

Exercise walk-through

14.3

Specific heat capacity and specific latent heat

A-Level Physics

Specific latent heat

Changing state takes energy at **constant temperature** – the **latent heat** :

$$L = \frac{Q}{m} \iff Q = mL, \quad [L] = \text{J kg}^{-1}$$

■ **specific latent heat of fusion**

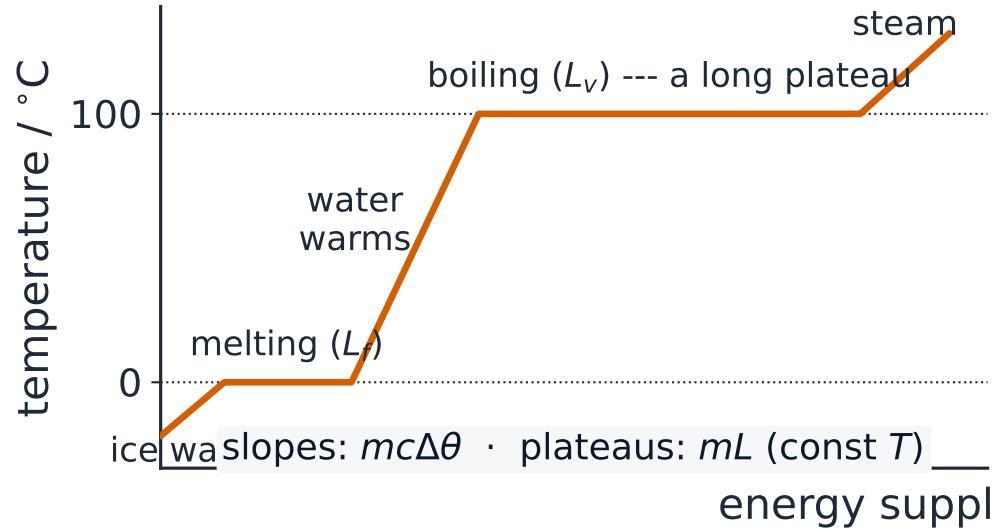
L_f : solid $\leftrightarrow$ liquid

■ **specific latent heat of vaporisation**

L_v : liquid $\leftrightarrow$ gas

Sloped = warming ($mc\Delta T$); **flat** = changing state (mL). Never mix the two.

Specific latent heat, in detail



Changing state takes energy at **constant temperature** – the **latent heat** :

$$L = \frac{Q}{m} \iff Q = mL, \quad [L] = \text{J kg}^{-1}$$

Why $L_v > L_f$

Bonds

melting breaks *some* bonds
– the particles stay close.
Boiling breaks *all* of them.

Work on the atmosphere

vapour has $\sim 10^3 \times$ the volume, so
it pushes the air back as it forms.

For water $L_v \approx 2.26 \times 10^6$ against $L_f \approx 3.34 \times 10^5 \text{ J kg}^{-1}$ – about **7 times** larger.

Worked example – boiling with a heater

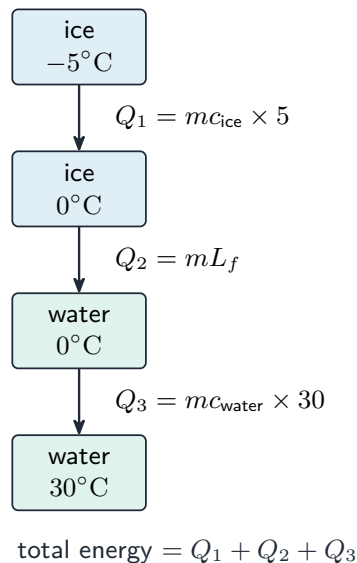
A 2.0 kW heater boils water already at 100 °C. How long to turn 0.10 kg into steam? ($L_v = 2.26 \times 10^6 \text{ J kg}^{-1}$)

$$Q = mL_v = 0.10 \times 2.26 \times 10^6 = 2.26 \times 10^5 \text{ J}$$

$$t = \frac{Q}{P} = \frac{2.26 \times 10^5}{2000} \approx 110 \text{ s}$$

Already **at** 100 °C, so there is **no** $mc\Delta T$ term – all the energy goes into the phase change.

Multi-step problems



Ice at $-5^{\circ}\text{C} \rightarrow$ water at 30°C is **three** stages:

- $Q_1 = mc_{\text{ice}} \times 5$ – warm the solid
- $Q_2 = mL_f$ – melt at 0°C
- $Q_3 = mc_{\text{water}} \times 30$ – warm the liquid

Add $Q_1 + Q_2 + Q_3$. Each phase change is a **separate** mL step at constant temperature – and the c of ice is not the c of water.

Exercises 2.1-2.3

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]

Exercises 2.1·2.3

2.1 Define **specific heat capacity**.

[1]

2.1

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

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]

2.2

- $Q = mc\Delta T$

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

2.3 Define **specific latent heat**.

[1]

2.3

- the energy needed to change the state of **unit mass** at **constant temperature**

Exercise 2.4

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]

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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

Exercise 3.1

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

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B a change of state

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D heating a gas

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

Exercise 3.2

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]

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3.2

- $Q = Pt$

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

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

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

Exercise 3.3

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]

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3.3

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

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

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

$$Q = mL + mc\Delta\theta : \quad 10\,500 \text{ J} = (0.030 \text{ kg})L + (0.030 \text{ kg})(4200 \text{ J kg}^{-1} \text{ K}^{-1})(5 \text{ K})$$

$$mL = Q - mc\Delta\theta = 10\,500 \text{ J} - 630 \text{ J} = 9870 \text{ J}$$

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

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- 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

Exercise 3.5 (a)

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]

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(a) **Define** the **specific heat capacity** of a substance. [2]

(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

Exercise 3.5 (b)

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 $2.26 \times 10^6 \text{ J kg}^{-1}$.

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

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

(b) $E = mc\Delta\theta$

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

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

(about 2.3 minutes)

Exercise 3.5 (c)

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 $2.26 \times 10^6 \text{ J kg}^{-1}$.

(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]

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(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]

(c) energy supplied = Pt

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

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

Exercise 3.5 (d)

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 $2.26 \times 10^6 \text{ J kg}^{-1}$.

(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]

Exercise 3.5 (d)

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(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]

(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