Radiatin Unit-6 (6.3) ①

11.1. INTRODUCTION

'Radiation' heat transfer is defined as "*the transfer of energy across a system boundary by means of an electromagnetic mechanism which is caused solely by a temperature difference.*" Whereas the heat transfer by conduction and convection takes place only in *the presence of medium, radiation heat transfer does not require a medium.* Radiation exchange, in fact, occurs most effectively in *vacuum.* Further, the rate of heat transfer *by conduction and convection* varies as the temperature difference to the *first power,* whereas the *radiant heat exchange* between two bodies depends on the difference between their temperature to the '*fourth power*'. Both the amount of radiation and the quality of radiation depend upon temperature. The *dissipation from the filament of a vacuum tube* or *the heat leakage through the evacuated walls of a thermos flask* are some familiar *examples* of heat transfer by radiation.

In Conduction & Convection $q \propto T$

In Radiation $q \propto T^4$

The contribution of *radiation* to heat transfer is very significant at high absolute temperature levels such as those prevailing in *furnaces, combustion chambers, nuclear explosions* and in *space applications.* The *solar energy* incident upon the earth is also governed by the *laws of radition.*

The energy which a radiating surface releases is *not continuous* but is in the form of successive and separate (discrete) packet or quanta of energy called *photons.* The photons are propagated through space as rays; the movement of swarm of photons is described as *electromagnetic waves.* The photons travel (with speed equal to that of light) in straight paths with unchanged frequency; when they approach the receiving surface, there occurs reconversion of wave motion into *thermal energy* which is partly absorbed, reflected or transmitted through the receiving surface (the magnitude of each fraction depends, upon the nature of the surface that receives the *thermal radiation*).

All types of electromagnetic waves are classified in terms of *wavelength* and are propagated at the speed of light (c) *i.e.*, 3×10^8 m/s. The electromagnetic spectrum is shown in Fig. 11.1. The distinction between one form of radiation and another lies only in its frequency (f) and wavelength (λ) which are related by

$$c = \lambda \times f \qquad \text{...(11.1)}$$

The *emission of thermal radiation* (range lies between wavelength of 10^{-7} m and 10^{-4} m) *depends upon the nature, temperature and state of the emitting surface*; however, *with gases the dependence is also upon the thickness of the emitting layer and the gas pressure*.

Thermal radiations exhibit characteristics similar to those of *visible light*, and *follow optical laws*. These can be *reflected, refracted* and are *subject to scattering and absorption when they pass through a media*. They get *polarised* and *weakened* in strength with inverse square of radial distance from the radiating surface.

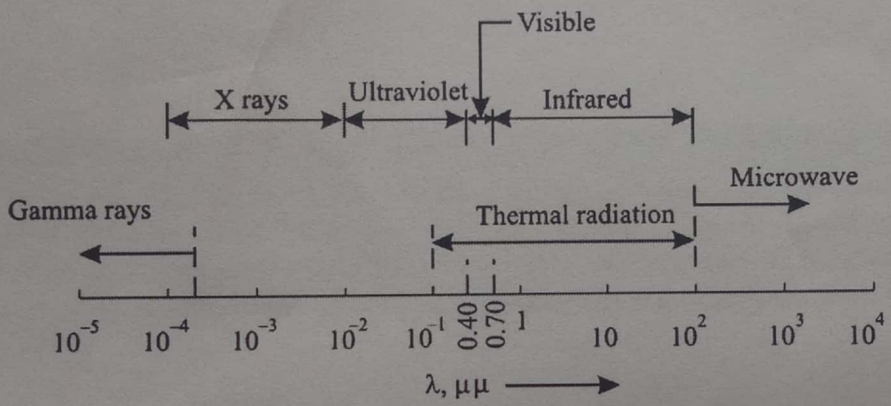


Fig. 11.1. Spectrum of electromagnetic radiation.

11.2. SURFACE EMISSION PROPERTIES

The rate of emission of radiation by a body depends upon the following factors:

(*i*) The temperature of the surface,

(*ii*) The nature of the surface, and

(*iii*) The wavelength or frequency of radiation.

The *parameters* which deal with the surface emission properties are given below :

(*i*) **Total emissive power (E).** The "*emissive power*" is defined as the *total amount of radiation emitted by a body per unit area and time*. It is expressed in W/m². The *emissive power of a black body*, according to Stefan-Boltzmann, is *proportional to absolute temperature to the fourth power.*

$$E_b = \sigma T^4 \text{ W/m}^2 \qquad \text{...(11.2)}$$

$$E_b = \sigma A T^4 \text{ W} \qquad \text{...(11.2 a)}$$

where, σ = Stefan-Boltzmann constant = 5.67×10^{-8} W/m² K⁴

(*ii*) **Monochromatic (spectral) emissive power (E_λ).** It is often necessary to determine the spectral distribution of the energy radiated by a surface. At any given temperature the amount of radiation emitted per unit wavelength varies at different wavelengths. For this purpose the *monochromatic emissive power* E_λ of the surface is used. It is defined as *the rate of energy radiated per unit area of the surface per unit wavelength.*

The total emissive power is given by,

$$E = \int_0^\infty E_\lambda \, d\lambda \text{ W/m}^2 \quad \text{...(11.3)}$$

(*iii*) **Emission from real surface-emissivity.** The emissive power from a real surface is given by

$$E = \varepsilon \sigma A T^4 \text{ W} \quad \text{...(11.4)}$$

where, ε = Emissivity of the material.

***Emissivity* (ε).** It is defined as the *ability of the surface of a body to radiate heat.* It is also defined as the *ratio of the emissive power of any body to the emissive power of a black body of equal temperature* (*i.e.*, $\varepsilon = \frac{E}{E_b}$). Its values varies for different substances ranging from 0 to 1. For a black body $\varepsilon = 1$, for a white body surface $\varepsilon = 0$ and for gray bodies it lies between 0 and 1. It may vary with temperature or wavelength.

11.3. ABSORPTIVITY, REFLECTIVITY AND TRANSMISSIVITY

When incident radiation (G) also called **irradiation** (defined as the *total incident radiation on a surface from all directions per unit time and per unit area of surface; expressed in* W/m² and denoted by (G)) impinges on a surface, three things happens; a part is *reflected* back (G_r), a part is *transmitted* through (G_t) and the remainder is *absorbed* (G_a), depending upon the characteristics of the body, as shown in Fig. 11.2.

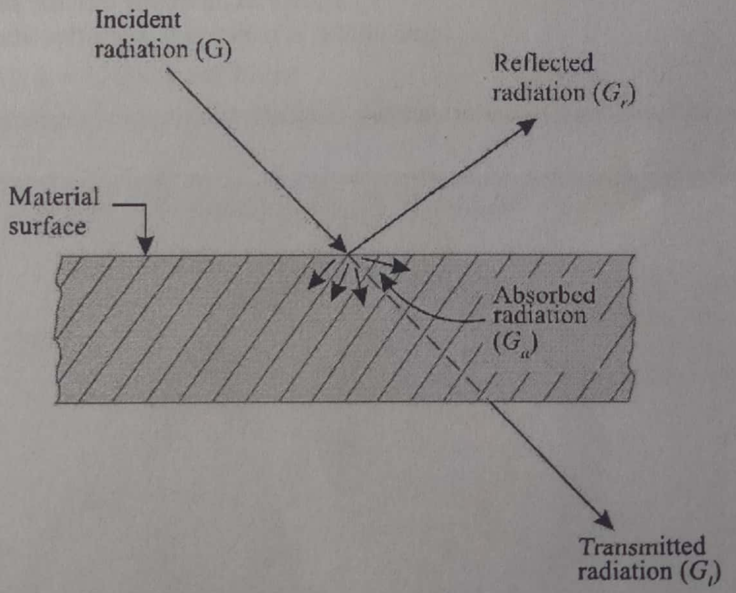


Fig. 11.2. Absorption, reflection and transmission of radiation.

By the conservation of energy principle,

$$G_a + G_r + G_t = G$$

Dividing both sides by G, we get

$$\frac{G_a}{G} + \frac{G_r}{G} + \frac{G_t}{G} = \frac{G}{G}$$

$$\alpha + \rho + \tau = 1 \quad \text{...(11.5)}$$

where α = *absorptivity* (or fraction of incident radiation absorbed),

ρ = *reflectivity* (or fraction of incident radiation reflected), and

τ = *transmittivity* (or fraction of incident radiation transmitted).

When the incident radiation is absorbed, it is converted into internal energy.

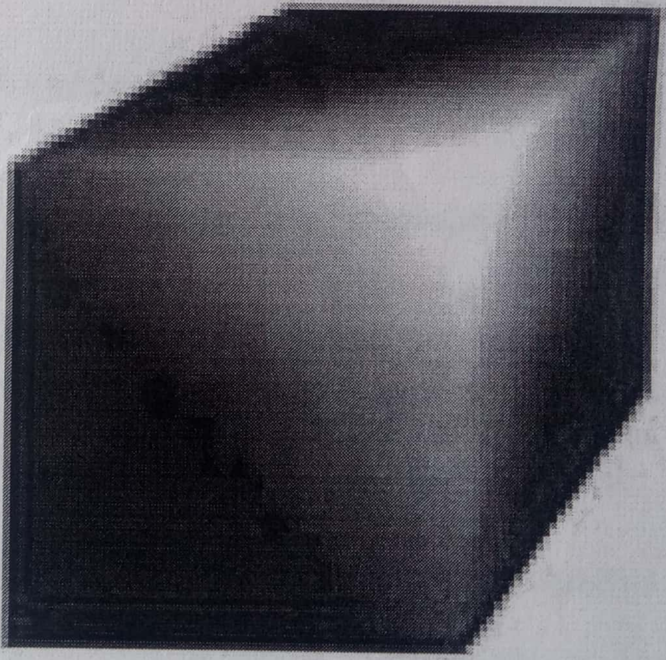
Black body: For perfectly absorbing body, $\alpha = 1, \rho = 0, \tau = 0$. Such a body is called a '*black body*' (i.e., *a black body is one which neither reflects nor transmits any part of the incident radiation but absorbs all of it*). In practice, a perfect black body ($\alpha = 1$) does not exist. However its concept is very important.

Opaque body: When no incident radiation is transmitted through the body, it is called an '*opaque body*'.

For the opaque body $\tau = 0$, and eqn. (11.5) reduces to

$$\alpha + \rho = 1 \qquad \text{...(11.6)}$$

Solids generally do not transmit unless the material is of very thin section. Metals absorb radiation within a fraction of a micrometre, and insulators within a fraction of a millimetre. Glasses and liquids are, therefore, generally considered as opaque.



A black body is theoretical perfect absorber, which absorbs radiation of all wavelength falling on it.

White body: If all the incident radiation falling on the body are reflected, it is called a '*white body*'.

For a white body, $\rho = 1, \alpha = 0$ and $\tau = 0$.

Gases such as hydrogen, oxygen and nitrogen (and their mixtures such as air) have a transmissivity of practically *unity*.

because all the radiant

Regular reflection implies that angle between the reflected beam and the normal to the *surface equals* the angle made by the incident radiation with the same normal. Reflection from highly polished and smooth surfaces approaches specular characteristics.

In a *diffused reflection*, the incident beam is reflected in *all directions*. Most of the engineering materials have rough surfaces, and these rough surfaces give diffused reflections.

Gray body: If the radiative properties, α, ρ, τ of a body are assumed to be uniform over the entire wavelength spectrum, then such a body is called *gray body*. A *gray body* is also defined as one *whose absorptivity of a surface does not vary with temperature and wavelength of the incident radiation* [$\alpha = (\alpha)_\lambda$ = constant.].

A *coloured body* is one whose absorptivity of a surface varies with the wavelength of radiation [$\alpha \neq (\alpha)_\lambda$].

11.4. CONCEPT OF A BLACK BODY

A black body is an object *that absorbs all the radiant energy reaching its surface* (for a black body $\alpha = 1$, $\rho = 0$, $\tau = 0$). No actual body is perfectly black; the concept of a black body is an idealization with which the radiation characteristics of real bodies can be conveniently compared.

A *black body* has the following *properties*:

(*i*) It absorbs all the incident radiation falling on it and does not transmit or reflect regardless of wavelength and direction.

(*ii*) It emits maximum amount of thermal radiations at all wavelengths at any specified temperature.

(*iii*) It is a *diffuse emitter* (*i.e.*, the radiation emitted by a black body is independent of direction).

Consider a hollow enclosure with a very small hole for the passage of incident radiation as shown in Fig. 11.4. Incident radiant energy passes through the small opening; some of this energy is absorbed by the inside surface and some is reflected. However, most of this energy is absorbed on a second incidence. Again, a small fraction is reflected. After a number of such reflections the amount unabsorbed is exceedingly small and very little of the original incident energy is reflected back out of the opening. A small hole leading into a cavity (Hohlraum) thus acts very nearly as a black body because all the radiant energy entering through it gets absorbed.

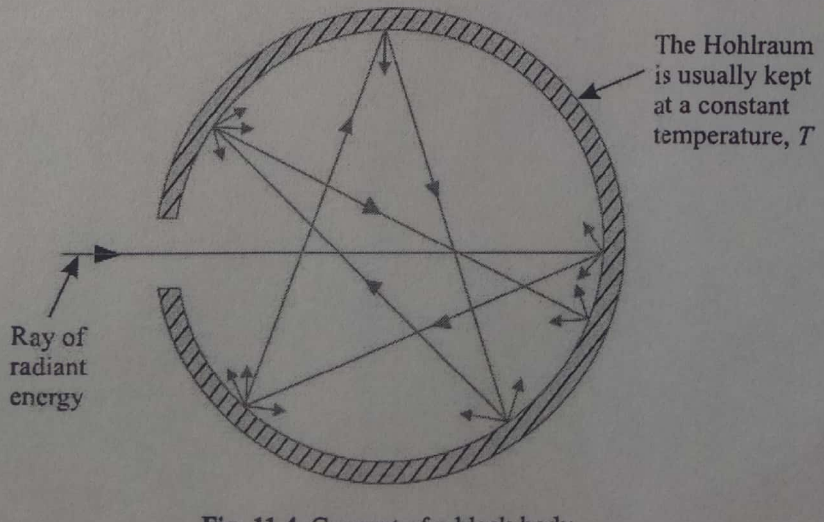


Fig. 11.4. Concept of a black body.

Isothermal furnaces, with small apertures, approximate a black body and are frequently used to *calibrate* heat flux gauges, thermometers and other radiometric devices.

11.5. THE STEFAN-BOLTZMANN LAW

The law states that *the emissive power of a black body is directly proprtional to the fourth power of its absolute temperature.*

i.e., $E_b = \sigma T^4$ ...(11.7)

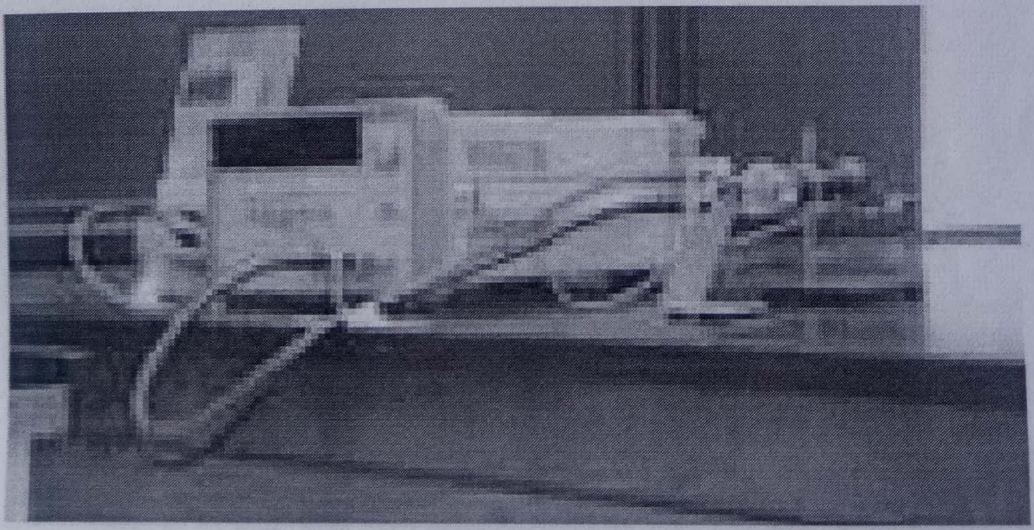
where, E_b = Emissive power of a black body, and

σ = Stefan-Boltzmann constant

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

Equation (11.7) can be rewritten as:

$$E_b = 5.67 \left(\frac{T}{100}\right)^4 \qquad \text{...(11.8)}$$



Experimental setup of Stefan-Boltzmann law

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