Notes For Bachelor of Science (TU)

BSC NOTES PDF COLLECTION

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MODERN PHYSICS [50 hours]

Course Contents:

9. **Atomic Structure: 9.1** The nuclear atom, 9.2 Rutherford scattering and its conclusions, 9.3 limitations of Rutherford model of atom, electron orbits, 9.4 atomic spectra, 9.5 the Bohr's atom, energy level diagram and spectra of hydrogen atom, 9.6 Frank-Hertz experiment and limitations of Bohr's model, 9.7 the Sommerfeld atom [8 hours]
10. **Many Electron Atom: 10.1** Electron spin, 10.2 Stern-Gerlach experiment, 10.3 Pauli's exclusion principle, 10.4 shells and subshells of electrons, 10.5 vector atom model, 10.6 LS coupling and s, p, d, f notation [5 hours]
11. **Atomic Spectra: 11.1** Fine structures of H, Na, He and Hg, 11.2 Paschen-Back effect, 11.3 Stark effect, 11.4 normal and 11.5 anomalous Zeeman effect [7 hours]
12. **Particle properties of waves: 12.1** Electromagnetic waves and its interaction with matter, 12.2 absorption, 12.3 photoelectric effect, 12.4 Compton scattering, 12.5 pair production, 12.6 photons and gravity [6 hours]
13. **X-ray Spectrum: 13.1** Characteristic X-ray, 13.2 X-ray diffraction and spectrometer, 13.3 fine structure of X-ray transitions, 13.4 Moseley's law and its application [4 hours]
14. **Nuclear Structure: 14.1** Proton-electron and proton-neutron hypothesis, 14.2 nuclear composition and its properties (mass, charge, density, magnetic and electric properties), 14.3 nuclear stability and binding energy, 14.4 Meson theory of nuclear forces [6 hours]
15. **Nuclear Transformations: 15.1** Radioactivity, law of radioactive disintegration, 15.2 law of successive disintegration, 15.3 half-life, mean life, natural radioactive series, 15.4 alpha, beta and gamma ray spectra, 15.5 absorption of α particles, range, 15.6 straggling and stopping power, 15.7 theory of α decay, 15.8 neutrino hypothesis of β-decay, 15.9 biological effects of ionizing radiation [7 hours]
16. **Particle Detectors and Accelerators: 16.1** Ionization chamber, 16.2 G. M. counter, 16.3 scintillation counter, 16.4 bubble chamber, 16.5 Cerenkov detectors, 16.6 semiconductor detectors, 16.7 linear accelerator, 16.8 cyclotron, 16.9 synchrocyclotron, 16.10 betatron, the 16.11 LHC project [7 hours]

(v) The integral of $I(\nu)$ overall ν is called I_T, represents the energy emitted per unit time per unit area, regardless of the frequency and it is found to increase with the fourth power of the temperature. This emprical fact is known as the Stefan Boltzmann law, i.e

$$I_T = \int_0^{\infty} I(\nu)\,d\nu = \sigma T^4$$ where, the

Stefan's constant $\sigma = 5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$.

Bohr's Atomic model :→ A model of the Hydrogen atom was proposed by Bohr in 1911. He assumed basically Rutherford nuclear model of the atom and tried to overcome the defects of his model. He proposed the following two postulates.

(I) An electron can not revolve round the nucleus in all possible orbits as suggested by the classical theory. The electron can revolve round the nucleus only in those allowed or permissible orbits for which the angular momentum of the electron is an integral multiple of $h/2\pi$. where h is planck's constant $= 6.64 \times 10^{-34}$ Js. These orbits are called stationary orbits and an electron revolving in these orbits doesnot radiate energy.

For an electron of mass m and v is the velocity of the electron in an orbit of radius r, then angular momentum $L = mvr$

$$L = mvr = mr\omega r = mr^2\omega =$$

$$\frac{nh}{2\pi} = mr^2\omega,$$ where, n is an integer and can take values $n = 1, 2, 3 \ldots\ldots$ which is calle principle quantum number. This eq^n is called Bohr's quantization condition.

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(II) An atom radiates energy only when an electron jumps from a stationary orbit of higher energy to one of lower energy. If the electrons ~~jumps from~~ jumps from an initial orbit of energy E_i (E_i) to a final orbit of energy E_f ($E_i > E_f$), a photon of frequency $\nu = \frac{E_i - E_f}{h}$ is emitted.

Bohr's Theory of Hydrogen atom:->

Based on the above (2) postulates, Bohr derived the formula for the radii of the stationary orbits and the total energy of the electron in the orbit.

Let us consider an atom (Hydrogen, $Z=1$), whose nucleus has a positive charge Ze and mass M) ~~as shown in fig 1.~~ ~~let~~ an electron of charge $(-e)$ and mass m move round the nucleus in an orbit of radius r. Since $M >> m$, the nucleus is stationary. as shown in fig 1.

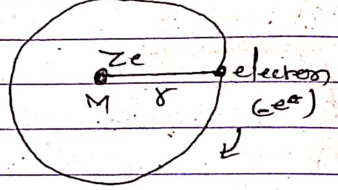


Fig 1.

The electrostatic force of attraction between the nucleus and the electron $= \frac{1}{4\pi\epsilon_0}(Ze)(-e) = \frac{-1}{4\pi\epsilon_0}\frac{Ze^2}{r^2}$ —(1)

The centrifugal force on the electron $= \frac{mv^2}{r}$ —(2)

The system will be stable if $\frac{mv^2}{r} = \frac{1}{4\pi\epsilon_0}\frac{Ze^2}{r^2}$ —(3)

According to Bohr's first postulate, $mvr = \frac{nh}{2\pi}$ or $v = \frac{nh}{2\pi r m}$

$$v^2 = \frac{n^2h^2}{4\pi^2 r^2 m^2}$$

Substituting this value of v^2 in eq^n ~~(2)~~ eq^n $v^2 = v^2$

$$\frac{m}{r}\left(\frac{n^2h^2}{4\pi^2 r^2 m^2}\right) = \frac{1}{4\pi\epsilon_0}\frac{Ze^2}{r^2}$$

$$r = \frac{n^2h^2\epsilon_0}{Ze^2\pi m}$$

The Radius of the n^{th} permissible orbit of hydrogen $r_n = \frac{n^2h^2\epsilon_0}{e^2\pi m}$ ($\because Z=1$) which shows that $r_n \propto n^2$.

Similary $r_2 = 2^2 r_1$
And $r_n = n^2 r_1$.

The radius of the first orbit for hydrogen atom $= r_1 = \frac{1^2 \times (6.625\times10^{-34})^2 \times (8.854\times10^{-12})}{\pi(1.6\times10^{-19})^2 \times (9.11\times10^{-31})}$ m

(2) $r_1 = 0.05$ nm (Bohr radius).

Velocity of the electron :-

from the Bohr's first postulate $v = \frac{nh}{2\pi rm}$

For the velocity of the electron in the n^{th} orbit is V_n ; $V_n = \frac{nh}{2\pi m r_n}$

putting the value of r_n then we get

$$V_n = \left(\frac{e^2}{2\varepsilon_0 nh}\right) \quad \therefore V_n \propto \frac{1}{n}$$

Which proves that, the electrons closer to the nucleus move with higher velocity than those lying far away.

Calculation of total energy :-

The total energy of the electron in any orbit is the sum of its kinetic and potential energies. The potential energy of the electron is considered to be zero when it is at an infinite distance from the nucleus. P.E of an electron is given by the work done in bringing the electrons from infinity to that orbit. This amount of work is obtained by integrating the electrostatic force of attraction between the nucleus and the electron from the limits $-\infty$ to r.

$$\text{P.E of the electron} = \int_{\infty}^{r} \frac{Ze^2}{4\pi\varepsilon_0 r^2}\,dr = \frac{-Ze^2}{4\pi\varepsilon_0 r}$$

$$\text{K.E of the electron} = \frac{1}{2}mv^2 = \frac{Ze^2}{8\pi\varepsilon_0 r} \qquad \boxed{mV^2 = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r}}$$

Total energy of the electron in the n^{th} orbit, $E_n = P.E + K.E$

$$= \frac{-Ze^2}{4\pi\varepsilon_0 r} + \frac{Ze^2}{8\pi\varepsilon_0 r} = \frac{-Ze^2}{8\pi\varepsilon_0 r}$$

substituting the value of r

$$E_n = \frac{-me^4 Z^2}{8\varepsilon_0^2 n^2 h^2}.$$ As the value of n increases, E_n increases.

Hence, the outer orbit have greater energies than the inner orbits.

Bohr's interepretation of the Hydrogen spectrum:->

If an electron jumps from an outer initial orbit n_2 of higher energy to an inner orbit n_1 of lower energy, the frequency of the radiation emitted is given by

$$\nu = (E_{n_2} - E_{n_1})/h.$$

or $$\nu = \cancel{\frac{E_{n_2} - E_{n_1}}{}} \frac{-me^4}{8\epsilon_0^2 h^2}\frac{1}{n_2^2} - \left(\frac{-me^4}{8\epsilon_0^2 h^2}\cdot\frac{1}{n_1^2}\right)$$

$$= \frac{me^4}{8\epsilon_0^2 h^3}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

The wave number $\bar{\nu}$ of a radiation is defined as the reciprocal of its wavelength, in the vaccum gives the number of waves contained in unit length in vaccum.

$$\bar{\nu} = 1/\lambda = \nu/c$$

$$\bar{\nu} = \frac{me^4}{8\epsilon_0^2 c h^3}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right) = R\left\{\frac{1}{n_1^2} - \frac{1}{n_2^2}\right\}$$

Where, $\frac{me^4}{8\epsilon_0^2 c h^3} = R$ and is known as Rydberg constant.

Spectral series of hydrogen atom:-

① Lyman Series :- When an electron jumps from second, third, ... etc orbits to the first orbit, we get the Lyman series which lies in the ultraviolet region.

Here, $n_1 = 1$ and $n_2 = 2, 3, 4, 5 \ldots$

$$\bar{\nu} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right); \quad n = 2, 3, 4, 5 \ldots$$

② Balmer Series :- When an electron jumps from outer orbits to the second orbit, $n_1 = 2$ and $n_2 = 3, 4, 5, \ldots$ etc

$$\bar{\nu} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$ This series is called Balmer series and lies in the visible region of the spectrum. The first line in the series ($n=3$) is called the H_α line, the second ($n=4$) the H_β line and so on.

(3) Paschen series :→ Paschen series in the infrared region are given by $n_1 = 3$ and $n_2 = 4, 5, 6, \ldots$ etc.

The number of wave. $\bar{\nu} = R\left(\frac{1}{3^2} - \frac{1}{n^2}\right)$; $n = 4, 5, 6 \ldots$ etc

(4) Bracket series :→

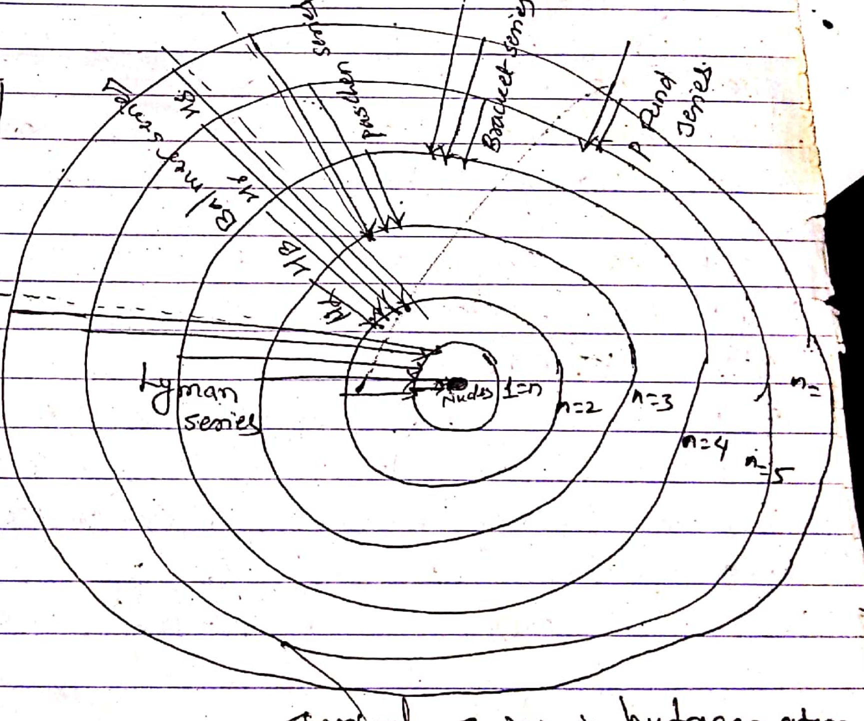
If $n_1 = 4$, and $n_2 = 6, 7, 8, \ldots$ we get ~~pfund~~ Bracket series lie in the very far infrared region of the hydrogen spectrum. ~~infrared~~

Wave number is $\bar{\nu} = R\left(\frac{1}{4^2} - \frac{1}{n^2}\right)$; $n = 5, 6, 7, \ldots$

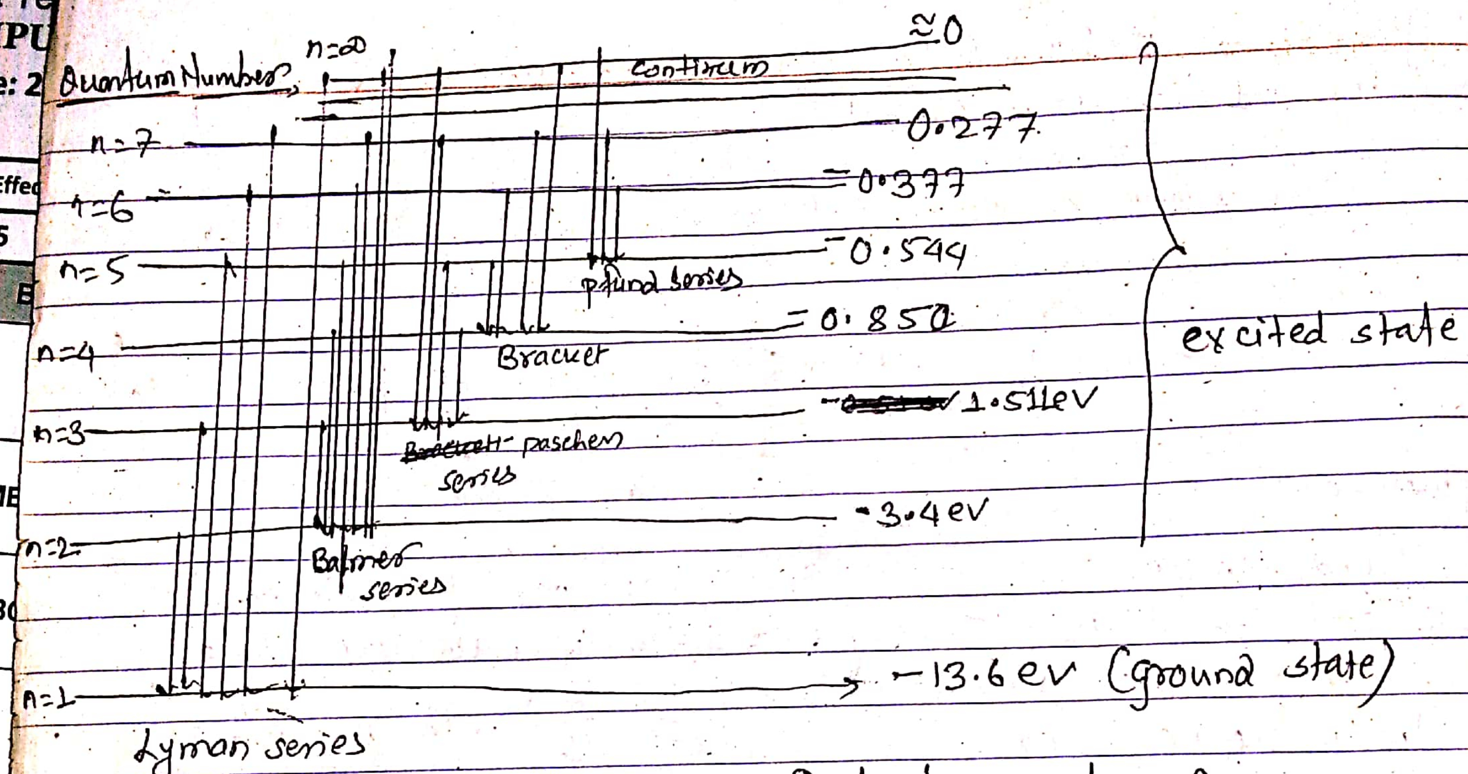
(5) Pfund series :→ When an electron jumps from outer orbits to the fifth inner orbits i.e if $n_1 = 5$ and $n_2 = 6, 7, 8, \ldots$ We get pfund series having wave numer $\bar{\nu} = R\left(\frac{1}{5^2} - \frac{1}{n^2}\right)$; where $n_2 = 6, 7, 8 \ldots$ lie in the very far infrared region.

Atomic Energy level diagram:-

The horizontal lines represent the energy levels of the different orbit of the Hydrogen atom. The transition of electron from one state to another state is indicated by vertical lines with arrows. The ground state has the least energy. As the principle Quantum number 'n' increases energy become less negative (i.e the energy increased). When 'n' approaches infinity, the energy approaches zero. so zero level is the maximum energy state. For large value of 'n' the energy levels are so close that they constitute as energy continum.



Spectral series in hydrogen atom.



atomic Energy level diagram of Hydrogen atom :

Energy spectra → [illegible] continuous [illegible]

Limitation of Bohr's Theory :- These are some limitations of the Bohr's theory of Hydrogen atom model.

Last ...

① Bohr's theory could explain the spectral lines of Hydrogen could not be explained ~~by Bohr's theory~~ the spectra of multi electron atoms (other than H)

② Bhor's theory does not give explanation why only circular orbits are possible around the nucleus.

③ Bohr's theory does not give explanation about the relative intensities of spectral lines.

④ Bohr's theory does not ~~explain~~ account for the wave nature of electrons

Experimental Determination of Critical Potentials :-

The existence of discrete energy levels in atoms was demonstred directly by Frank and Hertz in 1914. They studied the excitation and ionization of atoms of Mercury, Helium, Neon, etc and found that the atoms of different elements absorb different but definite energies i.e the energy states in atoms are quantized in nature.

A ~~a~~ schematic diagram of the experimental set up is shown in figure 1 ~~below~~. The mercury vapour is filled in a glass tube (T) at a pressure of about 1 mm of mercury. Electrons are produced by heating the filament (F) by a low tension battery (B). These

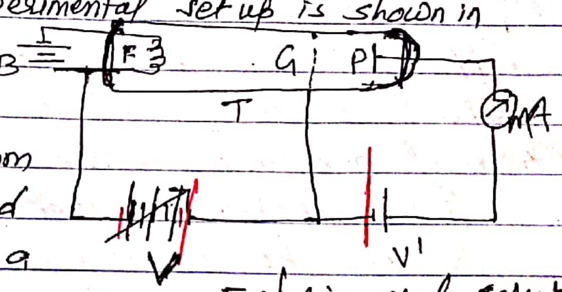
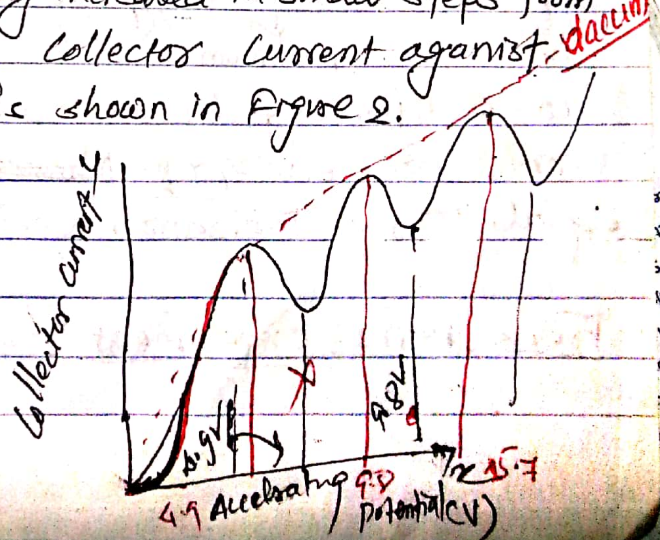


Fig 1 Experimental setup

electrons are accelerated toward a grid G by the potential difference V between F and G. V can be varied between 0 volts and 60 volts by a potentiometer arrangement. P is the collector plate which is kept at a slightly negative potential (V') ~~about~~ ~~0.5V~~ with respect to G. Thus, only those electrons from G can go to P which has kinetic energies greater than this potential difference. The milliammeter A measures the plate current. Keeping V' constant, V is gradually increased in small steps from zero upwards. A plot of the collector current against the accelerating potential V is shown in Figure 2.

Explanation of graph :-



Explanation of graph :-

First-dash line.

There is no collector current for $V < 0.5$ volts. Above this, the collector current increases countinuously. When the accelerating potential reaches a value 4.9 volt, current becomes maximum and then the current suddenly dips to minimum. Again when the p.d is gradually increased above 4.9 volt, the current gradually increases till another maximum is reached when the p.d is just 9.8 volts, then suddenly current again dips steeply to a minimum. So that every 4.9 volts significant decrease in the collector currects occurs. In the absence of any vapour, i.e a vacuum, I-V characteristics are shown by dotted lines.

The facts that there is no drop in current until $V = 4.9$ V indicates that the electrons do not lose energy through collisions until they have 4.9 eV of kinetic energy. When the electron collides with a heavy atom such as mercury there are two possible kinds of collisions: elastic and inelastic. In the case of elastic collision, the total energy of both particles before and after the collision is the same. The requirement that the total energy and momentum be conserved leads to the fact that the kinetic energy of the light particle is hardly changed, its velocity is ~~simply~~ little reversed. They will eventually be able to overcome the small retarding voltage V and contribute to the plate current. No drop in the current will be caused by this kind of collision. In the case of inelastic collisions, the external kinetic energy of the colliding particles becomes internal energy (i.e the Hg atoms absorb energy and are excited). Some of the electrons may lose enough energy to be prevented from reaching the plate by retarding potential V, that is drop in the current should occur for any value of V_0. So that the first excited state of Hg (the smallest amount of energy that the Hg can absorb) is 4.9 eV above the ground state. Similary, $2 \times 4.9 = 9.8$ eV second excited state and so one.

Limitation of Frank-Hertz Experiment:

① Frank and Hertz ~~[illegible]~~ observed the critical potential, but is not able to distinguish between excitation and ionization potentials.

② This method is not suitable for strongly electron negative gases like oxygen and ~~fluorine~~ fluorine because those gases attracts electron strongly

③ The actual value of critical potential is slightly less than the observed value. ~~because the velocity of collision is not zero~~