

Coefficient of Absorption or absorptivity or absorptance of a body is defined as the ratio of the quantity of radiant energy absorbed by the body in a given time to the quantity of radiant energy incident on the body in the same time.

$$a = \frac{Q_a}{Q} \text{ NO Unit}$$

NOTE: For a perfectly black body $a=1$

Coefficient of Reflection or reflectivity or reflectance of a body is defined as the ratio of the quantity of radiant energy reflected by the body in a given time to the quantity of radiant energy incident on the body in the same time.

$$r = \frac{Q_r}{Q} \text{ NO Unit}$$

NOTE: Polished surfaces are good reflectors and bad absorbers

Coefficient of Transmission or transmissivity or transmittance of a body is defined as the ratio of the quantity of radiant energy transmitted through the body in a given time to the quantity of radiant energy incident on the body in the same time.

$$t = \frac{Q_t}{Q} \text{ NO Unit}$$

NOTE: **Athermanous** substances are those which do not transmit any heat i.e. opaque to heat radiations ($t=0$). Example water, wood, Iron, Copper, Lampblack, moist air, benzene

NOTE: **Diathermanous** substances are those which are transparent to heat radiation (neither good absorbers nor good reflector). Example: glass, quartz, sodium chloride, hydrogen, oxygen, dry air, rock salt

NOTE: Value of a, r and t depends on material of the object as well as the wavelength of incident radiation. Hence, a athermanous or diathermanous object may, at some wavelength, also absorb heat.

Relationship between coefficients of absorption, transmission, reflection

By law of conservation of heat energy, total amount of radiant energy is equal to sum of energy absorbed, reflected and transmitted from the body

$$Q = Q_a + Q_r + Q_t \text{ Dividing both sides by } Q \text{ we get}$$

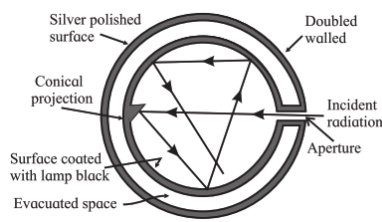
$$1 = \frac{Q_a}{Q} + \frac{Q_r}{Q} + \frac{Q_t}{Q}$$

Thus, $1 = a + r + t$

Perfectly black body (Ferry's Black Body)

A perfectly black body is one which absorbs all the heat energy radiated on it ($a=1, r=0, t=0$). Perfectly black body does not exist in nature, but lampblack, which absorbs 98% of the radiant heat incident on it, can be treated as a perfectly black body.

Ferry's black body is an artificially created black body. It consists of a double walled hollow metal sphere with an aperture (opening). Inner surface is coated with lampblack. There is conical projection exactly opposite to the aperture to avoid direct reflection of the incident radiant energy. The space between the two walls is evacuated to avoid loss of heat by conduction and convection.



The radiant energy enters the sphere and suffers multiple internal reflections. At each reflection about 98% of the radiant heat is absorbed by lampblack. After many multiple reflections, the radiant energy will be completely absorbed. Thus, **the aperture acts as a perfectly black body**.

NOTE: Similar working can be achieved using a cavity radiator that consist of a block of material with internal cavity.

Prevost's Theory

All bodies at temperature above 0K radiate thermal energy and also absorb radiations from its surroundings.

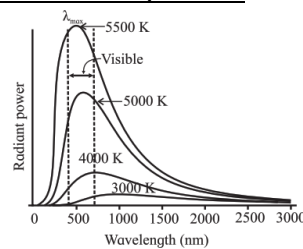
Hot bodies radiate at a higher rate than cooler bodies.

If a body radiates more than what it absorbs then its temperature decreases and vice versa

A body which is in thermal equilibrium with its surroundings, rate of absorption of radiation is same as the rate of emission of radiation.

Nature of black body radiation OR Spectrum of Black Body Radiation

Black body was heated to different temperatures and then allowed to cool. The radiation emitted by a black body is a mixture of many wavelengths. This study was carried out by Lummer and Pringsheim.



- For a given temperature, the intensity of radiation increases with wavelength and for certain wavelength its value is maximum. After that, with the increase in wavelength the intensity of heat radiation decreases.

- The energy emitted at a particular temperature is not uniformly distributed in the different wavelengths
- As the temperature increases, the energy emitted also increases
- The value of λ_m shifts to the shorter wavelength side, with increase in temperature

- The area enclosed by the graph with the X-axis gives the total energy emitted for the whole range of wavelengths of the spectrum at any given temperature. This area is found to increase according to the 4th power of the absolute temperature, i.e. $E \propto T^4$, which is Stefan's law.

Wein's displacement law states that the wavelength for which emissive or radiation power of blackbody is maximum is inversely proportional to the absolute temperature of the black body.

$$\lambda_{\max} \propto \frac{1}{T}$$

Thus, $\lambda_{\max} = \frac{b}{T}$, where $b = \text{Wien's constant} = 2.897 \times 10^{-3} \text{ mK}$

This law is useful in determining very high temperature of distant stars, sun, moon or celestial bodies.

Emissive/Radiant Power:

Every body having temperature above absolute zero, radiates energy to the surroundings. The quantity of radiant energy emitted by the body per unit time per unit surface area of the body at a given temperature is called its emissive or radiant power at that temperature.

$$E = \frac{Q}{At} \text{ , where } Q = \text{amount of radiant energy emitted}$$

$A = \text{surface area of the body}$

$t = \text{time for which the body radiates energy}$

SI Unit: J/m^2s or W/m^2 Dimensions: $[M^1L^0T^{-3}]$

Factors affecting Emissive Power: Temperature of the body, nature of the body, surface area of the body, nature of the surroundings and time.

NOTE: Emissive power of a perfectly black body is always greater than any other body at the same temperature.

Coefficient of emission (emissivity):

It is ratio of emissive power of the body at a given temperature to the emissive power of a perfectly black body at that same temperature.

Thus, $e = \frac{E}{E_b} = \frac{R}{R_b}$, E or $R = \text{emissive power of ordinary body at a given temp.}$
 E_b or $R_b = \text{emissive power of a perfectly black body at same given temperature.}$

For perfectly black body $e=1$

For perfect reflector, $e=0$

For ordinary bodies, $0 < e < 1$

*Thus, good absorbers are good emitter of heat.

*Emissivity is larger for rough surfaces and smaller for smooth and polished surfaces.

*Emissivity, to some extent, varies with temperature and wavelength of radiation.

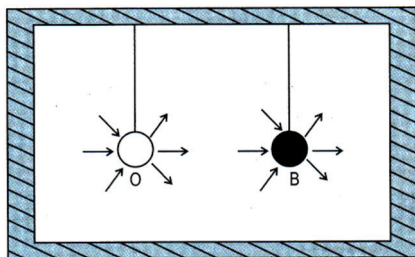
KIRCHHOFF'S LAW of RADIATION:

Kirchhoff's law states that the coefficient of absorption of a body is equal to its coefficient of emission at any given temperature.

$$a=e$$

But, coefficient of emission $e = \frac{E}{E_b}$. Thus, $a = \frac{E}{E_b}$ or $\frac{E}{a} = E_b$

So alternately, Kirchhoff's law can be stated as "At any given temperature, the ratio of the emissive power (E) to the coefficient of absorption (a) is



constant for all bodies and this constant is equal to emissive power (E_b) of a perfectly black body at that temperature.

O: Ordinary body and
B: Perfectly black body

Consider a large enclosed space which is thermally isolated from the surrounding. Such an enclosure is called a uniform temperature enclosure. O and B both have the same area A and are placed in this uniform temperature enclosure.

For O, E : emissive power
 e : coefficient of emission
 a : coefficient of absorption
 Q : the radiant energy incident per unit area per unit time on each body

For B,
 E_b : Emissive power

B will absorb all this incident energy (Q) and energy emitted per unit time per unit area by the perfectly black body B will be E_b .

In order to maintain its temperature

For B,
Energy emitted per unit area per unit time = Energy absorbed per unit area per unit time
 $E_b = Q$ (I)

O too has Q as the incident energy per unit area per unit time and energy absorbed per unit area per unit time is aQ and energy emitted per unit area per unit time by the ordinary body O will be E.

In order to maintain its temperature

For O,
Energy emitted per unit area per unit time = Energy absorbed per unit area per unit time
thus, $E = aQ$ or $Q = E/a$ (II)

Equating I and II we get,

$$E/a = E_b, \text{ thus } a = \frac{E}{E_b}$$

$$\text{But } \frac{E}{E_b} = e, \text{ Therefore, } a = e$$

Coefficient of absorption = Coefficient of emission

Thus Kirchhoff's law is consistent with Zeroth law of thermodynamics.

STEFAN'S LAW of RADIATION:

Stefan's law of radiation states that the amount of radiant energy emitted per unit time per unit surface area of perfectly black body is directly proportional to the fourth power of its absolute temperature.

Let, Q: Amount of radiant energy emitted by perfectly black body

A: Area of the perfectly black body

t: Time for which black body emits radiant energy

T: Absolute temperature of the perfectly black body

According to Stefan's law,

$$\frac{Q}{At} \propto T^4 \text{ or } R_b \propto T^4 \text{ where } R_b = \frac{Q}{At}$$

Where $R_b = E_b =$ emissive or radiation power of a black body

$$\text{Thus, } R_b = \sigma T^4,$$

$$\begin{aligned} \text{where } \sigma &= \text{Stefan's constant} = 5.67 \times 10^{-8} \text{ J/m}^2 \text{ sK}^4 \\ &= 5.67 \times 10^{-8} \text{ W/m}^2 \text{ K}^4 \\ &= 5.67 \times 10^{-5} \text{ erg/cm}^2 \text{ s}^{\circ} \text{ C}^4 \end{aligned}$$

Dimensions of σ are $[M^1 L^0 T^{-3} K^{-4}]$

For an ordinary body, $R = eR_b$ where e is coefficient of emission

For ordinary bodies Stefan's law can be modified as $R = e\sigma T^4$

If the perfectly black body, at temperature T, is placed in surroundings which is at a lower temperature T_0 then the energy radiated per unit time per unit area = σT^4 and the energy absorbed from the surroundings per unit time per unit area will be σT_0^4

Thus the net loss of energy by perfectly black body per unit time per unit area = $\sigma(T^4 - T_0^4)$

For ordinary bodies, the net loss of energy per unit time per unit area = $e\sigma(T^4 - T_0^4)$

NOTES:

- * Radiation does not need material medium
- * Radiation is the fastest mode of transfer of heat
- * Power radiated by a perfectly black body depends only on its temperature ($Q/t = \sigma AT^4$) and not on any other characteristic such as nature of surface, material or colour.
- * **Absorptive Power** : of a body at a given temperature is defined as the amount of radiant energy absorbed per unit area per unit time by a surface at that temperature.
- * A body which absorbs all radiation of all wavelengths would be called perfectly black body.
- * All bodies when heated emit the same kind of radiations which they absorb (called principle of equality of radiating and absorbing powers). Hence black surfaces such as charcoal are very luminous when heated.
- * Since λ_{max} reduces with increase in absolute temperature of the body hence white/yellow iron is hotter than red iron OR blue star is hotter than red star.

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