Development of Quantum Mechanics and failure of Classical mechanics:

The laws of Newtonian mechanics explained successfully the motion of cellestial bodies and other earthly objects. These laws along with the laws of thermodynamics and classical electrodynamics explained successfully the physical behaviour and bulk properties of matter. However, when the same laws were applied to the particles such as electrons, protons, neutrons, nucleus, etc. which are too small to be seen through the highest powered microscopes, serious difficulties were encountered. It means that the classical concepts are not valid in the region of atomic dimensions.

In microscopic world of atoms and molecules, the energy and moments were not having the same meaning as in the case of classical dynamics. On the other hand, these dynamic variables had a discrete value in a particular state of an atom and did not undergo change in a continuous manner from one state to another as one would be expecting under classical laws. Thus to include the new concepts,

the Newtonian laws of macroscopic world were modified. This incorporation of new concepts gave rise to the birth of a new mechanics called Quantum Mechanics which not only explained successfully many observed facts but also introduced revolution in our way of thinking.

Inadequacy of Classical Mechanics

(1) Stability of the atom

Experiments of Rutherford (1910) had established that an atom consisted of a heavy positively charged nucleus having dimensions very small compared to the atoms itself, surrounded by negatively charged electrons of very little mass. If the classical picture is adopted according to Earnshaw, the system will be stable only if the negatively charged electrons revolving around the positively charged heavy nucleus in a similar manner as the planets are revolving around the sun. But unlike the planets, the energy of the moving electrons should decrease because the accelerated charged particles such as electrons radiate out

energy continuously in the form of electromagnetic waves. Therefore, due to this continuous loss of energy an orbiting electron will come closer and closer to the nucleus and ultimately coalesces. This shows the instability of atom i.e, it is in contradiction to the observed fact of the stability of atoms. Thus the classical mechanics fails to explain the stability of the atom.

2. Spectrum of the hydrogen atom.

The classical mechanics did not explain the spectrum of the hydrogen atom. Experimentally, it was observed that the hydrogen spectrum consists of a discrete set of lines represented by

$$\bar{\nu} = R\left(\frac{1}{n_2^2} - \frac{1}{n_1^2}\right)$$

Where $\bar{\nu}$ is the wave number, R is Rydberg constant, n_1 and n_2 are the integers such that $n_1 > n_2$.

According to the classical theory the excited atoms of hydrogen emit electromagnetic radiation of all wavelengths continuously, while they emit the radiations of a certain wavelength only

This difficulty was latter on resolved by Bohr to some extent.

From the above discussion it is concluded that the classical mechanics does not hold good in the region of atomic dimensions.

Difficulties with classical theories of black-body radiation.

A perfectly black body is defined as one which absorbs all the heat radiations incident on it. Experimentally such a body is represented by a hollow chamber with a very small hole in the wall. When such a chamber is heated it emits heat rays of all types of wavelengths and heat radiation at a uniform temperature is known as black body radiation. In practice perfectly black body is not available. When a black body is heated, it emits radiations of all types of wavelengths according to its oscillating electromagnetic energy (the radiations from a heated body as rapid vibrating particles which is known as oscillators) these oscillators emit radiant energy in the form of electromagnetic

waves. The black body radiation on the basis of classical theories can be explained as follows:-

(i) At a given temperature, the energy is not uniformly distributed in the radiation spectrum of a hot body.

(ii) At a given temperature the intensity of radiations increases with increase in wavelength and at a particular wavelength its value is maximum. With further increase in wavelength, the intensity of heat radiations decreases.

[illegible] temperature λ_m decreases [illegible] wavelength corresponding to [illegible]

[illegible] relation is [illegible] and Rayleigh-[illegible] wavelength region but [illegible] intermediate expression on the basis of the following assumptions :-

(1) A black body radiator contains simple harmonic oscillator of molecular dimensions which can vibrate with all possible frequencies

(iv) The classical principle of equipartition of energy is not applicable to black body oscillators because this assumption would lead to the Rayleigh-Jean's expression. Instead it is assumed that the oscillator of the black body cannot have any amount of energy but has a discrete energy equal to the integral multiple of some minimum energy i.e.

$$E = nh\nu$$

where n is an integer, ν is the frequency of the oscillator and h is the Planck's [illegible]

Quantum theory [illegible] and photon

The quantum concept [illegible] in 1924 [illegible] that radiation [illegible] manner but in discrete packets of energy E having the frequency [illegible] that $E = h\nu$. These bundles or packets of radiant energy are termed as quanta or photons. This states that exchanges of energy between radiation and matter cannot take place continuously but are limited to discrete set of values 0, $h\nu$, $2h\nu$, $3h\nu$ - - - - -

(v)

According to Planck's law it is plausible to assume that same quantum structure is retained by radiation when it is travelling through space. This has made some revision in Newton's corpuscular nature of light or radiation. It is also remembered that photon nature of radiation regards that radiation is still exhibiting a wave phenomenon but its energy contents are given to the atoms in the form of quanta [illegible] the concentrated group of atoms.

[illegible] regarded as a particle [illegible] have to make an attempt [illegible] kinetic of a particle such [illegible] energy statistics etc.

[illegible]

[illegible] depends on multiples of $h\nu$, [illegible] constant and ν its frequency. [illegible] owing to modern ideas that limiting [illegible] energy is $\frac{1}{2}h\nu$ and other energies have been found to differ by an integral multiple of $h\nu$

If a photon undergoes interaction with matter, either it can be completely absorbed.

transferring all its energy or it may transfer part of its energy, and its frequency is adjusted to a lower value, thereby, maintaining its particle character. Hence energy is only dependent on the intrinsic property of the photons. Thus, the energy of the photon is independent on its intensity, depending only on its frequency.

(ii) Constant 'h' of photon :-

It denotes an elementary quantum or quantity of action. It is this constant which responsible for the discrete individuality of the photon which makes radiation behave like a particle. The dimension of h can be calculated as follows:

$$h = \frac{[\text{Energy}]}{[\text{Frequency}]} = \frac{[ML^2T^{-2}]}{[T^{-1}]}$$

$$= [ML^2T^{-1}]$$

$$= \text{Angular momentum}$$

Thus 'h' is defined as the smallest quantum of angular momentum of a particle.

As momentum is always associated with motion it means that h always represents motion. It was Bohr who ~~for the~~ first time assumed that electrons of an atom could revolve round in such orbits whose angular momentum is an integral multiple of $\frac{h}{2\pi}$.

(iii) Mass and momentum of photon :-

As photons have energy and are in motion with velocity c, a mass can be ascribed to them in accordance to the theory of relativity.

$$\text{Mass} = \frac{h\nu}{c^2}$$

It is having a momentum, compatible with its motion i.e

$$\text{Momentum} = \text{mass} \times \text{velocity}$$

$$= \frac{h\nu}{c^2} \times c = \frac{h\nu}{c} = \frac{h}{\lambda}$$

$$\text{Energy} = h\nu$$

$$= mc^2 = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}} c^2$$

or $$m_0 = \sqrt{1-\frac{v^2}{c^2}} \cdot \frac{h\nu}{c^2} \longrightarrow (1)$$

For photon, $v = c$ $\therefore$ $m_0 = 0$

[Energy of photon, $E = h\nu$, Rest mass of photon, $m_0 = 0$
Mass of photon, $m = h\nu/c^2$, Momentum of photon, $p = h/\lambda$]

As the photon always travels with the velocity of light c while its energy content $h\nu$ is always finite, it means that the rest mass m_0 of the photon approaches zero in such a way that as v approaches c its energy always approaches the value $h\nu$. Thus photon is not a particle in complete sense because a material particle must have a rest mass. Hence photon is always having a wave-structure, sometimes behaving in compact form like a wave

(iv) Non-electrical nature of photons

The photons constituting radiations are electrically neutral. They are not affected by electric or magnetic fields and also they do not increase ionicity by themselves. However, they can eject charged particles from matter when they impinge on atoms

(v) Photon statistics: It is possible to understand the different properties of radiation, which is made up of photons, by applying the laws of statistics to a large assembly of photons as is done in the kinetic theory of gases. However, there is an important difference between an ordinary

gas and the photon gas. The molecules of a gas move about with different velocities and different energies while the photons all travel with the same velocity c, though with different energies, $h\nu$.

Kinetic theory of gas is a statistical approach and in a similar manner, Bose and Einstein developed statistics of photons. The density and temperature of a gas are statistical concepts and in a similar manner, intensity and temperature of radiation are statistical concepts.

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Photoelectric Effect :-

Introduction :-

In 1887, Hertz conducted a series of experiment on production of electromagnetic waves by oscillating charges. The oscillations were initiated by a spark jumping across a gap between metal electrodes which were connected to a circuit containing inductance and capacitance. However, in course of his experiments, Hertz made the accidental discovery that the detector gap length could be increased without preventing a