

APPLIED PHYSICS 1

Chapter: Heat and Thermometry

Set 3: 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 -10 °C into °F and K.

Given: $C = -10 \text{ }^\circ\text{C}$

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

Solution:

$$F = (9/5)(-10) + 32 = -18 + 32 = 14$$

$$K = -10 + 273 = 263$$

Ans: 14 °F and 263 K.

Q2. Convert 140 °F into °C and K.

Given: $F = 140 \text{ }^\circ\text{F}$

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

Solution:

$$C = (5/9)(140 - 32) = (5/9) \times 108 = 60$$

$$K = 60 + 273 = 333$$

Ans: 60 °C and 333 K.

Q3. Normal human body temperature is 98.6 °F. Express it in °C and K.

Given: $F = 98.6\text{ °F}$

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

Solution:

$$C = (5/9)(98.6 - 32) = (5/9) \times 66.6 = 37$$

$$K = 37 + 273 = 310$$

Ans: 37 °C and 310 K.

Q4. The temperature of a body rises by 45 °F. What is the rise in temperature on the Celsius and Kelvin scales?

Given: $\Delta F = 45$

Formula: $\Delta C / 5 = \Delta F / 9$ (the 32 and 273 cancel for a difference)

Solution:

$$\Delta C = (5/9) \times 45 = 25$$

A change of 1 °C equals a change of 1 K, so $\Delta K = 25$

Ans: Rise = 25 °C = 25 K.

Q5. At what Celsius temperature is the Kelvin reading exactly twice the Celsius reading?

Given: $K = 2C$

Formula: $K = C + 273$

Solution:

$$2C = C + 273$$

$$C = 273$$

$$K = 2 \times 273 = 546$$

Ans: 273 °C (= 546 K).

B. Heat, Specific Heat and Calorimetry

Q6. Find the heat required to raise 5 kg of water from 15 °C to 65 °C. ($c = 4200\text{ J kg}^{-1}\text{ K}^{-1}$)

Given: $m = 5\text{ kg}$, $\Delta t = 50\text{ °C}$, $c = 4200$

Formula: $Q = m c \Delta t$

Solution:

$$Q = 5 \times 4200 \times 50$$

$$Q = 10,50,000\text{ J}$$

Ans: $Q = 1.05 \times 10^6\text{ J}$.

Q7. A 1000 W electric heater is used to heat 2 kg of water from 20 °C to 70 °C. Find the time taken, assuming no heat loss.

Given: $P = 1000 \text{ W}$, $m = 2 \text{ kg}$, $\Delta t = 50 \text{ }^{\circ}\text{C}$

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

Solution:

$$Q = 2 \times 4200 \times 50 = 4,20,000 \text{ J}$$

$$t = 420000 / 1000 = 420 \text{ s}$$

Ans: $t = 420 \text{ s} = 7 \text{ minutes}$.

Q8. How much heat is given out when a 2 kg iron block cools from 250 °C to 50 °C? (c of iron = 450 J kg⁻¹ K⁻¹)

Given: $m = 2 \text{ kg}$, $\Delta t = 200 \text{ }^{\circ}\text{C}$, $c = 450$

Formula: $Q = m c \Delta t$

Solution:

$$Q = 2 \times 450 \times 200$$

$$Q = 1,80,000 \text{ J}$$

Ans: $Q = 1.8 \times 10^5 \text{ J}$.

Q9. The heat capacity of a body of mass 4 kg is 2000 J K⁻¹. Find its specific heat and the heat needed to raise its temperature by 15 °C.

Given: $H = 2000 \text{ J K}^{-1}$, $m = 4 \text{ kg}$, $\Delta t = 15 \text{ }^{\circ}\text{C}$

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

Solution:

$$c = 2000 / 4 = 500 \text{ J kg}^{-1} \text{ K}^{-1}$$

$$Q = 2000 \times 15 = 30,000 \text{ J}$$

Ans: $c = 500 \text{ J kg}^{-1} \text{ K}^{-1}$ and $Q = 3 \times 10^4 \text{ J}$.

Q10. A 0.2 kg metal piece at 100 °C is dropped into 0.5 kg of water at 20 °C. The final temperature is 25 °C. Find the specific heat of the metal. (Neglect the calorimeter)

Given: $m_1 = 0.2 \text{ kg}$, $t_1 = 100 \text{ }^{\circ}\text{C}$; $m_2 = 0.5 \text{ kg}$, $t_2 = 20 \text{ }^{\circ}\text{C}$; $t = 25 \text{ }^{\circ}\text{C}$

Formula: Heat lost by metal = heat gained by water

Solution:

$$0.2 \times c \times (100 - 25) = 0.5 \times 4200 \times (25 - 20)$$

$$15 c = 10500$$

$$c = 700$$

Ans: $c = 700 \text{ J kg}^{-1} \text{ K}^{-1}$.

Q11. 3 kg of water at 50 °C is mixed with 2 kg of water at 20 °C. Find the temperature of the mixture.

Given: $m_1 = 3 \text{ kg}$, $t_1 = 50 \text{ °C}$; $m_2 = 2 \text{ kg}$, $t_2 = 20 \text{ °C}$

Formula: Heat lost = heat gained

Solution:

$$3 (50 - T) = 2 (T - 20)$$

$$150 - 3T = 2T - 40$$

$$190 = 5T, \text{ so } T = 38$$

Ans: Final temperature = 38 °C.

Q12. Find the water equivalent of an aluminium calorimeter of mass 150 g. (c of aluminium = 900 J kg⁻¹ K⁻¹)

Given: $m = 0.15 \text{ kg}$, $c = 900$, $c_w = 4200$

Formula: $W = m c / c_w$

Solution:

$$W = (0.15 \times 900) / 4200 = 135 / 4200$$

$$W = 0.0321 \text{ kg}$$

Ans: $W \approx 32.1 \text{ g}$.

Q13. 500 g of a metal (c = 0.1 cal g⁻¹ °C⁻¹) at 100 °C is dropped into a calorimeter of water equivalent 10 g containing 190 g of water at 20 °C. Find the final temperature.

Given: $m = 500 \text{ g}$, $c = 0.1$, $t_1 = 100 \text{ °C}$; water + calorimeter = 190 + 10 = 200 g at 20 °C

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

Solution:

$$500 \times 0.1 \times (100 - T) = 200 \times 1 \times (T - 20)$$

$$50 (100 - T) = 200 (T - 20)$$

$$5000 - 50T = 200T - 4000$$

$$9000 = 250T, \text{ so } T = 36$$

Ans: Final temperature = 36 °C.

C. Thermal Conductivity

Q14. A steel rod of cross-section 3 cm^2 and length 50 cm has its ends at 150°C and 50°C . Find the rate of heat flow. ($K = 50 \text{ W m}^{-1} \text{ K}^{-1}$)

Given: $A = 3 \times 10^{-4} \text{ m}^2$, $d = 0.5 \text{ m}$, $\Delta\theta = 100 \text{ K}$, $K = 50$

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

Solution:

$$Q/t = (50 \times 3 \times 10^{-4} \times 100) / 0.5$$

$$Q/t = 1.5 / 0.5 = 3$$

Ans: Rate of heat flow = 3 W.

Q15. A glass pane of area 1.5 m^2 and thickness 3 mm has a temperature difference of 15 K between its faces. Find the heat conducted in 1 minute. (K of glass = $1.0 \text{ W m}^{-1} \text{ K}^{-1}$)

Given: $A = 1.5 \text{ m}^2$, $d = 3 \times 10^{-3} \text{ m}$, $\Delta\theta = 15 \text{ K}$, $t = 60 \text{ s}$, $K = 1.0$

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

Solution:

$$\text{Rate: } Q/t = (1.0 \times 1.5 \times 15) / 0.003 = 22.5 / 0.003 = 7500 \text{ W}$$

$$Q = 7500 \times 60 = 4,50,000 \text{ J}$$

Ans: $Q = 4.5 \times 10^5 \text{ J}$.

Q16. A brass plate of area 0.04 m^2 and thickness 1 cm conducts heat at the rate of 2180 W. Find the temperature difference between its faces. (K of brass = $109 \text{ W m}^{-1} \text{ K}^{-1}$)

Given: $A = 0.04 \text{ m}^2$, $d = 0.01 \text{ m}$, $Q/t = 2180 \text{ W}$, $K = 109$

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

Solution:

$$\Delta\theta = (2180 \times 0.01) / (109 \times 0.04)$$

$$\Delta\theta = 21.8 / 4.36 = 5$$

Ans: Temperature difference = 5 K.

Q17. 54,000 J of heat flows in 10 minutes through a slab of area 0.3 m^2 and thickness 2 cm. Its faces are at 80°C and 20°C . Find the thermal conductivity of the material.

Given: $Q = 54000 \text{ J}$, $t = 600 \text{ s}$, $A = 0.3 \text{ m}^2$, $d = 0.02 \text{ m}$, $\Delta\theta = 60 \text{ K}$

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

Solution:

$$K = (54000 \times 0.02) / (0.3 \times 60 \times 600)$$

$$K = 1080 / 10800 = 0.1$$

Ans: $K = 0.1 \text{ W m}^{-1} \text{ K}^{-1}$.

Q18. Two rods of the same material and same length have radii in the ratio 1 : 2. For the same temperature difference across their ends, find the ratio of the rates of heat flow.

Given: $r_1 : r_2 = 1 : 2$; K , d and $\Delta\theta$ are the same

Formula: Q/t is proportional to A , and $A = \pi r^2$

Solution:

$$A_1 : A_2 = r_1^2 : r_2^2 = 1 : 4$$

$$(Q/t)_1 : (Q/t)_2 = A_1 : A_2 = 1 : 4$$

Ans: The ratio is 1 : 4.

Q19. Rod A ($K = 400 \text{ W m}^{-1} \text{ K}^{-1}$, length 0.5 m) and rod B ($K = 50 \text{ W m}^{-1} \text{ K}^{-1}$, length 0.25 m) have the same cross-section and the same temperature difference across them. Find the ratio of their rates of heat flow.

Given: $K_A = 400$, $d_A = 0.5 \text{ m}$; $K_B = 50$, $d_B = 0.25 \text{ m}$

Formula: Q/t is proportional to K/d

Solution:

$$\text{For A: } K/d = 400 / 0.5 = 800$$

$$\text{For B: } K/d = 50 / 0.25 = 200$$

$$(Q/t)_A : (Q/t)_B = 800 : 200 = 4 : 1$$

Ans: The ratio is 4 : 1.

Q20. A cork wall of area 1.5 m^2 and thickness 4 cm separates a cold room at 5°C from outside at 25°C . Find the heat entering in 8 hours. (K of cork = $0.04 \text{ W m}^{-1} \text{ K}^{-1}$)

Given: $A = 1.5 \text{ m}^2$, $d = 0.04 \text{ m}$, $\Delta\theta = 20 \text{ K}$, $t = 8 \times 3600 = 28800 \text{ s}$, $K = 0.04$

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

Solution:

$$\text{Rate: } Q/t = (0.04 \times 1.5 \times 20) / 0.04 = 30 \text{ W}$$

$$Q = 30 \times 28800 = 8,64,000 \text{ J}$$

Ans: $Q = 8.64 \times 10^5 \text{ J}$.

Q21. The copper base of a boiler has an area of 0.2 m^2 and a thickness of 5 mm. The inner surface is at 100°C and the outer surface is at 105°C . Find the rate of heat flow. (K of copper = $385 \text{ W m}^{-1} \text{ K}^{-1}$)

Given: $A = 0.2 \text{ m}^2$, $d = 5 \times 10^{-3} \text{ m}$, $\Delta\theta = 5 \text{ K}$, $K = 385$

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

Solution:

$$Q/t = (385 \times 0.2 \times 5) / 0.005$$

$$Q/t = 385 / 0.005 = 77,000$$

Ans: Rate of heat flow = $7.7 \times 10^4 \text{ W}$.

Q22. The ends of a metal rod 2 m long are kept at 100 °C and 20 °C. Find the temperature gradient and the temperature at a point 50 cm from the hot end (steady state).

Given: $L = 2 \text{ m}$, $\theta_1 = 100 \text{ °C}$, $\theta_2 = 20 \text{ °C}$

Formula: Temperature gradient = $\Delta\theta / d$

Solution:

$$\text{Gradient} = (100 - 20) / 2 = 40 \text{ K m}^{-1}$$

$$\text{Fall in temperature in } 0.5 \text{ m} = 40 \times 0.5 = 20 \text{ °C}$$

$$\text{Temperature at that point} = 100 - 20 = 80 \text{ °C}$$

Ans: Gradient = 40 K m^{-1} ; temperature at 50 cm = 80 °C .

D. Expansion of Solids

Q23. A steel wire is 20 m long at 30 °C. Find the change in its length when it is cooled to -10 °C. ($\alpha = 1.2 \times 10^{-5}$ per °C)

Given: $L_0 = 20 \text{ m}$, $\Delta t = 40 \text{ °C}$ (fall), $\alpha = 1.2 \times 10^{-5}$

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

Solution:

$$\Delta L = 20 \times 1.2 \times 10^{-5} \times 40$$

$$\Delta L = 9.6 \times 10^{-3} \text{ m}$$

Ans: Length decreases by 9.6 mm.

Q24. A copper rod 50 cm long at 0 °C becomes 50.085 cm at 100 °C. Find its coefficient of linear expansion.

Given: $L_0 = 50 \text{ cm}$, $\Delta L = 0.085 \text{ cm}$, $\Delta t = 100 \text{ °C}$

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

Solution:

$$\alpha = 0.085 / (50 \times 100)$$

$$\alpha = 0.085 / 5000 = 1.7 \times 10^{-5}$$

Ans: $\alpha = 1.7 \times 10^{-5}$ per °C.

Q25. A steel rod is 1 m long at 20 °C. At what temperature will its length increase by 2.4 mm? ($\alpha = 1.2 \times 10^{-5}$ per °C)

Given: $L_0 = 1 \text{ m}$, $\Delta L = 2.4 \times 10^{-3} \text{ m}$, $\alpha = 1.2 \times 10^{-5}$

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

Solution:

$$\Delta t = \Delta L / (L_0 \alpha) = (2.4 \times 10^{-3}) / (1 \times 1.2 \times 10^{-5}) = 200 \text{ °C}$$

$$\text{Final temperature} = 20 + 200 = 220 \text{ °C}$$

Ans: The rod must be heated to 220 °C.

Q26. A steel bridge is 200 m long. The temperature varies from -10 °C in winter to 40 °C in summer. Find the total change in its length. ($\alpha = 1.2 \times 10^{-5}$ per °C)

Given: $L_0 = 200$ m, $\Delta t = 40 - (-10) = 50$ °C, $\alpha = 1.2 \times 10^{-5}$

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

Solution:

$$\Delta L = 200 \times 1.2 \times 10^{-5} \times 50$$

$$\Delta L = 0.12 \text{ m}$$

Ans: Total change in length = 0.12 m = 12 cm.

Q27. An iron ring has an inner diameter of 100 cm at 20 °C. It is to be fitted on a wheel of diameter 100.12 cm. To what temperature should the ring be heated? ($\alpha = 1.2 \times 10^{-5}$ per °C)

Given: $d_0 = 100$ cm, required increase $\Delta d = 0.12$ cm, $\alpha = 1.2 \times 10^{-5}$

Formula: $\Delta d = d_0 \alpha \Delta t$ (diameter expands like length)

Solution:

$$\Delta t = \Delta d / (d_0 \alpha) = 0.12 / (100 \times 1.2 \times 10^{-5})$$

$$\Delta t = 0.12 / 1.2 \times 10^{-3} = 100 \text{ °C}$$

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

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

Q28. A steel rod and an aluminium rod, each 1 m long, are heated through 100 °C. Find the difference in their elongations. ($\alpha_{\text{steel}} = 1.2 \times 10^{-5}$, $\alpha_{\text{aluminium}} = 2.3 \times 10^{-5}$ per °C)

Given: $L_0 = 1$ m, $\Delta t = 100$ °C

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

Solution:

$$\text{Steel: } 1 \times 1.2 \times 10^{-5} \times 100 = 1.2 \times 10^{-3} \text{ m}$$

$$\text{Aluminium: } 1 \times 2.3 \times 10^{-5} \times 100 = 2.3 \times 10^{-3} \text{ m}$$

$$\text{Difference} = 2.3 - 1.2 = 1.1 \times 10^{-3} \text{ m}$$

Ans: Difference = 1.1 mm (aluminium expands more).

Q29. A circular steel plate of radius 10 cm at 20 °C is heated to 220 °C. Find the increase in its area. ($\alpha = 1.2 \times 10^{-5}$ per °C)

Given: $r = 10$ cm, $\Delta t = 200$ °C, $\alpha = 1.2 \times 10^{-5}$

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

Solution:

$$A_0 = 3.14 \times 100 = 314.16 \text{ cm}^2$$

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

$$\Delta A = 314.16 \times 2.4 \times 10^{-5} \times 200 = 1.508$$

Ans: Increase in area $\approx 1.51 \text{ cm}^2$.

Q30. A glass pane $1.2 \text{ m} \times 0.8 \text{ m}$ is heated through 40°C . Find the increase in its area. (α of glass = 9×10^{-6} per $^\circ\text{C}$)

Given: $A_0 = 1.2 \times 0.8 = 0.96 \text{ m}^2$, $\Delta t = 40^\circ\text{C}$, $\alpha = 9 \times 10^{-6}$

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

Solution:

$$\beta = 1.8 \times 10^{-5} \text{ per } ^\circ\text{C}$$

$$\Delta A = 0.96 \times 1.8 \times 10^{-5} \times 40 = 6.912 \times 10^{-4} \text{ m}^2$$

Ans: Increase in area $\approx 6.9 \text{ cm}^2$.

Q31. Find the percentage increase in the area of a metal sheet when its temperature rises by 100°C . ($\alpha = 1.1 \times 10^{-5}$ per $^\circ\text{C}$)

Given: $\Delta t = 100^\circ\text{C}$, $\alpha = 1.1 \times 10^{-5}$

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

Solution:

$$\Delta A / A_0 = 2 \times 1.1 \times 10^{-5} \times 100 = 2.2 \times 10^{-3}$$

$$\text{Percentage} = 2.2 \times 10^{-3} \times 100 = 0.22$$

Ans: Area increases by 0.22 %.

Q32. A steel cube of side 20 cm at 20°C is heated to 120°C . Find the increase in its volume. ($\alpha = 1.2 \times 10^{-5}$ per $^\circ\text{C}$)

Given: Side = 20 cm , so $V_0 = 8000 \text{ cm}^3$, $\Delta t = 100^\circ\text{C}$, $\alpha = 1.2 \times 10^{-5}$

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

Solution:

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

$$\Delta V = 8000 \times 3.6 \times 10^{-5} \times 100 = 28.8$$

Ans: Increase in volume = 28.8 cm^3 .

Q33. A solid has a volume of 400 cm^3 at 0°C and 400.96 cm^3 at 100°C . Find γ and α .

Given: $V_0 = 400 \text{ cm}^3$, $\Delta V = 0.96 \text{ cm}^3$, $\Delta t = 100^\circ\text{C}$

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

Solution:

$$\gamma = 0.96 / (400 \times 100) = 0.96 / 40000 = 2.4 \times 10^{-5}$$

$$\alpha = 2.4 \times 10^{-5} / 3 = 8 \times 10^{-6}$$

Ans: $\gamma = 2.4 \times 10^{-5}$ per $^\circ\text{C}$ and $\alpha = 8 \times 10^{-6}$ per $^\circ\text{C}$.

Q34. The coefficient of superficial expansion of a solid is 3.8×10^{-5} per $^{\circ}\text{C}$. Find α and γ .

Given: $\beta = 3.8 \times 10^{-5}$

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

Solution:

$$\alpha = \beta / 2 = 1.9 \times 10^{-5} \text{ per } ^{\circ}\text{C}$$

$$\gamma = 3\alpha = 3 \times 1.9 \times 10^{-5} = 5.7 \times 10^{-5} \text{ per } ^{\circ}\text{C}$$

Ans: $\alpha = 1.9 \times 10^{-5}$ and $\gamma = 5.7 \times 10^{-5}$ per $^{\circ}\text{C}$.

Q35. The density of aluminium at 0°C is 2700 kg m^{-3} . Find its density at 100°C . ($\alpha = 2.3 \times 10^{-5}$ per $^{\circ}\text{C}$)

Given: $\rho_0 = 2700 \text{ kg m}^{-3}$, $t = 100^{\circ}\text{C}$, $\alpha = 2.3 \times 10^{-5}$

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

Solution:

$$\gamma = 6.9 \times 10^{-5} \text{ per } ^{\circ}\text{C}, \text{ so } \gamma t = 6.9 \times 10^{-3}$$

$$\rho_t = 2700 / 1.0069 = 2681.5$$

Ans: Density at $100^{\circ}\text{C} \approx 2681.5 \text{ kg m}^{-3}$.

E. Expansion of Liquids

Q36. 250 cm^3 of glycerine at 0°C is heated to 60°C . Find the increase in its volume. ($\gamma = 4.9 \times 10^{-4}$ per $^{\circ}\text{C}$)

Given: $V_0 = 250 \text{ cm}^3$, $\Delta t = 60^{\circ}\text{C}$, $\gamma = 4.9 \times 10^{-4}$

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

Solution:

$$\Delta V = 250 \times 4.9 \times 10^{-4} \times 60$$

$$\Delta V = 7.35$$

Ans: Increase in volume = 7.35 cm^3 .

Q37. A glass flask is completely filled with 100 cm^3 of mercury at 0°C and heated to 80°C . Find the volume of mercury that overflows. (γ_{real} of mercury = 1.8×10^{-4} , α of glass = 9×10^{-6} per $^{\circ}\text{C}$)

Given: $V_0 = 100 \text{ cm}^3$, $\Delta t = 80^{\circ}\text{C}$

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

Solution:

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

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

$$\text{Overflow} = 100 \times 1.53 \times 10^{-4} \times 80 = 1.224$$

Ans: Volume overflowing = 1.224 cm^3 .

Q38. The apparent coefficient of expansion of a liquid in a vessel of $\alpha = 1.0 \times 10^{-5}$ per $^{\circ}\text{C}$ is 1.6×10^{-4} per $^{\circ}\text{C}$. Find the real coefficient of expansion of the liquid.

Given: $\gamma_a = 1.6 \times 10^{-4}$, $\alpha_{\text{vessel}} = 1.0 \times 10^{-5}$

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

Solution:

$$\gamma_g = 3 \times 1.0 \times 10^{-5} = 0.3 \times 10^{-4}$$

$$\gamma_r = 1.6 \times 10^{-4} + 0.3 \times 10^{-4} = 1.9 \times 10^{-4}$$

Ans: $\gamma_r = 1.9 \times 10^{-4}$ per $^{\circ}\text{C}$.

Q39. A tank holds 1000 litres of kerosene at 15°C . Find the increase in its volume when the temperature rises to 35°C . (γ of kerosene = 1.0×10^{-3} per $^{\circ}\text{C}$; ignore expansion of the tank)

Given: $V_0 = 1000 \text{ L}$, $\Delta t = 20^{\circ}\text{C}$, $\gamma = 1.0 \times 10^{-3}$

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

Solution:

$$\Delta V = 1000 \times 1.0 \times 10^{-3} \times 20$$

$$\Delta V = 20$$

Ans: Increase in volume = 20 litres.

F. Expansion of Gases; C_p and C_v

Q40. A gas occupies 300 cm^3 at 27°C . Find its volume at 127°C at constant pressure.

Given: $V_1 = 300 \text{ cm}^3$, $T_1 = 27 + 273 = 300 \text{ K}$, $T_2 = 127 + 273 = 400 \text{ K}$

Formula: $V_1 / T_1 = V_2 / T_2$

Solution:

$$300 / 300 = V_2 / 400$$

$$V_2 = 400$$

Ans: $V_2 = 400 \text{ cm}^3$.

Q41. A gas has a volume of 546 cm^3 at 0°C . Find its volume at -91°C at constant pressure.

Given: $V_0 = 546 \text{ cm}^3$, $t = -91^{\circ}\text{C}$

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

Solution:

$$V_t = 546 (1 - 91/273)$$

$$91 / 273 = 1/3, \text{ so } V_t = 546 \times 2/3 = 364$$

Ans: $V = 364 \text{ cm}^3$.

Q42. The pressure of a gas in a rigid vessel is 1.5 atm at 27 °C. Find the pressure at 87 °C.

Given: $P_1 = 1.5 \text{ atm}$, $T_1 = 300 \text{ K}$, $T_2 = 87 + 273 = 360 \text{ K}$

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

Solution:

$$P_2 = P_1 \times T_2 / T_1 = 1.5 \times 360 / 300$$

$$P_2 = 1.8$$

Ans: $P_2 = 1.8 \text{ atm}$.

Q43. For a gas, $C_p = 29.1 \text{ J mol}^{-1} \text{ K}^{-1}$. Find C_v and γ . ($R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$)

Given: $C_p = 29.1$, $R = 8.31$

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

Solution:

$$C_v = 29.1 - 8.31 = 20.79$$

$$\gamma = 29.1 / 20.79 = 1.40$$

Ans: $C_v \approx 20.8 \text{ J mol}^{-1} \text{ K}^{-1}$ and $\gamma \approx 1.40$.

Q44. For helium, $C_p = 20.8 \text{ J mol}^{-1} \text{ K}^{-1}$. Find C_v and γ . ($R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$)

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

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

Solution:

$$C_v = 20.8 - 8.31 = 12.49$$

$$\gamma = 20.8 / 12.49 = 1.67$$

Ans: $C_v \approx 12.5 \text{ J mol}^{-1} \text{ K}^{-1}$ and $\gamma \approx 1.67$.

Q45. Find the heat needed to raise the temperature of 2 moles of a diatomic gas by 10 K (i) at constant volume and (ii) at constant pressure. ($C_v = 20.8$, $C_p = 29.1 \text{ J mol}^{-1} \text{ K}^{-1}$)

Given: $n = 2$, $\Delta T = 10 \text{ K}$

Formula: $Q = n C \Delta T$

Solution:

$$(i) Q_v = 2 \times 20.8 \times 10 = 416 \text{ J}$$

$$(ii) Q_p = 2 \times 29.1 \times 10 = 582 \text{ J}$$

Difference = $582 - 416 = 166 \text{ J}$ (this is the work done by the gas, $n R \Delta T = 2 \times 8.31 \times 10 \approx 166 \text{ J}$)

Ans: $Q_v = 416 \text{ J}$ and $Q_p = 582 \text{ J}$.