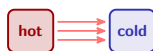


Temperature and Thermal Energy

A2 Physics ■ Topic 14

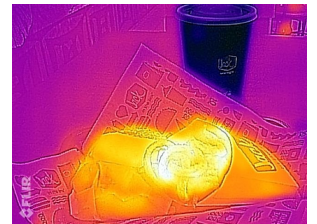
A-Level Physics



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

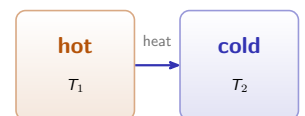
Temperature and Thermal Energy

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.

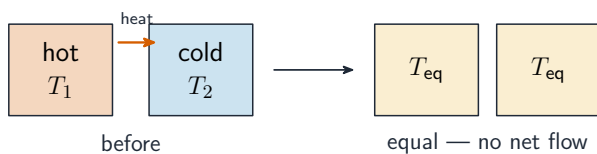
A thermometer works because it comes to equilibrium with whatever it touches – so it must be small enough not to change that temperature.



Temperature and Thermal Energy

Thermal equilibrium

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.

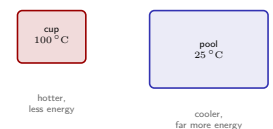
Temperature and Thermal Energy

Thermal equilibrium

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.



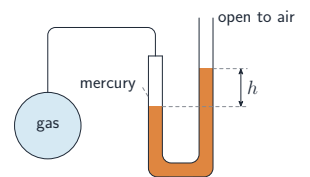
2 Measuring temperature

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.



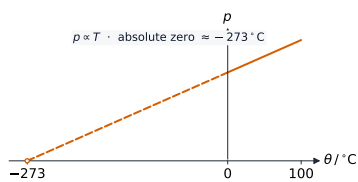
A thermometric property



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.

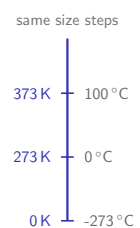
Cool *any* gas and extrapolate its p - θ line to zero pressure: every gas points at the **same** -273°C .

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.



4 Specific heat capacity

Temperature and Thermal Energy
Specific heat capacity

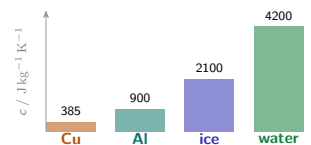
Specific heat capacity

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.

Temperature and Thermal Energy
Specific heat capacity

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):

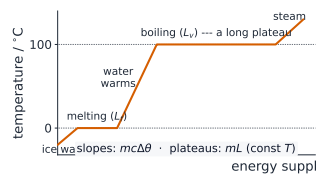
$$0.20 (80 - T_{\text{eq}}) = 0.30 (T_{\text{eq}} - 20) \\ \Rightarrow T_{\text{eq}} = 44 \text{ °C}$$

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.

5 Specific latent heat

Temperature and Thermal Energy
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** 熔化 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

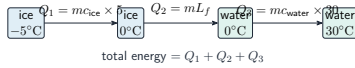
A 2.0 kW heater boils water already at 100 °C. How long to turn 0.10 kg into steam? ($L_v = 2.26 \times 10^6 \text{ J kg}^{-1}$)

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

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

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:

- $Q_1 = mc_{\text{ice}} \times 5$ – 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.

6 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

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