depends only on the temperature.

1.2 FAILURE OF CLASSICAL PHYSICS TO EXPLAIN ENERGY DISTRIBUTION IN THE SPECTRUM OF A BLACK BODY

Late in the nineteenth century a number of attempts were made to explain distribution of energy among wavelengths in the spéctrum of a black body by using laws of classical Physics. But the attempts were not very successfull. Two well-known classical laws with their limitations are as follows :

(1) Wien's Radiation Formula

In 1896 Wien derived the following formula for radiation from a black-body:

$$E_\lambda d\lambda = \frac{C_1}{\lambda^5} e^{-C_2/\lambda T} d\lambda \qquad ...(1)$$

where C_1 and C_2 are constants.

For obtaining the formula, the following arbitrary assumptions were made:

(1) The radiation inside a hollow enclosure is produced by resonators of molecular dimensions.

(2) The frequency of the radiation emitted is proportional to the kinetic energy of the resonator.

(3) The intensity of radiation of any particular wavelength is proportional to the number of resonators having required amount of energy.

Limitations of the formula :

The formula explains the experimental results fairly well for low values of λT, but for higher values it gives values of E_λ lower than the experimental values.

(2) Rayleigh-Jeans Law

In 1900 Lord Rayleigh applied the principle of equipartition of energy to the electromagnetic vibrations. Then with a contribution from J.H. Jeans this attempt led to the deduction of a formula for energy per unit volume inside an enclosure with perfectly reflecting walls. This formula is called the Rayleigh-Jeans law. According to this law the energy density, $U_\nu d\nu$, *i.e.*, the amount of energy per unit volume of the enclosure in the frequency range from ν to $\nu + d\nu$ is given by

$$U_\nu d\nu = \frac{8\pi\nu^2 kT}{c^3} d\nu \qquad ...(2)$$

where U_ν is the energy per unit volume per unit frequency range at frequency ν, k is Botzmann's constant and c is the speed of light in free space.

The Rayleigh-Jeans formula can be transformed in terms of the wavelength λ by using the relation:

$$\nu = \frac{c}{\lambda}$$

and

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

The energy $U_v dv$ contained in a frequency interval between v and v + dv is equal to that contained in a corresponding wavelength interval between v and $v + d\lambda$, and an increase in frequency corresponds to a decrease in wavelength.

$$\therefore \quad U_\lambda d\lambda = -U_v dv$$

$$= -\frac{8\pi}{c^3}\left(\frac{c}{\lambda}\right)^2 kT\left(-\frac{c}{\lambda^2}\right)d\lambda$$

$$= \frac{8\pi kT}{\lambda^4} d\lambda \qquad \text{... (3)}$$

This equation is another form of the Rayleigh-Jeans law,

Limitations of the law :

The law explains the experimental facts for very long wavelengths, but not for shorter wavelengths. According to the law as λ decreases, the energy density U_λ will continuously increase, and as λ tends to zero, U_λ approaches infinity (Fig. 1.2). This is contrary to the experimental results.

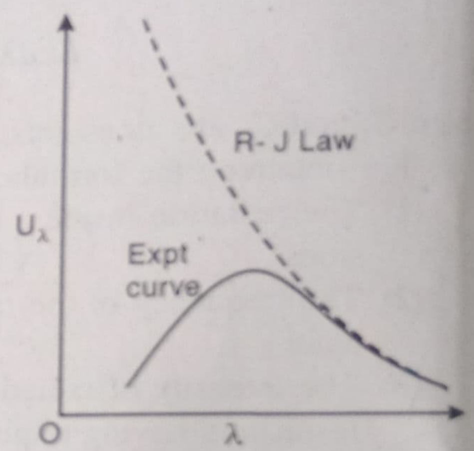

Fig. 1.2

The law leads to an absurd result which is as follows. The total energy of radiation per unit volume of the enclosure for all wavelengths from zero to infinity is given by :

$$U = \int_0^\infty U_\lambda d\lambda = \int_0^\infty \frac{8\pi kT}{\lambda^4} d\lambda$$

$$= 8\pi kT\left[-\frac{1}{3\lambda^3}\right]_0^\infty = \infty$$

This result shows that for a given quantity of radiant energy all the energy will finally be confined in vibrations of very small wavelengths. Thus, if the classical treatment is correct, on opening a shutter in the black body cavity, we would be bombarded with radiation of extremely short wavelengths. But, experimental results show that $U_\lambda d\lambda \to 0$ as $\lambda \to 0$. This discrepancy between the theoretical conclusion and the experimental result is called "ultraviolet catastrophe." This absurd result is because of the assumption that energy can be absorbed or emitted by the atomic oscillators continuously in any amount.

Thus, in the foregoing discussion on the distribution of energy in the spectrum of a black body classical theoretical physics failed to provide satisfactory explanation of the phenomenon. This led Max Planck to propose the quantum hypothesis.