HEAT TRANSFER

1. In general heat travels from one point to another whenever there is a difference of temperatures.
2. Heat flows from a body at higher temperature to a lower temperature.
3. Heat is transferred or propagated by three distinct processes, conduction, convection and radiation.
4. **Conduction :** It is a process in which the heat energy is transferred from a particle to particle, without the particles leaving the mean positions but vibrating with amplitudes which depend on the temperature. For conduction the medium is actively involved.
5. The substances through which heat is easily conducted or for which the rate of conduction is large are good conductors of heat. All metals are good conductors of heat. In metals thermal conduction is due to vibration of the atoms and free electrons.
6. The substances which do not conduct heat easily are bad conductors. The substances like cork, wood, cotton, wool are bad conductors. Almost all gases and liquids (except mercury) are poor conductors of heat. The bad conductors do not have the free electrons, therefore, they cannot conduct heat. Whatever little heat they can conduct is by vibrations of the molecules.

Coefficient of thermal conductivity :

7. In steady state, the amount of heat Q transmitted through a conductor is directly proportional to

   i) the temperature difference between the faces $(\theta_2 - \theta_1)$°C.

   ii) the area of the cross-section of the slab A.

   iii) the time of the flow of heat t.

   iv) inversely proportional to the distances between the two faces "d".

   $$Q \propto \frac{A(\theta_1 - \theta_2)t}{d}$$

   $$Q = \frac{KA(\theta_1 - \theta_2)t}{d};$$

   $$\left(\frac{Q}{t}\right) = \frac{\theta_1 - \theta_2}{(d/KA)}$$

   Where K is a constant that depends upon the nature of the material of the rod and is known as **coefficient of thermal conductivity**.
8. The value of K depends on temperature, increasing slightly with increasing temperature, but K can be taken to be practically constant

through out a substance if the temperature difference between its ends is not too great.

9. Coefficient of thermal conductivity is defined as the quantity of heat flowing per second across a cube of unit edge when its opposite faces have a temperature difference of 1°C. Unit of K is cal/cm/s/°C or $Wm^{-1}K^{-1}$.
10. The dimensional formula of K is $M^1L^1T^{-3}K^{-1}$.
11. **Temperature gradient :** Rate of change of temperature with distance is called temperature gradient.
12. Thermal conductivity of a good conductor is determined by Searle's apparatus or Forbe's method.
13. Thermal conductivity of a bad conductor is determined by Lee's method.
14. When conduction takes place through two layers of a composite wall with different thermal conductivities, then

$$\frac{Q}{t} = \frac{K_1A(\theta_1 - \theta)}{d_1} = \frac{K_2A(\theta - \theta_2)}{d_2};$$

$$\frac{Q}{t} = \frac{(\theta_1 - \theta_2)A}{\frac{d_1}{K_1} + \frac{d_2}{K_2}}$$

where θ is common temperature or interface temperature.

Interface temperature= $\dfrac{\frac{K_1\theta_1}{d_1} + \frac{K_2\theta_2}{d_2}}{\frac{K_1}{d_1} + \frac{K_2}{d_2}}$

15. If two slabs of thicknesses d_1 and d_2 and of thermal conductivities K_1 and K_2 are placed in contact, then the combination behaves as a single material of thermal conductivity K and is given by

K= $\dfrac{(d_1 + d_2)K_1K_2}{K_1d_2 + K_2d_1}$ or K= $\dfrac{d_1 + d_2}{\frac{d_1}{K_1} + \frac{d_2}{K_2}}$.

16. If three slabs have the same length and have cross-sectional areas A_1, A_2, A_3 respectively and when heat flows from the upper surface to the lower without loss of heat, then the equivalent conductivity K is given by

K= $\dfrac{K_1A_1 + K_2A_2 + K_3A_3}{A_1 + A_2 + A_3}$

17. The **thermometric conductivity or diffusivity** is defined as the ratio of the coefficient of thermal conductivity to the thermal capacity per unit volume of the material.

Thermal capacity per unit volume$=\left(\frac{m}{V}\right)s=\rho s$ where ρ is density of substance.

$\therefore$ Diffusivity $D=\frac{K}{\rho s}$

18.

Heat flow through a conducting rod	Current flow through a resistance
Heat current H $=\frac{dQ}{dt}$ = rate of heat flow $H=\frac{\Delta T}{R}=\frac{T.D.}{R}$ $R=\frac{l}{KA}$ K=thermal conductivity	Electric current i $=\frac{dq}{dt}$ = rate of charge flow $i=\frac{\Delta V}{R}=\frac{P.D}{R}$ $R=\frac{l}{\sigma A}$ σ=electrical conductivity

19. Thermal resistance of metal rod $R=\frac{L}{K.A}$ where L=length of the rod; A=area of cross-section, K=coefficient of thermal conductivity.
20. Unit of thermal resistance is KW^{-1}.
21. If different rods are connected in series, then heat flowing per second is same, i.e., $H_1=H_2=H_3$ and the net thermal resistance $R=R_1+R_2+R_3+\ldots$
22. If different rods are connected in parallel, then the net resistance R is given by $\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}+....$
23. Thermal resistivity is the reciprocal of thermal conductivity.
24. **Ingen-Haux experiment** is used to compare thermal conductivities of different materials. If L_1 and L_2 are the lengths of wax melted on rods of thermal conductivities K_1 and K_2, then
$$\frac{K_1}{K_2}=\frac{L_1^2}{L_2^2}$$
25. When the temperature falls below 0°C say to $-\theta$°C, the time taken for the thickness of ice growing from x_1 cm to x_2 cm on a lake is given by $t=\frac{\rho L}{2K\theta}(x_2^2-x_1^2)$ where ρ density of ice, K=coefficient of thermal conductivity of ice, L=latent heat of fusion of ice.

26. **Convection :** The transmission of heat from one part to another by the actual transfer of particles of matter is known as *convection*.
27. Although conduction does occur in liquids and gases also, heat is transported in these media mostly by convection.
28. Convection is the natural way of heat transmission in fluids. The region of a fluid when heated expands, becomes less dense and rises to the other parts of the fluids there by carrying heat.
29. Convection is a quicker process than conduction. For convection molecules must be relatively free.
30. A wind is a convection current in the atmosphere caused by unequal heating.
31. Trade winds and monsoons are convection currents on a global scale.
32. Near sea shore after the sun rise, the direction of wind is from sea towards the land (sea breeze) and after the sun set the direction of wind is from the land towards the sea (land breeze).
33. Types of convection : Convection is of two types.
    a) free convection or natural convection
    b) forced convection
34. Free or natural convection takes place in the still fluid, in this process the motion of the fluid particles will be due to their getting heated by the hot body.

    e.g., hot air rises by natural convection.

    In general natural convection is a consequence of gravity and always takes place vertically carrying the heat upwards.
35. Forced convection takes place when steady stream of air is sent past the hot air.

    E.g., cool air from open window enters the room and sends the hot air through ventilators.

RADIATION :

36. It is the process of transmission of heat from one place to another without any material medium.
37. It is a quick process than conduction and convection.
38. In this process medium is not heated.
39. **Thermal radiation :** The heat energy transferred between the objects without the help of any medium is known as thermal radiation or radiant energy. (or)

    Heat energy transferred by means of electromagnetic waves is thermal radiation.
40. Nature and properties of radiant energy :

i) It consists of long wavelength electromagnetic radiation.
ii) The wavelength of these waves is nearly 800 nm to 4,00,000 nm.
iii) It occupies the infrared region of the electromagnetic spectrum.
iv) It can be transmitted through vacuum.
v) These waves propagate in vacuum with a velocity 3×10^8 ms^{-1} like light waves.
vi) It obeys laws of reflection, refraction, interference, polarization and diffraction.
vii) The intensity of radiant energy obeys inverse square law.

41. Detectors of radiant energy :

i) To detect radiant energy Bolometer, thermopile, radiomicrometer, pyrometer are used.
ii) By using surface Bolometer radiation coming from the surface of a body is measured.
iii) By using linear Bolometer, the distribution of energy in a black body spectrum can be explained.
iv) Bolometer works on the principle that the resistance changes with temperature.

42. **Prevost's theory of heat exchanges :**

i) Every object emits and absorbs radiant energy at all temperatures except at absolute zero.

ii) The energy emitted by a body does not depend on the temperature of the surroundings.

iii) The rate of emission increases with the increase in the temperature of the body.

iv) If the body emits more energy than absorbed its temperature decreases.

v) If the body absorbs more radiant energy than it emits, its temperature increases.

vi) If two bodies continuously emit and absorb same amount of energy, then they are in dynamical thermal equilibrium.

43. The radiant energy emitted by a body depends on

a) the nature of the surface

b) surface area

c) temperature of the body

44. **Emissive power (e_λ) :**

i) The amount of energy emitted per second per unit surface area of a body at a given temperature for a given wavelength range (λ and $\lambda+d\lambda$) is called emissive power.

ii) At a given temperature if the radiations emitted have a wavelength difference $d\lambda$, then the emissive power is equal to $e_\lambda d\lambda$.

iii) S.I unit of emissive power is Wm^{-2} and its dimensional formula is MT^{-3}.

45. **Emissivity (e) :** The ratio of radiant energy emitted by a surface to radiant energy emitted by a black body under same conditions is called emissivity.

i) for a perfect black body emissivity e=1.

46. Absorptive power (a_λ) ;

i) At a given temperature, for a given wavelength range, the ratio of energy absorbed to the energy incident on the body is absorptive power.

$$a_\lambda = \frac{\text{Amount of radiant energy absorbed}}{\text{Amount of radiant energy incident}}$$

ii) For a perfect black body, the absorptive power, $a_\lambda=1$.

iii) A surface can have different absorptive powers for different wavelengths.

iv) Whenever radiant energy is incident on a surface, a part of it is absorbed, a part of it is reflected and the remaining part is transmitted through it.

47. Reflecting power (r) :

$$r = \frac{\text{Amount of radiant energy reflected}}{\text{Amount of radiant energy incident}}$$

48. Transmitting power (t) :

$$t = \frac{\text{Amount of energy transmitted}}{\text{Amount of radiant energy incident}}$$

49. $a_\lambda + r + t = 1$

Here $a\lambda$ is absorptive power, r is reflecting power and t is the transmitting power.

50. Perfect black body :

i) A body which completely absorbs all the heat radiation incident on it is called a perfect black body.

ii) Fery's black body and wien's black body are examples of artificial black bodies.

iii) A furnace coated with lampblack or platinum black absorbs about 98% of the radiation incident on it.

iv) A perfect black body is a good absorber and also a good emitter of heat.

v) The reflecting power of a black body is zero.

51. **Kirchoff's law :**

i) The ratio of emissive power to absorptive power of a substance is constant.

ii) This constant is equal to the emissive power of a perfect black body at the given temperature and wavelength.

i.e., $\frac{e_\lambda}{a_\lambda} = \text{constant} = E_\lambda$

where E_λ is the emissive power of perfect black body, e_λ and a_λ are emissive and absorptive powers of a given substance respectively.

iii) Good absorbers are good emitters.

iv) Poor absorbers are poor emitter.

52. Applications of Kirchhoff's law :

i) A piece of blue glass absorbs red wavelengths at ordinary temperature. When it is heated strongly and cooled it appears brighter than a piece of red glass.

ii) A piece of yellow glass absorbs blue wavelengths at ordinary temperatures when heated in dark room it appears blue because it emits blue colour.

iii) Fraunhoffer lines in solar spectrum can be explained on the basis of Kirchhoff's law. They are absorption lines.

iv) Black surfaces are good absorbers and so good emitters but bad reflectors.

v) Highly polished surfaces are bad absorbers and so bad emitters but good reflectors.

53. **Stefan's law :**

i) The amount of heat radiated by a black body per second per unit area is directly proportional to the fourth power of its absolute temperature.

$E \alpha T^4 \Rightarrow E = \sigma T^4$

where σ =stefan's constant

$=5.67 \times 10^{-8}\ Wm^{-2}k^{-4}$

ii) Dimensional formula of stefan's constant is $MT^{-3}T^{-4}$.

iii) Radiant energy emitted by a hot body per second=$eA\sigma T^4$ where e is the emissivity of the hot body, A its surface area, T its absolute temperature and σ the Stefan's constant.

iv) If the surface area of a body is more, it emits more heat energy. Hence it cools quickly.

v) A hot copper cube cools in a lesser time compared to a hot copper sphere of same mass because of least surface area for sphere.

vi) Stefan's law holds good when the surrounding medium of the black body is vacuum.

54. **Stefan-Boltzmann's law :**

If a black body at absolute temperature T is surrounded by an enclosure at absolute temperature To, then the rate of loss of heat energy by radiation per unit area is given by E=$\sigma(T^4 - T_o{}^4)$

55. **Newton's law of cooling :**

The rate of cooling of a hot body is directly proportional to the mean excess of temperature of the body above the surroundings, provided the difference in temperature of the body and the surroundings is small.

$\frac{d\theta}{dt} = K\left(\frac{\theta_1 + \theta_2}{2} - \theta_s\right)$ where K = $\frac{4A\sigma\theta_s^3}{ms}$

here $\frac{d\theta}{dt}$=Rate of cooling.

θ_1, θ_2 are the initial and final temperature of the body respectively. θ_s is temperature of surroundings and K is the cooling constant.

- Newtons law of cooling is applicable when (i) the heat lost by conduction is negligible and heat lost by the body is mainly by convection (ii) the hot body is cooled in uniformly stream lined flow of air or forced convection (iii) the temperature of every part of the body is same.
- Newtons law holds good for small temperature differences upto 30°C. In case of forced convection the law holds good for large difference of temperatures.

i) Rate of loss of heat of a hot body due to cooling $\frac{dQ}{dt} = ms\frac{d\theta}{dt}$

Here m = mass of the body
s = specific heat of the body

ii) Specific heat of a liquid can be determined using Newton's law of cooling.

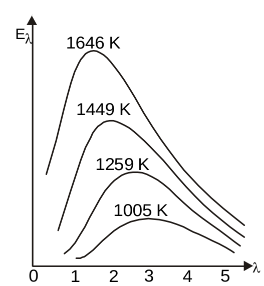
iii) If m_1, m_2 and m_3 are masses of the calorimeter, water and liquid, s_1, s_2 and s_3 are the specific heats of the calorimeter, water and liquid and t_1 and t_2 are the times taken by water and liquid to cool from θ_2 to θ_1°C, then $\frac{m_1s_1 + m_2s_2}{m_1s_1 + m_3s_3} = \frac{t_1}{t_2}$.

iv) Newton's law of cooling is a law connected with the process of convection.

v) It can be deduced from Stefan Boltzmann's law of radiation.

vi) A cube, a sphere, a circular plate of same material and same mass are heated to the same high temperature. Among them the sphere cools at the lower rate because of its least surface area.

56. Distribution of energy in black body spectrum :



i) The energy emitted by a black body contains large number of wavelengths.

ii) Energy emitted by a black body is not distributed uniformly among different wavelengths.

iii) At a given temperature, the energy increases with increasing wavelength and reaches a maximum value λ_m and decrease thereafter with increase in wavelength.

iv) As the temperature of black body increases, λ_m the wavelength corresponding to maximum energy decreases and shifts towards the shorter wavelength region.

v) The area under each curve represents total energy emitted by a black body at a particular temperature. The energy distribution curves can be explained by different laws of black body radiation like Wien's displacement law, Stefan's law, Ray Leigh-Jean's law and Planck's law.

vi) It can be deduced from Stefan Boltzmann's law of radiation.

57. **Wien's displacement law :**

The wavelength λ_m corresponding to maximum energy emitted by a black body is inversely proportional to its absolute temperature.

$\lambda_m T$=constant.

The value of constant is 2.9×10^{-3} mK.

i) Radiation emitted by a black body normally per unit surface area per second in unit wavelength range is known as its "monochromatic emissive power".

ii) Wien's energy temperature displacement law states that monochromatic energy density, E_m of the radiation of black body is proportional to the fifth power of its absolute temperature.

$E_m T^{-5}$=constant.

58. **Wien's formula :**

The amount of energy contained in a spectral region between wavelength, λ and $\lambda+d\lambda$ is given by $E_\lambda d\lambda = \frac{A\lambda^{-5}}{e^{b/\lambda T}} d\lambda$. Where A, b are constants.

i) Wien's law is valid only for shorter wavelengths.

59. **RayLeigh-Jean's law :**

The amount of energy contained in a spectral region between wavelengths, λ and $\lambda+d\lambda$ is given by $E_\lambda d\lambda = \frac{8\pi KT}{\lambda^4} d\lambda$.

where K = Boltzmann's constant.

i) Rayleigh-Jean's law holds good for longer wavelengths only.

ii) Planck's law :

iii) The entire region of black body radiant energy spectrum can be successfully explained by quantum theory proposed by Max Planck.

iv) Quantum theory proposes that any black body chamber contains simple harmonic oscillators of molecular dimensions.

v) The simple harmonic oscillators can absorb or emit energy (E) in discrete amounts only.

vi) The energy emitted in the form of discrete packets is proportional to its frequency i.e., $E \alpha \upsilon \Rightarrow E = h\upsilon$ where h = Planck's constant = 6.625×10^{-34} Js.

60. **Planck's radiation law :**

The amount of energy contained in a spectral region between wavelengths λ and $\lambda + d\lambda$ is given by $E_\lambda d\lambda = \frac{8\pi hc}{\lambda^5\left[e^{\frac{hc}{\lambda KT}} - 1\right]} d\lambda$

61. **Diathermanous substances :**

The substances which allow the heat radiations to pass through them without getting themselves heated are called "diathermanous" substances.

Ex : air, rock salt, fluorspar.

62. **Athermanourl substances :**

The substances which do not allow the heat radiations to pass through them, but absorb heat and get themselves heated are called "athermanous" substances. Ex : glass, moist air, water, wood.

i) Out of a rough black surface and polished black surface, the rough black surface emits more radiant energy than the polished black surface.

ii) Cloudy day is cooler than clear day and cloudy night is warmer than clear night because moist air is athermanous.

iii) Green houses are built with glass doors and roofs because glass is "athermanous".

iv) Cooking vessels are coated black outside because black surface is a good absorber and good emitter.