

APPLIED PHYSICS 1

Chapter: Heat and Thermometry

Set 4: Numerical Problems with Solutions

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

Formulae and Constants Used

Topic	Formula
Temperature scales	$C / 5 = (F - 32) / 9 = (K - 273) / 5$
Heat and calorimetry	$Q = m c \Delta t$; heat lost = heat gained; $W = m c / c_w$
Conduction	$Q = K A \Delta \theta t / d$; $Q / t = K A \Delta \theta / d$
Expansion of solids	$\Delta L = L_0 \alpha \Delta t$; $\Delta A = A_0 \beta \Delta t$; $\Delta V = V_0 \gamma \Delta t$; $\beta = 2\alpha$, $\gamma = 3\alpha$
Density	$\rho_t = \rho_0 / (1 + \gamma t)$
Liquids	$\gamma_{\text{real}} = \gamma_{\text{apparent}} + \gamma_{\text{vessel}}$
Gases	$V / T = \text{constant (constant P)}$; $P / T = \text{constant (constant V)}$; $T = t + 273$
Specific heats of gas	$C_p - C_v = R$; $\gamma = C_p / C_v$
Constants	$c_{\text{water}} = 4200 \text{ J kg}^{-1} \text{ K}^{-1} = 1 \text{ cal g}^{-1} \text{ }^\circ\text{C}^{-1}$; $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$

Tip: convert every quantity to SI units (m, kg, s, K) before substituting in a formula.

A. Temperature Scales

Q1. Convert 25 °C into °F and K.

Given: $C = 25 \text{ }^\circ\text{C}$

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

Solution:

$$F = (9/5) \times 25 + 32 = 45 + 32 = 77$$

$$K = 25 + 273 = 298$$

Ans: 77 °F and 298 K.

Q2. Convert 392 °F into °C and K.

Given: $F = 392 \text{ }^\circ\text{F}$

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

Solution:

$$C = (5/9)(392 - 32) = (5/9) \times 360 = 200$$

$$K = 200 + 273 = 473$$

Ans: 200 °C and 473 K.

Q3. Convert 350 K into °C and °F.

Given: $T = 350 \text{ K}$

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

Solution:

$$C = 350 - 273 = 77$$

$$F = (9/5) \times 77 + 32 = 138.6 + 32 = 170.6$$

Ans: 77°C and 170.6°F .

Q4. At what Celsius temperature is the Fahrenheit reading exactly 40 more than the Celsius reading?

Given: $F = C + 40$

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

Solution:

$$C / 5 = (C + 40 - 32) / 9 = (C + 8) / 9$$

$$9C = 5C + 40$$

$$4C = 40, \text{ so } C = 10$$

$$F = 10 + 40 = 50$$

Ans: 10°C ($= 50^\circ\text{F}$).

B. Heat, Specific Heat and Calorimetry

Q5. Find the heat required to raise the temperature of 750 g of copper from 20°C to 220°C . ($c = 390 \text{ J kg}^{-1} \text{ K}^{-1}$)

Given: $m = 0.75 \text{ kg}$, $\Delta t = 200^\circ\text{C}$, $c = 390$

Formula: $Q = m c \Delta t$

Solution:

$$Q = 0.75 \times 390 \times 200$$

$$Q = 58,500 \text{ J}$$

Ans: $Q = 5.85 \times 10^4 \text{ J}$.

Q6. How much heat is released when 1.5 kg of water cools from 80°C to 30°C ?

Given: $m = 1.5 \text{ kg}$, $\Delta t = 50^\circ\text{C}$, $c = 4200$

Formula: $Q = m c \Delta t$

Solution:

$$Q = 1.5 \times 4200 \times 50$$

$$Q = 3,15,000 \text{ J}$$

Ans: $Q = 3.15 \times 10^5 \text{ J}$.

Q7. A 2 kW immersion heater is used to heat 10 kg of water from 25 °C to 75 °C. Find the time required, assuming no heat loss.

Given: $P = 2000 \text{ W}$, $m = 10 \text{ kg}$, $\Delta t = 50 \text{ }^{\circ}\text{C}$

Formula: $Q = m c \Delta t$; $t = Q / P$

Solution:

$$Q = 10 \times 4200 \times 50 = 21,00,000 \text{ J}$$

$$t = 2100000 / 2000 = 1050 \text{ s}$$

Ans: $t = 1050 \text{ s} = 17.5 \text{ minutes}$.

Q8. A 0.3 kg metal block absorbs 7560 J of heat and its temperature rises from 20 °C to 80 °C. Find its specific heat.

Given: $m = 0.3 \text{ kg}$, $Q = 7560 \text{ J}$, $\Delta t = 60 \text{ }^{\circ}\text{C}$

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

Solution:

$$c = 7560 / (0.3 \times 60) = 7560 / 18$$

$$c = 420$$

Ans: $c = 420 \text{ J kg}^{-1} \text{ K}^{-1}$.

Q9. 400 g of water at 90 °C is mixed with 600 g of water at 30 °C. Find the temperature of the mixture.

Given: $m_1 = 400 \text{ g}$, $t_1 = 90 \text{ }^{\circ}\text{C}$; $m_2 = 600 \text{ g}$, $t_2 = 30 \text{ }^{\circ}\text{C}$

Formula: Heat lost = heat gained

Solution:

$$400 (90 - T) = 600 (T - 30)$$

$$36000 - 400T = 600T - 18000$$

$$54000 = 1000T, \text{ so } T = 54$$

Ans: Final temperature = 54 °C.

Q10. Three quantities of water, 0.2 kg at 60 °C, 0.3 kg at 20 °C and 0.5 kg at 40 °C, are mixed. Find the final temperature.

Given: $(m_1, t_1) = (0.2, 60)$, $(m_2, t_2) = (0.3, 20)$, $(m_3, t_3) = (0.5, 40)$

Formula: $T = (m_1 t_1 + m_2 t_2 + m_3 t_3) / (m_1 + m_2 + m_3)$

Solution:

$$\text{Numerator} = 0.2 \times 60 + 0.3 \times 20 + 0.5 \times 40 = 12 + 6 + 20 = 38$$

$$\text{Denominator} = 0.2 + 0.3 + 0.5 = 1.0$$

$$T = 38 / 1.0 = 38$$

Ans: Final temperature = 38 °C.

Q11. Find the water equivalent of a copper calorimeter of mass 120 g. (c of copper = 390 J kg⁻¹ K⁻¹)

Given: m = 0.12 kg, c = 390, c_w = 4200

Formula: $W = m c / c_w$

Solution:

$$W = (0.12 \times 390) / 4200 = 46.8 / 4200$$

$$W = 0.01114 \text{ kg}$$

Ans: W ≈ 11.1 g.

Q12. 0.1 kg of a metal at 100 °C is dropped into a calorimeter of water equivalent 0.01 kg containing 0.19 kg of water at 20 °C. The final temperature is 25 °C. Find the specific heat of the metal.

Given: m = 0.1 kg, t₁ = 100 °C; water + calorimeter = 0.19 + 0.01 = 0.2 kg at 20 °C; final t = 25 °C

Formula: Heat lost by metal = heat gained by water and calorimeter

Solution:

$$0.1 \times c \times (100 - 25) = 0.2 \times 4200 \times (25 - 20)$$

$$7.5 c = 4200$$

$$c = 560$$

Ans: c = 560 J kg⁻¹ K⁻¹.

Q13. How long will a 500 W heater take to raise the temperature of 3 kg of oil by 40 °C? (c of oil = 2100 J kg⁻¹ K⁻¹)

Given: P = 500 W, m = 3 kg, Δt = 40 °C, c = 2100

Formula: Q = m c Δt; t = Q / P

Solution:

$$Q = 3 \times 2100 \times 40 = 2,52,000 \text{ J}$$

$$t = 252000 / 500 = 504 \text{ s}$$

Ans: t = 504 s = 8.4 minutes.

C. Thermal Conductivity

Q14. A copper rod of length 40 cm and cross-section 2 cm^2 has its ends at 120°C and 20°C . Find the rate of heat flow. ($K = 385 \text{ W m}^{-1} \text{ K}^{-1}$)

Given: $d = 0.4 \text{ m}$, $A = 2 \times 10^{-4} \text{ m}^2$, $\Delta\theta = 100 \text{ K}$, $K = 385$

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

Solution:

$$Q / t = (385 \times 2 \times 10^{-4} \times 100) / 0.4$$

$$Q / t = 7.7 / 0.4 = 19.25$$

Ans: Rate of heat flow = 19.25 W.

Q15. An aluminium rod 30 cm long and 1 cm^2 in cross-section has a temperature difference of 60 K between its ends. Find the heat conducted in 5 minutes. ($K = 205 \text{ W m}^{-1} \text{ K}^{-1}$)

Given: $d = 0.3 \text{ m}$, $A = 10^{-4} \text{ m}^2$, $\Delta\theta = 60 \text{ K}$, $t = 300 \text{ s}$, $K = 205$

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

Solution:

$$\text{Rate: } Q / t = (205 \times 10^{-4} \times 60) / 0.3 = 1.23 / 0.3 = 4.1 \text{ W}$$

$$Q = 4.1 \times 300 = 1230 \text{ J}$$

Ans: $Q = 1230 \text{ J}$.

Q16. A wooden door of area 2 m^2 and thickness 4 cm has 30°C on the inside and 10°C on the outside. Find the heat conducted in one hour. (K of wood = $0.15 \text{ W m}^{-1} \text{ K}^{-1}$)

Given: $A = 2 \text{ m}^2$, $d = 0.04 \text{ m}$, $\Delta\theta = 20 \text{ K}$, $t = 3600 \text{ s}$, $K = 0.15$

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

Solution:

$$\text{Rate: } Q / t = (0.15 \times 2 \times 20) / 0.04 = 6 / 0.04 = 150 \text{ W}$$

$$Q = 150 \times 3600 = 5,40,000 \text{ J}$$

Ans: $Q = 5.4 \times 10^5 \text{ J}$.

Q17. A glass sheet of area 1 m^2 conducts heat at 500 W when the temperature difference between its faces is 10 K. Find its thickness. (K of glass = $1.0 \text{ W m}^{-1} \text{ K}^{-1}$)

Given: $A = 1 \text{ m}^2$, $Q / t = 500 \text{ W}$, $\Delta\theta = 10 \text{ K}$, $K = 1.0$

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

Solution:

$$d = (1.0 \times 1 \times 10) / 500$$

$$d = 0.02 \text{ m}$$

Ans: Thickness = 0.02 m = 2 cm.

Q18. A concrete wall of thickness 10 cm allows heat to flow at 240 W when the temperature difference across it is 15 K. Find the area of the wall. (K of concrete = $0.8 \text{ W m}^{-1} \text{ K}^{-1}$)

Given: $d = 0.1 \text{ m}$, $Q / t = 240 \text{ W}$, $\Delta\theta = 15 \text{ K}$, $K = 0.8$

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

Solution:

$$A = (240 \times 0.1) / (0.8 \times 15)$$

$$A = 24 / 12 = 2$$

Ans: Area = 2 m^2 .

Q19. In an experiment, 5760 J of heat flows in 4 minutes through a rod of cross-section 4 cm^2 and length 40 cm. The temperature difference between its ends is 75 K. Find the thermal conductivity of the rod.

Given: $Q = 5760 \text{ J}$, $t = 240 \text{ s}$, $A = 4 \times 10^{-4} \text{ m}^2$, $d = 0.4 \text{ m}$, $\Delta\theta = 75 \text{ K}$

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

Solution:

$$\text{Rate: } Q / t = 5760 / 240 = 24 \text{ W}$$

$$K = (24 \times 0.4) / (4 \times 10^{-4} \times 75) = 9.6 / 0.03$$

$$K = 320$$

Ans: $K = 320 \text{ W m}^{-1} \text{ K}^{-1}$.

Q20. Two rods of the same material and cross-section have lengths in the ratio 1 : 3. The temperature differences across them are in the ratio 2 : 1. Find the ratio of their rates of heat flow.

Given: $d_1 : d_2 = 1 : 3$; $\Delta\theta_1 : \Delta\theta_2 = 2 : 1$; K and A are the same

Formula: Q / t is proportional to $\Delta\theta / d$

Solution:

$$\text{For rod 1: } \Delta\theta / d = 2 / 1 = 2$$

$$\text{For rod 2: } \Delta\theta / d = 1 / 3$$

$$\text{Ratio} = 2 : 1/3 = 6 : 1$$

Ans: The ratio is 6 : 1.

Q21. Two slabs of the same thickness have thermal conductivities in the ratio 3 : 2 and areas in the ratio 1 : 2. For the same temperature difference, find the ratio of their rates of heat flow.

Given: $K_1 : K_2 = 3 : 2$; $A_1 : A_2 = 1 : 2$; d and $\Delta\theta$ are the same

Formula: Q / t is proportional to $K A$

Solution:

For slab 1: $K A = 3 \times 1 = 3$

For slab 2: $K A = 2 \times 2 = 4$

Ratio = 3 : 4

Ans: The ratio is 3 : 4.

Q22. The steel base of a pressure cooker has an area of 0.05 m^2 and a thickness of 4 mm. Heat flows through it at 5000 W. Find the temperature difference between its two surfaces. (K of steel = $50 \text{ W m}^{-1} \text{ K}^{-1}$)

Given: $A = 0.05 \text{ m}^2$, $d = 4 \times 10^{-3} \text{ m}$, $Q / t = 5000 \text{ W}$, $K = 50$

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

Solution:

$$\Delta\theta = (5000 \times 0.004) / (50 \times 0.05)$$

$$\Delta\theta = 20 / 2.5 = 8$$

Ans: Temperature difference = 8 K.

Q23. The faces of a slab 25 cm thick are at 90°C and 40°C . Find the temperature gradient and the heat flowing per second per unit area. ($K = 0.8 \text{ W m}^{-1} \text{ K}^{-1}$)

Given: $d = 0.25 \text{ m}$, $\Delta\theta = 50 \text{ K}$, $K = 0.8$

Formula: Gradient = $\Delta\theta / d$; $Q / (t A) = K \times \text{gradient}$

Solution:

$$\text{Gradient} = 50 / 0.25 = 200 \text{ K m}^{-1}$$

$$Q / (t A) = 0.8 \times 200 = 160$$

Ans: Gradient = 200 K m^{-1} ; heat flow per unit area = 160 W m^{-2} .

D. Expansion of Solids

Q24. A brass rod is 1.5 m long at 20 °C. Find its increase in length at 120 °C. ($\alpha = 1.9 \times 10^{-5}$ per °C)

Given: $L_0 = 1.5$ m, $\Delta t = 100$ °C, $\alpha = 1.9 \times 10^{-5}$

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

Solution:

$$\Delta L = 1.5 \times 1.9 \times 10^{-5} \times 100$$

$$\Delta L = 2.85 \times 10^{-3} \text{ m}$$

Ans: Increase in length = 2.85 mm.

Q25. An iron rod 80 cm long at 15 °C becomes 80.096 cm at 115 °C. Find α of iron.

Given: $L_0 = 80$ cm, $\Delta L = 0.096$ cm, $\Delta t = 100$ °C

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

Solution:

$$\alpha = 0.096 / (80 \times 100) = 0.096 / 8000$$

$$\alpha = 1.2 \times 10^{-5}$$

Ans: $\alpha = 1.2 \times 10^{-5}$ per °C.

Q26. A steel rail 25 m long is laid at 5 °C. The maximum temperature in summer is 45 °C. Find the gap that must be left between rails. ($\alpha = 1.2 \times 10^{-5}$ per °C)

Given: $L_0 = 25$ m, $\Delta t = 40$ °C, $\alpha = 1.2 \times 10^{-5}$

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

Solution:

$$\Delta L = 25 \times 1.2 \times 10^{-5} \times 40$$

$$\Delta L = 0.012 \text{ m}$$

Ans: Gap = 12 mm.

Q27. By what temperature rise will an aluminium rod increase in length by 0.1 %? ($\alpha = 2.5 \times 10^{-5}$ per °C)

Given: $\Delta L / L_0 = 0.1 \% = 10^{-3}$, $\alpha = 2.5 \times 10^{-5}$

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

Solution:

$$\Delta t = (\Delta L / L_0) / \alpha = 10^{-3} / (2.5 \times 10^{-5})$$

$$\Delta t = 40$$

Ans: Temperature rise = 40 °C.

Q28. A brass scale is correctly calibrated at 20 °C. What is the true length of an object that reads 100.00 cm on this scale at 40 °C? (α of brass = 1.9×10^{-5} per °C)

Given: Reading = 100 cm, $\Delta t = 20$ °C, $\alpha = 1.9 \times 10^{-5}$

Formula: The scale expands, so true length = reading $\times (1 + \alpha \Delta t)$

Solution:

$$\alpha \Delta t = 1.9 \times 10^{-5} \times 20 = 3.8 \times 10^{-4}$$

$$\text{True length} = 100 \times (1 + 0.00038) = 100.038$$

Ans: True length = 100.038 cm.

Q29. A steel pendulum rod is 1 m long at 20 °C. Find its length at 45 °C. ($\alpha = 1.2 \times 10^{-5}$ per °C)

Given: $L_0 = 1$ m, $\Delta t = 25$ °C, $\alpha = 1.2 \times 10^{-5}$

Formula: $L_t = L_0 (1 + \alpha \Delta t)$

Solution:

$$\Delta L = 1 \times 1.2 \times 10^{-5} \times 25 = 3 \times 10^{-4} \text{ m}$$

$$L_t = 1 + 0.0003 = 1.0003 \text{ m}$$

Ans: Length at 45 °C = 1.0003 m (increase of 0.3 mm).

Q30. A bimetallic strip is made of a brass strip and an iron strip, each 20 cm long at 0 °C. Find the difference in their lengths at 100 °C. (α brass = 1.9×10^{-5} , α iron = 1.2×10^{-5} per °C)

Given: $L_0 = 20$ cm, $\Delta t = 100$ °C

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

Solution:

$$\text{Brass: } 20 \times 1.9 \times 10^{-5} \times 100 = 0.038 \text{ cm}$$

$$\text{Iron: } 20 \times 1.2 \times 10^{-5} \times 100 = 0.024 \text{ cm}$$

$$\text{Difference} = 0.038 - 0.024 = 0.014 \text{ cm}$$

Ans: Difference = 0.014 cm = 0.14 mm (brass is longer, so the strip bends with brass on the outside).

Q31. A copper sheet 30 cm $\times$ 20 cm at 20 °C is heated to 220 °C. Find the increase in its area. ($\alpha = 1.7 \times 10^{-5}$ per °C)

Given: $A_0 = 30 \times 20 = 600 \text{ cm}^2$, $\Delta t = 200$ °C, $\alpha = 1.7 \times 10^{-5}$

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

Solution:

$$\beta = 3.4 \times 10^{-5} \text{ per } ^\circ\text{C}$$

$$\Delta A = 600 \times 3.4 \times 10^{-5} \times 200 = 4.08$$

Ans: Increase in area = 4.08 cm².

Q32. A circular hole of radius 2 cm is made in an aluminium plate. By how much does the area of the hole increase when the plate is heated through 100 °C? ($\alpha = 2.3 \times 10^{-5}$ per °C)

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

Formula: The hole expands like the material: $\Delta A = A_0 \beta \Delta t$, $\beta = 2\alpha$

Solution:

$$A_0 = \pi r^2 = 3.14 \times 4 = 12.57 \text{ cm}^2$$

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

$$\Delta A = 12.57 \times 4.6 \times 10^{-5} \times 100 = 0.0578$$

Ans: Increase in area of the hole $\approx 0.058 \text{ cm}^2$.

Q33. A copper sphere of radius 5 cm is heated through 100 °C. Find the increase in its volume. ($\alpha = 1.7 \times 10^{-5}$ per °C)

Given: $r = 5$ cm, $\Delta t = 100$ °C, $\alpha = 1.7 \times 10^{-5}$

Formula: $V_0 = (4/3) \pi r^3$; $\gamma = 3\alpha$; $\Delta V = V_0 \gamma \Delta t$

Solution:

$$V_0 = (4/3) \times 3.14 \times 125 = 523.6 \text{ cm}^3$$

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

$$\Delta V = 523.6 \times 5.1 \times 10^{-5} \times 100 = 2.67$$

Ans: Increase in volume $\approx 2.67 \text{ cm}^3$.

Q34. The volume of a solid increases by 0.36 % when it is heated through 100 °C. Find its coefficient of linear expansion.

Given: $\Delta V / V_0 = 0.36 \% = 3.6 \times 10^{-3}$, $\Delta t = 100$ °C

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

Solution:

$$\gamma = 3.6 \times 10^{-3} / 100 = 3.6 \times 10^{-5} \text{ per } ^\circ\text{C}$$

$$\alpha = 3.6 \times 10^{-5} / 3 = 1.2 \times 10^{-5}$$

Ans: $\alpha = 1.2 \times 10^{-5}$ per °C.

Q35. The coefficient of cubical expansion of a solid is 5.7×10^{-5} per °C. Find α and β .

Given: $\gamma = 5.7 \times 10^{-5}$

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

Solution:

$$\alpha = \gamma / 3 = 1.9 \times 10^{-5} \text{ per } ^\circ\text{C}$$

$$\beta = 2\alpha = 3.8 \times 10^{-5} \text{ per } ^\circ\text{C}$$

Ans: $\alpha = 1.9 \times 10^{-5}$ and $\beta = 3.8 \times 10^{-5}$ per °C.

Q36. The density of iron at 0 °C is 7870 kg m⁻³. Find its density at 200 °C. ($\alpha = 1.2 \times 10^{-5}$ per °C)

Given: $\rho_0 = 7870 \text{ kg m}^{-3}$, $t = 200 \text{ °C}$, $\alpha = 1.2 \times 10^{-5}$

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

Solution:

$$\gamma = 3.6 \times 10^{-5} \text{ per °C, so } \gamma t = 7.2 \times 10^{-3}$$

$$\rho_t = 7870 / 1.0072 = 7813.7$$

Ans: Density at 200 °C $\approx 7813.7 \text{ kg m}^{-3}$.

Q37. Concrete road slabs are 8 m long. The temperature varies from -5 °C to 45 °C. Find the total change in length of a slab, which decides the expansion gap. ($\alpha = 1.2 \times 10^{-5}$ per °C)

Given: $L_0 = 8 \text{ m}$, $\Delta t = 50 \text{ °C}$, $\alpha = 1.2 \times 10^{-5}$

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

Solution:

$$\Delta L = 8 \times 1.2 \times 10^{-5} \times 50$$

$$\Delta L = 4.8 \times 10^{-3} \text{ m}$$

Ans: Change in length = 4.8 mm.

E. Expansion of Liquids

Q38. 200 cm³ of ethyl alcohol at 0 °C is heated to 30 °C. Find the increase in its volume. ($\gamma = 11 \times 10^{-4}$ per °C)

Given: $V_0 = 200 \text{ cm}^3$, $\Delta t = 30 \text{ °C}$, $\gamma = 1.1 \times 10^{-3}$

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

Solution:

$$\Delta V = 200 \times 1.1 \times 10^{-3} \times 30$$

$$\Delta V = 6.6$$

Ans: Increase in volume = 6.6 cm³.

Q39. Find the increase in the volume of 250 cm³ of mercury when it is heated from 0 °C to 60 °C. ($\gamma_{\text{real}} = 1.8 \times 10^{-4}$ per °C)

Given: $V_0 = 250 \text{ cm}^3$, $\Delta t = 60 \text{ °C}$, $\gamma_r = 1.8 \times 10^{-4}$

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

Solution:

$$\Delta V = 250 \times 1.8 \times 10^{-4} \times 60$$

$$\Delta V = 2.7$$

Ans: Increase in volume = 2.7 cm³.

Q40. The real coefficient of expansion of an oil is 9.6×10^{-4} per $^{\circ}\text{C}$. Find its apparent coefficient of expansion in a steel vessel. (α of steel = 1.2×10^{-5} per $^{\circ}\text{C}$)

Given: $\gamma_r = 9.6 \times 10^{-4}$, $\alpha_s = 1.2 \times 10^{-5}$

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

Solution:

$$\gamma_g = 3.6 \times 10^{-5} = 0.36 \times 10^{-4}$$

$$\gamma_a = 9.6 \times 10^{-4} - 0.36 \times 10^{-4} = 9.24 \times 10^{-4}$$

Ans: $\gamma_a = 9.24 \times 10^{-4}$ per $^{\circ}\text{C}$.

Q41. A glass flask of volume 500 cm^3 is completely filled with oil at 0°C and heated to 50°C . How much oil overflows? (γ_{real} of oil = 7.0×10^{-4} , α of glass = 9×10^{-6} per $^{\circ}\text{C}$)

Given: $V_0 = 500 \text{ cm}^3$, $\Delta t = 50^{\circ}\text{C}$

Formula: Overflow = $V_0 \gamma_a \Delta t$; $\gamma_a = \gamma_r - \gamma_g$

Solution:

$$\gamma_g = 3 \times 9 \times 10^{-6} = 0.27 \times 10^{-4}$$

$$\gamma_a = 7.0 \times 10^{-4} - 0.27 \times 10^{-4} = 6.73 \times 10^{-4}$$

$$\text{Overflow} = 500 \times 6.73 \times 10^{-4} \times 50 = 16.825$$

Ans: Oil overflowing $\approx 16.8 \text{ cm}^3$.

Q42. The density of mercury at 0°C is 13600 kg m^{-3} . Find its density at 100°C . ($\gamma = 1.8 \times 10^{-4}$ per $^{\circ}\text{C}$)

Given: $\rho_0 = 13600 \text{ kg m}^{-3}$, $t = 100^{\circ}\text{C}$, $\gamma = 1.8 \times 10^{-4}$

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

Solution:

$$\gamma t = 1.8 \times 10^{-4} \times 100 = 0.018$$

$$\rho_t = 13600 / 1.018 = 13359.5$$

Ans: Density at $100^{\circ}\text{C} \approx 13,360 \text{ kg m}^{-3}$.

F. Expansion of Gases; C_p and C_v

Q43. A gas occupies 200 cm^3 at 27°C . Find its volume at 57°C at constant pressure.

Given: $V_1 = 200 \text{ cm}^3$, $T_1 = 300 \text{ K}$, $T_2 = 57 + 273 = 330 \text{ K}$

Formula: $V_1 / T_1 = V_2 / T_2$

Solution:

$$V_2 = V_1 \times T_2 / T_1 = 200 \times 330 / 300$$

$$V_2 = 220$$

Ans: $V_2 = 220 \text{ cm}^3$.

Q44. The volume of a gas is 2 litres at 0 °C. At what temperature will its volume be 3 litres at constant pressure?

Given: $V_0 = 2 \text{ L}$, $V_t = 3 \text{ L}$

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

Solution:

$$3 = 2 (1 + t / 273)$$

$$1.5 = 1 + t / 273$$

$$t / 273 = 0.5, \text{ so } t = 136.5$$

Ans: $t = 136.5 \text{ }^\circ\text{C}$.

Q45. A sealed can contains a gas at 2.5 atm and 27 °C. It is thrown into a fire and its temperature becomes 327 °C. Find the pressure of the gas (neglect the expansion of the can).

Given: $P_1 = 2.5 \text{ atm}$, $T_1 = 300 \text{ K}$, $T_2 = 327 + 273 = 600 \text{ K}$

Formula: $P_1 / T_1 = P_2 / T_2$ (constant volume)

Solution:

$$P_2 = 2.5 \times 600 / 300$$

$$P_2 = 5$$

Ans: $P_2 = 5 \text{ atm}$.

Q46. The pressure in a car tyre is 2.0 atm at 7 °C. After a long drive the temperature rises to 35 °C. Find the new pressure, assuming the volume remains constant.

Given: $P_1 = 2.0 \text{ atm}$, $T_1 = 7 + 273 = 280 \text{ K}$, $T_2 = 35 + 273 = 308 \text{ K}$

Formula: $P_1 / T_1 = P_2 / T_2$

Solution:

$$P_2 = 2.0 \times 308 / 280$$

$$P_2 = 2.2$$

Ans: $P_2 = 2.2 \text{ atm}$.

Q47. For air, the specific heats are $c_p = 1005 \text{ J kg}^{-1} \text{ K}^{-1}$ and $c_v = 718 \text{ J kg}^{-1} \text{ K}^{-1}$. Find $c_p - c_v$ and γ .

Given: $c_p = 1005$, $c_v = 718$

Formula: difference = $c_p - c_v$; $\gamma = c_p / c_v$

Solution:

$$c_p - c_v = 1005 - 718 = 287$$

$$\gamma = 1005 / 718 = 1.40$$

Ans: $c_p - c_v = 287 \text{ J kg}^{-1} \text{ K}^{-1}$ and $\gamma \approx 1.40$.

Q48. For a diatomic gas, $\gamma = 1.4$ and $C_v = 20.8 \text{ J mol}^{-1} \text{ K}^{-1}$. Find C_p and verify Mayer's relation. ($R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$)

Given: $\gamma = 1.4$, $C_v = 20.8$

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

Solution:

$$C_p = 1.4 \times 20.8 = 29.12$$

$$C_p - C_v = 29.12 - 20.8 = 8.32, \text{ which is nearly equal to } R = 8.31$$

Ans: $C_p \approx 29.1 \text{ J mol}^{-1} \text{ K}^{-1}$; Mayer's relation is verified.

Q49. Find the heat needed to raise the temperature of 3 moles of a monatomic gas by 20 K (i) at constant volume and (ii) at constant pressure. ($C_v = 12.5$, $C_p = 20.8 \text{ J mol}^{-1} \text{ K}^{-1}$)

Given: $n = 3$, $\Delta T = 20 \text{ K}$

Formula: $Q = n C \Delta T$

Solution:

$$(i) Q_v = 3 \times 12.5 \times 20 = 750 \text{ J}$$

$$(ii) Q_p = 3 \times 20.8 \times 20 = 1248 \text{ J}$$

$$\text{Extra heat at constant pressure} = 1248 - 750 = 498 \text{ J, which is nearly } n R \Delta T = 3 \times 8.31 \times 20 = 498.6 \text{ J}$$

Ans: $Q_v = 750 \text{ J}$ and $Q_p = 1248 \text{ J}$.