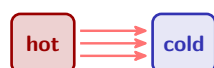


Temperature and Thermal Energy

A2 Physics ■ Topic 14

A-Level Physics



Temperature and Thermal Energy

What we will cover

- 1 Thermal equilibrium
- 2 Measuring temperature
- 3 The kelvin & absolute zero
- 4 Specific heat capacity
- 5 Specific latent heat
- 6 Recap

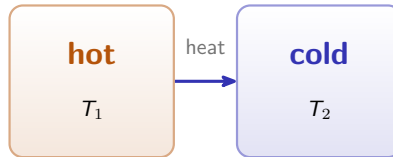


1 Thermal equilibrium

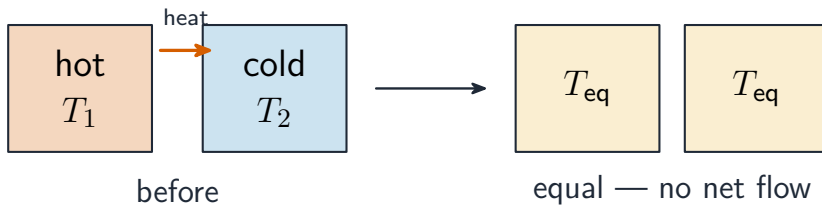
Thermal equilibrium

Two bodies in contact exchange energy until they reach the same **temperature** 温度 – **thermal equilibrium** 热平衡. Heat flows from the hotter to the colder. Once they match, the net flow is zero.

A thermometer works because it comes to equilibrium with whatever it touches – so it must be small enough not to change that temperature.



What equilibrium means

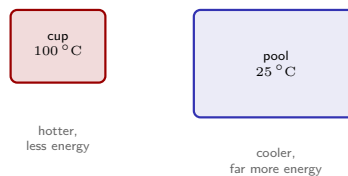


Net energy flows from hot to cold until the two are at the **same temperature** — that is what a thermometer waits for before it reads.

Temperature is not energy

Temperature fixes the **direction** of heat flow. It does **not** say how much **thermal energy** 热能 a body holds.

A cup of water at 100°C holds far **less** energy than a pool at 25°C – but metal dropped in the cup **gains** energy, and in the pool **loses** it.



2 Measuring temperature

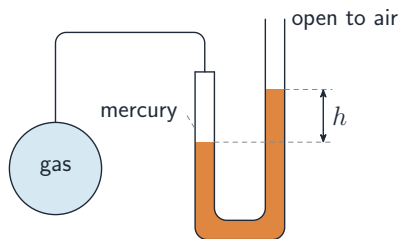
Temperature and Thermal Energy
└ Measuring temperature

Making a thermometer

Any property that changes **repeatably** with temperature will do:

- liquid **density** 密度 – liquid-in-glass
- gas volume (or pressure) – gas thermometer
- **resistance** 电阻 of a metal
- **thermocouple** 热电偶 e.m.f.

Two thermometers agree **only** at the **calibration points** – in between, each follows its own property's curve.



Temperature and Thermal Energy
└ Measuring temperature

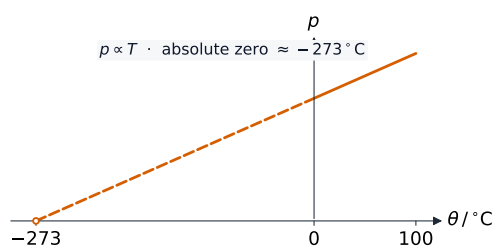
A thermometric property



Any property that varies reproducibly with temperature will do — here the length of a liquid column.

3 The kelvin

Absolute zero



The **thermodynamic scale** 热力学温度 leans on no single substance – only on the laws of thermodynamics. Its unit is the **kelvin** 开尔文. At **absolute zero** 绝对零度 (0 K) a system holds its least possible **internal energy** 内能.

Cool *any* gas and extrapolate its p - θ line to zero pressure: every gas points at the **same** -273°C .

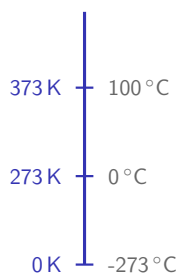
Kelvin and Celsius

$$T/\text{K} = \theta/^\circ\text{C} + 273.15$$

- $0^\circ\text{C} = 273.15\text{ K}$; $100^\circ\text{C} = 373.15\text{ K}$
- a kelvin and a degree Celsius are the **same size**
- so a **difference** of 1 K *is* 1°C

Gas laws and energy equations need **kelvin**. Using $^\circ\text{C}$ there is simply wrong – but for a ΔT either unit works.

same size steps



4 Specific heat capacity

Temperature and Thermal Energy

└ Specific heat capacity

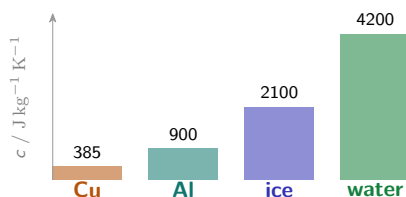
Specific heat capacity

Specific heat capacity 比热容 is the energy to raise **unit mass** by **one kelvin**:

$$c = \frac{Q}{m\Delta T} \iff Q = mc\Delta T$$

$$[c] = \text{J kg}^{-1} \text{K}^{-1}.$$

Water's $c \approx 4200$ is far above any solid here – which is why it is such a good coolant, and why the oceans steady the climate.



Temperature and Thermal Energy

└ Specific heat capacity

Worked example – heating water

Heat 0.50 kg of water from 20 to 100 °C.
($c = 4200 \text{ J kg}^{-1} \text{K}^{-1}$)

A **difference** is the same in K and °C, so $\Delta T = 80$:

$$Q = mc\Delta T = 0.50 \times 4200 \times 80 \\ = 1.68 \times 10^5 \text{ J} = 168 \text{ kJ}$$

Do **not** convert 20 and 100 to kelvin first – the 273.15 cancels in the subtraction. Convert only where an **absolute** T is needed.

Worked example – mixing

Mix 0.20 kg of water at 80 °C with 0.30 kg at 20 °C, no heat lost. Find the final temperature.

heat lost by the hot = heat gained by the cold
(c cancels):

$$0.20 (80 - T_{\text{eq}}) = 0.30 (T_{\text{eq}} - 20)$$

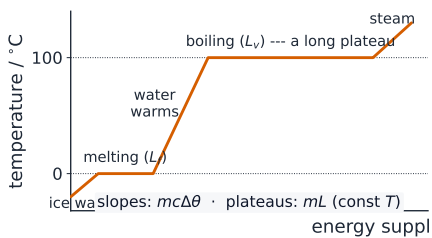
$$\Rightarrow T_{\text{eq}} = 44^\circ\text{C}$$

Write both sides as a **positive** energy: (hot – T_{eq}) and (T_{eq} – cold). The answer sits nearer the **bigger** mass – here 44, not 50.

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Specific latent heat

Specific latent heat



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

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

- **fusion** 融化 L_f : solid $\leftrightarrow$ liquid
- **vaporisation** 汽化 L_v : liquid $\leftrightarrow$ gas

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

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.

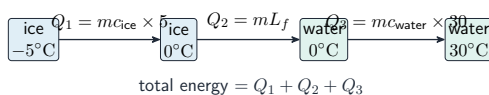
Worked example – boiling with a heater

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:

- $Q_1 = m c_{\text{ice}} \times 5$ – warm the solid
- $Q_2 = m L_f$ – melt at 0°C
- $Q_3 = m c_{\text{water}} \times 30$ – 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.

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Recap

Temperature and Thermal Energy

└ Recap

Topic 14 – key takeaways

1 Equilibrium

equal temperature = no *net* heat flow

2 Kelvin

$T/\text{K} = \theta/^{\circ}\text{C} + 273.15$; use K in gas laws

3 Heating

$Q = mc\Delta T$ – temperature changes

4 Changing state

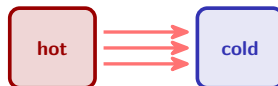
$Q = mL$ – temperature does *not* change

Temperature and Thermal Energy

└ Recap

Check yourself

- 1 Convert 27°C to kelvin.
- 2 Which equation for melting ice at 0°C ?
- 3 Why is a flat part of a heating curve flat?
- 4 Does the hotter body always hold more energy?



Answers 1. 300.15 K 2. $Q = mL_f$ 3. energy breaks bonds, not raising T 4. no