

APPLIED PHYSICS 1

Chapter: Heat and Thermometry

Important Questions, Solution Steps and Numerical Problems

Exam-oriented practice material for Engineering (Diploma / Degree) students

Topics Covered

- Concept of heat and temperature; basic concepts of measurement of heat and temperature
- Modes of heat transfer: conduction, convection and radiation (with examples)
- Coefficient of thermal conductivity and simple numerical problems
- Expansion of solids, liquids and gases; coefficients of linear, superficial and cubical expansion of solids and the relation among them
- Specific heats C_p and C_v of a gas and their relationship (mention only)

How this exercise is arranged

- **Section A** - Very short answer questions (1 mark each)
- **Section B** - Short answer questions (2 to 3 marks each)
- **Section C** - Long answer questions (5 marks each) with derivations and examples
- **Section D** - Numerical problems with step-by-step solutions
- **Section E** - Formula sheet for quick revision

Useful constants used in the numericals

Quantity	Value
Specific heat of water	$4200 \text{ J kg}^{-1} \text{ K}^{-1}$ ($1 \text{ cal g}^{-1} \text{ }^\circ\text{C}^{-1}$)
Mechanical equivalent of heat	$1 \text{ cal} = 4.2 \text{ J}$ (approx.)
Universal gas constant, R	$8.31 \text{ J mol}^{-1} \text{ K}^{-1}$
Absolute zero	$0 \text{ K} = -273 \text{ }^\circ\text{C}$

SECTION A: Very Short Answer Questions (1 mark each)

Q1. Define heat. Write its SI unit.

Ans: Heat is a form of energy which flows from a body at higher temperature to a body at lower temperature. SI unit: joule (J). Other units: calorie, kilocalorie.

Q2. Define temperature. Write its SI unit.

Ans: Temperature is the degree of hotness or coldness of a body. It decides the direction of heat flow. SI unit: kelvin (K).

Q3. Write the relation between calorie and joule.

Ans: 1 calorie = 4.2 J (more exactly 4.186 J).

Q4. What are the fixed points of the Celsius scale?

Ans: Lower fixed point (LFP) = 0 °C (melting point of pure ice). Upper fixed point (UFP) = 100 °C (boiling point of water at normal pressure). The interval is divided into 100 equal parts. In Fahrenheit these are 32 °F and 212 °F; in Kelvin, 273 K and 373 K.

Q5. Write the relation among Celsius, Fahrenheit and Kelvin scales.

Ans: $C/5 = (F - 32)/9 = (K - 273)/5$.

Q6. Name the instruments used to measure temperature and heat.

Ans: Temperature is measured by a thermometer; heat is measured by a calorimeter.

Q7. State the principle of calorimetry.

Ans: Heat lost by the hot body = heat gained by the cold body (when no heat is lost to the surroundings).

Q8. Define specific heat of a substance. Give its SI unit.

Ans: Specific heat is the amount of heat required to raise the temperature of 1 kg of the substance by 1 K (or 1 °C). Unit: $\text{J kg}^{-1} \text{K}^{-1}$.

Q9. Define heat capacity and water equivalent.

Ans: Heat capacity = heat required to raise the temperature of the whole body by 1 K = $m \times c$ (unit J K^{-1}). Water equivalent = mass of water which requires the same amount of heat as the body for the same rise in temperature, $W = mc/c_w$.

Q10. Which mode of heat transfer needs no material medium?

Ans: Radiation.

Q11. In which state of matter does conduction mainly occur? In which does convection occur?

Ans: Conduction mainly occurs in solids; convection occurs in fluids (liquids and gases).

Q12. Define coefficient of thermal conductivity. Write its unit.

Ans: It is the quantity of heat flowing per second through a slab of unit area and unit thickness when the temperature difference between its faces is 1 K. Unit: $\text{W m}^{-1} \text{K}^{-1}$.

Q13. Write the dimensional formula of thermal conductivity.

Ans: $[\text{M L T}^{-3} \text{K}^{-1}]$.

Q14. Give two examples each of good conductors and bad conductors (insulators) of heat.

Ans: Good conductors: copper, silver, aluminium. Bad conductors: wood, glass, rubber, air, cork, asbestos.

Q15. Define coefficient of linear expansion.

Ans: It is the increase in length per unit original length per unit rise in temperature. $\alpha = \Delta L / (L_0 \Delta t)$. Unit: per $^{\circ}\text{C}$ (or K^{-1}).

Q16. State the relation among α , β and γ of a solid.

Ans: $\beta = 2\alpha$ and $\gamma = 3\alpha$, i.e. $\alpha : \beta : \gamma = 1 : 2 : 3$.

Q17. At what temperature does water have maximum density?

Ans: At 4°C (277 K); its density is 1000 kg m^{-3} at this temperature.

Q18. What is the coefficient of volume expansion of an ideal gas at constant pressure?

Ans: $\gamma_p = 1/273$ per $^{\circ}\text{C}$ (or $1/273 \text{ K}^{-1}$).

Q19. Which is greater for a gas: C_p or C_v ?

Ans: C_p is greater than C_v .

Q20. Write the relation between C_p and C_v (Mayer's relation).

Ans: $C_p - C_v = R$ (for one mole of gas, R in $\text{J mol}^{-1} \text{K}^{-1}$).

Q21. Which thermometer is used to measure the temperature of the human body?

Ans: Clinical thermometer (mercury-in-glass type, range about 35°C to 42°C).

SECTION B: Short Answer Questions (2 to 3 marks each)

Q1. Distinguish between heat and temperature.

Heat	Temperature
Form of energy that flows due to temperature difference	Degree of hotness or coldness of a body
Measured by a calorimeter	Measured by a thermometer
SI unit: joule (J)	SI unit: kelvin (K)
Depends on mass, nature of substance and temperature	Does not depend on the mass of the body
Cause of temperature change	Effect (decides the direction of heat flow)

Q2. Why are white or light-coloured clothes preferred in summer and dark clothes in winter?

Ans: Dark surfaces are good absorbers (and good emitters) of radiant heat, while light/white surfaces are good reflectors. In summer, white clothes reflect most of the heat radiation from the Sun and keep us cool. In winter, dark clothes absorb more radiation and keep us warm.

Q3. Why does a metal spoon feel colder than a wooden spoon in winter although both are at the same temperature?

Ans: Metal is a good conductor, so heat flows quickly from our hand to the spoon and we feel cold. Wood is a bad conductor, so very little heat flows away from the hand and it does not feel cold.

Q4. Why is the freezer of a refrigerator kept at the top and a room heater at the bottom?

Ans: This is based on convection. The freezer cools the air near it; the cold air is denser and sinks, while warmer air rises to the freezer, so the whole compartment cools. A heater at the bottom warms the air, which becomes lighter and rises, and cold air moves down to take its place, so the whole room warms.

Q5. Why are cooking utensils made of metal but have handles of wood or plastic?

Ans: The metal body is a good conductor, so heat passes quickly from the flame to the food. Wood or plastic is a bad conductor, so the handle stays cool and can be held safely.

Q6. Why is a small gap left between two rails in a railway track?

Ans: Rails expand in summer because of the rise in temperature. If no gap is left, the rails would bend or buckle and may cause accidents. The gap allows free expansion.

Q7. Why does a thick glass tumbler crack when hot water is poured into it suddenly?

Ans: Glass is a bad conductor. The inner surface becomes hot and expands, but the outer surface remains cold and does not expand. This unequal expansion produces stress and the glass cracks. Pyrex glass has a very low coefficient of expansion and does not crack easily.

Q8. Why do telephone and electric wires sag in summer and become tight in winter?

Ans: Wires expand in summer (length increases) and sag. In winter they contract and become tight. That is why wires are not stretched tightly when they are installed.

Q9. Define the coefficients of linear, superficial and cubical expansion of a solid.

Let L_0 , A_0 , V_0 be the original length, area and volume, and Δt the rise in temperature.

- **Linear (α):** $\alpha = \Delta L / (L_0 \Delta t)$, increase in length per unit length per $^{\circ}\text{C}$
- **Superficial (β):** $\beta = \Delta A / (A_0 \Delta t)$, increase in area per unit area per $^{\circ}\text{C}$
- **Cubical (γ):** $\gamma = \Delta V / (V_0 \Delta t)$, increase in volume per unit volume per $^{\circ}\text{C}$

Q10. What is meant by real and apparent expansion of a liquid? Write the relation between them.

Ans: A liquid is always heated in a vessel which also expands. The expansion that appears to an observer, ignoring the expansion of the vessel, is called apparent expansion. The actual expansion of the liquid, which takes the expansion of the vessel into account, is the real expansion. $\gamma_{\text{real}} = \gamma_{\text{apparent}} + \gamma_{\text{vessel}}$

Q11. What is the anomalous expansion of water? State one importance.

Ans: Most liquids expand on heating, but water contracts when heated from 0°C to 4°C and expands only above 4°C . So water has maximum density at 4°C . In cold regions the surface water of a lake freezes first, while the water below stays at about 4°C , so fish and aquatic life survive.

Q12. What is a bimetallic strip? Mention one use.

Ans: It consists of two strips of different metals (for example brass and iron) of equal length riveted together. On heating, the metal with the larger α expands more, so the strip bends with that metal on the outer (convex) side. It is used in thermostats (electric iron, refrigerators, heaters) and fire alarms.

Q13. Why is a mercury thermometer widely used? (Properties of mercury)

Mercury is chosen as the thermometric liquid because:

- it expands uniformly over a wide range of temperature
- it is a good conductor of heat and has a low specific heat, so it quickly attains the temperature of the body
- it does not wet glass and is opaque and shiny, so it is easy to read
- it has a high boiling point (357°C) and a freezing point of -39°C , which gives a wide range

Q14. Why is a Thermos (vacuum) flask double-walled, evacuated and silvered?

Ans: It is designed to stop all three modes of heat transfer. The vacuum between the double walls stops conduction and convection. The silvered (shiny) surfaces reflect radiation and reduce loss by radiation. The stopper is made of cork or plastic, which is a bad conductor.

Q15. Why does the sea breeze blow during the day and the land breeze at night?

Ans: During the day, land heats faster than the sea (lower specific heat). Air above the land becomes hot and rises, and cooler air from the sea moves in: this is the sea breeze. At night, land cools faster, so warm air above the sea rises and cool air from the land moves towards the sea: this is the land breeze. Both are examples of convection.

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SECTION C: Long Answer Questions (5 marks each)

Q1. Explain the concept of heat and temperature. Describe the different temperature scales and their conversion.

Heat: Heat is a form of energy that is transferred from one body to another because of a temperature difference. It flows from the hot body to the cold body until both reach the same temperature (thermal equilibrium). Its SI unit is joule; 1 calorie = 4.2 J.

Temperature: Temperature is the measure of the degree of hotness or coldness of a body. From the molecular point of view, it is a measure of the average kinetic energy of the molecules of the body. Its SI unit is kelvin.

Temperature scales:

Scale	Lower fixed point (ice)	Upper fixed point (steam)	No. of divisions
Celsius (°C)	0	100	100
Fahrenheit (°F)	32	212	180
Kelvin (K)	273	373	100

Conversion formulae: $C / 5 = (F - 32) / 9 = (K - 273) / 5$

Hence $F = (9/5)C + 32$, $C = (5/9)(F - 32)$ and $K = C + 273$.

Heat and temperature are different: two bodies at the same temperature may contain different amounts of heat (a bucket of water at 50 °C has more heat than a cup of water at 50 °C).

Q2. Explain the basic concepts of measurement of heat and temperature.

(a) Measurement of temperature is done with a thermometer. A thermometer works on the principle that some physical property of a substance (volume, pressure, electrical resistance, emf) changes regularly with temperature. Common types:

Thermometer	Principle	Approx. range / use
Mercury-in-glass	Expansion of mercury	-39 °C to 357 °C; laboratory use
Alcohol-in-glass	Expansion of alcohol	-115 °C to 78 °C; very low temperatures
Clinical thermometer	Expansion of mercury (with a constriction)	35 °C to 42 °C; human body
Platinum resistance	Resistance of metal increases with temperature	-200 °C to 1200 °C; accurate industrial use
Thermocouple	Seebeck effect (emf at the junction of two metals)	Up to about 1500 °C; furnaces
Optical pyrometer	Brightness of the radiation emitted by a hot body	Above 800 °C; very hot bodies, no contact

(b) Measurement of heat is done with a calorimeter (a metal vessel with a stirrer, kept in an insulating jacket). It is based on the **principle of calorimetry**: heat lost by hot bodies = heat gained by cold bodies.

Heat absorbed or released: $Q = m c \Delta t$, where m = mass, c = specific heat, Δt = change in temperature.

Heat capacity = $m c$ ($J K^{-1}$) and water equivalent $W = m c / c_w$.

Q3. Describe the modes of heat transfer (conduction, convection and radiation) with examples.

Heat can be transferred from one place to another in three ways.

1. Conduction: Transfer of heat through a solid from the hotter end to the colder end, molecule to molecule, *without the bodily movement of the molecules*. It takes place mainly in solids.

- Heating one end of a metal rod makes the other end hot too
- A spoon kept in hot tea becomes hot
- Heat passing through the bottom of a cooking pan
- Iron box (press) heating the cloth

2. Convection: Transfer of heat in fluids (liquids and gases) by the actual movement of the heated particles. Hot fluid becomes lighter and rises, cold (denser) fluid comes down and sets up convection currents.

- Heating of water in a vessel (water at the bottom heats and rises)
- Sea breeze and land breeze; formation of winds
- Heating of a room by a heater; ventilators near the ceiling
- Cooling in a refrigerator

3. Radiation: Transfer of heat in the form of electromagnetic waves (infrared) without any material medium and without heating the medium. It travels with the speed of light.

- Heat from the Sun reaching the Earth through empty space
- Warmth felt near a fire or an electric bulb
- Heat of a hot iron rod felt at a distance

Conduction	Convection	Radiation
Mainly in solids	In liquids and gases	Needs no medium
Molecules vibrate but do not move from place	Molecules actually move	By electromagnetic waves
Slow process	Slow process	Fastest (speed of light)
Travels in a straight or curved path	Travels along the path of the current	Travels in a straight line

Q4. Define coefficient of thermal conductivity. Derive its expression and give its unit and dimension.

Consider a slab (or rod) of cross-sectional area A and thickness (length) d . Its two faces are kept at temperatures θ_1 and θ_2 ($\theta_1 > \theta_2$) and heat flows steadily from the hot face to the cold face perpendicular to the faces. Experiments show that the quantity of heat Q flowing in time t is:

- directly proportional to the area A
- directly proportional to the temperature difference ($\theta_1 - \theta_2$)
- directly proportional to the time t
- inversely proportional to the thickness d

Combining these, $Q = K A (\theta_1 - \theta_2) t / d$, where K is a constant called the coefficient of thermal conductivity of the material.

Rate of heat flow: $Q / t = K A (\theta_1 - \theta_2) / d$. Therefore $K = Q d / [A (\theta_1 - \theta_2) t]$.

Definition: K is the quantity of heat flowing per second through a slab of unit area and unit thickness when the temperature difference between its two faces is 1 K (in the steady state).

Unit: $W m^{-1} K^{-1}$ ($J s^{-1} m^{-1} K^{-1}$). **Dimension:** $[M L T^{-3} K^{-1}]$.

Approximate values of K ($W m^{-1} K^{-1}$):

Material	K	Material	K
Silver	429	Glass	1.0
Copper	385	Water	0.6
Aluminium	205	Wood	0.15
Iron	80	Air	0.024

Note: A material with large K (metals) is a good conductor, used for cooking vessels, heat exchangers and boilers. A material with small K (wood, glass wool, cork, asbestos) is an insulator, used in the handles of utensils, walls of refrigerators and furnaces.

Q5. Explain the expansion of solids. Define α , β and γ and prove the relation $\alpha : \beta : \gamma = 1 : 2 : 3$.

When a solid is heated, the amplitude of vibration of its atoms increases and the average distance between them increases. So the solid expands in length, area and volume. This is called thermal expansion.

(i) Linear expansion: $L_t = L_0 (1 + \alpha t)$, so $\alpha = (L_t - L_0) / (L_0 t)$.

(ii) Superficial expansion: $A_t = A_0 (1 + \beta t)$, so $\beta = (A_t - A_0) / (A_0 t)$.

(iii) Cubical expansion: $V_t = V_0 (1 + \gamma t)$, so $\gamma = (V_t - V_0) / (V_0 t)$.

Relation between α , β and γ

Take a square plate of side L_0 at $0^\circ C$. Its area is $A_0 = L_0^2$. At temperature t , each side becomes $L_t = L_0 (1 + \alpha t)$.

$$A_t = L_t^2 = L_0^2 (1 + \alpha t)^2 = A_0 (1 + 2\alpha t + \alpha^2 t^2)$$

Since α is very small (about 10^{-5}), α^2 is negligible. So $A_t = A_0 (1 + 2\alpha t)$.

Comparing with $A_t = A_0 (1 + \beta t)$: $\beta = 2\alpha$.

Take a cube of side L_0 at 0°C . Its volume is $V_0 = L_0^3$. At t , $V_t = L_0^3 (1 + \alpha t)^3 = V_0 (1 + 3\alpha t + 3\alpha^2 t^2 + \alpha^3 t^3)$.

Neglecting higher powers of α : $V_t = V_0 (1 + 3\alpha t)$. Comparing with $V_t = V_0 (1 + \gamma t)$: $\gamma = 3\alpha$.

Hence $\alpha : \beta : \gamma = 1 : 2 : 3$.

Approximate values of α (per $^\circ\text{C}$):

Material	$\alpha (\times 10^{-6})$	Material	$\alpha (\times 10^{-6})$
Aluminium	23	Steel / Iron	12
Brass	19	Glass (ordinary)	9
Copper	17	Pyrex glass	3

Q6. Explain the expansion of liquids.

Liquids have no shape of their own, so only their **volume (cubical) expansion** is considered.

They expand much more than solids (γ of liquids is about 10 to 100 times that of solids) because the intermolecular forces in liquids are weaker.

Since a liquid is kept in a container that also expands, two coefficients are defined:

- **Real (absolute) expansion γ_r** : the true increase in volume of the liquid per unit volume per $^\circ\text{C}$, when the expansion of the vessel is taken into account.
- **Apparent expansion γ_a** : the increase in volume per unit volume per $^\circ\text{C}$ as it appears to the observer, ignoring the expansion of the vessel.

Relation: $\gamma_r = \gamma_a + \gamma_g$ (γ_g = coefficient of cubical expansion of the vessel material).

Anomalous expansion of water: from 0°C to 4°C , water contracts on heating, so its volume is minimum and density is maximum (1000 kg m^{-3}) at 4°C . Above 4°C it expands normally. As a result, in cold countries only the top layer of a lake freezes and aquatic life survives below.

Approximate γ of liquids (per $^\circ\text{C}$): mercury 1.8×10^{-4} , glycerine 4.9×10^{-4} , alcohol 11×10^{-4} .

Q7. Explain the expansion of gases. State the coefficients of volume expansion and pressure coefficient.

Gases expand much more than solids and liquids. The volume of a gas depends on both temperature and pressure, so we consider two cases.

(i) Coefficient of volume expansion (γ_p) at constant pressure: It is the increase in volume per unit volume at 0°C per $^\circ\text{C}$ rise in temperature, keeping the pressure constant.

$$\gamma_p = (V_t - V_0) / (V_0 t) = 1/273 \text{ per } ^\circ\text{C}, \text{ so } V_t = V_0 (1 + t/273) \text{ (Charles' law).}$$

(ii) Pressure coefficient (γ_v) at constant volume: It is the increase in pressure per unit pressure at 0°C per $^\circ\text{C}$ rise in temperature, keeping the volume constant.

$$\gamma_v = (P_t - P_0) / (P_0 t) = 1/273 \text{ per } ^\circ\text{C}, \text{ so } P_t = P_0 (1 + t/273) \text{ (Gay-Lussac's law).}$$

Statement of Charles' law: At constant pressure, the volume of a fixed mass of gas increases (or decreases) by $1/273$ of its volume at 0°C for every 1°C rise (or fall) in temperature. In terms of absolute temperature, V is proportional to T .

Real gases at low pressure have nearly the same coefficient, $1/273$ per $^{\circ}\text{C}$, and an ideal gas follows it exactly. Therefore $\gamma_p = \gamma_v = 1/273$ per $^{\circ}\text{C}$.

Q8. Define the specific heats C_p and C_v of a gas and state the relation between them (mention only).

A gas can have many specific heats, because its heat absorption depends on how the gas is allowed to expand. Two principal specific heats are:

- **C_v (specific heat at constant volume):** heat required to raise the temperature of 1 kg (or 1 mole) of a gas by 1 K when the volume is kept constant.
- **C_p (specific heat at constant pressure):** heat required to raise the temperature of 1 kg (or 1 mole) of a gas by 1 K when the pressure is kept constant.

Relation (Mayer's relation): $C_p - C_v = R$ (for one mole of gas in mechanical units, $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$). C_p is always greater than C_v because at constant pressure, extra heat is needed to do external work during expansion.

The ratio $\gamma = C_p / C_v$ is always greater than 1 (about 1.67 for monatomic and 1.40 for diatomic gases).

Q9. Describe the engineering applications and precautions of thermal expansion.

- **Railway tracks:** small gaps are left between rails to allow expansion in summer
- **Bridges and buildings:** expansion joints and rollers are provided at one end of girders
- **Concrete roads and slabs:** gaps filled with bitumen or tar are left between slabs
- **Fitting iron tyres on wheels:** the tyre is made slightly smaller, heated so that it expands, fitted on the wheel, and then cooled so that it grips tightly
- **Riveting of steel plates:** red-hot rivets contract on cooling and hold the plates firmly
- **Bimetallic strip:** used in thermostats, fire alarms and circuit breakers
- **Pipelines:** expansion loops or bends are provided to absorb expansion
- **Clocks and pendulums:** compensated pendulums and Invar (very low α) are used to keep time accurate
- **Glassware:** Pyrex (low α) is used in laboratory glassware and ovens to avoid cracking

SECTION D: Numerical Problems with Solutions

Q1. Convert 50 °C into °F and K.

Given: $C = 50\text{ }^{\circ}\text{C}$

Formula: $F = (9/5) C + 32$; $K = C + 273$

Solution:

$$F = (9/5) \times 50 + 32 = 90 + 32 = 122$$

$$K = 50 + 273 = 323$$

Ans: 122 °F and 323 K.

Q2. Convert 104 °F into °C and K.

Given: $F = 104\text{ }^{\circ}\text{F}$

Formula: $C = (5/9)(F - 32)$; $K = C + 273$

Solution:

$$C = (5/9)(104 - 32) = (5/9) \times 72 = 40$$

$$K = 40 + 273 = 313$$

Ans: 40 °C and 313 K.

Q3. At what temperature do the Celsius and Fahrenheit scales give the same reading?

Given: $C = F = x$

Formula: $C / 5 = (F - 32) / 9$

Solution:

$$x / 5 = (x - 32) / 9$$

$$9x = 5x - 160$$

$$4x = -160, \text{ so } x = -40$$

Ans: $-40\text{ }^{\circ}\text{C} = -40\text{ }^{\circ}\text{F}$.

Q4. How much heat is required to raise the temperature of 2 kg of water from 20 °C to 70 °C? ($c = 4200\text{ J kg}^{-1}\text{ K}^{-1}$)

Given: $m = 2\text{ kg}$, $c = 4200\text{ J kg}^{-1}\text{ K}^{-1}$, $\Delta t = 70 - 20 = 50\text{ }^{\circ}\text{C}$

Formula: $Q = m c \Delta t$

Solution:

$$Q = 2 \times 4200 \times 50$$

$$Q = 4,20,000\text{ J}$$

Ans: $Q = 4.2 \times 10^5\text{ J}$.

Q5. Calculate the heat required to raise the temperature of a 500 g copper block from 30 °C to 130 °C. (c of copper = 390 J kg⁻¹ K⁻¹)

Given: m = 500 g = 0.5 kg, c = 390 J kg⁻¹ K⁻¹, Δt = 100 °C

Formula: Q = m c Δt

Solution:

$$Q = 0.5 \times 390 \times 100$$

$$Q = 19,500 \text{ J}$$

Ans: 19,500 J (= 19.5 kJ).

Q6. 200 g of water at 80 °C is mixed with 300 g of water at 20 °C. Find the final temperature of the mixture.

Given: m₁ = 200 g, t₁ = 80 °C; m₂ = 300 g, t₂ = 20 °C

Formula: Heat lost by hot water = heat gained by cold water

Solution:

Let the final temperature be T (c is the same for both, so it cancels).

$$200 (80 - T) = 300 (T - 20)$$

$$16000 - 200T = 300T - 6000$$

$$22000 = 500T, \text{ so } T = 44$$

Ans: Final temperature = 44 °C.

Q7. A copper calorimeter has a mass of 100 g. Find its water equivalent. (c of copper = 390 J kg⁻¹ K⁻¹, c of water = 4200 J kg⁻¹ K⁻¹)

Given: m = 0.1 kg, c = 390, c_w = 4200

Formula: W = m c / c_w

Solution:

$$W = (0.1 \times 390) / 4200 = 39 / 4200$$

$$W = 0.00929 \text{ kg}$$

Ans: W ≈ 9.3 g.

Q8. A copper rod of length 0.5 m and cross-sectional area 4 cm² has its ends at 100 °C and 20 °C. Find the rate of heat flow along the rod. (K of copper = 385 W m⁻¹ K⁻¹)

Given: d = 0.5 m, A = 4 cm² = 4 × 10⁻⁴ m², Δθ = 100 - 20 = 80 K, K = 385

Formula: Q / t = K A Δθ / d

Solution:

$$Q / t = (385 \times 4 \times 10^{-4} \times 80) / 0.5$$

$$Q / t = 12.32 / 0.5 = 24.64 \text{ J s}^{-1}$$

Ans: Rate of heat flow ≈ 24.6 W.

Q9. A glass window of area 2 m^2 and thickness 4 mm has temperature 25°C inside and 5°C outside. Find the heat conducted through it in 10 minutes. (K of glass = $1.0 \text{ W m}^{-1} \text{ K}^{-1}$)

Given: $A = 2 \text{ m}^2$, $d = 4 \text{ mm} = 4 \times 10^{-3} \text{ m}$, $\Delta\theta = 20 \text{ K}$, $t = 10 \text{ min} = 600 \text{ s}$, $K = 1.0$

Formula: $Q = K A \Delta\theta t / d$

Solution:

$$Q = (1.0 \times 2 \times 20 \times 600) / (4 \times 10^{-3})$$

$$Q = 24000 / 0.004 = 6 \times 10^6 \text{ J}$$

Ans: $Q = 6 \times 10^6 \text{ J}$ (rate = 10,000 W).

Q10. In an experiment, 9600 J of heat flows in 2 minutes through a metal plate of area 0.01 m^2 and thickness 5 cm when its faces are at 100°C and 80°C . Find the coefficient of thermal conductivity.

Given: $Q = 9600 \text{ J}$, $t = 120 \text{ s}$, $A = 0.01 \text{ m}^2$, $d = 0.05 \text{ m}$, $\Delta\theta = 20 \text{ K}$

Formula: $K = Q d / (A \Delta\theta t)$

Solution:

$$K = (9600 \times 0.05) / (0.01 \times 20 \times 120)$$

$$K = 480 / 24 = 20$$

Ans: $K = 20 \text{ W m}^{-1} \text{ K}^{-1}$.

Q11. Two rods of the same material and same length have cross-sectional areas in the ratio 1 : 3. If the temperature difference across both is the same, find the ratio of the rates of heat flow.

Given: $A_1 : A_2 = 1 : 3$; K , d and $\Delta\theta$ are the same

Formula: $Q / t = K A \Delta\theta / d$

Solution:

$$Q_1/t : Q_2/t = A_1 : A_2$$

$$= 1 : 3$$

Ans: The ratio of heat flow is 1 : 3.

Q12. The cork wall of a refrigerator has an area of 2 m^2 and a thickness of 5 cm. The inside is at 5°C and the outside at 35°C . Find the heat entering in one hour. (K of cork = $0.04 \text{ W m}^{-1} \text{ K}^{-1}$)

Given: $A = 2 \text{ m}^2$, $d = 0.05 \text{ m}$, $\Delta\theta = 30 \text{ K}$, $t = 3600 \text{ s}$, $K = 0.04$

Formula: $Q = K A \Delta\theta t / d$

Solution:

$$\text{Rate: } Q / t = (0.04 \times 2 \times 30) / 0.05 = 2.4 / 0.05 = 48 \text{ W}$$

$$Q = 48 \times 3600 = 1,72,800 \text{ J}$$

Ans: $Q \approx 1.73 \times 10^5 \text{ J}$.

Q13. A steel girder is 50 m long at 10 °C. Find the increase in its length at 40 °C. (α of steel = 1.2×10^{-5} per °C)

Given: $L_0 = 50$ m, $\alpha = 1.2 \times 10^{-5}$ /°C, $\Delta t = 30$ °C

Formula: $\Delta L = L_0 \alpha \Delta t$

Solution:

$$\Delta L = 50 \times 1.2 \times 10^{-5} \times 30$$

$$\Delta L = 0.018 \text{ m}$$

Ans: Increase in length = 0.018 m = 18 mm.

Q14. A metal rod of length 1 m at 0 °C becomes 1.0019 m at 100 °C. Find its coefficient of linear expansion.

Given: $L_0 = 1$ m, $L_t = 1.0019$ m, $t = 100$ °C

Formula: $\alpha = (L_t - L_0) / (L_0 t)$

Solution:

$$\alpha = (1.0019 - 1) / (1 \times 100)$$

$$\alpha = 0.0019 / 100 = 1.9 \times 10^{-5}$$

Ans: $\alpha = 1.9 \times 10^{-5}$ per °C.

Q15. A brass rod is 2 m long at 20 °C. To what temperature must it be heated to increase its length by 3.8 mm? ($\alpha = 1.9 \times 10^{-5}$ per °C)

Given: $L_0 = 2$ m, $\Delta L = 3.8$ mm = 3.8×10^{-3} m, $\alpha = 1.9 \times 10^{-5}$

Formula: $\Delta L = L_0 \alpha \Delta t$

Solution:

$$\Delta t = \Delta L / (L_0 \alpha) = (3.8 \times 10^{-3}) / (2 \times 1.9 \times 10^{-5})$$

$$\Delta t = 3.8 \times 10^{-3} / 3.8 \times 10^{-5} = 100 \text{ °C}$$

$$\text{Final temperature} = 20 + 100 = 120 \text{ °C}$$

Ans: The rod must be heated to 120 °C.

Q16. Rails of length 12 m are laid at 15 °C. The maximum temperature in summer is 55 °C. What gap should be left between rails? ($\alpha = 1.1 \times 10^{-5}$ per °C)

Given: $L_0 = 12$ m, $\Delta t = 55 - 15 = 40$ °C, $\alpha = 1.1 \times 10^{-5}$

Formula: $\Delta L = L_0 \alpha \Delta t$

Solution:

$$\Delta L = 12 \times 1.1 \times 10^{-5} \times 40$$

$$\Delta L = 5.28 \times 10^{-3} \text{ m}$$

Ans: Gap = 5.28 mm (about 5.3 mm).

Q17. A square copper plate of side 10 cm at 0 °C is heated to 100 °C. Find the increase in its area. (α of copper = 1.7×10^{-5} per °C)

Given: Side = 10 cm, so $A_0 = 100 \text{ cm}^2$, $\Delta t = 100 \text{ °C}$, $\alpha = 1.7 \times 10^{-5}$

Formula: $\beta = 2\alpha$; $\Delta A = A_0 \beta \Delta t$

Solution:

$$\beta = 2 \times 1.7 \times 10^{-5} = 3.4 \times 10^{-5} \text{ per °C}$$

$$\Delta A = 100 \times 3.4 \times 10^{-5} \times 100 = 0.34$$

Ans: Increase in area = 0.34 cm^2 .

Q18. An iron block has a volume of 500 cm^3 at 20 °C. Find the increase in its volume at 120 °C. (α of iron = 1.2×10^{-5} per °C)

Given: $V_0 = 500 \text{ cm}^3$, $\Delta t = 100 \text{ °C}$, $\alpha = 1.2 \times 10^{-5}$

Formula: $\gamma = 3\alpha$; $\Delta V = V_0 \gamma \Delta t$

Solution:

$$\gamma = 3 \times 1.2 \times 10^{-5} = 3.6 \times 10^{-5} \text{ per °C}$$

$$\Delta V = 500 \times 3.6 \times 10^{-5} \times 100 = 1.8$$

Ans: Increase in volume = 1.8 cm^3 .

**Q19. (a) The coefficient of linear expansion of a solid is 1.2×10^{-5} per °C. Find β and γ .
(b) If γ of a solid is 3.3×10^{-5} per °C, find α .**

Formula: $\beta = 2\alpha$; $\gamma = 3\alpha$

Solution:

$$(a) \beta = 2 \times 1.2 \times 10^{-5} = 2.4 \times 10^{-5} \text{ per °C}$$

$$\gamma = 3 \times 1.2 \times 10^{-5} = 3.6 \times 10^{-5} \text{ per °C}$$

$$(b) \alpha = \gamma / 3 = 3.3 \times 10^{-5} / 3 = 1.1 \times 10^{-5} \text{ per °C}$$

Ans: (a) $\beta = 2.4 \times 10^{-5}$, $\gamma = 3.6 \times 10^{-5}$ per °C; (b) $\alpha = 1.1 \times 10^{-5}$ per °C.

Q20. 100 cm^3 of mercury at 0 °C is heated to 50 °C. Find the increase in its volume. (γ_{real} of mercury = 1.8×10^{-4} per °C)

Given: $V_0 = 100 \text{ cm}^3$, $\Delta t = 50 \text{ °C}$, $\gamma_r = 1.8 \times 10^{-4}$

Formula: $\Delta V = V_0 \gamma_r \Delta t$

Solution:

$$\Delta V = 100 \times 1.8 \times 10^{-4} \times 50$$

$$\Delta V = 0.9$$

Ans: Increase in volume = 0.9 cm^3 .

Q21. The real coefficient of expansion of mercury is 1.8×10^{-4} per $^{\circ}\text{C}$ and α of glass is 9×10^{-6} per $^{\circ}\text{C}$. Find the apparent coefficient of expansion of mercury in a glass vessel.

Given: $\gamma_r = 1.8 \times 10^{-4}$, $\alpha_g = 9 \times 10^{-6}$

Formula: $\gamma_a = \gamma_r - \gamma_g$; $\gamma_g = 3\alpha_g$

Solution:

$$\gamma_g = 3 \times 9 \times 10^{-6} = 2.7 \times 10^{-5} \text{ per } ^{\circ}\text{C}$$

$$\gamma_a = 1.8 \times 10^{-4} - 0.27 \times 10^{-4} = 1.53 \times 10^{-4}$$

Ans: $\gamma_a = 1.53 \times 10^{-4}$ per $^{\circ}\text{C}$.

Q22. A gas occupies 273 cm^3 at 0°C at constant pressure. Find its volume at 27°C and at 100°C .

Given: $V_0 = 273 \text{ cm}^3$, $\gamma_p = 1/273$ per $^{\circ}\text{C}$

Formula: $V_t = V_0 (1 + t / 273)$

Solution:

$$\text{At } 27^{\circ}\text{C: } V = 273 (1 + 27/273) = 273 + 27 = 300 \text{ cm}^3$$

$$\text{At } 100^{\circ}\text{C: } V = 273 (1 + 100/273) = 273 + 100 = 373 \text{ cm}^3$$

Ans: 300 cm^3 at 27°C and 373 cm^3 at 100°C .

Q23. For a monatomic gas, $C_v = 12.5 \text{ J mol}^{-1} \text{ K}^{-1}$. Find C_p and γ . ($R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$)

Given: $C_v = 12.5 \text{ J mol}^{-1} \text{ K}^{-1}$, $R = 8.31$

Formula: $C_p - C_v = R$; $\gamma = C_p / C_v$

Solution:

$$C_p = C_v + R = 12.5 + 8.31 = 20.81$$

$$\gamma = 20.81 / 12.5 = 1.66$$

Ans: $C_p \approx 20.8 \text{ J mol}^{-1} \text{ K}^{-1}$ and $\gamma \approx 1.66$.

SECTION E: Formula Sheet (Quick Revision)

Topic	Formula
Temperature scales	$C / 5 = (F - 32) / 9 = (K - 273) / 5$
Heat absorbed / released	$Q = m c \Delta t$
Heat capacity; water equivalent	$m c; W = m c / c_w$
Principle of calorimetry	Heat lost = Heat gained
Thermal conduction	$Q = K A (\theta_1 - \theta_2) t / d; Q / t = K A \Delta \theta / d$
Thermal conductivity	$K = Q d / [A (\theta_1 - \theta_2) t]; \text{unit } W m^{-1} K^{-1}$
Linear expansion	$L_t = L_0 (1 + \alpha t); \alpha = \Delta L / (L_0 \Delta t)$
Superficial expansion	$A_t = A_0 (1 + \beta t); \beta = \Delta A / (A_0 \Delta t)$
Cubical expansion	$V_t = V_0 (1 + \gamma t); \gamma = \Delta V / (V_0 \Delta t)$
Relation among coefficients	$\beta = 2\alpha; \gamma = 3\alpha; \alpha : \beta : \gamma = 1 : 2 : 3$
Liquids	$V_{\text{real}} = V_{\text{apparent}} + V_{\text{vessel}}$
Gases (constant pressure)	$V_t = V_0 (1 + t / 273); \gamma_p = 1 / 273 \text{ per } ^\circ C$
Gases (constant volume)	$P_t = P_0 (1 + t / 273); \gamma_v = 1 / 273 \text{ per } ^\circ C$
Specific heats of a gas	$C_p - C_v = R; \gamma = C_p / C_v > 1$

Important points to remember

- Heat is energy (J); temperature is the degree of hotness (K). Heat flows from higher to lower temperature.
- Conduction: solids. Convection: liquids and gases. Radiation: no medium needed.
- Metals are good conductors (large K); wood, glass, air, cork are insulators (small K).
- α, β, γ are in the ratio 1 : 2 : 3. Water is densest at 4 °C.
- For all gases at constant pressure, $\gamma_p = 1/273 \text{ per } ^\circ C$. C_p is always greater than C_v .
- Always convert units (cm to m, g to kg, min to s, °C to K for differences) before substituting in a formula.