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Planck's Quantum Theory

Introduction to Modern Physics:- Before 1900, most of the experimental result could be explained on the basis of classical theoretical physics. Discovery of electron by J. J. Thomson in 1897 showed that it behaved like a Newtonian particle. The wave nature of light was suggested by the diffraction experiment of Young in 1803 and was put on firmer foundation by Maxwell in 1864 by establishing the connection between optical and electrical phenomenon.

There is difficulties in explaining the discoveries of X-rays and radioactivity, the spectral distribution of thermal radiation from a black body, the low temperature specific heats of solids and appearance of only five degrees of freedom in the motion of a free diatomic molecule at ordinary temperature.

Plank in 1990 was able to explain the black body spectrum in terms of the assumed emission and absorption of electromagnetic radiation in discrete quanta, Einstein also explained the photoelectric effect on this quantum idea. ~~The dual nature of electromagnetic radiation thus became established~~. In 1924, de Broglie suggested that matter also has a dual character. Before this suggestion all the experimental evidence had indicated that matter was composed of discrete Newtonian particles. Davisson and Germer (1927) and G. P. Thomson (1928) observed the diffraction of electrons by crystals and thus confirmed de Broglie's hypothesis.

Bohr in 1913 made two postulates. The first postulate was that an atomic system can exist in particular stationary or quantized states, each of which corresponds to a definite energy of the system and the transitions from one stationary state to another are accompanied by the gain or loss of an amount of energy equal to the energy difference between the two states, and the energy gained or lost appears as a quantum of electromagnetic radiation. The second postulate was that a radiation quantum has frequency equal to the energy divided by the Planck's constant. These postulates could explain Ritz combination principle and the Franck Hertz experiment.

Bohr in 1923 introduced correspondence principle to make use of the classical theory as a limiting case to infer some properties of the atomic systems.

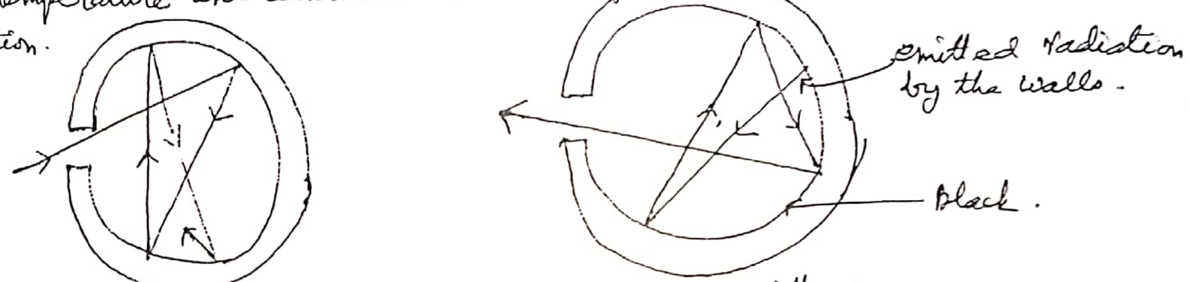
The new theory of quantum mechanics is based on two principles. The first of these is the uncertainty principle developed by Heisenberg in 1927. According to this principle, it is impossible to specify precisely and simultaneously the values of both members of particular pairs of physical variables that describe the behaviour of an atomic system.

Complimentary principle was introduced by Bohr in 1928 according to which the atomic phenomenon cannot be described with the completeness demanded by classical dynamics. We cannot prove in a single experiment that matter (or light) has both wave and [illegible] contradict each other

The fundamental difference between Newtonian mechanics and quantum mechanics can be ~~a~~ summarised as follows. Newtonian mechanics is concerned with the motion of a particle under the action of applied forces and it takes for granted that such quantities as the particle's position, mass, velocity, acceleration etc. can be measured accurately at every instant. Quantum mechanics, on the other hand assumes, that the position and momentum of a particle cannot be accurately measured at the time, it only gives the most probable value of the observed quantity. Newtonian mechanics is nothing but an approximate version of quantum mechanics. The Newtonian mechanics deals with macroscopic bodies and Quantum mechanics deals with the observables in the atomic realm, and as such is applicable both for macroscopic and microscopic bodies.

Quantum mechanics is the theory which attempts to explain the behaviour of matter and interaction with energy on the scale of atoms and atomic particles i.e., particles of the size of the order of 10^{-10} m. Phenomena such as motion of mechanical objects involving distances larger than about 10^{-6} m can be explained satisfactorily by laws of classical theoretical physics. However, certain phenomena such as spectral distribution of energy in black body radiation photo electric effect etc and phenomena involving distances of the order of 10^{-10} m could not be explained by classical mechanics. These limitations or failure of classical mechanics led to the development of quantum mechanics. ~~the~~ The energy distribution in the spectrum of a black body was successfully explained by Max Planck in 1900 who proposed the ~~a revolutio~~ revolutionary concept of quantum hypothesis. This was the origin of the quantum theory.

<u>Black Body</u> <u>Radiation</u> :- Only the quantum theory of light can explain its origin. Every substance emits electromagnetic radiation, the character of which depends upon the nature and temperature of the substance. The radiation inside an enclosure maintained at a constant temperature is known as black-body radiation or simply black radiation and the enclosure behaves as a perfectly black body. A perfectly black body is one that absorbs radiations of all wavelengths incident upon it regardless of frequency. An ideal absorber of radiant energy, is a uniform temperature enclosure (say a spherical shell) with a small hole in it. When any radiation enters the hole it suffers repeated reflections from the inner walls until it is finally absorbed as shown in figure 1. Therefore, the opening behaves like a perfect absorber. Conversely, the radiations emitted by the walls (when the chamber is heated) and escaping the opening, will be of the same nature as emitted by a perfectly black body. Such a cavity maintained at a desired temperature will constitute a source of black body radiation also known as cavity radiation.



An ideal absorber　　　　An ideal emitter.

Fig.1:- A practical black body

The black-body radiation is closely analogous with perfect gas. In kinetic theory, the perfect gas is pictured as being an assembly of particles having all velocities from 0 to ∞ and moving in all directions, the black-body radiation is also proceeding in all directions and is composed of waves of all wavelengths. Further the black-body radiation can be regarded as a thermo dynamical system and its energy and entropy calculated just as in the case of perfect gas. The analogy between the two has been pushed further. Radiant energy or radiation is now regarded as having particle nature. It is believed to consist of discrete particles called photons which retain their total stock of energy intact throughout and may lose their energy only on interaction with matter. The photons in a black-body may have all energies from 0 to ∞ and may be moving in all possible directions just like the molecules of a perfect gas.

The energy distributed among different wavelengths in black-body radiation process was first introduced by Wien in 1983. He showed that $E_\lambda d\lambda$ the amount of energy emitted by a black-body at a temperature T and contained in the spectral region included within the wavelengths λ and $\lambda + d\lambda$ is of the form

$$E_\lambda d\lambda = \frac{A}{\lambda^5} f(\lambda T)\, d\lambda \qquad \text{---(1)}$$

where A is a constant and $f(\lambda T)$ is a function of the product (λT).

This law can also be written as

$$u_\lambda \, d\lambda = \frac{A}{\lambda^5} f(\lambda T) \, d\lambda \qquad \text{---- (2)}$$

where $u_\lambda d\lambda$ is the energy density (energy per unit volume) in the wavelength range λ to $\lambda + d\lambda$.

In terms of frequency range ν and $\nu + d\nu$ the above law can be written as

$$u_\nu \, d\nu = B\nu^2 \phi(\nu/T) \, d\nu \qquad \text{--- (3)}$$

where B is another constant.

Rayleigh and Jean also showed above problem by using classical considerations that the energy density of wavelengths lying between λ and $\lambda + d\lambda$ in an enclosure is given by

$$u_\lambda \, d\lambda = \frac{8\pi}{\lambda^4} kT \, d\lambda \qquad \text{---- (4)}$$

In terms of the frequency range ν and $\nu + d\nu$ the energy density $u_\nu d\nu$ is given by

$$u_\nu \, d\nu = \frac{8\pi \nu^2}{c^3} kT \, d\nu \qquad \text{--- (5)}$$

The above eqn (4) and (5) is known as Rayleigh - Jean's law.
Rayleigh - Jean's law which results from an application of the equipartition law, agrees well with the experimental results at low frequencies as shown in Fig. 2, but predicts that the energy density u_ν would increase to infinity with increase in the frequency ν without giving any point of maximum emission.

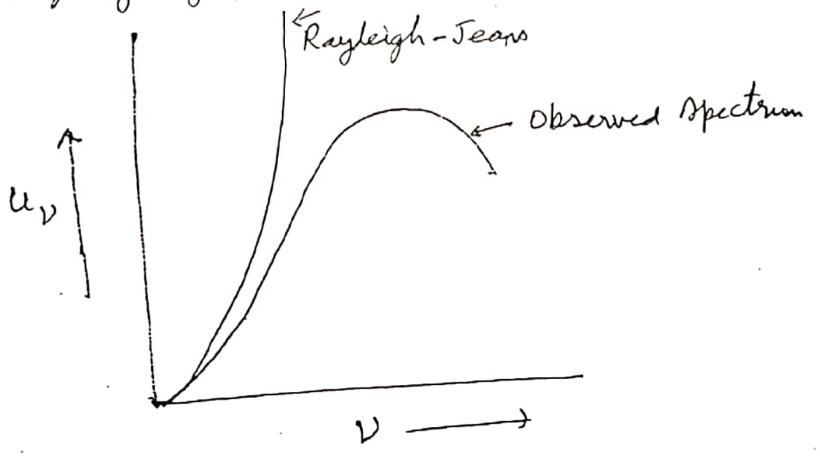


Fig. 2 :- Comparison of Rayleigh-Jean's law with observed results

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<u>Characteristics of Black Body Radiation</u> :- It was discovered by Kirchoff that

(i) a black body not only completely absorbs all the incident radiation but also conversely behaves as a perfect radiator when heated, and.

(ii) the radiation from such a body depends only on the temperature to which it is raised and not on the nature i.e. material, shape and size of the body.

(iii) the cavity radiation is more intense ~~that~~ than the radiation from a non-black body at the same temperature this is why the hole appears brighter than the outer wall of the cavity.

(iv) the total energy emitted per second per unit surface area of the hole, E is directly proportional to the fourth power of the absolute temperature T of the cavity

$$E = \sigma T^4 \quad \text{(Stefan's law)}$$

where σ is the Stefan's Boltzmann constant

(v) the spectral distribution of energy in the black body radiation at a given temperature is independent of the material, shape and size of the body.

In the study of black body radiation, a special interest was laid on the spectral distribution of energy in the emitted radiation i.e. how the energy is distributed among the various wavelengths in the spectrum and at what wavelength is most of the energy emitted.

THE ULTRAVIOLET CATASTROPHE :- In the Rayleigh Jeans formula, as ν increases, corresponding to the ultraviolet region of the spectrum, since the rate at which energy is radiated increases as ν^2, so, in the limit of infinitely high frequency; $u_\nu d\nu$ should approach infinity. But in reality, we know that $u_\nu d\nu \rightarrow 0$ as $\nu \rightarrow \infty$ i.e. the discrepancy between theory and experiment was at once recognised as crucial, and this was known as the ultraviolet catastrophe i.e. failure of the formula in the ultraviolet region of spectrum - a consequence of derivation based on the classical physics.

At any temperature T, the total energy of radiation is given by

$$u = \int_0^\infty u_\nu d\nu = \int_0^\infty \frac{8\pi kT}{c^3} \nu^2 d\nu$$

is predicted by Rayleigh Jean's formula to be infinite, which is against the Stefan's law. In reality, the energy density falls to 0 as $\nu \rightarrow \infty$. This discrepancy became known as the ultraviolet catastrophe of classical physics.

These shortcomings of classical theory were overcome by Planck's quantum hypothesis.

PLANCK'S HYPOTHESIS :- Plank in 1901 introduced an entirely new idea to explain the distribution of energy among the various wave-length of the black body radiation. He pointed out that the atoms of the walls of the cavity radiator behave as oscillators, each with a characteristic frequency of oscillation. These oscillators emit electromagnetic radiant energy into the cavity and also absorb the same from it, and maintain an equilibrium state. He argued that the ~~element~~ elementary radiators in black body radiate and absorb energy in integral multiples of a definite quantum of energy, the size of the 'energy-packet' or 'quantum' depends on natural frequency ν_0 of the oscillators i.e.

$$E_0 = h\nu_0$$

where h is a universal constant known as Planck's constant. The value of $h = 6.626 \times 10^{-27}$ erg-sec $= 6.626 \times 10^{-34}$ Joule-sec.

* Planck's Quantum theory of Radiation (see new page) ⟶

PLANCK'S LAW OF RADIATION :- In 1900 the German Physicist Max Planck ultimately giving the most satisfactory formula for energy density of blackbody radiation, for which he had to make certain assumptions of far-reaching consequences which later gave birth to quantum theory of radiation. Planck radiation formula can be written as

$$u_\lambda d\lambda = \frac{8\pi hc}{\lambda^5} \cdot \frac{1}{e^{hc/\lambda kT} - 1} d\lambda \quad \text{--- (1)}$$

The above formula reduces to Wien's law or Rayleigh's law depending upon the values of λT. If λT is small, $e^{hc/k\lambda T} \gg 1$ and therefore neglecting one in comparison with the exponential, we can write

$$u_\lambda d\lambda = \frac{8\pi hc}{\lambda^5} e^{-\frac{hc}{\lambda kT}} d\lambda$$

which is Wien's law.
If λT is large $e^{hc/\lambda kT}$ may be expanded and $(e^{hc/\lambda kT} - 1)$ can be put to be equal to $\frac{hc}{\lambda kT}$. Therefore,

$$u_\lambda d\lambda = \frac{8\pi hc}{\lambda^5} \frac{\lambda kT}{hc} d\lambda$$

or

$$u_\lambda d\lambda = \frac{8\pi}{\lambda^4} kT \, d\lambda$$

which is the Rayleigh-Jean's law.

In order to arrive at the eqⁿ (1), Planck imagined that a black-body enclosure is filled up not only with radiation but also with molecules of perfect gas. As at that time the mechanism of emission of light by atomic vibrations or of absorption of light by molecules or atoms and therefore of any direct exchange of energy between the radiation and the gas molecules was not known, Planck introduced resonators or oscillators of molecular dimensions for transferring energy from the radiation to the gas molecules. He assumed that these resonators do not emit radiation continuously but only when the energy absorbed by them reaches a certain minimum value ϵ or its integral multiple. Thus, a resonator having an energy $(\alpha + d\alpha)\epsilon$, where α is a whole number and $d\alpha$ is a fraction, would not emit until the energy absorbed from the radiation becomes $(\alpha+1)\epsilon$ when it would emit the energy ϵ and then revert back to the State with the energy $\alpha\epsilon$. Thus, resonators with energy content

$$\epsilon, 2\epsilon, 3\epsilon, ----, \alpha\epsilon, ---$$

would radiate energy ϵ.

Let $N_0, N_1, N_2, N_3, ---- N_\alpha, ---$ be the number of resonators having energy $0, \epsilon, 2\epsilon, 3\epsilon, ---, \alpha\epsilon, ---$. Then the total number of resonators will be

$$N = \sum_{\alpha=0}^{\infty} N_\alpha$$

According to Maxwell's law, the probability that a resonator possesses the energy ϵ is given by $e^{-\epsilon/kT}$ and the probability that it has an energy $\alpha\epsilon$ is $e^{-\epsilon\alpha/kT}$.

Thus
$$N_\alpha = N_0 e^{-\alpha\epsilon/kT}$$

Therefore the total number of resonators,

$$N = N_0 + N_0 e^{-\epsilon/kT} + N_0 e^{-2\epsilon/kT} + ---- + N_0 e^{-\alpha\epsilon/kT} + ----$$

$$= N_0\left[1 + e^{-\epsilon/kT} + e^{-2\epsilon/kT} + ---- + e^{-\alpha\epsilon/kT} + ---\right]$$

$$= \sum_{\alpha=0}^{\infty} N_0 e^{-\alpha\epsilon/kT} = N_0 \frac{1}{1 - e^{-\epsilon/kT}} \quad ----(1)$$

The total energy $E = \sum_{\alpha=0}^{\infty} N_\alpha \alpha\epsilon = \sum_{\alpha=0}^{\infty} N_0 e^{-\alpha\epsilon/kT} \cdot \alpha\epsilon$

Differentiating above equation with respect to $\frac{1}{kT}$

$$\frac{dN}{d(\frac{1}{kT})} = \sum_{\alpha=0}^{\infty} -N_0 e^{-\alpha\epsilon/kT} \alpha\epsilon = \frac{-N_0 \epsilon e^{-\epsilon/kT}}{(1 - e^{-\epsilon/kT})^2} = N_0 \epsilon \frac{e^{-\epsilon/kT}}{(1 - e^{-\epsilon/kT})^2} \quad --(2)$$

* Planck's Quantum Theory of Radiation :- Max Planck ~~(1900)~~ put forth the quantum theory to explain the experimentally obtained energy distribution in the spectrum of black body radiation. He made following two assumptions of far reaching consequence.

(1) An atom, identified as an atomic oscillator, possesses quantised energies which are given by

$$E = nh\nu$$

where ν is frequency of oscillator, h is universal constant and n is an integer.

(2) The atomic oscillators radiate or absorb energy in discrete manner (not continuously as desired classically). When an oscillator changes from one quantized energy state to other. If change in n is one (i.e. $\Delta n = 1$), then above equation gives

$$\Delta E = (\Delta n) h\nu$$

or $$\Delta E = h\nu$$

Thus, Planck hypothesised that an atomic oscillator absorbs or emit energy in integral multiple of a definite energy unit, $h\nu$ called quanta, So according to quantum postulate energy exchange between radiation and matter occurs in small packets of energy $= h\nu$ (not in continuous fashion). These small bundles or packets of energy (latter called photon by Einstein) propagate like particles having speed of light.

Energy of a photon, $E_i \propto$ frequency (ν) of light

or $$E = h\nu$$
$$= \frac{hc}{\lambda}$$

According to special theory of relativity, mass and energy are co-related by the expression

$$E = mc^2$$

Then, energy, $h\nu$ of the photon is equivalent to mass, m

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

So, photon momentum, $p = \text{mass} \times \text{speed} = \frac{h\nu}{c^2} \times c = \frac{h\nu}{c} = \frac{h}{\lambda}$

If any material surface receives or gives off n photon, then the total energy absorbed or emitted by the surface will be

$$W = n.h\nu$$

The origin of the quantum theory of radiation was the Planck's hypothesis.

Einstein (1905) applied ~~that~~ Planck's quantum theory of light to successfully explain photoelectric effect and Compton (1923) applied to explain Compton effect, which offer direct evidence for discrete energy transaction between ~~rad~~ radiation and matter.

From Eqs (1) and (2), the mean energy of the resonator is given by,

$$\frac{E}{N} = \frac{\epsilon e^{-\epsilon/kT}}{1-e^{-\epsilon/kT}}$$

$$= \frac{\epsilon}{e^{\epsilon/kT}-1} \quad \text{---- (3)}$$

This shows that the average energy of the resonator is not equal to kT as given by equipartition law but is equal to

$$\frac{\epsilon}{(e^{\epsilon/kT}-1)}$$

according to the quantum law. However in the limit $\epsilon \to 0$

$$e^{\epsilon/kT}-1 \approx \frac{\epsilon}{kT}$$

and the average energy given by Eq (3) becomes kT in agreement with the equipartition law.

Planck showed that the energy density u_ν of radiation of frequency ν is given by,

$$u_\nu = \frac{8\pi\nu^2}{c^3} E_\nu \quad \text{---- (4)}$$

where $E_\nu = \frac{E}{N}$ is the average energy of a resonator emitting radiation of frequency ν. Hence, the energy density of resonators emitting radiation of frequency lying between ν and $\nu+d\nu$ is given by

$$u_\nu d\nu = \frac{8\pi\nu^2}{c^3} \cdot \frac{\epsilon}{e^{\epsilon/kT}-1} d\nu \quad \text{---- (5)}$$

According to Wien's law, the energy density u_ν of radiation of frequency ν depends upon temperature only through a function of $\frac{\nu}{T}$. This requirement can be fulfilled by Eq. (5) if we assume that the energy of the resonator, ϵ is proportional to ν i.e., if we write $\epsilon = h\nu$ where the constant of proportionality h is known as the Planck's constant. We therefore get

$$u_\nu d\nu = \frac{8\pi h\nu^3}{c^3} \frac{1}{e^{h\nu/kT}-1} d\nu \quad \text{---- (6)}$$

or using

$$\nu = \frac{c}{\lambda} \quad \text{or} \quad d\nu = -\frac{c}{\lambda^2} d\lambda$$

we get

$$u_\lambda d\lambda = \frac{8\pi hc}{\lambda^5} \cdot \frac{1}{e^{ch/\lambda kT}-1} d\lambda \quad \text{---- (7)}$$

The Eqns (6) and (7) give the energy density for wavelength λ in the spectrum of black body and represent the Planck's law of radiation. Planck's formula fits the experimental curve very closely as shown in figure (3). This law of distribution of energy is based on the assumption that the emission of radiation is discontinuous and takes place in packets or quanta of ϵ..

The Planck's constant 'h' and the Boltzmann's constant 'k' can be evaluated by comparison with experiment. The total energy obtained by integrating Planck's distribution (Eqn 6) over the whole spectrum, must depend upon temperature in accordance with Stefan's law:

$$u = \int_0^\infty u_\nu d\nu = \frac{4\sigma}{c} T^4 \quad \text{---- (8)}$$

where σ is the Stefan's constant.

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If this integral is evaluated using the Eqn (6) the value of σ comes out to be,

$$\sigma = \frac{2\pi^5 k^4}{15 h^3 c^2} \qquad ----(9)$$

Planck's law must yield a maximum energy at wavelength λ_m predicted by Wien's law

$$\lambda_{max} T = b$$

where b is a constant.

The position of the maximum can be found from the condition that $\frac{du_\lambda}{d\lambda} = 0$, with u_λ given by the Eqn 7). We get the result

$$\lambda_{max} T = \frac{ch}{4.965 k} = \text{Constant} \qquad ---(10)$$

Hence $\lambda_{max} T$ is a constant in agreement with the experiment.

The values of the constants h and k can be calculated from Eqn (9) and (10) using the experimentally known values of Stefan's constant σ and Wien's constant $b (= \lambda_{max} T)$.

$$h = 6.625 \times 10^{-34} \text{ joule/sec.}$$

$$k = 1.380 \times 10^{-23} \text{ joule}/^\circ K.$$

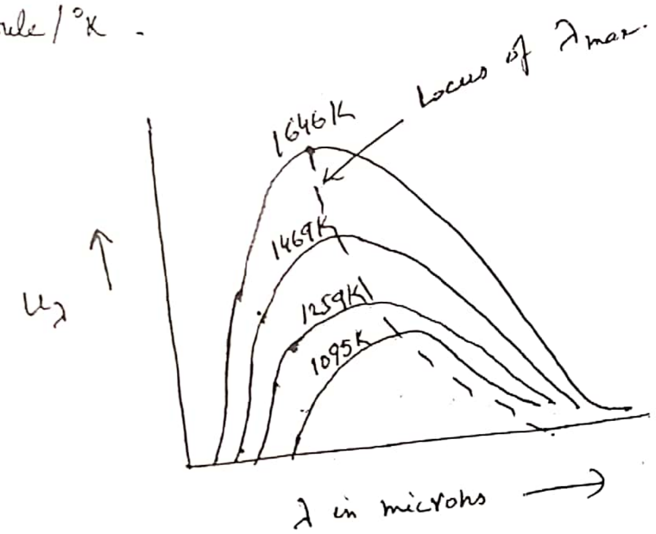

Fig. 3.

STEFAN'S LAW FROM PLANCK'S FORMULA :– Planck's radiation formula in terms of frequency is

$$u_\nu d\nu = \frac{8\pi h}{c^3} \cdot \frac{\nu^3 \, d\nu}{(e^{h\nu/kT}-1)}$$

The total energy density u within the cavity is the integral of the energy density over all frequencies.

$$U = \int_0^\infty u_\nu d\nu$$

$$= \frac{8\pi h}{c^3} \int_0^\infty \frac{\nu^3 \, d\nu}{(e^{h\nu/kT}-1)}$$

Put $\frac{h\nu}{kT} = x$, so that $\nu = \frac{kT}{h} x$

and

$$d\nu = \frac{kT}{h} dx \text{ , then}$$

$$u = \frac{8\pi h}{c^3} \frac{k^4 T^4}{h^4} \int_0^\infty \frac{x^3}{(e^x-1)} dx$$

The value of the integral $\int_0^\infty \frac{x^3}{e^x-1} dx = \frac{\pi^4}{15}$

Thus,

$$u = \frac{8\pi^5 k^4 T^4}{15 c^3 h^3} = aT^4$$

where 'a' is a universial constant.

The total energy density is proportional to the fourth power of the absolute temperature of the cavity walls. Therefore, the energy radiated by a black body per second per unit area is also proportional to T^4 i.e.

$$u = \sigma T^4$$

This is Stefan's–Boltzmann law and Stefan's constant,

$$\sigma = 5.67 \times 10^{-8} \, W/m^2 K^4 .$$

PROPERTIES OF PHOTONS :– (1) Photons are indivisible quanta of electromagnetic energy.

(2) The intensity of radiation (I) is equal to the number of a photons (N) crossing per unit area per second multiplied by $h\nu$ (the energy content of a photon):

$$I = N h\nu$$

Thus for a given frequency, the intensity depends upon the number of photons and has no relation with the energy of individual photons.

(3) The energy content of the photon is independent of intensity but is proportional to the frequency of radiation e.g. blue photons have larger energy content than red photons, x-ray photons have considerably larger energy content than visible light photons.

(4) They retain their identity until they are completely absorbed by some atom.

(5) All photons have a zero rest mass and travel with the speed of light in vacuum.

(6) Since, $E^2 = p^2c^2 + m_0^2 c^4$, $(m_0 = 0)$ $E = h\nu$, therefore, photon has a momentum given by

$$p = \frac{E}{c} = \frac{h\nu}{c}$$

(7) The existence of momentum for a photon implies that it must have an effective mass. This can be computed by mass-energy relation ($E = mc^2$) as 12.

$$m = \frac{E}{c^2} \text{ or } m = \frac{h\nu}{c^2}$$

(8) Photons are electrically neutral and hence are unaffected by electric or magnetic fields. They do not ionise. The ordinary methods used in the case of charged particles cannot be used to detect them or measure their energy or intensity. In fact, all instruments used in their analysis are sensitive not to them as such but to the secondary effects produced by their interaction with matter.

Origin of Quantum ~~Theory~~ Physics.

~~Inadequacies of Classical Mechanics~~ :-

Introduction to ~~ato~~ Inadequacies of classical mechanics

In 1902 Lenard found that the velocity or kinetic energy of the electron emitted from an illuminated metal was independent of the intensity of the particular incident monochromatic light. It appeared to vary only with the wavelength or frequency of the incident light.

$E = h\nu$

Further, for a given metal, no electrons were emitted when it was illuminated by light of wavelength longer than a particular wavelength, called the threshold wavelength, no matter how great was the intensity of the light beam. But as soon as the metal was illuminated by light whose wavelength was lower than the threshold wavelength electrons were emitted. Even though the light beam was made extremely weak in intensity, it was estimated that the electrons were emitted about 10^{-9} second after exposure to the light, that is, practically simultaneously with exposure to the weak light.

Classical or wave theory :- On the wave theory of light, the so-called classical theory, these results are very surprising.

If we assume light is sent out in waves from a source, the greater the intensity of the light the greater will be the energy per second reaching the illuminated plate. So the classical theory can explain why the number of electrons emitted increases as the light intensity increases.

But it cannot explain the result that the velocity or kinetic energy of the emitted electrons is independent of the intensity of the incident light beam.

According to the classical theory, the greater the intensity of the beam, the greater should be the kinetic energy of the emitted electrons because the energy per second reaching the plate increases with the intensity of the light.

Further, for the classical theory electrons should always be emitted by light of any wavelength if the incident light beam is strong enough. Experiment, however, shows that however intense the light beam, no electrons are emitted if the wavelength is ~~lower~~ greater than the threshold value.

Experiments show that (1) the maximum energy of the emitted electrons is not proportional to the light intensity and that (2) electrons are not emitted for all wavelengths, which contradicts the classical (wave) theory of light.

The Photoelectric Effect

Sailent (Features of:)

INADEQUACIES OF CLASSICAL MECHANICS :- There are many important experimental results which could not be explained on the basis of classical mechanics. Some of them are :-

(1) Stability of atoms and molecules :- According to classical mechanics, the atom is stable. When the electron revolves around the nucleus in a circular orbit, it has acceleration. We know that any accelerating charge emits the radiation, the electron during its motion round the nucleus should have emitted energy continuously and as a result the radius of revolution would have reduced continuously and ultimately the electron would have merged into the nucleus. But this is against the stability of the atom. According to classical theory it could not explain the stability of the atoms and molecules. The classical theory, has to no explaination to the behavior in the region of atomic dimensions.

(2) The atomic spectra :- The characteristic frequency emission or absorption by the elements.

(3) The regularities among the spectral lines.

(4) The specific heat of solids at low temperature

(5) The black body radiation. The quantity and quality of the emitted radiation depends only on the temperature of the body and not on the nature of the material of the body. The radiation emitted at a particular temperature consists of wide range of frequencies with different intensities.

(6) The photo-electric effect. The photoelectric emission and scattering of free electrons (photo-electric effect and compton effect).

(7) The emission of X-rays, radioactivity and other nuclear activities.

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