

Solutions: thermal physics, midterm test

Marking scheme. Total: 50 marks. The lifebuoy parts are worth 30 marks (60 %): this is the pass mark. Rounding differences in the last digit are accepted.

I Multiple choice

[10]

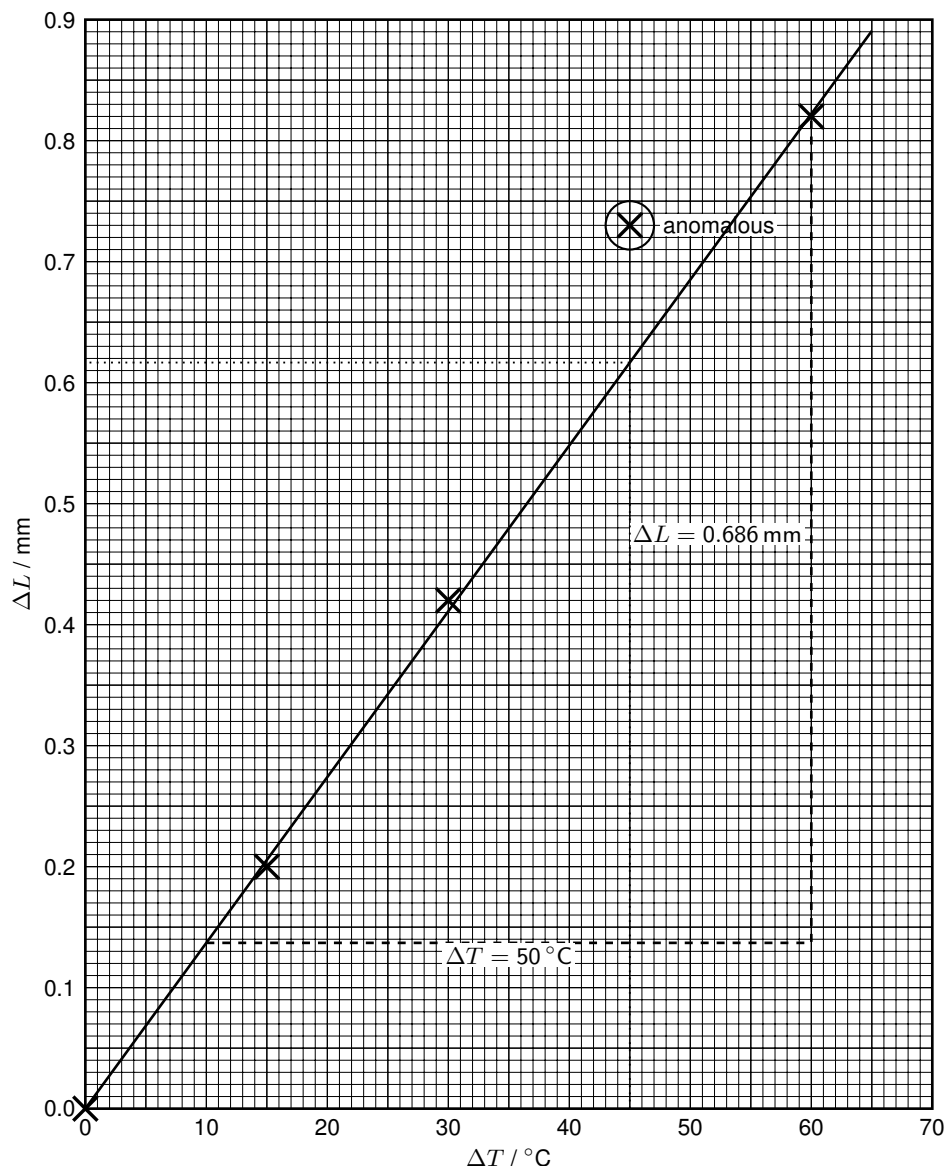
1. **B.** Heat is energy transferred because of a temperature difference. [1]
2. **C.** $T = 47 + 273 = 320 \text{ K}$. [1]
3. **A.** A narrower tube makes the liquid column move further for each degree. [1]
4. **D.** ΔL is proportional to L_0 : twice the length gives twice the expansion, 1.0 mm. [1]
5. **C.** The particles vibrate with a larger amplitude and are, on average, slightly further apart. [1]
6. **A.** Pressure comes from collisions of the particles with the walls. [1]
7. **B.** Specific heat capacity: the energy needed to raise 1 kg by 1°C . [1]
8. **D.** $Q = mc\Delta T = 2.0 \times 4200 \times 10 = 84\,000 \text{ J}$. [1]
9. **C.** $E = Pt = 1000 \times 60 = 60\,000 \text{ J}$. [1]
10. **A.** A matt black surface is a better emitter of infrared radiation. [1]

Check and common mistakes. Question 2: 310 K comes from adding 263 instead of 273. Question 4: 0.75 mm and 0.25 mm come from adding or halving instead of multiplying. Question 8: 42 000 J comes from forgetting the mass, or using 5 K; 8400 J from a factor-ten slip. Question 9: 16.7 J comes from dividing 1000/60 instead of multiplying.

II Alternative to practical

[20]

- (a) Independent variable: the temperature rise ΔT . Dependent variable: the increase in length ΔL . [2]
- (b) $\Delta T = 45^\circ\text{C}$ (the reading $\Delta L = 0.73 \text{ mm}$). [1]
- (c) The reading is much larger than the trend: the other points follow about $0.0137 \text{ mm}/^\circ\text{C}$, which would give about 0.62 mm at 45°C , and the next reading (0.82 mm) is only slightly larger. [1]
- (d) Axes labelled $\Delta T / ^\circ\text{C}$ (horizontal) and $\Delta L / \text{mm}$ (vertical). One mark for each axis. [2]
- (e) Five points plotted correctly, each to within half a small square: 3 marks; 3–4 points correct: 2 marks; 1–2 points: 1 mark. [3]
- (f) One thin ruled straight line through (or very close to) the origin and the four consistent points, balanced about the line. The point at 45°C is not used. [2]
- (g) $\Delta L \approx 0.62 \text{ mm}$ (accept 0.60 to 0.64). [1]
- (h) Triangle on the line, as large as possible. For example: $\Delta L = 0.823 - 0.137 = 0.686 \text{ mm}$ and $\Delta T = 60 - 10 = 50^\circ\text{C}$, so gradient = $0.0137 \text{ mm}/^\circ\text{C}$ (accept 0.0130 to 0.0145). [2]
- (i) $\Delta L = \alpha L_0 \Delta T$, so the gradient $\Delta L / \Delta T$ equals αL_0 . [1]
- (j) $\alpha = \frac{\text{gradient}}{L_0}$. Gradient in metres: $0.0137 \times 10^{-3} = 1.37 \times 10^{-5} \text{ m}/^\circ\text{C}$. $\alpha = \frac{1.37 \times 10^{-5}}{0.800} = 1.7 \times 10^{-5} / ^\circ\text{C}$ (accept 1.6 to 1.8). [3]
- (k) Copper. [1]
- (l) Any one of: repeat each reading and average; use a dial gauge with a finer resolution; take more temperatures; insulate the jacket and wait until the rod reaches the water temperature. [1]



Check and common mistakes. Millimetres not converted: $\alpha = 0.0137/0.800 = 0.017/^\circ\text{C}$, a thousand times too large. L_0 forgotten (gradient read as α): $\alpha = 1.4 \times 10^{-5}/^\circ\text{C}$, which points to steel, wrongly. Gradient multiplied by L_0 instead of divided: $1.1 \times 10^{-5}/^\circ\text{C}$, again steel. The anomalous point included in the line: gradient $0.0145 \text{ mm}/^\circ\text{C}$, $\alpha = 1.8 \times 10^{-5}/^\circ\text{C}$, and the closest metal becomes brass instead of copper. Reasonableness: α for metals is of order 10^{-5} per $^\circ\text{C}$.

III Structured questions

[10]

- (a) Solid: particles touching, in a regular pattern, vibrating about fixed positions. Liquid: particles touching but in a disordered arrangement. Gas: particles far apart, in random positions. One mark for each state. [3]
 - (b) In a gas the particles are far apart and move freely and fast, with almost no forces between them, so they spread out to fill the container. In a solid the particles are held in fixed positions. [1]
- (a) (i) Conduction. [1] (ii) Radiation. [1]
 - (b) Metals have free electrons that move through the structure and carry energy quickly, in addition to the vibrations of the particles. In plastics there are no free electrons: energy passes only from one vibrating particle to the next, which is much slower. [2]
- Heat is energy transferred because of a temperature difference; a body does not “have heat”. The

spoon feels hot because its temperature is high: its particles have a high average kinetic energy, so it has a lot of thermal energy. [2]

Check and common mistakes. Question 1(a): gas particles drawn touching or in a regular pattern; solid particles drawn far apart. Question 2(a)(ii): convection given for the person at the fire; hot air rises and does not travel sideways, so it is radiation. Question 3: “temperature is the amount of heat” repeats the original error.

IV Problems

[10]

1. (a) $\Delta L = \alpha L_0 \Delta T$, where ΔL is the increase in length, α the linear expansion coefficient, L_0 the original length and ΔT the change in temperature. [2]
- (b) $\Delta T = 65 - 15 = 50^\circ\text{C}$; $\Delta L = 1.7 \times 10^{-5} \times 2.00 \times 50 = 1.7 \times 10^{-3} \text{ m} = 1.7 \text{ mm}$. [2]
2. (a) $Q = mc \Delta T$. [1]
- (b) $E = Pt$. [1]
- (c) With no loss $E = Q$: $Pt = mc \Delta T$, so $t = \frac{mc \Delta T}{P}$. [2]
- (d) $\Delta T = 45 - 15 = 30^\circ\text{C}$; $t = \frac{2.0 \times 4200 \times 30}{1500} = \frac{252\,000}{1500} = 168 \text{ s} (\approx 2.8 \text{ min})$. [2]

Check and common mistakes. Problem 1: $\Delta T = 65^\circ\text{C}$ (final temperature used as the change) gives 2.2 mm; the answer left in metres (0.0017 m) when millimetres were asked. Problem 2: kW used as W: $t = 168\,000 \text{ s}$; $\Delta T = 45^\circ\text{C}$ gives 252 s. Reasonableness: a heater of 1.5 kW warms 2 kg of water by 30°C in a few minutes.