EXAM PAPERS PRACTICE

A Level Physics CIE

14. Temperature

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14.1 Measuring Temperature

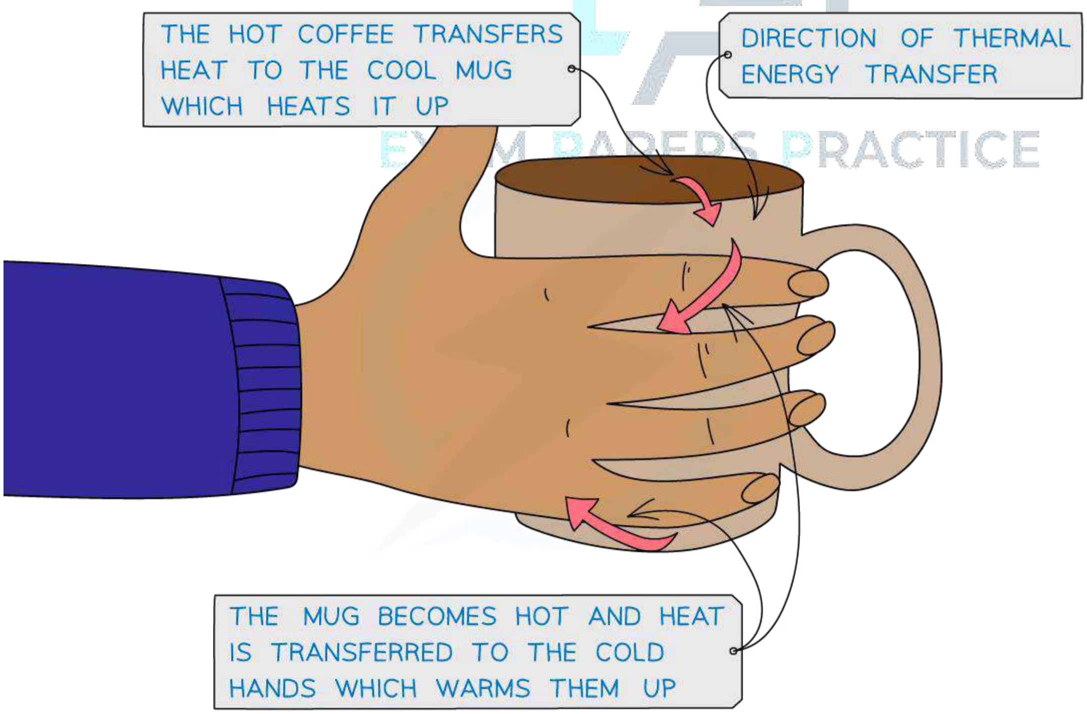
14.1.1 Thermal Energy Transfer

Thermal Energy Transfer

- The conservation of energy states that energy is never created or destroyed, only transferred from one form to another
- When a thermometer is placed in a beaker of boiling water, the thermometer reading increases
  - This is because the thermometer is a lot cooler than the water
- The thermometer gradually becomes hotter from the thermal energy (or heat) transferring from the water to the thermometer
- The definition of thermal energy is given below:

Thermal energy is defined as the energy possessed by an object due to its temperature. Thermal energy is transferred from a region of higher temperature to a region of lower temperature

- The energy will continue to be transferred until both the thermometer and the water are at the same temperature
- This means temperature tells us the **direction of energy flow** when two regions are in contact (from hotter to cooler)



Thermal energy is transferred from the hot coffee to the mug and to the cold hands

- The mechanism by which the thermal energy is transferred is by either conduction, convection or radiation

Exam Tip

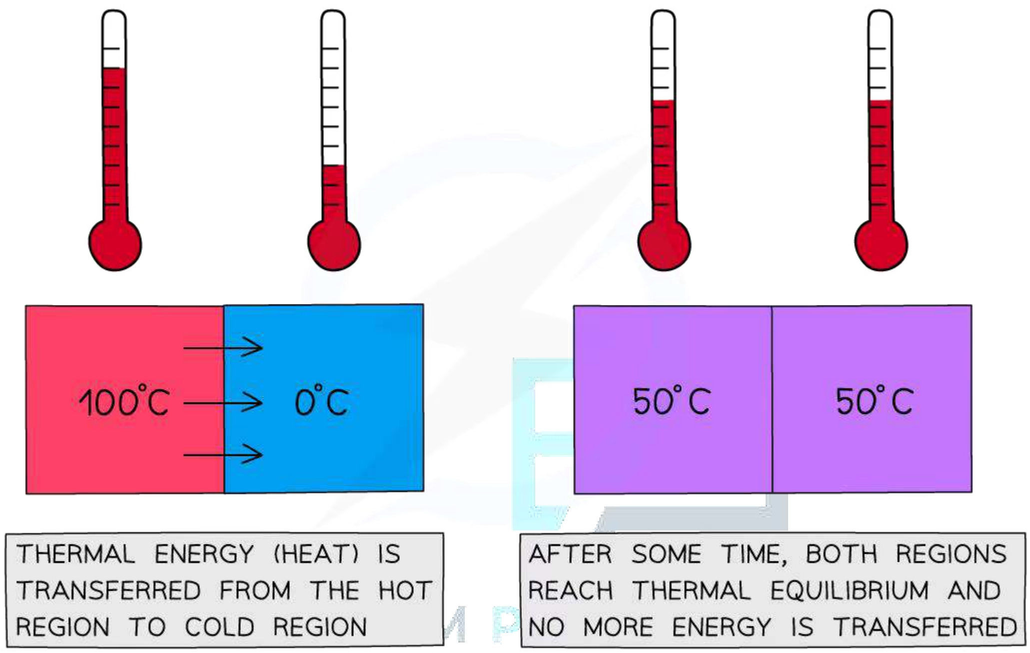
Sometimes the direction of heat transfer might seem counterintuitive to what we observe in everyday life. When ice is placed in room temperature water, it melts. This is because the water transfers heat energy to the ice (not the ice giving it's 'cold' to the water).

Defining Thermal Equilibrium

- Thermal energy is **always** transferred from a hotter region to lower region
- Thermal equilibrium is defined as:

When two substances in physical contact with each other no longer exchange any heat energy and both reach an equal temperature

- There is no longer thermal energy transfer between the regions



Two regions of different temperatures reaching thermal equilibrium after some time

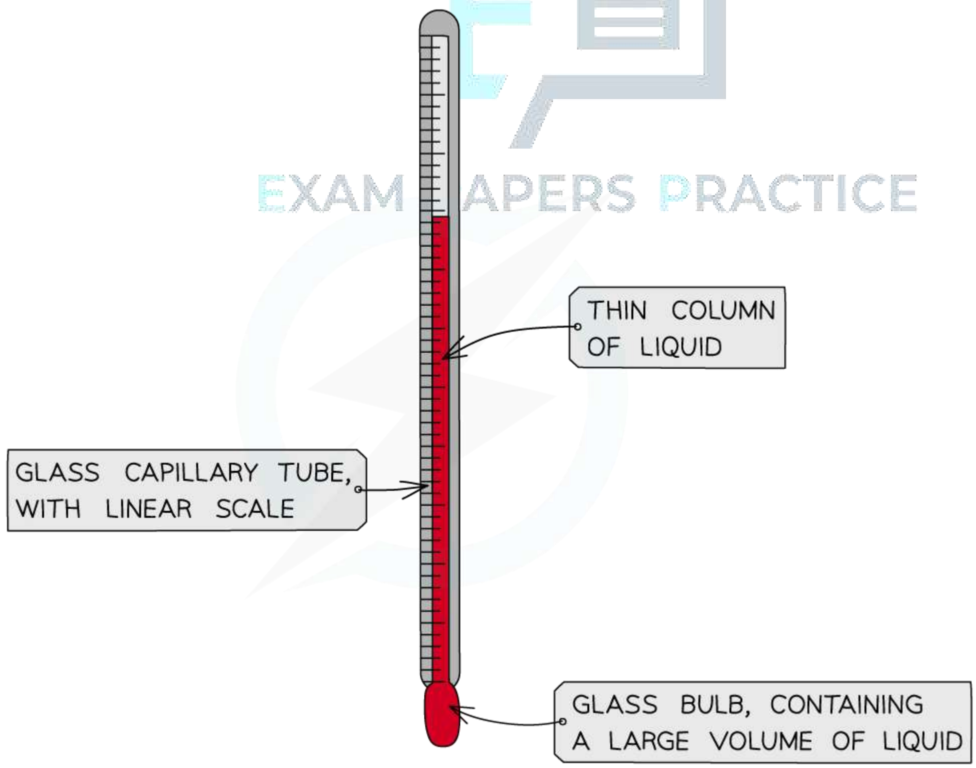
- The two regions need to be in contact for this to occur
- The hotter region will cool down and the cooler region will heat up until they reach the same temperature
- The final temperature when two regions are in thermal equilibrium depends on the initial temperature difference between them
- An example of this is ice in room temperature water. The ice cubes heat up from the energy transfer from the water and the water cools down due to the ice until the water's temperature is in thermal equilibrium

Measurement of Temperature

- A thermometer is any device that is used to measure temperature
- Each type of thermometer uses a physical property of a material that varies with temperature – examples of such properties include:
  - The density of a liquid
  - The volume of a gas at constant pressure
  - Resistance of a metal
  - e.m.f. of a thermocouple
- In each case, the thermometer must be calibrated at two or more known temperatures (commonly the boiling and melting points of water, 0°C and 100°C respectively) and the scale divided into equal divisions

The Density of a Liquid

- A liquid-in-glass thermometer depends on the density change of a liquid (commonly mercury)
- It consists of a thin glass capillary tube containing a liquid that **expands** with temperature
- A scale along the side of the tube allows the temperature to be measured based on the length of liquid within the tube



As the bulb is heated, the liquid expands and moves along the capillary tube

Volume of a Gas at Constant Pressure

- The volume of an ideal gas is directly proportional to its temperature when at constant pressure (Charles's law)

$$V \propto T$$

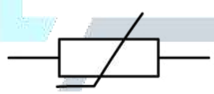
- As the temperature of the gas increases, its volume increases and vice versa
- A gas thermometer must be calibrated – by knowing the temperature of the gas at a certain volume, a temperature scale can be determined depending on how quickly the gas expands with temperature

Resistance of a Metal

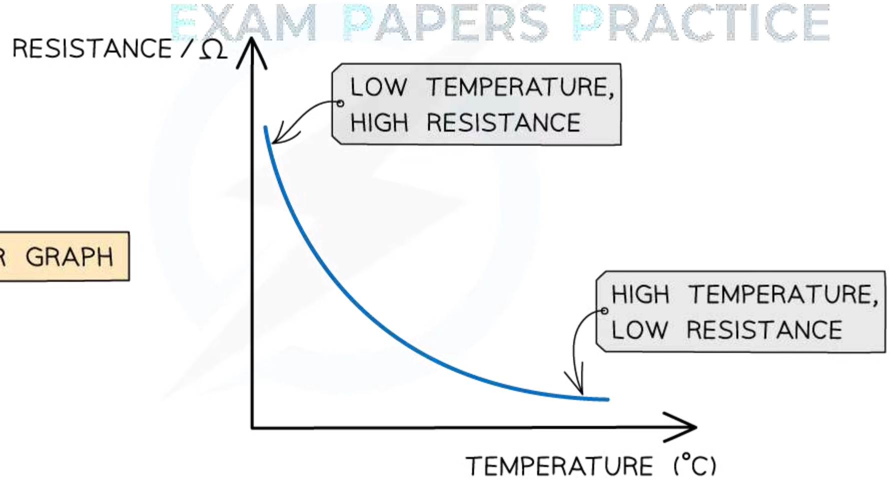
- Recall that electrical resistance changes with temperature e.g. the resistance of a filament lamp increases when current increases through it
  - For metals: resistance increases with temperature at a steady rate
  - For thermistors: resistance changes rapidly over a narrow range of temperatures

- As a thermistor gets hotter, its resistance decreases
- This means a thermometer based on a thermistor can be used to measure a range of temperatures
- The relationship between the resistance and temperature is non-linear
  - This means the graph of temperature against resistance will be a curved line and the thermistor will have to be calibrated

THERMISTOR CIRCUIT SYMBOL



THERMISTOR GRAPH



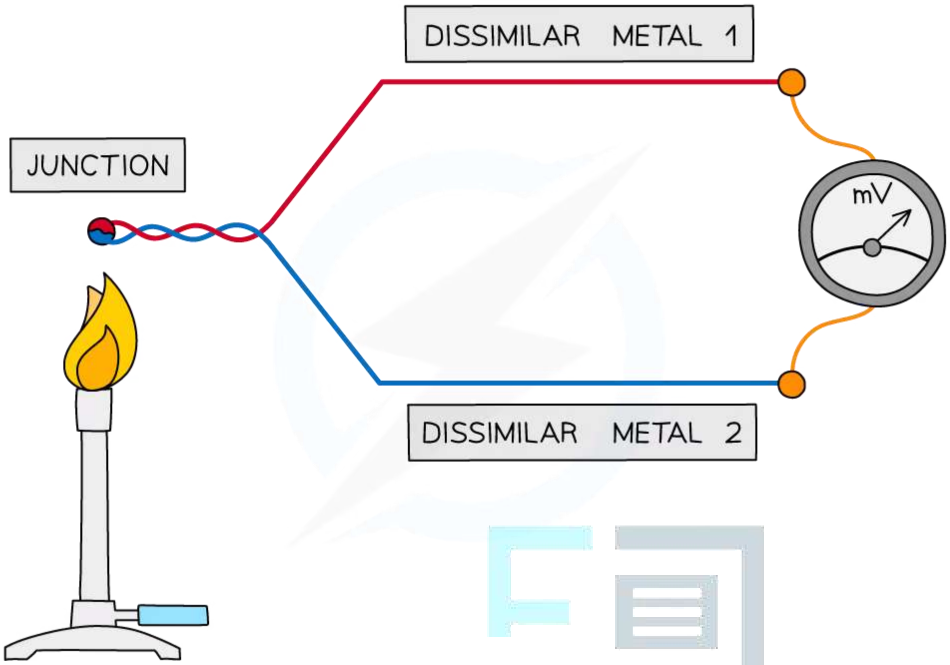
As the temperature of a thermistor increases, its resistance decreases

E.M.F. of a Thermocouple

- A thermocouple is an electrical device used as the sensor of a thermometer
- It consists of two wires of different, or dissimilar, metals attached to each other, producing a junction on one end

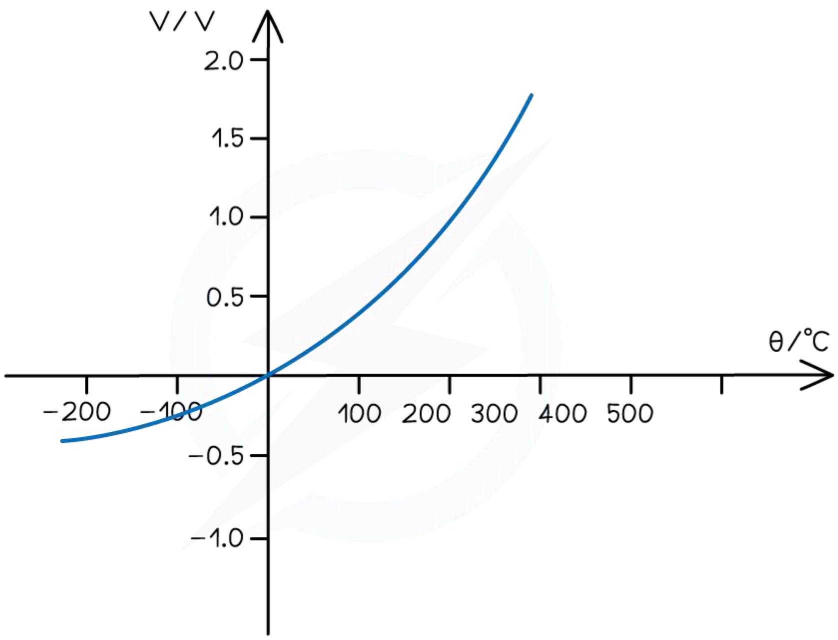
- The opposite ends are connected to a voltmeter

- When this junction is heated, an e.m.f. is produced between the two wires which is measured on the voltmeter
- The greater the difference in temperature between the wires, the greater the e.m.f



A thermocouple consists of two dissimilar wires connected together

- However, a thermocouple requires calibration since the e.m.f. does not vary linearly with temperature
- The graph against e.m.f. and temperature is a positive, curved line



The e.m.f. and temperature are not directly proportional in a thermocouple

Exam Tip

Remember to relate how the temperature is measured for different types of thermometer back to the scenario in the question. For example, make sure you say: the temperature increases as the **volume of gas increases** or the temperature increases as the **e.m.f. between the two wires increases**.

Scale of Thermodynamic Temperature

- As an everyday scale of temperature, Celsius (^oC) is the most familiar
- This scale is based on the properties of water – the freezing point of water was taken as taken as 0 ^oC and the boiling point as 100 ^oC
  - However, there is nothing special about these two temperatures
  - The freezing and boiling point of water will actually change as its pressure changes

- The Celsius scale is used to measure the temperature in a liquid-in-glass thermometer
  - However, the expansion of the liquid might be non-linear

- Other temperature scales include:
  - Fahrenheit, commonly used in the US
  - Kelvin, used in thermodynamics

- The Kelvin scale is known as the **thermodynamic scale** and was designed to overcome the problem with scales of temperature
- The thermodynamic scale is said to be an absolute scale that is not defined in terms of a property of any particular substance
- This is because thermodynamic temperatures **do not depend** on the property of any particular substance

Absolute Zero

- On the thermodynamic (Kelvin) temperature scale, absolute zero is defined as:

  The lowest temperature possible. Equal to 0 K or –273.15 °C

- It is not possible to have a temperature lower than 0 K
  - This means a temperature in Kelvin will **never** be a negative value

- Absolute zero is defined in kinetic terms as:

  The temperature at which the atoms and molecules in all substances have zero kinetic and potential energy

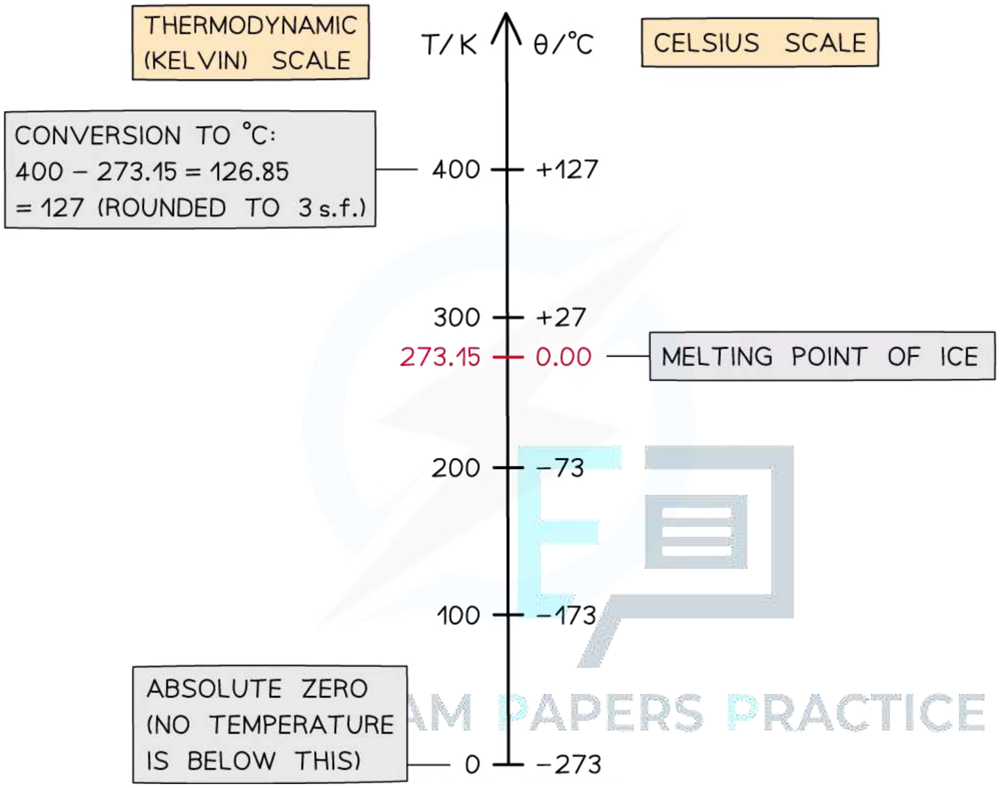
- This means for a system at 0 K, it is not possible to remove any more energy from it
- Even in space, the temperature is roughly 2.7 K, just above absolute zero

Using the Kelvin Scale

- To convert between temperatures θ in the Celsius scale, and T in the Kelvin scale, use the following conversion:

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

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



Conversion chart relating the temperature on the Kelvin and Celsius scales

- The divisions on both scales are equal. This means:

A change in a temperature of 1 K is equal to a change in temperature of 1 °C

Worked Example

In many ideal gas problems, room temperature is considered to be 300 K.What is this temperature in Celsius?

Step 1: Kelvin to Celsius equation

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

Step 2: Substitute in value of 300 K

$$300 \text{ K} - 273.15 = 26.85 \ ^{\circ}C$$

Exam Tip

If you forget in the exam whether it's $+273.15$ or -273.15, just remember that 0 ^oC = 273.15 K. This way, when you know that you need to $+273.15$ to a temperature in degrees to get a temperature in Kelvin. For example: 0 ^oC + 273.15 = 273.15 K.

14.2 Phase Changes

14.2.1 Specific Heat Capacity

Defining Specific Heat Capacity

- The specific heat capacity of a substance is defined as:

The amount of thermal energy required to raise the temperature of 1 kg of a substance by 1 °C

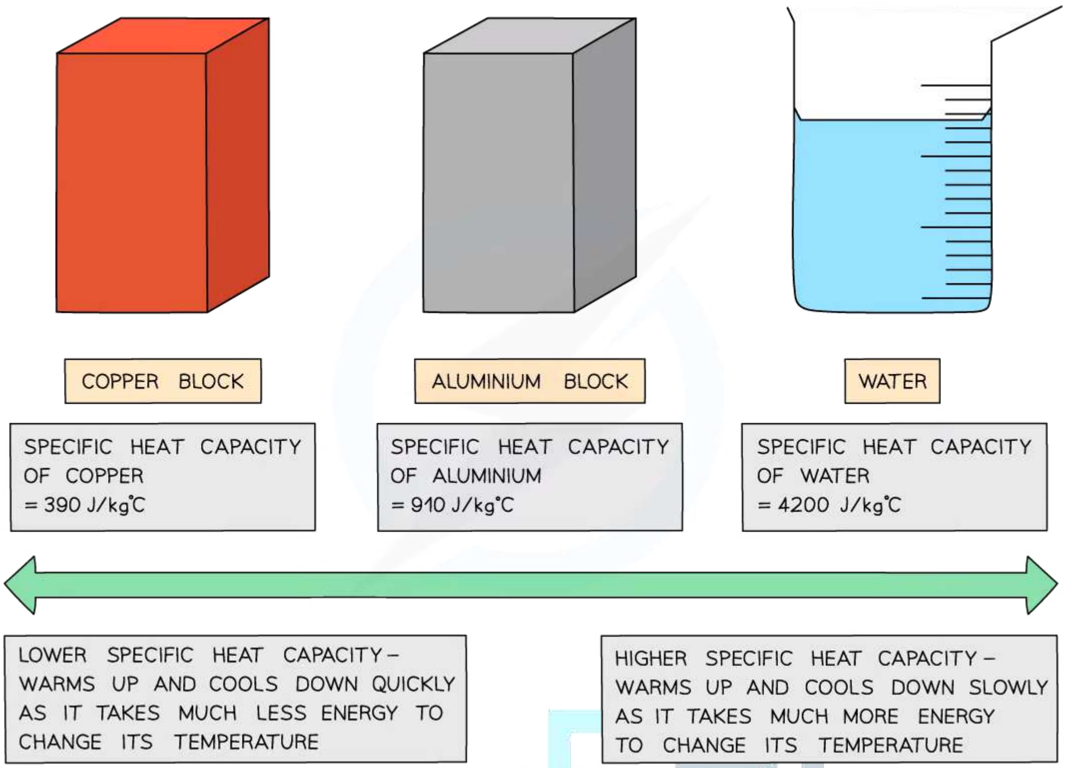
- This quantity determines the amount of energy needed to change the temperature of a substance
- The specific heat capacity is measured in units of **Joules per kilogram per Kelvin** (J kg^{-1} K^{-1}) or **Joules per kilogram per Celsius** (J kg^{-1} $°C^{-1}$) and has the symbol ***c***
  - Different substances have different specific heat capacities
  - Specific heat capacity is mainly used in liquids and solids
- From the definition of specific heat capacity, it follows that:
  - The heavier the material, the more thermal energy that will be required to raise its temperature
  - The larger the change in temperature, the higher the thermal energy will be required to achieve this change

Calculating Specific Heat Capacity

- The amount of thermal energy Q needed to raise the temperature by $\Delta\theta$ for a mass m with specific heat capacity c is equal to:

$$\Delta Q = mc\Delta\theta$$

- Where:
  - ΔQ = change in thermal energy (J)
  - m = mass of the substance you are heating up (kg)
  - c = specific heat capacity of the substance (J $kg^{-1}K^{-1}$or J kg^{-1} $°C^{-1}$)
  - $\Delta\theta$ = change in temperature (K or °C)



Low v high specific heat capacity

- If a substance has a **low** specific heat capacity, it heats up and cools down quickly
- If a substance has a **high** specific heat capacity, it heats up and cools down slowly
- 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

Table of values of specific heat capacity for various substances

Substance	Specific heat capacity / $J\,kg^{-1}K^{-1}$
Aluminium	910
Copper	390
Lead	126
Glass	500 – 680
Water	4200
Mercury	140

- Good electrical conductors, such as copper and lead, are also excellent conductors of heat due to their low specific heat capacity

Worked Example

A kettle is rated at 1.7 kW. A mass of 650 g of a liquid at 25°C is poured into a kettle.When the kettle is switched on, it takes 3.5 minutes to start boiling.Calculate the specific heat capacity of the liquid.

Step 1: Calculate the Energy from the power and time

$$\text{Energy} = \text{Power} \times \text{Time}$$

$$\text{Power} = 1.7\ \text{kW} = 1.7 \times 10^3\ \text{W}$$

$$\text{Time} = 3.5\ \text{minutes} = 3.5 \times 60 = 210\ \text{s}$$

$$\text{Energy} = 1.7 \times 10^3 \times 210 = 3.57 \times 10^5\ \text{J}$$

Step 2: Thermal energy equation

$$\Delta Q = mc\Delta\theta$$

Step 3: Rearrange for specific heat capacity

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

Step 4: Substitute in values

$$m = 650\ \text{g} = 650 \times 10^{-3}\ \text{kg}$$

$\Delta\theta = 100 - 25 = 75^{o}C$

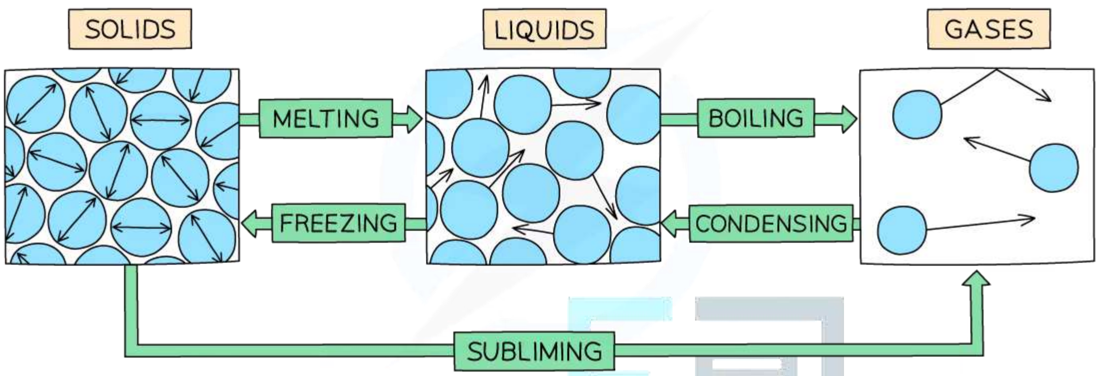
$$c = \frac{3.57 \times 10^5}{650 \times 10^{-3} \times 75} = 7323.07... = 7300 \text{ J kg}^{-1}\,^{o}\text{C}^{-1} \text{ (2 s.f)}$$

Exam Tip

The difference in temperature $\Delta\theta$ will be exactly the same whether the temperature is given in Celsius or Kelvin. Therefore, there is no need to convert between the two since the **difference** in temperature will be the same for both units.

Defining Latent Heat Capacity

- 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

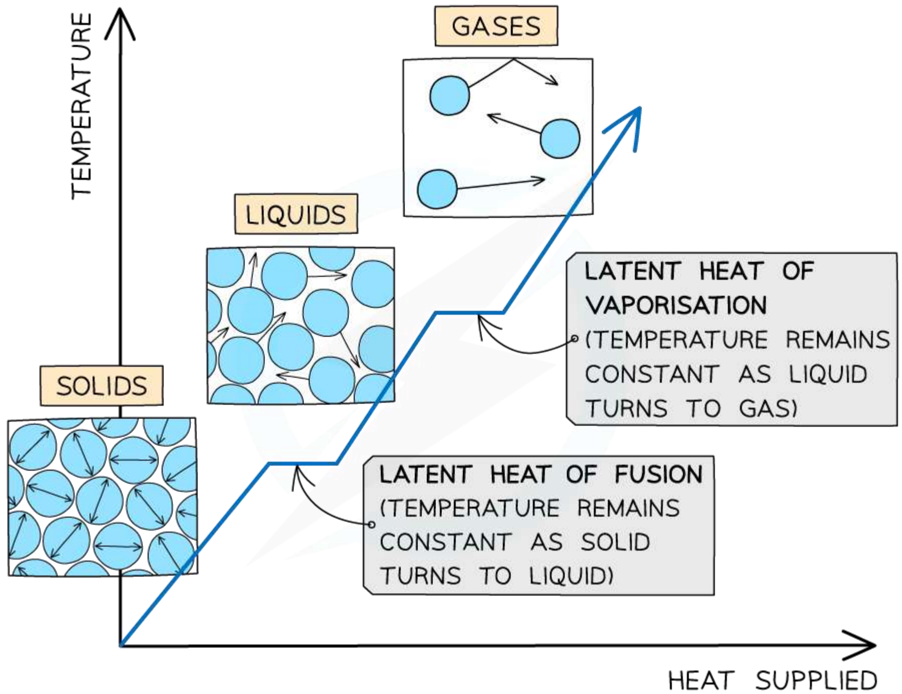


The example of changes of state between solids, liquids and gases

- 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 1 kg of mass 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)



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 1 kg 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 1 kg 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 Q required to melt or vaporise a mass of m with latent heat L is:

$$Q = Lm$$

- Where:
  - Q = amount of thermal energy to change the state (J)
  - L = latent heat of fusion or vaporisation (J kg^{-1})
  - m = mass of the substance changing state (kg)

- The values of latent heat for water are:
  - Specific latent heat of fusion = 330 kJ kg^{-1}
  - 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 they 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 the molecules, hence this requires much more energy

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.

Step 1: Write the thermal energy required to change state equation

$$Q = Lm$$

Step 2: Rearrange for latent heat

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

Step 3: Substitute in the values

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

$$\mathbf{Q = 0.6\ MJ = 0.6 \times 10^{6}\ J}$$

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

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

Exam Tip

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