A2 Level Physics

Chapter 9 - Thermodynamics

9.3.1 Thermal Properties of Materials

Notes

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Specific Heat Capacity

When you heat a material, the molecules gain kinetic energy and begin to move faster. The material heats up as a result.

Different objects/materials require different amounts of energy to change the temperature. The temperature rise (or fall) $(\Delta\theta)$ of an object depends on:

1) **The mass (m) of the object:**

The larger the mass of the object, the smaller the temperature rise (or fall) for the same heat supplied to (or extracted from) the object.

$$\boldsymbol{\Delta\theta \propto \frac{1}{m}}$$

2) **The amount of energy (E) supplied to (or extracted from) the object:**

The temperature rise (or fall) for a given mass is proportional to the amount of heat supplied to (or extracted from) the object.

$$\boldsymbol{\Delta\theta \propto E}$$

3) **The material or substances used to create the object:**

With the same amount of heat supplied to (or taken from) an object, objects of the same mass but different materials experience a different temperature rise (or fall). This fact is taken into consideration by a quantity known as the object's Heat Capacity.

The heat capacity, C, is the heat supplied (or taken from) an object to raise (or lower) its temperature by 1K (or 1°C) .

So the greater the heat capacity of the object, the smaller the temperature rise (or fall) for the same amount of heat supplied to (or extracted from) it.

Heat capacity is only relevant to a particular object. Specific heat capacity (c) is a much more useful quantity and is a property of a material.

Specific Heat Capacity

The specific heat capacity (c) of a substance is the amount of energy required to increase the temperature of 1kg of the substance by 1K without a change of state.

The unit of specific heat capacity (c) is:

$$\boldsymbol{J\ kg^{-1}\ K\ or\ J\ kg^{-1}\ ^{\circ}\mathrm{C}^{-1}}$$

The amount of Energy (E) that must be supplied to a mass (m) of a substance with a specific heat capacity (c) in order to produce a temperature rise $(\Delta\theta)$ is calculated using the formula:

$$\boldsymbol{E = mc\Delta\theta}$$

Where:

- E = energy supplied measured in J,
- m = mass of the substance measured in kg,
- c = specific heat capacity measured in $J\ kg^{-1}\ K^{-1}$,
- $\Delta\theta$ = the change in temperature measured in $\mathrm{kelvins}, K$.

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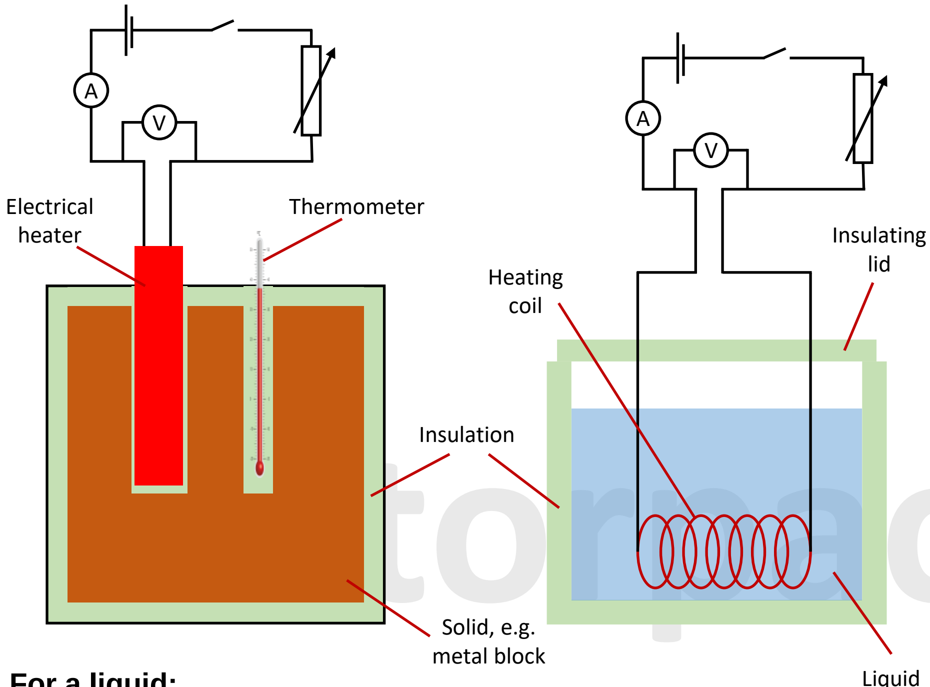
Measurement of Specific Heat Capacity using electrical methods



For a liquid:

- Put the liquid in a vessel with a thermometer and an electric heater.
- Connect a voltmeter across the electric heater and an ammeter in series between the supply and the heater.

For a solid:

- Two holes should be drilled into the metal block.
- In the holes, place an electric heater and a temperature sensor.
- Connect a voltmeter across the electric heater and an ammeter in series between the supply and the heater.

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Measurement of Specific Heat Capacity using electrical methods

Measurements:

- Measure the mass of the liquid/solid
- Current (I), voltage (V), and time (t) should all be measured. The variable resistor can be used to change the current and voltage to achieve the desired current and voltage values.
- Measure the initial temperature (θ_i) of the liquid/solid.
- Heat the liquid/solid for a set amount of time (say 5 minutes) and record the final temperature (θ_f).

Use the specific heat capacity formula:

$$c = \frac{IVt}{m\Delta\theta}$$

Energy supplied to the heater is: $E = IVt$

Where $\Delta\theta = \theta_f - \theta_i$

Uncertainties:

- Heat losses. Insulation is used to prevent this.
- False temperature reading for liquid. The problem is solved by stirring the liquid.
- The temperature continues to climb after the heater is turned off. Therefore take the highest reading.

Reduce error and improve accuracy by allowing the liquid and solid to cool to room temperature before repeating the experiment with a lower voltage and current (controlled with the resistor variable) and repeating the steps.

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Latent Heat

Energy is required to melt a solid or boil or evaporate a liquid in order to break the bonds that hold the particles together. Latent heat is the energy required for this.

The heat energy that a body absorbs during melting or evaporation and gives off during solidification (freezing) or condensation is known as latent heat. It's named latent (which means "hidden") because it causes a state change but not a temperature change.

The greater the mass of the substance, the more energy it takes to change its state. As a result, the specific latent heat is defined per kg:

The specific latent heat (L) of fusion or vaporisation is the amount of thermal energy required to be gained or lost to change the state of 1kg of a substance.

Which gives:

$$E = mL$$

Where:

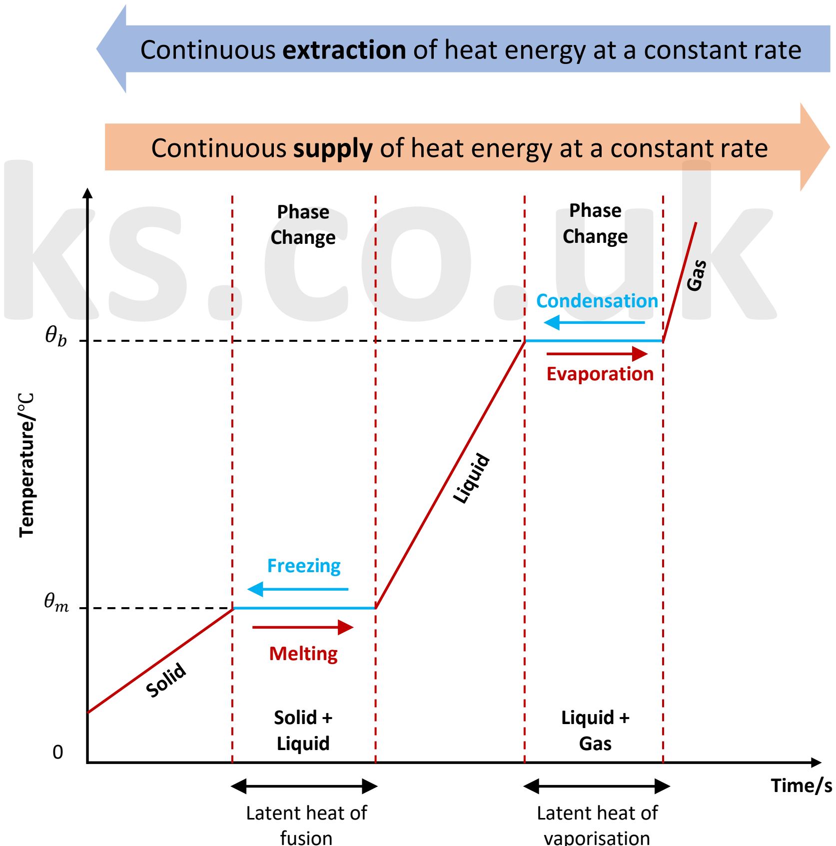
- E = Energy measured in J,
- m = mass of the substance measured in kg,
- L = specific latent heat measured in $J\ kg^{-1}$.

Latent Heat

The diagram below shows what happens when heat energy is continually supplied to a solid or continuously extracted from a gas.

Diagram read from left to right => Shows events when heat energy is continuously applied to a solid.

Diagram read from right to left => Shows the reverse where heat energy is being extracted from a gas.



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Latent Heat

Starting on the left, with a solid that is well below the melting point (θ_m), we can see how the heat applied causes the solid's temperature to rise until it approaches the melting point.

Continued heating does not result in any further temperature rise until the solid has completely melted.

The heat supplied (or extracted) to cause the phase change from solid to liquid (or liquid to solid) without a change of temperature, is called the latent heat of fusion.

When all of the solid has melted, the temperature of the resulting liquid rises until it reaches boiling point (θ_b), at which point vaporisation happens across the liquid's volume (and not just at the surface).

Continued heating will not result in any further temperature rise until all of the liquid has vaporised.

The heat supplied (or extracted) to cause the phase change from liquid to vapour (or vapour to liquid) without a change of temperature, is called the latent heat of vaporisation.

Once all of the liquid has vaporised, the temperature will rise again as the gas or vapour is heated.

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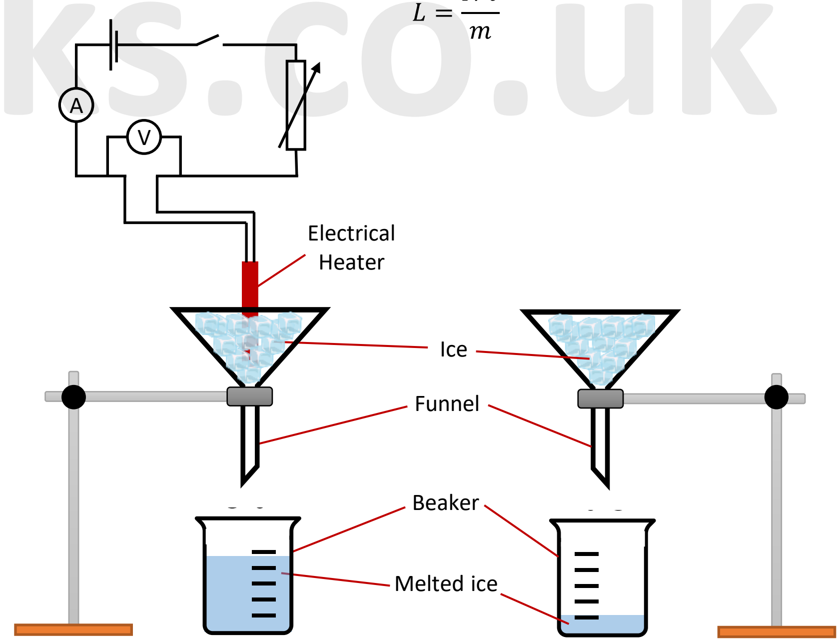
Measurement of Specific Latent Heat of Fusion using electrical methods

The experiment determines ice's specific latent heat of fusion as it transforms into water:

- To begin, prepare the equipment by placing the ice in two funnels above a beaker. In one of the funnels place an the electric heater into the ice.
- Connect the heater to a power supply in a circuit with an ammeter and voltmeter.
- Turn on the heater for 15 minutes and record the circuit's current and voltage.
- At the end, measure the mass of the water in the two beakers; the difference between these masses is ice melted by the heater.
- Find the latent heat of fusion using:

$$L = \frac{IVt}{m}$$



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Measurement of Specific Latent Heat of Vaporisation using electrical methods

The specific latent heat of vaporisation of a liquid is determined in this experiment:

Set up the equipment as in the diagram shown opposite.

With a heater, heat the liquid while measuring the voltage and current with an ammeter and voltmeter.

When the liquid boils, the vapour escapes into the condenser and gathers in a beaker below.

Measure the mass gathered in the beaker over a period of time.

We can derive the following equation from the latent heat equation:

$$I_1 V_1 t = m_1 L + Q$$

Where:

- Q = the energy wasted as heat to the surroundings.

Repeat the experiment again, but this time with a different voltage and current but keep the same time period.

This experiment's equation will be:

$$I_2 V_2 t = m_2 L + Q$$

By subtracting one equation from the other, we can remove the unknown Q, this leaves:

$$(I_2 V_2 - I_1 V_1)t = (m_2 - m_1)L$$

All of these variables, except L, are known, therefore we can rearrange the equation to determine the specific latent heat of vaporisation.

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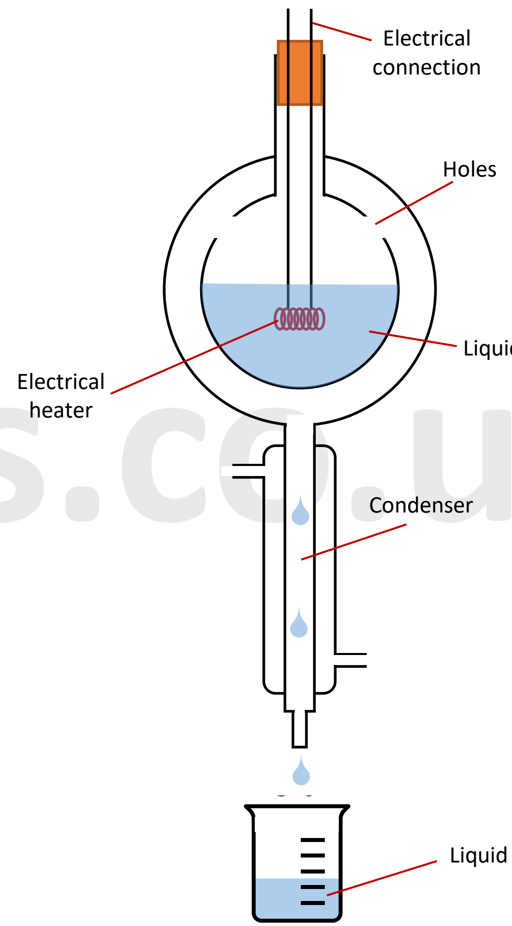
Measurement of Specific Latent Heat of Vaporisation using electrical methods



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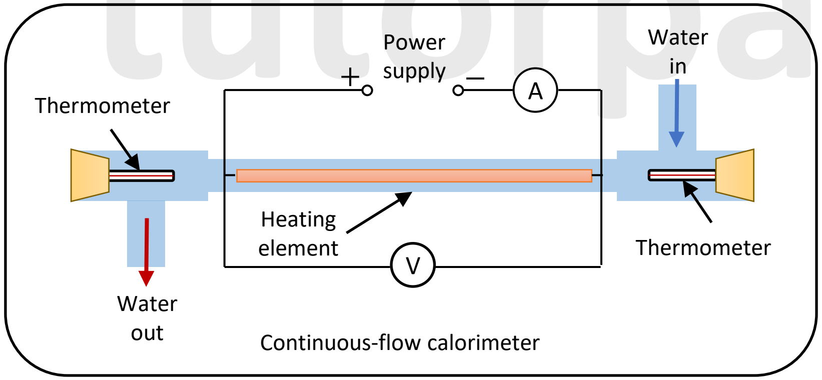
Continuous Flow (AQA Only)

When a fluid runs constantly over a heating element, it is referred to as continuous flow heating. Energy is transferred to the fluid as it flows. You can use a continuous flow calorimeter (shown below) to determine the specific heat capacity (in this case of water):

Set up the experiment as shown below, and let the water flow at a steady rate until the temperature of the water out remains constant.

- Record the flow rate of the water and the duration of the experiment, t, (in order to find the mass of water).
- Measure the temperature difference, $\Delta\theta$, between the thermometers (of the water from the point where it comes in to the point where it flows out). Note the current, I, and potential difference, V as well.
- The energy supplied to the water is $Q = mc\Delta\theta + H$, where H is the heat lost to the surrounding.



- Re-do the experiment, adjusting only the power supply's p.d. and the flow rate (mass) so $\Delta\theta$ remains constant. For each experiment, you should now have an equation:

$$Q_1 = m_1 c\Delta\theta + H \text{ and } Q_2 = m_2 c\Delta\theta + H$$

Continuous Flow (AQA Only)

- The values of c, $\Delta\theta$ and H are the same, so $Q_2 - Q_1 = (m_2 - m_1)c\Delta\theta$.

Rearranging gives: $c = \frac{Q_2 - Q_1}{(m_2 - m_1)\Delta\theta}$.

- Q is the electrical energy supplied over time t in each case, therefore you can use $Q = VIt$ to determine Q_1 and Q_2, and hence the specific heat capacity of water (c).
- The heat losses (H) will be the same for each repeat of the experiment as long as the $\Delta\theta$ and the time period t are both the same.

Errors may occur during the experiment, such as:

- Changes in the temperature of the water flowing in causing random error.
- Thermometers may not be calibrated properly causing systematic error.

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Please see '9.3.2 Thermal Properties of Materials worked examples' pack for exam style questions.

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