

9. In which of the following processes, convection does not take place primarily ?
(A) sea and land breeze (B) boiling of water
(C) heating air around a furnace (D) warming of glass of bulb due to filament
10. The coefficient of linear expansion of a crystal in one direction is α_1 and that in every direction perpendicular to it is α_2 . The coefficient of cubical expansion is :
(A) $\alpha_1 + \alpha_2$ (B) $2\alpha_1 + \alpha_2$ (C) $\alpha_1 + 2\alpha_2$ (D) None of these

RADIATION**Section - 4**

In radiation, heat is transferred from one body to other or to the surroundings even in the absence of any medium in the intervening space. Heat energy of the sun is transmitted to earth through radiations.

Radiation is only a mode of transfer of energy by transverse electromagnetic waves. While studying heat radiations (Radiant energy), we are concerned with thermal radiations which form the **infra-red region** of electromagnetic waves. All bodies emit heat to the surroundings at all temperatures and at all times. When the temperature of a body remains constant, it emits as much heat to the surroundings as it gains from them. The body is then in a state of **dynamic (thermal) equilibrium**.

Black Body :

A black body may be described as one that completely absorbs the radiations of all wavelengths falling upon it. There is no substance which exactly behaves like a black body as described.

Hollow Enclosure :

A hollow enclosure, kept at constant temperature behaves like a *black body*. If a small hole is made in such a enclosure, it will act as perfectly black body towards the incident radiations. Any ray getting into the enclosure through the hole will be internally reflected not be able to escape. Any radiation coming out of a narrow hole made in a *hollow enclosure* is generally referred to as **black body radiation** or **cavity radiation**.

Emissive Power :

It is the total amount of energy radiated by a body (at a particular temperature) per second per unit area of the surface.

E : energy radiated per second per unit area of the surface.

$$E = \frac{1}{A} \frac{\Delta Q}{\Delta t}$$

where A : surface area, $\frac{\Delta Q}{\Delta t}$: heat radiated per sec from the surface

Stefan's Law :

The energy emitted per second per unit area of a black body (emissive power = E) is proportional to the fourth power of the absolute temperature.

i.e., $E = \sigma T^4$ σ : Stefan's constant = $5.67 \times 10^{-8} \text{ J/m}^2/\text{s/K}^4$.

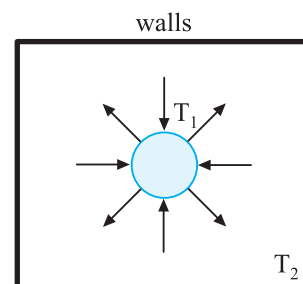
For any other body :

$$E = \epsilon \sigma T^4 \quad \epsilon : \text{emissivity of body} \quad (\epsilon = 1 \text{ for a black body})$$

Net Heat Loss from the Surface of a Body

The rate at which a body radiates energy is determined by the temperature of the body, but the rate at which it absorbs energy by radiation depends on the temperature of its surroundings. When a body is hotter than its surroundings, the rate of emission exceeds the rate of absorption; there is net loss of energy, and the body cools down, unless it is heated by some other means. When a body is cooler than its surroundings, the rate of absorption is greater than the rate of emission, and its temperature rises. At thermal equilibrium the two rates are equal.

Hence for a body at a temperature of T_1 , surrounded by walls at a temperature T_2 (as in figure), the net rate of loss (or gain) of energy per sec by radiation is



$$H_{net} = A \epsilon \sigma T_1^4 - A \epsilon \sigma T_2^4$$

$$H_{net} = A \epsilon \sigma (T_1^4 - T_2^4)$$

Newton's Law of Cooling :

It states that the rate of heat loss from a hot body to the surroundings (dQ/dt) is given by:

$$\frac{dQ}{dt} = kA (\theta - \theta_0) \quad A : \text{surface area} \quad ; \quad k : \text{constant}$$

θ : absolute temperature of body θ_0 : absolute temperature of surroundings

$\theta - \theta_0$: difference in temperature

$$\frac{dQ}{dt} = Ms \frac{d\theta}{dt}$$

M : mass of the body s : specific heat of body

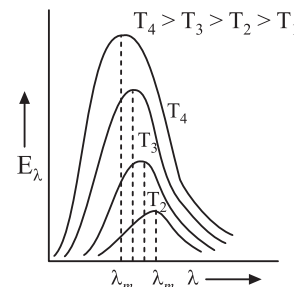
$d\theta/dt$ = rate of fall of temperature (rate of cooling)

$$\Rightarrow Ms \frac{d\theta}{dt} \propto A (\theta - \theta_0)$$

Wien's Law :

The distribution of energy among the wavelengths of radiations emitted from a BLACK BODY was studied by Lummer and Pringsheim. The energy contained over a wide range of wavelengths of radiations emitted by black body is not equally divided. It was found that the relative intensities of different wavelengths depend upon the absolute temperature of the radiator. The energy distribution (E) in the spectrum for the temperature range $893K$ to $1893 K$ was found and plotted against the wavelengths (λ). The general shape of the curve is same for all temperature. From the graph it was analysed that :

- For a particular temperature, the graph is continuous one spreading from a minimum to a maximum at the other end and has a wavelength where the emission is maximum (λ_m).
- As the temperature increases, the minimum cut off wavelength shifts to a lower value and the wavelength where emission is maximum (λ_m) also shifts to a lower value.



He deduced that : $\lambda_m T = \text{constant}$

where λ_m = wavelength corresponding to maximum energy at a particular temperature

The value of constant is $2.9 \times 10^{-3} m K = 0.29 cm K$. The above statement is known as *Wien's Displacement Law*.

Illustration - 22 The emissivity of tungsten is approximately 0.35. A tungsten sphere 1 cm in radius is suspended within a large evacuated enclosure whose walls are at 300 K. What power input is required to maintain the sphere at a temperature of 3000 K if heat conduction along the supports is neglected ? $\sigma = 5.67 \times 10^{-8} S.I. \text{ units}$.

SOLUTION :

Net heat lost by sphere per second

$$H_{net} = \epsilon \sigma A (T^4 - T_0^4)$$

where T = temperature of sphere = 3000 K

T_0 = temperature of surrounding = 300K

$$A = 4 \pi r^2 = 4 \pi (0.01)^2$$

To maintain constant temperature,

Power input required = net heat loss per sec from the surface

$$P_{input} = \epsilon \sigma A (T^4 - T_0^4)$$

$$P_{input} = 0.35 \times 5.67 \times 10^{-8} \times 4 \pi (0.01)^2 \times (3000^4 - 300^4) \\ = 2019.8 \text{ watts.}$$

Illustration - 23 Two solid copper spheres of radii $r_1 = 15 \text{ cm}$ and $r_2 = 20 \text{ cm}$ are both at a temperature of 60°C . If the temperature of surroundings is 50°C , then find :

- (a) the ratio of the heat loss per second from their surfaces initially. (b) the ratio of rates of cooling initially.

SOLUTION :

$$(a) \text{ The ratio of heat loss } = \frac{H_1}{H_2} = \frac{(dQ/dt)_1}{(dQ/dt)_2}$$

$$\Rightarrow \frac{H_1}{H_2} = \frac{K A_1 (60 - 50)}{K A_2 (60 - 50)}$$

(by using Newton's Law of cooling)

$$\Rightarrow \frac{H_1}{H_2} = \frac{A_1}{A_2} = \frac{r_1^2}{r_2^2} = \left(\frac{15}{20}\right)^2 = \frac{9}{16}$$

$$(b) \text{ The ratio of initial rates of cooling } = \frac{(d\theta/dt)_1}{(d\theta/dt)_2}$$

We have $\frac{H_1}{H_2} = \left(\frac{r_1}{r_2}\right)^2$

$$\Rightarrow \frac{M_1 s (d\theta/dt)_1}{M_2 s (d\theta/dt)_2} = \left(\frac{r_1}{r_2}\right)^2 \Rightarrow \frac{(d\theta/dt)_1}{(d\theta/dt)_2} = \left(\frac{r_1}{r_2}\right)^2 \frac{M_2}{M_1}$$

$$= \left(\frac{r_1}{r_2}\right)^2 \left(\frac{r_2}{r_1}\right)^3 = \frac{r_2}{r_1} = \frac{20}{15} = \frac{4}{3}$$

As the spheres have the same densities, the ratio of their masses is equal to the ratio of their volumes.

Illustration - 24 Two identical spheres A and B are suspended in a vacuum chamber which is maintained at a temperature of 50°C . Find the ratio of the heat lost per sec. from the surfaces of the spheres if :

- (a) A and B are at temperatures 60°C and 55°C respectively.
 (b) A and B are at temperatures 250°C and 200°C respectively.

SOLUTION :

Net heat loss per sec. per unit area
 $= \epsilon \sigma (T^4 - T_0^4)$ from Stefan's Law

If $T - T_0$ is small as compared to the temperature of surroundings, we have :

Net heat loss per sec. per unit area
 $= (\text{constant}) \times (T - T_0)$
 (From Newton's Law of cooling)

- (a) Here the temperature difference is small and hence we can use Newton's Law of cooling.

$$\Rightarrow E_A \propto (60 - 50) \quad \text{and} \quad E_B \propto (55 - 50)$$

Hence $\frac{E_A}{E_B} = \frac{10}{5} = 2$

- (b) As the temperature difference is not negligible as compared to the temperature of surrounding, we use Stefan's Law for accurate answer.

$$E_A \propto (250 + 273)^4 - (50 + 273)^4$$

$$E_B \propto (200 + 273)^4 - (50 + 273)^4$$

Hence $\frac{E_A}{E_B} = \frac{523^4 - 323^4}{473^4 - 323^4} = 1.632$

Illustration - 25 A body cools down from 60°C to 55°C in 30 seconds. Using Newton's Law of cooling, calculate the approximate time taken by same body to cool down from 55°C to 50°C . Assume that the temperature of surroundings is 45°C .

SOLUTION :

Assume that a body cools down from temperature θ_i to θ_f in t seconds, and θ_0 is the temperature of surroundings.

Applying Newton's Law of cooling,

According to Newton's Law of cooling,

$$\frac{d\theta}{dt} = -K(\theta - \theta_0) \quad ; \quad \theta_0 = 45^\circ\text{C}$$

$$\int \frac{d\theta}{\theta - 45} = -K \int dt \quad (k \text{ is a constant.})$$

From $t = 0^\circ\text{C}$ to $t = 30\text{s}$, θ changes from 60°C to 55°C .

$$\Rightarrow \int_{60}^{55} \frac{d\theta}{\theta - 45} = -K \int_0^{30} dt \quad \dots\dots\dots\text{(i)}$$

$$\int_{55}^{50} \frac{d\theta}{\theta - 45} = -K \int_{30}^t dt \quad \dots\dots\dots\text{(ii)}$$

Divide (ii) by (i) to get :

$$\frac{t-30}{30} = \frac{\log \frac{50-45}{55-45}}{\log \frac{55-45}{60-45}}$$

$$\frac{t-30}{30} = \frac{\log 2}{\log 3/2}$$

$$t = 30 \left(1 + \frac{\log 2}{\log 3/2} \right) = 81.28 \text{ s}$$

Time from $\theta = 55^\circ\text{C}$ to $\theta = 50^\circ\text{C}$ is $(t-30)$

$$= (81.28-30) = 51.28 \text{ s}$$

Alternate Method : (for approximately answer)

$$\frac{d\theta}{dt} \propto (\theta - \theta_0) \Rightarrow \frac{\Delta\theta}{\Delta t} \propto (\theta_{av} - \theta_0)$$

$$\frac{60-55}{30} \propto \left(\frac{60+55}{2} - 45 \right)$$

$$\frac{55-50}{t} \propto \left(\frac{55+50}{2} - 45 \right)$$

Divide to get :

$$\frac{5/30}{5/t} = \frac{57.5-45}{52.5-45} \Rightarrow t = 50 \text{ s}$$

Illustration - 26 Three discs A, B and C having radii 2, 4 and 6 cm respectively are coated with carbon black. Wavelengths for maximum intensity for the three discs are 300, 400 and 500 nm respectively. If Q_A , Q_B and Q_C are power emitted by A, B, and C respectively, then :

- (A) Q_A will be maximum (B) Q_B will be maximum
(C) Q_C will be maximum (D) $Q_A = Q_B = Q_C$

SOLUTION : (B)

By Wien's Law,

$$\lambda_{\max} T = \text{constant}$$

$$\Rightarrow \lambda_1 T_1 = \lambda_2 T_2 = \lambda_3 T_3$$

$$\text{Let } 3T_1 = 4T_2 = 5T_3 = a$$

By Stefan's Law,

$$Q = \sigma AT^4 \Rightarrow Q \propto r^2 T^4$$

$$\Rightarrow \frac{Q_A}{r_1^2 T_1^4} = \frac{Q_B}{r_2^2 T_2^4} = \frac{Q_C}{r_3^2 T_3^4}$$

$$\frac{3^4 Q_A}{2^2 a^4} = \frac{4^4 Q_B}{4^2 a^4} = \frac{5^4 Q_C}{6^2 T_3^4}$$

$$81Q_A = 64Q_B = \frac{625}{9}Q_C$$

$$\Rightarrow Q_B \text{ is maximum (B is correct)}$$

Illustration - 27 Two bodies A and B have thermal emissivities of 0.01 and 0.81 respectively. The outer surface areas of the two bodies are the same. The two bodies radiate energy at the same rate. The wavelength λ_B , corresponding to the maximum spectral radiance in the radiation from B, is shifted from the wavelength corresponding to the maximum spectral radiance in the radiation from A by $1.00 \mu\text{m}$. If the temperature of A is 5802 K :

- (A) the temperature of B is 1934 K (B) $\lambda_B = 1.5 \mu\text{m}$
(C) the temperature of B is 11604 K (D) the temperature of B is 2901 K

SOLUTION : (AB)

$$T_A = 5802 \text{ K.}$$

By Stefan's Law,

$$\text{Energy radiated per sec} = \epsilon \sigma AT^4$$

$$\Rightarrow \epsilon_A \sigma AT_A^4 = \epsilon_B \sigma AT_B^4$$

$$0.01 T_A^4 = 0.81 T_B^4$$

$$T_A = 3T_B \Rightarrow T_B = 1934 \text{ K.}$$

By Wien's Law,

$$\lambda_A T_A = \lambda_B T_B$$

$$3\lambda_A = \lambda_B$$

We also have $\lambda_B - \lambda_A = 1 \mu m$

$$\Rightarrow 3\lambda_A - \lambda_A = 1$$

$$\Rightarrow \lambda_A = 0.5 \mu m$$

$$\text{and } \lambda_B = 1.5 \mu m$$

Hence A and B are correct answers.

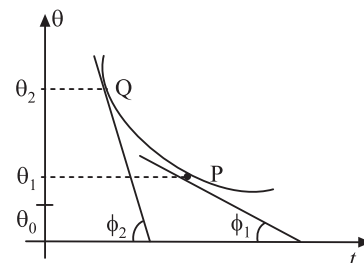
Illustration - 28 A body cools in a surrounding which is at a constant temperature of θ_0 . Assume that it obeys Newton's law of cooling. Its temperature θ is plotted against time t . Tangents are drawn to the curve at the points $P(\theta = \theta_1)$ and $Q(\theta = \theta_2)$. These tangents meet the time axis at angle of ϕ_2 and ϕ_1 as shown. Then:

$$(A) \quad \frac{\tan \phi_2}{\tan \phi_1} = \frac{\theta_1 - \theta_0}{\theta_2 - \theta_0}$$

$$(B) \quad \frac{\tan \phi_2}{\tan \phi_1} = \frac{\theta_2 - \theta_0}{\theta_1 - \theta_0}$$

$$(C) \quad \frac{\tan \phi_1}{\tan \phi_2} = \frac{\theta_1}{\theta_2}$$

$$(D) \quad \frac{\tan \phi_1}{\tan \phi_2} = \frac{\theta_2}{\theta_1}$$



SOLUTION : (B)

$$\tan \phi = \text{slope of tangent} = \frac{d\theta}{dt} = \text{rate of cooling}$$

By Newton's Law of cooling, $\frac{d\theta}{dt}$ is proportional to temperature difference between body and surroundings.

$$\left. \frac{d\theta}{dt} \right|_{at P} \propto (\theta_1 - \theta_0)$$

$$\left. \frac{d\theta}{dt} \right|_{at Q} \propto (\theta_2 - \theta_0)$$

$$\Rightarrow \frac{\tan \phi_2}{\tan \phi_1} = \frac{\theta_2 - \theta_0}{\theta_1 - \theta_0}$$

$\Rightarrow$ B is correct.

IN-CHAPTER EXERCISE - B

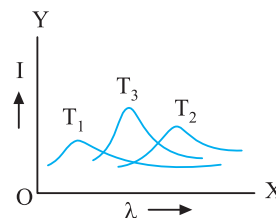
1. A small blackened solid copper sphere of radius 2 cm is placed in an evacuated enclosure whose walls are kept at $100^\circ C$. At what rate must energy be supplied to the sphere to keep its temperature constant at $127^\circ C$?
 $\sigma = 5.67 \times 10^{-8}$ in S.I. units.

Choose the correct alternative. Only One choice is Correct.

2. The plots of intensity versus wavelength for three bodies at temperature T_1 , T_2 and T_3 respectively are as shown. Their temperatures are such that :

$$(A) \quad T_1 > T_2 > T_3 \quad (B) \quad T_1 > T_3 > T_2$$

$$(C) \quad T_2 > T_3 > T_1 \quad (D) \quad T_3 > T_2 > T_1$$



3. An ideal Black-body at room temperature is thrown into a furnace. It is observed that :
 (A) initially it is the darkest body and at later time the brightest
 (B) it is the darkest body at all time
 (C) it cannot be distinguished at all time
 (D) initially it is the darkest body and at later times it cannot be distinguished

4. MATCH THE COLUMN:

Column - I

- (A) Ice formation in a lake
 (B) The mode not associated with solids
 (C) Water heated in a round bottomed flask
 (D) Land breeze

Column - II

- (P) Molecular transfer leads to uniform heat content
 (Q) Heat transfer by convection
 (R) Time taken is inversely proportional to ambient temperature.
 (S) Process of heat transfer by conduction

5. A planet is at an average distance d from the sun, and its average surface temperature is T . Assume that the planet receives energy only from the sun, and loses energy only through radiation from its surface. Neglect atmospheric effects.

If $T \propto d^{-n}$, the value of n is :

- (A) 2 (B) 1 (C) $1/2$ (D) $1/4$

6. A system S receives heat continuously from an electrical heater of power 10 W. The temperature of S becomes constant at 50°C when the surroundings temperature is 20°C . After the heater is switched off, S cools from 35.1°C to 34.9°C in 1 minute.

The heat capacity of S is :

- (A) $100\text{ J}^\circ\text{C}$ (B) $300\text{ J}^\circ\text{C}$ (C) $750\text{ J}^\circ\text{C}$ (D) $1500\text{ J}^\circ\text{C}$

ELASTICITY

Section - 5

The **deforming force** is the external force applied to a body which tends to change the size or shape of the body. Under the action of deforming force, a body opposes any change in its shape and size due to the net effect of internal molecular forces. The resulting force which opposes the deformation is known as restoring force.

Illustration the concept :**When one tries to stretch a spring**

- The force acting on the spring (F_1) is the deforming force.
- The force exerted by the spring to oppose the deforming action is the restoring force (F_2).
- By Newton's third Law, we can say that F_1 and F_2 are equal and opposite forces ; forming an Action- Reaction pair.

The property of a body due to which it opposes the action of the deforming forces is called as **Elasticity**.

- A material is said to be elastic if it returns back to its original shape or size, when the deforming forces are removed. Plastic materials on the other hand, remain permanently distorted when the deforming forces are removed.
- There are a number of elastic moduli (young's modulus, bulk modulus, shear modulus) that measure the response of an elastic solid which is acted upon by the deforming forces.
- The deforming force is measured (described) in terms of a physical quantity, the stress, that it develops in the body. The deformation of the solid is described in terms of a physical quantity the strain, that is created in the body as a result of deformation force.
- First, we will define the mathematical meaning of the stress and strain.