CHP. 20
ATOMIC SPECTRA

The branch of physics, which deals with study of extra nuclear part of an atom, is called "**atomic physics**."

SPECTROSCOPY.

Def — "The branch of physics which deals with the investigation of wavelength and intensities of electromagnetic radiations emitted or absorbed by atom, is called spectroscopy."

The radiations emitted from a source when passed through a dispersing device such as prism, diffraction grating etc; split up into their component waves. The visible set of components waves is called "**optical spectrum**" or "**visible spectrum**".

The range of optical spectrum lies between 4000 Å to 7000 Å (from violet to red).

TYPES OF SPECTRA

1 — Continuous spectra
2 — Band spectra
3 — Discrete spectra or line spectra

① CONTINUOUS SPECTRA.

Def — "A radiation spectrum consisting of a continuously distributed over a frequency range without being broken up into lines or bands is called a 'continuous spectrum.'"

These are generally produced in infrared and visible regions because of hot solid bodies.

e.g; black body radiation spectrum

② BAND SPECTRA.

Def — "A spectrum which consists of a no. of bands or closely spaced lines of emitted or absorbed radiations is called a band spectrum."

e.g; Molecular Spectrum

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Atomic Spectra

③ DISCRETE OR LINE SPECTRA.

Def — " A line spectrum which consists of discrete lines corresponding to single wavelength or frequency of emitted or absorbed radiation is called discrete or line spectrum

e.g; Atomic spectra such as hydrogen spectrum.

A Spectrum of light emitted by a source, whether continuous or a line spectrum is called an **emission spectrum**. An **absorption spectrum**, on the other hand, is obtained when light with a continuous spectrum passes through a substance. The wavelength absorbed by a substance appear in their reduced intensity. **e.g;** when white light pass through atom vapours and look at the transmitted light with a spectrometer, we find series of dark lines corresponding to the wavelength that have been absorbed. The spectrum of Sun light is an absorption spectrum

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20.1 ATOMIC SPECTRA:

Def — " When atomic gas or vapour at low Pressure is excited by passing an electrical discharge through it, the emitted radiations of certain specific wavelengths are called atomic spectra."

An experimental arrangement to observe such atomic spectra as shown in fig.

For better results, a spectrometer with diffraction grating is used.

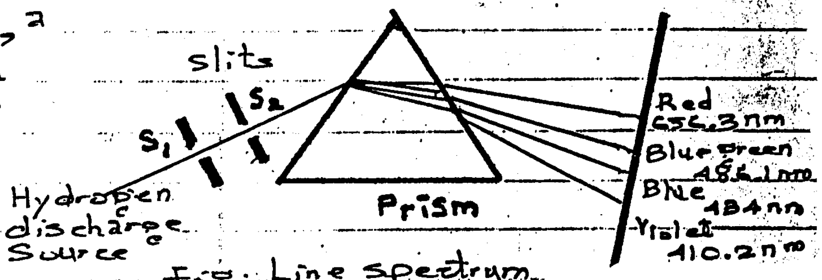

Fig: Line spectrum of hydrogen

Atomic Spectra

If the slit in front of the source is narrow rectangle then the print on the photographic plate is in the form of line. Due to this reason, this spectrum is called line spectrum.

The spectrum of each element contains certain number of lines of particular wavelengths or frequencies that show definite regularities. As the spectrum of each element is different from the other, therefore these regularities were used to identify the elements during the second half of the 19th century. These regularities were classified into certain groups called **spectral series**. It was studied by different scientists and following observations were made by them.

1— The spectra of no two elements are alike, which means that each element has its own characteristic spectrum.

2— The spectrum of an element consists of a no. of series. These series are spread not only over the visible region but in the infrared and the U.V region of the spectrum.

3— All series of spectra either belonging to the same element or to different elements are similar in general appearance; the difference being in their location in the wavelength and in the no. of lines which can be observed clearly.

4— The spectral lines are well separated at one end, the sepration decreases rapidly and it becomes so small that the lines cannot be distinguished from each other. The line at the end of the series is called series limit. Beyond the series limit, the spectra becomes continuous.

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HISTORICAL BACKGROUND.

A Scientific study of Spectra of elements becomes possible only when the wavelength could be measured accuratly. **Young** in 1801 was the first to make such estimates of wavelength based on interference. Twenty years later **Fraunhofer** developed the diffraction grating and mapped 576 lines out of the 25000 lines in the solar spectrum. He assigned letters such as A, B, C, D_1, D_2 etc to identify the most prominent ones.

J J Balmer in 1885, discovered four lines of wavelengths 656.3, 486.1, 434.0 and 410.2nm in the visible spectrum of hydrogen atom. He showed that the wavelength "λ" of all the lines can be expressed by means of a simple formula =

$$\boxed{\lambda = 3646 \times \frac{n^2}{n^2-4}} \quad \text{where } n = 3, 4, 5 \text{ or } 6.$$

Soon after this, a Britsh astronomer **William Huggins** discovered a no. of other spectrum lines produced by hydrogen in the U.V region by the same formula. At very large values of "n", the lines are closer, merging at the limiting value 364.6 nm.

• SPECTRUM OF HYDROGEN

The lines of the spectrum of hydrogen were first studied by J.J Balmer in 1885 called the Balmer series in the visible region of electromagnetic spectrum. A typical hydrogen spectrum was found to contain **five** such series. In 1896 J R Rydberg modified the results of Balmer in a more generalized form for the wavelength "λ" of all the possible spectral lines of hydrogen in the following mathematical form.

$$\frac{1}{\lambda} = R\left(\frac{1}{p^2} - \frac{1}{n^2}\right)$$

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Where R = Rydberg constt $= 1.0974 \times 10^{7}\ m^{-1}$,
$P = 1, 2, 3, \ldots\ldots$ and $n = P+1, P+2, \ldots\ldots$

All the series along with their emperical formulas are given below:

1— Lyman Series (U.V region) $\frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right)$, where $n = 2, 3, \ldots \infty$

2— Balmer Series (visible region) $\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$, where $n = 3, 4, \ldots\ldots \infty$

3— Paschen Series (Infrared region) $\frac{1}{\lambda} = R\left(\frac{1}{3^2} - \frac{1}{n^2}\right)$, where $n = 4, 5, \ldots \infty$

4— Bracket series (Far infrared region) $\frac{1}{\lambda} = R\left(\frac{1}{4^2} - \frac{1}{n^2}\right)$, where $n = 5, 6, 7 \ldots \infty$

5— Pfund Series (Far infrared region) $\frac{1}{\lambda} = R\left(\frac{1}{5^2} - \frac{1}{n^2}\right)$, where $n = 6, 7, 8 \ldots \infty$

N.B: The spectral lines get closer and closer with increasing value of 'n' till they merge at a point called series limit at $n = \infty$

20.2 BOHR'S MODEL OF THE HYDROGEN ATOM:

In order to explain the emperical results obtained by Rydberg to explain hydrogen spectrum, Neils Bohr, in 1913, formulated a model of hydrogen atom. This theory is a mixture of classical ideas and modern idea of Planck's quantum theory. So, it is a **Semi classical theory**. It is based on following postulates:

POSTULATE 1 An electron in circular orbit around the nucleus of hydrogen atom called discrete stationary states of the atom, then no energy is being absorbed or emitted. The emission or absorption of energy is possible only when the electron jumps from one orbit to the other.

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Atomic Spectra

POSTULATE 2 An electron revolves in circular orbit around the nucleus of hydrogen atom in fixed orbits for which

Angular momentum of electron $= \frac{nh}{2\pi} = n\hbar$

or $\boxed{mvr = \frac{nh}{2\pi}}$ —— ①

Where $n = 1, 2, 3 \ldots$ is called the principal quantum number, 'm' is the mass of the electron, 'v' is the velocity of the orbiting electron, and 'h' is planck's constant.

POSTULATE 3

Whenever an electron jumps from high energy state E_n to a low energy state E_p, a photon of energy 'hf' is emitted so that

$\boxed{hf = E_n - E_p}$ —— ②

Where $f = \frac{c}{\lambda}$ is the frequency of radiation emitted i.e; photon.

(A) DE-BROGLIE'S INTERPRETATION OF BOHR'S ORBITS.

Bohr's theory had successfully explained the emission of atomic spectra of various atoms and their uniqueness that identifies them from spectra of other elements. But it did not answer that:

(i) Why electrons do not radiate energy while revolving in their orbits?

(ii) Why they revolve only along certain allowed orbits?

According to De-Broglie's hypothesis, electrons while revolving round their orbits have waves associated with them. As we know that energy of stationary waves remain conserved within the wave. Therefore it was assumed that electrons revolve round only in those orbits in which stationary waves are set up by the waves associated with these revolving electrons i.e; only those orbits are permissible, the circumference of which is integral multiple of these associated waves. (P.T.O)

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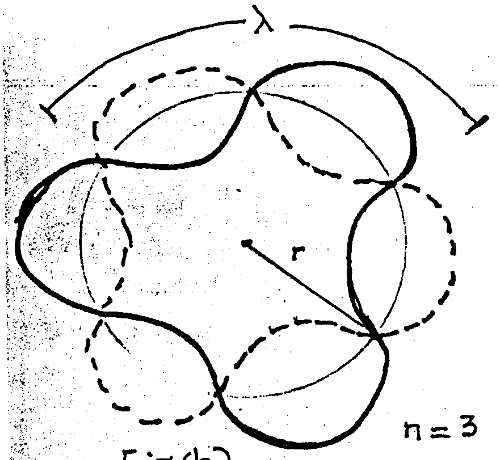

fig (b)

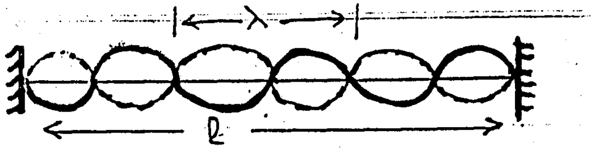

fig (a) Stationary wave for n = 3 on a string.

$\therefore \; l = n\lambda = 3\lambda$

fig (b), (c) standing de Broglie waves of electrons around the circumference of Bohr orbits.

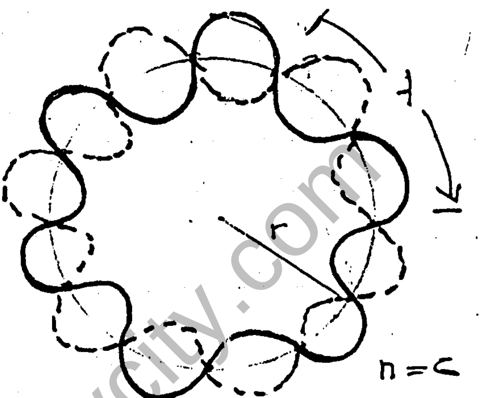

fig (c)

If a string of length 'l' is stretched between two fixed pegs, stationary vibrations are produced by the formula $l = n\lambda$, where n is an integer. Suppose that if the same string is bend into a circle of radius 'r', then stationary waves for n = 3 [fig (b)] or n = 6 [fig (c)] are shown. If $2\pi r$ is the circumference of the circle, then

$$l = 2\pi r = n\lambda$$

$$\text{or} \quad \lambda = \frac{2\pi r}{n} \quad \text{——— ③}$$

From de-Broglie's relation momentum of an electron is

$$P = \frac{h}{\lambda}$$

$$\text{or} \quad \lambda = \frac{h}{P} = \frac{h}{mv} \quad \text{——— ④} \qquad \because P = mv$$

Comparing eq. ③ and ④, we have

$$\frac{h}{mv} = \frac{2\pi r}{n}$$

$$\text{or} \quad \boxed{mvr = \frac{nh}{2\pi}} \quad \text{——— ⑤}$$

which is postulate 2.

It shows how stationary orbits around the nucleus have been justify by wave property of electron.

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(B) QUANTIZED RADII.

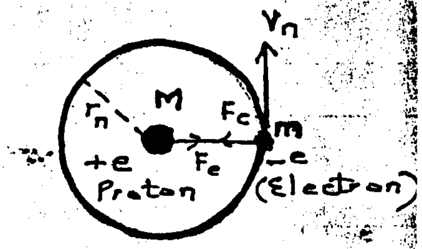

fig.

Consider a hydrogen atom in which electron moving with velocity 'V_n' is in circular orbit of radius 'r_n' as shown. From Bohr postulate II, we can write;

$$mV_n r_n = \frac{nh}{2\pi}$$

$$\text{or} \quad V_n = \frac{nh}{2\pi m r_n} \quad \text{———} ⑥$$

Due to circular motion;

$$F_c = \frac{mV_n^2}{r_n} \quad \text{———} ⑦$$

This force is provided by Coulomb's force of attraction of proton on the electron, so

$$F_e = \frac{Ke^2}{r_n^2} \quad \text{———} ⑧$$

Where 'e' is the magnitude of charge on electron as well as on the hydrogen nucleus consisting of a single proton. Thus

$$F_c = F_e$$

$$\text{or} \quad \frac{mV_n^2}{\cancel{r_n}} = \frac{Ke^2}{r_n^{\cancel{2}}}$$

$$\text{or} \quad r_n = \frac{Ke^2}{mV_n^2} \quad \text{———} ⑨$$

Putting value of 'V_n' from eq. ⑥ into eq. ⑨, we have

$$r_n = \frac{Ke^2}{m \times \left(\frac{nh}{2\pi m r_n}\right)^2} = \frac{Ke^2}{\cancel{m} \times \frac{n^2h^2}{4\pi^2 m^{\cancel{2}} r_n^2}}$$

$$\cancel{r_n} = Ke^2 \times \frac{4\pi^2 m r_n^{\cancel{2}}}{n^2h^2}$$

$$\text{or} \quad \boxed{r_n = \frac{n^2h^2}{4\pi^2 K m e^2}} \quad \text{———} ⑩$$

Where $n = 1, 2, 3$ -------

This is the radius of the nth allowed orbit

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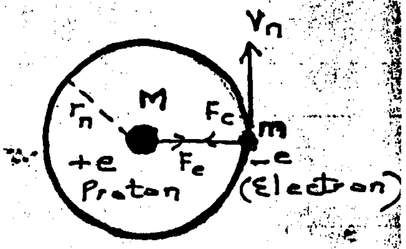
(B) QUANTIZED RADII.



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$$\text{or} \quad r_n = \frac{Ke^2}{mV_n^2} \quad \text{———} ⑨$$

Putting value of 'V_n' from eq. ⑥ into eq. ⑨, we have

$$r_n = \frac{Ke^2}{m \times \left(\frac{nh}{2\pi m r_n}\right)^2} = \frac{Ke^2}{\cancel{m} \times \frac{n^2h^2}{4\pi^2 m^{\cancel{2}} r_n^2}}$$

$$\cancel{r_n} = Ke^2 \times \frac{4\pi^2 m r_n^{\cancel{2}}}{n^2h^2}$$

$$\text{or} \quad \boxed{r_n = \frac{n^2h^2}{4\pi^2 Kme^2}} \quad \text{———} ⑩$$

Where $n = 1, 2, 3$ - - - - - -

This is the radius of the nth allowed orbit

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Substituting the values of h, m, K and e, we get

$$r_n = n^2 \times \frac{(6.625\times10^{-34})^2}{4\times(3.14)^2\times9.11\times10^{-31}\times9\times10^{9}\times(1.6\times10^{-19})^2}$$

$$r_n = n^2 \times 0.53\times10^{-10}\ m$$

$$= n^2 \times 0.53\ \mathring{A}$$

$$= n^2 \times 0.053\times10^{-9}\ m$$

or $\boxed{r_n = n^2 \times 0.053\ nm}$ —— ⑪

For **first orbit**, n = 1, we get

$$r_1 = 0.053\ nm$$

This agrees with the experimentally measured values and is called the first Bohr orbit radius of the hydrogen atom.

Similarly, for the **Second orbit**, n = 2, we get

$$r_2 = 4\times0.053\ nm = 0.212\ nm$$

for n = 3;

$$r_3 = 9\times0.053\ nm = 0.477\ nm$$

and so on.

Hence, $r_n = r_1, 4r_1, 9r_1, 16r_1, \ldots\ldots$

RESULT: This shows that the radii of the allowed orbits are in the ratio 1 : 4 : 9 : 16. These values of radii of electronic orbits are quantized.

SPEED OF ELECTRON.

The speed of electron in the nth orbit can be found by putting the value of 'r_n' from eq ⑨ in eq ⑥, we have

$$V_n = \frac{nh}{2\pi m r_n} = \frac{nh}{2\pi m\times\left(\frac{n^2h^2}{4\pi^2Kme^2}\right)}$$

$$V_n = \frac{\cancel{n}\cancel{h}}{\cancel{2\pi}\cancel{m}}\times\frac{\overset{2}{\cancel{4\pi^2}}K\cancel{m}e^2}{n^{\cancel{2}}h^{\cancel{2}}} = \boxed{\frac{2\pi Ke^2}{nh}}$$ —— ⑫

This is the expression for the speed of electron in the nth orbit.

For higher orbits (n = 1, 2, 3 .....), 'n' increases, V_n decreases i.e; $V_n \propto \frac{1}{n}$

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(C) QUANTIZED ENERGIES.

The total energy E_n of an electron in the Bohr's orbit is the sum of its K.E and P.E;

$E_n = K.E + P.E$ ——— ⑬

As $F_c = F_e$

$\therefore \quad \dfrac{mv_n^2}{\cancel{r_n}} = \dfrac{Ke^2}{r_n^{\cancel{2}}}$

$mv_n^2 = \dfrac{Ke^2}{r_n}$ ——— ⑭

K.E. The kinetic energy of the electron in nth orbit is

$K.E = \dfrac{1}{2} m v_n^2$ ——— ⑮

$\therefore \quad K.E = \dfrac{1}{2} \times \dfrac{Ke^2}{r_n}$ ——— ⑯

P.E. Value of P.E is;

P.E = Work done on a body against a force

P.E = (Force) × (distance)

$= \dfrac{Kq_1q_2}{r_n^2} \times r_n$

$U = P.E = \dfrac{K(+e)(-e)}{r_n^2} \times \cancel{r_n} = \dfrac{-Ke^2}{r_n}$ ——— ⑰

Putting the values of K.E and P.E from eq. ⑯ and ⑰ into eq. ⑬, we have

$E_n = \dfrac{Ke^2}{2r_n} + \left(\dfrac{-Ke^2}{r_n}\right)$

$E_n = \dfrac{Ke^2 - 2Ke^2}{2r_n} = -\dfrac{Ke^2}{2r_n}$ ——— ⑱

From eq ⑩ for $r_n = \dfrac{n^2h^2}{4\pi^2Kme^2}$, eq. ⑱ becomes;

$$E_n = -\frac{Ke^2}{2 \times \left(\frac{n^2h^2}{4\pi^2Kme^2}\right)} = \frac{-Ke^2}{\cancel{2}} \times \frac{\overset{2}{\cancel{4}}\pi^2Kme^2}{n^2h^2}$$

$$E_n = -\frac{1}{n^2} \times \left(\frac{2\pi^2Kme^4}{h^2}\right) = -\frac{1}{n^2} \times E_o$$

$\therefore \quad \boxed{E_n = -\dfrac{E_o}{n^2}}$ ——— ⑲ where $E_o = \dfrac{2\pi^2Kme^4}{h^2} = \text{constt}$

$$E_o = \frac{2 \times (3.14)^2 \times (9 \times 10^{9})(9.11 \times 10^{-31})(1.6 \times 10^{-19})^4}{(6.6 \times 10^{-34})^2}$$

$E_o \simeq 2.18 \times 10^{-19}\ J$ $\qquad \because 1eV = 1.6 \times 10^{-19} J$

or $\quad E_o \simeq \dfrac{2.18 \times 10^{-19}}{1.6 \times 10^{-19}}\ eV = 13.6\ eV$

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Hence $E_n = -\frac{13.6\,ev}{n^2} = \frac{-E_o}{n^2}$ ——— (20)

The negative sign shows that energy must be supplied from some external source to remove it from the atom or from lower energy orbit to higher energy orbit.

Eq.(20) shows the total energy of an electron in nth orbit of hydrogen atom. Its value increases with the increase of value of "n".

The lowest energy state corresponding to $n=1$, is called the ground state or normal state;

$$E_1 = -E_o = -13.6\,ev$$

for $n = 2, 3, 4 \ldots\ldots$, we get the allowed energy levels of a hydrogen atom to be;

$$E_2 = -\frac{E_o}{4} = -3.4\,ev$$

$$E_3 = \frac{-E_o}{9} = -1.51\,ev$$

$$\vdots$$

$$E_\infty = \frac{-E_o}{\infty} = 0$$

These are called quantized energy states.

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RELATED TERMS:

(a) IONIZATION ENERGY.

"The energy required to completely remove an electron from an atom is called ionization energy."

The ionization energy to the electron may be provided by collision with an external electron.

Thus ground state energy, $E_o = \frac{-2\pi^2 k\, m e^4}{h^2} = -13.6$ ev is the required energy to completely remove an electron from the first Bohr orbit.

(b) IONIZATION POTENTIAL.

"The min potential through which the external electron should be accelerated, so that it can supply the required ionization energy is called ionization potential."

For hydrogen its value is 13.6 volts.

(C) GROUND STATE OR NORMAL STATE.

"Normally the electron in the hydrogen atom is in the lowest energy state corresponding to $n=1$, this state is called ground state or normal state."

(d) EXCITED STATE.

"When electron is in higher orbit, it is said to be in the excited state." The atom may be excited by collision with externally accelerated electron.

(e) EXITATION ENERGY.

"The energy required to excite (lift the electron from its ground state to higher energy orbit) in hydrogen atom is called its excitation energy."

(F) EXCITATION POTENTIAL.

"The potential through which an electron should be accelerated so that on collision it can lift the electron in the atom from its ground state to some higher state is known as excitation potential."

NOTE: An atom may possess only limited no. of ionization energies but a large no. of excitation energies.

HYDROGEN EMISSION SPECTRUM: (ENERGY LEVEL DIAGRAM)

According to Bohr's postulate III, the spectral lines are emitted from hydrogen atom when an electron jumps from higher energy (outer) orbit 'n' to a lower energy orbit 'p'. The difference of energy between the two orbits appears in the form of photon of energy hf. Thus,

$$E = hf = \frac{hc}{\lambda} = E_n - E_p \text{ ———— } ①$$

According to Bohr's atomic theory, the energy of the electron in nth orbit is given by;

$$E_n = -\frac{E_o}{n^2} \text{ ———— } ②$$

The energy of the electron in the pth orbit is;

$$E_p = -\frac{E_o}{p^2} \text{ ———— } ③$$

where $n > p$

Putting the values of eq ② and ③ in eq ①, we get

$$hf = -\frac{E_o}{n^2} - \left(-\frac{E_o}{p^2}\right)$$

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or $hf = \frac{E_0}{p^2} - \frac{E_0}{n^2} = E_0\left(\frac{1}{p^2} - \frac{1}{n^2}\right)$

$\because c = f\lambda$ or $f = \frac{c}{\lambda}$

$$\frac{hc}{\lambda} = E_0\left(\frac{1}{p^2} - \frac{1}{n^2}\right)$$

$$\frac{1}{\lambda} = \frac{E_0}{hc}\left(\frac{1}{p^2} - \frac{1}{n^2}\right) = \boxed{R_H\left(\frac{1}{p^2} - \frac{1}{n^2}\right)} \quad \text{—— ④}$$

where $\frac{E_0}{hc} = R_H \Rightarrow E_0 = R_H hc$

where R_H is called Rydberg constant, and $p = 1, 2, 3 \ldots\ldots$ & $n = p+1, p+2, p+3, \ldots\ldots$

Eq. ④ gives the wavelength of the radiation of hydrogen atom and agrees well with the latest measured value for hydrogen atom.

Rydberg const $= R_H = \frac{E_0}{hc} = \frac{13.6\,eV}{6.6\times10^{-34}(3\times10^{8})}$

$R_H = 1.0974\times10^{7}\,m^{-1}$

Vertical lines indicate the electron jump and the horizontal lines represent the energy of electrons in different orbits. The energy of the electron is not the same in various orbits. These levels are all negative, showing that electron does not have enough energy to escape from the atom. As the electron cannot stay in the excited state, it must return to its lowest energy level. The electron may not necessarily return to ground state in a single jump but may return in more than one jump, thus emitting more than one wavelength.

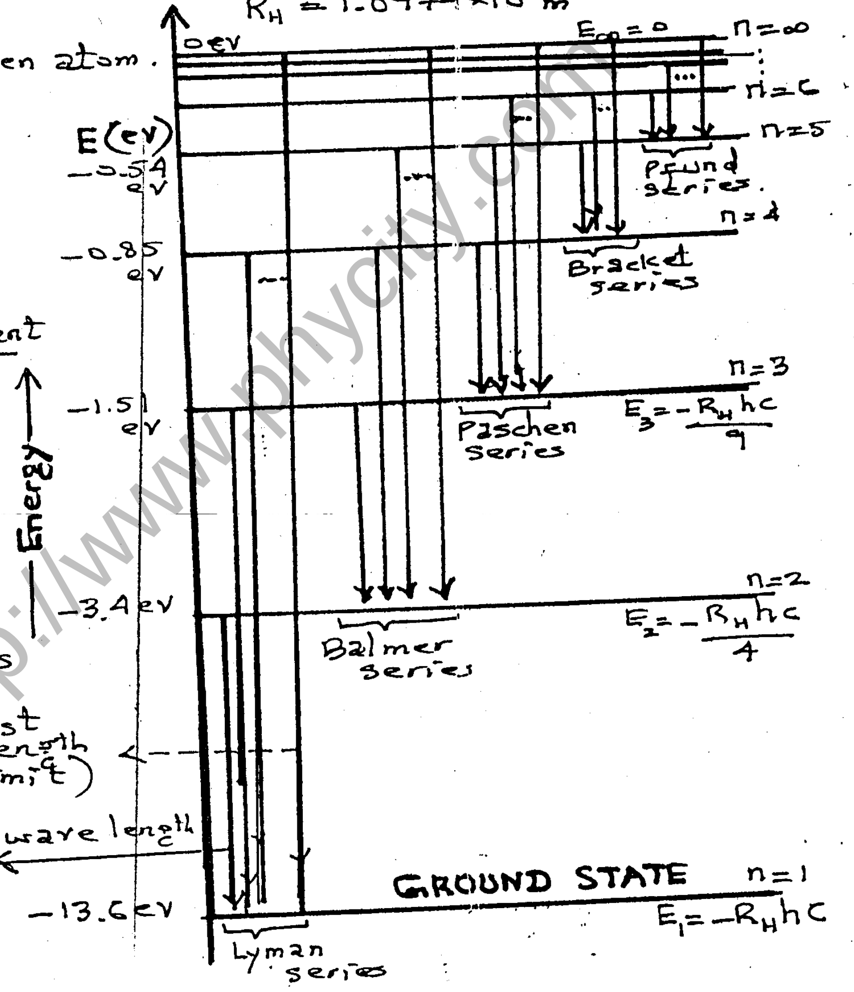

Fig: Energy level diagram

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A set of spectral lines depending upon the level to which an excited electron falls is called **a Series** and emission of photon when electron transist from higher to lower state is called **energy level diagram**.

EXAMPLE 20.1

Find the speed of electron in the first Bohr orbit.

DATA - First orbit (ground state) $= n = 1$

Colomb's constant $= K = 9\times10^{9}\ N\,m^{2}C^{-2}$

Charge on electron $= e = 1.6\times10^{-19}\ C$

Plancks constant $= h = 6.63\times10^{-34}\ J\times S$

Speed of electron $= V = ?$

Sol. As

$$V_n = \frac{2\pi K e^2}{n h}$$

Putting values, we get;

$$V_n = \frac{2\times3.14\times9\times10^{9}\times(1.6\times10^{-19})^2}{1\times6.63\times10^{-34}}$$

$$V_n = \boxed{2.18\times10^{6}\ m\,s^{-1}}$$

20.3 INNER SHELL TRANSITIONS AND CHARACTERISTICS X-RAYS :

The jumps (or transitions) of electrons in the hydrogen or other light elements produces the emission of spectral lines in the infrared, visible or ultraviolet region of electromagnetic spectrum due to small energy difference in the transition levels.

In heavy atoms (large atomic no. Z) have large no. of electrons which are assumed to revolve in concentric shell at increasing distance from the nucleus. These shells are labelled as K, L, M, N shell etc. The 'K' shell being closest to the nucleus, the 'L' shell next, and so on

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Chapter 20

Atomic Spectra

TRANSITION OF ELECTRON.

" The jumping of electron from one orbit to the other, when energy is absorbed or emitted by it, is called transition of electron"

X-RAYS:

The inner shell electrons are tightly bound and large amount of energy is required for Their excitation from Their normal energy state. After excitation, when one electron returns to its normal state, photon of large energy are emitted, known as x-rays. Thus

" Transition of inner shell electron in heavy atom give rise to the emission of high energy photon called **x-rays**".

The frequency or energy of x-rays is much greater then the frquency of ordinary light. Its wavelength is 10^{-10} m = 1Å is shorter than U-V.

These x-rays consists of series of specific frq. or wavelengths and hence are called **characteristic x-rays**. The characteristic x-rays are used for the study of atomic structure and periodic table of electrons.

Their wavelength extend in the region from about 10^{-8} m to 10^{-12} m in the electromagnetic spectrum.

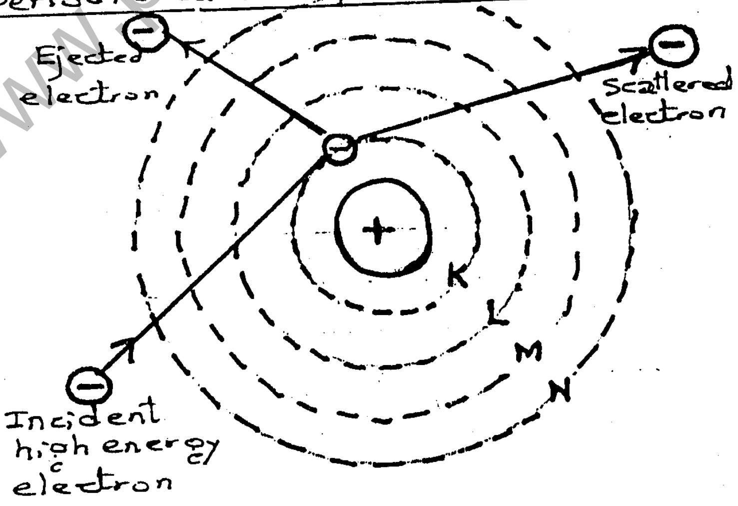

Fig.

PRODUCTION OF X-RAYS.

The production of x-rays is a reverse process of Photoelectric effect. (x-rays are produced when target metal is bombarded by electrons while in photoelectric

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effect, the electrons are produced when light waves are incident on a metal surface).

In 1895, x-rays were discovered by a German Scientist, Dr Röntgen and they were orginally called Röntgen rays.

PRINCIPLE.

When fast moving electrons strike a metal surface, photons of high frequency or energy are emitted, which are called x-rays.

CONSTRUCTION

A modern x-rays unit developed by Dr Coolidge in 1913 consists of the following parts.

1— A high vacuum tube of glass or metal, called x-ray tube.

2— A Source of electrons i.e; cathode plate.

3— A system to supply high P.d to accelerate the electrons and Low P.d for the filament.

4— A metal target 'T' of tungsten or cadmium which serve as anode.

5— Cooling system to remove heat generated at the target.

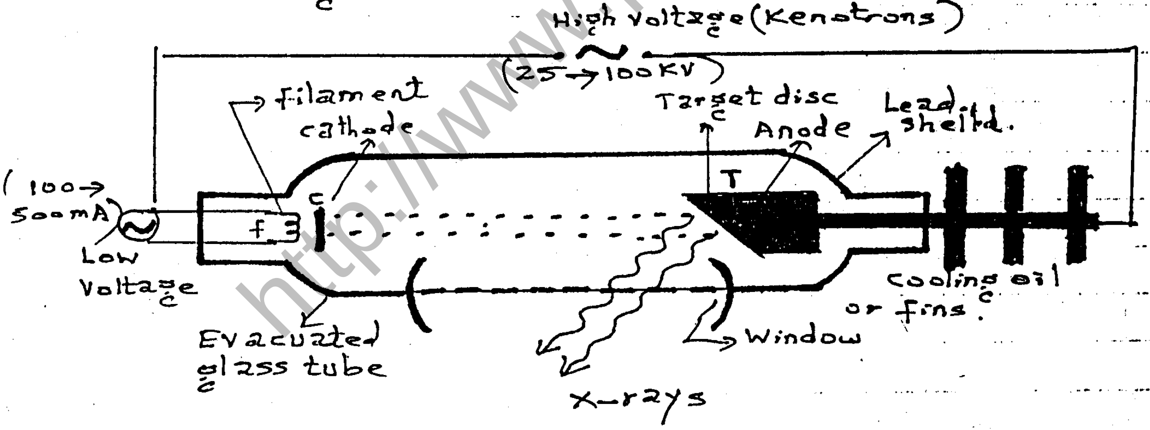

Fig: x-ray tube

WORKING.

The filament 'F' is heated to a desired temp. by varying the filament current from the low tension power supply (a.c) and thus the no. of electrons emitted from the cathode are controlled (quantity of x-rays). The electrons are accelerated by

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applying high P.d from high tension supply (d.c) between the anode and the cathode (quality x-rays). The accelerated electrons are suddenly decelerated on striking the target and some of the K.E is converted into electromagnetic energy as x-rays. The K.E with which the electrons strike the target is given by;

$$K.E = Ve \quad \text{——— (1)}$$

K_α X-RAYS.

Suppose that fast moving electrons of energy Ve strike a target made of heavy metal such as cadmium, molybdenum ($Z=42$), tungsten ($Z=74$), platinium ($Z=78$) etc. It may be possible that in collision, the electrons in the inner most shells, such as K or L will be knocked out.

Suppose that an electron from K-shell is removed from the atom, then a vacancy of electron (or hole) is produced in the K-shell. The electron from L-shell jumps to occupy the hole in the K-shell emitting a photon of energy $hf_{K\alpha}$ called K_α x-ray which is given by

$$hf_{K\alpha} = E_K - E_L \quad \text{——— (2)}$$

K_β X-RAYS.

It is also possible that the electron from the 'M' shell, jump to occupy the hole in the K-shell. The photon emitted are K_β x-rays with energies;

$$hf_{K\beta} = E_K - E_M \quad \text{——— (3)}$$

There are so many other probabilities i.e. $hf_{L\alpha}$, $hf_{L\beta}$ etc; which are called characteristic x-rays because their energy and frequency depend upon the nature of the target anode. The characteristic x-rays appear as discrete lines on the continuous spectrum of x-rays as shown in graph

CONTINUOUS X-RAY SPECTRUM.

If a graph is plotted between wavelength and their relative intensities, sharp spikes are obtained on high voltage curve corresponding to high P.d.

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Atomic Spectra

18—20

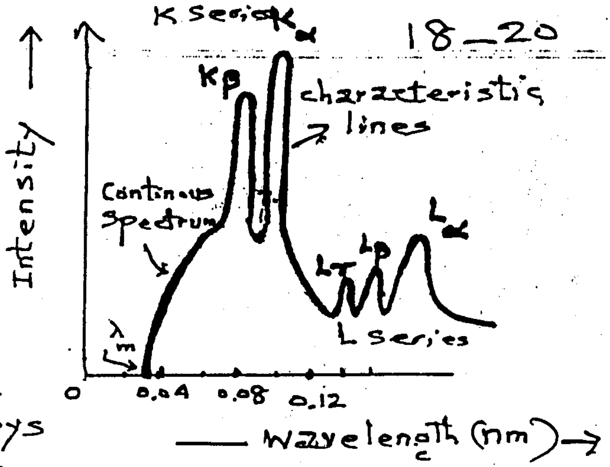

Fig:

The continuous spectrum is due to an effect known as **bremsstrahlung** or **breaking radiation**. When the fast moving electrons bombard the target, x-rays are produced. A few electrons lose all their energy in the first collision with the target atoms. This give the most energetic x-rays or x-rays of max. frq. f_{max}. In this case when the electrons lose all their energy in the first collision, the entire K.E appears as a photon of energy hf_{max}, i.e;

$$K.E = hf_{max}.$$

Other electrons do not lose all their energy in the first collision. They may suffer a no. of collision before coming to rest. This will give rise to photon of smaller energy or x-rays of smaller frq. Thus the continuous spectrum is obtained due to deceleration of impacting electrons.

Def — "The x-rays which are emitted in all directions and with a continuous range of frequencies are called continuous x-rays."

PROPERTIES OF X-RAYS.

1— They travel in straight lines with speed of light.

2— They are not deflected by electric and magnetic fields which shows that they are chargeless.

3— They can be diffracted by crystals. This property is used in crystallography.

4— They cause ionization in gases and this property is used to find out the intensity of x-rays and eject electrons from certain metal (Photoelectric effect)

5— They can produce fluorescence in many substances like zinc sulphide, barium platinocyanide or cadmium tungstate by exciting their atoms.

6— The photographic film is blankened.

7— They can damage living cells (tissues)

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8 — X-rays are highly penetrating radiations and their power of penetration depends upon the density of the material on which they fall. The denser the substance, the smaller the penetration. They can pass through even those substances which are opaque to ordinary light i.e; wood and flesh.

9 — Compton effect can be observed with them.

10 — Like light, they are electromagnetic waves of very short wavelength (frq. higher than U.V) and show reflection, refraction, interference, diffraction and polarization under suitable arrangements.

USES OF X-RAYS.

1 — High energy X-rays are used to destroy cancer cells within the body.

2 — X-rays are used at custom and security posts to detect arms, explosive materials and contraband goods

3 — X-rays are widely used in industry e.g; X-rays photographs show hidden flaws such as cracks, air holes or imperfections in welds.

4 — They are most used in medical diagnostics and treatment. Bone fractures, foreign material such as safety pin swallowed by the patient or the diseased such as tuberculousis can be detected. X-rays can easily pass through flesh because its atoms are of small atomic no, so they absorb less X-rays and appear dark on the photographic film. Whereas bones absorb more X-rays because their atoms are of greater atomic no. and hence they appear lighter on the photographic plate.

5 — They can destroy living cells in the body as they must be handled with care.

6 — X-rays are used to retouching and alternations by exposing the underlayers of paintings.

7 — X-rays can penetrate several centimeters into a solid matter so they can be used to visualize the interiors of the materials such as dislocation of bones or defects in structural steel.

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CAT SCANNER.

There are several vastly improved x-ray techniques, one widely used system is **computerized axial tomography, CAT Scanner**.

The x-ray source produces a thin fan shaped beam that is detected on the opposite side of the subject by an array of several hundred detectors in a line. Each detector measures absorption of x-ray along a thin line through the subject. The entire apparatus is rotated around the subject in the plane of the beam during a few seconds. The changing reactions of the detector are recorded digitally.

A computer processes this information and reconstruct a picture of different density over an entire cross-section of the subject. Density difference on the order of one percent can be detected with CAT-scans.

Tumors and other anomalies which are very small in size and cannot be seen with older techniques, can be detected by CAT-Scanner.

BIOLOGICAL EFFECTS OF X-RAYS.

1— X-rays cause damage to living tissue. As x-ray photon are absorbed in tissues, they break molecular bonds and create highly reactive free radicals (such as H and OH). These disturb the working and structure of proteins and especially genetic material.

2— Young and rapidly growing cells are particularly susceptible (اثر پذیر), hence x-rays are useful for selective destruction of cancer cells. On the other hand a cell which is damaged by x-rays but it may survive to produce generation of deffective cells. Thus x-ray can cause cancer.

3— Excessive x-rays radiation exposure can cause changes in their productive system that will effect the organism's offspring.

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20.4 UNCERTAINTY WITHIN THE ATOM.

Uncertainty principle explain that electron cannot exist inside the nucleus, it can exist in the atom but outside the nucleus.

Due to the dual nature of matter, there is always an uncertainty in the measurement of position and momentum of a particle simultaneously.

Heisenberg showed that this uncertainty is given by;

$$(\Delta P)(\Delta x) \geqslant \frac{h}{2\pi}$$

$$\text{or} \quad (\Delta P)(\Delta x) \simeq h \quad \text{———} ①$$

where ΔP and Δx denotes the uncertainty in the measurement of momentum and position respectively.

- **Electron is not present inside the nucleus.**

We consider a typical nucleus of 10^{-14} m radius. Therefore, max. uncertainty in the measurement of position of electron inside the nucleus is of the order of 10^{-14} m i.e; $\Delta x \simeq 10^{-14}$ m

The corresponding unertainty in the electron's momentum ΔP is calculated;

$$\Delta P \simeq \frac{h}{\Delta x} \quad \text{———} ②$$

$$\Delta P \simeq \frac{6.63\times10^{-34}\ \text{J}\cdot\text{s}}{10^{-14}\ \text{m}} = 6.63\times10^{-20}\ \text{kg m s}^{-1} \quad \text{———} ③$$

As

$$\Delta P = m\,\Delta V$$

$$\text{or} \quad \Delta V = \frac{\Delta P}{m} = \frac{6.63\times10^{-20}}{9.11\times10^{-31}}$$

$$\therefore \quad \Delta V \simeq 7.3\times10^{10}\ \text{m s}^{-1} \quad \text{———} ④$$

Hence for the electron to be confined to a nucleus, its speed must be greater than the speed of light. But this is impossible by the theory of relativity. Thus we conclude that an electron can never be found inside a nucleus.

- **Existence of electron outside the nucleus of atom.**

The radius of the hydrogen atom is about 5×10^{-11} m. So the max. value in the uncertainty in the measurement of position of particle is, $\Delta x = 5\times10^{-11}$ m

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Applying the uncertainty principle;

$$\Delta P \simeq \frac{h}{\Delta x}$$

$$\text{or} \quad \Delta V \simeq \frac{h}{m \Delta x} \qquad (\because \Delta P = m \Delta V)$$

$$\therefore \quad \Delta V \simeq \frac{6.6 \times 10^{-34}}{9.11 \times 10^{-31} \times 5 \times 10^{-11}} \simeq 1.46 \times 10^{7} \ m s^{-1}$$

This speed of the electron is less than the speed of light, therefore it can exist in the atom but outside the nucleus.

20.5 LASER :

The name **Laser** stands for light amplification stimulated emission of radiation.

Def — "A Laser is a device which produces narrow, intense, monochromatic, unidirectional and coherent beam of light, based on stimulated emission of radiation.

The light emitted by an ordinary light source is not only incoherent but also emitted in all directions.

A **Laser** has the following properties;

1— It is monochromatic (of one frq. or one wavelength)

2— It is Coherent (crests and troughs of beam are in phase)

3— It is unidirectional

The principle is based on the fact, proved theoretically by Einstein in 1917, than an excited atom can be stimulated to return from higher energy state to lower energy state before its natural time if the atom, in its excited state, is to hit by another photon of the same energy as the photon to be emitted. Thus the incident photon and the stimulated photon which are in phase, can in turn stimulate other excited atoms to produce amplified beam. The first device in which the process of stimulated emission was used to produce amplification of radiation was the ammonium maser

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(Maser stands for microwave amplification by stimulated emission of radiation). The first optical maser called **Laser** was a ruby laser developed in 1960.

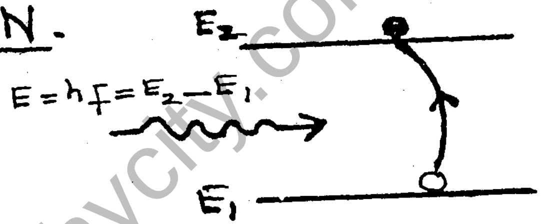
• LASER PRINCIPLE.

The working principle of a laser is based upon;

1 — Spontaneous emission
2 — Stimulated emission
3 — Population inversion
4 — Metastable state.

INDUCED ABSORPTION.

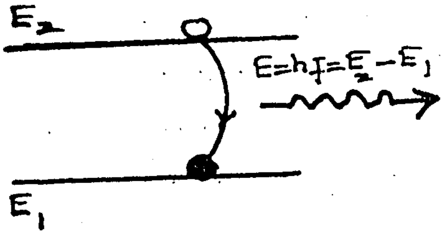
Def — "The incident photon is absorbed by an atom in the ground state to the excited state is called induced absorption or stimulated absorption."



fig(a)

⊛ SPONTANEOUS EMISSION.

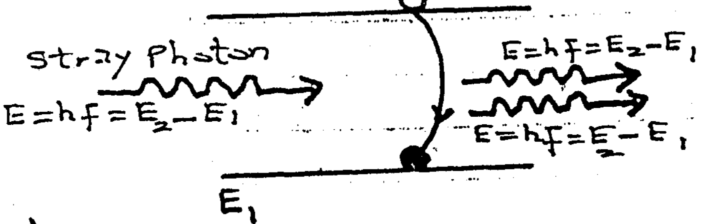
Def — "The emission of Photon when atom return from excited state to ground state spontaneously, is called spontaneous emission."



fig(b)

⊛ STIMULATED EMISSION.

Def — "A process of speed up atomic transistion to lower levels is called stimulated emission or induced emission."



fig(c)

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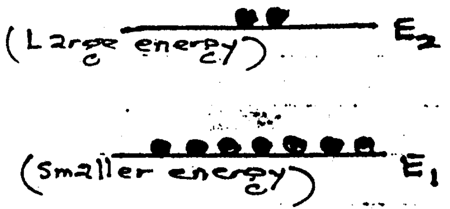
NORMAL POPULATION.

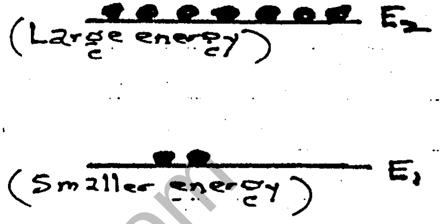
Def — "The no. of atoms in the ground state are more as compared to no. of atoms in the excited state is called normal population."



fig(d)

⊛ POPULATION INVERSION.

Def — "If the no. of atoms in the excited state are more as compared to no. of atoms in the ground state, then the inversion is known as Population inversion."



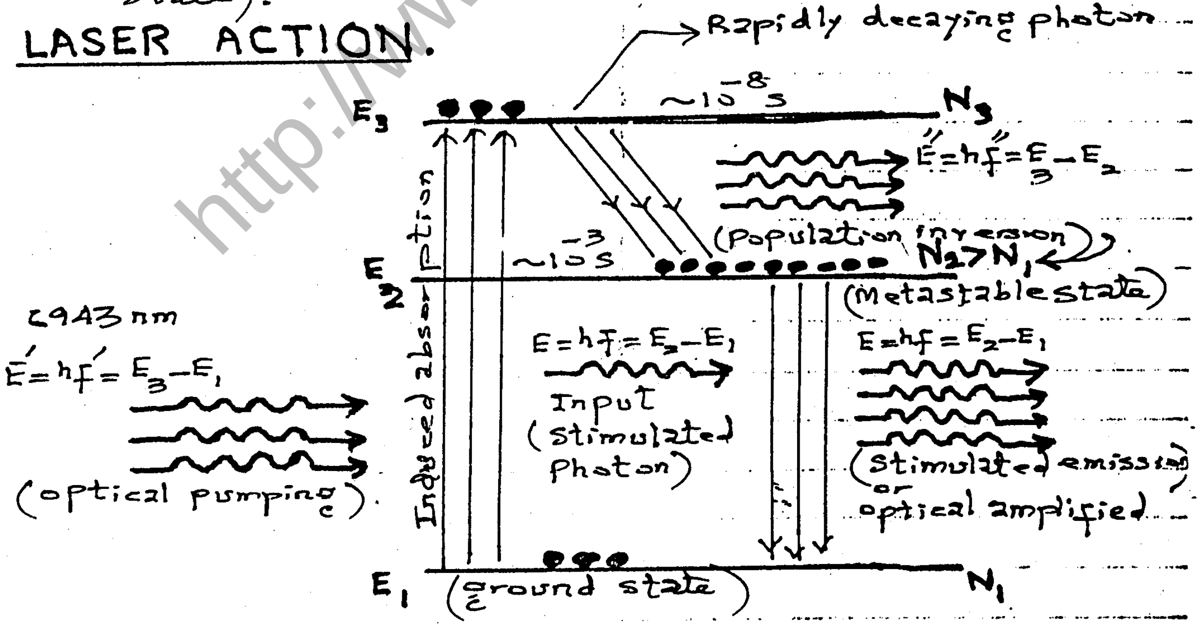
fig(e)

⊛ METASTABLE STATE.

Def — "A metastable state is a higher excited energy state in which an excited electrons can stay for longer time."

i.e; Electron can take comparatively longer time to deexcite spontaneously (fall to lower state).

• LASER ACTION.



fig(f)

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Let us consider a material whose atoms
can exist in three different states as shown
in fig (f).

State with energy E_1 is the ground state which is
the most stable state. E_3 is the excited state in
which the atoms can exist only for a short interval
of 10^{-8}s. E_2 is the metastable state in which the
atoms can exist for 10^{-3}s (even 1 s), much longer
than 10^{-8}s.

Let us suppose that the incident photon of
energy $hf = E_3 - E_1$ raise the atom from ground state
E_1 to the excited state E_3, but the excited atoms
donot decay back to E_1.

The atoms which are excited up to E_3 state
have a chance to do excite spontaneously to
state E_2, the atoms reach state E_2 must faster
than they leave state E_2. So, we can get more
atoms in the excited state E_2 than the atoms
in state E_1 or E_3. This situation is called population
inversion. When population inversion has been reached,
the action of a laser becomes simple. The atoms
in the metastable state E_2 are bombarded by photons
of energy $hf = E_2 - E_1$. This results a stimulated
emission, giving an intense and monochromatic
beam of light in the direction of incident photon.

- **UNIDIRECTIONAL & COHERENT**

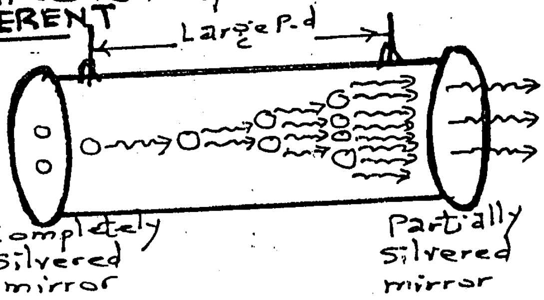

fig (g)

The emitted photon
must be confined in
the assembly long
enough to stimulate
further emission from
other excited atoms.
This is achieved by
using mirrors at the
two ends of the
assembly. One end and the other end is partially
is made totally reflected, laser beam to escape.
transparent to allow the forth between the
As the photons move back and

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reflecting mirrors they continue to stimulate other excited atoms to emit photons. As the process continues the number of photons multiply, and the resulting radiation is, therefore, much more intense and coherent than light from ordinary source.

• KINDS OF LASERS.

There are different types of Lasers whose power range varies from milliwatts to Megawatts. Laser are classified to the three major kinds;

1 — Solid Laser
2 — Liquid Laser
3 — Gas Laser

① SOLID LASER.

In solid laser, a fluorescent crystal such as that of a ruby, glass or a semiconductor is used as light amplifying substance.
Ruby is a crystal of Aluminium Oxide in which some of the Aluminium atoms are replaced by chromium atoms which gives ruby its characteristic colour. Ruby atoms have an excited state at about 1.8 eV level E_2 and laser beam is produced by atoms falling from this level to ground state.

② LIQUID LASER.

The liquid lasers usually make use of a dye dissolved in methanol or a similar liquid, as light amplifying substance.

③ GAS LASER.

In gas lasers, a gas or a mixture of gases is used as light amplifying medium. **For example,** helium-neon, argon ion and carbondioxide gas, and nitrogen gas lasers are most widely used as gas lasers.

HELIUM NEON LASER.

It is a most common type of gas laser used in physics laboratories because of its colour purity and minimal beam spread. Helium-neon laser is

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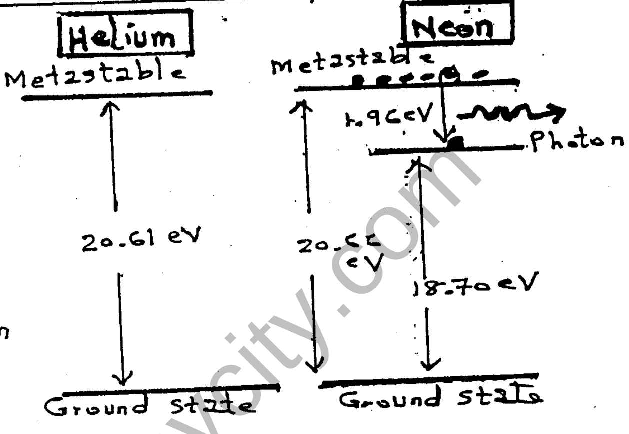
compact, portable, high coherence, easily usable and relatively inexpensive source of laser light. Laser action is obtained from the transitions of the neon atoms (active medium), while helium is added to the gas mixture to greatly enhance the efficiency of the pumping process by about 200 times. It's discharge tube is filled with 85% helium and 15% neon gas. Helium and neon have nearly identical metastable states.



Fig(h)

The high voltage electric discharge excites the electrons in some of the **helium** atoms to the 20.61 eV state. In this population inversion in **neon** is obtained by direct collision with same energy electrons of helium atoms. Thus, excited helium atoms collide with neon atoms, each transferring its own 20.61 eV of energy to an electron in the neon atom along with 0.05 eV of K.E from the moving atom. As a result, the electrons in the neon atoms are raised to 20.66 eV state. In this way, a population inversion is kept in the neon gas relative to an energy level of 18.70 eV. Spontaneous emission from neon atom start laser action and stimulated emission causes the electrons in the neon to drop from 20.66 eV to the 18.70 eV level and red laser light of wavelength 632.8 nm corresponding to 1.96 eV energy is produced.

N.B The helium neon laser oscillates on many wavelengths which includes 632.8 nm (Red), 543 nm (green) and the infrared at 1.15 μm & 3.39 μm and many other wavelengths. But $\lambda = 632.8$ nm (Red) has becomes the most popular due to its visibility to human eye.

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USES OF LASER IN MEDICINE AND INDUSTRY.

1— Laser beams are used as surgical tool for "welding" detached retina.

2— The narrow intense beam of Laser can be used to destroy tissue in a localized area.

3— A finely focussed laser beam can be used to destroy cancerous and pre-cancerous cells.

4— Lasers are used to break the stone in human kidney and gallstones. The device is known as **lithotripter** or (**lithrotripmeter**).

5— Heat produced by laser seals off capillaries and lymph vessels to prevent spread of the disease.

6— A laser beam has many uses in surgery. Skin tumour are normally darker in colour. When the tumour is exposed to laser beam, the heat produced destroys the tissues quickly without any bleeding.

7— Lasers can be used for telecommunication along optical fibres.

8— Laser beam can be used to produce 3-D images of objects in a process called **holography**.

9— A laser beam can drill tiny holes in the hardest material such as steel and diamond and for welding in electric circuit.

10— Laser is used as P.E source for inducing fusion reaction.

11— Lasers also have military application as laser guided missiles can destroy aircrafts and tanks.

12— A laser beam can be used to develop hidden finger print.

13— A laser can be used for the photographic recording of output data of a computer.

14— A laser beam can be used as range finder over large distance.

15— The lasers can be used as very sensitive detectors of pollution in the atmosphere.

16— They are used to guide aircraft during landing in bad weather.

17— Lasers can be used for the separation of isotopes and thus for the enrichment of Uranium.

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