

Heating, melting and boiling: energy calculations

Physics grades 9-10 (GCSE · IGCSE · O Level · Class 9-10) · Lesson

Quick answer: Specific heat capacity is the energy needed to warm 1 kg of a material by 1 °C, and energy transferred equals $m \times c \times \Delta\theta$. Specific latent heat is the energy needed to change the state of 1 kg without changing its temperature, and the energy equals $m \times L$. Heating curves combine both.

Level: Physics grades 9-10 (GCSE · IGCSE · O Level · Class 9-10) · **Curriculum:** GCSE P3, IGCSE 2.2

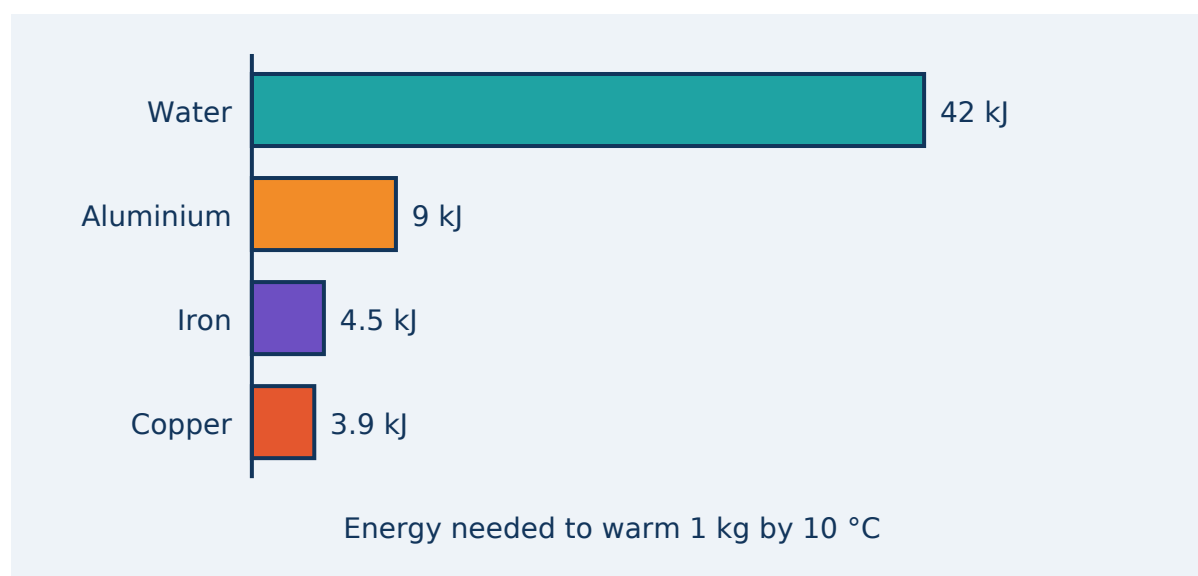
What is specific heat capacity?

Put a pan of water and a steel spoon on the same hot plate and the spoon is too hot to touch long before the water is even warm. The two objects receive energy at a similar rate, yet their temperatures climb at very different speeds. The reason is a property called specific heat capacity.

Definition

The **specific heat capacity** c of a material is the energy needed to raise the temperature of 1 kg of it by 1 °C. Its unit is J/(kg °C).

Water has a very large value, 4200 J/(kg °C), so it takes a lot of energy to warm and gives out a lot when it cools. Metals have small values and heat up quickly.



Water needs far more energy than metals for the same temperature rise.

How do you calculate the energy needed to change temperature?

Formula

$$\Delta E = m \times c \times \Delta\theta$$

ΔE = energy transferred in joules (J) · m = mass in kilograms (kg) · c = specific heat capacity in J/(kg °C) · $\Delta\theta$ = temperature change in °C (final minus initial).

Always convert grams to kilograms first. The temperature *change* is the same in °C and in K, so you can subtract the two readings directly.

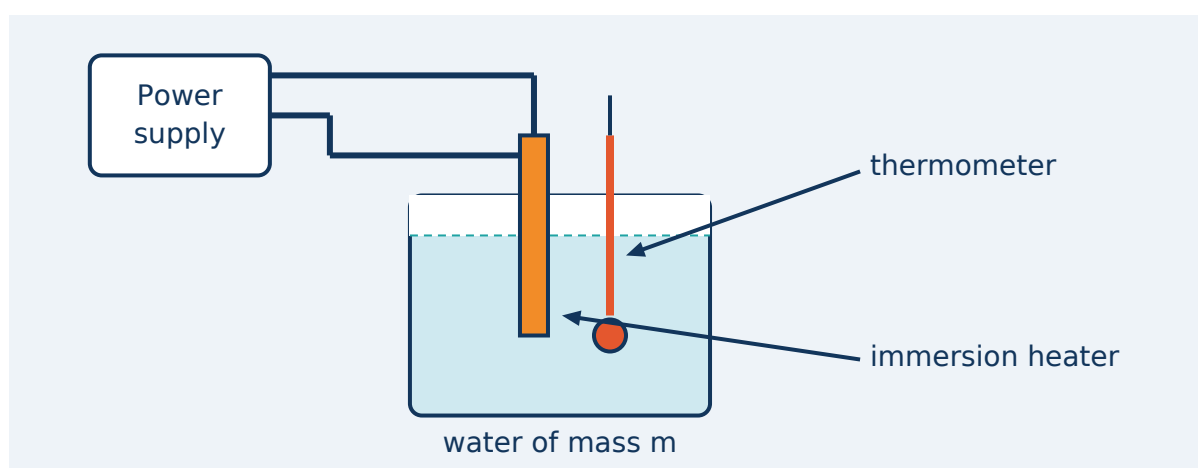
Worked example 1

Aarav in Pune warms 1.5 kg of water from 22 °C to 78 °C for his bath.

$$\Delta\theta = 78 - 22 = 56 \text{ °C}$$

$$\Delta E = 1.5 \times 4200 \times 56 = 352\,800 \text{ J}$$

Answer: **$3.5 \times 10^5 \text{ J}$** (2 s.f.).



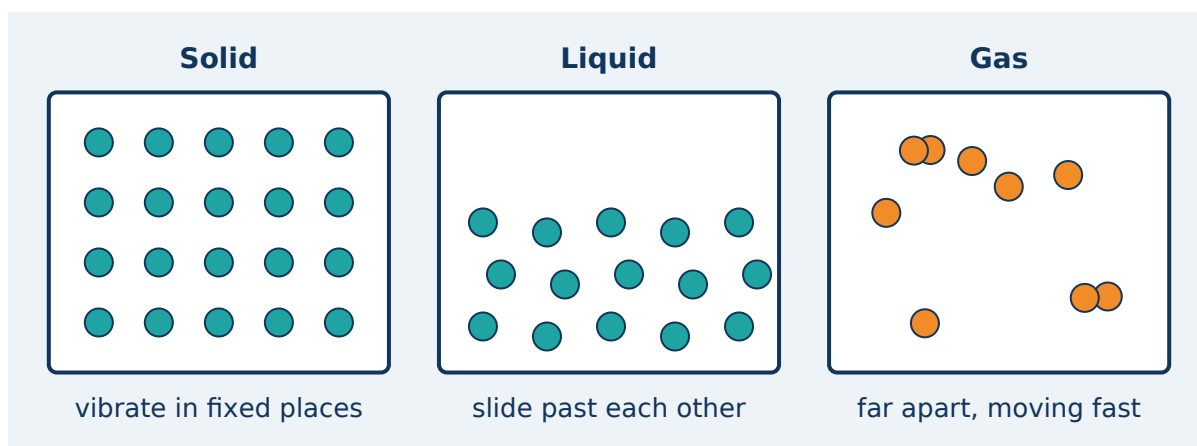
Heating water electrically: the energy supplied equals power $\times$ time.

How do you measure it in a school lab?

An electric heater supplies a known amount of energy: $E = P \times t$, where P is power in watts and t is time in seconds. If the heater is 50 W and runs for 120 s, it supplies 6000 J. Measuring the temperature rise of a known mass then gives c . Some energy always escapes to the air, so the measured value is a little too large unless the block is well insulated.

What is latent heat?

While a solid melts or a liquid boils, energy keeps flowing in but the temperature does not change. The energy is used to break the bonds between particles, not to make them move faster.



Latent heat changes the way particles are arranged, not how fast they move on average.

Definition

The **specific latent heat** L is the energy needed to change the state of 1 kg of a substance without changing its temperature. Unit: J/kg.

Formula

$$E = m \times L$$

E = energy in J · m = mass changing state in kg · L = specific latent heat in J/kg. Use L_f for melting (fusion) and L_v for boiling (vaporisation).

Substance	Specific heat capacity c (J/(kg °C))	Latent heat of water
Water	4200	Melting: 3.34×10^5 J/kg
Ice	2100	Boiling: 2.26×10^6 J/kg
Steam	2000	(boiling is about 7 times melting)
Aluminium	900	—
Iron	450	—
Copper	390	—

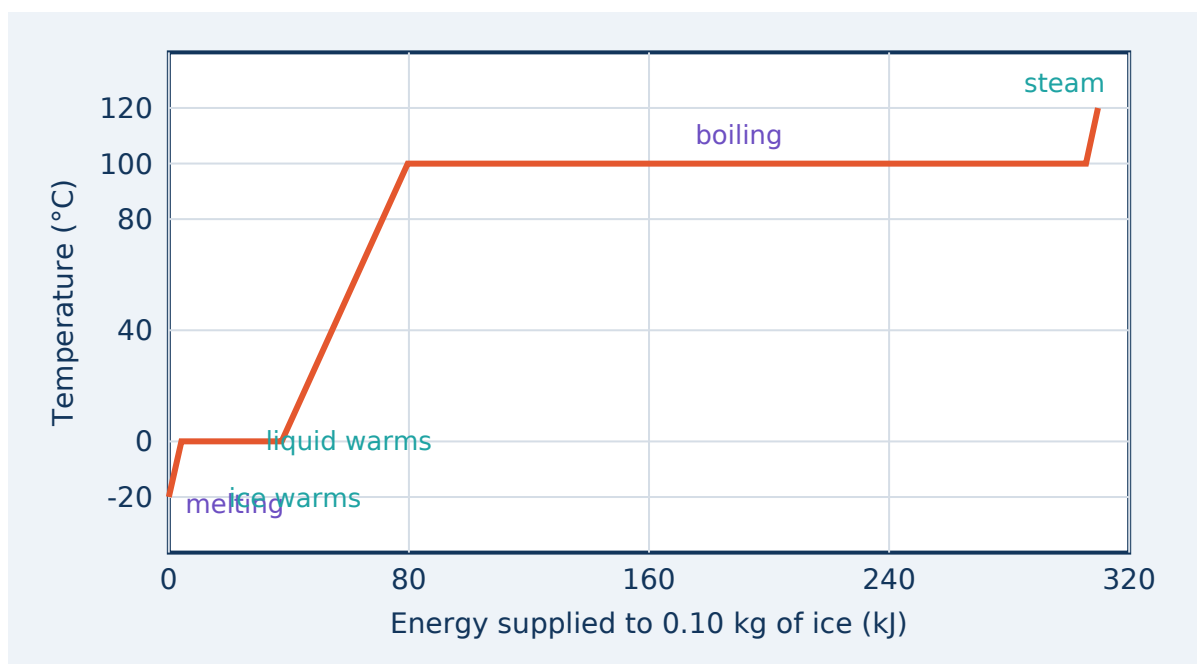
Worked example 2

Chiamaka in Lagos melts 0.45 kg of ice at 0 °C in a cool box test.

$$E = m L_f = 0.45 \times 334\,000 = 150\,300 \text{ J}$$

Answer: **1.5×10^5 J**. The temperature stays at 0 °C until all the ice has melted.

How do you read a heating curve?



Heating curve for 0.10 kg of water: the long flat part is boiling, the short one is melting.

Sloping parts show the temperature rising while a single state is heated; use $m c \Delta\theta$. Flat parts show a change of state; use $m L$. For 0.10 kg of water the boiling step needs 226 kJ, almost seven times the 33.4 kJ for melting, because boiling must pull the particles completely apart.

Common mistake

Do not use $m c \Delta\theta$ during a flat part of the graph. The temperature change is zero there, but energy is still being transferred. Use $m L$ instead.

Lina's tip

Ask yourself one question first: is the temperature changing, or is the state changing? Temperature changing means $m c \Delta\theta$. State changing means $m L$. Add the steps for a full journey.

Key points to remember

- $\Delta E = m c \Delta\theta$, with c in $\text{J}/(\text{kg } ^\circ\text{C})$, m in kg and $\Delta\theta$ in $^\circ\text{C}$
- $E = m L$, with L in J/kg ; the temperature stays constant during a change of state
- Water: $c = 4200 \text{ J}/(\text{kg } ^\circ\text{C})$, $L_{\text{melting}} = 3.34 \times 10^5 \text{ J}/\text{kg}$, $L_{\text{boiling}} = 2.26 \times 10^6 \text{ J}/\text{kg}$
- Electrical heating: $E = P \times t$ (watts $\times$ seconds = joules)
- Flat sections of a heating curve are changes of state

Heating, melting and boiling: energy calculations: frequently asked questions

What is the unit of specific heat capacity?

The unit is joules per kilogram per degree Celsius, $\text{J}/(\text{kg } ^\circ\text{C})$. Because a change of $1 ^\circ\text{C}$ equals a

change of 1 K, J/(kg K) means the same thing.

Why does water have a high specific heat capacity?

Water needs 4200 J to warm each kilogram by 1 °C, because its molecules store a lot of energy in their bonds and motion. This is why water is a good coolant and why coastal areas have mild climates.

Why does temperature stay constant when ice melts?

The energy supplied breaks the bonds holding the particles in a rigid pattern. It increases the potential energy of the particles, not their average kinetic energy, so the temperature does not rise.

What is the difference between specific heat capacity and latent heat?

Specific heat capacity concerns a temperature change within one state. Latent heat concerns a change of state at constant temperature. They use different formulae: $m c \Delta\theta$ and $m L$.

Do I convert °C to kelvin in these calculations?

No. Only the temperature difference is used, and a difference of 1 °C equals a difference of 1 K. Convert grams to kilograms, though.