4.2 Thermal energy transfers (full B.1)

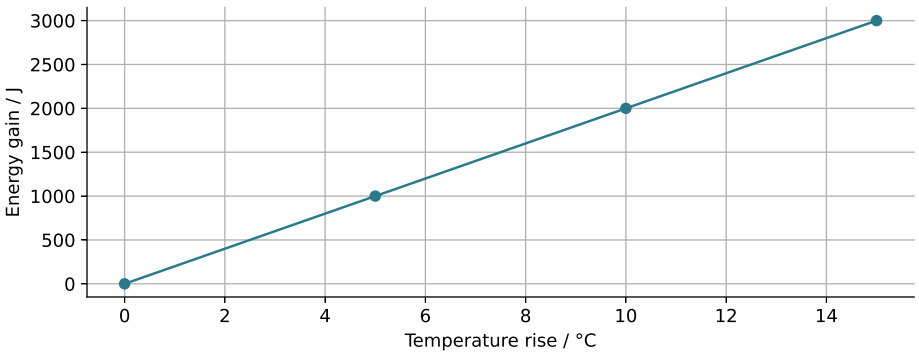
Name: _____ Class: _____ Date: _____ **Total: 25 marks**

KEY WORDS internal energy • specific latent heat • emissivity

Objective

Practise the full guide B.1 toolkit: Kelvin temperature and mean kinetic energy (E_k = 3/2 k_B T), Q = mcΔT and Q = mL, the conduction rate ΔQ/Δt = kAΔT/Δx, Stefan–Boltzmann L = σAT^4 with apparent brightness b = L/$4\pi d^2$, Wien's λ_max T = 2.9×10^{-3} m · K, and emissivity. Original practice; not an official IB paper.

1 Key knowledge and worked examples



■ **The B.1 equation set**

$$E_k = \tfrac{3}{2}k_B T \qquad Q = mc\Delta T \qquad Q = mL \qquad \frac{\Delta Q}{\Delta t} = \frac{kA\Delta T}{\Delta x}$$

$$L = \sigma A T^4 \qquad b = \frac{L}{4\pi d^2} \qquad \lambda_{\max} T = 2.9\times10^{-3}\ \mathrm{m\cdot K} \qquad \text{emissivity} = \frac{\text{power per unit area}}{\sigma T^4}$$

Worked check. A star radiates like a black body of radius 7.0×10^8 m at 5800 K: $L = 5.7\times10^{-8}\times4\pi(7.0\times10^8)^2\times5800^4 \approx 4\times10^{26}$ W.

2 Practice

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 ($k_B = 1.38\times10^{-23}$ 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]

2.4 A metal rod ($k = 50$, A = 2.0×10^{-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 Exam-style questions

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]

3.2 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]

Solutions

Original-task marking: M1 method, A1 accuracy, B1 reasoning.

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

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

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

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

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

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.

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 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.