

APPLIED PHYSICS 1

Chapter: Heat and Thermometry

Set 2: More Important Questions, Solution Steps and Numerical Problems

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

Topics Covered

- Concept of heat and temperature; measurement of heat and temperature (calorimetry, thermal equilibrium, absolute scale)
- 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 and their relation
- Specific heats C_p and C_v of a gas and their relationship (mention only)

How this set 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)
- **Section D** - Numerical problems with step-by-step solutions
- **Section E** - Quick revision sheet

Useful constants used in the numericals

Quantity	Value
Specific heat of water	$4200 \text{ J kg}^{-1} \text{ K}^{-1}$
Specific heat of aluminium	$900 \text{ J kg}^{-1} \text{ K}^{-1}$
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. State the zeroth law of thermodynamics.

Ans: If two bodies A and B are each in thermal equilibrium with a third body C, then A and B are also in thermal equilibrium with each other. This law is the basis of temperature measurement.

Q2. What is thermal equilibrium?

Ans: Two bodies in contact are in thermal equilibrium when they are at the same temperature and there is no net flow of heat between them.

Q3. What is absolute zero?

Ans: The lowest possible temperature, $0\text{ K} = -273\text{ }^{\circ}\text{C}$ (more exactly $-273.15\text{ }^{\circ}\text{C}$), at which the volume of an ideal gas would theoretically become zero.

Q4. Write the SI unit of heat capacity.

Ans: J K^{-1} (joule per kelvin).

Q5. Which has the higher specific heat, water or iron?

Ans: Water ($4200\text{ J kg}^{-1}\text{ K}^{-1}$ against about 450 for iron).

Q6. Define temperature gradient. Write its unit.

Ans: Temperature gradient is the rate of change of temperature with distance along the direction of heat flow $= \Delta\theta / d$. Unit: K m^{-1} .

Q7. Is heat a scalar or a vector quantity?

Ans: Heat is a scalar quantity (it is a form of energy).

Q8. Which mode of heat transfer takes place in vacuum?

Ans: Radiation (for example, heat from the Sun).

Q9. What is thermal expansion?

Ans: The increase in the dimensions (length, area or volume) of a body when its temperature rises.

Q10. Write the units of β and γ .

Ans: Per $^{\circ}\text{C}$ (or K^{-1}), same as α .

Q11. Name an alloy having a very low coefficient of expansion.

Ans: Invar (an alloy of iron and nickel).

Q12. What happens to the density of a solid when it is heated?

Ans: It decreases, because the volume increases while the mass remains constant.

Q13. Which surface is a better absorber of heat radiation, black or white?

Ans: A black (dull) surface.

Q14. What is a convection current?

Ans: The circulation of a fluid caused by hot, lighter fluid rising and cold, denser fluid sinking.

Q15. Write the CGS unit of thermal conductivity.

Ans: $\text{cal s}^{-1} \text{cm}^{-1} \text{ } ^\circ\text{C}^{-1}$.

Q16. State Charles' law in one line.

Ans: At constant pressure, the volume of a fixed mass of gas is directly proportional to its absolute temperature (V is proportional to T).

Q17. What is the value of $\gamma = C_p / C_v$ for a monatomic gas?

Ans: About 1.67.

Q18. Which instruments are used to measure the temperature of a furnace?

Ans: A thermocouple or an optical pyrometer.

Q19. Convert 0 K into $^\circ\text{C}$.

Ans: $^\circ\text{C} = \text{K} - 273 = 0 - 273 = -273 \text{ } ^\circ\text{C}$.

Q20. What is a thermostat?

Ans: A device that keeps the temperature of an appliance constant by switching the heating circuit on and off using a bimetallic strip.

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

Q1. Why are ice blocks wrapped in sawdust or covered with a blanket to keep them from melting?

Ans: Sawdust and wool have many tiny air pockets. Air is a very bad conductor of heat, so very little heat from the surroundings reaches the ice.

Q2. Why do woollen clothes keep us warm in winter?

Ans: Wool traps a lot of air between its fibres. Trapped air is a bad conductor, so it stops the heat of the body from escaping to the cold surroundings.

Q3. Why does a bird fluff up its feathers in winter?

Ans: Fluffing the feathers traps more air between them. This air layer acts as an insulator and reduces heat loss from the body.

Q4. Why is water used as a coolant in car radiators and for heating in hot-water bottles?

Ans: Water has a very high specific heat. It can absorb or give out a large amount of heat for a small change in temperature, so it is an efficient carrier of heat.

Q5. Why is the climate of coastal areas moderate while that of deserts is extreme?

Ans: Water has a high specific heat, so the sea heats up and cools down slowly and keeps nearby land mild. Sand has a low specific heat, so deserts become very hot in the day and very cold at night.

Q6. Why are the outer bottoms of cooking vessels blackened while the inside is kept shiny?

Ans: The blackened bottom absorbs more heat radiation from the flame. The shiny inside is a poor emitter, so it reduces heat loss by radiation and keeps the food hot.

Q7. Why do water pipes burst in very cold weather?

Ans: Water freezes at 0 °C and expands (the volume of ice is about 9% more than water). The expanding ice exerts a large force on the walls and bursts the pipe.

Q8. Why is a tight metal lid of a glass jar loosened by dipping it in hot water?

Ans: Metal has a larger coefficient of expansion than glass. On heating, the lid expands more than the glass neck and becomes loose.

Q9. Why are expansion bends or loops provided in long steam pipes?

Ans: Hot steam makes the pipe expand. The bends absorb the expansion and prevent the pipe from buckling or damaging its supports.

Q10. Why is alcohol thermometer preferred to mercury thermometer in very cold regions?

Ans: Mercury freezes at -39 °C, but alcohol freezes at about -115 °C, so an alcohol thermometer can measure very low temperatures.

Q11. Why is platinum used for sealing electric wires into glass bulbs?

Ans: The coefficient of expansion of platinum is almost equal to that of glass. Both expand and contract equally, so the glass does not crack when the bulb heats and cools.

Q12. Why do gases expand much more than solids and liquids on heating?

Ans: The intermolecular forces in gases are almost negligible, so the molecules move freely and the volume increases a lot. In solids the strong forces restrict expansion.

Q13. Why are hot-water pipes and boilers wrapped with glass wool or asbestos?

Ans: These materials are bad conductors of heat. They reduce the heat lost to the surroundings by conduction.

Q14. Why is C_p greater than C_v for a gas? (mention only)

Ans: At constant pressure, the gas expands and does external work, so extra heat is needed over and above that required to raise the temperature. At constant volume no work is done.

Hence $C_p > C_v$.

SECTION C: Long Answer Questions (5 marks each)

Q1. State the principle of calorimetry. Describe how the specific heat of a solid is determined by the method of mixtures.

Principle of calorimetry: When hot and cold bodies are mixed and no heat is lost to the surroundings, the heat lost by the hot body is equal to the heat gained by the cold body.

Apparatus: calorimeter with stirrer, thermometer, insulating jacket, steam heater, physical balance, the solid and water.

Procedure:

- Weigh the empty calorimeter with its stirrer (mass m_c).
- Fill it about half with water and weigh again to find the mass of water m_w . Note the initial temperature t_2 .
- Weigh the solid (mass m) and heat it in the steam heater to about $t_1 = 100^\circ\text{C}$.
- Quickly transfer the hot solid into the calorimeter, stir well and note the highest steady temperature t .

Calculation:

Heat lost by the solid = $m c (t_1 - t)$

Heat gained by water and calorimeter = $(m_w c_w + m_c c_c)(t - t_2)$

By the principle of calorimetry: $c = (m_w c_w + m_c c_c)(t - t_2) / [m (t_1 - t)]$

Precautions: transfer the solid quickly, stir gently, keep the calorimeter polished and in an insulating jacket, and avoid splashing of water.

Q2. Explain convection in detail. Distinguish between natural and forced convection with examples.

Convection is the transfer of heat in a liquid or gas by the actual movement of the heated fluid. When a fluid is heated, it expands, its density decreases and it rises. The cold, denser fluid from above sinks to take its place. This circulation, called a **convection current**, carries heat from the hot region to the cold region.

Natural convection: the fluid moves due to differences in density caused by heating, without any external agent.

- Heating of water in a beaker or boiler
- Sea breeze (day) and land breeze (night); trade winds
- Rising of smoke through a chimney; ventilators near the ceiling
- Ocean currents

Forced convection: the fluid is made to move by a fan, pump or blower.

- Cooling of a car engine by a water pump and radiator fan
- Room cooler, exhaust fan, hair dryer
- Blood circulation by the heart (pump)

Remember: convection is not possible in solids, because their particles cannot move from place to place.

Q3. Describe the properties of heat radiation. How do different surfaces absorb, reflect and emit radiation? Give applications.

Properties of thermal radiation:

- It travels in the form of electromagnetic waves (mainly infrared) with the speed of light
- It needs no material medium and does not heat the medium through which it passes
- It travels in straight lines and obeys the laws of reflection and refraction
- Every body at a temperature above 0 K emits it, and a hotter body emits more

When radiation falls on a body, a part is absorbed, a part is reflected and a part may be transmitted.

Surface	Absorption	Reflection	Emission
Dull black	Very good	Very poor	Very good
White / shiny (polished)	Poor	Very good	Poor

Rule: a good absorber of radiation is also a good emitter, and a good reflector is a poor absorber and a poor emitter. A perfect *black body* absorbs all radiation falling on it.

Applications: solar cooker and solar water heater (black absorbing surface with glass cover), greenhouse, Thermos flask (silvered walls), white clothes in summer, polished metal teapots (keep tea hot longer), and painting of aircraft and storage tanks with aluminium paint.

Q4. Describe a simple laboratory method to determine the coefficient of linear expansion of a metal rod.

Apparatus: a metal rod, a steam jacket with a boiler, a thermometer, a screw gauge or spherometer (to measure the small change in length) and a metre scale.

Procedure:

- Measure the length L_0 of the rod with a scale at room temperature t_1 .
- Fix the rod inside the steam jacket with one end clamped and the other end touching the screw gauge; take the initial reading.
- Pass steam through the jacket until the thermometer shows a steady temperature t_2 (about 100 °C).
- Take the new reading of the screw gauge. The difference of the two readings gives the increase in length ΔL .

Calculation: $\alpha = \Delta L / [L_0 (t_2 - t_1)]$ per °C.

Precautions: the rod must be clamped firmly at one end, the steam must be dry, and the readings must be taken only after the temperature becomes steady.

Q5. Show that the density of a substance decreases with a rise in temperature. Derive the expression for the density at temperature t .

Let m be the mass of a body. Its density at 0°C is ρ_0 and its volume is V_0 . At temperature t , the density is ρ_t and the volume is V_t .

The mass does not change with temperature, so $m = \rho_0 V_0 = \rho_t V_t$

From the expansion of volume, $V_t = V_0 (1 + \gamma t)$

Hence $\rho_0 V_0 = \rho_t V_0 (1 + \gamma t)$, giving $\rho_t = \rho_0 / (1 + \gamma t)$

As γt is very small, $\rho_t \approx \rho_0 (1 - \gamma t)$.

Conclusion: $\rho_t < \rho_0$, so the density decreases when the temperature rises. This is why the heated fluid rises in convection currents. (Water between 0°C and 4°C is an exception.)

Q6. Derive the relation between the real and apparent coefficients of expansion of a liquid.

Let V_0 be the volume of a liquid at 0°C in a vessel. The liquid is heated to $t^\circ\text{C}$. Let γ_r = real coefficient of expansion of the liquid, γ_a = apparent coefficient and γ_g = coefficient of cubical expansion of the vessel.

Real increase in the volume of the liquid = $V_0 \gamma_r t$

Increase in the internal volume of the vessel = $V_0 \gamma_g t$

The apparent increase seen by the observer is the difference between the two:

$$V_0 \gamma_a t = V_0 \gamma_r t - V_0 \gamma_g t$$

Cancelling $V_0 t$: $\gamma_r = \gamma_a + \gamma_g$

The real expansion of a liquid is the sum of its apparent expansion and the expansion of the vessel. If the vessel does not expand at all, then $\gamma_r = \gamma_a$.

Q7. What is the absolute scale of temperature? Explain how it follows from Charles' law.

According to Charles' law, at constant pressure $V_t = V_0 (1 + t / 273) = V_0 (273 + t) / 273$.

If we define a new temperature $T = (273 + t)$ in kelvin, then $V_t = (V_0 / 273) \times T$, that is **V is directly proportional to T**.

If $t = -273^\circ\text{C}$, then $V_t = 0$. That is, at -273°C the volume of an ideal gas would become zero.

No temperature below this is possible. This temperature is called the **absolute zero**.

The scale that starts from absolute zero is the absolute (Kelvin) scale: **$T (\text{K}) = t (^\circ\text{C}) + 273$** . A change of 1 K equals a change of 1°C , and the ice point (0°C) is 273 K and the steam point (100°C) is 373 K.

The Kelvin scale does not depend on the properties of any particular substance and is the SI scale of temperature.

Q8. Write short notes on: (a) thermostat, (b) compensated pendulum, (c) expansion joints.

(a) Thermostat: It uses a bimetallic strip (for example brass and iron) in the electric circuit of the heater. When the temperature rises above a set value, the strip bends and breaks the circuit. When it cools, the strip straightens and the circuit closes again. Used in electric irons, geysers, ovens and refrigerators.

(b) Compensated pendulum: The length of an ordinary clock pendulum changes with temperature, so the clock gains or loses time. In a compensated (gridiron) pendulum, rods of two different metals (steel and brass) are arranged so that the expansion of one cancels the expansion of the other and the effective length stays constant. Invar is also used for the same purpose.

(c) Expansion joints: Gaps or flexible joints provided in railway tracks, bridges, concrete roads, long pipelines and buildings, so that the structure can expand and contract freely with temperature and does not crack or buckle.

Poly Notes Hub

SECTION D: Numerical Problems with Solutions

Q1. Convert 77 °F into °C and K.

Given: $F = 77\text{ °F}$

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

Solution:

$$C = (5/9)(77 - 32) = (5/9) \times 45 = 25$$

$$K = 25 + 273 = 298$$

Ans: 25 °C and 298 K.

Q2. Convert 300 K into °C and °F.

Given: $T = 300\text{ K}$

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

Solution:

$$C = 300 - 273 = 27$$

$$F = (9/5) \times 27 + 32 = 48.6 + 32 = 80.6$$

Ans: 27 °C and 80.6 °F.

Q3. At what Celsius temperature is the Fahrenheit reading exactly three times the Celsius reading?

Given: $F = 3C$

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

Solution:

$$C / 5 = (3C - 32) / 9$$

$$9C = 15C - 160$$

$$6C = 160, \text{ so } C = 26.67$$

Ans: $C \approx 26.7\text{ °C}$ (and $F = 80\text{ °F}$).

Q4. How much heat is required to raise the temperature of 3 kg of aluminium from 25 °C to 125 °C? ($c = 900\text{ J kg}^{-1}\text{ K}^{-1}$)

Given: $m = 3\text{ kg}$, $c = 900$, $\Delta t = 100\text{ °C}$

Formula: $Q = m c \Delta t$

Solution:

$$Q = 3 \times 900 \times 100$$

$$Q = 2,70,000\text{ J}$$

Ans: $Q = 2.7 \times 10^5\text{ J}$.

Q5. A body of mass 250 g absorbs 5000 J of heat and its temperature rises by 40 °C. Find its specific heat.

Given: $m = 0.25 \text{ kg}$, $Q = 5000 \text{ J}$, $\Delta t = 40 \text{ °C}$

Formula: $c = Q / (m \Delta t)$

Solution:

$$c = 5000 / (0.25 \times 40) = 5000 / 10$$

$$c = 500$$

Ans: $c = 500 \text{ J kg}^{-1} \text{ K}^{-1}$.

Q6. A 0.5 kg metal piece at 100 °C is dropped into 0.4 kg of water at 20 °C. The final temperature is 30 °C. Find the specific heat of the metal. (Neglect the calorimeter; c of water = $4200 \text{ J kg}^{-1} \text{ K}^{-1}$)

Given: $m_1 = 0.5 \text{ kg}$, $t_1 = 100 \text{ °C}$; $m_2 = 0.4 \text{ kg}$, $t_2 = 20 \text{ °C}$; $t = 30 \text{ °C}$

Formula: Heat lost by metal = heat gained by water

Solution:

$$0.5 \times c \times (100 - 30) = 0.4 \times 4200 \times (30 - 20)$$

$$35 c = 16800$$

$$c = 480$$

Ans: $c = 480 \text{ J kg}^{-1} \text{ K}^{-1}$.

Q7. 100 g of water at 60 °C is mixed with 400 g of water at 10 °C. Find the final temperature.

Given: $m_1 = 100 \text{ g}$, $t_1 = 60 \text{ °C}$; $m_2 = 400 \text{ g}$, $t_2 = 10 \text{ °C}$

Formula: Heat lost = heat gained

Solution:

$$100 (60 - T) = 400 (T - 10)$$

$$6000 - 100T = 400T - 4000$$

$$10000 = 500T, \text{ so } T = 20$$

Ans: Final temperature = 20 °C.

Q8. A calorimeter of water equivalent 20 g contains 180 g of water at 20 °C. 200 g of water at 70 °C is added. Find the final temperature.

Given: Water equivalent of calorimeter = 20 g; cold water = 180 g at 20 °C; hot water = 200 g at 70 °C

Formula: Heat lost = heat gained

Solution:

Total cold mass (water + calorimeter) = 180 + 20 = 200 g

$$200 (70 - T) = 200 (T - 20)$$

$$70 - T = T - 20, \text{ so } 2T = 90, T = 45$$

Ans: Final temperature = 45 °C.

Q9. An iron rod 1 m long and 2 cm² in cross-section has its ends at 100 °C and 0 °C. Find the rate of heat flow. (K of iron = 80 W m⁻¹ K⁻¹)

Given: d = 1 m, A = 2 × 10⁻⁴ m², Δθ = 100 K, K = 80

Formula: Q / t = K A Δθ / d

Solution:

$$Q / t = (80 \times 2 \times 10^{-4} \times 100) / 1$$

$$Q / t = 1.6$$

Ans: Rate of heat flow = 1.6 W.

Q10. An aluminium plate of area 0.5 m² and thickness 5 cm has a temperature difference of 10 K between its faces. Find the rate of heat flow. (K = 205 W m⁻¹ K⁻¹)

Given: A = 0.5 m², d = 0.05 m, Δθ = 10 K, K = 205

Formula: Q / t = K A Δθ / d

Solution:

$$Q / t = (205 \times 0.5 \times 10) / 0.05$$

$$Q / t = 1025 / 0.05 = 20,500$$

Ans: Rate of heat flow = 2.05 × 10⁴ W.

Q11. A brick wall of area 10 m² and thickness 20 cm has 30 °C inside and 10 °C outside. Find the heat conducted per day. (K of brick = 0.6 W m⁻¹ K⁻¹)

Given: A = 10 m², d = 0.2 m, Δθ = 20 K, t = 24 × 3600 = 86400 s, K = 0.6

Formula: Q = K A Δθ t / d

Solution:

$$\text{Rate: } Q / t = (0.6 \times 10 \times 20) / 0.2 = 120 / 0.2 = 600 \text{ W}$$

$$Q = 600 \times 86400 = 5.184 \times 10^7 \text{ J}$$

Ans: Q ≈ 5.18 × 10⁷ J per day.

Q12. 15000 J of heat flows in 5 minutes through a rod of cross-section 5 cm^2 and length 20 cm when the ends have a temperature difference of 50 K. Find the thermal conductivity of the rod.

Given: $Q = 15000 \text{ J}$, $t = 300 \text{ s}$, $A = 5 \times 10^{-4} \text{ m}^2$, $d = 0.2 \text{ m}$, $\Delta\theta = 50 \text{ K}$

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

Solution:

$$K = (15000 \times 0.2) / (5 \times 10^{-4} \times 50 \times 300)$$

$$K = 3000 / 7.5 = 400$$

Ans: $K = 400 \text{ W m}^{-1} \text{ K}^{-1}$.

Q13. Two rods A and B of the same material and cross-section have lengths 20 cm and 40 cm. The temperature difference across each is the same. Find the ratio of the rates of heat flow.

Given: $d_A = 20 \text{ cm}$, $d_B = 40 \text{ cm}$; K , A and $\Delta\theta$ are the same

Formula: $Q / t = K A \Delta\theta / d$, so Q / t is proportional to $1 / d$

Solution:

$$(Q/t)_A : (Q/t)_B = 1/d_A : 1/d_B = 1/20 : 1/40 \\ = 2 : 1$$

Ans: The ratio is 2 : 1.

Q14. A copper wire is 100 m long at 10°C . Find its increase in length at 40°C . ($\alpha = 1.7 \times 10^{-5}$ per $^\circ\text{C}$)

Given: $L_0 = 100 \text{ m}$, $\Delta t = 30^\circ\text{C}$, $\alpha = 1.7 \times 10^{-5}$

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

Solution:

$$\Delta L = 100 \times 1.7 \times 10^{-5} \times 30$$

$$\Delta L = 0.051 \text{ m}$$

Ans: Increase in length = 0.051 m = 5.1 cm.

Q15. An aluminium rod 2 m long at 20°C becomes 2.00276 m at 80°C . Find α of aluminium.

Given: $L_0 = 2 \text{ m}$, $\Delta L = 0.00276 \text{ m}$, $\Delta t = 60^\circ\text{C}$

Formula: $\alpha = \Delta L / (L_0 \Delta t)$

Solution:

$$\alpha = 0.00276 / (2 \times 60) = 0.00276 / 120$$

$$\alpha = 2.3 \times 10^{-5}$$

Ans: $\alpha = 2.3 \times 10^{-5}$ per $^\circ\text{C}$.

Q16. A brass rod and an iron rod differ in length by 14 cm at all temperatures. Find their lengths at 0 °C. ($\alpha_{\text{brass}} = 1.9 \times 10^{-5}$, $\alpha_{\text{iron}} = 1.2 \times 10^{-5}$ per °C)

Given: Difference in length remains constant, so the expansion of both rods is equal

Formula: $L_b \alpha_b \Delta t = L_i \alpha_i \Delta t$

Solution:

$$L_b \times 19 = L_i \times 12, \text{ so } L_i = (19/12) L_b \text{ (the iron rod is longer)}$$

$$L_i - L_b = 14, \text{ so } (19/12 - 1) L_b = 14$$

$$(7/12) L_b = 14, \text{ so } L_b = 24 \text{ cm}$$

$$L_i = 24 + 14 = 38 \text{ cm}$$

Ans: Brass rod = 24 cm and iron rod = 38 cm.

Q17. An aluminium sheet 2 m × 1 m at 0 °C is heated to 100 °C. Find the increase in its area. ($\alpha = 2.3 \times 10^{-5}$ per °C)

Given: $A_0 = 2 \text{ m}^2$, $\Delta t = 100 \text{ °C}$, $\alpha = 2.3 \times 10^{-5}$

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

Solution:

$$\beta = 4.6 \times 10^{-5} \text{ per °C}$$

$$\Delta A = 2 \times 4.6 \times 10^{-5} \times 100 = 9.2 \times 10^{-3} \text{ m}^2$$

Ans: Increase in area = $9.2 \times 10^{-3} \text{ m}^2$ (= 92 cm²).

Q18. A circular hole of diameter 4 cm is drilled in a brass plate at 20 °C. What is its diameter at 120 °C? (α of brass = 1.9×10^{-5} per °C)

Given: $d_0 = 4 \text{ cm}$, $\Delta t = 100 \text{ °C}$, $\alpha = 1.9 \times 10^{-5}$

Formula: A hole expands exactly like the material around it: $d = d_0 (1 + \alpha \Delta t)$

Solution:

$$\Delta d = 4 \times 1.9 \times 10^{-5} \times 100 = 7.6 \times 10^{-3} \text{ cm}$$

$$d = 4 + 0.0076 = 4.0076 \text{ cm}$$

Ans: New diameter = 4.0076 cm (the hole becomes larger).

Q19. An aluminium block has a volume of 200 cm³ at 0 °C. Find the increase in volume at 100 °C. ($\alpha = 2.3 \times 10^{-5}$ per °C)

Given: $V_0 = 200 \text{ cm}^3$, $\Delta t = 100 \text{ °C}$, $\alpha = 2.3 \times 10^{-5}$

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

Solution:

$$\gamma = 6.9 \times 10^{-5} \text{ per °C}$$

$$\Delta V = 200 \times 6.9 \times 10^{-5} \times 100 = 1.38$$

Ans: Increase in volume = 1.38 cm³.

Q20. The density of copper at 0 °C is 8.9 g cm⁻³. Find its density at 100 °C. ($\alpha = 1.7 \times 10^{-5}$ per °C)

Given: $\rho_0 = 8.9 \text{ g cm}^{-3}$, $t = 100 \text{ °C}$, $\alpha = 1.7 \times 10^{-5}$

Formula: $\rho_t = \rho_0 / (1 + \gamma t)$; $\gamma = 3\alpha$

Solution:

$$\gamma = 5.1 \times 10^{-5} \text{ per } ^\circ\text{C}, \text{ so } \gamma t = 5.1 \times 10^{-3}$$

$$\rho_t = 8.9 / 1.0051 = 8.855$$

Ans: Density at 100 °C $\approx 8.855 \text{ g cm}^{-3}$.

Q21. Find the increase in volume of 500 cm³ of alcohol when it is heated from 0 °C to 40 °C. ($\gamma = 11 \times 10^{-4}$ per °C)

Given: $V_0 = 500 \text{ cm}^3$, $\Delta t = 40 \text{ °C}$, $\gamma = 1.1 \times 10^{-3}$

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

Solution:

$$\Delta V = 500 \times 1.1 \times 10^{-3} \times 40$$

$$\Delta V = 22$$

Ans: Increase in volume = 22 cm³.

Q22. The apparent coefficient of expansion of a liquid in a glass vessel is 1.4×10^{-4} per °C. Find the real coefficient of expansion of the liquid. (α of glass = 9×10^{-6} per °C)

Given: $\gamma_a = 1.4 \times 10^{-4}$, $\alpha_g = 9 \times 10^{-6}$

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

Solution:

$$\gamma_g = 2.7 \times 10^{-5} = 0.27 \times 10^{-4}$$

$$\gamma_r = 1.4 \times 10^{-4} + 0.27 \times 10^{-4} = 1.67 \times 10^{-4}$$

Ans: $\gamma_r = 1.67 \times 10^{-4}$ per °C.

Q23. A gas has a volume of 500 cm³ at 0 °C. Find its volume at 91 °C at constant pressure.

Given: $V_0 = 500 \text{ cm}^3$, $t = 91 \text{ °C}$

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

Solution:

$$V_t = 500 (1 + 91/273)$$

$$91/273 = 1/3, \text{ so } V_t = 500 \times 4/3 = 666.7$$

Ans: $V \approx 666.7 \text{ cm}^3$.

Q24. The pressure of a gas at 0 °C is 2 atm. It is heated to 54.6 °C at constant volume. Find the final pressure.

Given: $P_0 = 2 \text{ atm}$, $t = 54.6 \text{ °C}$

Formula: $P_t = P_0 (1 + t / 273)$

Solution:

$$54.6 / 273 = 0.2$$

$$P_t = 2 \times (1 + 0.2) = 2.4$$

Ans: $P = 2.4 \text{ atm}$.

Q25. At what temperature will the volume of a gas, initially at 27 °C, double at constant pressure?

Given: $T_1 = 27 + 273 = 300 \text{ K}$, $V_2 = 2 V_1$

Formula: $V / T = \text{constant}$ (Charles' law)

Solution:

$$V_1 / T_1 = V_2 / T_2$$

$$T_2 = T_1 \times (V_2 / V_1) = 300 \times 2 = 600 \text{ K}$$

$$t = 600 - 273 = 327 \text{ °C}$$

Ans: $T_2 = 600 \text{ K} = 327 \text{ °C}$.

Q26. For a diatomic gas, $C_v = 20.8 \text{ J mol}^{-1} \text{ K}^{-1}$. Find C_p and γ . ($R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$)

Given: $C_v = 20.8$, $R = 8.31$

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

Solution:

$$C_p = 20.8 + 8.31 = 29.11$$

$$\gamma = 29.11 / 20.8 = 1.40$$

Ans: $C_p \approx 29.1 \text{ J mol}^{-1} \text{ K}^{-1}$ and $\gamma \approx 1.40$.

SECTION E: Quick Revision Sheet

Topic	Formula / Key point
Absolute scale	$T \text{ (K)} = t \text{ (}^\circ\text{C)} + 273$; V is proportional to T at constant pressure
Method of mixtures	$m_c (t_1 - t) = (m_w c_w + m_c c_c)(t - t_2)$
Conduction	$Q / t = K A \Delta\theta / d$; rate is proportional to A and $\Delta\theta$, and inversely proportional to d
Linear expansion	$\Delta L = L_0 \alpha \Delta t$
Area expansion	$\Delta A = A_0 \beta \Delta t$ with $\beta = 2\alpha$
Volume expansion	$\Delta V = V_0 \gamma \Delta t$ with $\gamma = 3\alpha$
Density and temperature	$\rho_t = \rho_0 / (1 + \gamma t) \approx \rho_0 (1 - \gamma t)$
Liquids	$V_{\text{real}} = V_{\text{apparent}} + V_{\text{vessel}}$
Gases	$V_t = V_0 (1 + t / 273)$; $P_t = P_0 (1 + t / 273)$
Specific heats of gas	$C_p - C_v = R$; $\gamma = C_p / C_v$ (1.67 monatomic, 1.40 diatomic)

Points to remember

- A good absorber of radiation is also a good emitter; a good reflector is a poor absorber.
- Bad conductors such as air, wool, sawdust and glass wool are used as heat insulators.
- A hole in a plate expands like the plate material when heated.
- If the difference in length of two rods is to remain constant, then $L_1 \alpha_1 = L_2 \alpha_2$.
- Density of a substance decreases on heating (water between 0 °C and 4 °C is the exception).
- Convert all units to SI (cm to m, g to kg, min to s) before using the formulae.