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# POSTAL BOOK PACKAGE 2024

# CONTENTS

# MECHANICAL ENGINEERING

**Objective Practice Sets**

## Heat Transfer

# 1 CHAPTER
# Introduction and Basic Concepts

## MCQ and NAT Questions

**Q.1** Consider the following materials:
1. Carbon 2. Mica
3. Bakelite 4. Fibre glass

Which of these materials are good conductors of heat, but bad conductors of electricity
(a) 1 only (b) 2 only
(c) 2 and 3 (d) 3 and 4

**Q.2** Heat transmission is directly linked with the transport of medium itself, i.e., there is actual or bulk motion of heated particles during
(a) conduction only
(b) convection only
(c) radiation only
(d) conduction as well as radiation

**Q.3** Choose the correct statement
(a) Thermal conductivity for metals decreases with increase in temperature
(b) Thermal conductivity for gases and insulating material decreases with increase in temperature
(c) Thermal conductivity is not a function of temperature
(d) Thermal conductivity increases with increase in temperature irrespective of material

**Q.4** Arrange the following substance in increasing order of thermal conductivity.
1. Copper 2. Aluminium
3. Water 4. Air

Which one of the following sequence is correct?
(a) 4-3-2-1 (b) 4-3-1-2
(c) 3-4-2-1 (d) 3-4-1-2

**Q.5** The inner surface of a plane brick wall is at 50°C and the outer surface is at 25°C. The rate of heat transfer per $m^2$ of the surface area of the wall, which is 220 mm thick is (the thermal conductivity of the bricks is 0.51 W/m K).
(a) 20.65 $W/m^2$ (b) 32.75 $W/m^2$
(c) 47.62 $W/m^2$ (d) 57.95 $W/m^2$

**Q.6** All the three modes of heat transmission are involved in
(a) melting of ice
(b) cooling of a small metal casting in a quenching bath
(c) heat flow through the walls of a refrigerator
(d) automobile engine equipped with a thermo-syphon cooling system

**Q.7** A steel plate of thickness 5 cm and thermal conductivity 20 W/mK is subjected to a uniform heat flux of 800 $W/m^2$ on one surface '*A*' and heat transfer coefficient of 80 $W/m^2K$ from the other surface '*B*' into the ambient air at $T_\infty$ of 25°C. The temperature of the surface '*B*' transferring heat by convection is
(a) 25°C (b) 35°C
(c) 45°C (d) 55°C

**Q.8** For a composite wall made of three layers, of three layers, *A*, *B* and *C* of different material wall thickness and temperature difference across the wall faces of layer *A*, *B* and *C* are 20cm and 100°C, 15cm and 180°C, 25cm and 100°C respectively. Which one of the following is correct? (assume area of each layer is same).
(a) Layer *A* has highest thermal conductivity (*k*)
(b) Layer *B* has highest thermal conductivity (*k*)
(c) Layer *C* has highest thermal conductivity (*k*)
(d) All layers have equal thermal conductivity.

**Q.9** The heat conducted through a wall of thickness $\delta$ is given by

$$Q = -kA\frac{dT}{dx} = -kA\left(\frac{T_2 - T_1}{\delta}\right)$$

which amongst the following is not a correct statement?
(a) the term ($\delta/kA$) is called thermal resistance
(b) the term ($kA/\delta$) is called thermal conductance
(c) the factor ($Q/A$) is called thermal loading
(d) the temperature gradient ($dT/dx$) is positive

**Q.10** Heat conduction in gases is due to
(a) electromagnetic waves
(b) motion of electrons
(c) mixing motion of the different layers of the gas
(d) elastic impact of molecules

**Q.11** Arrangement of silver, air, aluminium and lead in order of increasing thermal conductivity at room temperature yields
(a) Air, Aluminium, Silver, Lead
(b) Air, Aluminium, Lead, Silver
(c) Lead, Air, Aluminium, Silver
(d) Air, Lead, Aluminium, Silver

**Q.12** Thermal diffusivity is
(a) a dimensionless parameter
(b) function of temperature
(c) a physical property of the material
(d) none of these

**Q.13** Your finger sticks to an ice tray just taken from the refrigerator, Which factor has more effect on this phenomenon?
(a) The inside temperature of the freezer (Suppose it's working properly)
(b) The humidity of the air
(c) The heat capacity of both your finger and the tray
(d) The thermal conductivity of the tray

**Q.14** Which of the following is used to measure the temperature inside a furnace
(a) Gas thermometer
(b) Optical pyrometer
(c) Alcohol thermometer
(d) Mercury thermometer

**Q.15** A cold liquid is stored in spherical vessel in order to
(a) reduce rate of heat transfer
(b) increase rate of heat transfer
(c) prevent the liquid from freezing
(d) none of these

**Q.16** Which one of the following is correct, in context of thermal diffusivity of liquid and gas
(a) $\alpha_{gas} > \alpha_{liquid}$
(b) $\alpha_{gas} < \alpha_{liquid}$
(c) $\alpha_{gas} = \alpha_{liquid}$
(d) Depend on other factors

**Q.17** The unit of thermal diffusivity is
(a) $m^2/hr^oC$ (b) $kJ/m^2hr$
(c) $m/hr^oC$ (d) $m^2/hr$

**Q.18** The ratio of thermal conductivity to electrical conductivity is equal to
(a) Prandtl number (b) Schmidt number
(c) Lorentz number (d) Lewis number

**Q.19** Hot coffee in a cup is allowed to cool. Its cooling rate is measured and found to be greater than the value calculated by conduction, convection and radiation measurement. The difference is due to
(a) properties of coffee changing with temperature
(b) currents of air flow in the room
(c) underestimation of emissivity of coffee
(d) evaporation

**Q.20** The Fourier law of heat conduction is valid for
(a) One dimensional only
(b) Two dimensional only
(c) Three dimensional only
(d) None of these

**Q.21** Match the property with their units

| | Property | | Units |
|---|---|---|---|
| A. | Bulk modulus | 1. | W/s |
| B. | Thermal conductivity | 2. | $N/m^2$ |
| C. | Heat transfer coefficient | 3. | $N/m^3$ |
| D. | Heat flow rate | 4. | W |
| | | 5. | W/mK |
| | | 6. | $W/m^2K$ |

Codes:

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 1 | 2 | 6 | 5 |
| (b) | 2 | 5 | 6 | 4 |
| (c) | 2 | 6 | 4 | 1 |
| (d) | 1 | 5 | 3 | 2 |

**Q.22** In a case of one dimensional heat conduction in a medium with constant properties, $T$ is the temperature at position $x$, at time $t$. Then $\frac{\partial T}{\partial t}$ is proportional to

(a) $\frac{T}{x}$ (b) $\frac{\partial T}{\partial x}$

(c) $\frac{\partial^2 T}{\partial x \partial t}$ (d) $\frac{\partial^2 T}{\partial x^2}$

**Q.23** Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

**List-I**

**A.** Momentum transfer
**B.** Mass transfer
**C.** Heat transfer

**List-II**

**1.** Thermal diffusivity
**2.** Kinematic viscosity
**3.** Diffusion coefficient

**Codes:**

| | A | B | C |
|---|---|---|---|
| (a) | 2 | 3 | 1 |
| (b) | 1 | 3 | 2 |
| (c) | 3 | 2 | 1 |
| (d) | 1 | 2 | 3 |

**Q.24** Heat is mainly transferred by conduction, convection and radiation in
(a) insulated pipes carrying hot water
(b) refrigerator freezer coil
(c) boiler furnaces
(d) condensation of steam in a condenser

**Q.25** **Assertion (A):** Cork is a good insulator.
**Reason (R):** Good insulators are highly porous.
(a) Both **A** and **R** are individually true and **R** is the correct explanation of **A**
(b) Both **A** and **R** are individually true but **R** is not the correct explanation of **A**
(c) **A** is true but **R** is false
(d) **A** is false but **R** is true

**Q.26** A long glass cylinder of inner diameter = 0.2 m and outer diameter = 0.4 m carries hot fluid inside. If the thermal conductivity of glass = 1.00 W/mK, the thermal resistance (K/W) per unit length of the cylinder is

**Q.27** Heat is being transferred conductively from a cylindrical nuclear reactor fuel rod of 60 mm diameter to water at 75°C, under steady state condition, the rate of heat generation within the fuel element is 2000 kW/m$^3$ and the convective heat transfer coefficient is 1 kW/m$^2$K, the outer surface temperature of the fuel element would be _____ K.

## Multiple Select Questions (MSQ)

**Q.28** An electric hot plate is maintained at a temperature of 350°C and is used to keep a solution boiling at 95°C. The solution is contained in a cast iron ($k$ = 50 W/mK) vessel of wall thickness 25 mm, which is enameled to a thickness of 0.8 mm. The heat transfer coefficient for the boiling solution is 5.5 W/m$^2$K and thermal conductivity of enamel is 1.05 W/mK. Which of the following is(are) correct?
(a) The overall heat transfer coefficient is 692.65 W/m$^2$K.
(b) The overall heat transfer coefficient is 1059.63 W/m$^2$K.
(c) The rate of heat transfer per unit area is 176.63 kW/m$^2$.
(d) The rate of heat transfer per unit area is 270.2 kW/m$^2$.

**Q.29** Which of the following statements is/are correct with respect to conduction heat transfer?
(a) Heat transfer takes place by molecular lattice vibrational energy and due to free electron transfer in solids.
(b) If all other factors remains same (i.e. area, temperature gradients same), then conduction heat transfer by brass will be more than copper.
(c) All electrically good conductor are in general good conductors of heat also.
(d) Diamond is having the highest thermal conductivity among all known materials.

**Q.30** Which of the following statements is/are correct?
(a) Thermal conductivity is a thermophysical property of a material.
(b) Heat conduction occurs in gases by molecular momentum transfer.
(c) With increase in temperature thermal conductivity of gases decreases.
(d) Liquids are better conductors of heat than gases.

**Q.31** Which of the following statements is/are correct about a black body?
(a) A black body is considered as an ideal emitter.

(b) A black body is considered as a perfect absorber.
(c) A black body is considered as non-diffusive in nature.
(d) Snow and Ice are also considered as black body.

Q.32 Which of the following statements is/are correct?
(a) In free convection heat transfer the motion of the fluid occurs naturally due to buoyancy forces.
(b) Radiation heat transfer does not require any material medium for its propagation.
(c) All bodies at all temperature emit thermal radiation except the body at 0 K.
(d) Radiation heat transfer dominates over conduction and convection when the temperature difference is sufficiently large.

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## Answers Introduction and Basic Concepts

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1. (a) | 2. (b) | 3. (a) | 4. (a) | 5. (d) | 6. (d) | 7. (b) | 8. (c) |
| 9. (d) | 10. (d) | 11. (d) | 12. (c) | 13. (d) | 14. (b) | 15. (a) | 16. (a) |
| 17. (d) | 18. (c) | 19. (d) | 20. (a) | 21. (b) | 22. (d) | 23. (a) | 24. (c) |
| 25. (a) | 26. (0.055) | 27. (378) | 28. (a, c) | 29. (a, c, d) | 30. (a, b, d) | 31. (a, b, d) | 32. (a, b, c, d) |

## Explanations Introduction and Basic Concepts

**1. (a)**

Mica, Bakelite and fibre glass are insulator material and carbon in the form of diamond is the good conductor of heat but bad conductor of electricity.

**2. (b)**

Actual movement of particles of the medium is present in convection only.

**3. (a)**

For gases $k$ increases with increase in temperature and decrease with increase in molecular weight.

**4. (a)**

| Substance | $k$(w/m-K) |
|---|---|
| Copper | 386 |
| Aluminium | 175.6 |
| Water | 0.51 |
| Air | 0.022 |

**5. (d)**

$$q = k\frac{\Delta T}{\Delta x} = \frac{0.51\times 25}{0.22} = 57.95\ \text{W/m}^2$$

**6. (d)**

In syphon cooling system all modes conduction, convection and radiation takes place. Since it has high temperatures therefore radiation heat transfer is also significant.

**7. (b)**

$$Q = kA\frac{\Delta T}{\Delta x} = hA\Delta T$$
$$800 = 80\,(T_B - 25)$$
$$T_B = 35^\circ\text{C}$$

**8. (c)**

$$\because\ Q = \frac{k_1A_1\Delta t_1}{L_1} = \frac{k_2A_2\Delta t_2}{L_2} = \frac{k_3A_3\Delta t_3}{L_3}$$
$$\therefore\ A_1 = A_2 = A_3 = A$$
$$\therefore\ Q = \frac{k_1\,.\,\Delta t_1}{L_1} = \frac{k_2\,.\,\Delta t_2}{L_2} = \frac{k_3\,.\,\Delta t_3}{L_3}$$
$$\therefore\ Q = \frac{k_1(100)}{20} = \frac{k_2(180)}{15} = \frac{k_3(100)}{25}$$
$$\therefore\ 5k_1 = 12k_2 = 4k_3$$
$$\therefore\ \boxed{k_3 > k_1 > k_2}$$

**9. (d)**

$\frac{\delta}{kA}$ in thermal resistance

$\frac{Q}{A}$ in thermal loading

$\frac{dT}{dx}$ is negative in the direction of heat flow

**10. (d)**

Heat conduction in gases is due to collision of gases molecules. It is due to its elastic impact of molecules.

**11. (d)**

According to their thermal conductivity
for Air, $k$ = 0.022 W/mK
for Aluminium, $k$ = 205 W/mK
for Silver, $k$ = 407 W/mK
Hence correct sequence is
Air, Lead, Aluminium, Silver

**12. (c)**

Thermal diffusivity ($\alpha$) is a physical property of the material.

**13. (d)**

Due to high temperature difference between your finger and the tray, some heat will be transferred to the tray, depending on its capacity for thermal conductivity.
Since the surface of your skin is naturally moisturized (it's not a function of the air humidity), the loss of heat will cause a thin layer of ice to form on the skin which in turn sticks to the tray.
No matter how dry is the air and how cold is the freezer, your finger will not stick to a wooden tray whose thermal conductivity is low. So the most important factor is the thermal conductivity of the tray.

**14. (b)**

Optical pyrometers are non-contact type temperature measuring instruments. Hence, they are used to measure temperature inside a furnace.

**15. (a)**

Spherical vessel to reduce heat transfer as it offers the maximum thermal resistance.

**16. (a)**

Since thermal diffusivity, $\alpha = \frac{k}{\rho c}$

$(\rho c)_{liquid} > (\rho c)_{gas}$
$(\alpha)_{gas} > (\alpha)_{liquid}$

**17. (d)**

Thermal diffusivity, $\alpha = \frac{k}{\rho C}$

Hence its unit = $m^2$/hr or $m^2$/sec
Note that unit of thermal diffusivity and kinematic viscosity is same.

**18. (c)**

The ratio of thermal conductivity to electrical conductivity is always constant for all the conductors at the given temperature. This is know as Wideman and Frange law.

i.e. $\frac{k}{\sigma T}$ = constant

The constant is known as Lorentz number (Lo) whose value is equal to $2.045 \times 10^{-8}$ W/$\mu K^2$.

**19. (d)**

Some heat is also lost in evaporation. The vapours of water is not accounted in these 3 modes of heat transfer.

**20. (a)**

While deriving Fourier law of heat conduction some assumptions are made, which are
1. Steady state condition
2. One-directional heat transfer
3. No heat generation
4. Material is homogeneous and isotropic

**21. (b)**

Bulk modulus ($k$) = N/$m^2$
Thermal conductivity ($k$) = W/mK
Heat transfer coefficient ($h$) = W/$m^2$K
Heat flow rate ($q$) = Watt (W)

**22. (d)**

The equation of heat transfer in Cartesian coordinates without heat generation is

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = \frac{\rho c_p}{k}\frac{\partial T}{\partial t}$$

For one dimensional heat transfer,

$$\frac{\partial^2 T}{\partial x^2} = \frac{\rho c_p}{k}\frac{\partial T}{\partial t}$$

*i.e.*, $$\frac{\partial T}{\partial t} \propto \frac{\partial^2 T}{\partial x^2}$$

**23. (a)**

Momentum transfer — Kinematic viscosity

Kinematic viscosity: $\nu = \frac{\mu}{\rho}$

Mass transfer — diffusion coefficient

Molecular diffusion is governed by Fick's law

$$N_A = \frac{m_A}{A} = -D_{AB}\frac{dc_A}{dx}$$

where, $N_A$ = mass flux of species $A$

$D_{AB}$ = diffusion coefficient

$\frac{dc_A}{dx}$ = concentration of gradient for species $A$.

Heat transfer — Thermal diffusivity

Thermal diffusivity: $\alpha = \frac{k}{\rho c_p}$

**24. (c)**

Because for radiation to be comparable the magnitude of temperature difference should be large enough. Convection & conduction is also predominant in boiler furnace.

**25. (a)**

In porous cavities available in insulating materials the ambient air may go and gets entrapped. Air being bad conductor of heat it may offer insulation.

**26. (0.055)**

Given data: $d_1 = 0.2$ m

$$\therefore \quad r_1 = \frac{d_1}{2} = \frac{0.2}{2} = 0.1\,\text{m}$$

$d_2 = 0.4$ m

$$\therefore \quad r_2 = \frac{d_2}{2} = \frac{0.4}{2} = 0.2\,\text{m}$$

$k = 2$ W/mK

Thermal resistance,

$$R_t = \frac{1}{2\pi k l}\log_e\frac{r_2}{r_1}$$

$$= \frac{1}{2\times 3.14\times 2\times 1}\log_e\left(\frac{0.2}{0.1}\right)$$

$$= 0.055\ \text{K/W}$$

**27. (378)**

Given data: $d = 50$ mm $= 0.06$ m

$T_o = 75°C$; $q_G = 2000$ kW/m$^3$

$h_o = 1$ kW/m$^2$K

Applying energy balance equation,

Rate of heat generation = Rate of convective heat transfer

$q_G \times$ Volume of fuel rod $= h_o A(T_s - T_o)$

$$q_G \times \frac{\pi}{4}d^2 \times l = h_o \times \pi d l (T_s - T_o)$$

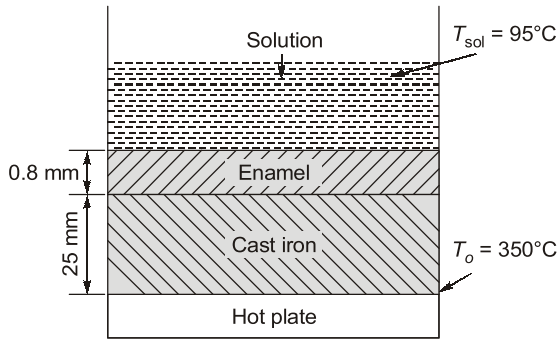
$$\frac{d\,q_G}{4} = h_o(T_s - T_o)$$

$$\frac{0.06\times 2000}{4} = 1\,(T_s - 75)$$

$$T_s = 105°C = 378\ \text{K}$$

**28. (a, c)**

Let overall heat transfer coefficient is $U$.




$$\frac{1}{U} = \frac{x_{CI}}{k_{CI}} + \frac{x_{enamel}}{k_{enamel}} + \frac{1}{h_{solution}}$$

$$\frac{1}{U} = \left(\frac{0.025}{50}\right) + \frac{0.0008}{1.05} + \frac{1}{5500}$$

$U = 692.65$ W/m$^2$K

Heat transfer rate per unit area, $q = U(T_o - T_{sol})$

$= 692.65 \times (350 - 95)$

$= 176.625$ kW/m$^2$.

**29. (a, c, d)**

1. 30% of conduction heat transfer takes place by molecular lattice vibrational energy transfer and 70% of conduction heat transfer takes place by free electron transfer in solids.
2. Thermal conductivity of pure metal is more than its alloys.
3. All electrically good conductors are in general good conductor of heat also because of the presence of abundant number of free electrons.

4. Thermal conductivity of diamond = 2300 W/mK. The highest thermal conductivity of diamond is due to its perfect crystalline molecular lattice arrangement.

**30. (a, b, d)**

1. Thermal conductivity is a thermophysical property of a material which tells about the ability of the material to allow the heat energy to get conducted through the material more rapidly.
2. Heat conduction occurs in gases by molecular momentum transfer. In general gases are very bad conductor of heat. With increase in temperature thermal conductivity of gases increases because at higher temperature greater molecular activity may result in more number of collisions per unit time and hence more momentum transfer rate.
3. Liquids are better conductors of heat than gases. Among all liquids Hg has highest thermal conductivity.

**31. (a, b, d)**

A black body is the body which absorbs all the thermal radiation incident or falling upon the body. A black body is an ideal emitter, perfect absorber and diffusive in nature. Snow and Ice are examples of black body. A thermally black body may not appear black in colour to the human eye.

**32. (a, b, c, d)**

In free convection heat transfer the motion of the fluid occurs naturally due to buoyancy forces arising out of density changes of fluid because of its temperature change.

Radiation heat transfer does not require any material medium for its propagation and hence occurs by electromagnetic wave propagation travelling with the speed of light.

Radiation heat transfer completely predominates over conduction and convection particularly when the temperature difference is sufficiently large.

All bodies at all temperature emit thermal radiation except the body at 0 K.

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