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.

$$a = \frac{Q_a}{Q}$$, 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.

$$r = \frac{Q_r}{Q}$$, 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.

$$t = \frac{Q_t}{Q}$$, 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

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

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

$Q = Q_a + Q_r + Q_t$, Dividing both sides by Q we get

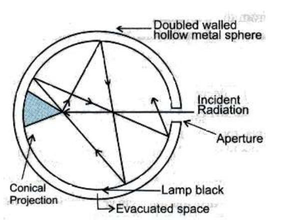
$$1 = \frac{Q_a}{Q} + \frac{Q_r}{Q} + \frac{Q_t}{Q}$$

Thus, $1 = a + r + t$

Perfectly black body (Ferry's Black Body)

A perfectly black body is one which absorbs all the heat energy radiant 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 a aperture (opening). Inner surface is coated with lampblack.

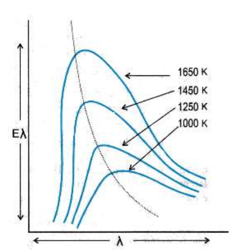


There is conical projection exactly opposite to the aperture to avoid direct reflection of the incident radiant energy. The space between the two walls is evacuated to avoid loss of heat by conduction and convection.

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.

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, ie $E \propto T^4$, which is Stefan's law.

Wein's displacement law states that the wavelength for which emissive 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 = Wien's constant = 2.898 x 10^{-3} mK**

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

Emissive 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 power at that temperature.

$E = \frac{Q}{At}$, where Q = amount of radiant energy emitted
A = surface area of the body
t = time for which the body radiates energy

SI Unit: J/m²s or W/m² 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.

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, $e = \frac{E}{E_b}$ where E=emissive power of ordinary body at a given temp.
E_b=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, e < 1
Thus, good absorbers are good emitter of heat.

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.

NOTE: A body which absorbs all radiation of all wavelengths would be called perfectly black body.

NOTE: 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.

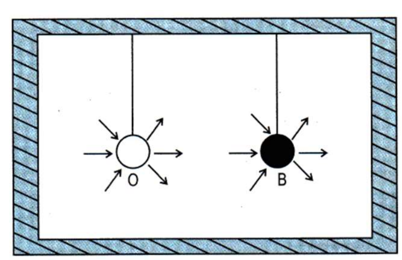
KIRCHHOFF's LAW of RADIATION:

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

For B, E_b: Emissive power

Q: the radiant energy incident per unit time per unit area of each body.
AQ: total radiant energy incident per unit time on each body

B will absorb all this incident energy (AQ) and energy emitted per unit time by the perfectly black body B will be AE_b.
In order to maintain its temperature
For B,
Energy emitted per unit time = Energy absorbed per unit time
$AE_b = AQ$, thus, $E_b = Q$ ……………………(I)

O too has AQ as the incident energy per unit time and energy absorbed per unit time is aAQ and energy emitted per unit time by the ordinary body O will be AE.
In order to maintain its temperature
For O,
Energy emitted per unit time = Energy absorbed per unit time
AE = aAQ, thus, E = aQ or Q = E/a …………..(II)
Equating I and II we get,
$E/a = E_b$, thus $a = \frac{E}{E_b}$

But $\frac{E}{E_b} = e, \quad Therfore, a = e$

Coefficient of absorption = Coefficient of emission
Thus Kirchhoff's law is consistent with Zeroeth 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,

$$\frac{Q}{At} \alpha\, T^4 \quad or \quad E_b \alpha\, T^4 \quad where\ E_b = \frac{Q}{At} = emissive\ powr\ of\ black\ body$$

Thus, $\boldsymbol{E_b = \sigma T^4}$,

$$where\ \sigma = Stefan's\ constant = 5.67\ X\ 10^{-8} J/m^2 s K^4 = 5.67\ X\ 10^{-8} W/m^2 K^4 = 5.67\ X\ 10^{-5} erg/cm^2 s^o C^4$$

Dimensions of σ are [$M^1 L^0 T^{-3} K^{-4}$]
For an ordinary body, $E = eE_b$ where e is coefficient of emission

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

If the perfectly black body, at temperature T, is placed in surroundings which is at a lower temperature T_o 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_o^4

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

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

NEWTON's LAW OF COOLING

Newton's law of cooling states that the rate of loss of heat by the body is directly proportional to the excess of temperature of the body over the surroundings provided the excess is small.

Let θ be the temperature of the body and θ_o be the temperature of the temperature of the surroundings
The rate of loss of heat α $(\theta - \theta_o)$

$$\boldsymbol{\frac{dQ}{dt} = K(\theta - \theta_0)}, where\ K\ is\ constant\ of\ proportionality$$

But Q=msθ where m=mass of the body; s=specific heat of the body

Thus, $\frac{dQ}{dt} = ms\frac{d\theta}{dt}$, $where\ \frac{d\theta}{dt}$ is the rate of fall of temperature

Thus, $\frac{dQ}{dt} = K(\theta - \theta_0)\ becomed\ ms\frac{d\theta}{dt} = K(\theta - \theta_0)$

$$Hence, \frac{d\theta}{dt} = \frac{K}{ms}(\theta - \theta_0) \qquad Hence, \boldsymbol{\frac{d\theta}{dt}\ \alpha(\theta - \theta_0)}$$

Alternative statement of Newton's law of cooling is, the rate of fall of temperature of the body is directly proportional to the excess temperature of the body over surroundings, provided the excess is small.

Limitation:

- It can be used only when the excess temperature of the body over surroundings is small
- This law is not a radiation law since energy is also lost by convection and conduction

GREENHOUSE Effect

Earth's surface absorbs thermal energy from the sun and becomes a source of thermal radiation. The wavelength of this radiation is in infrared region. A large portion of this emitted radiation is absorbed by greenhouse gases CO_2, CH_4, N_2O, chloroflurocarbons and tropospheric ozone O_3, which heats up the atmosphere and gives more energy to earth, resulting in a warmer surface temperature. This further increases the intensity of thermal radiations from the surface of earth. This process repeats till no radiation is available for absorption. This heating of the earth's surface and atmosphere is known as Greenhouse effect. Without Greenhouse effect, the temperature of earth would have been – 18 ºC.
The concentration of these Greenhouses gasses has increased due to human activities. Thus the earth has become warmer on average. This causes many problems to human life, plants and animals, faster melting of the ice caps, rise in sea level and risk of coastal cities getting submerged.