Edexcel International A Level (IAL) Physics

Your notes

Thermal Energy Transfer

Contents

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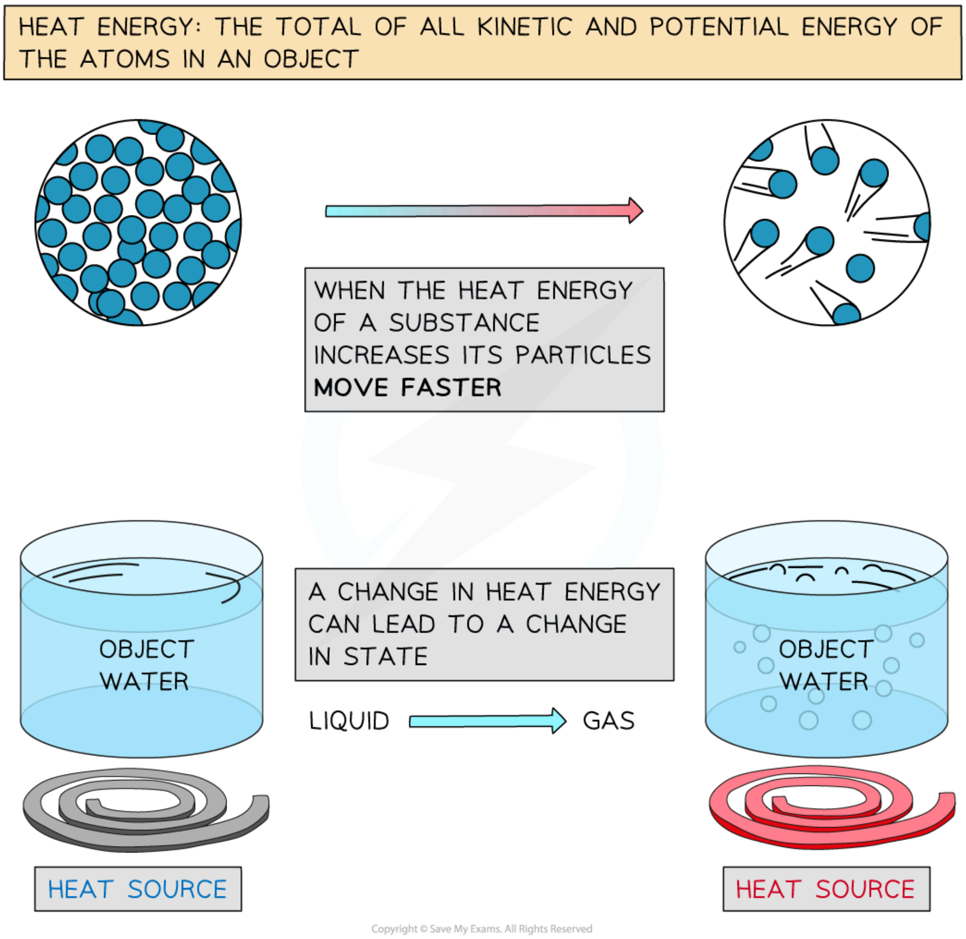
Specific Heat Capacity

- Specific heat capacity is defined as:

The energy required to raise the temperature of one kilogram of a substance by one kelvin

- The increase in temperature of an object depends on:
  - The amount of heat energy transferred
  - The mass of the object
  - The specific heat capacity of the material from which the object is made



Explanation of Heat Energy

- The energy input is in the form of **heat** energy
- The amount of **heat** energy needed is given by the equation:

$$\Delta E = mc\Delta\theta$$

- Where:
  - ΔE = change in heat energy, in joules (J)
  - m = mass, in kilograms (kg)
  - c = specific heat capacity, in joules per kilogram per degree Kelvin (J/kg K **or** J/kg °C)
  - $\Delta\theta$ = change in temperature, in Kelvin or Celsius
- (The symbol Δ in Maths is used to denote a change in value)

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Examples of heat energy

- The thermodynamic **Kelvin temperature scale** is defined as:

  An absolute temperature scale where each degree is the same size as those on the Celsius scale

- Different materials:

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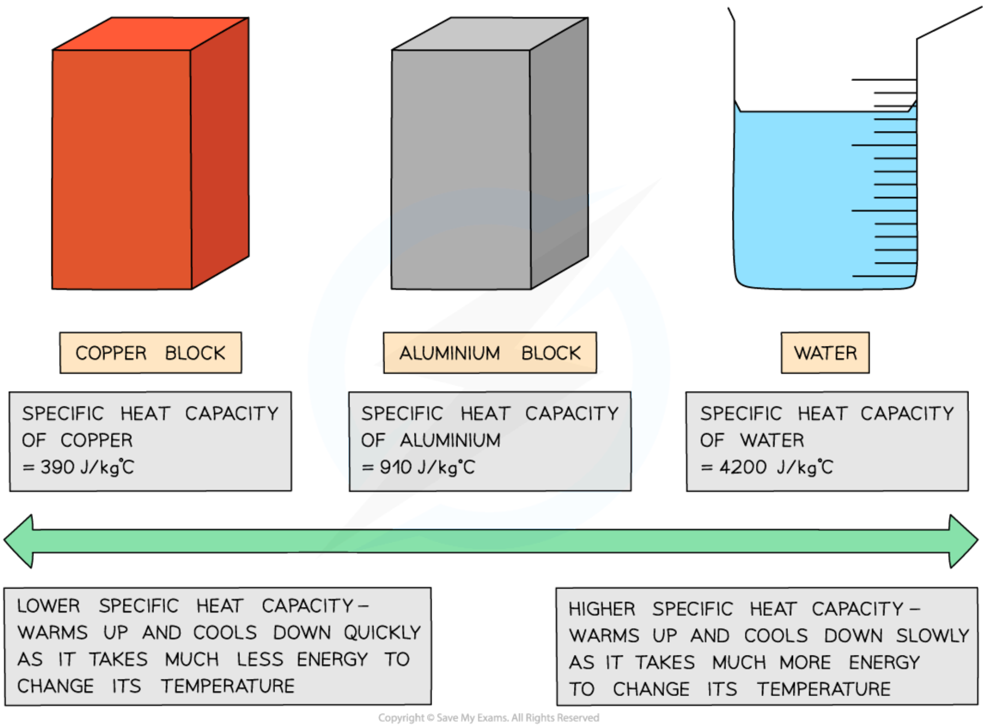
- Have different specific heat capacities because of their molecular structure
- Have different rises in temperature for the same change in heat energy

- Specific heat capacity is mainly used for **liquids** and **solids**
- Good electrical conductors, such as copper and lead, are **excellent conductors of heat** due to their **low** specific heat capacity
    - On the other hand, **water** has a **very high** specific heat capacity, making it ideal for **heating** homes as the water remains hot in a radiator for a long time
- The specific heat capacity of different substances determines how **useful** they would be for a specific purpose eg. choosing the best material for kitchen appliances



Low v high specific heat capacity

- The specific heat capacity of some substances are given in the table below as examples:

Table of values of specific heat capacity for various substances

Substance	Specific Heat Capacity ($J\ kg^{-1}\ K^{-1}$)
Water	4200
Ice	2200
Aluminium	900
Copper	390
Gold	130

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Worked Example

Water of mass 0.48 kg is increased in temperature by 0.7 K. The specific heat capacity of water is 4200 $J\ kg^{-1}K^{-1}$. Calculate the amount of energy transferred to the water.

Answer:

Step 1: Write down the known quantities

- Mass, m = 0.48 kg
- Change in temperature, $\Delta\theta$ = 0.7 K
- Specific heat capacity, c = 4200 $J\ kg^{-1}K^{-1}$

Step 2: Write down the relevant equation

$$\Delta E = mc\Delta\theta$$

Step 3: Calculate the energy transferred by substituting in the values

$$\Delta E = (0.48) \times (4200) \times (0.7) = 1411.2$$

Step 4: Round the answer to 2 significant figures

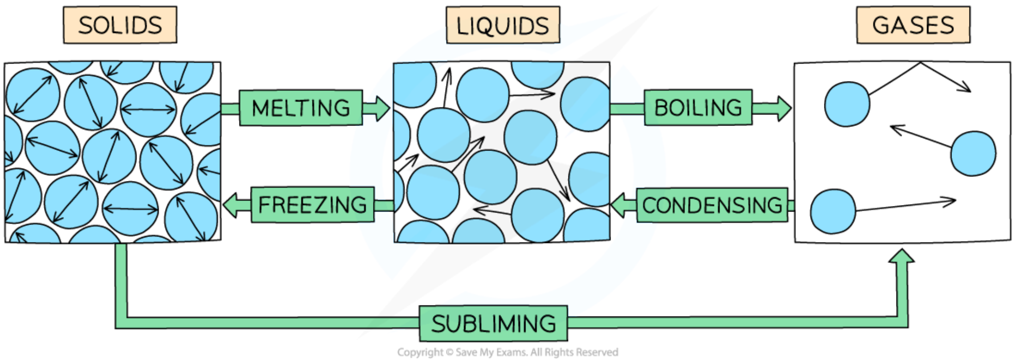
$$\Delta E = 1400\ J$$

Examiner Tips and Tricks

You will always be given the specific heat capacity of a substance, so you do not need to memorise any values. Make sure that Δθ is the **change** in temperature, therefore, it can be in K or °C.

Specific Latent Heat

- Energy is required to change the **state** of substance
- Examples of changes of state are:
  - Melting = solid to liquid
  - Evaporation/vaporisation/boiling = liquid to gas
  - Sublimation = solid to gas
  - Freezing = liquid to solid
  - Condensation = gas to liquid



The example of changes of state between solids, liquids and gases

- When a substance changes state, there is **no temperature change**
- The energy supplied to change the state is called the **latent heat** and is defined as:

  The thermal energy required to change the state of one kilogram of a substance without any change of temperature

- There are two types of latent heat:
  - Specific latent heat of **fusion** (melting)
  - Specific latent heat of **vaporisation** (boiling)

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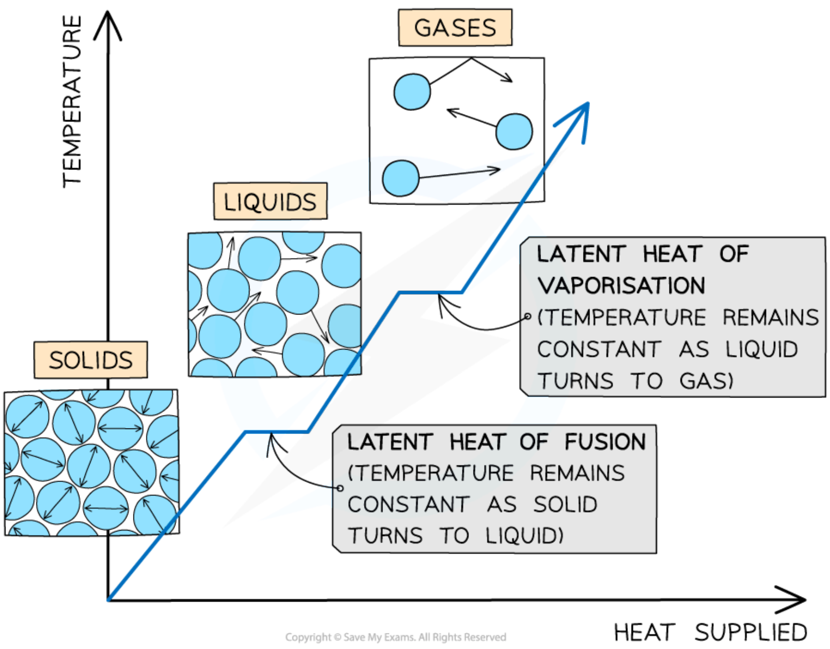

The changes of state with heat supplied against temperature. There is no change in temperature during changes of state

- The specific latent heat of **fusion** is defined as:

The thermal energy required to convert one kilogram of solid to liquid with no change in temperature

  - This is used when melting a solid or freezing a liquid

- The specific latent heat of **vaporisation** is defined as:

The thermal energy required to convert one kilogram of liquid to gas with no change in temperature

  - This is used when vaporising a liquid or condensing a gas

Calculating Specific Latent Heat

- The amount of energy ΔE required to melt or vaporise a mass of m with latent heat L is:

$$\Delta E = L\Delta m$$

- Where:
  - ΔE = amount of heat energy to change the state (J)
  - L = latent heat of fusion or vaporisation (J kg^{-1})
  - Δm = change in mass of the substance changing state (kg)
- The values of latent heat for water are:
  - Specific latent heat of fusion = 330 kJ kg^{-1}

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- Specific latent heat of vaporisation = 2.26 MJ kg^{-1}
- Therefore, evaporating 1 kg of water requires roughly **seven times** more energy than melting the same amount of ice to form water
- The reason for this is to do with intermolecular forces:
  - **When ice melts**: energy is required to just increase the molecular separation until molecules can flow freely over each other
  - **When water boils**: energy is required to completely separate the molecules until there are no longer forces of attraction between them, hence this requires much more energy

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Worked Example

The energy needed to boil a mass of 530 g of a liquid is 0.6 MJ. Calculate the specific latent heat of the liquid and state whether it is the latent heat of vaporisation or fusion.

Answer:

Step 1: Substitute in the values

$$\Delta m = 530 \text{ g} = 530 \times 10^{-3} \text{ kg}$$

$$\Delta E = 0.6 \text{ MJ} = 0.6 \times 10^{6} \text{ J}$$

$$L = \frac{0.6 \times 10^{6}}{530 \times 10^{-3}} = 1.132 \times 10^{6}\ J\,kg^{-1} = 1.1\ MJ\,kg^{-1}\ (2\ s.f.)$$

L is the latent heat of vaporisation because the change in state is from liquid to gas (boiling)

Examiner Tips and Tricks

Use these reminders to help you remember which type of latent heat is being referred to:

- Latent heat of fusion = imagine 'fusing' the liquid molecules together to become a solid
- Latent heat of vaporisation = "water vapour" is steam, so imagine vaporising the liquid molecules into a gas

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Core Practical 12: Calibrating a Thermistor

Aim of the Experiment

- To calibrate a thermistor so it can be used as a thermometer

Variables

- Independent variable = temperature (°C)
- Dependent variable = resistance of thermistor (Ω)
- Control variables:
  - Temperature gradient controlled by stirring

Equipment

- Power source
- Thermistor
- Fixed resistor
- Ohm-meter
- Bunsen burner, tripod and gauze
- Beaker filled with crushed ice
- Stirring rod
- Liquid in glass or mercury thermometer with range -10 - 100°C
- Resolution of measuring equipment:
  - Thermometer = 1°C
  - Ohm-meter = 0.01 Ω

Method

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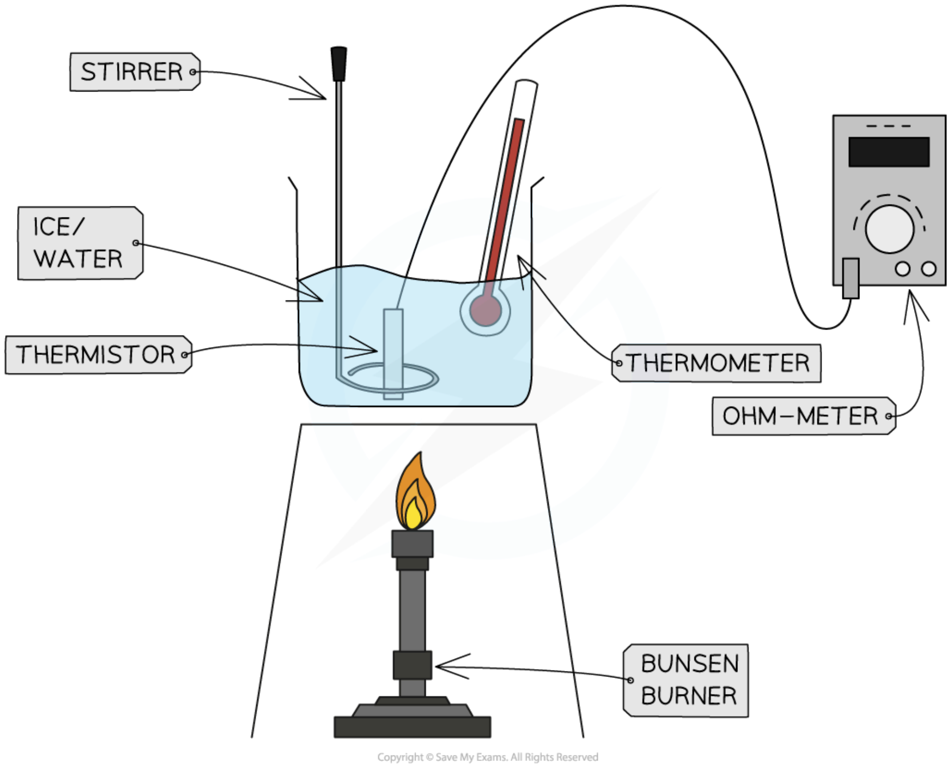

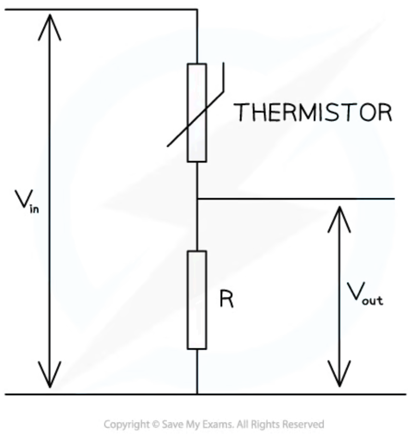

- Set up the equipment with the thermistor immersed in the ice, the ohm-meter connected to record the resistance of the thermistor by placing it in parallel across it, and the fixed resistor in series with the thermistor
- Place the beaker of ice onto the tripod, without lighting the Bunsen burner
- Measure and record the temperature and reading on the ohm-meter
- Light the Bunsen burner and keep to a gentle flame
- Stir the ice / water gently at all times to keep the temperature as even as possible throughout the beaker

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- At approximately 5°C intervals record the new temperature and resistance reading
- Continue until the water is boiling

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Analysis

- Plot a graph of resistance against temperature
- Use the temperature graph to find the resistance at a given temperature

Evaluating the Experiment

Systematic Errors:

- Read the thermometer at eye level
- Check the zero error on the ohm-meter by connecting the leads across the terminals

Random Errors:

- Allow time for the temperature to reach equilibrium
- Stir the water before readings
- Ensure thermometer bulb is completely submerged in the water and level with the thermistor
- Turn off current between readings to avoid heating in the wires

Safety Considerations

- Risk of instability, use a stand and clamp to support leads
- Hot equipment and boiling water must be handled with care and allowed to cool down where possible
- Keep plastic cables / leads away from hot metal
- Check the voltage limit of the thermistor and stay within guidelines

Core Practical 13: Investigating Specific Latent Heat

Aims of the Experiment

- To determine the specific latent heat of ice

Variables:

- Independent variable = Energy of the heater (Joulemeter) (J)
- Dependent variable = The temperature, *T* of the ice/water (°C)
- Control variables:
  - Repeat readings with same energy supplied by heater
  - Mass of ice in each set up
  - Time for experiment in each set up

Equipment List

Equipment	Purpose
2 x funnels with filter paper	Hold the ice so when it melts it drips through the funnel opening
3 x retort stands	To hold the funnels and heater in place above the beakers
300 g of crushed ice and spoon	The heater will melt the ice
2 x 250 cm^3 beakers	To collect the water from the melted ice
2 x thermometer	To measure the temperature of the melting ice
2 x electronic balances	To measure the mass of the melted ice
1 x joulemeter and power supply	To heat the ice

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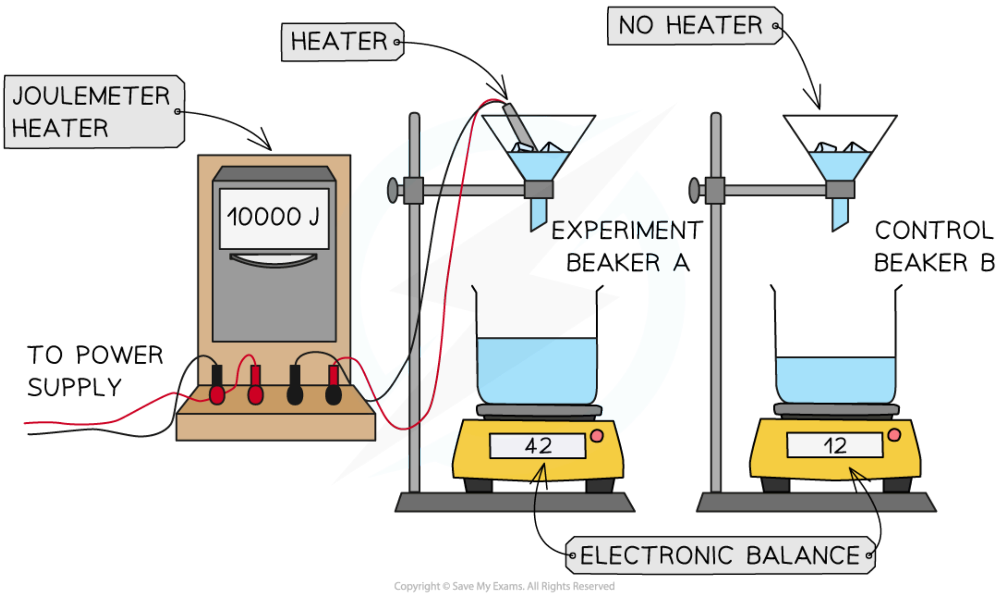
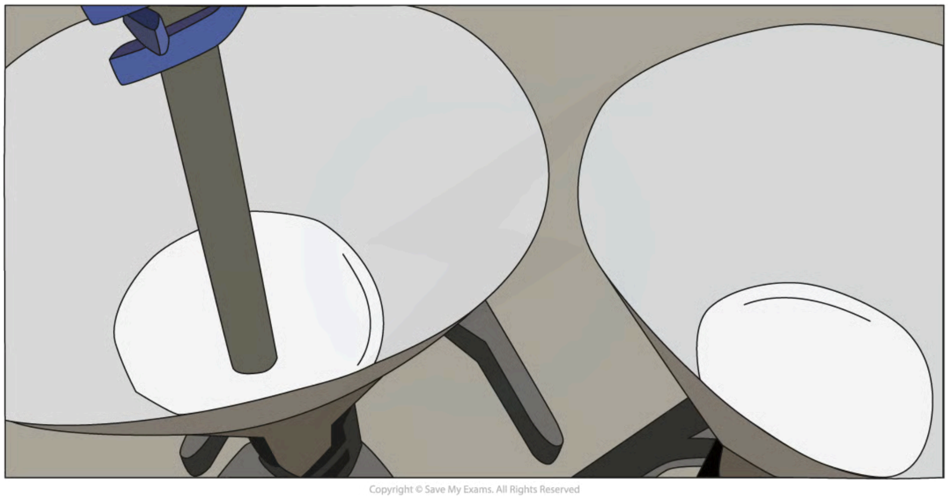
- Resolution of measuring equipment:
  - Joulemeter = 1 J
  - Electronic balance = 0.1 g
  - Thermometer = 0.1 °C

Method



1. Set up the experiment and the control

- Attach the funnels to retort stands, place the filter paper inside and add a heater (also on a retort stand) inside one of the funnels - ensure the heater is not touching the funnel



- Use a spoon and an electronic balance to measure out 50 g of crushed ice into a beaker and pour into each funnel
- Add a beaker below each funnel and place on top of an electronic balance

2. Wait until the ice reaches 0 °C.

- This is when it starts to melt and water starts to drip out of both funnels into the beakers below.
- Check the temperature with a thermometer in each funnel

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3. Turn on the heater
   - Set the heater to supply 10, 000 Joules of energy to the experiment funnel
4. Wait until the reading on the Joulemeter says 10, 000 J
   - Turn the heater off
5. Read and record the mass of each beaker of water on each electronic balance
6. Repeat the experiment at least 3 times and calculate the average mass, *m* for the water in each beaker
   - m_A = average mass of water in beaker A
   - m_B = average mass of water in beaker B
7. Calculate the mass of the melted ice and convert into kg
   - $\Delta m = m_A - m_B$
   - Mass in g ÷ 1000 = Mass in kg
8. Calculate the specific latent heat of fusion of ice to water using the equation $\Delta E = L\Delta m$
   - ΔE = Energy supplied by the heater = 10 000 J
   - L = Specific latent heat of fusion
   - Δm = mass of ice

$$L = \frac{\Delta E}{\Delta m}$$

Sample Results Table:

	Mass of water in Beaker A/g	Mass of water in Beaker B/g
Experiment 1	42	12
Experiment 2	43	12
Experiment 3	41	11
Average mass/g	42	11.6
Average mass/kg	0.042	0.0116

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Analysis of Results

- The results obtained a latent heat of fusion of 330 000 J
- The actual value of the latent heat of fusion for ice is 334 000 J

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- The percentage error in this value is $\frac{334\ 000 - 330\ 000}{334\ 000} \times 100$ = 1.2%

Evaluating the Experiment

Systematic Errors:

- Make sure you zero the electronic balances when the beakers are empty
- Always check that the ice has reached 0 °C by reading the thermometer at eye level
- This experiment requires accurate determination of energy transfers
  - To improve the accuracy, consider applying lagging or insulation to the funnels and beakers - this will reduce the amount of energy lost to the surroundings

Random Errors:

- The heater should be switched off and allowed to cool between readings
  - So the rate of heating and the starting temperature of the heater is the same
- Calculate the average mass of the water
  - This will reduce random errors in the reading
  - Repeat the experiment at least 3 times

Safety Considerations

- Ensure no water gets on the electronic balance
  - Wipe up any spillages immediately and turn off the balance
- Do not touch the heating element with your fingers, as it could be hot and burn your skin
- Do not handle ice with your bare hands, use a spoon to measure it into the beaker

Worked Example

A student conducts an experiment to find the latent heat of fusion for ice

They obtain the following table of results:

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	Mass of water in Beaker A/g	Mass of water in Beaker B/g
Experiment 1	42	12
Experiment 2	41	13
Experiment 3	42	13
Average mass/g		
Average mass/kg		

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Calculate the latent heat of fusion.

Answer:

Step 1: Complete the average mass row in the table

- The average mass is calculated by adding all 3 masses together and then dividing by 3

	Mass of water in Beaker A/g	Mass of water in Beaker B/g
Experiment 1	42	12
Experiment 2	41	13
Experiment 3	42	13
Average mass/g	42	12.6
Average mass/kg	0.042	0.0126

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Step 2: Calculate the average mass in kg

- Mass in g ÷ 1000 = Mass in kg

Step 3: Calculate the latent heat of fusion

- Calculate the specific latent heat of fusion of ice to water using the equation ***ΔE = LΔm***
  - ΔE = Energy supplied by the heater = 10, 000 J
  - L = Specific latent heat of fusion
  - Δm = mass of ice
  - Rearrange the equation $L = \frac{\Delta E}{\Delta m}$
  - So, $L = \frac{10\,000}{0.03}$ = 340136 J kg^{-1} = 340 000 J

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