3.4 Specific latent heat and heating graphs

Name: _____ Class: _____ Date: _____ **Total: 26 marks**

KEY WORDS specific latent heat • latent heat

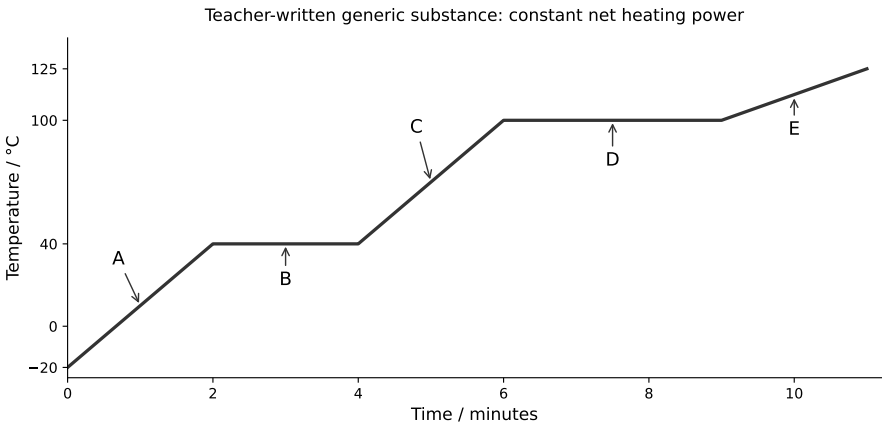
Objective

Use $E = mL$, distinguish fusion from vaporisation, read heating graphs with plateaus, and tell specific latent heat from specific heat capacity. Original questions for spec statement 4.3.2.3.

1 Key knowledge and worked examples

$$E = mL$$

- E energy for the change of state in J; m **mass that changes state** in kg; L **specific latent heat** in J/kg.
- **Specific latent heat**: the energy to change the state of **one kilogram** with **no temperature change**.
- **Fusion** is solid ↔ liquid; **vaporisation** is liquid ↔ gas. For water, vaporisation has a much larger specific latent heat than fusion; use the value for the specified material and change.



Rising = kinetic energy ($mc\Delta\theta$); flat = latent heat (mL).

Graph rules:

- **Rising section**: energy enters the particles' kinetic energy; use $\Delta E = mc\Delta\theta$.
- **Flat section**: a state is changing; use $E = mL$ over the whole plateau.
- At the same constant net heating power, plateau duration is proportional to mL. The drawn generic substance has a longer boiling plateau; this does not establish a universal ratio for all materials.
- Cooling reverses the state-change sequence: pure substances freeze or condense at constant temperature at constant pressure, releasing latent heat. Durations depend on the rate of energy transfer.

The one-mark check the exam loves:

	Temperature	**Equation**
specific heat capacity	changes	$\Delta E = mc\Delta\theta$
specific latent heat	constant	$E = mL$

Worked example. A 30 W heater runs for 11 minutes and boils off 6.6×10^{-3} kg of water already at 100 °C. Find L.

- Energy from power and time (seconds!): $E = Pt = 30 \times 660 = 19\,800$ J.

$$L = \frac{E}{m} = \frac{19\,800}{6.6 \times 10^{-3}} = 3.0 \times 10^{6} \text{ J/kg}$$

- Check: water's vaporisation value is 2.26×10^{6} J/kg; with heater losses not subtracted, an over-estimate is expected – say so if asked to evaluate.

Worked example (mass that changes state). A freezer removes 680 000 J from water at 0 °C; $L_f = 3.34 \times 10^{5}$ J/kg.

$$m = \frac{E}{L} = \frac{680\,000}{3.34 \times 10^{5}} = 2.0 \text{ kg freezes}$$

- Only the water already at 0 °C counts: energy removed while cooling *towards* 0 °C uses $mc\Delta\theta$, not mL.

2 Practice

2.1 Ice at 0 °C has $L_f = 3.34 \times 10^{5}$ J/kg. Calculate the energy to melt 0.030 kg. [2]

2.2 A heater supplies 45 000 J and vaporises 0.020 kg of a liquid already at its boiling point. Calculate L. [2]

2.3 State the difference between specific heat capacity and specific latent heat. [2]

3 Exam-style questions

3.1 A student boils water in an open beaker.

(a) The water's temperature stays at 100 °C while it boils. Explain why, using internal energy. [2]

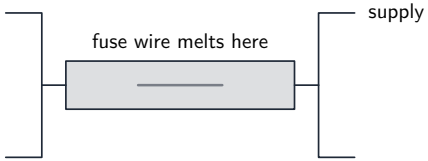
(b) 0.030 kg of water turns to steam; $L_v = 2.26 \times 10^6$ J/kg. Calculate the energy needed for this change of state. [2]

(c) Some water evaporated before reaching 100 °C. Explain how this affects the student's value for the specific latent heat. [2]

3.2 A heater supplies 1.02 J while a fuse wire melts at its melting point. The specific latent heat of fusion of the wire is 60 kJ/kg.

(a) Assuming all supplied energy melts the wire, calculate its mass. [3]

(b) Energy is also transferred to the surroundings while the wire melts. Explain whether the true mass is larger or smaller than your answer. [2]



$E = 1.02$ J at melting point; $L_f = 60$ kJ/kg

3.3 A freezer freezes 1.5 kg of water at 0 °C in 50 minutes. Assume the net rate of energy removal is the same during freezing and subsequent cooling. $L_f = 3.34 \times 10^5$ J/kg.

(a) Calculate the energy the freezer removes from the water. [2]

(b) Calculate the freezer's power output to the water's thermal store. [3]

(c) The ice then cools from 0 °C to −18 °C; ice has $c = 2100$ J/kg °C. Calculate the energy removed in this stage. [2]

(d) Explain why the second stage is quicker than the first. [2]

Solutions

2.1

$$E = mL = 0.030 \times 3.34 \times 10^5 = \mathbf{1.0 \times 10^4}\ \text{J}$$

(substitution 1, answer with unit 1.)

2.2

$$L = \frac{E}{m} = \frac{45\,000}{0.020} = \mathbf{2.25 \times 10^6}\ \text{J/kg}$$

(rearrangement 1, answer 1.)

2.3 Specific heat capacity is the energy to raise the temperature of one kilogram by one degree Celsius – a temperature **change**; specific latent heat is the energy to change the state of one kilogram with **no** temperature change.

3.1 (a) The supplied energy increases the particles' potential energy as they break free of the liquid; their average kinetic energy – and so the temperature – stays constant until all the water has boiled. (b)

$$E = mL_v = 0.030 \times 2.26 \times 10^6 = \mathbf{6.8 \times 10^4}\ \text{J}$$

(c) If water already left by evaporation, less than 0.030 kg actually boiled at 100 °C for the measured energy; with the full 0.030 kg in the calculation, L comes out too **small**.

3.2 (a) Convert: $L = 60$ kJ/kg $= 60\,000$ J/kg (C1).

$$m = \frac{E}{L} = \frac{1.02}{60\,000} = \mathbf{1.7 \times 10^{-5}}\ \text{kg}$$

(rearrangement C1, answer A1.) (b) Some of the 1.02 J input is transferred to the surroundings, so less than 1.02 J melts the wire; with $m = E_{\text{melting}}/L$ and the same L, the true melted mass is **smaller** than the no-loss estimate.

3.3 (a)

$$E = mL_f = 1.5 \times 3.34 \times 10^5 = \mathbf{5.0 \times 10^5}\ \text{J}$$

(b) Convert: 50 min = 3000 s (C1).

$$P = \frac{E}{t} = \frac{5.01 \times 10^5}{3000} = \mathbf{170}\ \text{W (2 s.f.)}$$

(C1, A1.) (c)

$$\Delta E = mc\Delta\theta = 1.5 \times 2100 \times 18 = \mathbf{56\,700}\ \text{J} \approx 5.7 \times 10^4\ \text{J}$$

(C1, A1.) (d) Cooling the ice needs only 5.7×10^4 J against 5.0×10^5 J for freezing – about a ninth of the energy; freezing releases energy as the particle arrangement changes and potential energy decreases; cooling the solid lowers average kinetic energy.