

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 融化 • 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

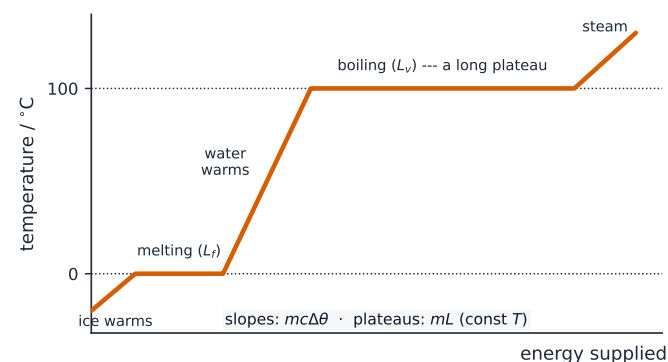
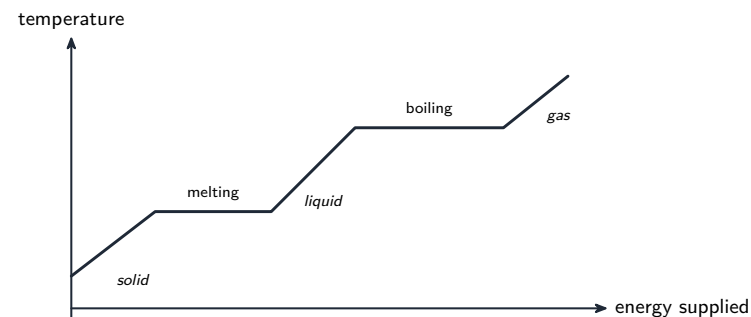
The energy to raise unit mass by one kelvin:

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

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

■ 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): $Q = Pt = 50 \times 100 = 5000 \text{ J}$, so $c = \frac{Q}{m\Delta T} = \frac{5000}{0.30 \times 8.0} = 2100 \text{ J kg}^{-1} \text{K}^{-1}$.

■ 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 $m_m c_m \Delta T_m = m_w c_w \Delta T_w$: $0.50 c_m (90 - 22) =$

$$0.40 \times 4200 \times (22 - 15), \text{ so } c_m = \frac{11760}{0.50 \times 68} = 346 \text{ J kg}^{-1} \text{ K}^{-1}.$$

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 ($c = 4200 \text{ J kg}^{-1} \text{ K}^{-1}$). [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. ($c_{\text{water}} = 4200 \text{ J kg}^{-1} \text{ K}^{-1}$.) 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 $4200 \text{ J kg}^{-1} \text{ K}^{-1}$ and its specific latent heat of vaporisation is $2.26 \times 10^6 \text{ J kg}^{-1}$.

(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

Each answer shows the steps, then the **result**.

2.1

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

2.2

- $Q = mc\Delta T$

$$Q = (0.50 \text{ kg})(4200 \text{ J kg}^{-1} \text{ K}^{-1})(80 \text{ K}) = \mathbf{1.68 \times 10^5 \text{ J}}$$

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 inter-molecular bonds
- the vapour occupies a far greater volume, so work is done **pushing back the atmosphere** — energy that melting barely needs

3.1 B

- latent heat is the energy for a **change of state**
- A** is specific heat capacity; **C** is a temperature rise; **D** is power

3.2

- $Q = Pt$

$$Q = (60 \text{ W})(120 \text{ s}) = 7200 \text{ J}$$

- $c = Q/(m\Delta T)$

$$c = \frac{7200 \text{ J}}{(0.25 \text{ kg})(9.6 \text{ K})} = \mathbf{3000 \text{ J kg}^{-1} \text{ K}^{-1}}$$

3.3

- energy lost by the water = $m_{\text{w}}c\Delta T$

$$Q = (0.25 \text{ kg})(4200 \text{ J kg}^{-1} \text{ K}^{-1})(15 - 5) \text{ K} = 10\,500 \text{ J}$$

- this melts the ice **and** warms the melted ice from 0 to 5°C

$$10\,500 \text{ J} = (0.030 \text{ kg})L + (0.030 \text{ kg})(4200 \text{ J kg}^{-1} \text{ K}^{-1})(5 \text{ K})$$

$$(0.030 \text{ kg})L = 10\,500 \text{ J} - 630 \text{ J} = 9870 \text{ J}$$

$$L = \frac{9870 \text{ J}}{0.030 \text{ kg}} = \mathbf{3.3 \times 10^5 \text{ J kg}^{-1}}$$

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) $E = mc\Delta\theta$

$$E = (0.80 \text{ kg})(4200 \text{ J kg}^{-1} \text{ K}^{-1})(100 - 18) \text{ K} = 2.75 \times 10^5 \text{ J}$$

$$t = \frac{E}{P} = \frac{2.75 \times 10^5 \text{ J}}{2000 \text{ W}} = \mathbf{138 \text{ s}}$$

(about 2.3 minutes)

(c) energy supplied = Pt

$$E = (2000 \text{ W})(240 \text{ s}) = 4.8 \times 10^5 \text{ J}$$

$$m = \frac{E}{L} = \frac{4.8 \times 10^5 \text{ J}}{2.26 \times 10^6 \text{ J kg}^{-1}} = \mathbf{0.21 \text{ kg}}$$

(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