Exercise walk-through

Specific heat capacity and specific latent heat ▪ 14.3

eXercise

You must be able to

- use $Q = mc\Delta T$ and $Q = mL$ (fusion vs vaporisation)
- measure c **electrically** ($Q = VIt$) and by the **method of mixtures**
- read a **heating curve**; explain why $L_{\text{vap}} > L_{\text{fusion}}$

Method — Specific heat capacity

The energy to raise unit mass by one kelvin:

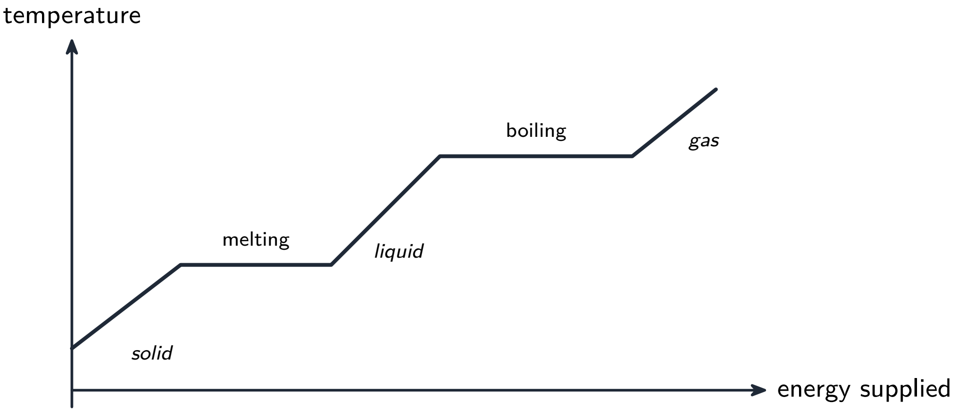
$$c = \frac{Q}{m\Delta T} \iff Q = mc\Delta T \quad (\mathrm{J\ kg^{-1}\ K^{-1}}).$$

Worked example. Heat 0.50 kg of water from 20 to 100 °C ($c = 4200$): $\Delta T = 80$, so $Q = 0.50 \times 4200 \times 80 = 1.68 \times 10^5$ J.

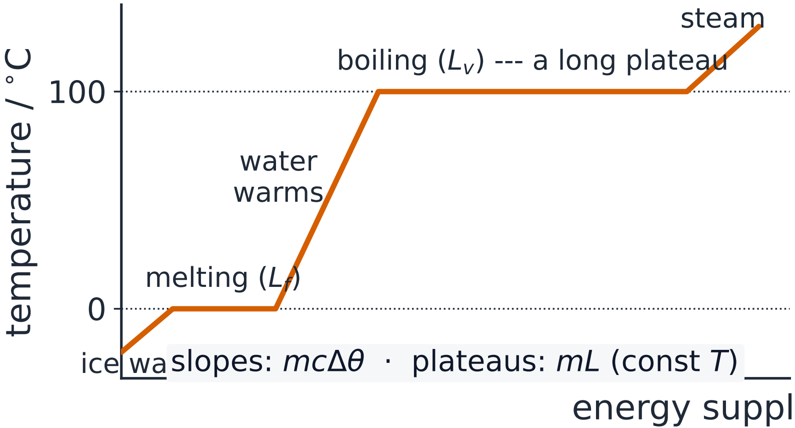
Method — Specific latent heat and the heating curve

Latent heat $Q = mL$ is the energy for a **change of state** at constant temperature — **fusion** (melting) or **vaporisation** (boiling). On a heating curve the **sloped** parts heat one phase ($Q = mc\Delta T$); the **flat plateaus** are changes of state ($Q = mL$): $L_{\text{vap}} > L_{\text{fusion}}$: vaporising must **fully separate** the molecules (and push back the atmosphere), whereas melting only **loosens** the lattice.

Method — Specific latent heat and the heating curve



Method — Specific latent heat and the heating curve



A heating curve through changes of state

Method — Measuring c — electrical method

An electrical heater supplies $Q = VIt = Pt$, which equals $mc\Delta T$.
Worked example. A 50 W heater warms 0.30 kg of a liquid by 8.0 K in 100 s (no losses): $Q = Pt = 50 \times 100 = 5000$ J, so $c = \dfrac{Q}{m\Delta T} = \dfrac{5000}{0.30 \times 8.0} = 2100$ J kg^{-1} K^{-1}.

Method — Method of mixtures

In an **insulated** container, **energy lost by the hot body = energy gained by the cold body** (include any change of state).
Worked example. A 0.50 kg metal block at 90 °C is put into 0.40 kg of water at 15 °C; they settle at 22 °C. Then $m_\mathrm{m} c_\mathrm{m} \Delta T_\mathrm{m} = m_\mathrm{w} c_\mathrm{w} \Delta T_\mathrm{w}$:
$0.50\, c_\mathrm{m}(90 - 22) = 0.40 \times 4200 \times (22 - 15)$, so $c_\mathrm{m} = \dfrac{11760}{0.50 \times 68} = 346$ J kg^{-1} K^{-1}.

Practice 2.1 ▪ 1 mark

Define **specific heat capacity**.

Solution 2.1

Method: Specific heat capacity

Worked steps

The energy needed to raise the temperature of **unit mass** (1 kg) by **one kelvin** **B1**.

Practice 2.2 ▪ 2 marks

Find the energy needed to heat 0.50 kg of water from 20 °C to 100 °C ($c = 4200$ J kg^{-1} K^{-1}).

Solution 2.2

Method: Specific heat capacity

Worked steps

$Q = mc\Delta T = 0.50 \times 4200 \times 80 = 1.68 \times 10^5$ J **M1** **A1**.

Practice 2.3 ▪ 1 mark

Define **specific latent heat**.

Solution 2.3

Method: Specific latent heat and the heating curve

Worked steps

The energy needed to change the state of **unit mass** at **constant temperature** **B1**.

Practice 2.4 ▪ 3 marks

Explain, in terms of the separation of the molecules and the work done pushing back the atmosphere, why the specific latent heat of **vaporisation** of a substance is much greater than its specific latent heat of **fusion**.

Solution 2.4

Method: Specific latent heat and the heating curve

Worked steps

Melting only **loosens** the lattice: the molecules stay about the same distance apart, so only some of the bonds have to be broken B1. Boiling must separate the molecules **completely**, breaking essentially all of the intermolecular bonds B1. On top of that, the vapour occupies a far greater volume, so work is done **pushing back the atmosphere** — energy that melting barely needs B1.

Exam-style 3.1 ▪ 1 mark

On a heating curve, the **flat** sections represent:

A heating a solid

B a change of state

C cooling

D heating a gas

Solution 3.1

Method: Specific latent heat and the heating curve

A heating a solid

B a change of state ✓

C cooling

D heating a gas

Worked steps

B — a change of state.

Exam-style 3.2 ▪ 3 marks

A 60 W heater is used to find the specific heat capacity of a 0.25 kg metal block. In 120 s the temperature rises by 9.6 K. Calculate c (assume no heat loss).

Solution 3.2

Worked steps

$Q = Pt = 60 \times 120 = 7200$ J **M1**; $c = \dfrac{Q}{m\Delta T} = \dfrac{7200}{0.25 \times 9.6}$ **M1** $= 3000$ J kg^{-1} K^{-1} **A1**.

Exam-style 3.3 ▪ 4 marks

A 0.030 kg ice cube at 0 °C is added to 0.25 kg of water at 15 °C in an insulated cup. All the ice melts and the final temperature is 5.0 °C. ($c_{\text{water}} = 4200$ J kg^{-1} K^{-1}.) Calculate the **specific latent heat of fusion** of ice.

Solution 3.3

Method: Specific latent heat and the heating curve

Worked steps

Energy lost by the water $= m_w c\Delta T = 0.25 \times 4200 \times (15 - 5) = 10\,500$ J **M1**; this melts the ice **and** warms the melted ice from 0 to 5 °C: $10\,500 = 0.030L + 0.030 \times 4200 \times 5$ **M1**; $0.030L = 10\,500 - 630 = 9870$ **M1**; $L = 3.3 \times 10^5$ J kg^{-1} **A1**.

Exam-style 3.4 ▪ 2 marks

Explain, in terms of **particles**, why energy is needed to melt a solid even though the temperature does not rise.

Solution 3.4

Method: Specific latent heat and the heating curve

Worked steps

The energy is used to **break the bonds** between particles (increase their potential energy / separate them) **B1**, not to increase their kinetic energy, so the temperature stays constant **B1**.

Exam-style 3.5 ▪ 2 marks

An electric heater of power 2.0 kW is used to warm 0.80 kg of water in an open beaker. The specific heat capacity of water is 4200 J kg^{-1} K^{-1} and its specific latent heat of vaporisation is 2.26×10^{6} J kg^{-1}.

(a) **Define** the **specific heat capacity** of a substance.

(b) The water starts at 18 °C. **Determine** the time taken to raise it to 100 °C, assuming no energy is lost.

(c) The heater is left on for a further 4.0 minutes once the water is boiling. **Determine** the mass of water that boils away.

(d) In practice the measured time in **(b)** is longer than the calculated one. **Suggest** two reasons, and **state** which of your calculated answers, (b) or (c), is affected more by them.

Solution 3.5

Method: Specific heat capacity

Worked steps

(a) The energy required to raise the temperature of **unit mass** of the substance by **one kelvin** (or one degree Celsius) **B1**, without any change of state **B1**.

(b) $E = mc\Delta\theta = 0.80 \times 4200 \times (100 - 18) = 2.75 \times 10^5$ J **M1** **M1**;

$t = \dfrac{E}{P} = \dfrac{2.75 \times 10^5}{2000} = 138$ s, about 2.3 minutes **A1**.

(c) Energy supplied $= Pt = 2000 \times 240 = 4.8 \times 10^5$ J **M1**; $m = \dfrac{E}{L} = \dfrac{4.8 \times 10^5}{2.26 \times 10^6}$ **M1** $= 0.21$ kg **A1**.

(d) Any two of: thermal energy is lost to the surroundings and to the beaker; the

Solution 3.5

beaker itself must be warmed; some water evaporates before boiling; the heater is not 100% efficient **B1** **B1**. Part **(c)** is affected more **B1** — the water is then at its highest temperature, so the temperature difference with the room is greatest and the rate of energy loss is largest, and it lasts longer.