OCR A A Level Thermal Properties of Matter solutions

Matching solutions and teaching prompts for the class review

Specification points covered

- 5.1.3(a) Define and use specific heat capacity c using E = mcΔθ.
- 5.1.3(b)(i-ii) Determine specific heat capacity by an electrical method.
- 5.1.3(c) Define and use specific latent heat of fusion and vaporisation using E = mL.
- 5.1.3(d)(i-ii) Determine specific latent heat by an electrical method.
- 5.1.2(f-g) Relate temperature and changes of state to changes in internal energy.

Teaching focus

Ask pupils to name the energy stage before choosing an equation: warming, changing state, or warming after the change.
In practical answers, every measurement should be linked to E = VIt and c = E/(mΔθ); apparatus lists alone are not enough.

1. Thermal properties

1. Define specific heat capacity. [1 mark]

Answer / mark points: Specific heat capacity is the energy required per unit mass to raise the temperature of a substance by 1 K, without a change of state.

Teacher prompt / common error: Require energy per unit mass per kelvin. A numerical equation alone is not a definition.

2. Define specific latent heat and distinguish between the specific latent heat of fusion and the specific latent heat of vaporisation. [2 marks]

Answer / mark points: Specific latent heat is the energy required per unit mass to change the state of a substance without a change in temperature. Fusion refers to the solid-liquid change; vaporisation refers to the liquid-gas change.

Teacher prompt / common error: The defining phrase is 'without a change in temperature'. Fusion is solid-liquid; vaporisation is liquid-gas.

3. A 0.420 kg aluminium electronics housing has a specific heat capacity of 900 J kg^{-1} K^{-1}. Calculate the energy required to raise its temperature from 18.0 °C to 52.0 °C. [1 mark]

Answer / mark points: $E = mc\Delta\theta = 0.420 \times 900 \times (52.0 - 18.0) = 1.2852 \times 10^4$ J $\approx 1.29 \times 10^4$ J.

Teacher prompt / common error: One-operation substitution: 34.0 K may also be written as a 34.0 °C temperature change.

4. The drone electronics transfer thermal energy to the housing at a constant rate of 36.0 W. Calculate the minimum time taken to produce this temperature rise if no energy is transferred to the surroundings. [1 mark]

Answer / mark points: $t = E / P = 1.2852 \times 10^4 / 36.0 = 357$ s, or 5.95 min.

Teacher prompt / common error: Power is energy transferred per unit time. The result is a minimum because losses were excluded.

2. Protecting the electronics

5. In a field test the same temperature rise takes 420 s. Calculate the mean rate at which energy is transferred from the housing to the surroundings. [2 marks]

Answer / mark points: Energy supplied = Pt = 36.0 × 420 = 1.512×10^4 J. Energy transferred to the surroundings = $1.512 \times 10^4 - 1.2852 \times 10^4$ = 2268 J. Mean power loss = 2268 / 420 = 5.40 W.

Teacher prompt / common error: Separate energy stored by the housing from the larger electrical input, then divide the difference by time.

6. The same energy calculated in question 3 is transferred to a 0.420 kg polymer housing with specific heat capacity 1500 J kg^{-1} K^{-1}. Calculate the temperature rise of the polymer housing. [1 mark]

Answer / mark points: $\Delta\theta = E / (mc) = 1.2852 \times 10^4 / (0.420 \times 1500) = 20.4$ K.

Teacher prompt / common error: The temperature change is in kelvin; for a temperature difference the numerical value is the same in °C.

7. Using only thermal considerations, decide which housing would slow the temperature rise of the electronics more effectively. Explain your choice. [2 marks]

Answer / mark points: The polymer housing would slow the temperature rise more effectively. For the same mass and energy transfer it has the greater specific heat capacity, so its temperature increases by less.

Teacher prompt / common error: Model the comparison precisely: greater c gives a smaller increase in temperature for fixed E and m.

3. The phase-change cartridge

8. A 0.250 kg phase-change cartridge is already at its melting temperature. Its specific latent heat of fusion is 1.80×10^5 J kg^{-1}. Calculate the energy absorbed when the cartridge melts completely. [1 mark]

Answer / mark points:	$E = mL_f = 0.250 \times 1.80 \times 10^5 = 4.50 \times 10^4$ J.
Teacher prompt / common error:	The cartridge starts at its melting temperature, so no $mc\Delta\theta$ stage is required.

9. During flight, energy enters this cartridge at a net rate of 28.0 W. Calculate the time taken to melt it completely. Give your answer in minutes. [1 mark]

Answer / mark points:	$t = E / P = 4.50 \times 10^4 / 28.0 = 1.61 \times 10^3$ s = 26.8 min.
Teacher prompt / common error:	Use the net rate given. Conversion from seconds to minutes is essential.

10. A second cartridge contains 0.300 kg of solid material initially at 20.0 °C. Its melting temperature is 48.0 °C and its specific heat capacity as a solid is 2100 J kg^{-1} K^{-1}. Calculate the energy needed to heat the solid to its melting temperature. [1 mark]

Answer / mark points:	$E = mc\Delta\theta = 0.300 \times 2100 \times (48.0 - 20.0) = 1.764 \times 10^4$ J = 17.6 kJ.
Teacher prompt / common error:	This is the first stage of a multi-stage transfer. Stop at the melting temperature.

11. The second cartridge receives a total of 60.0 kJ. Its specific latent heat of fusion is 1.65×10^5 J kg^{-1}. Calculate the mass that melts after the cartridge reaches 48.0 °C. [2 marks]

Answer / mark points:	Energy available for melting = 60.0 - 17.64 = 42.36 kJ. $m = E / L_f = 42.36 \times 10^3 / (1.65 \times 10^5) = 0.257$ kg.
Teacher prompt / common error:	Only the energy remaining after warming can melt the material. The mass melted cannot exceed 0.300 kg.

12. Calculate the mass of material that remains solid after the 60.0 kJ transfer. [1 mark]

Answer / mark points:	Mass remaining solid = 0.300 - 0.2567 = 0.0433 kg, or 43.3 g.
Teacher prompt / common error:	Use the unrounded mass from question 11 before subtracting.

4. Severe heating and evaporative cooling

13. In a more severe test the second cartridge receives 80.0 kJ. Its specific heat capacity after melting is 2500 J kg^{-1} K^{-1}. Calculate its final temperature. Assume that it melts completely and that no energy is transferred to the surroundings. [3 marks]

Answer / mark points: Energy to reach 48.0 °C and melt completely = 17.64 kJ + (0.300 × 1.65 × 10^5) / 1000 = 67.14 kJ. Energy heating the liquid = 80.0 - 67.14 = 12.86 kJ. Δθ = 12.86 × 10^3 / (0.300 × 2500) = 17.1 K. Final temperature = 48.0 + 17.1 = 65.1 °C.
Teacher prompt / common error: Three stages must appear: warm the solid, melt all of it, then warm the liquid.

14. A separate evaporative cooler removes water vapour at 6.0 g min^{-1}. The specific latent heat of vaporisation of water is 2.3 × 10^6 J kg^{-1}. Calculate the mean thermal power removed by evaporation. [2 marks]

Answer / mark points: Mass flow rate = 6.0 × 10^{-3} / 60 = 1.0 × 10^{-4} kg s^{-1}. P = (m / t)L_v = 1.0 × 10^{-4} × 2.3 × 10^6 = 230 W.
Teacher prompt / common error: Convert both grams to kilograms and minutes to seconds before using SI units.

15. Explain why the temperature of a pure substance stays constant while it changes state, even though its internal energy increases. [2 marks]

Answer / mark points: During the change of state, the energy increases the intermolecular potential energy as particles separate or rearrange. Their average random kinetic energy stays constant, so the temperature stays constant while internal energy increases.
Teacher prompt / common error: Temperature and average random kinetic energy stay constant. Do not say that the energy is 'used up'.

5. Electrical determination of specific heat capacity

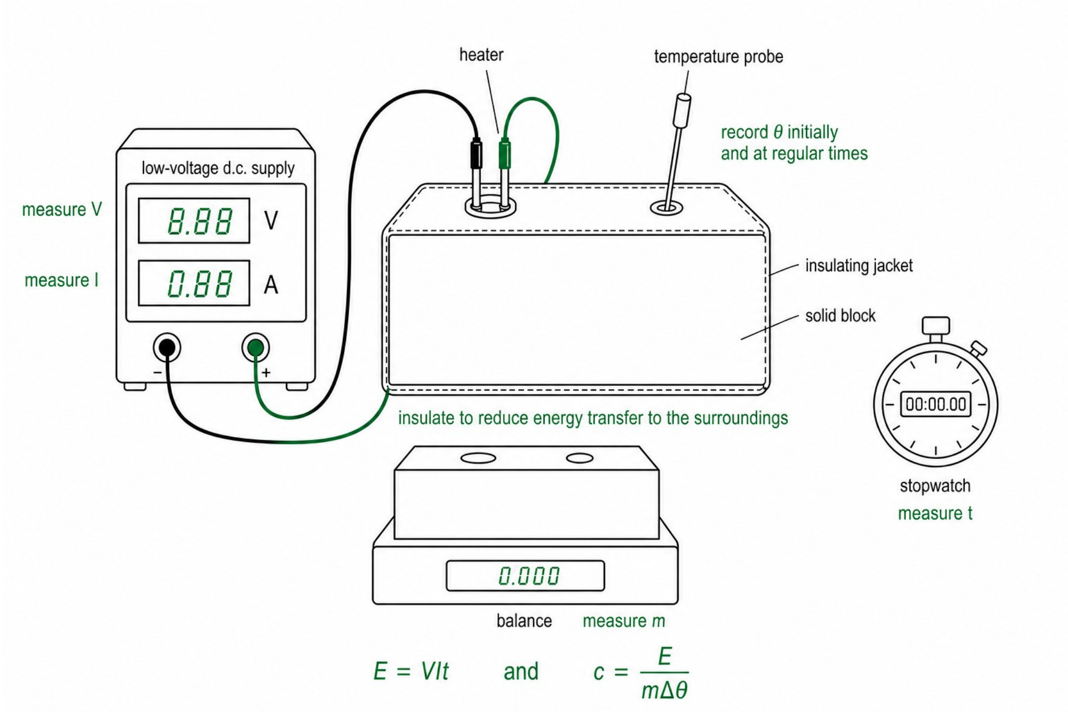

Figure 1: measurements and analysis

16. Figure 1 shows apparatus used to determine the specific heat capacity of a prototype alloy block. State the purpose of the insulating jacket and explain why the block is weighed before the heater and probe are fitted. [2 marks]

Answer / mark points: The jacket reduces energy transfer from the block to the surroundings. The mass needed in $E = mc\Delta\theta$ is the mass of the block alone, not the heater, probe or insulation.	
Teacher prompt / common error: Insulation improves the energy-transfer assumption; the equation requires the block's mass only.	

17. During one trial, V = 12.0 V, I = 2.40 A and t = 360 s. Calculate the electrical energy supplied by the heater. [1 mark]

Answer / mark points: $E = VIt = 12.0 \times 2.40 \times 360 = 1.0368 \times 10^4$ J $\approx 1.04 \times 10^4$ J.	
Teacher prompt / common error: Accept Pt with P = VI. Use the measured values rather than a nominal heater rating.	

18. The block has mass 0.850 kg and its temperature increases from 19.4 °C to 30.6 °C. Use your answer to question 17 to calculate the specific heat capacity of the block. [2 marks]

Answer / mark points: $\Delta\theta = 30.6 - 19.4 = 11.2$ K. $c = E / (m\Delta\theta) = 1.0368 \times 10^4 / (0.850 \times 11.2) = 1.09 \times 10^3$ J kg^{-1} K^{-1}.	
Teacher prompt / common error: Require $\Delta\theta = 11.2$ K and the unit J kg^{-1} K^{-1}.	

6. Analyse, evaluate and plan

19. The calculated value is greater than the accepted value. Explain how energy transfer to the surroundings could cause this result. [2 marks]

Answer / mark points: The calculation assumes that all of VIt increases the internal energy of the block. If some energy is transferred to the surroundings, the measured $\Delta\theta$ is smaller than it would be for that energy input. Using the full VIt therefore makes the calculated value of c too large.

Teacher prompt / common error: The calculated c is overestimated because VIt is treated as energy delivered only to the block.

20. Using Figure 1 and your work in questions 16–19, describe a complete electrical method to determine the specific heat capacity of the block as accurately as possible. Include the measurements, procedure, analysis, improvements and one relevant safety precaution. [6 marks]

Answer / mark points: Measure the mass m of the dry block using a balance. Insert the heater and temperature probe into separate holes, using thermal paste if needed for good thermal contact, and wrap the block in insulation. Record the initial temperature. Connect the heater to a low-voltage d.c. supply; measure V and I and start the stopwatch as the heater is switched on. Record temperature at regular times while keeping V and I steady. Calculate $E = VIt$ and $\Delta\theta$, then calculate $c = E / (m\Delta\theta)$. A stronger analysis is to plot temperature against time, use the initial gradient and calculate $c = VI / (m \times \text{gradient})$, reducing the effect of increasing heat loss. Repeat and compare or average results; use a greater safe temperature rise, insulation and cooling-curve correction to reduce uncertainty. Switch off the supply before handling the hot block and allow it to cool.

Teacher prompt / common error: For Level 3, expect a coherent sequence that links measured m, V, I, t and $\Delta\theta$ to $E = VIt$ and $c = E/(m\Delta\theta)$, plus credible heat-loss control or correction, repeat/graph analysis and safety. Do not award a list of apparatus without a usable method.

Six-mark language check

A Level 3 response is ordered and quantitative: measure m, V, I, t and $\Delta\theta$; calculate VIt; then calculate c.
It also improves validity with insulation or a heat-loss correction, supports reliability with repeat readings or a graph, and includes a relevant hot-apparatus precaution.