14.3 Specific heat capacity and specific latent heat

Name: __________ Class: __________ Date: __________ **Total: 28 marks**

KEY WORDS specific heat capacity 比热容 • latent heat 潜热 • specific latent heat 比潜热 • fusion 熔化 • vaporisation 汽化

Objective

Build the skills to answer exam questions on **specific heat capacity** and **specific latent heat**.

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 $L_{\text{vap}} > L_{\text{fusion}}$

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

Specific heat capacity

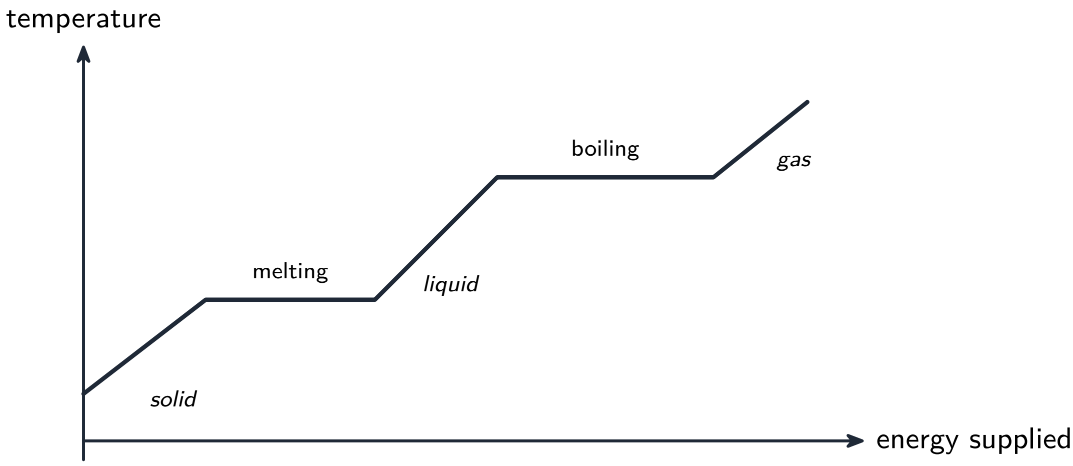
The energy to raise unit mass by one kelvin:

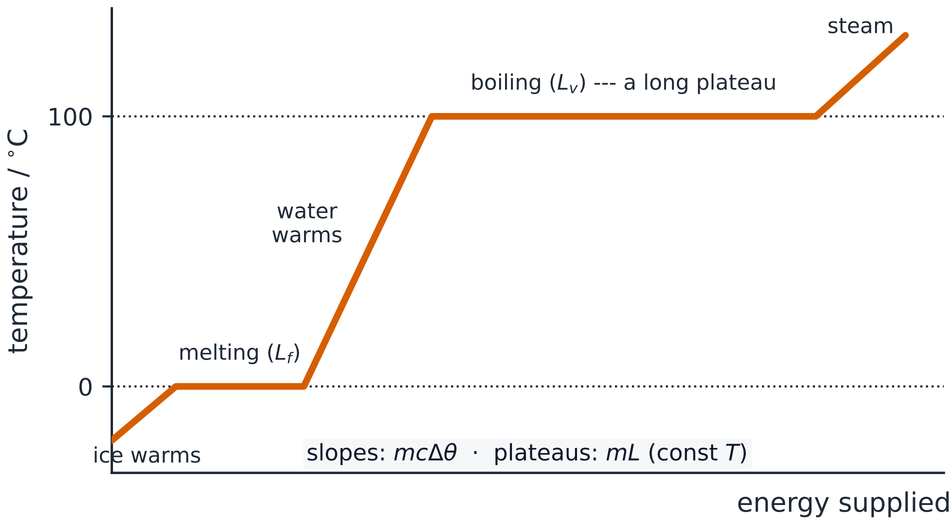
$$c = \frac{Q}{m\Delta T} \iff Q = mc\Delta T \quad (\text{J kg}^{-1}\,\text{K}^{-1}).$$

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.

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 ($Q = mL$):





A heating curve through changes of state

$L_{\text{vap}} > L_{\text{fusion}}$: vaporising must **fully separate** the molecules (and push back the atmosphere), whereas melting only **loosens** the lattice.

■ 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 $c = \dfrac{Q}{m\Delta T} = \dfrac{5000}{0.30 \times 8.0} = 2100\ \text{J kg}^{-1}\,\text{K}^{-1}$.

■ 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 $m_\text{m}c_\text{m}\Delta T_\text{m} = m_\text{w}c_\text{w}\Delta T_\text{w}$: $0.50\,c_\text{m}(90 - 22) =$

$0.40 \times 4200 \times (22 - 15)$, so $c_{\mathrm{m}} = \dfrac{11760}{0.50 \times 68} = 346\ \mathrm{J\ kg^{-1}\ K^{-1}}$.

2 Practice

Now apply the methods above.

2.1 Define **specific heat capacity**. [1]

2.2 Find the energy needed to heat 0.50 kg of water from 20 °C to 100 °C ($c = 4200\ \mathrm{J\ kg^{-1}\ K^{-1}}$). [2]

2.3 Define **specific latent heat**. [1]

2.4 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**. [3]

3 Exam-style questions

3.1 On a heating curve, the **flat** sections represent: [1]

- **A** heating a solid
- **B** a change of state
- **C** cooling
- **D** heating a gas

3.2 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). [3]

3.3 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. [4]

3.4 Explain, in terms of **particles**, why energy is needed to melt a solid even though the temperature does not rise. [2]

3.5 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. [2]

(b) The water starts at 18 °C. **Determine** the time taken to raise it to 100 °C, assuming no energy is lost. [3]

(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. [3]

(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. [3]

Solutions

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

2.2 $Q = mc\Delta T = 0.50 \times 4200 \times 80 = 1.68 \times 10^5$ J.

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

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

3.1 **B** — a change of state.

3.2 $Q = Pt = 60 \times 120 = 7200$ J; $c = \dfrac{Q}{m\Delta T} = \dfrac{7200}{0.25 \times 9.6} = 3000$ J kg^{-1} K^{-1}.

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

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

3.5 (a) The energy required to raise the temperature of **unit mass** of the substance by **one kelvin** (or one degree Celsius), without any change of state.
(b) $E = mc\Delta\theta = 0.80 \times 4200 \times (100 - 18) = 2.75 \times 10^5$ J; $t = \dfrac{E}{P} = \dfrac{2.75 \times 10^5}{2000} = 138$ s, about 2.3 minutes.
(c) Energy supplied $= Pt = 2000 \times 240 = 4.8 \times 10^5$ J; $m = \dfrac{E}{L} = \dfrac{4.8 \times 10^5}{2.26 \times 10^6} = 0.21$ kg.
(d) Any two of: thermal energy is lost to the surroundings and to the beaker; the beaker itself must be warmed; some water evaporates before boiling; the heater is not 100% efficient. Part **(c)** is affected more — 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.