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Chapter -1

Introduction to classical Theory

& Quantum theory

In India teacher of Upanishadic time explain through meditation,realization visualized the entire universe as one,interconnected,and interpenetrated by the ultimate reality which they called Brahma. The world starting from atom to the uniuverse is nothing but manifestation of that eternal reality. Scientists visualized the universe as material universe only and tried to find out the laws and truth behind the process occurring in this material world. Galileos discovery, Newtons classical mechanics,Keplers law of planetory motion, Mandeleefs periodic table, Faradays discovery of electromagnetism, Maxwells work on electricity,establishement of the kinetic theory of gas, thermodynamics, Boltzmanns work on statistical thermodynamics established the sense of confidence of exact science so deeply that no one finds it necessary to question "what is the reality behind matter"?

Classical Machanics is a branch of classical science whose basic concepts are:

(i) Continuous variation of physical quantities.
(ii) The principal of classical determinism
(iii) The analytical methods of studying objects and phenomenon.

Science it deals with motion, and macro-particles are not always in motion, it cannot be the whole of classical physics. In terms of classical mechanics the macro world surrounding us consisits of matter characterised by mass, position,momentum and energy. Position and momentum are simultaneously knowable. By the end of the nineteenth century,the atomic theory was deep rooted in the minds of people.Energy can be carried out due to motion of the particles as well as wave motion.

Great discoveries in electromagnetism by Maxwell equations that rotating charge radiates energy and hence may generate light.P.Hertz proved this conclusively in 1887.

Some experimental discovery which could not be explained by classical physics are

1. Black body radiation (by Lummer and Pringsheim in 1893-1897).
2. Photo electric effect(Studied by Hallwachs in Hertzs laboratory in 1887).
3. Compton effect (Discoveredin 1992 by A.H.Compton).
4. Specific heat of solids(Temperature studied by Nerst and Co-workers)
5. Spectra of hydrogen atom(Studied by Lyman, Balmer,Ritz in 1908).

Classical mechanics provides us a material model of the nature while quaantum mechanics provides a more accurate mathematical model of nature. These two are complementary to each other.

Black body and blackbody radiation:-

When radiant energy falls on the surface of body, a part of it is reflected, a part is absorbed and rest is transmitted.The total energy is not absorbed because the surface of ordinary bodies are not perfect absoebers of radiation. If the radiant energy is allowed to fall on the blackened metallic surface or carbon black, it is found that energy is almost completely absorbed that is called perfectly black body. The absorption is found to be more perfect if we take hollow sphere blackened on the inside and having a hole for the entry of the radiation. This is beacuse any radiation that enters through the hole is reflected over again and again by the wall of the sphere till finally it is completely absorbed. Black body is a perfect absorber as well as perfect radiator which radiates the maximum amount of energy for a given temperature.

Kirchhoffs law:-The relation between the energy absorbed and the energy emmited by a body may be calculated qualitatively. Take two ball blacl ball(B) and white ball (W) are suspended are suspended with the help of insulating thread. As the balls can also absorb as well as emit radiation, it is found that the balls also acquire the temperature of the enclosure which remains constant so long as the temperature of the enclosure which remains constant so long as the temperature of the enclosure remain constant. This shows that a good absorber is a good radiator while a poor absorber is a poor radiator. Kirchhofs law state that" At any temperature, the ratio of the emissive power of a body to the absorptive power is constant of the nature of the surface and is equal to the emissive power of a perfectly black body.

E_s= Emissive power (Energy emitted by the surface per unit time per unit area)

A_s= Absorptive power of the substance per unit area per unit time.

According to Kirchhoffs law

$E_s/A_s=E_B$

Let suppose Q is the amount of radiation incident per unit area per second on a body. If A_s is the absorbing power Then the radiation absorbed by the body per unit time per second=A_S X Q.

Amount of radiation emmited per unit area per second = Amount of radiation absorbed by the body per unit area per second.

Thus $E_S=A_S \times Q$

For perfectly black body, $A_S=A_B=1$ and E_S may be replaced by E_B where A_B and E_B represent the adsorptive power and the emissive power of a perfectly black body.

$E_B=Q$

or$E_s= A_S \times E_B$

$E_s/A_S=E_B$ where is E_B is constant represent the Kirchhoffs law.

Black Body Radiation

With increase in temperature the energy radiated per unit area per unit time from any surface increases rapidly and simultaneously. On the basis of Stefan in 1879 showed that the total amount of energy E radiated by the perfectly black body per unit area per unit time is directly proportional to the fourth power of its absolute temperature T.

$E \alpha T^4$

$E = \sigma T^4$ where σ is called Stefans constant, its value is 5.6697×10^{-5}

Energy emitted by a black body at any temperature does not consist of a single frequency and is also not uniformly distributed along the spectrum. The black body radiationwere obtained by heating a carbon tube electrically.The radiant energy may be analysed by passing it through a prism and breaking it up into radiations of various wavelengths. The energy associated with different wave lengths can be measured. Lummer and Pringsheim in 1899 studied experimentally the spectral distribution of energy of black body radiation amongst different wavelengths at different temperatures. Graphs are plotted between the monochromatic emittance$E_{□}V_s$□ for each temperature.

Observations:- (a)At a particular temperature the distribution of energy is not uniform among various wavelengths of the radiation emitted by the Black body.

(b)For each temperature there is a wave length at which the energy radiated is maximum.

(c)With increase in temperature the maximum shifts higher but towards lower wave lengths. It shows at higher temperature Energy increases but wave length decreases.

(d) The area of the graph for a particular temperature gives the total energy emitted by the black body per unit area per second. The area of the curve increases with increase in temperature and it is found the area is proportional to the fourth power of the absolute temperature.

(e) □mT=Constant. (Which is called Wiens displacement law.) This law is able explain why the colour of visible light radiation changes from red to yellow as the temperature of the hot body is increased. According Rayleigh-Jeans radiation law on the basis of classical mechanics

$E_{□} = 8\pi hc/□^4 \times e^{-hc}/kT□$

Where $E_{□}$= is the emissive power of the black body corresponding to wavelength □,c is the velocity of light, h is the planks constant,K is the Boltzmann constant, T is absolute temperature.

Planks Radiation law

Energy is emitted or absorbed not continuously, but discontinuously in the form of packets of energy called quanta. The energy of each quantum is given by the relation,E =h√, where √ is the frequency of radiation and h is called planks constant.Thus the total energy emitted or absorbed is either unit quantum i.e. h√ is a whole number or multiple of n.

Iso thermal method is used by Lummer and Pringsheim. From the isothemal curves about the distribution of energy in the black body radiation,$\square_m$ corresponding to maximum emission of energy are noted. Substituting these values constants are calculated. This varifies the Planks distribution law equation.

Photoelectric Effect:-

When a beam of light with frequency equal to or greater than a particular value called threshold frequency is allowed to strike the surface of a metal, electrons are ejected instantaneously from the surface of metal. This effect is called photoelectric effect.

If the kinetic energy of the electrons is plotted against the friquency of the incident light a graph of straight is obtained.

Graphs:-

K.E = $h(\surd - \surd_0)$, Where $\surd_0$ is the minimum frequency below which no electrons are emitted and h is planks constant. This photoelectric effect was completely explained by Einstein by the hypothesis. If the energy of the less than threshold energy ejected electron from metal surface is not possible. kinetic energy of the ejected electron is directly proportional to the energy of incident radiation. The intensity of light determines only the number of electrons emitted from the metal surface.

(i) The electrons are ejected only if the frequency of the incident light is equal to or greater than a minimum value, called threshold frequency.

(ii) The electrons are ejected instantaneously that means there is no time interval between hitting of metal surface by the light and emission of electrons.

(iv) The kinetic energy of the emitted electrons depends upon the frequency of the incident light.

(v) The number of electrons emitted is prpportional to the intensity of the incident light.

According to classical theory ,Energy of light depends on its intensity. Thus if the surface of a metal is exposed continuously to the light of any frequency, the electron should keep on gaining energy and ultimately the energy is so high that electron should leave the metal atom. But actually this does not happen. Einstein explained quatum of light called photon has energy equal to h√ . When photon hit the metal surface, it transfers its energy to the electron. Energy equal to threshold value is used up for bringing about ionisation and the remaining energy is converted into the kinetic energy of the electron.

$$h\surd = h\surd_0 + \frac{1}{2} mv^2$$

If the frequency of the incident light is equal to the threshold value, electron will be emitted without any Kinetic energy. Intensity of light means the number of photons hitting the metal surface per unit time. Thus increase in intensity increases the number of electrons emitted but will have no effect on their kinetic energy.

Heat Capacity of Solids

According to classical physics the heat capacity of all monoatomic solids should be constant and equal to 3R. However ,experimentally it is found to be true only at high temperature. At low temperature the value is found to be less than 3R and the value approach zero. Einstein explained the variation of heat capacity with temperature again by using Planks theory of quantaisation.

According to classical law of equipartition of energy , each atom in solid has mean vibrational energy=3KT. Thus one mole of monoatomic solid the total vibrational energy will be

$E = N_0(3KT) = 3RT.$

$C_V = (dE/dT)_V = 3R$

Atomic and molecular spectra

In view of the failure of classical mechanics to explain the phenomenon associated with the small particles, Matrix mechanics forwarded to explain these phenomenona by Heisenberg. The other is called wave mechanics forwarded by Schrodinger in 1926. Is is based on De-Broglie dual character of matter.

The branch of science which takes into consideration de-Broglie concept of dual nature of matter and planks quantum theory and is able to explain the phenomena related to small particles is known as quantum mechanics. The basic equation is known as Schrodinger wave equation which can be derived by some basic postulates of quantum mechanics.

Classical mechanics:-

It deals with macroscopic particles. It is based on Newtons laws of motion as well as Maxwells electromagnetic wave theory according to which any amount of energy may be emitted or absorbed continuously. The state of a system is defined by specifying all the forces acting on the particles as well as their positions and velocities. The future state then can be predicted with certainty.

Quantum Mechanics:-It deals with microscopic particles. It takes into account Heisenbergs Uncertainty principle and de-Broglie concept of dual nature matter (particle nature and wave nature). It is based on Planks quantum theory according to which only discreate values of energy are emitted or absorbed. It gives probabilities of finding the particles at various locations in space.

(i)When the velocity of the macroscopic body is much less than the velocity of light, quantum mechanics gives the same results as Newtons classical mechanics.

(ii) When the planks constant approched the limit ($h \to 0$) ,the time independent Schrodinger wave equation reduces to Newtons Second law.

(iii) When the system is in highly excited state(principal quantum number is very high) both mechanics give the same results. It is called Bohrscorrespondance principle or principle of complementarity.

The Hydrogen Atomic Spectrum Consists of Several Series.

When any atom is subjected to high temperature or an electrical discharge, emits electromagnetic radiation of characteristic frequencies. That means each atom has a characteristic emission spectrum which consists of discrete frequencies, they are called line spectra. Adetailed analysis of the hydrogen atomic spectra turned out to be a major step in the elucidation of the electronic structure of atoms. In 1885 Swiss Scientist, Johann Balmer, showed that a plot of the frequency of the lines versus $1/n^2$ of the emission lines in the visible region of the spectrum could be described by the equation(n=3,4,5...) is linear .Balmer showed that the frequencies of the emission lines in the visible region of the spectrum could be described by the equation

√= $8.2202x10^{14}(1-4/n^2)$Hz, The Rydberg formula for all the lines in the hydrogen atomic spectrum is given by wave number=1/□=$109680(1/n_1^2 - 1/n_2^2)$ where $n_2>n_1$. The first four series of lines making up the hydrogen atomic spectrum are(i) Lyman series $n_1=1$, $n_2=2,3,4....$ in the Ultraviolet region. (ii) Balmer series $n_1=2$, $n_2=3,4,5....$ Visible region. (iii) Paschen series$n_1=3$, $n_2=4,5,6...$ near infrared region. (iv) Bracket series $n_1=4$, $n_2= 5,6,7....$ Infrared region.

Louis de Broglie Postulated That Matter Has Wavelike Properties.

In 1924 French scientist named Louis de-Broglie reasoned that if light can display this wave –particle duality, then matter appears particle like, might also display wave like properties under certain conditions. □= h/p deBroglie argued that both light and matter obey this equation.

When a beam of X rays is directed at a crystalline substance, the beam is scattered in a definite manner characteristic of the atomic structure of the crystalline substance.This phenomenon is called x-ray diffraction and occurs because the interatomic spacing in the crystal are about the same as the wave length of the x-rays. The x-rays scatter from the foil in the ring of different diameters. The distance between the rings are determined by the interatomic spacing in the metal foil. The similarity of the two patterns shows that both x-rays and electrons do indeed behave analogously in these experiments. The wave property of electrons is used in electron microscopes. The wave length of the electrons can be controlled through an applied voltage.

Heisenberg Uncertainty principle:-Consider a measurement of the position of an electron. If we wish to locate the electron within the distance Δx, then we must use a measuring device that has a spatial resolution less than Δx.One way to achieve this resolution is to use light with a wave length on the order of □ = Δx. For the electron to be seen a photon must interact or collide in some way with the electron, for otherwise the photon will just pass right by and the electron will appear transparent. During collision some of this momentum will be transfered to the electron. The very act of locating the electron leads to a change in its momentum. If we wish to locate the electron more accurately, we must use light with a smaller wave length. Consequently, the photons in the light beam will have greater momentum because of the relation p =h/□ .. Some of the momentum of photons must be transfered to electron in the process of locating it, the momentum change of the electron become greater. 1920 German physicist Werner Heisenberg, who showed that it is not possible to determine exactly how much momentum is transfered to the electron. This means if we wish to locate an electron to within a region Δx, there will be an uncertainty in the momentum of the electron. $\Delta x.\Delta P > h/4\Pi$