

NCERT Chapter 10: Thermal Properties of Matter

EXERCISES - DETAILED ANSWER KEY

10.1 The triple points of neon and carbon dioxide are 24.57 K and 216.55 K respectively. Express these temperatures on the Celsius and Fahrenheit scales.

Solution:

For **Neon (24.57 K)**:

- **Celsius conversion:** $T = t_c + 273.15$
 - $t_c = T - 273.15 = 24.57 - 273.15 = -248.58^\circ\text{C}$
- **Fahrenheit conversion:** $t_F = (9/5)t_c + 32$
 - $t_F = (9/5)(-248.58) + 32 = -415.44 + 32 = -383.44^\circ\text{F}$

For **Carbon dioxide (216.55 K)**:

- **Celsius conversion:**
 - $t_c = 216.55 - 273.15 = -56.60^\circ\text{C}$
- **Fahrenheit conversion:**
 - $t_F = (9/5)(-56.60) + 32 = -101.88 + 32 = -69.88^\circ\text{F}$

Answer:

- Neon: -248.58°C , -383.44°F
 - CO_2 : -56.60°C , -69.88°F
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10.2 Two absolute scales A and B have triple points of water defined to be 200 A and 350 B. What is the relation between T_A and T_B ?

Solution:

The triple point of water is 273.16 K on the Kelvin scale.

For scale A: 273.16 K corresponds to 200 A

For scale B: 273.16 K corresponds to 350 B

Since both scales are absolute scales, they are proportional to the Kelvin scale:

- $T_A = (200/273.16) \times T$
- $T_B = (350/273.16) \times T$

To find relation between T_A and T_B :

$$T_A/T_B = (200/273.16)/(350/273.16) = 200/350 = 4/7$$

Answer: $T_A = (4/7)T_B$ or $T_B = (7/4)T_A$

10.3 The electrical resistance in ohms of a certain thermometer varies with temperature according to the approximate law: $R = R_0[1 + \alpha(T - T_0)]$. The resistance is 101.6 Ω at the triple-point of water 273.16 K, and 165.5 Ω at the normal melting point of lead (600.5 K). What is the temperature when the resistance is 123.4 Ω ?

Solution:

Given:

- At $T_1 = 273.16$ K: $R_1 = 101.6 \Omega$
- At $T_2 = 600.5$ K: $R_2 = 165.5 \Omega$

- Find T when $R = 123.4 \Omega$

Step 1: Find R_0 and α using given data

At triple point ($T_1 = 273.16 \text{ K}$):

$$101.6 = R_0[1 + \alpha(273.16 - T_0)]$$

At melting point of lead ($T_2 = 600.5 \text{ K}$):

$$165.5 = R_0[1 + \alpha(600.5 - T_0)]$$

Step 2: Taking ratio to eliminate R_0 : $165.5/101.6 = [1 + \alpha(600.5 - T_0)]/[1 + \alpha(273.16 - T_0)]$

$$1.629 = [1 + \alpha(600.5 - T_0)]/[1 + \alpha(273.16 - T_0)]$$

Let's assume $T_0 = 273.16 \text{ K}$ (triple point as reference):

$$165.5/101.6 = [1 + \alpha(600.5 - 273.16)]/[1 + \alpha(0)]$$

$$1.629 = [1 + \alpha(327.34)]/1$$

$$1.629 = 1 + 327.34\alpha$$

$$\alpha = 0.629/327.34 = 1.92 \times 10^{-3} \text{ K}^{-1}$$

Step 3: Find R_0 : $101.6 = R_0[1 + 0] = R_0$ Therefore, $R_0 = 101.6 \Omega$

Step 4: Find temperature when $R = 123.4 \Omega$: $123.4 = 101.6[1 + 1.92 \times 10^{-3}(T - 273.16)]$
 $123.4/101.6 = 1 + 1.92 \times 10^{-3}(T - 273.16)$
 $1.214 = 1 + 1.92 \times 10^{-3}(T - 273.16)$
 $0.214 = 1.92 \times 10^{-3}(T - 273.16)$
 $T - 273.16 = 0.214/(1.92 \times 10^{-3}) = 111.5$
 $T = 273.16 + 111.5 = 384.66 \text{ K}$

Answer: $T = 384.7 \text{ K}$

10.4 Answer the following:

(a) The triple-point of water is a standard fixed point in modern thermometry. Why? What is wrong in taking the melting point of ice and the boiling point of water as standard fixed

points (as was originally done in the Celsius scale)?

Solution:

Why triple point is preferred:

1. **Unique temperature:** Triple point occurs at one specific temperature and pressure
2. **Reproducibility:** Can be reproduced precisely in any laboratory
3. **No pressure dependence:** Temperature is uniquely defined
4. **Pure substance:** No impurities affect the measurement

Problems with melting/boiling points:

1. **Pressure dependence:** Both melting and boiling points change with atmospheric pressure
2. **Impurity effects:** Dissolved gases or impurities alter the temperatures
3. **Atmospheric variations:** Different locations have different atmospheric pressures
4. **Less reproducible:** Difficult to maintain standard conditions consistently

(b) There were two fixed points in the original Celsius scale as mentioned above which were assigned the number 0°C and 100°C respectively. On the absolute scale, one of the fixed points is the triple-point of water, which on the Kelvin absolute scale is assigned the number 273.16 K. What is the other fixed point on this (Kelvin) scale?

Solution:

The Kelvin scale has only **one fixed point**: the triple point of water at 273.16 K.

The second "fixed point" is actually the **absolute zero** at 0 K, which is a theoretical point where all molecular motion ceases. This is not experimentally achievable but is defined as the zero of the absolute temperature scale.

(c) The absolute temperature (Kelvin scale) T is related to the temperature t_c on the Celsius scale by $t_c = T - 273.15$. Why do we have 273.15 in this relation, and not 273.16?

Solution:

- **273.16:** Exact value assigned to triple point of water by definition
- **273.15:** Approximate value used for conversion between Celsius and Kelvin scales

The difference arises because:

1. Original Celsius scale defined 0°C as ice point, not triple point
2. Ice point (273.15 K) is slightly different from triple point (273.16 K)
3. For practical conversions, 273.15 is used to maintain compatibility with traditional Celsius scale
4. The 0.01 K difference accounts for the difference between ice point and triple point

(d) What is the temperature of the triple-point of water on an absolute scale whose unit interval size is equal to that of the Fahrenheit scale?

Solution:

The Fahrenheit scale has 180 divisions between ice and steam points.

The Celsius scale has 100 divisions between the same points.

Therefore, $1^\circ\text{F} = (100/180)^\circ\text{C} = (5/9)^\circ\text{C}$

Since the absolute scale has Fahrenheit-sized units:

Triple point temperature = $273.16\text{ K} \times (180/100) = 273.16 \times 1.8 = 491.69^\circ\text{R}$

Answer: 491.7°R (degrees Rankine)

10.5 Two ideal gas thermometers A and B use oxygen and hydrogen respectively.

The following observations are made:

Temperature	Pressure thermometer A	Pressure thermometer B
Triple-point of water	$1.250 \times 10^5 \text{ Pa}$	$0.200 \times 10^5 \text{ Pa}$
Normal melting point of sulphur	$1.797 \times 10^5 \text{ Pa}$	$0.287 \times 10^5 \text{ Pa}$

(a) What is the absolute temperature of normal melting point of sulphur as read by thermometers A and B?

Solution:

For ideal gas at constant volume: $P \propto T$

For thermometer A: $P_1/T_1 = P_2/T_2$ $(1.250 \times 10^5)/273.16 = (1.797 \times 10^5)/T_2$ $T_2 = (1.797 \times 10^5 \times 273.16)/(1.250 \times 10^5) = 392.69 \text{ K}$

For thermometer B: $(0.200 \times 10^5)/273.16 = (0.287 \times 10^5)/T_2$ $T_2 = (0.287 \times 10^5 \times 273.16)/(0.200 \times 10^5) = 392.39 \text{ K}$

Answer:

- Thermometer A: 392.7 K
- Thermometer B: 392.4 K

(b) What do you think is the reason behind the slight difference in answers of thermometers A and B? What further procedure is needed in the experiment to reduce the discrepancy between the two readings?

Solution:

Reasons for difference:

1. **Non-ideal behavior:** Real gases deviate from ideal gas law
2. **Intermolecular forces:** Different gases have different intermolecular interactions
3. **Gas density effects:** Higher density gases show more deviation
4. **Temperature dependence:** Deviations increase at higher temperatures

Procedure to reduce discrepancy:

1. **Use lower gas pressures:** Approach ideal gas behavior
 2. **Extrapolate to zero pressure:** Take measurements at various pressures and extrapolate $P \rightarrow 0$
 3. **Use lighter gases:** Hydrogen shows less deviation than oxygen
 4. **Correct for gas imperfections:** Apply virial equation corrections
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10.6 A steel tape 1m long is correctly calibrated for a temperature of 27.0°C. The length of a steel rod measured by this tape is found to be 63.0 cm on a hot day when the temperature is 45.0°C. What is the actual length of the steel rod on that day? What is the length of the same steel rod on a day when the temperature is 27.0°C? Coefficient of linear expansion of steel = $1.20 \times 10^{-5} \text{ K}^{-1}$.

Solution:

Given:

- Tape length at 27°C: $L_0 = 1\text{m}$
- Temperature of measurement: $T_1 = 45^\circ\text{C}$
- Calibration temperature: $T_0 = 27^\circ\text{C}$
- Measured length: 63.0 cm
- $\alpha_{\text{steel}} = 1.20 \times 10^{-5} \text{ K}^{-1}$

Step 1: Length of tape at 45°C $L_{\text{tape}} = L_0[1 + \alpha(T_1 - T_0)]$ $L_{\text{tape}} = 1[1 + 1.20 \times 10^{-5}(45 - 27)]$ $L_{\text{tape}} = 1[1 + 1.20 \times 10^{-5} \times 18]$ $L_{\text{tape}} = 1[1 + 2.16 \times 10^{-4}] = 1.000216 \text{ m}$

Step 2: Actual length of rod at 45°C Since tape has expanded, 63.0 cm on expanded tape corresponds to: Actual length = $0.630 \times (1.000216/1.000) = 0.630 \times 1.000216 = 0.6301 \text{ m} = 63.01 \text{ cm}$

Step 3: Length of rod at 27°C The rod also contracts when cooled from 45°C to 27°C: $L_{27} = L_{45}[1 - \alpha(T_1 - T_0)]$ $L_{27} = 63.01[1 - 1.20 \times 10^{-5} \times 18]$ $L_{27} = 63.01[1 - 2.16 \times 10^{-4}]$ $L_{27} = 63.01 \times 0.999784 = 62.99 \text{ cm}$

Answer:

- Actual length at 45°C: 63.01 cm
 - Length at 27°C: 62.99 cm
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10.7 A large steel wheel is to be fitted on to a shaft of the same material. At 27°C, the outer diameter of the shaft is 8.70 cm and the diameter of the central hole in the wheel is 8.69 cm. The shaft is cooled using 'dry ice'. At what temperature of the shaft does the wheel slip on the shaft? Assume coefficient of linear expansion of the steel to be constant over the required temperature range: $\alpha_{\text{steel}} = 1.20 \times 10^{-5} \text{ K}^{-1}$.

Solution:

Given:

- Shaft diameter at 27°C: $d_1 = 8.70 \text{ cm}$
- Hole diameter: $d_2 = 8.69 \text{ cm}$
- $T_1 = 27^\circ\text{C}$

- $\alpha = 1.20 \times 10^{-5} \text{ K}^{-1}$

For wheel to slip on shaft: shaft diameter = hole diameter

Step 1: Set up equation The shaft contracts when cooled: $d_1[1 + \alpha(T_2 - T_1)] = d_2$

Step 2: Solve for T_2 $8.70[1 + 1.20 \times 10^{-5}(T_2 - 27)] = 8.69$ $1 + 1.20 \times 10^{-5}(T_2 - 27) = 8.69/8.70$ $1 + 1.20 \times 10^{-5}(T_2 - 27) = 0.9988$ $1.20 \times 10^{-5}(T_2 - 27) = -0.0012$ $T_2 - 27 = -0.0012/(1.20 \times 10^{-5}) = -100$ $T_2 = 27 - 100 = -73^\circ\text{C}$

Answer: $T = -73^\circ\text{C}$

10.8 A hole is drilled in a copper sheet. The diameter of the hole is 4.24 cm at 27.0°C . What is the change in the diameter of the hole when the sheet is heated to 227°C ? Coefficient of linear expansion of copper = $1.70 \times 10^{-5} \text{ K}^{-1}$.

Solution:

Given:

- Initial diameter: $d_0 = 4.24 \text{ cm}$
- $T_1 = 27^\circ\text{C}$, $T_2 = 227^\circ\text{C}$
- $\alpha_{\text{copper}} = 1.70 \times 10^{-5} \text{ K}^{-1}$

Key concept: A hole in a sheet expands as if it were made of the same material.

Step 1: Apply linear expansion formula $d = d_0[1 + \alpha(T_2 - T_1)]$ $d = 4.24[1 + 1.70 \times 10^{-5}(227 - 27)]$ $d = 4.24[1 + 1.70 \times 10^{-5} \times 200]$ $d = 4.24[1 + 3.40 \times 10^{-3}]$ $d = 4.24 \times 1.0034 = 4.254 \text{ cm}$

Step 2: Calculate change $\Delta d = d - d_0 = 4.254 - 4.24 = 0.014 \text{ cm} = 0.14 \text{ mm}$

Answer: Increase in diameter = $0.014 \text{ cm} = 0.14 \text{ mm}$

10.9 A brass wire 1.8 m long at 27°C is held taut with little tension between two rigid supports. If the wire is cooled to a temperature of -39°C, what is the tension developed in the wire, if its diameter is 2.0 mm? Co-efficient of linear expansion of brass = $2.0 \times 10^{-5} \text{ K}^{-1}$; Young's modulus of brass = $0.91 \times 10^{11} \text{ Pa}$.

Solution:

Given:

- $L_0 = 1.8 \text{ m}$, $T_1 = 27^\circ\text{C}$, $T_2 = -39^\circ\text{C}$
- $d = 2.0 \text{ mm} = 2.0 \times 10^{-3} \text{ m}$
- $\alpha = 2.0 \times 10^{-5} \text{ K}^{-1}$
- $Y = 0.91 \times 10^{11} \text{ Pa}$

Step 1: Calculate thermal strain When wire cools, it tries to contract but is prevented by rigid supports. Thermal strain = $\alpha(T_1 - T_2) = 2.0 \times 10^{-5} \times [27 - (-39)]$ Thermal strain = $2.0 \times 10^{-5} \times 66 = 1.32 \times 10^{-3}$

Step 2: Calculate stress using Young's modulus Stress = $Y \times \text{strain} = 0.91 \times 10^{11} \times 1.32 \times 10^{-3} = 1.20 \times 10^8 \text{ Pa}$

Step 3: Calculate tension Cross-sectional area = $\pi(d/2)^2 = \pi(1.0 \times 10^{-3})^2 = \pi \times 10^{-6} \text{ m}^2$ Tension = Stress $\times$ Area = $1.20 \times 10^8 \times \pi \times 10^{-6}$ Tension = 377 N

Answer: Tension = 377 N

10.10 A brass rod of length 50 cm and diameter 3.0 mm is joined to a steel rod of the same length and diameter. What is the change in length of the combined rod at 250°C, if the original lengths are at 40.0°C? Is there a 'thermal stress' developed

at the junction? The ends of the rod are free to expand. Co-efficient of linear expansion of brass = $2.0 \times 10^{-5} \text{ K}^{-1}$, steel = $1.2 \times 10^{-5} \text{ K}^{-1}$.

Solution:

Given:

- $L_1 = L_2 = 0.50 \text{ m}$ (brass and steel lengths)
- $T_1 = 40^\circ\text{C}$, $T_2 = 250^\circ\text{C}$
- $\alpha_{\text{brass}} = 2.0 \times 10^{-5} \text{ K}^{-1}$
- $\alpha_{\text{steel}} = 1.2 \times 10^{-5} \text{ K}^{-1}$

Step 1: Expansion of brass rod $\Delta L_{\text{brass}} = L_1 \times \alpha_{\text{brass}} \times (T_2 - T_1)$
 $\Delta L_{\text{brass}} = 0.50 \times 2.0 \times 10^{-5} \times (250 - 40)$
 $\Delta L_{\text{brass}} = 0.50 \times 2.0 \times 10^{-5} \times 210 = 2.1 \times 10^{-3} \text{ m} = 2.1 \text{ mm}$

Step 2: Expansion of steel rod $\Delta L_{\text{steel}} = L_2 \times \alpha_{\text{steel}} \times (T_2 - T_1)$
 $\Delta L_{\text{steel}} = 0.50 \times 1.2 \times 10^{-5} \times 210$
 $= 1.26 \times 10^{-3} \text{ m} = 1.26 \text{ mm}$

Step 3: Total expansion Total $\Delta L = \Delta L_{\text{brass}} + \Delta L_{\text{steel}} = 2.1 + 1.26 = 3.36 \text{ mm}$

Step 4: Thermal stress analysis Since the ends are free to expand and both rods are joined at the junction, each rod can expand independently. The junction moves, but there's no constraint preventing expansion.

No thermal stress is developed because:

1. Ends are free to expand
2. No external constraint prevents natural expansion
3. Junction simply moves to accommodate different expansions

Answer:

- Change in length = 3.36 mm
 - No thermal stress developed
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10.11 The coefficient of volume expansion of glycerine is $49 \times 10^{-5} \text{ K}^{-1}$. What is the fractional change in its density for a 30°C rise in temperature?

Solution:

Given:

- $\alpha_V = 49 \times 10^{-5} \text{ K}^{-1}$
- $\Delta T = 30^\circ\text{C}$

Step 1: Relationship between density and volume Mass remains constant, so: $\rho_1 V_1 = \rho_2 V_2$ Therefore:

$$\rho_2 / \rho_1 = V_1 / V_2$$

Step 2: Volume expansion $V_2 = V_1 [1 + \alpha_V \times \Delta T]$ $V_2 = V_1 [1 + 49 \times 10^{-5} \times 30]$ $V_2 = V_1 [1 + 1.47 \times 10^{-2}] = V_1 \times 1.0147$

Step 3: Density change $\rho_2 / \rho_1 = V_1 / V_2 = 1 / 1.0147 = 0.9855$

Step 4: Fractional change Fractional change = $(\rho_2 - \rho_1) / \rho_1 = \rho_2 / \rho_1 - 1 = 0.9855 - 1 = -0.0145$

Answer: Fractional decrease in density = 0.0145 or 1.45%

10.12 A 10 kW drilling machine is used to drill a bore in a small aluminium block of mass 8.0 kg. How much is the rise in temperature of the block in 2.5 minutes, assuming 50% of power is used up in heating the machine itself or lost to the surroundings. Specific heat of aluminium = $0.91 \text{ J g}^{-1} \text{ K}^{-1}$.

Solution:

Given:

- Power = 10 kW = 10,000 W
- Time = 2.5 min = 150 s
- Mass = 8.0 kg = 8000 g
- Efficiency = 50% (for heating the block)
- $s_{\text{Al}} = 0.91 \text{ J g}^{-1} \text{ K}^{-1}$

Step 1: Energy supplied to the block Total energy = Power $\times$ Time = $10,000 \times 150 = 1.5 \times 10^6 \text{ J}$

Energy used for heating block = $50\% \times 1.5 \times 10^6 = 7.5 \times 10^5 \text{ J}$

Step 2: Temperature rise $Q = ms\Delta T$ $7.5 \times 10^5 = 8000 \times 0.91 \times \Delta T$ $\Delta T = (7.5 \times 10^5)/(8000 \times 0.91) = 103^\circ\text{C}$

Answer: Temperature rise = 103°C

10.13 A copper block of mass 2.5 kg is heated in a furnace to a temperature of 500°C and then placed on a large ice block. What is the maximum amount of ice that can melt? (Specific heat of copper = $0.39 \text{ J g}^{-1} \text{ K}^{-1}$; heat of fusion of water = 335 J g^{-1}).

Solution:

Given:

- Mass of copper = 2.5 kg = 2500 g
- Initial temperature of copper = 500°C
- Final temperature = 0°C (thermal equilibrium with ice)
- $s_{\text{Cu}} = 0.39 \text{ J g}^{-1} \text{ K}^{-1}$

- $L_f = 335 \text{ J g}^{-1}$

Step 1: Heat lost by copper $Q = m \times s \times \Delta T$ $Q = 2500 \times 0.39 \times (500 - 0)$ $Q = 2500 \times 0.39 \times 500 = 487,500 \text{ J}$

Step 2: Mass of ice melted Heat gained by ice = Heat lost by copper $m_{\text{ice}} \times L_f = 487,500$ $m_{\text{ice}} \times 335 = 487,500$ $m_{\text{ice}} = 487,500/335 = 1455 \text{ g} = 1.46 \text{ kg}$

Answer: Maximum ice that can melt = 1.46 kg

10.14 In an experiment on the specific heat of a metal, a 0.20 kg block of the metal at 150°C is dropped in a copper calorimeter (of water equivalent 0.025 kg) containing 150 cm³ of water at 27°C. The final temperature is 40°C. Compute the specific heat of the metal. If heat losses to the surroundings are not negligible, is your answer greater or smaller than the actual value for specific heat of the metal?

Solution:

Given:

- Mass of metal = 0.20 kg
- Initial temperature of metal = 150°C
- Water equivalent of calorimeter = 0.025 kg
- Volume of water = 150 cm³ = 0.15 kg
- Initial temperature of water = 27°C
- Final temperature = 40°C
- $s_{\text{water}} = 4186 \text{ J kg}^{-1} \text{ K}^{-1}$

Step 1: Heat lost by metal $Q_{\text{lost}} = m_{\text{metal}} \times s_{\text{metal}} \times (150 - 40) = 0.20 \times s_{\text{metal}} \times 110$

Step 2: Heat gained by water and calorimeter $Q_{\text{gained}} = (m_{\text{water}} + \text{water equivalent}) \times s_{\text{water}} \times (40 - 27)$
 $Q_{\text{gained}} = (0.15 + 0.025) \times 4186 \times 13$
 $Q_{\text{gained}} = 0.175 \times 4186 \times 13 = 9517 \text{ J}$

Step 3: Apply principle of calorimetry Heat lost = Heat gained $0.20 \times s_{\text{metal}} \times 110 = 9517$
 $s_{\text{metal}} = 9517 / (0.20 \times 110) = 432.6 \text{ J kg}^{-1} \text{ K}^{-1}$

Effect of heat losses: If heat is lost to surroundings, the calculated specific heat will be **smaller** than the actual value because:

- Less heat is gained by water and calorimeter
- We assume all heat lost by metal goes to water/calorimeter
- In reality, some heat escapes to surroundings

Answer:

- Specific heat = $433 \text{ J kg}^{-1} \text{ K}^{-1}$
- Calculated value is smaller than actual

10.15 Given below are observations on molar specific heats at room temperature of some common gases.

Gas	Molar specific heat (C_v) $\text{cal mol}^{-1} \text{ K}^{-1}$
Hydrogen	4.87
Nitrogen	4.97
Oxygen	5.02
Nitric oxide	4.99
Carbon monoxide	5.01
Chlorine	6.17

The measured molar specific heats of these gases are markedly different from those for monatomic gases. Typically, molar specific heat of a monatomic gas is 2.92 cal/mol K. Explain this difference. What can you infer from the somewhat larger (than the rest) value for chlorine?

Solution:

Explanation of differences:

Monatomic gases ($C_v = 2.92$ cal/mol K):

- Only translational kinetic energy (3 degrees of freedom)
- $C_v = (3/2)R = 1.5 \times 1.987 = 2.98$ cal/mol K ≈ 2.92 cal/mol K

Diatomic gases ($C_v \approx 4.97$ cal/mol K):

- Translational kinetic energy (3 degrees of freedom)
- Rotational kinetic energy (2 degrees of freedom)
- Total: 5 degrees of freedom
- $C_v = (5/2)R = 2.5 \times 1.987 = 4.97$ cal/mol K

Analysis of given data:

1. **H₂, N₂, O₂, NO, CO:** All show $C_v \approx 5.0$ cal/mol K
 - Consistent with diatomic molecules
 - 5 degrees of freedom (3 translational + 2 rotational)
 - Vibrational modes not excited at room temperature
2. **Chlorine (Cl₂):** $C_v = 6.17$ cal/mol K
 - Higher than other diatomic gases
 - Indicates partial excitation of vibrational modes
 - Heavier molecule $\rightarrow$ lower vibrational frequencies

- Some vibrational energy storage at room temperature

What can be inferred about chlorine:

- Being heavier, Cl_2 has lower vibrational frequencies
- Some vibrational modes begin to be excited at room temperature
- Contribution from vibrational energy storage increases C_v
- Trend: heavier diatomic molecules have higher C_v at room temperature

Answer: The difference arises from the number of degrees of freedom. Diatomic gases have 5 degrees of freedom (3 translational + 2 rotational) compared to 3 for monatomic gases. Chlorine's higher value indicates partial vibrational excitation due to its heavier mass and lower vibrational frequencies.

10.16 A child running a temperature of 101°F is given an antipyrin (i.e. a medicine that lowers fever) which causes an increase in the rate of evaporation of sweat from his body. If the fever is brought down to 98°F in 20 minutes, what is the average rate of extra evaporation caused by the drug. Assume the evaporation mechanism to be the only way by which heat is lost. The mass of the child is 30 kg. The specific heat of human body is approximately the same as that of water, and latent heat of evaporation of water at that temperature is about 580 cal g^{-1} .

Solution:

Given:

- Initial temperature: $T_1 = 101^\circ\text{F}$
- Final temperature: $T_2 = 98^\circ\text{F}$
- Time: $t = 20 \text{ min} = 1200 \text{ s}$

- Mass of child: $m = 30 \text{ kg} = 30,000 \text{ g}$
- Specific heat $\approx s_{\text{water}} = 1 \text{ cal g}^{-1} \text{ }^{\circ}\text{F}^{-1}$
- Latent heat of evaporation: $L = 580 \text{ cal g}^{-1}$

Step 1: Heat to be removed from body $Q = ms\Delta T = 30,000 \times 1 \times (101 - 98) = 90,000 \text{ cal}$

Step 2: Mass of water evaporated Heat removed by evaporation $= m_{\text{evap}} \times L$
 $90,000 = m_{\text{evap}} \times 580$
 $m_{\text{evap}} = 90,000/580 = 155.2 \text{ g}$

Step 3: Rate of evaporation Rate $= m_{\text{evap}}/\text{time} = 155.2 \text{ g} / 20 \text{ min} = 7.76 \text{ g/min}$

Answer: Average rate of extra evaporation $= 7.76 \text{ g/min}$

10.17 A 'thermacole' icebox is a cheap and efficient method for storing small quantities of cooked food in summer in particular. A cubical icebox of side 30 cm has a thickness of 5.0 cm. If 4.0 kg of ice is put in the box, estimate the amount of ice remaining after 6 h. The outside temperature is 45°C, and co-efficient of thermal conductivity of thermacole is $0.01 \text{ J s}^{-1} \text{ m}^{-1} \text{ K}^{-1}$. [Heat of fusion of water = $335 \times 10^3 \text{ J kg}^{-1}$]

Solution:

Given:

- Cubical box side: $a = 30 \text{ cm} = 0.30 \text{ m}$
- Wall thickness: $d = 5.0 \text{ cm} = 0.05 \text{ m}$
- Initial ice mass: $m_0 = 4.0 \text{ kg}$
- Time: $t = 6 \text{ h} = 21,600 \text{ s}$
- Outside temperature: $T_1 = 45^{\circ}\text{C}$

- Inside temperature: $T_2 = 0^\circ\text{C}$ (ice melting)
- Thermal conductivity: $K = 0.01 \text{ J s}^{-1} \text{ m}^{-1} \text{ K}^{-1}$
- Latent heat of fusion: $L_f = 335 \times 10^3 \text{ J kg}^{-1}$

Step 1: Calculate surface area for heat transfer For a cube, total surface area = $6a^2$ $A = 6 \times (0.30)^2 = 6 \times 0.09 = 0.54 \text{ m}^2$

Step 2: Calculate rate of heat transfer Using Fourier's law: $H = KA(T_1 - T_2)/d$ $H = 0.01 \times 0.54 \times (45 - 0)/0.05$ $H = 0.01 \times 0.54 \times 45/0.05 = 4.86 \text{ W}$

Step 3: Total heat transferred in 6 hours $Q = H \times t = 4.86 \times 21,600 = 104,976 \text{ J}$

Step 4: Mass of ice melted Heat required to melt ice: $Q = m \times L_f$ $104,976 = m \times 335 \times 10^3$ $m = 104,976/(335 \times 10^3) = 0.313 \text{ kg}$

Step 5: Remaining ice Remaining ice = $4.0 - 0.313 = 3.69 \text{ kg}$

Answer: Ice remaining after 6 hours = 3.69 kg

10.18 A brass boiler has a base area of 0.15 m^2 and thickness 1.0 cm . It boils water at the rate of 6.0 kg/min when placed on a gas stove. Estimate the temperature of the part of the flame in contact with the boiler. Thermal conductivity of brass = $109 \text{ J s}^{-1} \text{ m}^{-1} \text{ K}^{-1}$; Heat of vaporisation of water = $2256 \times 10^3 \text{ J kg}^{-1}$.

Solution:

Given:

- Base area: $A = 0.15 \text{ m}^2$
- Thickness: $d = 1.0 \text{ cm} = 0.01 \text{ m}$
- Rate of boiling: $6.0 \text{ kg/min} = 0.1 \text{ kg/s}$

- $K_{\text{brass}} = 109 \text{ J s}^{-1} \text{ m}^{-1} \text{ K}^{-1}$
- $L_v = 2256 \times 10^3 \text{ J kg}^{-1}$
- Water temperature: $T_2 = 100^\circ\text{C}$

Step 1: Rate of heat transfer needed for boiling $H = \text{mass rate} \times \text{latent heat}$ $H = 0.1 \times 2256 \times 10^3 = 225,600 \text{ W}$

Step 2: Apply Fourier's law for conduction $H = KA(T_1 - T_2)/d$ $225,600 = 109 \times 0.15 \times (T_1 - 100)/0.01$
 $225,600 = 109 \times 15 \times (T_1 - 100)$ $225,600 = 1635 \times (T_1 - 100)$ $T_1 - 100 = 225,600/1635 = 138^\circ\text{C}$ $T_1 = 100 + 138 = 238^\circ\text{C}$

Answer: Temperature of flame = 238°C

10.19 Explain why:

(a) A body with large reflectivity is a poor emitter

Solution: According to Kirchhoff's law, good absorbers are good emitters and vice versa.

- Reflectivity + Absorptivity = 1 (for opaque bodies)
- High reflectivity $\rightarrow$ Low absorptivity $\rightarrow$ Poor absorption
- Poor absorbers are poor emitters by Kirchhoff's law
- This maintains thermal equilibrium - if a body reflected most radiation but emitted well, it would heat up indefinitely

(b) A brass tumbler feels much colder than a wooden tray on a chilly day

Solution: The sensation depends on the rate of heat conduction from your hand.

- Thermal conductivity of brass $\gg$ thermal conductivity of wood
- Brass conducts heat away from your hand much faster

- Faster heat loss creates sensation of "coldness"
- Both objects are at same temperature, but brass feels colder due to higher heat transfer rate
- Your hand temperature drops faster when touching brass

(c) An optical pyrometer (for measuring high temperatures) calibrated for an ideal black body radiation gives too low a value for the temperature of a red hot iron piece in the open, but gives a correct value for the temperature when the same piece is in the furnace

Solution: In open air:

- Iron piece has emissivity $e < 1$ (not a perfect black body)
- Emitted radiation intensity = $e \times$ (black body intensity)
- Pyrometer calibrated for black body radiation interprets lower intensity as lower temperature
- Reading is too low by factor related to emissivity

In furnace:

- Furnace cavity acts like a black body
- Multiple reflections ensure complete absorption
- Iron piece reaches thermal equilibrium with furnace walls
- Radiation received matches black body radiation at that temperature
- Pyrometer gives correct reading

(d) The earth without its atmosphere would be inhospitably cold

Solution: Greenhouse effect of atmosphere:

- Atmosphere is transparent to visible light from sun
- Earth's surface absorbs solar radiation and heats up
- Earth emits infrared radiation (longer wavelength)

- Atmospheric gases (CO₂, H₂O vapor) absorb IR radiation
- Re-radiated energy partially returns to Earth's surface
- This traps heat and raises Earth's temperature

Without atmosphere:

- No greenhouse effect
- All IR radiation from Earth escapes directly to space
- Average temperature would be about -18°C instead of +15°C
- No thermal insulation from atmospheric blanket

(e) Heating systems based on circulation of steam are more efficient in warming a building than those based on circulation of hot water

Solution: Steam heating advantages:

- Steam at 100°C condenses to water at 100°C
- Releases latent heat of vaporization (2256 kJ/kg)
- Much larger heat transfer per unit mass
- Water cooling from 100°C to 80°C releases only: $1 \times 4.18 \times 20 = 83.6$ kJ/kg

Comparison:

- Steam condensation: 2256 kJ/kg
 - Hot water cooling (20°C drop): 83.6 kJ/kg
 - Steam provides ~27 times more heat per kg
 - More efficient heat transfer and distribution
 - Smaller mass flow rates required
-

10.20 A body cools from 80°C to 50°C in 5 minutes. Calculate the time it takes to cool from 60°C to 30°C. The temperature of the surroundings is 20°C.

Solution:

Given:

- Initial cooling: 80°C to 50°C in 5 minutes
- Find: Time to cool from 60°C to 30°C
- Surrounding temperature: $T_1 = 20^\circ\text{C}$

Using Newton's Law of Cooling: For small temperature differences: Rate $\propto$ Temperature difference

Method 1 - Average Temperature Approach:

First case:

- Average temperature = $(80 + 50)/2 = 65^\circ\text{C}$
- Temperature difference from surroundings = $65 - 20 = 45^\circ\text{C}$
- Temperature drop = $80 - 50 = 30^\circ\text{C}$
- Rate = $30^\circ\text{C}/5 \text{ min} = 6^\circ\text{C}/\text{min}$ at 45°C difference

Second case:

- Average temperature = $(60 + 30)/2 = 45^\circ\text{C}$
- Temperature difference = $45 - 20 = 25^\circ\text{C}$
- Temperature drop = $60 - 30 = 30^\circ\text{C}$

Using rate proportionality: $\text{Rate}_1/\text{Rate}_2 = (\text{Temp difference}_1)/(\text{Temp difference}_2)$ $6/\text{Rate}_2 = 45/25$

$$\text{Rate}_2 = 6 \times 25/45 = 3.33^\circ\text{C}/\text{min}$$

$$\text{Time} = \text{Temperature drop}/\text{Rate} = 30/3.33 = 9 \text{ minutes}$$

Method 2 - Exponential Law Approach:

From Newton's law: $T = T_1 + (T_0 - T_1)e^{(-kt)}$

First case (80°C to 50°C): $50 = 20 + (80 - 20)e^{(-5k)}$ $30 = 60e^{(-5k)}$ $e^{(-5k)} = 0.5$ $-5k = \ln(0.5) = -0.693$ $k = 0.1386 \text{ min}^{-1}$

Second case (60°C to 30°C): $30 = 20 + (60 - 20)e^{(-kt)}$ $10 = 40e^{(-kt)}$ $e^{(-kt)} = 0.25$ $-kt = \ln(0.25) = -1.386$ $t = 1.386/0.1386 = 10 \text{ minutes}$

Answer: Time = 10 minutes (using exact exponential method)