Exercise walk-through

6.2 Thermal energy transfers (full B.1)

International Baccalaureate · IB Diploma · Physics · HL

Thermal · 3.1

Reasoning

Temperature relates to particle motion in a model; internal energy includes kinetic and potential contributions. During a change of state, energy can change particle arrangements rather than temperature. Measure mass, electrical input and temperature change for an insulated block. Ensure the temperature sensor has good contact, allow time for equilibration, and consider energy transferred to the surroundings.

Thermal · 4.1

Reasoning

State the known values and their units. Choose the relation because its assumptions fit this case, then rearrange before substitution. Known: a 0.50 kg block gains 2,000 J and rises 10 °C. Use $E = mc\Delta T$. Rearranging gives $c = E/(m\Delta T)$. $c = 2{,}000/(0.50\times10) = 400$ J per kilogram per degree. Heat loss would make the value inferred from electrical input too large.

Melt first, then warm

1. **Set the model** Warm $0.40\,\mathrm{kg}$ of ice at $0^\circ\mathrm{C}$ to water at $30^\circ\mathrm{C}$. Use $L_f = 3.34 \times 10^5\,\mathrm{J/kg}$ and $c = 4186\,\mathrm{J/(kg\,K)}$.
2. **Calculate** Melting: $mL_f = 1.34 \times 10^5\,\mathrm{J}$. Warming: $mc\Delta T = 5.02 \times 10^4\,\mathrm{J}$. Total $= 1.84 \times 10^5\,\mathrm{J}$.

Decision

Temperature stays constant during melting. Use latent heat for the phase change and specific heat for warming.

Exercises 2.1·2.3

2.1 Convert 27 °C to kelvin, and a change of 45 K to Celsius degrees. [2]

2.2 Calculate the mean kinetic energy of a gas molecule at 300 K ($k_B = 1.38 \times 10^{-23}$ J/K). [2]

2.3 0.50 kg of water cools from 80 °C to 30 °C ($c = 4186$ J/(kg · K)). Calculate Q. [2]

Exercises 2.1·2.3

2.1 Convert 27 °C to kelvin, and a change of 45 K to Celsius degrees. [2]

2.1 $T = 27 + 273 = 300$ K; a temperature change is the same on both scales: 45 K = 45 Celsius degrees.

2.2 Calculate the mean kinetic energy of a gas molecule at 300 K ($k_B = 1.38 \times 10^{-23}$ J/K). [2]

2.2 $E_k = \frac{3}{2} \times 1.38 \times 10^{-23} \times 300 = 6.2 \times 10^{-21}$ J.

2.3 0.50 kg of water cools from 80 °C to 30 °C ($c = 4186$ J/(kg · K)). Calculate Q. [2]

2.3 $Q = 0.50 \times 4186 \times 50 = 1.0 \times 10^5$ J.

Exercises 2.4·3.1

2.4 A metal rod ($k = 50$, A $= 2.0\times10^{-4}$ m^2, length 0.40 m) has ends 100 K apart. Calculate the conduction rate. [3]

2.5 A black body's spectrum peaks at 970 nm. Calculate its temperature. [2]

3.1 A 1.2 kW heater warms 2.0 kg of ice at 0 °C. Calculate the energy to melt the ice ($L_f = 3.34\times10^5$ J/kg), the further energy to reach 25 °C, and the minimum total heating time. [5]

Exercises 2.4·3.1

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2.4 $\Delta Q/\Delta t = 50 \times 2.0 \times 10^{-4} \times 100/0.40 = 2.5$ W.

2.5 A black body's spectrum peaks at 970 nm. Calculate its temperature. [2]

2.5 $T = 2.9 \times 10^{-3}/9.7 \times 10^{-7} = 3.0 \times 10^{3}$ K.

3.1 A 1.2 kW heater warms 2.0 kg of ice at 0 °C. Calculate the energy to melt the ice ($L_f = 3.34\times10^{5}$ J/kg), the further energy to reach 25 °C, and the minimum total heating time. [5]

3.1 Melt: $Q_1 = 2.0 \times 3.34 \times 10^{5} = 6.68 \times 10^{5}$ J. Warm: $Q_2 = 2.0 \times 4186 \times 25 = 2.1 \times 10^{5}$ J. Total $= 8.8 \times 10^{5}$ J; time $= 8.8 \times 10^{5}/1200 = 7.3 \times 10^{2}$ s $\approx$ 12 minutes.

Exercises 3.2·3.3

3.2 A planet orbits a star of luminosity 4.0×10^{26} W at a distance of 1.5×10^{11} m. Calculate the apparent brightness, and the power incident on the planet's cross-section (πR^2, R = 6.4×10^6 m). [5]

3.3 A radiator surface (2.0 m^2, 340 K) has emissivity 0.80. Calculate the power radiated, and compare it with a black body at the same temperature. [4]

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3.2 $b = 4.0 \times 10^{26}/(4\pi(1.5 \times 10^{11})^2) = 1.41 \times 10^3$ W/m^2. Cross-section $= \pi(6.4 \times 10^6)^2 = 1.3 \times 10^{14}$ m^2; power $= 1.4 \times 10^3 \times 1.3 \times 10^{14} = 1.8 \times 10^{17}$ W.

3.3 A radiator surface (2.0 m^2, 340 K) has emissivity 0.80. Calculate the power radiated, and compare it with a black body at the same temperature. [4]

3.3 Black body: $L = 5.7 \times 10^{-8} \times 2.0 \times 340^4 = 1.52 \times 10^3$ W. Radiator: $0.80 \times 1.52 \times 10^3 = 1.22 \times 10^3$ W – 20 % less than the black body, as emissivity scales the radiated power directly.