrons and electrons in C^{12} and C^{14}.

Solution : The atomic number of C^{12} is 6. So in it number of electrons $=6$

Number of protons $=6$; Number of neutrons $=12-6=6$

The atomic number of C^{14} is 6. So in it number of electrons $=6$

Number of protons $=6$; Number of neutrons $=14-6=8$

Example :13 Predict the number of electrons, protons and neutrons in the two isotopes of magnesium with atomic number 12 and atomic weights 24 and 26.

Solution : Isotope of the atomic weight 24, i.e. ${}_{12}Mg^{24}$. We know that

Number of protons $=$ Number of electrons $=12$

Further, Number of neutrons $=$ Atomic weight $-$ Atomic number $=24-12=12$

Similarly, In isotope of the atomic weight 26, i.e. ${}_{12}Mg^{26}$

Number of protons $=$ Number of electrons $=12$

Number of neutrons $=26-12=14$

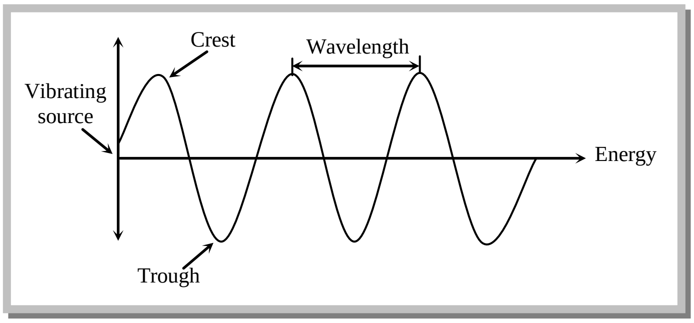
Electromagnetic Radiations

(1) Light and other forms of radiant energy propagate without any medium in the space in the form of waves are known as *electromagnetic radiations*. These waves can be produced by a charged body moving in a magnetic field or a magnet in a electric field. e.g. $\alpha-$rays, $\gamma-$rays, cosmic rays, ordinary light rays etc.

(2) **Characteristics:** (i) All electromagnetic radiations travel with the velocity of light. (ii) These consist of electric and magnetic fields components that oscillate in directions perpendicular to each other and perpendicular to the direction in which the wave is travelling.

(3) A wave is always characterized by the following five characteristics:

(i) ***Wavelength***: The distance between two nearest crests or nearest troughs is called the wavelength. It is denoted by λ (lambda) and is measured is terms of centimeter(cm), angstrom(Å), micron(μ) or nanometre (nm).



$1\AA = 10^{-8}\ cm = 10^{-10}\ m$

$1\mu = 10^{-4}\ cm = 10^{-6}\ m$

$1nm = 10^{-7}\ cm = 10^{-9}\ m$

$1cm = 10^{8}\ \AA = 10^{4}\ \mu = 10^{7}\ nm$

(ii) ***Frequency***: It is defined as the number of waves which pass through a point in one second. It is denoted by the symbol ν (nu) and is expressed in terms of cycles (or waves) per second (cps) or hertz (Hz).

$\lambda\nu =$ distance travelled in one second $=$ velocity $=$c

$$\boxed{\nu = \frac{c}{\lambda}}$$

(iii) ***Velocity***: It is defined as the distance covered in one second by the wave. It is denoted by the letter 'c'. All electromagnetic waves travel with the same velocity, i.e., $3 \times 10^{10}\ cm/\sec$.

$$\boxed{c = \lambda\nu = 3 \times 10^{10}\ cm/\sec}$$

Thus, a wave of higher frequency has a shorter wavelength while a wave of lower frequency has a longer wavelength.

(iv) ***Wave number***: This is the reciprocal of wavelength, i.e., the number of wavelengths per centimetre. It is denoted by the symbol $\bar{\nu}$ (nu bar). It is expressed in cm^{-1} or m^{-1}.

$$\boxed{\bar{\nu} = \frac{1}{\lambda}}$$

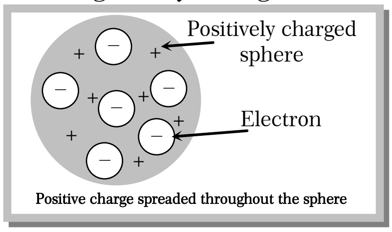
(v) ***Amplitude***: It is defined as the height of the crest or depth of the trough of a wave. It is denoted by the letter 'A'. It determines the intensity of the radiation.

The arrangement of various types of electromagnetic radiations in the order of their increasing or decreasing wavelengths or frequencies is known as ***electromagnetic spectrum***.

Name	Wavelength (Å)	Frequency (Hz)	Source
Radio wave	$3 \times 10^{14} - 3 \times 10^{7}$	$1 \times 10^{5} - 1 \times 10^{9}$	Alternating current of high frequency
Microwave	$3 \times 10^{7} - 6 \times 10^{6}$	$1 \times 10^{9} - 5 \times 10^{11}$	Klystron tube
Infrared (IR)	$6 \times 10^{6} - 7600$	$5 \times 10^{11} - 3.95 \times 10^{16}$	Incandescent objects
Visible	$7600 - 3800$	$3.95 \times 10^{16} - 7.9 \times 10^{14}$	Electric bulbs, sun rays
Ultraviolet (UV)	$3800 - 150$	$7.9 \times 10^{14} - 2 \times 10^{16}$	Sun rays, arc lamps with mercury vapours
X-Rays	$150 - 0.1$	$2 \times 10^{16} - 3 \times 10^{19}$	Cathode rays striking metal plate
γ – Rays	0.1 – 0.01	$3 \times 10^{19} - 3 \times 10^{20}$	Secondary effect of radioactive decay
Cosmic Rays	0.01- zero	3×10^{20} – infinity	Outer space

Thomson's model

(1) Thomson regarded atom to be composed of positively charged protons and negatively charged electrons. The two types of particles are equal in number thereby making atom electrically neutral.



(2) He regarded the atom as a positively charged sphere in which negative electrons are uniformly distributed like the seeds in a water melon.

(3) This model failed to explain the line spectrum of an element and the scattering experiment of Rutherford.

Rutherford's nuclear model

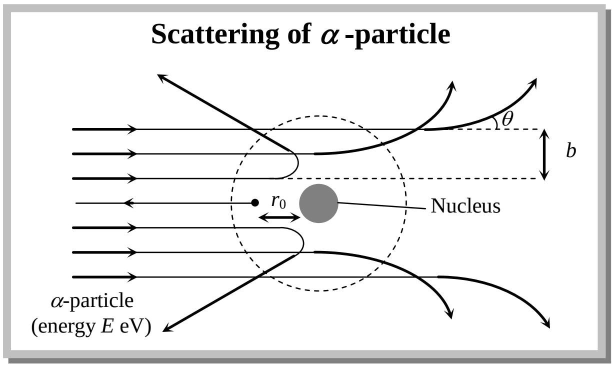
(1) Rutherford carried out experiment on the bombardment of thin (10^{-4} mm) Au foil with high speed positively charged $\alpha-$particles emitted from Ra and gave the following observations, based on this experiment :

(i) Most of the $\alpha-$ particles passed without any deflection.

(ii) Some of them were deflected away from their path.

(iii) Only a few (one in about 10,000) were returned back to their original direction of propagation.

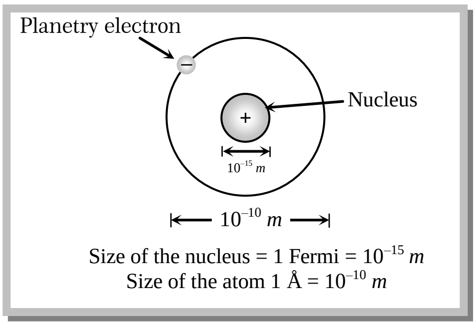
(iv) The scattering of $\alpha-$ particles $\propto \dfrac{1}{\sin^4\left(\dfrac{\theta}{2}\right)}$.



(2) From the above observations he concluded that, an atom consists of

(i) ***Nucleus*** which is small in size but carries the entire mass i.e. contains all the neutrons and protons.

(ii) ***Extra nuclear part*** which contains electrons. This model was similar to the solar system.



(3) **Properties of the Nucleus**

(i) Nucleus is a small, heavy, positively charged portion of the atom and located at the centre of the atom.

(ii) All the positive charge of atom (i.e. protons) are present in nucleus.

(iii) Nucleus contains neutrons and protons, and hence these particles collectively are also referred to as ***nucleons.***

(iv) The ***size*** of nucleus is measured in ***Fermi*** (1 Fermi = 10^{-13} cm).

(v) The ***radius*** of nucleus is of the order of 1.5×10^{-13} $cm.$ to 6.5×10^{-13} $cm.$ i.e. 1.5 to 6.5 Fermi. Generally the radius of the nucleus (r_n) is given by the following relation,

$$\boxed{r_n = r_o(= 1.4 \times 10^{-13}\ cm) \times A^{1/3}}$$

This exhibited that nucleus is 10^{-5} times small in size as compared to the total size of atom.

(vi) The ***Volume*** of the nucleus is about $10^{-39}\,cm^3$ and that of atom is $10^{-24}\,cm^3$, i.e., volume of the nucleus is 10^{-15} times that of an atom.

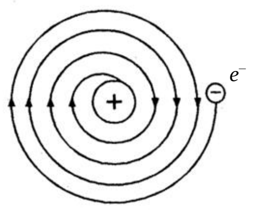
(vii) The **density** of the nucleus is of the order of $10^{15}\,g\,cm^{-3}$ or 10^{8} tonnes cm^{-3} or $10^{12}\,kg/cc$. If nucleus is spherical than,

$$\boxed{\text{Density} = \frac{\text{mass of the nucleus}}{\text{volume of the nucleus}} = \frac{\text{mass number}}{6.023\times10^{23}\times\frac{4}{3}\pi r^3}}$$

(4) **Drawbacks of Rutherford's model**

(i) It does not obey the ***Maxwell theory of electrodynamics,*** according to it "A small charged particle moving around an oppositely charged centre continuously loses its energy". If an electron does so, it should also continuously lose its energy and should set up spiral motion ultimately failing into the nucleus.

(ii) It could not explain the line spectra of $H-$ atom and discontinuous spectrum nature.



Unstability of atom

Example:14 Assuming a spherical shape for fluorine nucleus, calculate the radius and the nuclear density of fluorine nucleus of mass number 19.

Solution : We know that,

$r = (1.4\times10^{-13})A^{1/3} = 1.4\times10^{-13}\times19^{1/3} = 3.73\times10^{-13}\,cm$ (A for F=19)

Volume of a fluorine atom $= \frac{4}{3}\pi r^3 = \frac{4}{3}\times3.14\times(3.73\times10^{-13})^3 = 2.18\times10^{-37}\,cm^3$

Mass of single nucleus $= \frac{\text{Mass of one mol of nucleus}}{\text{Avogadro' s number}} = \frac{19}{6.023\times10^{23}}\,g$

Thus Density of nucleus $= \frac{\text{Mass of single nucleus}}{\text{Volume of single nucleus}} = \frac{10}{6.023\times10^{23}}\times\frac{1}{2.18\times10^{-37}} = 7.616 = 10^{13}\,g\,cm^{-1}$

Example: 15 Atomic radius is the order of $10^{-8}\,cm$, and nuclear radius is the order of $10^{-13}\,cm$. Calculate what fraction of atom is occupied by nucleus.

Solution : Volume of nucleus $= (4/3)pr^3 = (4/3)p\times(10^{-13})^3\,cm^3$

Volume of atom $= (4/3)pr^3 = (4/3)p\times(10^{-8})^3\,cm^3$

$\therefore \frac{V_{nucleus}}{V_{atom}} = \frac{10^{-39}}{10^{-24}} = 10^{-15}$ or $V_{nucleus} = 10^{-15}\times V_{atom}$

Planck's Quantum theory and Photoelectric effect

Planck's Quantum theory

(1) ***Max Planck*** (1900) to explain the phenomena of 'Black body radiation' and 'Photoelectric effect' gave quantum theory. This theory extended by ***Einstein*** (1905).

(2) If the substance being heated is a black body (which is a perfect absorber and perfect radiator of energy) the radiation emitted is called ***black body radiation.***

(3) ***Main points***

(i) The radiant energy which is emitted or absorbed by the black body is not continuous but discontinuous in the form of small discrete packets of energy, each such packet of energy is called a '**quantum**'. In case of light, the quantum of energy is called a '**photon**'.

(ii) The energy of each quantum is directly proportional to the frequency (ν) of the radiation, i.e.

$$E \propto \nu \text{ or } E = h\nu = \frac{hc}{\lambda}$$

where, $h =$ Planck's constant $= 6.62\times10^{-27}$ *erg. sec.* or 6.62×10^{-34} *Joules* sec.

(iii) The total amount of energy emitted or absorbed by a body will be some whole number quanta. Hence $E = nh\nu$, where n is an integer.

(iv) The greater the frequency (i.e. shorter the wavelength) the greater is the energy of the radiation.

thus, $\dfrac{E_1}{E_2} = \dfrac{\nu_1}{\nu_2} = \dfrac{\lambda_2}{\lambda_1}$

(v) Also $E = E_1 + E_2$, hence, $\dfrac{hc}{\lambda} = \dfrac{hc}{\lambda_1} + \dfrac{hc}{\lambda_2}$ or $\dfrac{1}{\lambda} = \dfrac{1}{\lambda_1} + \dfrac{1}{\lambda_2}$

Example: 16 suppose $10^{-17}\,J$ of energy is needed by the interior of human eye to see an object. How many photons of green light ($\lambda = 550\,nm$) are needed to generate this minimum amount of energy?

(a) 14 (b) 28 (c) 39 (d) 42

Solution: (b) Let the number of photons required $= n$

$$n\frac{hc}{\lambda} = 10^{-17}\,;\quad n = \frac{10^{-17}\times\lambda}{hc} = \frac{10^{-17}\times550\times10^{-9}}{6.626\times10^{-34}\times3\times10^{8}} = 27.6 = 28 \text{ photons}$$

Example: 17 assuming that a 25 watt bulb emits monochromatic yellow light of wave length $0.57\,\mu$. The rate of emission of quanta per sec. will be

(a) $5.89\times10^{13}\text{ sec}^{-1}$ (b) $7.28\times10^{17}\text{ sec}^{-1}$ (c) $5\times10^{10}\text{ sec}^{-1}$ (d) $7.18\times10^{19}\text{ sec}^{-1}$

Solution: (d) Let n quanta are evolved per sec.

$$n\left[\frac{hc}{\lambda}\right] = 25\,J\text{ sec}^{-1}\,;\quad n\frac{6.626\times10^{-34}\times3\times10^{8}}{0.57\times10^{-6}} = 25\,;\quad n = 7.18\times10^{19}\text{ sec}^{-1}$$

Photoelectric effect

(1) When radiations with certain minimum frequency (ν_0) strike the surface of a metal, the electrons are ejected from the surface of the metal. This phenomenon is called *photoelectric effect* and the electrons emitted are called *photo-electrons*. The current constituted by photoelectrons is known as photoelectric current.

(2) The electrons are ejected only if the radiation striking the surface of the metal has at least a minimum frequency (ν_0) called *Threshold frequency*. The minimum potential at which the plate photoelectric current becomes zero is called *stopping potential*.

(3)The velocity or kinetic energy of the electron ejected depend upon the frequency of the incident radiation and is independent of its intensity.

(4) The number of photoelectrons ejected is proportional to the intensity of incident radiation.

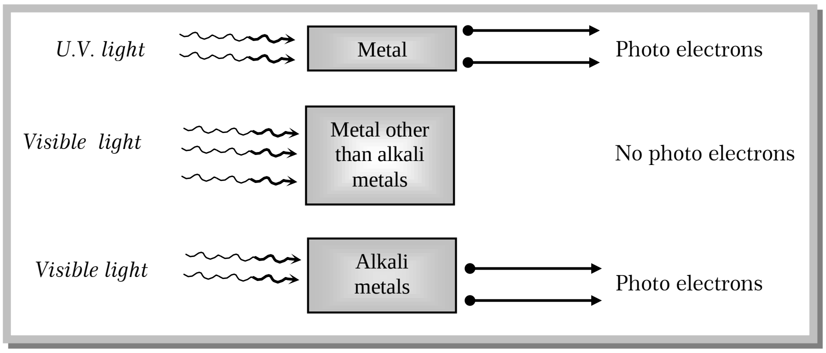
(5) *Einstein's photoelectric effect equation*: According to Einstein,

Maximum kinetic energy of the ejected electron = absorbed energy – threshold energy

$$\boxed{\frac{1}{2}mv_{\max}^2 = h\nu - h\nu_0 = hc\left[\frac{1}{\lambda} - \frac{1}{\lambda_0}\right]}$$

Where, ν_0 and λ_0 are threshold frequency and threshold wavelength.

Note : ❑ Nearly all metals emit photoelectrons when exposed to *u.v.* light. But alkali metals like lithium, sodium, potassium, rubidium and caesium emit photoelectrons even when exposed to visible light.



❑ Cesium (*Cs*) with lowest ionization energy among alkali metals is used in photoelectric cell.

Q.1 Calculate the wavelength of the radiation that would cause photo dissociation of chlorine molecule if the Cl- Cl bond energy is 243 KJ/mol.

Q.2 Suppose 10^{-17} J of light energy is needed by the interior of the human eye to see an object. How many photons of green light (λ = 550 nm) are needed to generate this minimum amount of energy.

Q.3 A photon having λ = 854 Å causes the ionization of a nitrogen atom. Give the I.E. per mole of nitrogen in KJ.

Q.4 Calculate the threshold frequency of metal if the binding energy is 180.69 KJ mol^{-1} of electron.

Q.5 Calculate the binding energy per mole when threshold frequency to the wavelength of 240 nm.

Q.6 A metal was irradiated by light of frequency 3.2×10^{15} S^{-1}. The photoelectron produced had its KE, 2 times the KE of the photoelectron which was produced when the same metal was irradiated with a light of frequency 2.0×10^{15} S^{-1}. What is work function?

Q.7 U.V. light of wavelength 800 Å & 700 Å falls on hydrogen atoms in their ground state & liberates electrons with kinetic energy 1.8 eV and 4 eV respectively. Calculate Planck's constant.

Q.8 The dissociation energy of H_2 is 430.53 KJ/mol. If H_2 is exposed to radiant energy of wavelength 253.7 nm, what % of radiant energy will be converted into K.E.

Q.9 A potential difference of 20 KV is applied across an X-ray tube. Find the minimum wavelength of X-ray generated.

Q.10 The K.E. of an electron emitted from tungsten surface is 3.06 eV. What voltage would be required to bring the electron to rest?

Answer Key

Q.1	4.9×10^{-7} m	Q.2	28 photons	Q.3	1403 KJ/mol	Q.4	4.5×10^{14} s^{-1}
Q.5	497 KJ/mol	Q.6	319.2 KJ/mol	Q.7	6.57×10^{-34} Js		
Q.8	8.68 %	Q. 9	0.62 Å	Q.10	3.06 V		