ATOMIC SPECTRA

SPECTROSCOPY

The branch of physics which deals with the investigation of wavelengths and intensities of electromagnetic radiation emitted or absorbed by atoms is called spectroscopy.

Spectroscopy deals with the study of spectra produced by atoms. It includes three types of spectra produced by atoms given as

(i) Continuous spectra.
(ii) Band spectra.
(iii) Line or Discrete spectra.

CONTINUOUS SPECTRA

The spectrum produced by radiations emitted by black body is an example of continuous spectra.

BAND SPECTRA

The spectrum produced by radiations emitted by molecules is an example of band spectra.

LINE OR DISCRETE SPECTRA

The spectrum produced by radiations emitted by atomic gas or vapour is an example of line or discrete spectra.

ATOMIC SPECTRA

At ordinary pressure, electric current can not pass through the gases or vapours. If the pressure is reduced much less than the atmospheric pressure, then electric current can easily pass through the gases or vapours which excited the atomic gases or vapours. On de-excitation, the radiations are emitted from the atoms of the atomic gases or vapours. The spectrum produced by the radiations emitted by the atoms, called atomic spectra.

Atomic spectra contains certain specific wavelengths, Figure (a) shows the experimental arrangement for observing the spectra of different atoms. Actually, spectrometer is used for observing clear atomic spectra with the help of diffraction grating or prism.

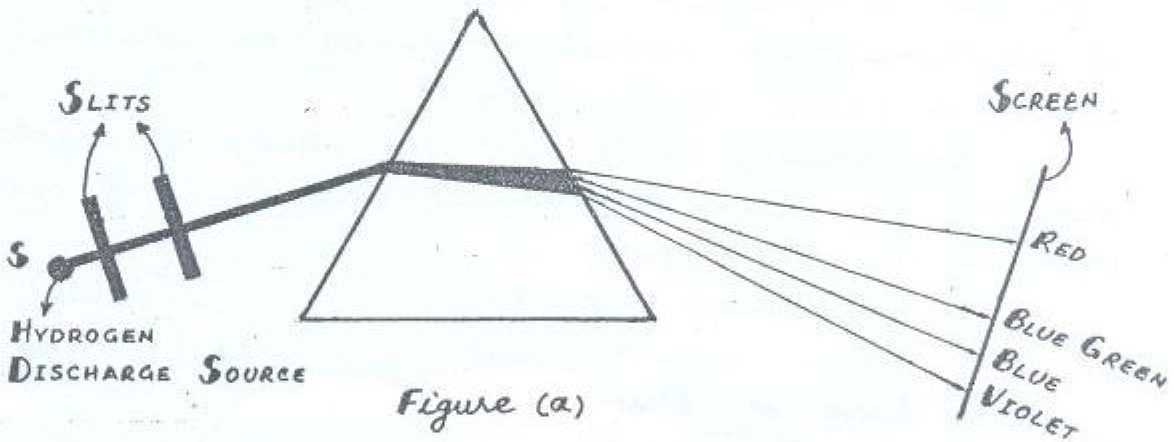


Figure (a)

SPECTRUM OF HYDROGEN ATOM

When light from a hydrogen discharge source S is allowed to fall on a glass prism, then the print on the plate or screen is in the form of lines if slit in front of the source S is narrow rectangle. For this reason the spectrum obtained is line spectrum. It is the fact that the spectrum of any element contains a set of particular wavelengths or frequencies that show definite regularities.

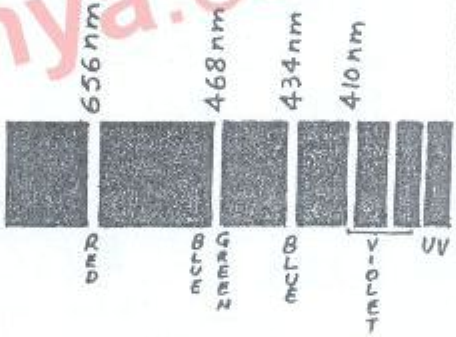


Figure (b)

These regularities were classified into certain groups, called the spectral series. The first spectral series was identified by J. J. Balmer in 1885 in the spectrum of hydrogen. This series is called the Balmer series and it lies in the visible region of the electromagnetic spectrum as shown in figure (b).

BALMER SERIES

It lies in the visible region of the hydrogen spectrum. The results obtained by Balmer were expressed in 1896 by J.R. Rydberg in the following mathematical form

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

Where n is an integer and R_H is the Rydberg's constant. Its value is

$$n = 3, 4, 5, \ldots$$

$$R_H = 1.0974 \times 10^7\ m^{-1}$$

The spectral lines of hydrogen in the ultra-violet and infra-red regions fall into several other series given as

LYMAN SERIES

It lies in the ultraviolet (invisible) region. Lyman series contains the wavelengths given by the relation.

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

Where $n = 2, 3, 4, \ldots$

PASCHEN SERIES

This series lies in the infra-red (invisible) region. The wavelengths of various lines of this series is given by the relation.

$$\boxed{\frac{1}{\lambda} = R_H\left(\frac{1}{3^2} - \frac{1}{n^2}\right)}$$

Where $n = 4, 5, 6, \ldots$

BRACKETT SERIES

This series lies in the low infra-red region. The wavelengths of various lines of this series is given by the relation.

$$\boxed{\frac{1}{\lambda} = R_H\left(\frac{1}{4^2} - \frac{1}{n^2}\right)}$$

Where $n = 5, 6, 7, ------$.

PFUND SERIES

This series lies in very low infra-red region. The wavelengths of various lines of this series is given by the relation.

$$\boxed{\frac{1}{\lambda} = R_H\left(\frac{1}{5^2} - \frac{1}{n^2}\right)}$$

Where $n = 6, 7, 8, -------$

The general formula for the wavelengths of the spectral lines of different spectral series is

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

Where

$p = 1, 2, 3, ---------------$.

$n = (p+1), (p+2), (p+3), ------$

BOHR'S MODEL OF THE HYDROGEN ATOM

In order to explain the empirical results obtained by Rydberg, Neils Bohr in 1913, proposed a model of hydrogen atom using classical physics and Planck's quantum theory. Bohr's model based on the following three postulates.

POSTULATE I

An electron, bound to the nucleus in an atom, can move around the nucleus in certain circular orbits without radiating energy. These orbits are called the discrete stationary states of the atom.

POSTULATE II

Only those stationary orbits are allowed for electrons for which orbital angular momentum is equal to an integral multiple of $\frac{h}{2\pi}$ i-e;

Orbital Angular Momentum $= n\left(\frac{h}{2\pi}\right)$

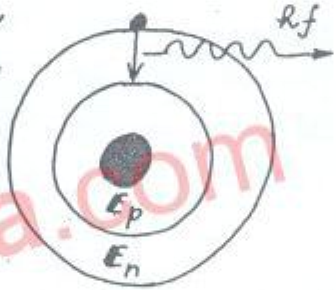
$$\boxed{mvr = \frac{nh}{2\pi}}$$

Where $n = 1, 2, 3, \text{------}$ and is called the principal quantum number.

m = Mass of orbiting electron
v = Velocity of orbiting electron
r = Radius of stationary orbit
h = Planck's constant $= 6.63 \times 10^{-34}\ J.s$

POSTULATE III

Whenever an electron makes a transition, that is jumps from high energy state E_n to a lower energy state E_p, the a photon of energy hf is emitted so that



$$\boxed{E_n - E_p = hf}$$

Where $f = c/\lambda$ = Frequency of radiation emitted.

de-BROGLIE'S INTERPRETATION OF BOHR'S ORBITS

When Bohr's theory is formulated, then there was no justification for the first two postulates, while third postulate had made some roots in Planck's theory. Later on with the development of de-Broglie's hypothesis, some justification could be seen in postulate II.

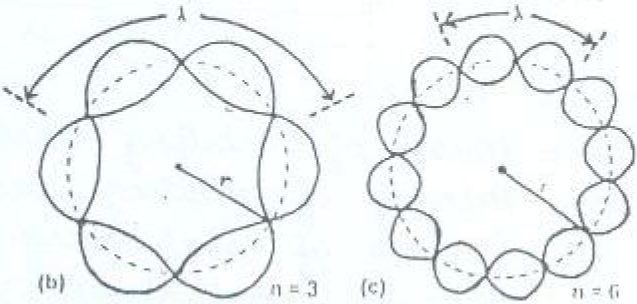
This fact is explained as below.

Consider a string of length l connected between two rigid supports as shown in fig.(a). If stationary vibrations or waves are produced in the string, then the wavelength of waves is

$$\lambda = \frac{l}{n}$$

$$\Rightarrow \quad l = n\lambda \longrightarrow ①$$

(a)



(b) (c)

Where n is an integer. Suppose that the string is bent into a circle of radius r as shown in figure (b) and (c) where stationary waves are produced for $n = 3$ and $n = 6$. Now length of the string l is equal to the circumference of the circle $2\pi r$, so

$$l = 2\pi r$$

Put this value in equation ①

$$\therefore \quad 2\pi r = n\lambda$$

$$\Rightarrow \quad \lambda = \frac{2\pi r}{n} \longrightarrow ②$$

According to de-Broglie's hypothesis, the wavelength of electron is

$$\lambda = \frac{h}{P} \qquad (\because P = mv)$$

$$\Rightarrow \quad \lambda = \frac{h}{mv} \longrightarrow ③$$

Comparing equation ② and ③, we get

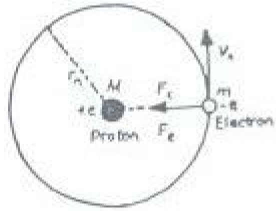
$$\frac{2\pi r}{n} = \frac{h}{mv}$$

$$\Rightarrow \quad \boxed{mvr = \frac{nh}{2\pi}}$$

Which is postulate II of Bohr's model.

QUANTIZED RADII OF HYDROGEN ATOM

Consider a hydrogen atom having a single proton of charge '$+e$' in the nucleus and single electron of charge '$-e$' moving with velocity v_n in a stationary circular orbit of radius r_n as shown in figure.



The Coulomb's or electrostatic force between the electron and nucleus is given as

$$F_e = \frac{K q_1 q_2}{r_n^2} \qquad (\because q_1 = q_2 = e)$$

$$\Rightarrow \quad F_e = \frac{K e \cdot e}{r_n^2} = \frac{K e^2}{r_n^2} \longrightarrow (1)$$

Where K is Coulomb's constant given as

$$K = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \ N \cdot m^2 \cdot C^{-2}$$

As electron is moving in circular orbit, so it must have centripetal force given as

$$F_c = \frac{m v_n^2}{r_n} \longrightarrow (2)$$

This centripetal force is provided by the Coulomb's force, so

$$F_c = F_e$$

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$$\Rightarrow \quad \frac{m v_n^2}{r_n} = \frac{K e^2}{r_n^2}$$

$$\Rightarrow \quad r_n = \frac{K e^2}{m v_n^2} \longrightarrow (3)$$

According to Bohr's second postulate

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

$$\Rightarrow \quad v_n = \frac{n h}{2\pi m r_n} \qquad \text{(Taking square)}$$

$$\Rightarrow \quad v_n^2 = \frac{n^2 h^2}{4\pi^2 m^2 r_n^2}$$

Put this value in equation (3), we get

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

$$\Rightarrow \quad r_n = \left(\frac{4\pi^2 m Ke^2}{n^2h^2}\right) r_n^2$$

$$\Rightarrow \quad \boxed{r_n = \frac{n^2h^2}{4\pi^2 m Ke^2}} \longrightarrow (4)$$

For first orbit, $n=1$

$$r_1 = \frac{h^2}{4\pi^2 m Ke^2}$$

Put in equation (4), we get

$$\boxed{r_n = n^2 r_1} \longrightarrow (5)$$

By putting the values of constants h, π, m, K and e, we get value of r_1 as

$$r_1 = \frac{h^2}{4\pi^2 m Ke^2}$$

$$\Rightarrow \quad r_1 = \frac{(6.63\times10^{-34})^2}{4\times(3.14)^2\times9.1\times10^{-31}\times9\times10^9\times(1.6\times10^{-19})^2}$$

$$\Rightarrow \quad r_1 = 0.053\times10^{-9}\,m$$

$$\Rightarrow \quad \boxed{r_1 = 0.053\,nm}$$

This agrees with the experimentally measured values and is called the first Bohr orbit radius of the hydrogen atom. According to Bohr theory, the radii of different stationary orbits of the electrons in the hydrogen atom are given by

$$\boxed{r_n = r_1,\ 4r_1,\ 9r_1,\ 16r_1,\ -----}$$

Speed Of Electron

According to Bohr's second postulate

$$m v_n r_n = \frac{nh}{2\pi}$$

$$\Rightarrow \quad v_n = \frac{nh}{2\pi m r_n}$$

Put value of r_n from equation (4)

$$\therefore \quad v_n = \frac{nh}{2\pi m\left(\frac{n^2h^2}{4\pi^2 mKe^2}\right)}$$

$$\Rightarrow \quad \boxed{v_n = \frac{2\pi Ke^2}{nh}} \longrightarrow (6)$$

Which is the relation for speed of the electron in the nth orbit of hydrogen atom.

Quantized Energies Of Hydrogen Atom Orbits

The total energy E_n of the electron in the Bohr orbit is the sum of the kinetic energy K.E. and the potential energy U i-e;

$$E_n = K.E. + U \longrightarrow (1)$$

Kinetic Energy

As the centripetal force needed to move the electron around the nucleus in circular orbit is provided by the Coulomb's force between the nucleus and the electron, so

$$F_c = F_e$$

$$\Rightarrow \quad \frac{mv_n^2}{r_n} = \frac{Ke^2}{r_n^2}$$

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$$\Rightarrow \quad mv_n^2 = \frac{Ke^2}{r_n}$$

Where K.E. of electron is

$$K.E. = \frac{1}{2}mv_n^2 \qquad \left(\because mv_n^2 = \frac{Ke^2}{r_n}\right)$$

$$\Rightarrow \quad \boxed{K.E. = \frac{Ke^2}{2r_n}} \longrightarrow (2)$$

Potential Energy

As the absolute electric potential V at a distance r_n from nucleus of charge '+e' is given by

$$V = \frac{Ke}{r_n}$$

As electric potential is the work done per unit charge, so that the potential energy of an electron having charge '$-e$' is given as

$$P.E. = \text{Electric Potential} \times \text{Charge}$$

$$\Rightarrow \quad U = V \times (-e)$$

$$\Rightarrow \quad U = \frac{Ke}{r_n} \times (-e) = -\frac{Ke^2}{r_n} \longrightarrow (3)$$

TOTAL ENERGY

The total energy E_n of the electron in the Bohr orbit is given by equation (1) as

$$E_n = K.E. + U$$

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

$$\Rightarrow \quad E_n = \frac{Ke^2}{2r_n} - \frac{Ke^2}{r_n} = \frac{Ke^2 - 2Ke^2}{2r_n}$$

$$\Rightarrow \quad E_n = -\frac{Ke^2}{2r_n} \longrightarrow (4)$$

As radius of the Bohr orbit is

$$r_n = \frac{n^2h^2}{4\pi^2 mKe^2}$$

Put this value in equation (4), we get

$$E_n = \frac{-Ke^2}{2\left(\frac{n^2h^2}{4\pi^2 mKe^2}\right)}$$

$$\Rightarrow \quad E_n = -\frac{Ke^2}{2} \cdot \frac{4\pi^2 mKe^2}{n^2h^2}$$

$$\Rightarrow \quad E_n = -\frac{1}{n^2}\left(\frac{2\pi^2 mK^2e^4}{h^2}\right)$$

$$\Rightarrow \quad \boxed{E_n = -\frac{E_o}{n^2}} \longrightarrow (5)$$

Where

$$E_o = \frac{2\pi^2 mK^2e^4}{h^2} = \text{Constant}$$

Putting the values of π, m, K, e and h, we get

$$\boxed{E_o = \frac{2\pi^2 mK^2e^4}{h^2} = 13.6\ eV}$$

Which is the energy required to completely remove an electron from the first Bohr orbit. This is called ionization energy.

For $n = 1, 2, 3, \text{-------}$, we get the allowed energy levels of a hydrogen atom as

$$\boxed{E_n = -E_o\ ,\ -\frac{E_o}{4}\ ,\ -\frac{E_o}{9}\ ,\ -\frac{E_o}{16}\ ,\ ----}$$

Ground or Normal State

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

Excited State

When the electron is in the first Bohr orbit, it is said to be in the ground state. When the electron is in higher orbit, it is said to be in the excited state.

Excitation Energy

The energy needed to lift an electron from ground state to any higher energy state is called excitation energy.

Excitation Potential

The potential through which an electron can lift from its ground state to some higher energy state is called excitation potential.

Ionization Energy

The energy required to completely remove an electron from its ground state is called ionization energy.

OR

The energy required to lift an electron from its ground state to infinite energy state is called ionization energy.

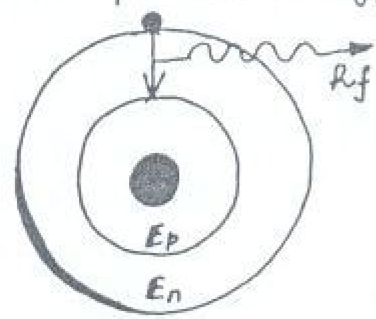
Ionization Potential

The potential through which an electron is removed from the atom is called ionization potential.

HYDROGEN EMISSION SPECTRUM
OR PROVE THAT WAVELENGTH OF SPECTRAL LINES IS

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

Consider that the electron in the hydrogen atom is in the excited state n with energy E_n and makes a transition to a lower energy state p with energy E_p where $E_p < E_n$.



According to Bohr's atomic theory, the energy of the electron in the pth and nth orbit is

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

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

According to third postulate of Bohr's atomic theory, when electron jumps from higher orbit (nth) to lower orbit (pth), then the energy will be emitted as a photon of energy hf. i-e;

$$hf = E_n - E_p$$

Put values of E_n and E_p, we get

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

$$\Rightarrow \quad hf = E_o\left(\frac{1}{p^2} - \frac{1}{n^2}\right) \longrightarrow (1)$$

As

$$c = f\lambda \Rightarrow f = c/\lambda$$

Put this value in equation (1)

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

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

$$\Rightarrow \quad \boxed{\frac{1}{\lambda} = R_H\left(\frac{1}{p^2} - \frac{1}{n^2}\right)} \longrightarrow (2)$$

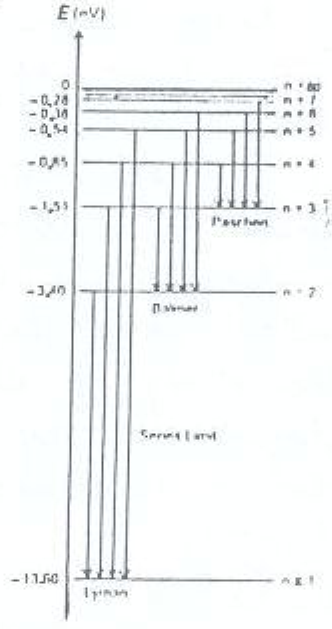
Do You Know?

Photon must have energy exactly equal to the energy difference between the two shells for excitation of an atom but an electron with K.E greater that the required difference can excite the gas atoms

Where R_H is the Rydberg constant given as

$$R_H = \frac{E_o}{hc} = 1.0974 \times 10^7\ m^{-1}$$

ENERGY LEVEL DIAGRAM



Energy level diagram for the hydrogen atom.

Figure shows the energy level diagram in the hydrogen atom. In figure, the horizontal lines represents the different energy levels while the vertical lines represents the electron transitions.

If the transitions takes place from different higher energy states and ending at energy level corresponding to $n=1$, then we get Lyman series.

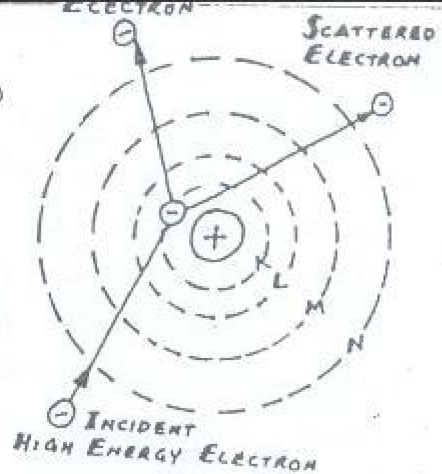
For transitions at $n=2$, we get Balmer series.

For transitions at $n=3$, we get Pascher series.
For transitions at $n=4$, we get Brackett series.
For transitions at $n=5$, we get Pfund series.

INNER SHELL TRANSITIONS AND CHARATER-ISTIC X-RAYS

The electron transitions in the hydrogen or other light elements results in the emission of spectral lines in the infra-red, visible or ultraviolet region of electromagnetic spectrum due to small energy differences in the transition levels.

In case of heavy atoms, electrons are assumed to be arranged in concentric shells named as K, L, M, N, O etc. The K-shell is closest to the nucleus, the L-shell next and so on as shown in figure. The inner shell electrons are tightly bound to their nucleus and large amount of energy is required for their excitation from their normal energy state. After excitation, when an electron returns to its normal state, photons of larger energy are emitted. Thus transition of inner shell electrons in heavy atoms gives rise to the emission of high energy photons, known as X-rays.



These X-rays consists of series of specific wavelengths or frequencies and hence are called characteristic X-rays.
The study of characteristic X-rays spectra has played a very important role in the study of atomic structure and the periodic table of elements.

X-RAYS

X-rays are similar to ligh but having much shorter wavelength in the range of 5×10^{-7} cm to 6×10^{-10} cm approximately.

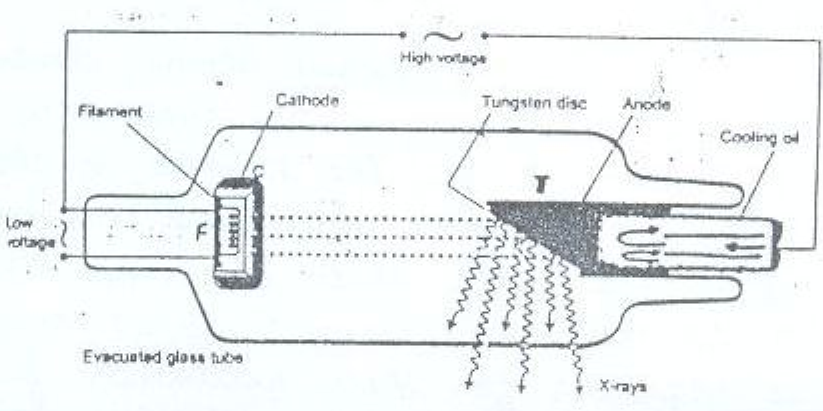
X-rays are discovered by German Physicist Rontgen in 1895.

PRINCIPLE

When fast moving electrons strike a metal surface, photons of higher frequency are emitted, called X-rays.

PRODUCTION OF X-RAYS

X-rays can be produced by the following arrangement as shown in figure.



This arrangement consists of following parts.

(i) A high vacuum tube, called X-ray tube.

(ii) A source of electrons C (cathode plate) to produce electrons.

(iii) A system to supply high potential difference to accelerate electrons.

(iv) A metal target T which acts as anode.

When the cathode C is heated by the filament F, it emits electrons which are accelerated towards the anode target T. If V is the potential difference betweent the cathode C and anode T, then the K.E. of the electrons with which they strike the target T is given as

$$\boxed{K.E. = Ve} \longrightarrow (1)$$

Consider that the fast moving electrons of energy 'Ve' strike a target T made of cadmium or any other heavy element. These fast moving electrons collide with the electrons of metal target T and transfer their energy to the electrons of the target T. It may knocked out the electrons from the innermost shells such as K or L shells.

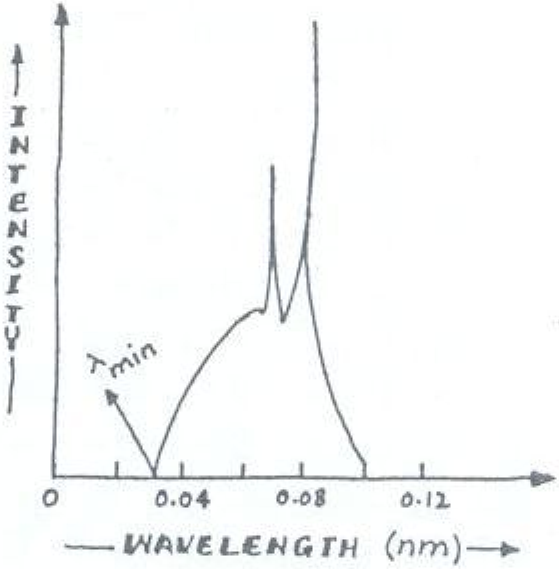
Suppose that one of the electrons in the K-shell is removed and so creating a vacancy or hole in the K-shell. The electron from the L-shell jumps to occupy the hole in the K-shell and hence emitting a photon of energy $hf_{K\alpha}$, called the K_α X-ray given as

$$\boxed{hf_{K\alpha} = E_L - E_K} \longrightarrow (2)$$

It is also possible that the electron from the M-shell may also jump to occupy the hole in the K-shell and emitting a photon of energy $hf_{K\beta}$, called the K_β X-ray given as

$$\boxed{hf_{K\beta} = E_M - E_K} \longrightarrow (3)$$

These photons give rise to K-series of X-rays. Similarly, the holes created in the L and M-shells are occupied by transitions of electrons from higher states producing more X-rays. The X-rays produced due to the transitions from higher states to L and M-shells give rise to L-series and M-series of X-rays and so on.



The photons emitted due to inner-shell transitions are called characteristic X-rays because their energies depend upon the type of the material. The characteristic X-rays appear as discrete lines on a continuous spectrum as shown in the graph.

THE CONTINUOUS X-RAY SPECTRUM

The X-rays which are emitted in all directions and with a continuous range of frequencies are known as continuous X-rays. The continuous X-ray spectrum is obtained due to deceleration of the colliding electrons. This continuous X-ray spectrum is due to an effect, known as BREMSSTRAHLUNG OR BREAKING RADIATION.

When the fast moving electrons bombarded the target, they are suddenly slowed down on impact with the target. We know that accelerating electrons or charges emits electromagnetic radiations. Hence, these impacting electrons emit radiation as they are decelerating by the target. As the rate of deceleration is very large, the emitted radiation is of short wavelength and so the bremsstrahlung is in the X-ray region.

If the electrons lose all their kinetic energy in the first collision, the whole energy will be appears as maximum energy of X-ray photon energy hf_{max} i-e;

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

The wavelength λ_{min} corresponds to frequency f_{max} as shown in graph. The electrons which do not lose all their energy in the first collision, they may suffer a number of collisions before coming to rest. In this case, the X-rays of smaller energy or longer wavelength will be emitted.

Hence, the continuous X-ray spectrum is obtained due to deceleration of impacting electrons.

PROPERTIES AND USES OF X-RAYS

X-rays have many practical uses in medicine and industry.

1. X-rays can penetrate several centimetres into a solid matter, so they can be used to visualize the interiors of the materials which are opaque to ordinary light such as fractured bones or defects in structure of steel etc.

The solid object to be visualized is placed between an X-ray source and a large sheet of photographic film. The darkening of the film is proportional to the intensity of radiation. A crack or air bulb in the object allows large amount of X-ray to pass which appears as dark area on the photographic film. As density of flesh is less than the density of bones so less intense X-rays pass through the bones because bones absorb large amount of incident X-rays. This has small effect on the photographic film and hence its image becomes clear on photographic film.

In flesh, light elements like carbon, hydrogen and oxygen predominates. These elements allow greater amount of incident X-rays to pass through them.

2. CAT Scanner

CAT scanner is an improved technique of X-ray. It is an instrument which is used in computerized axial topography.

In CAT scanning, the X-ray source produces a thin fan-shaped beam that is directed on opposite side of the subject by an array of several hundred detectors in a line. Each detector detects the intensity of X-rays after passing 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 detectors are recorded digitally. A computer processes this information and reconstructs a picture of different densities over an entire cross-section of the subject. Density differences of the order of one percent can be detected with CAT scanner.

Tumors and other anomalies which are very small in size can be detected which can not be detected by old techniques.

3. Biological Effects Of X-Rays

(i) X-rays damage the living tissues.

(ii) Molecular bonds in tissues may break due to the absorption of X-rays in tissues and create highly reactive free radicals such as H and OH. These free radicals can disturb molecular structure of the proteins and especially the genetic material.

(iii) Young and rapidly growing cells are particularly susceptible. So, X-rays are useful for selective destruction of cancer cells.

(iv) A cell may be damaged by X-rays but survive, continue dividing and produce defective cells. Hence, X-rays can cause cancer.

(v) If an organism shows no apparent damage, then excessive X-rays exposure can cause changes in their productive system that will affect the organism's offspring.

General Properties Of X-Rays

(i) X-rays are similar to light but of shorter wavelength in the range of 5×10^{-7} cm to 6×10^{-10} cm.

(ii) X-rays can penetrate several centimetres into a solid and used to see the interiors of the materials which are opaque to ordinary light.

(iii) X-rays can be used to detect the objects hidden in parcels.

(iv) X-rays can be used to detect the fractured bones.

(v) X-rays can detect the defects in the structure of steel.

(vi) X-rays can be used to diagnose various diseases.

(vii) X-rays can effect the photographic film.

Uncertainty Within The Atom

Question: Can an electron exist inside nucleus?

The characteristic of dual nature of matter is a fundamental limitation in the accuracy of the simultaneous measurement of the position and momentum of a particle.

HEISENBERG showed this fact and is given by the equation

$$\Delta P \, \Delta x \geq \frac{h}{2\pi}$$

However, the uncertainty is more significant with in the atom. One interesting question is whether electrons are present in atomic nuclei can be tested by using above relation.

As the radius of typical nuclei are less than 10^{-14} m. For an electron which exist inside such a nucleus, the maximum uncertainty in its position is of the order of 10^{-14} m i-e;

$$\Delta x = 10^{-14}\,m$$

So, the corresponding uncertainty in the momentum of electron is

$$\Delta P \Delta x \geq \frac{h}{2\pi}$$

$$\Rightarrow \quad \Delta P \geq \frac{h}{2\pi \Delta x}$$

$$\Rightarrow \quad \Delta P \geq \frac{6.63 \times 10^{-34}}{2 \times 3.14 \times 10^{-14}} = 1.05 \times 10^{-20}\,Kg.m.s^{-1}$$

As

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

$$\Rightarrow \quad \Delta V = \frac{\Delta P}{m}$$

$$\Rightarrow \quad \Delta V = \frac{1.05 \times 10^{-20}}{9.1 \times 10^{-31}}$$

$$\Rightarrow \quad \boxed{\Delta V = 1.15 \times 10^{10}\,m.s^{-1}}$$

or

$$\boxed{\Delta V \geq 1.15 \times 10^{10}\,m.s^{-1}}$$

Hence, for an electron to be exist inside a nucleus, its speed must be greater than $10^{10}\,m.s^{-1}$ that is greater than the speed of light. Because this is impossible as no material particle can move with the speed of light. Thus we must conclude that an electron can never be found inside a nucleus.

QUESTION: Can an electron exist inside the atom?

The existance of an electron within an atom can be tested by using Heisenberg's relation

$$\Delta P \Delta x \geq \frac{h}{2\pi}$$

or $$\Delta P \geq \frac{h}{2\pi \Delta x}$$

As the radius of hydrogen atom is about $5\times10^{-11}m$, so the maximum uncertainty of position of electron to be exist within the atom is

$$\Delta x = 5\times10^{-11}m$$

Applying Heisenberg's uncertainty principle to the momentum of electron in the atom, we have

$$\Delta P \geq \frac{h}{2\pi \Delta x}$$

Where

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

$$\Rightarrow \quad \Delta V = \frac{\Delta P}{m}$$

$$\Rightarrow \quad \Delta V = \frac{h}{2\pi m\Delta x} \quad \left(\because \Delta P \geq \frac{h}{2\pi \Delta x}\right)$$

$$\Rightarrow \quad \Delta V = \frac{6.63\times10^{-34}}{2\times3.14\times9.1\times10^{-31}\times5\times10^{-11}}$$

$$\Rightarrow \quad \boxed{\Delta V = 1.10\times10^{7}\ m.s^{-1}.}$$

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

LASER

Laser is the abbriviation for LIGHT AMPLIFICATION by STIMULATED EMISSION of RADIATION.

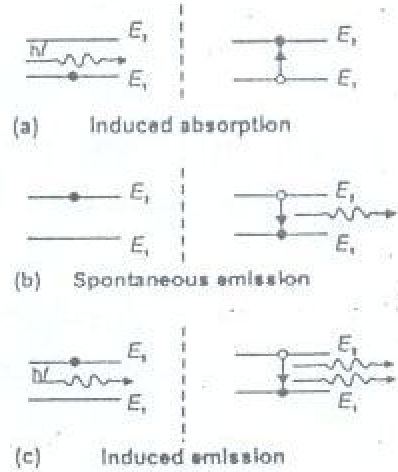
Laser is a device for producing an intense, monochromatic and unidirectional coherent beam of visible light.

PRINCIPLE OF LASER

The working principle of Laser depends upon the stimulated emission of radiations.

SPONTANEOUS AND STIMULATED EMISSION

Consider a sample of free atoms some of which are in the ground state with energy E_1 and some in the excited state E_2 as shown in the figure. Let the photons of energy $hf = E_2 - E_1$ are incident on this sample. These photons can interact with atoms in two different ways.



(a) Induced absorption

(b) Spontaneous emission

(c) Induced emission

In figure (a), the incident photon is absorbed by an atom in the ground state E_1. As a result, atom is raised in the excited state. <u>This process is called Stimulated or Induced Absorption.</u>

Once the atom is in the excited state, two things can happen to the atom.

(i) It may decay by spontaneous emission as shown in figure (b) in which the atom emits a photon of energy $hf = E_2 - E_1$ in any arbitrary direction.

(ii) The other way for the atom in the excited state is to decay by Stimulated or Induced Emission. as shown in figure (c).

<u>Stimulated emission may be defined as</u>

<u>"A process of speeding up atomic transitions to lower levels."</u>

In this case, the incident photon of energy $hf = E_2 - E_1$ induces the atom to decay by emitting a photon that travels in the direction of the incident photon. For each incident photon we will have two photons going in the same direction. In this way an amplified and unidirectional coherent beam will be produced. This is only possible if there is more stimulated or induced emission than spontaneous emission.

LASER Action or Operation

Laser operation depends upon the existance of two factors in the atoms of a material.

(i) Metastable States

(ii) Population Inversion

Metastable States

An excited state in which an excited electron stay longer than usual is called a metastable state.

In ordinary excited states, the excited electrons or excited atoms can stay for 10^{-8} s only. In such excited states, Laser operation does not build up because atoms de-excited spontaneously and stimulated emission can not take place. Those excited states in which excited electrons can stay much longer about 10^{-3} s or more so that the stimulated emission can take place and Laser action can build up, are called metastable states.

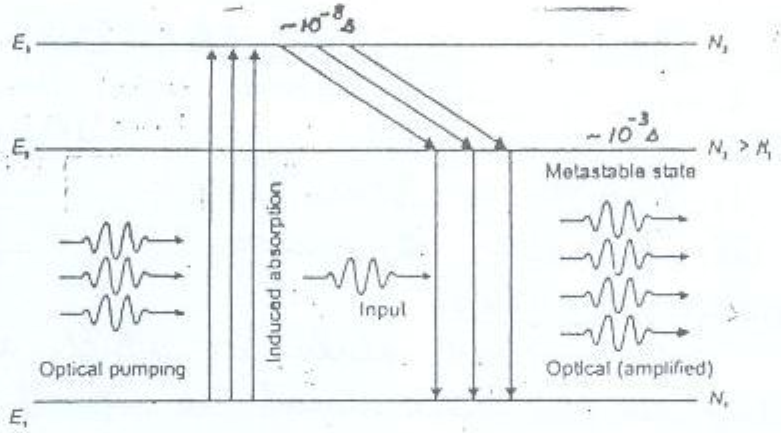
Population Inversion

That situation in which there are more atoms in the excited state than in the ground state is called population inversion.

This situation is necessary for Laser action. In this condition, the incident photon has more chances to be absorbed by the excited atom than the ground state atom, so that stimulated emission can take place rather spontaneous emission.

Explanation

Consider a simple case of a material in which atoms can stay in three different energy states as shown in figure. The energy state E_1 is the ground state, E_3 is the excited state in which the atoms can stay only for 10^{-8} s and E_2 is the metastable state in which atoms can stay for about 10^{-3} s which is much longer

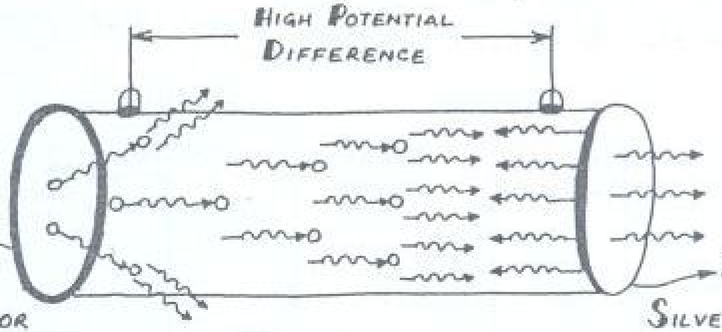


than 10^{-8} s. The transitions from or to the metastable state only after relatively longer time and are difficult as compared to the other excited states. Hence, instead of direct excitation to this state, the electrons are excited to higher levels for spontaneous fall to metastable state.

Consider that the incident photons of energy $hf = E_3 - E_1$ raise the atoms from the ground state E_1 to the excited state E_3 but the excited atoms do not decay back to E_1. The atoms decay spontaneously from state E_3 to state E_2. These atoms reach state E_2 much faster than they leave state E_2. So, there are more atoms in state E_2 than state E_1. This situation is known as population inversion. Once the population has been reached, the Laser action is simple to achieve.

Now the atoms in the metastable state E_2 are bombarded by photons of energy $hf = E_2 - E_1$, resulting in an induced emission or stimulated emission, giving an intense, coherent beam of light in the direction of the incident photon.

The emitted photons 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 of the assembly is made totally reflecting and the other end is partially transparent to allow the Laser beam to escape as shown in figure below.



As the photons move back and forth between the reflecting mirrors, they continue to stimulate other excited atoms to emit photons. As the process continues, the number of photons will be emitted and the resulting radiation is much more intense and coherent than the light from ordinary sources. Such intense and coherent beam of light produced by stimulated emission is called **LASER**.

TYPES OF LASER

Lasers are of three types

(i) Solid Lasers
(ii) Liquid Lasers
(iii) Gas Lasers

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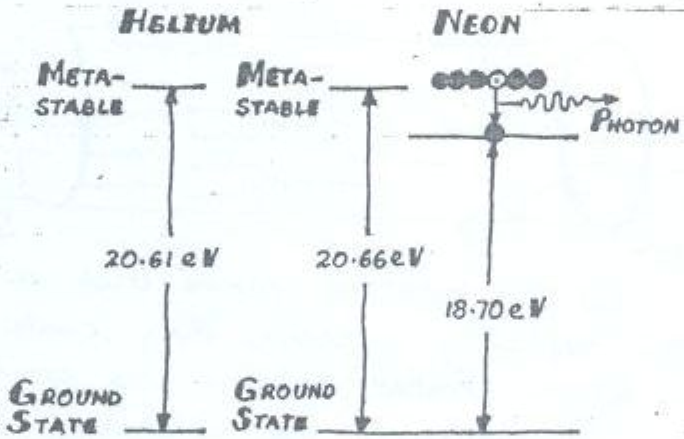
HELIUM - NEON LASER

It is a most common type of gas Lasers used in physics laboratories.

The discharge tube of He - Ne Laser is filled with 85% of helium gas and 15% of neon gas. By chance, He and Ne have nearly equal meta-stable states located at 20.61 eV and 20.66 eV level respectively. The high voltage electric discharge excites the electrons in some of the He atoms to 20.61 eV state. In this Laser, population inversion in Ne atoms is achieved by direct collisions with same energy electrons of He atoms.

Thus excited He atoms collide with Ne atoms and each He atom transferring its own 20.61 eV energy to an electron in the Ne atom along with 0.05 eV K.E. from the moving atom.



As a result, the electrons in Ne atoms are raised to the 20.66 eV state. In this way, a population inversion is set up in the Ne gas relative to an energy level of 18.70 eV. Spontaneous emission from Ne atoms start Laser action and stimulated emission causes electrons in the Ne 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 generated as shown in figure.

USES OF LASER IN MEDICINE AND INDUSTRY

1. Laser beams are used as surgical tool for welding detached retinas.
2. The narrow intense beam of Laser can be used to destroy tissues in a localized area.
3. Finely focused beam of Laser has been used to destroy cancereous cell.
4. The heat of Laser seals off capillaries and lymph vessels to prevent spread of the disease.

5. Lasers are used to break kidney stone.
6. Lasers are used to cut and weld steel and drill tiny holes in hard materials.
7. Laser beam is useful to surveyors for lining up equipment especially in inaccessible locations.
8. Laser is potential energy source for inducing fusion reactions.
9. Lasers can be used for telecommunication along optical fibres.
10. Lasers can be used to produce three dimensional images of objects in a process, called "HOLOGRAPHY".

QUESTIONS

20.1. *Bohr's theory of hydrogen atom is based upon several assumptions. Do any of these assumptions contradict classical Physics?*

Ans. The continuously revolving electron, in one orbit do not radiate / absorb energy, this assumption is against classical Physics. Also electron can have distinct energy values is the assumption which also contradicts the classical Physics.

20.2. *What is meant by a line spectrum? Explain, how line spectrum can be used for the identification of elements?*

Ans., The light beam coming from a thin rectangular slit when dispersed to get spectrum gives image of the thin rectangular slit (of small width) in different colours on the screen. These appear as separate coloured lines, such a spectrum is called line spectrum.

Different elements emit line spectrum of different set of wavelengths. This makes us easy to identify the elements.

20.3. *Can the electron in the ground state of hydrogen absorb a photon of energy 13.6 eV and greater than 13.6 eV?*

Ans. The energy greater than 13.6 eV cannot be absorbed by electron in ground state of hydrogen atom because this not suits to excite it higher state than ionization.

20.4. *How can the spectrum of hydrogen contain so many lines when hydrogen contains one electron.*

Ans. Hydrogen atom has only one electron but there are infinit number of energy states. The transition of electron between every two of these states give new wavelength. So a large number of different energy transitions are possible therefore, a large number of different wavelengths are possible to be emitted.

20.5. *Is energy conserved when an atom emits a photon of light?*

Ans. The law of conservation of energy is satisfied when a photon of radiation is emitted from an atom. Because the energy absorbed by atom during its excitation is exactly equal to energy emitted during its de excitation.

20.6. *Explain why a glowing gas gives only certain wavelength of light and why that gas is capable of absorbing the same wavelengths? Give a reason why it is transparent to other wavelengths?*

Ans. The atoms of glowing gas emit the wavelengths of radiations which lie in its spectrum. The same wavelength it can absorb because these are suitable for excitation pass through the gas because the corresponding energy is not acceptable by the gas to excite the gas atoms.

20.7. *What do we mean when we say that the atom is excited?*

Ans. When any one or more electrons in an atom are as not in their allotted orbits but these may have gone to higher levels by absorbing energy from outside the atom. Then atom is said to be in excited state.

20.8. *Can X-rays be reflected, refracted, diffracted and polarized just like any other waves? Explain.*

Ans. X-rays are similar in nature to ordinary light, so it can be reflected, refracted, diffracted and polarized.

20.9. *What are the advantages of lasers over ordinary light?*

Ans. The laser light is intense and coherent, so it does not spread while passing through a medium, its energy can be focussed at a point to get enough energy for welding, cutting, and as surgical tool; which ordinary light can not do.

20.10. *Explain why laser action could not occur without population inversion between atomic levels?*

Ans. When a large percentage of atoms of a sample are in population inversion, then large number of coherent photons along same direction of motion could be obtained to form laser light. It is impossible without population inversion situation.