英华国际学校
YINGHUA INTERNATIONAL SCHOOL

Cambridge IGCSE Physics
Thermal Physics

By: Chaoyang Chu

Section 2.1

Kinetic model of matter

2.1.1 States of matter
2.1.2 The kinetic model of matter
2.1.3 Forces & the kinetic theory
2.1.4 Gases & the kinetic theory

Section 2.1

Kinetic model of matter

2.1.1 **States of matter**

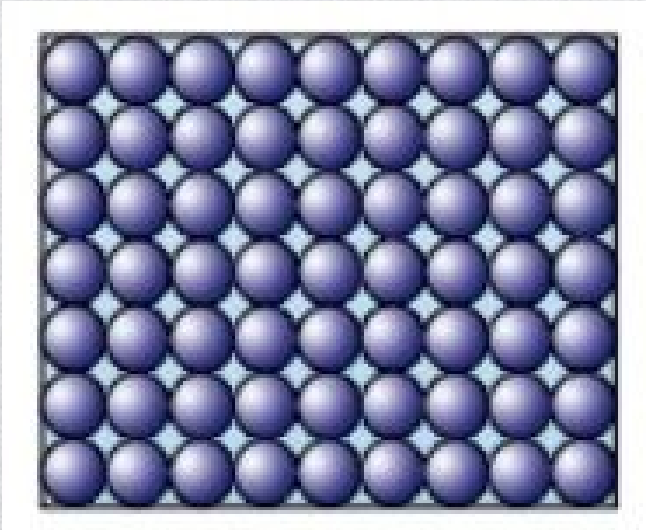
2.1.2 The kinetic model of matter

2.1.3 Forces & the kinetic theory

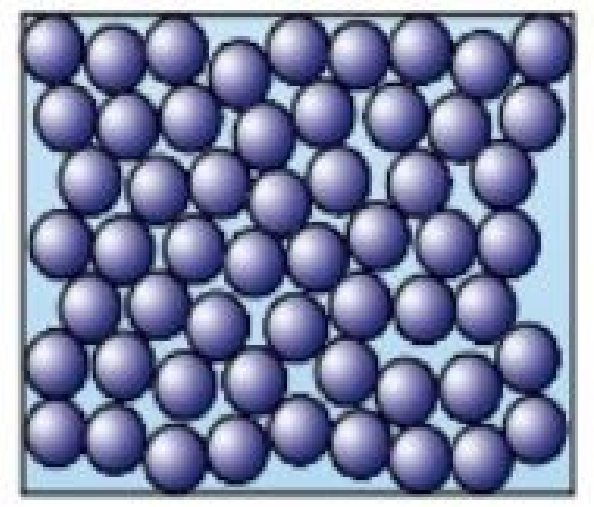
2.1.4 Gases & the kinetic theory

States of Matter

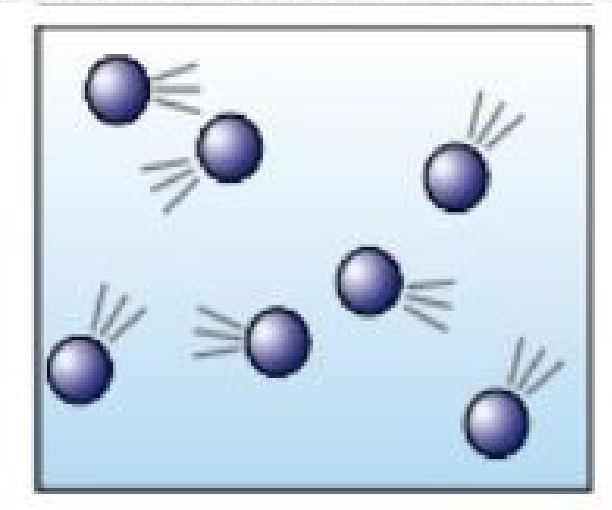
- Matter is any substance that occupies physical space.
- Matter exists in 3 states, solid, liquid, and gas.
- To distinguish the 3 states, think in terms of shape and size.



Solids



Liquids



Gases

Physical properties of solids, liquids, and gases

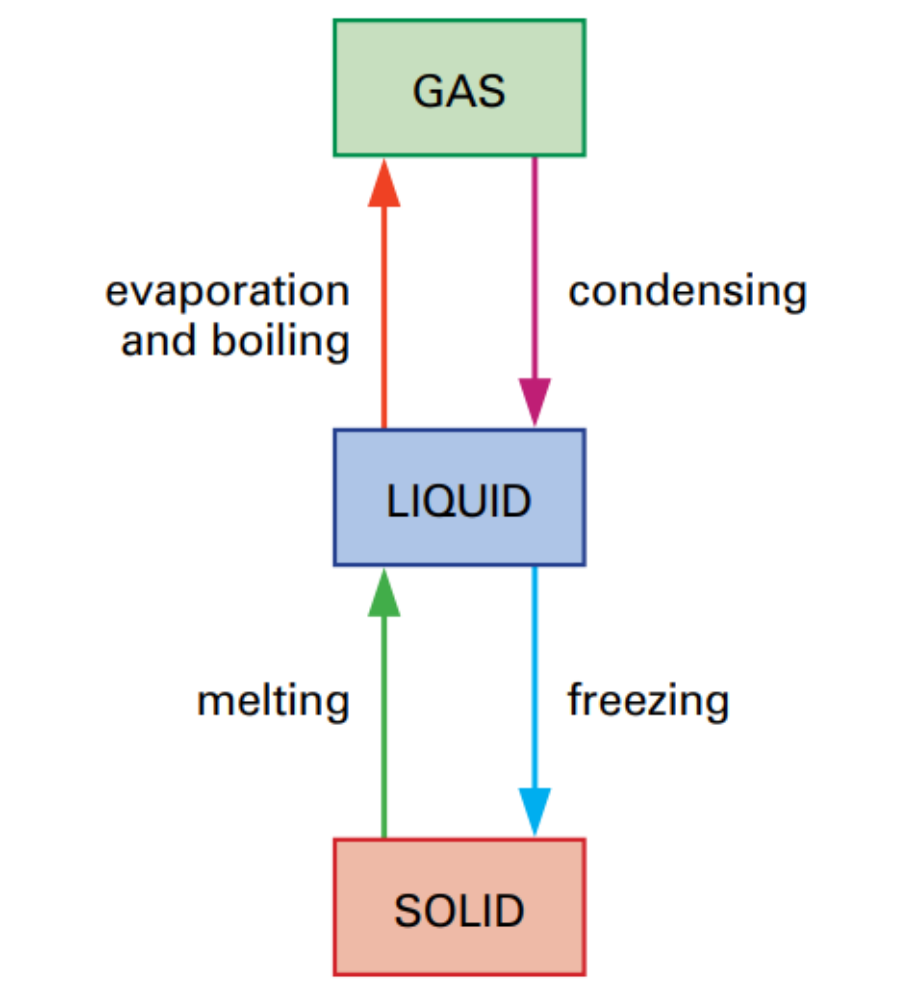
State	Size	Shape
Solid	occupies a fixed volume	has a fixed shape
Liquid	occupies a fixed volume	takes the shape of its container
Gas	expands to fill its container	takes the shape of its container

Physical properties of solids, liquids, and gases

Solid	Liquid	Gas
rigid	not rigid	Not rigid
Very difficult to compress	Difficult to compress	Easy to compress
Cannot flow	Can flow	Can flow
Keeps its shape (fixed shape)	Takes the shape of the bottom of the container	Fills the entire container

- Substances that can flow are called fluids. **All liquids and gases are fluids**.

Changes of States



Section 2.1

Kinetic model of matter

2.1.1 States of matter

2.1.2 **The kinetic model of matter**

2.1.3 Forces & the kinetic theory

2.1.4 Gases & the kinetic theory

Kinetic (particle) Model of Matter

Kinetic model of matter:

- Kinetic means ‘related to movement’
- In this model, the things that are moving are the particles of which matter is made
- The model thus has an alternative name: **the particle model of matter**.
- The matter is made up of **identical particles**, each is considered as **a small, solid, inelastic sphere**.

Kinetic (particle) Model of Matter

State	Arrangement of particles	Movement of particles
Solid	The particles are packed closely together. Notice that each particle is in close contact with all of its neighbours. In a solid such as a metal, each atom may be in contact with 12 neighbouring atoms.	Because the particles are so tightly packed, they cannot move around. However, they do move a bit. They are able to vibrate about a fixed position. The hotter the solid, the more they vibrate.
Liquid	The particles are packed slightly less closely together (compared with a solid). Each particle is still in close contact with most of its neighbours, but fewer than in the case of a solid. The general arrangement is slightly more jumbled and disorderly.	Because the particles are slightly less tightly packed than in a solid, they have the opportunity to move around within the bulk of the liquid. Hence the particles are both vibrating and moving from place to place.
Gas	Now the particles are widely separated from one another. They are no longer in contact, unless they collide with each other. In air, the average separation between the particles is about ten times their diameter.	The particles are now moving freely about, bouncing off one another and off the walls of their container. In air at room temperature, their average speed is about 500 m/s.

*The arrangement and movement of particles in the 3 different states of matter.

Kinetic (particle) Model of Matter

Solids	- **Strong forces of attraction** hold the particles close together in affixed, **regular arrangement**. - The particles don't have much **energy** so they can only **vibrate about their fixed positions**
Liquids	- There're **weaker forces of attraction** between the particles. - The particles are close together, but can move past each other, and form **irregular arrangements**. - They have **more energy** than the particles in a solid – they **move in random directions** and **at low speeds**.
Gases	- There are almost **no forces of attraction** between the particles. - The particles have **more energy** than those in liquids and solids – They are **free to move**, and travel in random directions and **at high speeds**.

Brownian Motion

Evidence for the kinetic model:

- In the 1820s, the movement of the particles of a gas was investigated by a Scottish botanist, **Robert Brown**. He was using a microscope to study **pollen grains** when he noticed tiny particles jiggling about. This motion is now known as Brownian motion, and it happens because the moving particles are constantly buffeted by the fast-moving particles of the air.
- *When we observe Brownian motion, we are not seeing particles of air or water. We are seeing their* ***effects on larger, visible particles***.

Brownian Motion

Evidence for the kinetic model:

Brownian motion: *the movement of* ***small particles suspended*** *in a gas or a liquid, caused by molecular bombardment*

- If smoke is introduced into a glass cell and observed through a microscope, the smoke particles can clearly be seen. The smoke particles appear to be in **random motion**. This is because they are constantly **being hit by the other** rapidly moving particles, in the air, in the glass cell.
- This is evidence that the particles in air are in **constant random motion**. It shows that **massive particles may be moved by light, fast-moving particles**.

Study Questions

Describe the motion of the atoms in a solid.

..... [1]

[Total: 1]

Complete the sentence. Choose from the words in the box.

solid	liquid	gas

The atoms are usually arranged in regular patterns in a ..... . [1]

[Total: 1]

Complete the sentence. Choose from the words in the box.

solid	liquid	gas

The state of matter with the lowest density is a ..... . [1]

[Total: 1]

Study Questions

Describe the motion of the atoms in a solid.

(atoms) vibrate/oscillate (about a fixed position) ..... [1]

[Total: 1]

Complete the sentence. Choose from the words in the box.

solid	liquid	gas

The atoms are usually arranged in regular patterns in a solid. [1]

[Total: 1]

Complete the sentence. Choose from the words in the box.

solid	liquid	gas

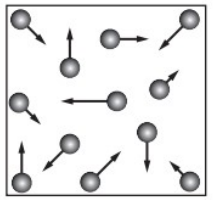
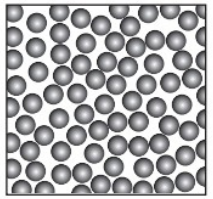
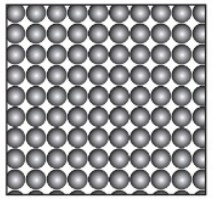
The state of matter with the lowest density is a gas. [1]

[Total: 1]

Study Questions

There are three states of matter.

Draw three lines, each line connecting a state of matter to the diagram representing the arrangement of the particles in that state of matter.

state of matter	diagram
solid	
liquid	
gas	

[1]

Study Questions

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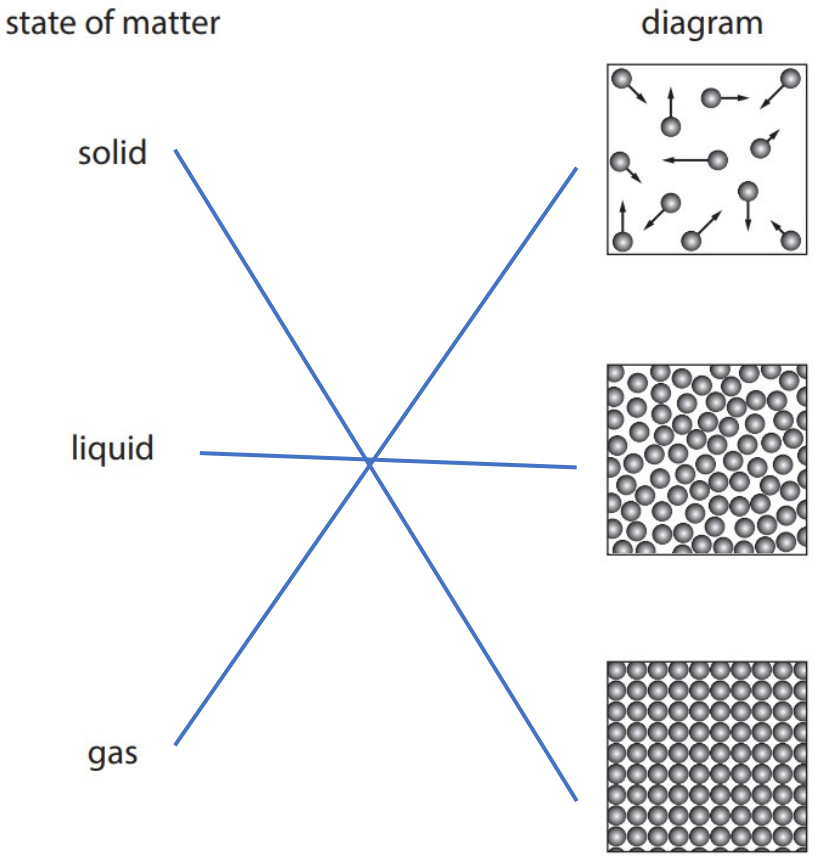
Draw three lines, each line connecting a state of matter to the diagram representing the arrangement of the particles in that state of matter.



[1]

Explanations using the kinetic model

The kinetic model of matter can be used to explain many observations:

- Liquids take up the shape of their container, because their particles are free to move about within the bulk of the liquid.
- Gases fill their container, because their particles can move freely about.
- Solids retain their shape, because the particles are packed tightly together.
- Gases diffuse (spread out) from place to place, so that, for example, we can smell perfume across the room. The perfume particles spread about because they are freely mobile.
- Most solids expand when they melt. The particles are slightly further apart in a liquid than in a solid.

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2.1.3 **Forces & the kinetic theory**

2.1.4 Gases & the kinetic theory

Forces & the kinetic theory

- Why do the particles that make up a solid or a liquid stick together? There must be **attractive forces** between them. Without attractive forces to hold together the particles that make up matter, there would be no solids or liquids, only gases.

- Another way to refer to these forces is to say that there are **bonds** between the particles. Each particle of a solid is strongly bonded to its neighbors. This is because the forces between particles are strongest when the particles are close together.

Kinetic theory & changes of state

What happens to these attractive forces as a solid is heated?

- The particles start to vibrate more and more strongly. Eventually, the particles vibrate sufficiently for some of the bonds to be broken, and a liquid is formed.
- Heat the material more and eventually the particles have sufficient energy for all of the attractive forces between particles to be overcome. The material becomes a gas.
- In a gas, the particles are so far apart and moving so fast that they do not stick together.
- If you cool down a gas (see next slide), the particles move more slowly. As they collide with one another, there is more chance that they will stick together.
- Keep cooling the gas and eventually all of the particles stick together to form a liquid.

Kinetic theory & changes of state

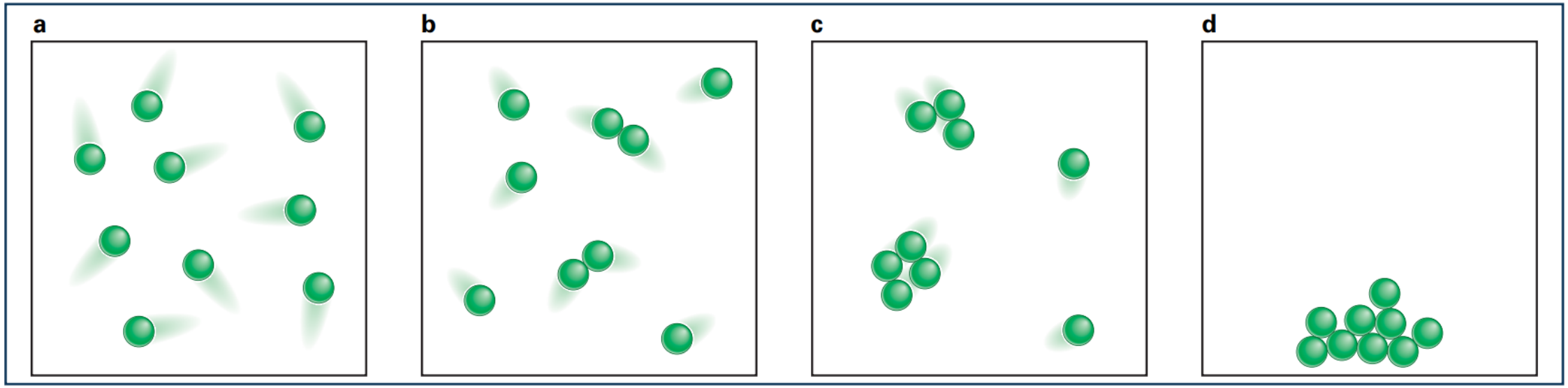

Figure 9.8 **a** As a gas is cooled, it starts to condense. **b** The particles move more slowly and they start to stick together, because of the attractive forces between them. **c** As their energy gets less, they clump together in bigger and bigger groups. **d** Finally, they form a liquid.

Kinetic theory & changes of state

- The gas particles are moving fast **in all directions**. If the gas is placed in **a sealed container**, when the particles hit the sides of the container, they rebound and so exert a **force** on the walls of the container. Hence, there is a pressure on the side of the container equal to the force exerted divided by the area of the side ($P = F/A$).

- If the **temperature** of the gas increases, the average speed of the particles and the number of collisions per second increases. Hence, the **force** exerted on the container by the particles is greater and so the pressure increases.

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2.1.4 **Gases & the kinetic theory**

Pressure of a gas

Particle theory says **colliding gas particles create pressure**:

- As gas particles move about, they randomly bang into each other and whatever else gets in the way.
- Gas particles are vey light, but they are not massless. When they collide with something, they **exert a force** on it and their momentum and direction change. In a sealed container, gas particles smash against the container's walls – creating an outward **pressure**.
- This pressure depends on **how fast the particle are going** and **how often they hit the walls**.
  - If you heat a gas, the particles move faster and have more energy in their kinetic stores. This increase in energy means the particles hit the container walls harder and more frequently, resulting in a larger **force**, creating more **pressure**. In fact, **temperature (in K) and pressure are proportional** – double the temperature for a fixed amount of gas, and you double the pressure.
  - If you put the same fixed amount of gas in a bigger container, the pressure will decrease, because there will be fewer collisions between the gas particles and the container's walls. When the volume's reduced, the particles get more squashed up and so they hit the walls more frequently, producing a larger force over a smaller surface area, which increases the pressure.

Pressure of a gas

- The gas particles are moving fast **in all directions**. If the gas is placed in **a sealed container**, when the particles hit the sides of the container, they rebound and so exert a **force** on the walls of the container. Hence, there is a pressure on the side of the container equal to the force exerted divided by the area of the side ($P = F/A$).
- If the **temperature** of the gas increases, the average speed of the particles and the number of collisions per second increases. Hence, the **force** exerted on the container by the particles is greater and so the pressure increases.

Gases & the kinetic theory

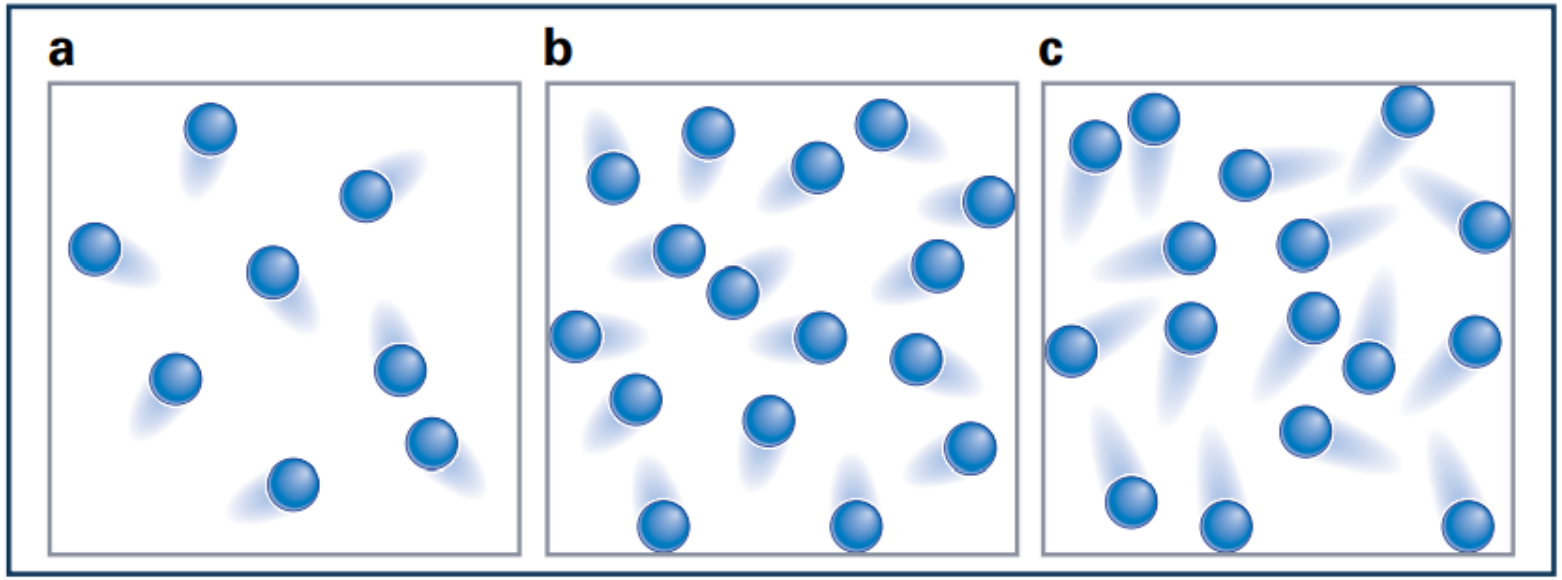


Figure 9.10 **a** The particles of a gas move around inside its container, bumping into the sides. **b** Doubling the number of particles means twice the mass, twice the density and twice the pressure. **c** At a higher temperature, the particles move faster. They have more kinetic energy, and this is what a thermometer records as a higher temperature.

Gases & the kinetic theory

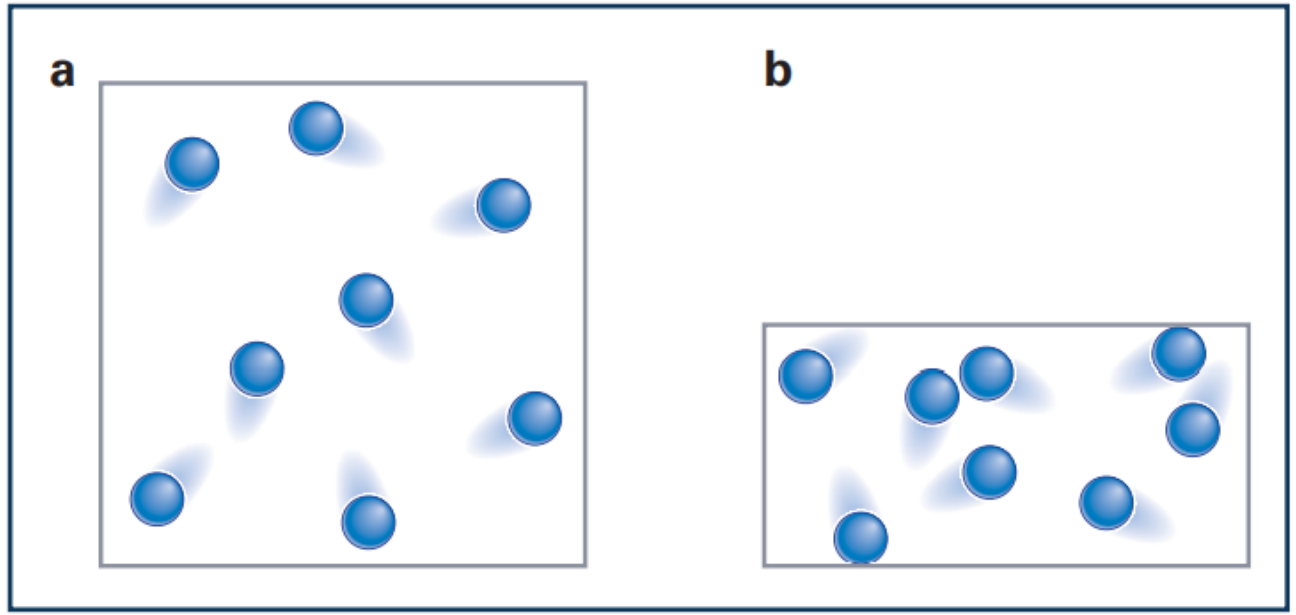
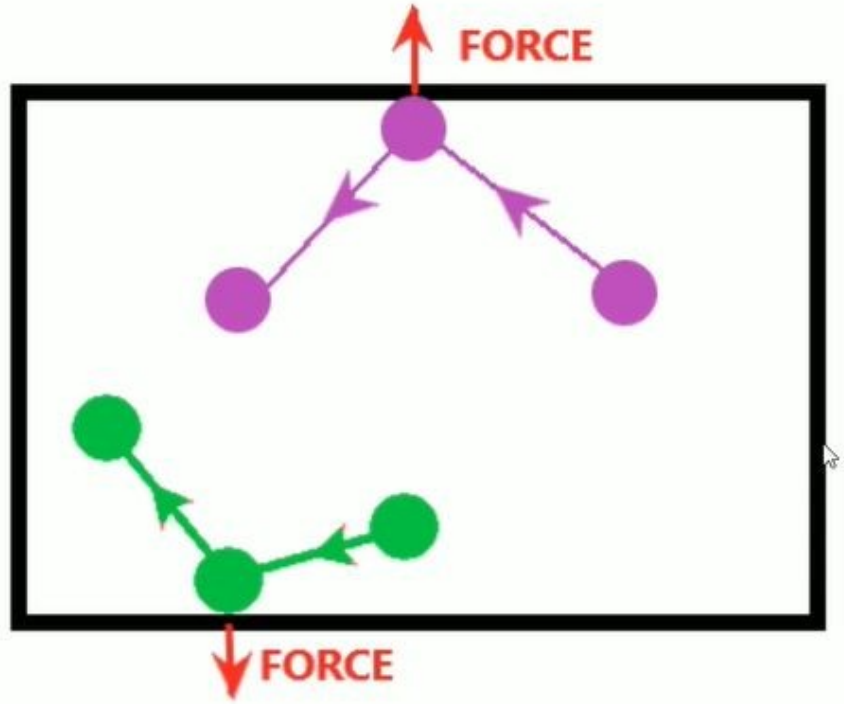
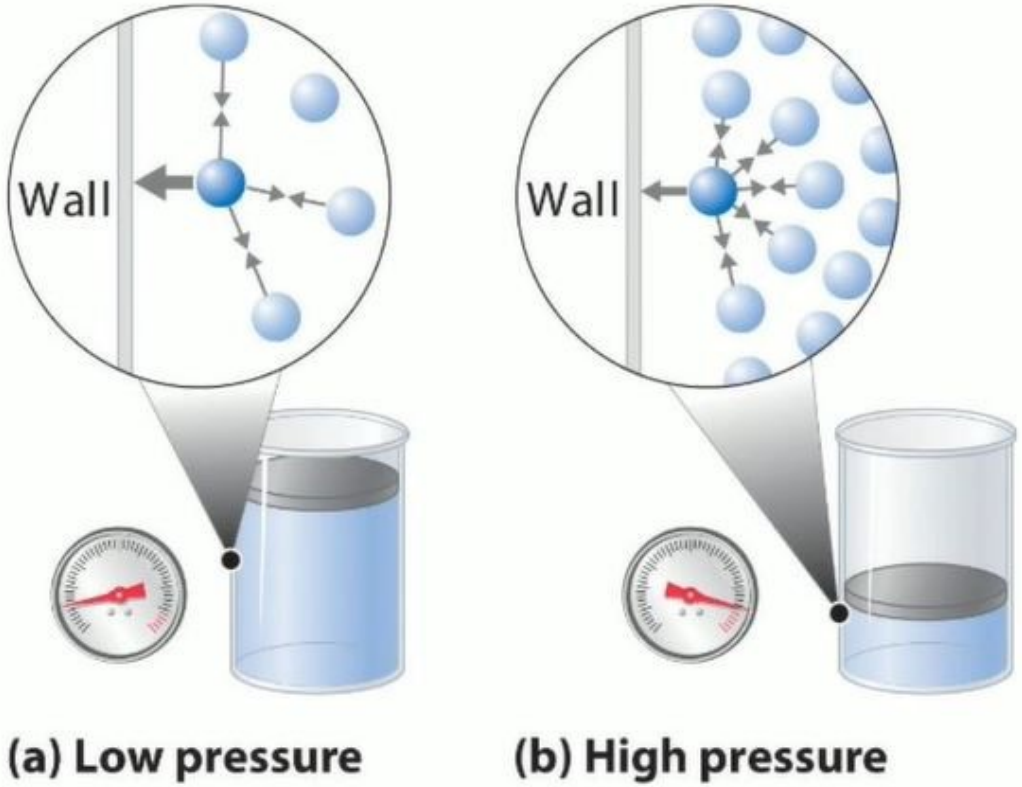


Figure 9.11 With the same number of particles in half the volume, in **b** there are twice as many collisions per second with the walls of the container, compared to **a**. The result is twice the pressure in **b** as in **a**.

Pressure of a gas

- Pressure of a gas is defined as **a change of momentum** of particles striking the walls of the container, **exerting force**





Boyle's law

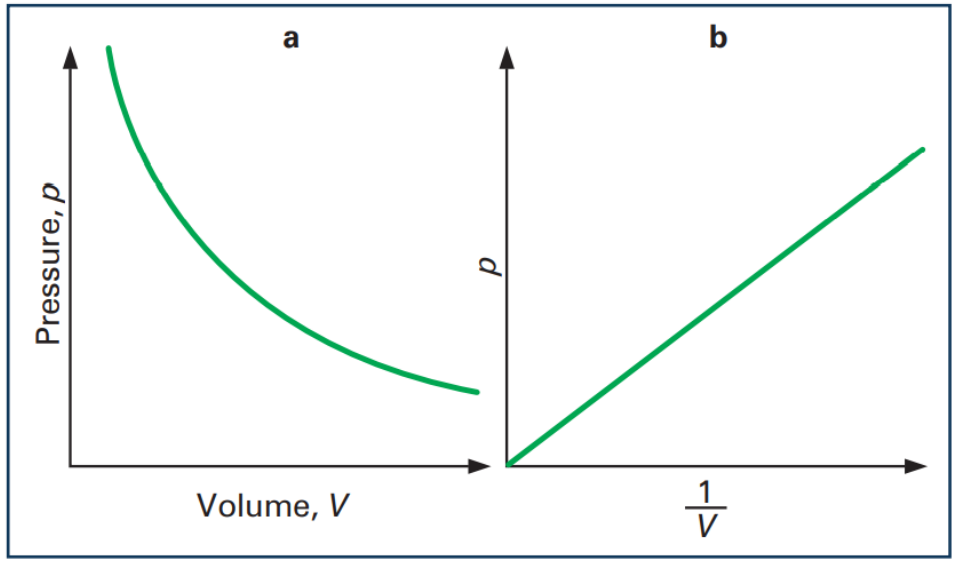


Figure 9.13 Two graphs to represent the results of a Boyle's law experiment. **a** The graph of pressure against volume shows that increasing the pressure causes a decrease in the volume. **b** The mathematical relationship between p and $1/V$ can be seen from this graph. Since it is a straight line through the origin, we can say that pressure is inversely proportional to volume (and vice versa).

Can we find a mathematical relationship between the pressure p and the volume v of the gas when **the temperature of the gas remains constant** throughout?

The relationship between p and v was investigated by Robert Boyle, an English physicist and chemist. He published his results in 1662.

Boyle's law

Boyle's law: the variation of volume of a gas with applied pressure

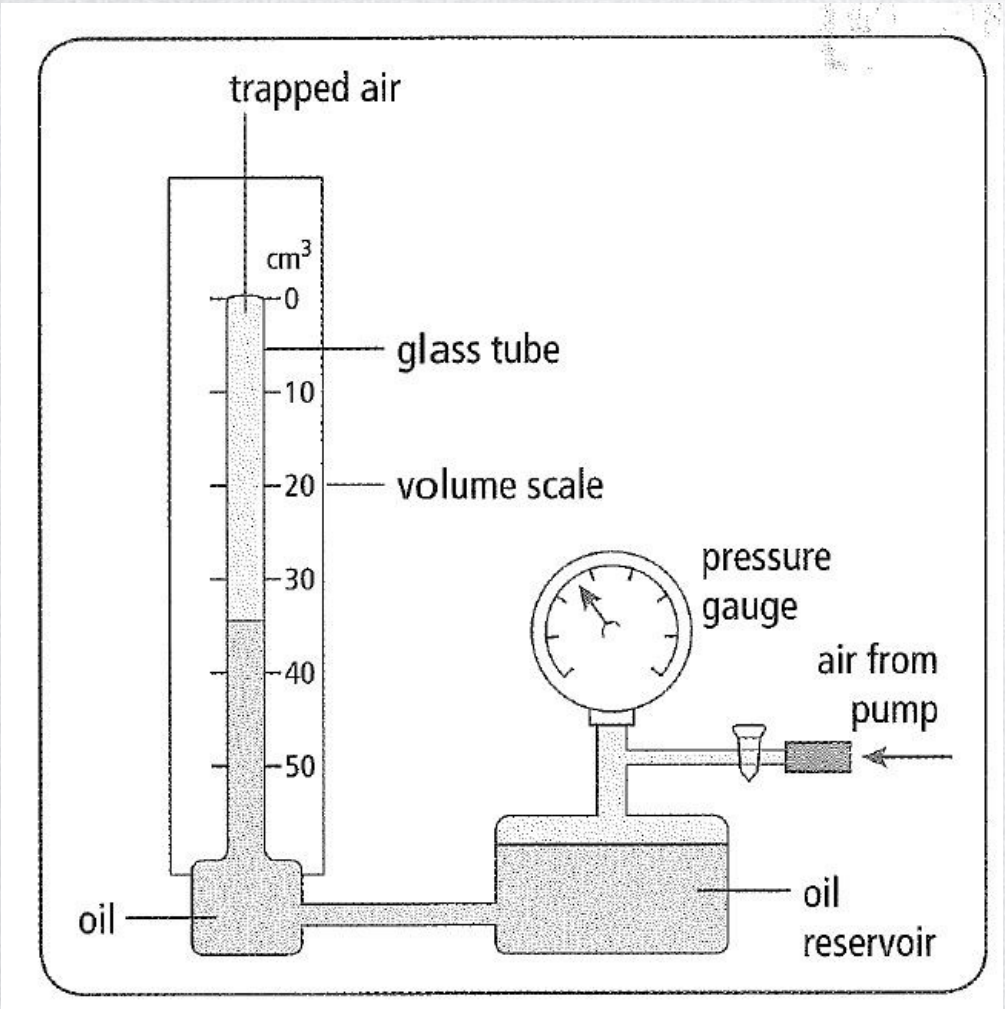
- Experimental procedure:

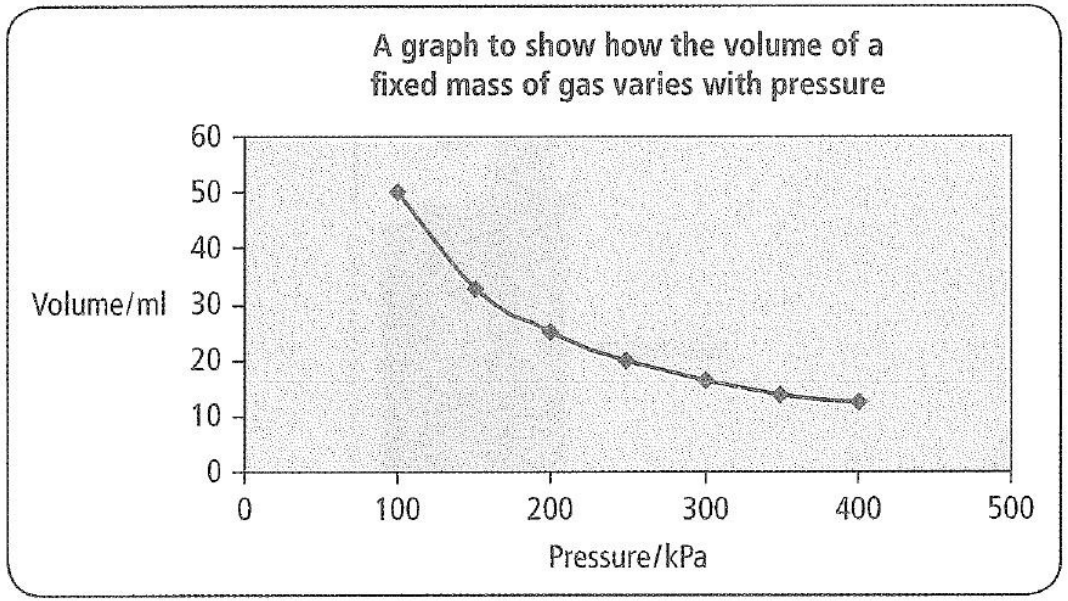
The pressure on a fixed mass of gas is varied by using a foot pump and measured using a pressure gauge **at constant temperature**. The volume of the gas is recorded as the pressure is increased.

- Results:

As the graph shows (next slide), when **the pressure on the gas is increased, the volume of the gas decreases**. If the pressure is doubled, the volume of the gas halves. **The volume is inversely proportional to the pressure applied**.

Boyle's law





▲ A graph to show how the volume of a fixed mass of gas varies with pressure

- The volume of a fixed mass of a gas is inversely proportional to its pressure, provided its temperature remains constant.

Pressure of a gas

- Higher temperature (at constant volume) → stronger collisions against container wall → exerts more force on container wall → increase pressure
- Lower volume (at constant temperature) → stronger & more frequent collisions against container wall → exerts more force on container wall → increases pressure
- **P·V = constant**

  where P = pressure

  V = volume
- $\boldsymbol{initial\ pressure\ \times initial\ volume = final\ pressure\ \times final\ volume}$

$$\boldsymbol{P_1V_1 = P_2V_2}$$

- **Boyle's law** states that **for a fixed mass of gas at a constant temperature, the volume is inversely proportional to the applied pressure**.

Pressure of a gas

At constant temperature :

$$P \cdot V = constant$$

$$P_1 \cdot V_1 = P_2 \cdot V_2$$

where

P_1 *and* V_1 *are starting conditions*

P_2 *and* V_2 *are* final *conditions*

- For a fixed mass of gas at a constant temperature
- This is applied to **ideal gas**. Ideal gases are gases that are well behaved.

Particle Theory

Study question:

An ideal gas held at a pressure of 310 kPa is compressed to a third of its original volume. Calculate the new pressure of the gas.

Particle Theory

Study question:

An ideal gas held at a pressure of 310 kPa is compressed to a third of its original volume. Calculate the new pressure of the gas.

$$V_2 = \frac{1}{3}V_1$$

$$\frac{V_1}{V_2} = 3$$

$$P_1V_1 = P_2V_2$$

$$P_2 = \frac{P_1V_1}{V_2}$$

$$P_2 = 310 \times 3 = 930\ kPa$$

Temperature & Particle Theory

Energy in particles' kinetic energy stores is proportional to temperature

- Particle theory says that gasses consist of very small particles which are constantly moving in completely random directions. The particles hardly take up any space – most of the gas is empty space.
- The particles constantly collide with and bounce off each other and the container walls.
- If you **increase the temperature of a gas**, you give its particles **more energy**. If you double the temperature (in kelvins), you double the average energy in the kinetic energy stores of the particles.
- The temperature of a gas (in kelvins) is proportional to average energy in kinetic energy stores of its particles.
- As the temperature of a gas increases, the average kinetic energy of the particles increases and so the average speed of the particles increases.

THANK YOU

Section 2.2

Thermal properties of matter

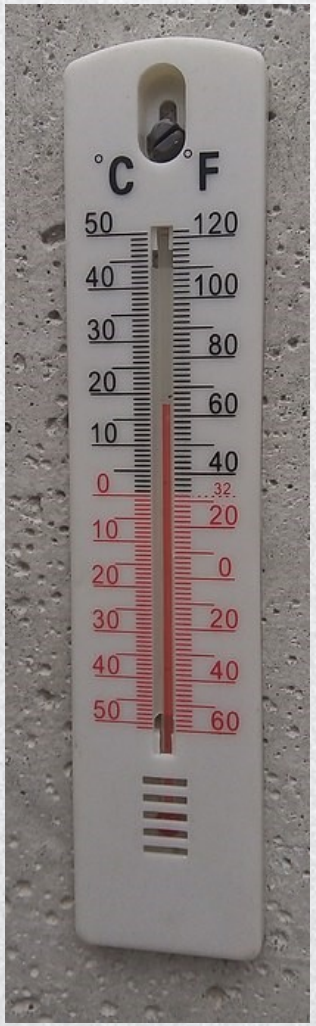
2.2.1 **Temperature & temperature scales**

2.2.2 Thermal expansion

2.2.3 Thermal capacity

2.2.4 Melting, boiling and evaporation

Measurement of temperature



Measurement of temperature

How can we define temperature?

Temperature is the measure of **hotness or coldness** expressed in terms of any of several **scales**, including **Kelvin, Fahrenheit, and Celsius**. Temperature indicates the direction in which heat energy will spontaneously flow—i.e. from a hotter body (one at a higher temperature) to a colder body (one at a lower temperature).

Measurement of temperature

- **Temperature**: measure of **average kinetic energy** of the individual particles.

- The **Celsius scale of temperature** is defined by its **two fixed points**:
  - the freezing point of pure water: 0 ◦C
  - the boiling point of pure water: 100 ◦C (in standard atmospheric conditions).

- The **Kelvin scale of temperature** is defined by the **vibrations of particles**. At **absolute zero**, (0 kelvin or 0 K) particles have zero kinetic energy and no longer vibrate. Compared to the Celsius scale, this occurs at **-273 ◦C** . The two scales have the same sized degree, 1 ◦C is 274 K so 2 ◦C is 275 K.

Measurement of temperature

The Celsius scale:

- Galileo is credited with devising **the first thermometer**, **in 1593**. The air inside the flask expanded and contracted as the temperature rose and fell. This made the level of the **water** in the tube change. This could only indicate changes in temperature over a narrow range, and proved unsatisfactory because **water evaporated** from the reservoir.
- Andres Celsius, working in Sweden, devised a more successful thermometer which had **a volume of mercury** in an **enclosed and evacuated tube**, with no change of liquid loss by evaporation.

Measurement of temperature

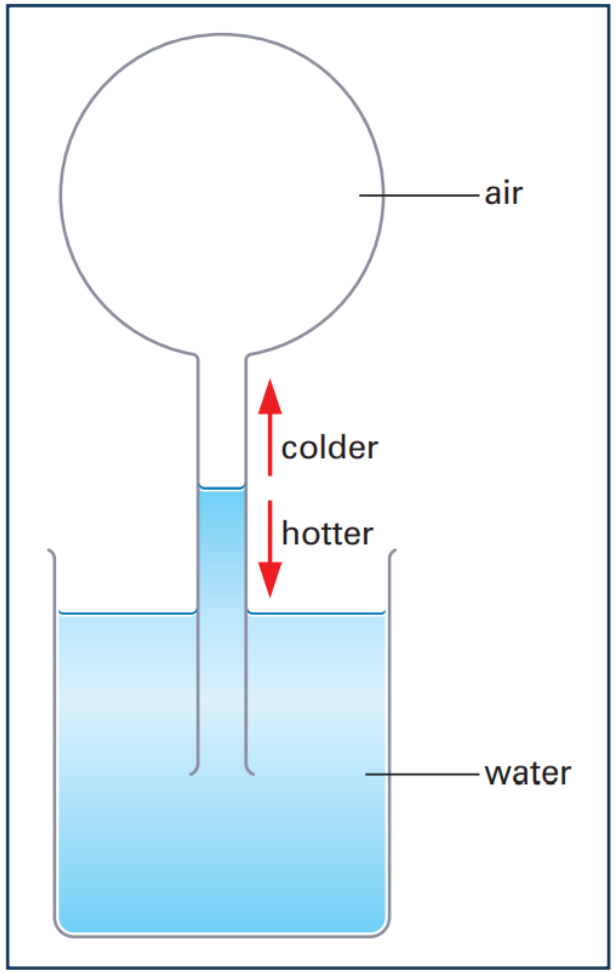


Figure 10.3 The idea behind Galileo's thermometer, the first of all thermometers. It had only a narrow operating range and no scale. As water evaporated and air dissolved in the water, the reading became unreliable.

Figure 10.4 A modern Celsius-scale liquid-in-glass thermometer, with a fixed quantity of mercury sealed in a glass tube.

Temperature & Internal Energy

- **Internal energy:** the total energy of all of the particles
  - ✓ Energy contained within the system
  - ✓ If an object is heated, since the particles gain more kinetic energy, the internal energy is increased
  - ✓ Temperature is a way of measuring the average internal energy of a substance

Temperature & Internal Energy

How and why a thermometer can tell us the temperature of a substance?

Temperature & Particle Theory

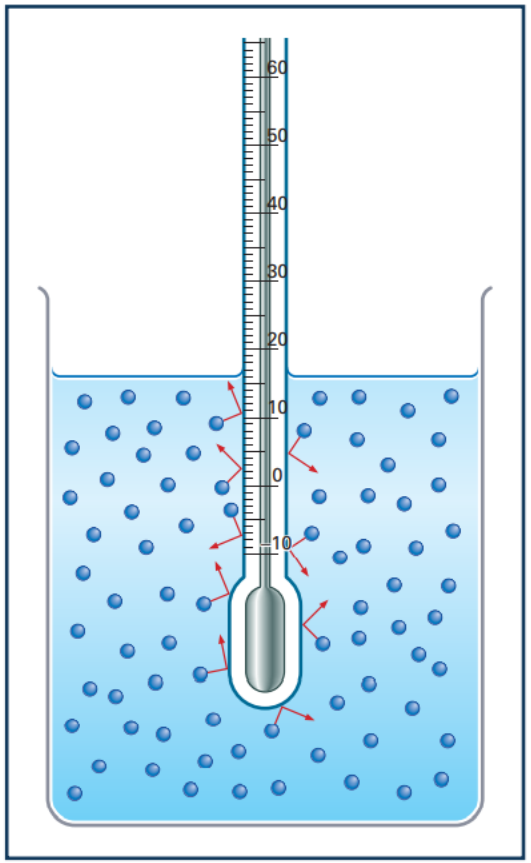


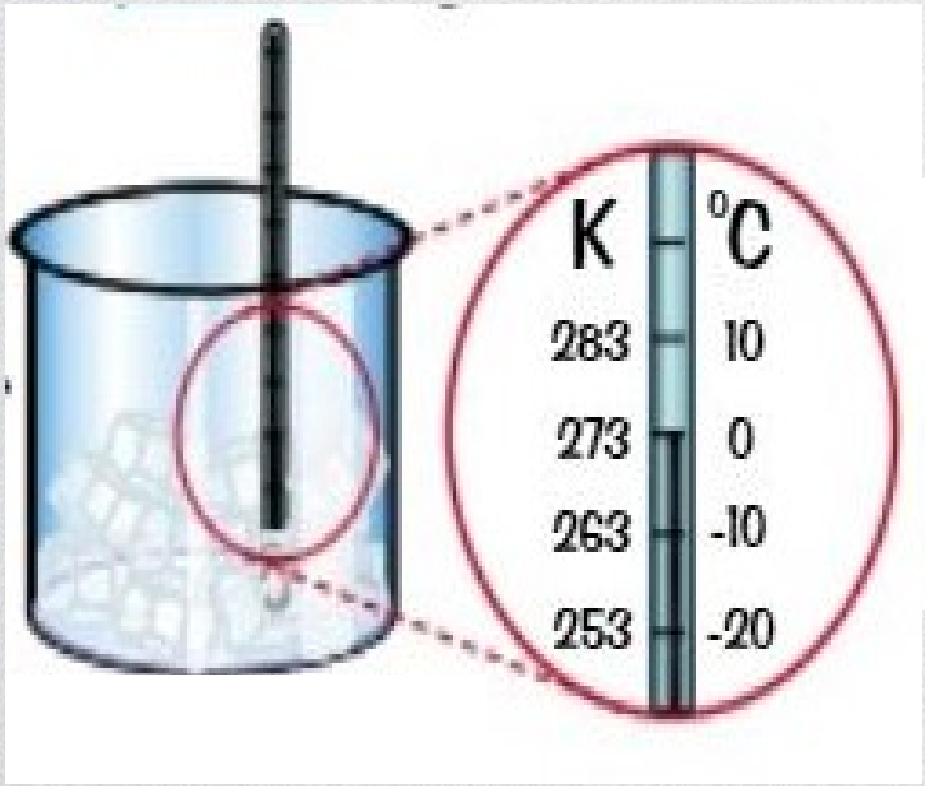
Figure 10.2 A thermometer placed in hot water is bombarded by the fast-moving water molecules. It absorbs some of their energy. Eventually, it reaches the same temperature as the water and gives the correct reading.

As shown in this figure, a thermometer measuring the temperature of some hot water, the molecules of the water are rushing about very rapidly, because the water is hot.

They collide with the thermometer and share their energy with it. The bulb of the thermometer gets hotter.

Eventually, the thermometer bulb is at the same temperature as the water. The water and the thermometer bulb are in the **thermal equilibrium** with one another (Energy is not being transferred from one to the other).

Temperature & Particle Theory



	Absolute zero	Freezing point of water	Boiling point of water
Celsius scale	–273 °C	0 °C	100 °C
Kelvin scale	0 K	273 K	373 K

Temperature & Particle Theory

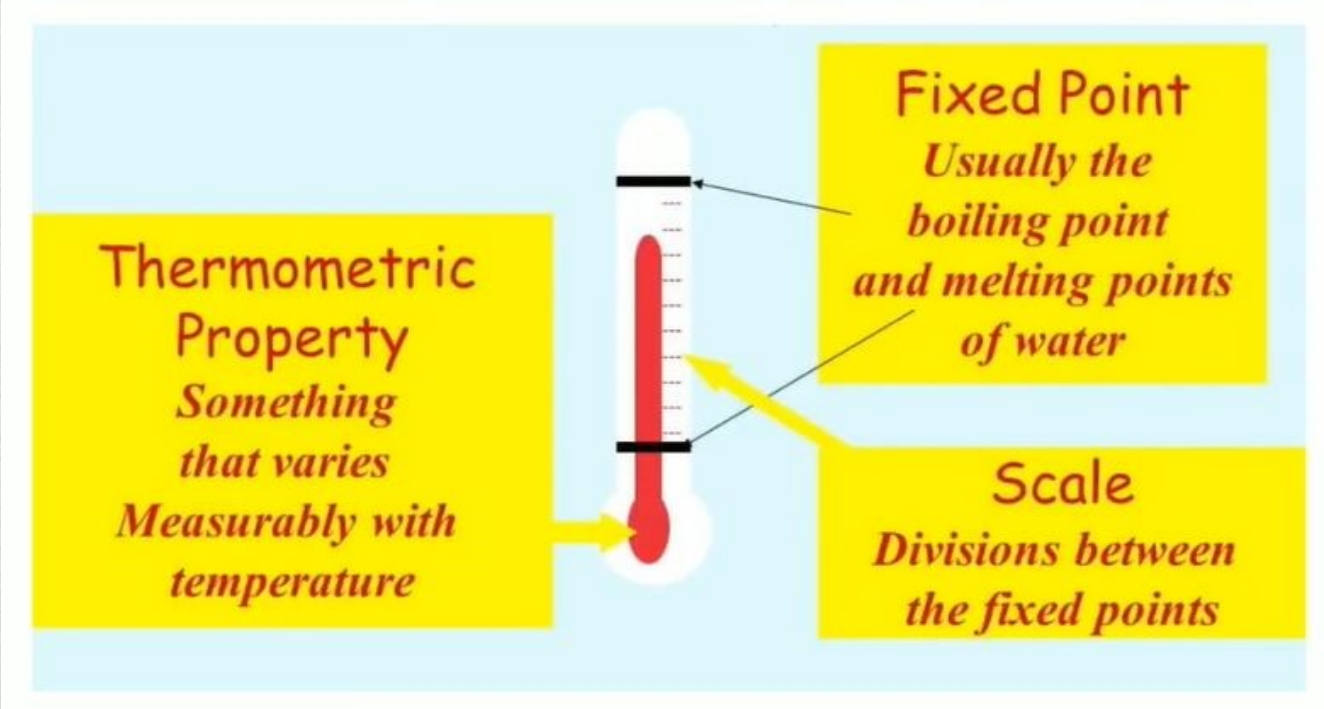
Absolute zero is as cold as stuff can get – 0 Kelvins

- If you increase the temperature of something, you give its particles more energy – they move about more quickly or vibrate more. Similarly, if you cool a substance down, you reduce the energy for the particles.
- **The coldest that anything can ever get is -273 ◦C – this temperature is known as absolute zero.** At absolute zero, the particles have as little energy in their kinetic stores as it's possible to get.
- Absolute zero is the start of the Kelvin scale of temperature.
- A temperature change of 1 ◦ C is also a change of 1 kelvin. The two scales are similar – **the only difference is where the zero occurs**.
- To convert from degrees Celsius to Kelvins, just add (+) 273. And to convert from Kelvins to degrees Celsius, just subtract (-) 273.

Examples of thermometers

- **Liquid-in-glass**: expansion of liquids
- **Thermistor**: A thermistor is an electrical component whose **resistance decreases with temperature**. It allows more current to flow when the temperature increases. The **current reading is converted to a temperature reading** on a digital meter.
- A **thermocouple** is made from **2 different types of metal**, which are joined together to form two junctions. When there is a difference in temperature between the junctions, a small potential difference is created that depends on the temperature difference between the two junctions. The "hot junction" is placed in the substance whose temperature is to be measured. The potential difference between the hot and the cold junctions is then measured. **The greater the temperature of the hot junction, the greater the potential difference. The potential difference is then converted to a temperature reading.**

Measurement of Temperature



- Physical property that varies with temperature
  - ✓ Thermal expansion
  - ✓ Electrical resistance
  - ✓ Potential difference
- Two fixed points
- Scale

Measurement of Temperature

Fixed points:

- To define a temperature scale, two **reference temperatures** called fixed points must be used
- These are temperatures at which certain particular physical properties manifest themselves i.e. freezing / boiling
- Celsius scale is defined by freezing point of water (0) and boiling point of water (100)

Types of Thermometers

Liquid-in-glass thermometers

- Liquid expansion
- Convenient to carry
- Limited range of temperatures
- Delayed temperature reading

Thermocouple

- Voltage differences
- Large range and accuracy
- Instant temperature readings

Study Questions

The graduations on a liquid-in-glass thermometer are equally spaced.

For the equal spacing of the graduations to be correct, state:

1. an assumption that is made about the liquid in the thermometer

.....

2. an assumption that is made about the structure of the thermometer.

.....

[2]

Study Questions

1. has uniform / linear expansion **OR** has equal expansion for each degree of temperature rise (1) **2.** has capillary / tube of constant cross-sectional area / diameter / radius / bore / width / thickness (1)	**2**

Temperature & Particle Theory

Study question:

Find the value of 25◦ in Kelvins.

Temperature & Particle Theory

Study question:

Find the value of 25◦ in Kelvins.

$$25 + 273 = 298 \text{ Kelvins}$$

THANK YOU

Section 2.2

Thermal properties of matter

2.2.1 Temperature & temperature scales

2.2.2 **Thermal expansion**

2.2.3 Thermal capacity

2.2.4 Melting, boiling and evaporation

Thermal Expansion

- Solids, liquids, and gases expand when **heating**
- This is because particles **gain more kinetic energy** when heated, and therefore **gain more separation** from neighboring particles
- The extend of expansion varies:
  - ✓ Solids expand the least
  - ✓ Liquids expand more than solids
  - ✓ Gases expand more than liquids

Thermal Expansion of Solids

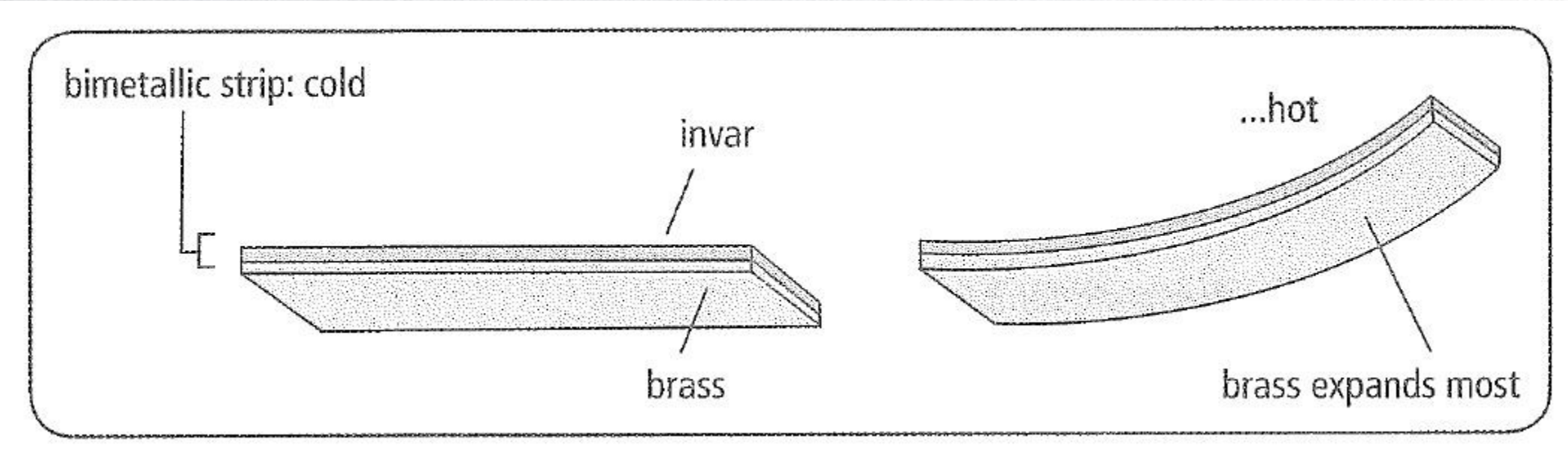
- **Railway tracks** have a small gap to account for thermal expansion
- If there were no gaps, the expansion would cause **misalignment problems**

The rails in the above image are the result of the thermal expansion and lack of gap between the adjacent rails.

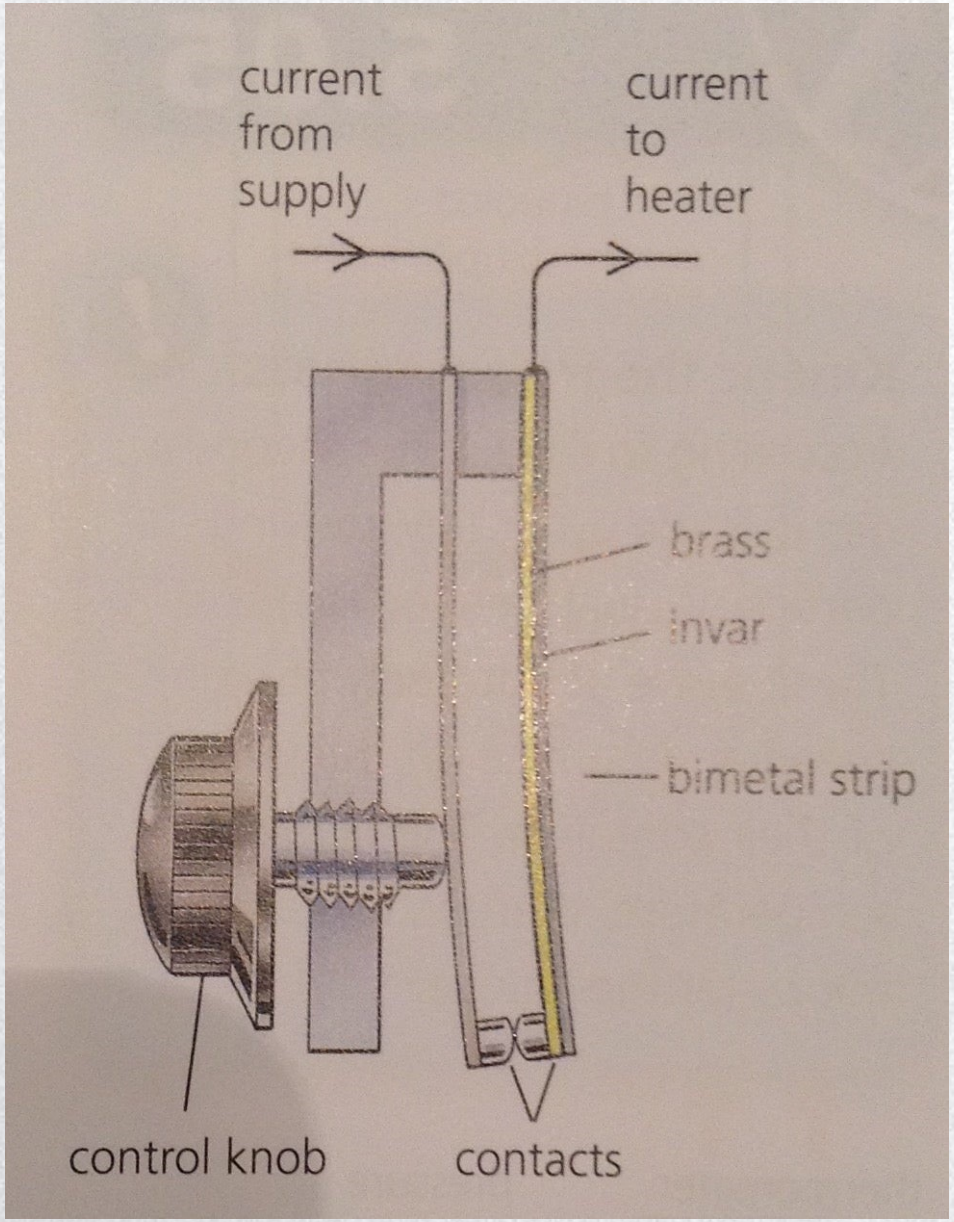
These gaps give room for expansion during hot weather

Thermal Expansion of Solids

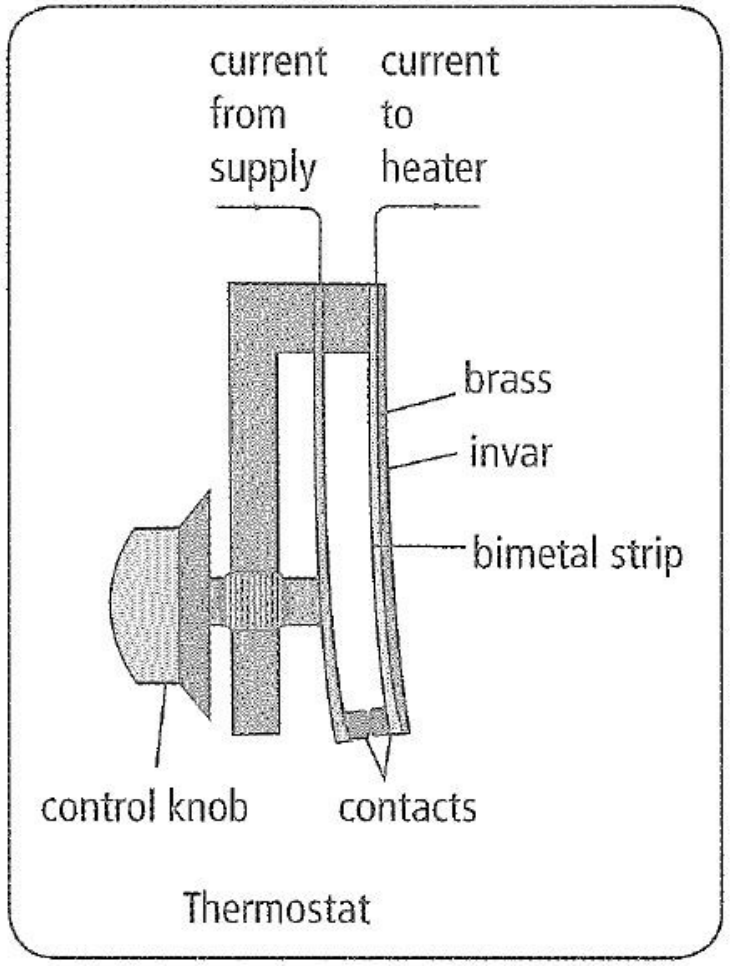
- The expansion of metals can be used in a **bimetallic strip**.
- When the strip is heated, 1 metal expands more than the other and so the strip bends. The higher the temperature, the more the strip bends.



Thermal Expansion of Solids



Thermal Expansion of Solids

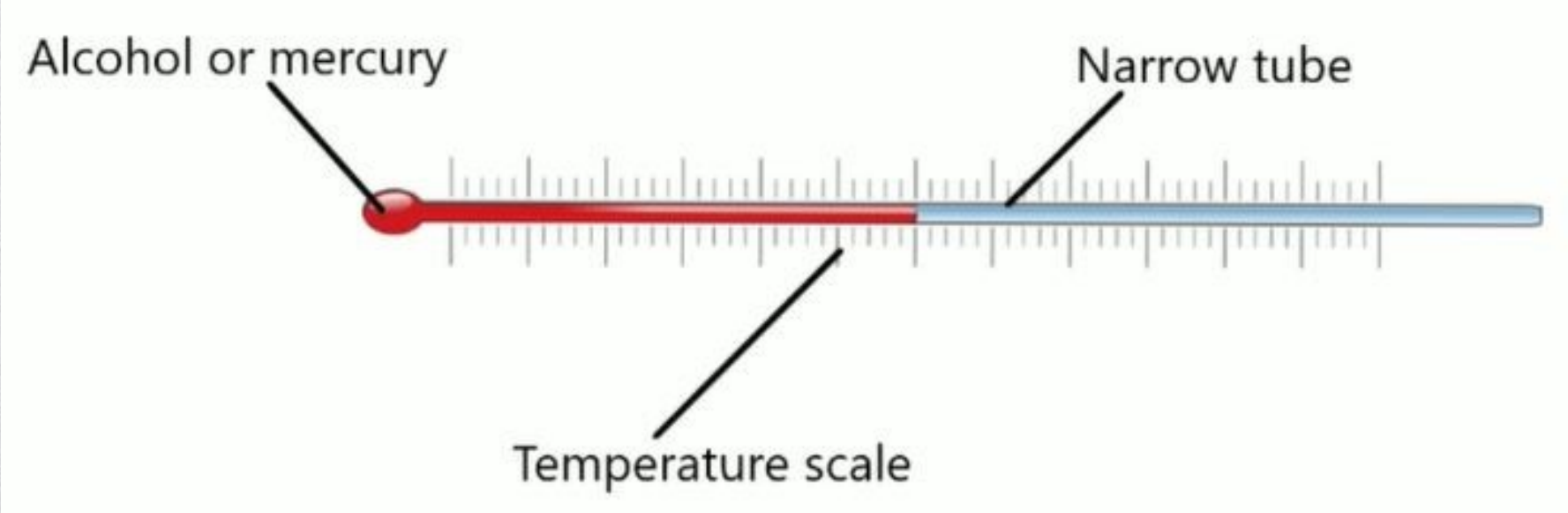


▲ Thermostat

- In a **thermostat**, when the temperature rises, the **bimetallic strip bends** and **the contacts separate**, **switching off** the current to the heater. When the temperature falls, the strip goes back to its original position and the heater is **switched on** again. The temperature at which this occurs can be altered using the adjustable control knob.

Thermal Expansion of Liquids

- Liquids expand more than solids when heated, enough for the effect to be visible.
- Thermal expansion of liquids are used in **liquid-in-glass thermometers**.
- When thermometer placed in hot liquid, the **alcohol or mercury** expands
- This forces the liquid to move up the narrow tube



Thermal Expansion of Gases

- Gases expand more than liquids when heated. When temperature of a gas is increased, particles gain more kinetic energy.
- This means the gas will take up more space (volume) if allowed. If the gas is free to expand, it expands.

THANK YOU

Section 2.2

Thermal properties of matter

2.2.1 Temperature & temperature scales

2.2.2 Thermal expansion

2.2.3 **Thermal capacity**

2.2.4 Melting, boiling and evaporation

Temperature & Internal Energy

- **Internal energy:** the *total* energy of *all* of the particles
  - ✓ Energy contained within the system
  - ✓ If an object is heated, since the particles gain more kinetic energy, the internal energy is increased

- **Temperature:** a measure of the *average* kinetic energy of the *individual* particles

Thermal Capacity

Thermal capacity:

- Thermal capacity is defined as **the amount of heat to be supplied to an object to produce a unit change in its temperature.**
- High thermal capacity means it takes a lot of energy to raise their temperature by a certain amount.
- The thermal capacity of an object depends on the material from which it is made and its mass.
- Objects made of non-metals and liquids have higher thermal capacities.
- $Thermal\ capacity = \frac{E}{\Delta T}$
- The **SI unit** of heat capacity is **joule per kelvin (J/K), non-SI unit** would be **J/°C**.

Thermal Capacity

- When heat energy is supplied to an object, its **internal energy** increases. This is because the molecules move faster so they have more kinetic energy. When an object's internal energy increases, the corresponding increase in temperature depends on its **thermal capacity**.

Thermal Capacity

A wood-burning stove is made of iron. The mass of the wood-burning stove is 85 kg.

The specific heat capacity of iron is 460 J / kg °C.

Calculate the thermal capacity of the wood-burning stove.

thermal capacity = ... [2]

[Total: 2]

Thermal Capacity

(C =) m c **OR** 85 × 460 (1) 3.9×10^4 J / °C (1)	**2**

Thermal Capacity

Water has a specific heat capacity of 4200 J / (kg °C) and a boiling point of 100 °C.

A mass of 0.30 kg of water at its boiling point is poured into a copper container which is initially at 11 °C. After a few seconds, the temperature of the container and the water are both 95 °C.

(a) Calculate the energy transferred from the water.

energy transferred = ... [2]

(b) Calculate the thermal capacity of the copper container.

thermal capacity of the copper container = ... [2]

[Total: 4]

Thermal Capacity

(E =) $mc\Delta T$ **OR** 0.30 × 4200 × (100 – 95) (1) 6300 J (1)	**2**
(C =) $E \div \Delta T$ **OR** 6300 ÷ 84 (1) 75 J / °C (1)	**2**

Thermal Capacity

A solar panel receives energy from the Sun at a rate of 5.0 kW.

Thermal energy is transferred from the solar panel to water with an efficiency of 20%.

Cold water of mass 15 kg enters the solar panel every hour.

The specific heat capacity of water is 4200 J / (kg °C).

Calculate the temperature increase of the water.

temperature increase = ... °C [4]

[Total: 4]

Thermal Capacity

E = mc ΔT in any form **OR** (E =) mc ΔT (1) efficiency = (energy) output / (energy) input in any form (1) 15 × 4200 × ΔT = 5000 × 3600 × 0.2 (1) (ΔT = 5000 × 3600 × 0.2 / 15 × 4200 =) 57 °C (1)	**4**

Specific Heat Capacity

The specific heat capacity of a substance is **the energy required to change the temperature of an object by 1 ◦C per Kg of mass**.

Energy required = mass × specific heat capacity × temperature change

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

	ΔE (J)	m (kg)	ΔT (◦ C)
Water	4200	1	1
Mercury	139	1	1

Specific Heat Capacity

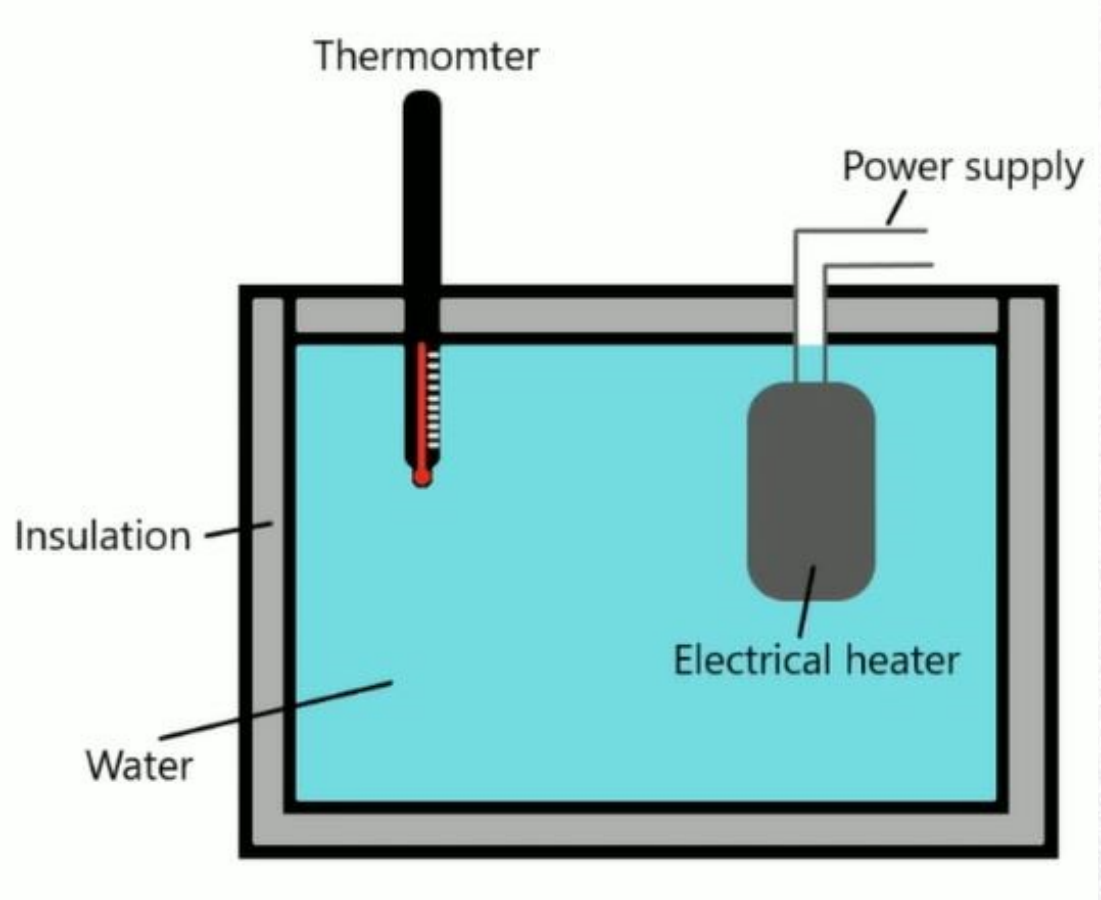
- The **specific heat capacity** of a material is the energy required to raise the temperature of 1 Kg of the material by 1 ◦C .
- Some materials need more energy to increase the temperature than the others (e. g. you need 4200 J to warm 1 kg of water by 1 ◦C , but only 139 J to warm 1 kg of mercury by 1 ◦C).
- Materials that need to gain lots of energy to warm up also release lots of energy when they cool down again. They store a lot of energy for a given change in temperature.
- Unit: **J/(kg °C)**

Specific heat capacity of water

$$c = \frac{\Delta E}{m\Delta T}$$

We need:

- Mass of substance (m)
- Temperature change of substance (ΔT)
- Energy used to cause this temperature change (ΔE)



Specific heat capacity of water

- 0.5 kg water is used into a container with insulation

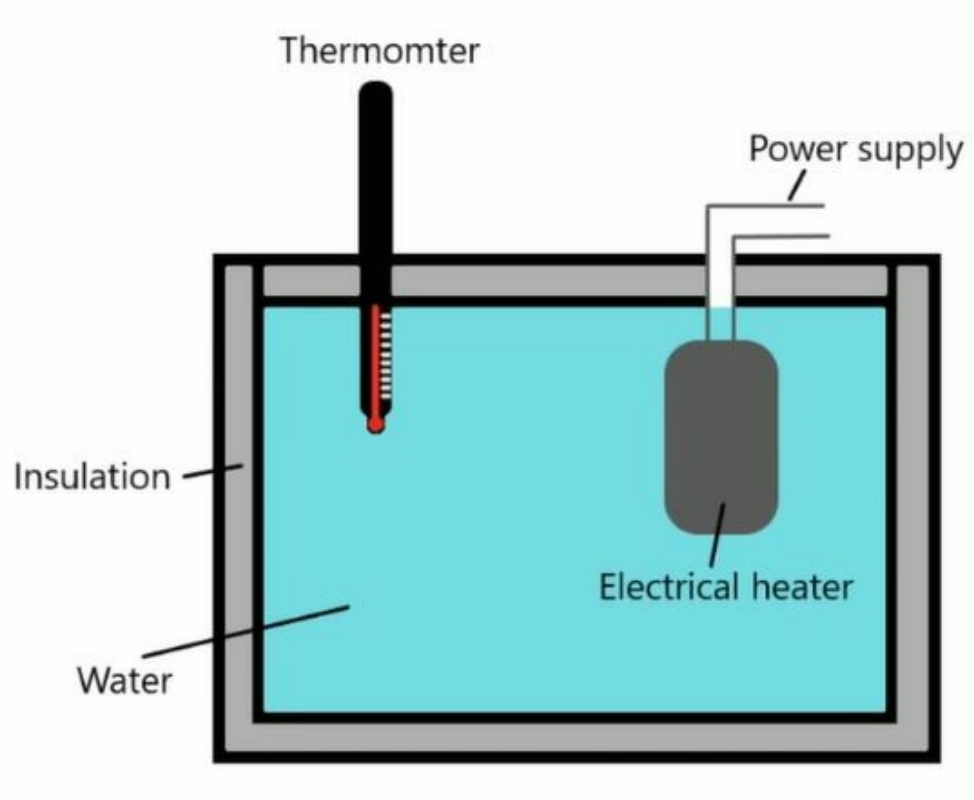
- A **thermometer** is used to measure the temperature of the water

- An electrical heater with known **power (50 W)** is placed in the water

- Initial temperature reading is taken

- The heater is switched on and a timer is started simultaneously

- Timer is stopped when the temperature sies by **10 ◦C**



Specific heat capacity of water

Energy supplied by heater (E) = power × time =

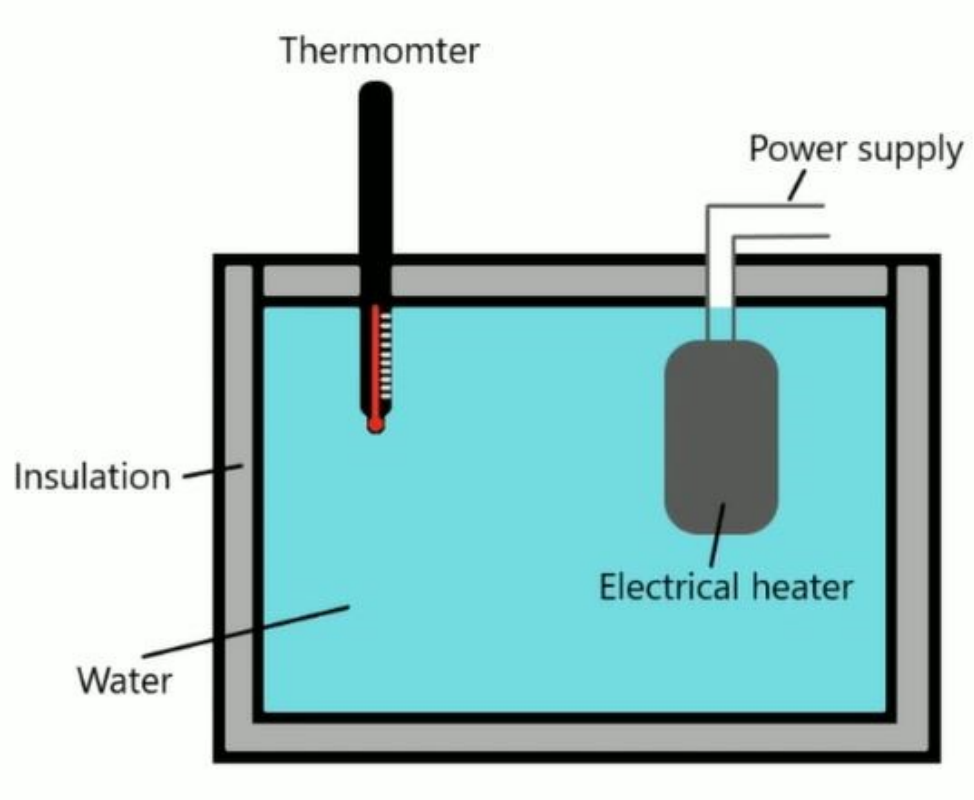
50 W × 420 s = 21000 J

Mass of water (m) = 0.50 kg

Change in temperature (ΔT) = 10 ◦C

$$c = \frac{\Delta E}{m\Delta T} = \frac{21000}{0.50 \times 10} = 4200\ J/(kg{\circ}\mathrm{C})$$

In reality, a lot of energy from the heater would not be transferred 100% to the water, so the value would be a bit different.



Specific Heat Capacity

Study question:

If a metal has a specific heat capacity of 420 J/kg ◦C, calculate how much the temperature of a 0.20 kg block of the metal will increase by if 1680 J of energy are supplied to it.

Specific Heat Capacity

Study question:

If a metal has a specific heat capacity of 420 J/kg ◦C, calculate how much the temperature of a 0.20 kg block of the metal will increase by if 1680 J of energy are supplied to it.

$$\Delta \mathrm{E} = mc\Delta T$$

$$\Delta \mathrm{T} = \frac{\Delta E}{mc} = \frac{1680}{0.20 \times 420} = 20\ \circ\boldsymbol{C}$$

Specific latent heat

- **Energy** must be supplied to a substance to melt it or boil it – in other words, to make it **change states**.
- This **energy does not increase the substance's temperature**, and for this reason it is known as **latent heat** (the word "latent" means "hidden").
- Latent heat of **fusion** ("fusion" means "melting"):
  - ✓ Energy required to **a solid into a liquid**
- Latent heat of **vaporization**:
  - ✓ Energy required to change a liquid into a gas
- To compare different substances fairly, we measure **the energy required to change the state of 1 kg of the substances**, so **specific latent heat** is defined as shown.

Specific latent heat

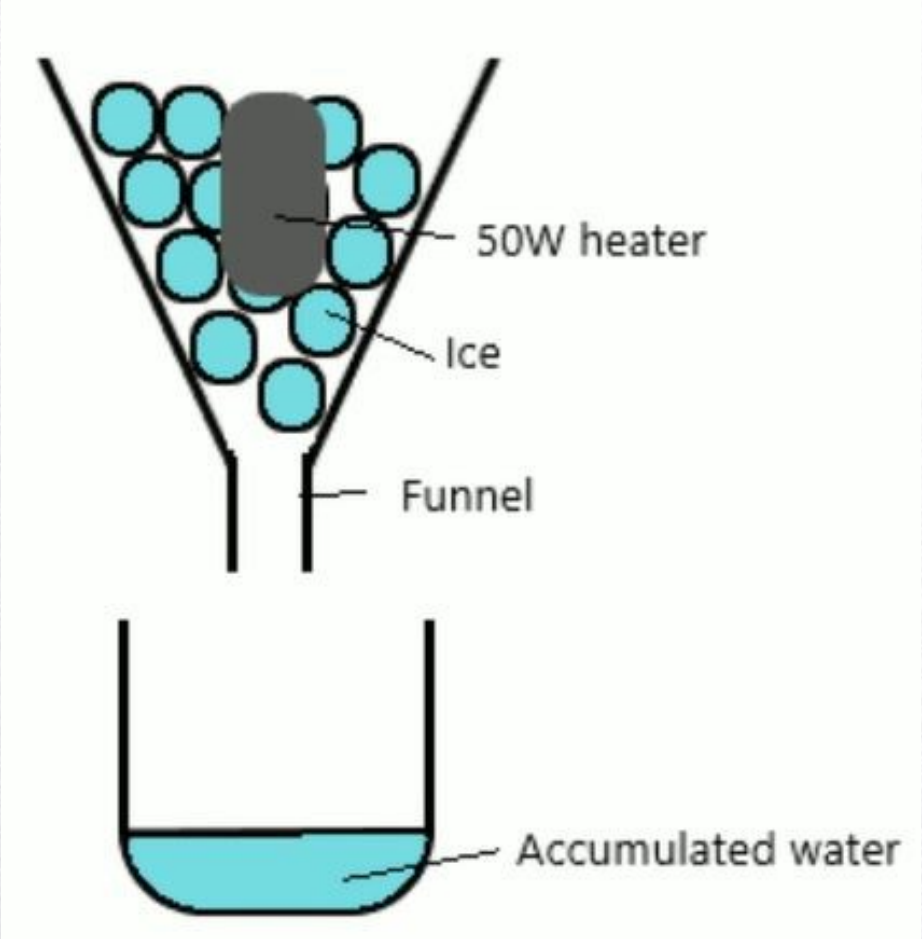
- **Specific latent heat of fusion (fusion means melting):**
  - ✓ Energy required to **melt** 1 kg of **solid** at its **melting point** with no change in temperature (energy per kilogram required to cause a substance to change state from **solid to liquid** at its **melting** point)
- **Specific latent heat of vaporization**:
  - ✓ Energy required to **vaporize** 1 kg of **liquid** at **boing point** with no change in temperature (energy per kilogram required to cause a substance to change state from **liquid to gas** at its **boiling** point)

$$Energy\ required = \text{mass} \times specific\ latent\ heat$$

$$\text{Energy} = \text{m} \times \text{L}$$

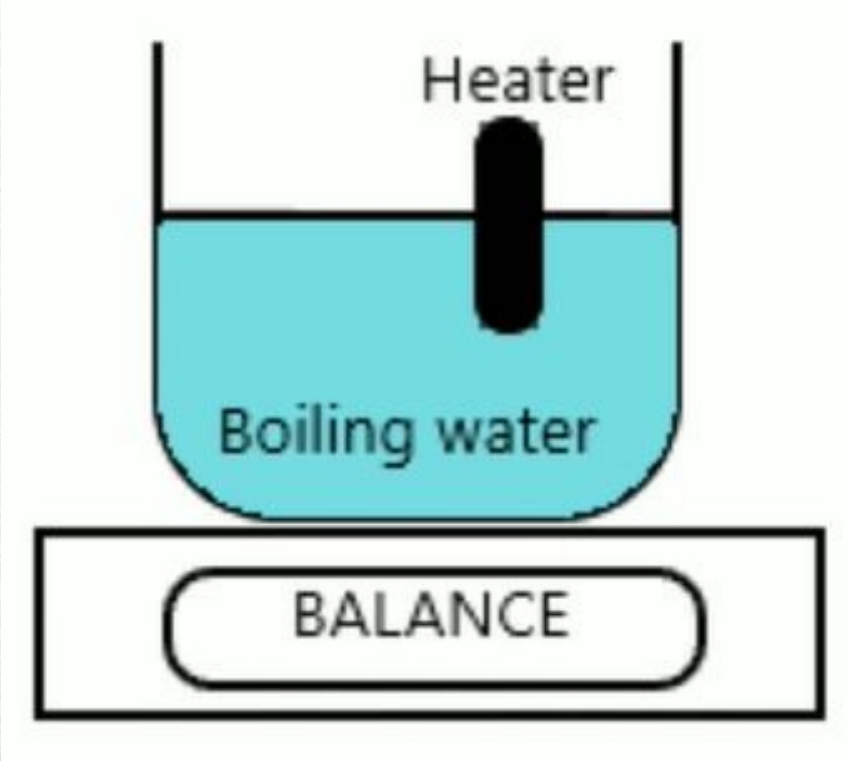
Specific latent heat of fusion of ice

- Fill a funnel with ice and place a beaker beneath it
- Place a 50W heater in the ice
- Turn on the heater and start the timer immediately
- After 10 min (600 s) turn off the heater
- Measure the mass of the accumulated water in the beaker
- Lets assume that we accumulated a total of 0.1 L of water in 10 min.
- Energy supplied (E) = power × time = 50 × 600 = 30 000 J
- M = 0.1 L
- L = 30000/0.1 = 300 000 J/kg



Specific latent heat of vaporization of water

- Part fill a beaker with water and place on a balance
- Place a 50W heater in the water
- Switch the heater wait water to boil
- Once water is boiling start the timer and take the balance reading
- When the mass reading has decreased by 0.1 kg, stop the timer
- Let s assume it took 4600 s to reduce the mass by 0.1 kg
- Energy supplied (E) = power × time = 50 × 4600 = 230 000J
- $\Delta m = 0.1$ L
- L = 230000/0.1 = 2 300 000 J/kg



THANK YOU

Section 2.2

Thermal properties of matter

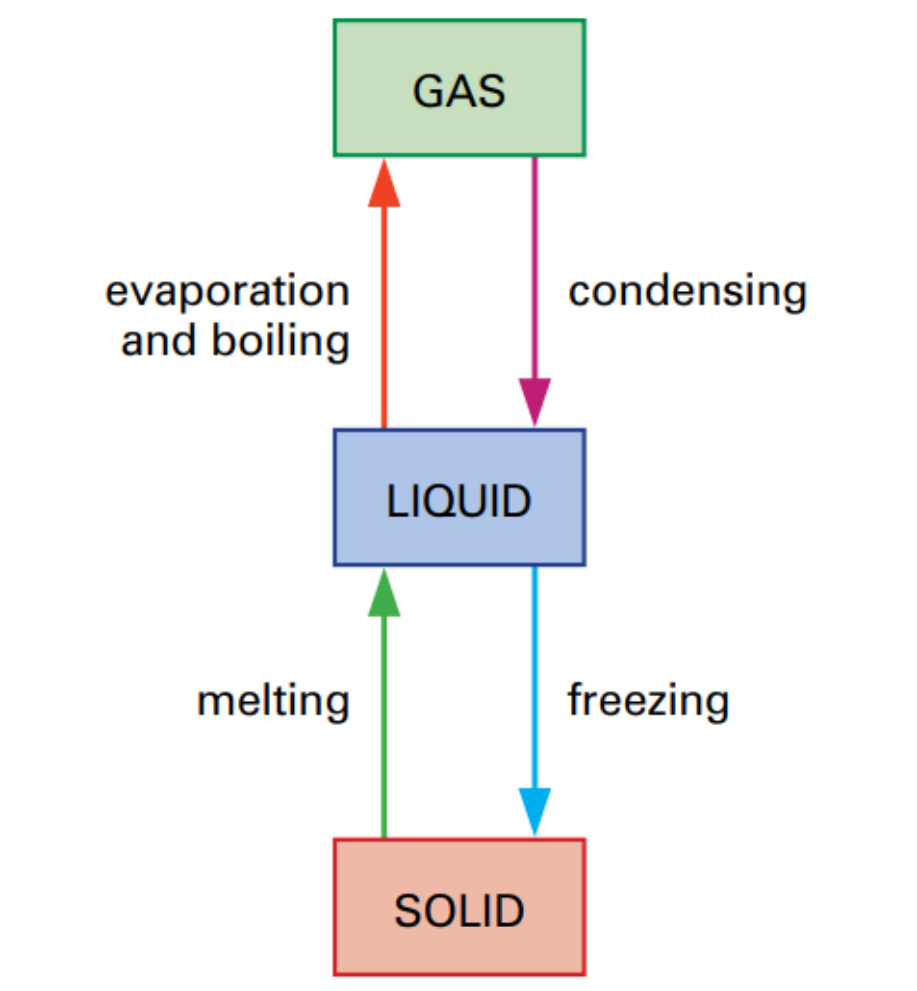
2.2.1 Temperature & temperature scales

2.2.2 Thermal expansion

2.2.3 Thermal capacity

2.2.4 **Melting, boiling and evaporation**

Changes of States

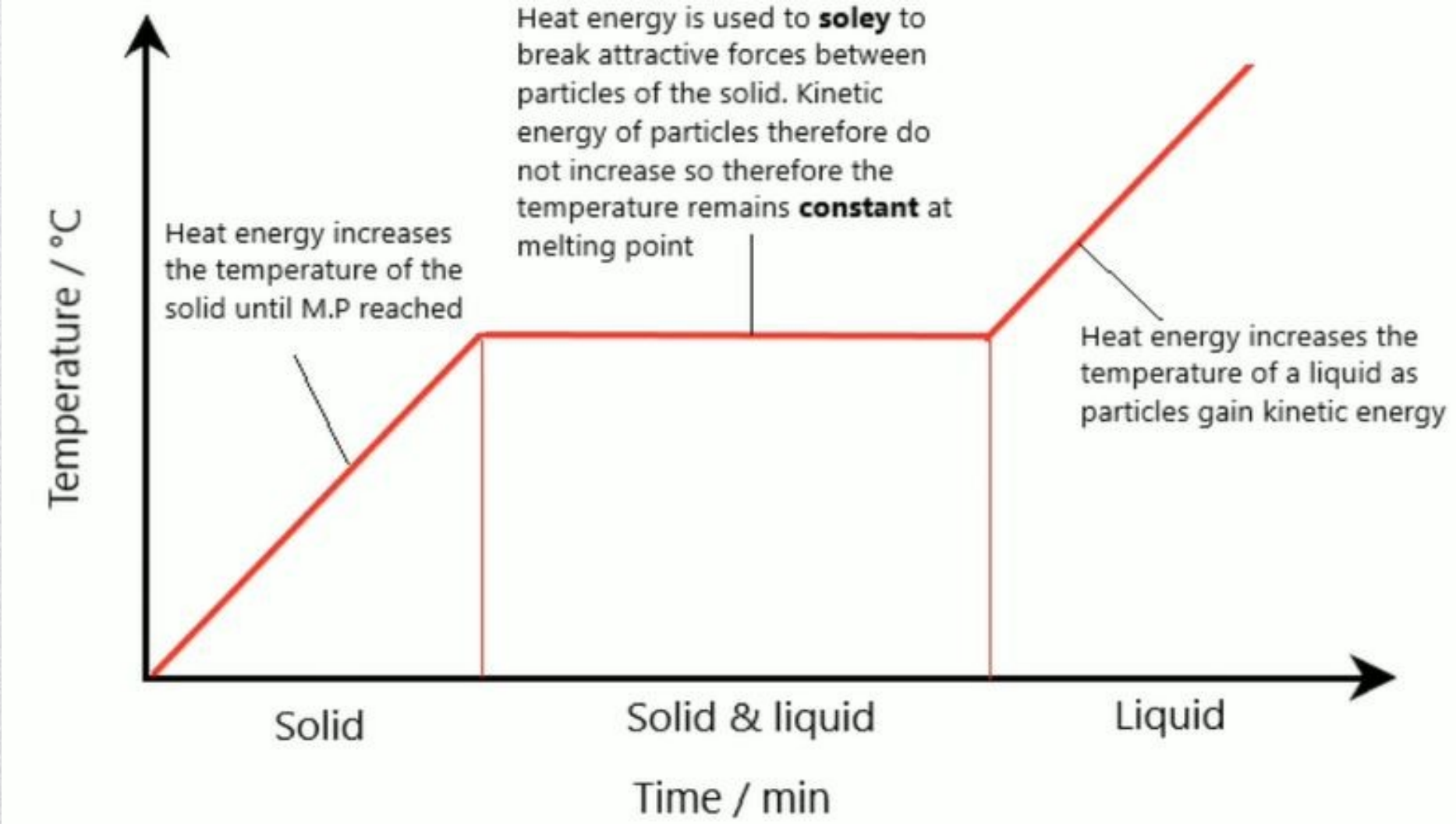


Changes of States & Particle (Kinetic) Theory

- The energy in a substance's thermal energy store is held by its particles in their kinetic energy stores – this is what the thermal energy store actually is.

- When you **heat** a liquid, the **extra energy** is transferred into the particles' **kinetic energy stores**, making them move faster. Eventually, when enough of the particles have enough energy to **overcome their attraction** to each other, **big bubbles of gas form in the liquid**– this is **boiling**.
  - ✓ The **boiling point** is the temperature at which a liquid becomes a gas.
- It is similar when you heat a solid. The extra energy makes the particles vibrate faster until eventually the force between them are partly overcome and the particles start to move around – this is **melting**.
  - ✓ The **melting point** of a substance is the temperature at which it turns from a solid to a liquid.
- When a substance is **condensing or freezing**, **bonds are forming** between particles, which ***releases energy***. This means the temperature doesn't go down until all of the substance has changed state.

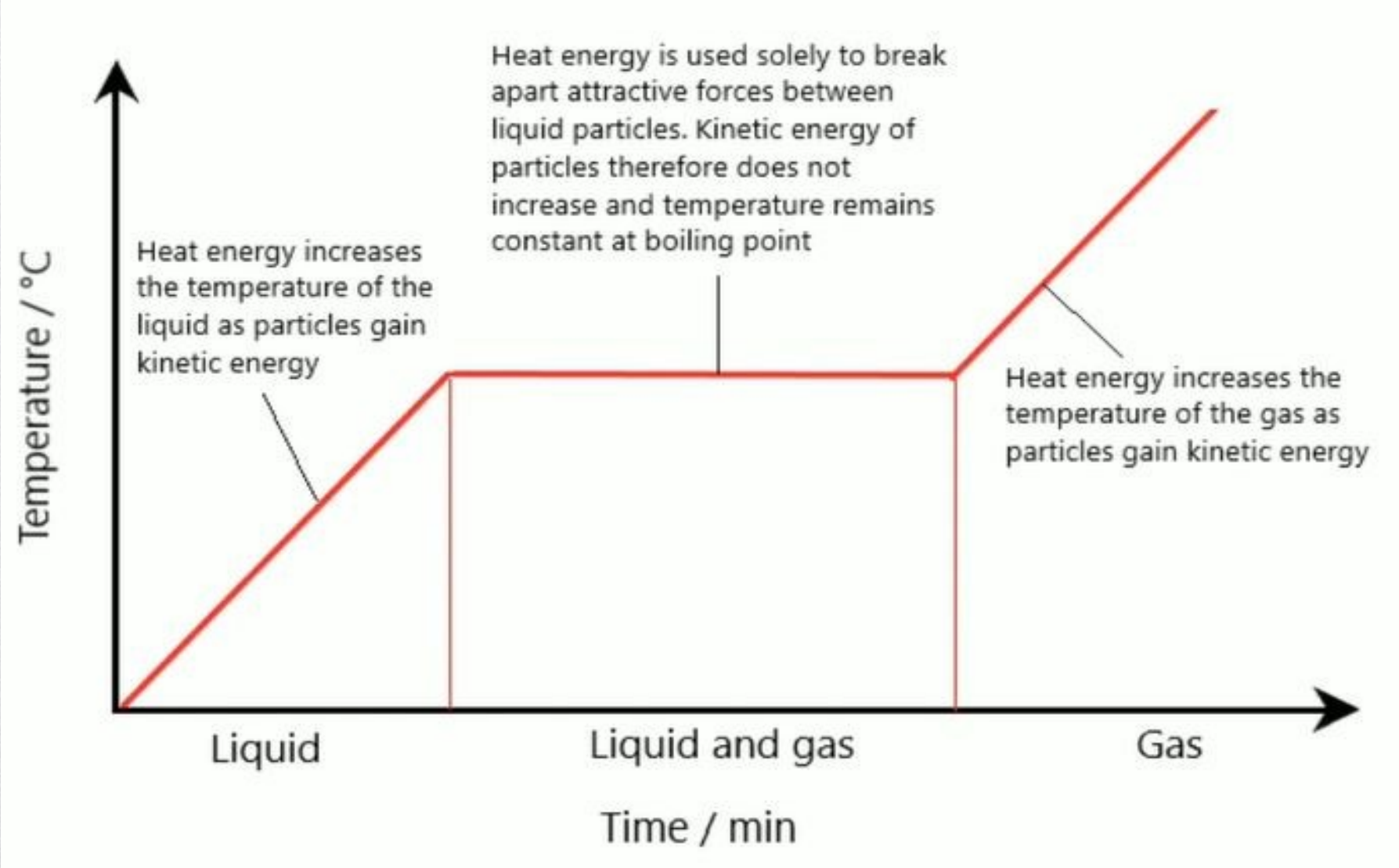
Melting


Heat energy is used to **soley** to break attractive forces between particles of the solid. Kinetic energy of particles therefore do not increase so therefore the temperature remains **constant** at melting point
Heat energy increases the temperature of the solid until M.P reached
Heat energy increases the temperature of a liquid as particles gain kinetic energy
Temperature / °C
Solid
Solid & liquid
Liquid
Time / min

Melting

- Solid → Liquid
- As solid is heated, temperature rises until melting point is met
- Once melting point reached, solid will transition into liquid
- **During transition phase, temperature is constant**
- Once solid has fully melted, temperature of liquid rises again
- **Latent heat of fusion** is the energy required to melt a solid at melting point

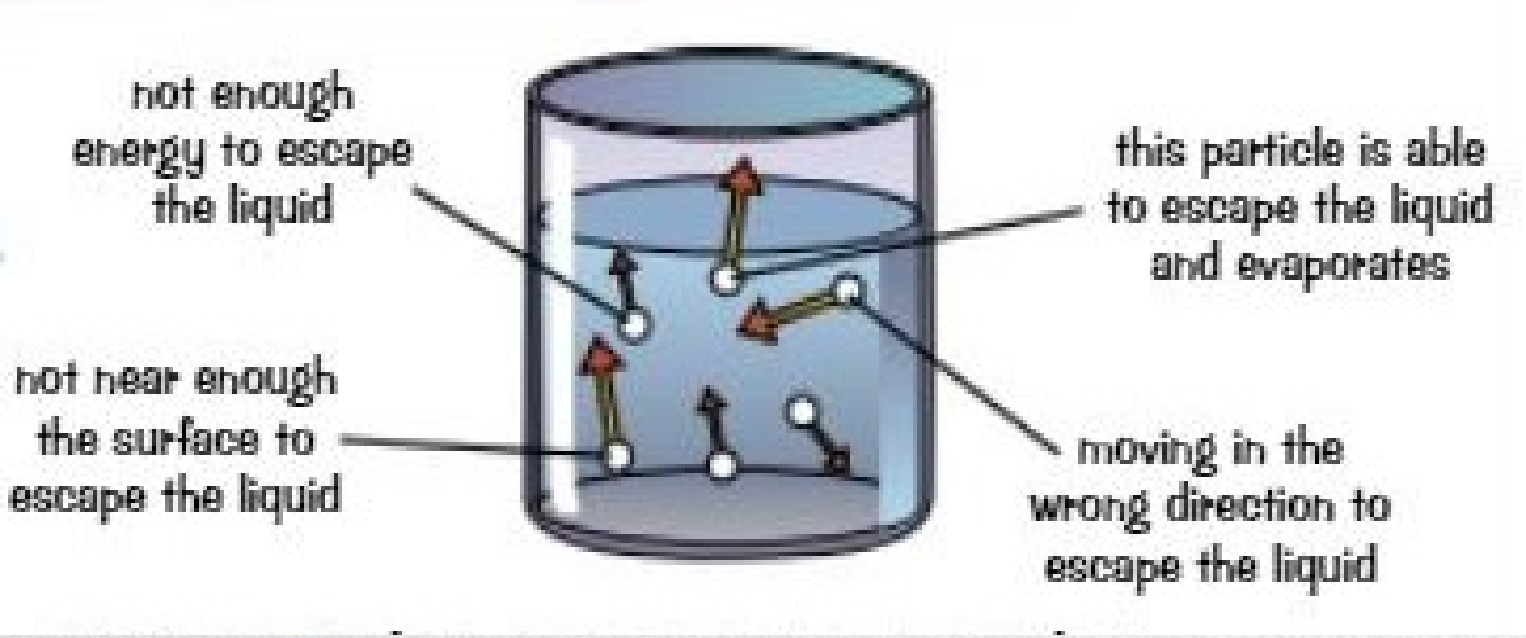
Boiling


Heat energy is used solely to break apart attractive forces between liquid particles. Kinetic energy of particles therefore does not increase and temperature remains constant at boiling point
Heat energy increases the temperature of the liquid as particles gain kinetic energy
Heat energy increases the temperature of the gas as particles gain kinetic energy
Temperature / °C
Liquid
Liquid and gas
Gas
Time / min

Boiling

- Liquid → Gas
- As liquid is heated, temperature rises until boiling point is met
- Once boiling point reached, **temperature stays constant** as liquid becomes a gas
- Once liquid has fully boiled into gas, temperature of gas begins to rise
- **Latent heat of vaporization** is the energy required to vapourize a liquid at boing point

Evaporation



Evaporation

Observation	Explanation
A liquid evaporates more rapidly when it is **hotter**.	At a higher temperature, more of the particles of the liquid are **moving fast** enough to escape from the surface.
A liquid evaporates more quickly when it is spread out, so that it has a **greater surface area**	With a greater surface area, more of the particles are **close to the surface**, and so they can escape more easily.
A liquid evaporates more quickly when **a draught blows across its surface**.	A draught is **moving air**. When particles escape from the water, they are blown away so that they cannot fall back in to the water.

Evaporation

- Evaporation is the change from **liquid to gas below the boiling point**
- Not all particles in a liquid have the same kinetic energy
- Some particles may be moving quicker (higher energy), and some may be moving slower (lower energy)
- Particles with a large amount of kinetic energy may **overcome attractive forces and escape the surface of the liquid as a gas**
- Since most energetic particles escape, it will **lower the temperature (average kinetic energy) of the liquid**
- Factors that cause **increased evaporation**:
    1. higher temperature
    2. Larger surface area
    3. More air flow over surface of the liquid

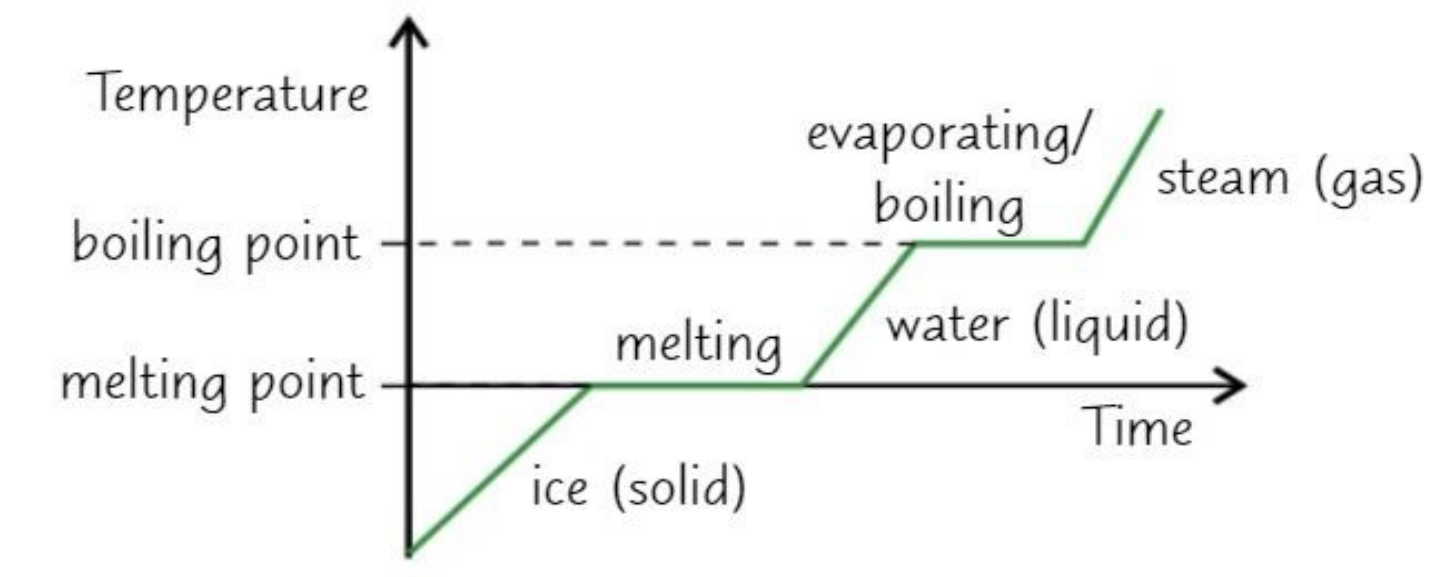
Evaporation

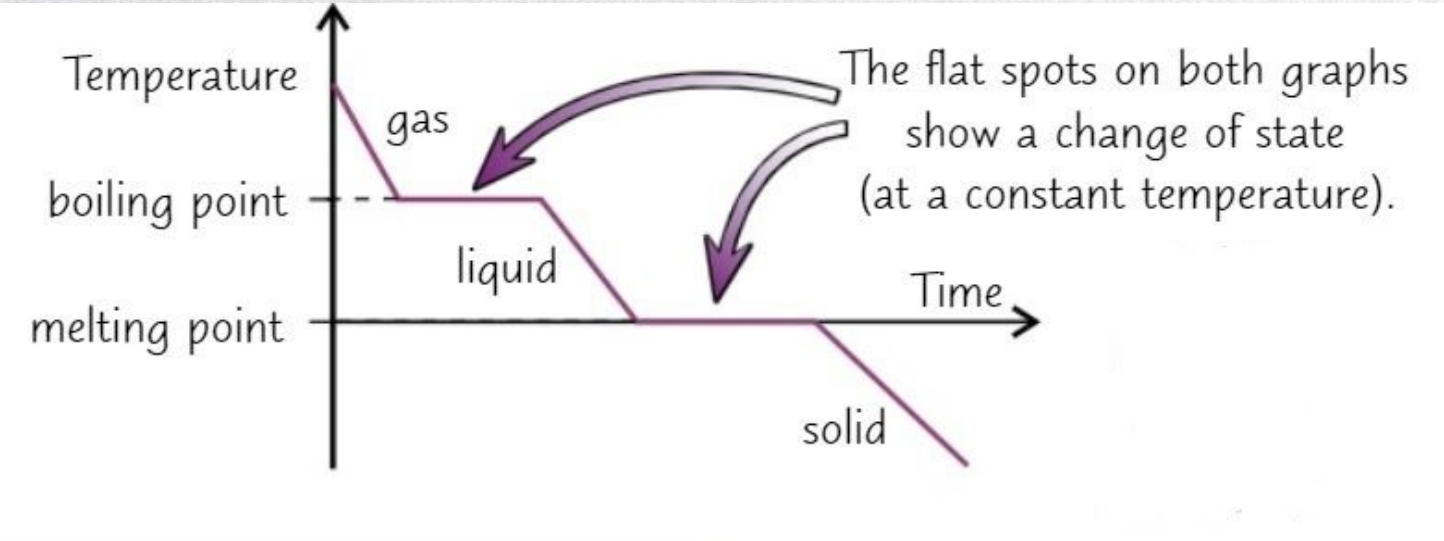
- Evaporation is when particles escape from a liquid and become gas particles.
- Particles can evaporate from a liquid at temperatures that are much lower than the liquid's boiling point.
- **Particles near the surface of a liquid** can escape and become gas particles if:
  - ✓ The particles are **traveling in the right direction** to escape the liquid.
  - ✓ The particles are **traveling fast enough** to over the attractive forces of the other particles in the liquid
- The fastest particles (with the most energy) are most likely to evaporate from the liquid – so when they do, the average speed and energy in the kinetic energy stores of the remaining particles decreases.
- This decrease in average particle energy means the temperature of the remaining liquid falls – the liquid cools.
- The cooling effect can be really useful.

Boiling vs. Evaporation

Boiling vs. Evaporation	
Common	Change in state from liquid to gas
Differences	- Boiling occurs at a fixed temperature; Evaporation can occur at all temperatures, including below the boiling point - Evaporation decreases the temperature of the remaining liquid; During boiling the temperature remains constant

Temperature





Kinetic Theory

Study question:

Explain why particles are able to escape a liquid before it reaches its boiling point.

Kinetic Theory

Study question:

Explain why particles are able to escape a liquid before it reaches its boiling point.

Particles ***near the surface*** of the liquid can escape if they are travelling in the ***right direction*** and they have ***enough energy in their kinetic energy stores*** to overcome the ***attractive forces*** of the other particles in the liquid.

THANK YOU

Section 2.3

Transfer of thermal energy

2.3.1 Conduction

2.3.2 Convection

2.3.3 Radiation

Section 2.3

Transfer of thermal energy

2.3.1 Conduction

2.3.2 Convection

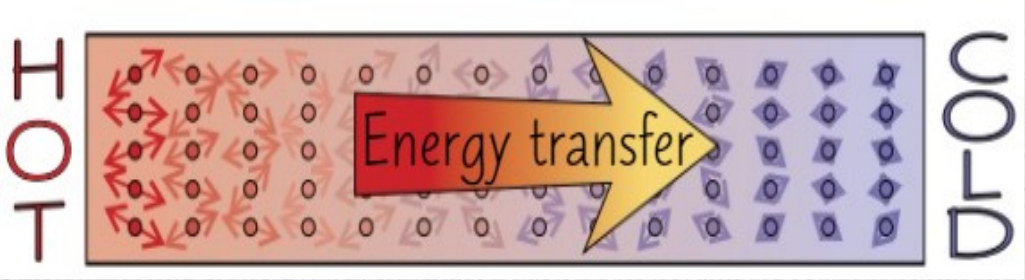
2.3.3 Radiation

Energy transfer by heating in three ways

- Energy can be transferred by heating through **conduction**, **convection**, and **radiation**.
- **Conduction & convection** are energy transfers that involve the transfer of energy by **particles**.
  - ✓ **Conduction** is form of energy transfer by heating in **solids**.
  - ✓ **Convection** is the main form the main of energy transfer by heating in **liquids and gases**.
- Thermal **radiation** is the transfer of energy by heating by **infrared electromagnetic waves**.
- Emission of thermal **radiation occurs in solids, liquids, and gasses**. Any object can both absorb and emit thermal radiation, whether or not conduction or convection are also taking place.
- The **bigger the temperature difference**, the **faster** energy is transferred between the thermal energy stores of a body and its surrounding.

Conduction

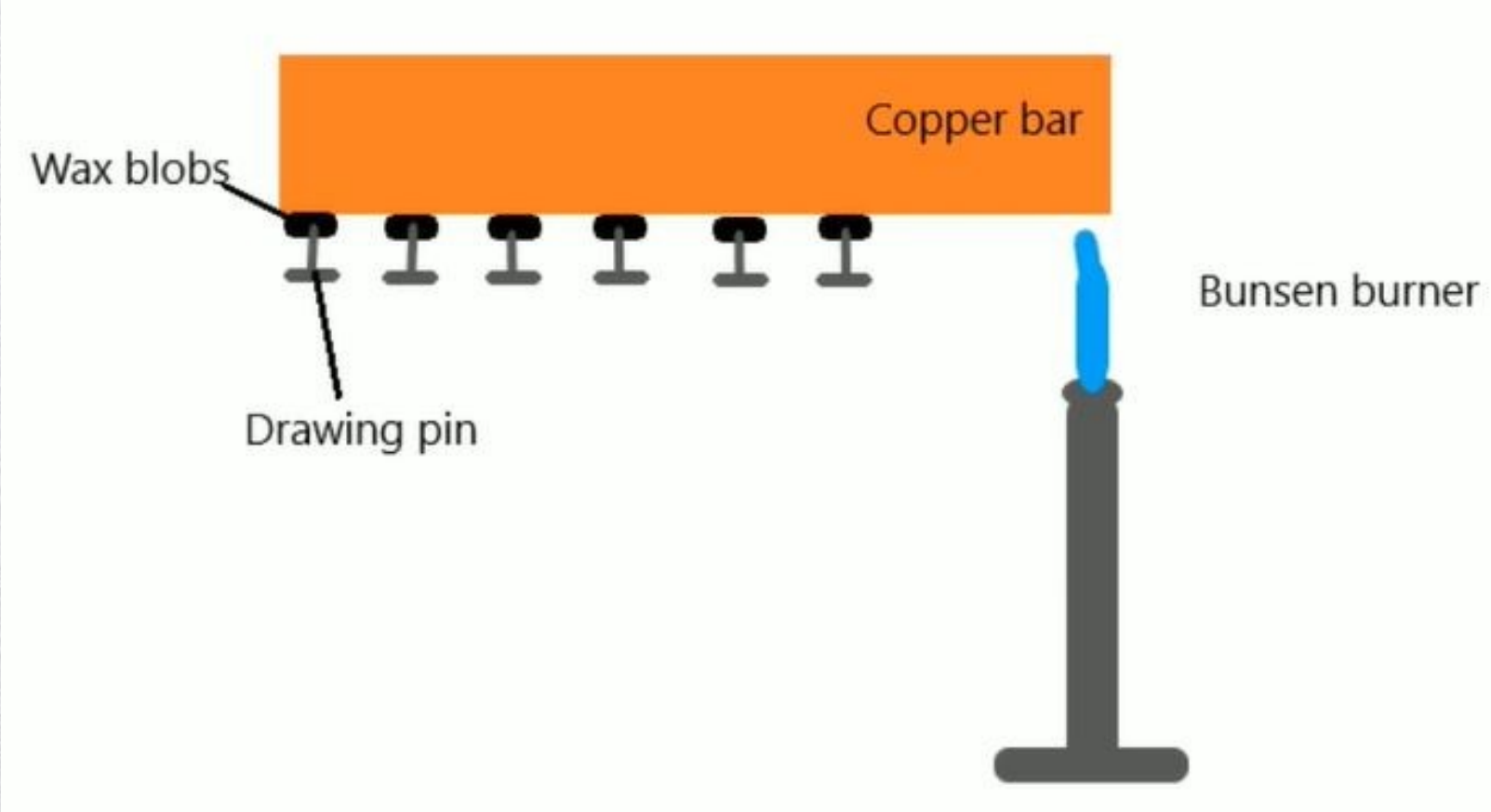
- **Thermal conduction** is the process where vibrating particles transfer energy from their kinetic energy store to the kinetic energy stores of neighboring particles.
  - ✓ Conduction occurs mainly in **solids**
  - ✓ In a solid, the particles <u>are held tightly together</u>, so when one particle vibrates, it collides with other particles nearby and the vibrations quickly pass from particle to particle.
  - ✓ This process continues through the solid and gradually some of the energy is passed all the way through the solid, causing a rise in temperature at the other side of the solid. It's then usually transferred to the thermal energy stores of the surroundings (or anything else touching the object).



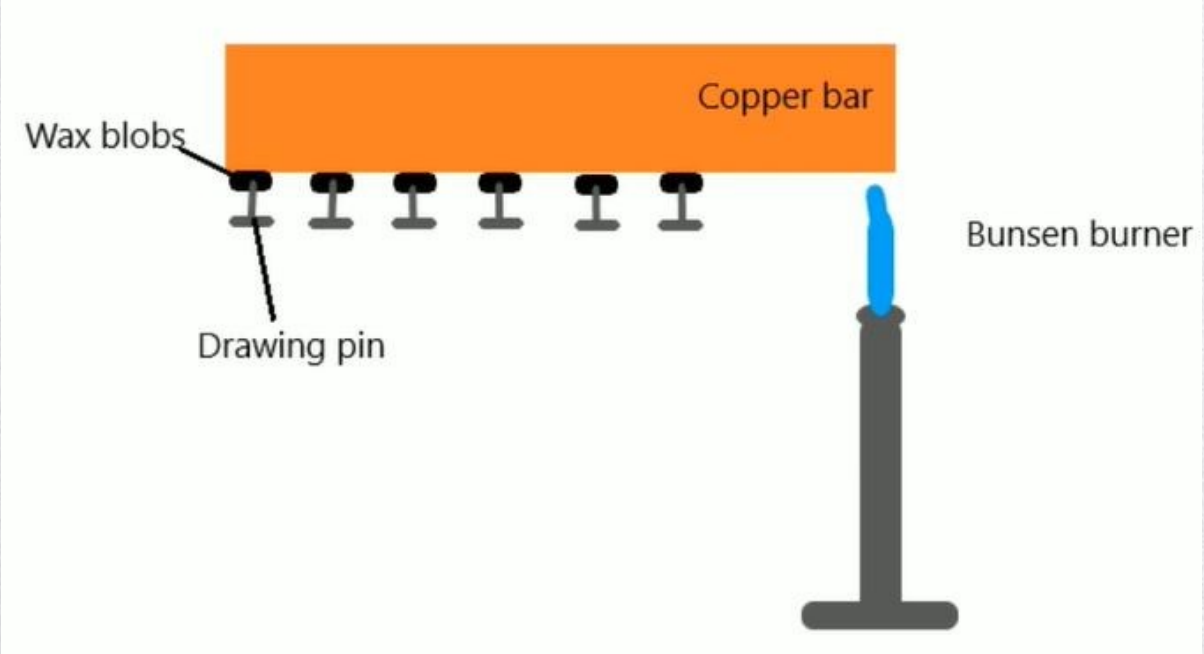
Conduction – Good conductors

- **Conduction** is the process by which **heat or electricity** is directly transmitted through the material of a substance.
- It occurs via molecular vibrations (transfer of kinetic energy through the structure)
- Metals are good conductors because of their structures:
  - ✓ When one end of metal is heated, particles gain kinetic energy and vibrate quicker
  - ✓ This causes neighboring particles to vibrate quicker and results in a domino effect across the structure
  - ✓ Through the transfer of kinetic energy in the form of vibrations, heat is transferred from one end to the other
  - ✓ Free electrons are highly mobile and rapidly quickens the transmission of energy

Metal Conduction Experiment

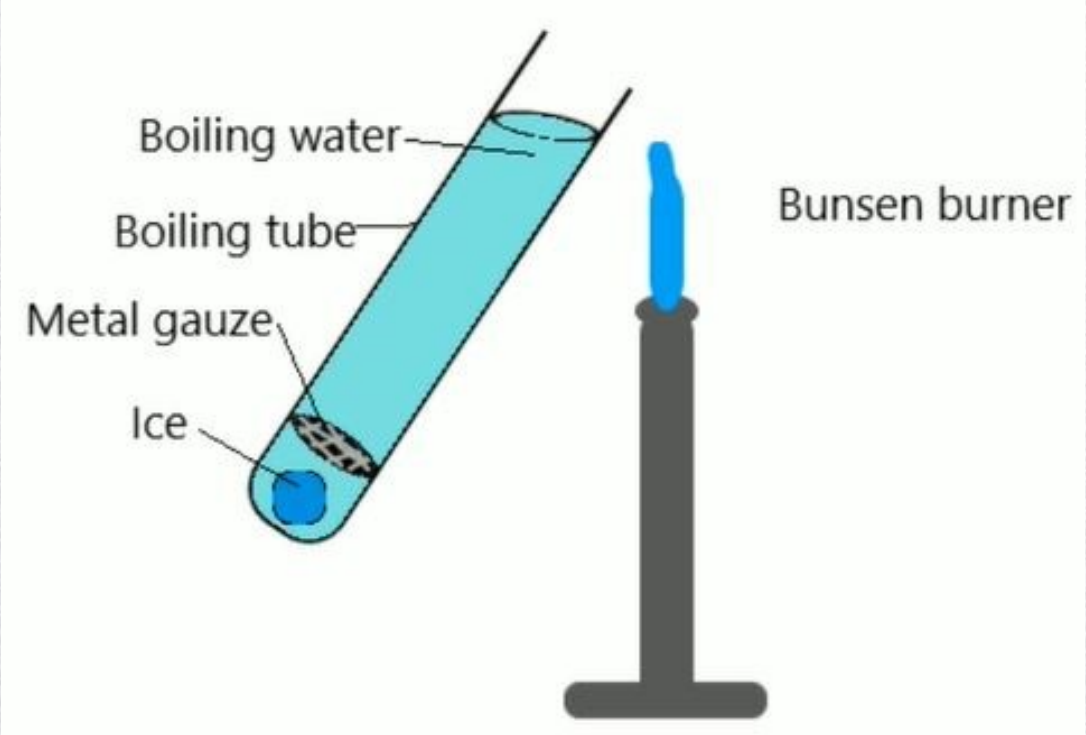


Metal Conduction Experiment

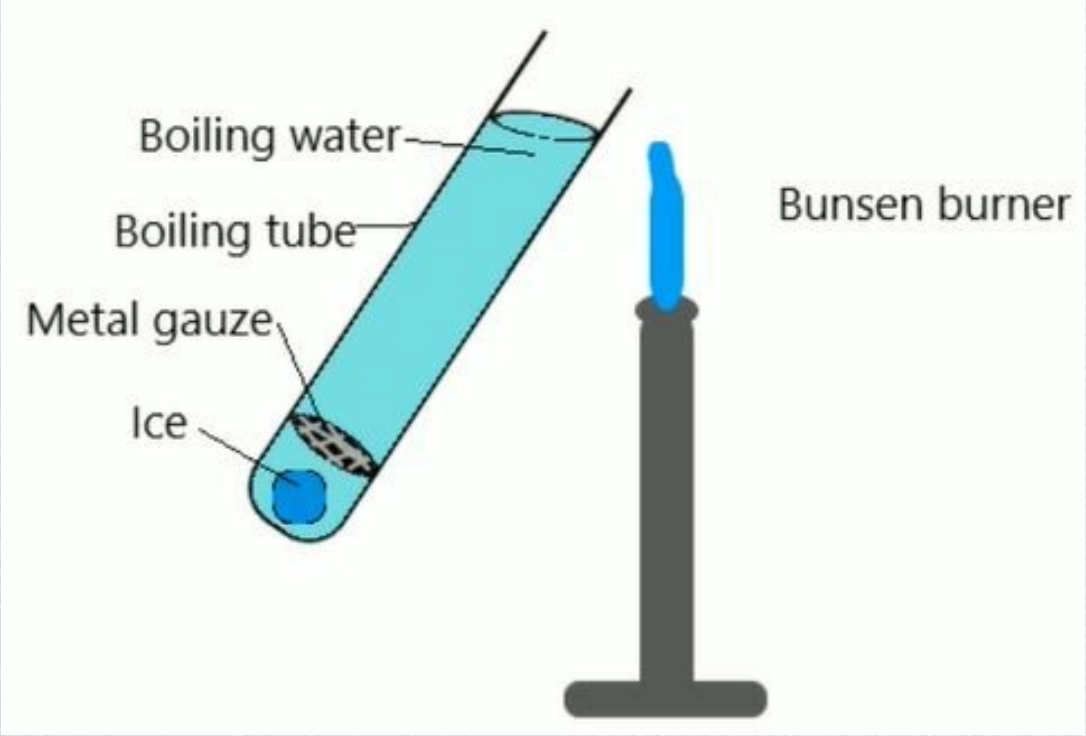


- Demonstration of copper being a good conductor
- As copper bar is heated, the drawing pins will fall of one (from the one closest to the heat)
- This is because the metal conducts heat from the hot end to the cold end
- Heat melts the wax and therefore drops the pins

Conduction – Poor conductors



Conduction – Poor conductors



- **Insulators** are poor conductors such as rubber
- **Absence of free electrons** makes the passage of vibrations / kinetic energy very difficult
- Pure
  - As the water at the**water is a poor conductor** top of boiling tube is heated, it eventually boils
  - However, the ice at the bottom does not melt
  - Heat therefore does not reach the bottom of the tube

Conduction

Study question:

Name the main form of energy transfer by heating in a solid.

Conduction

Study question:

Name the main form of energy transfer by heating in a solid.

Conduction

THANK YOU

Section 2.3

Transfer of thermal energy

2.3.1 Conduction

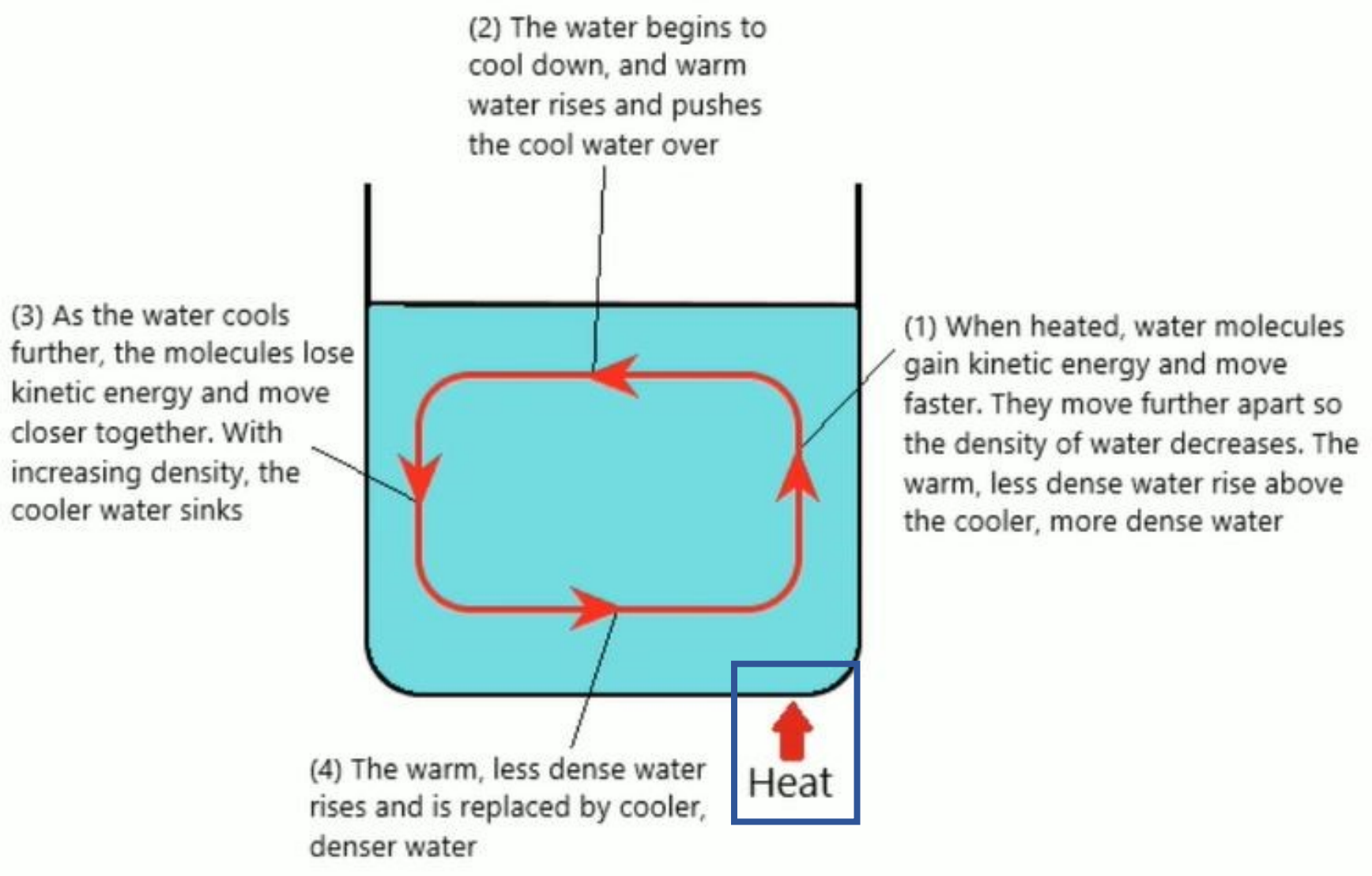
2.3.2 Convection

2.3.3 Radiation

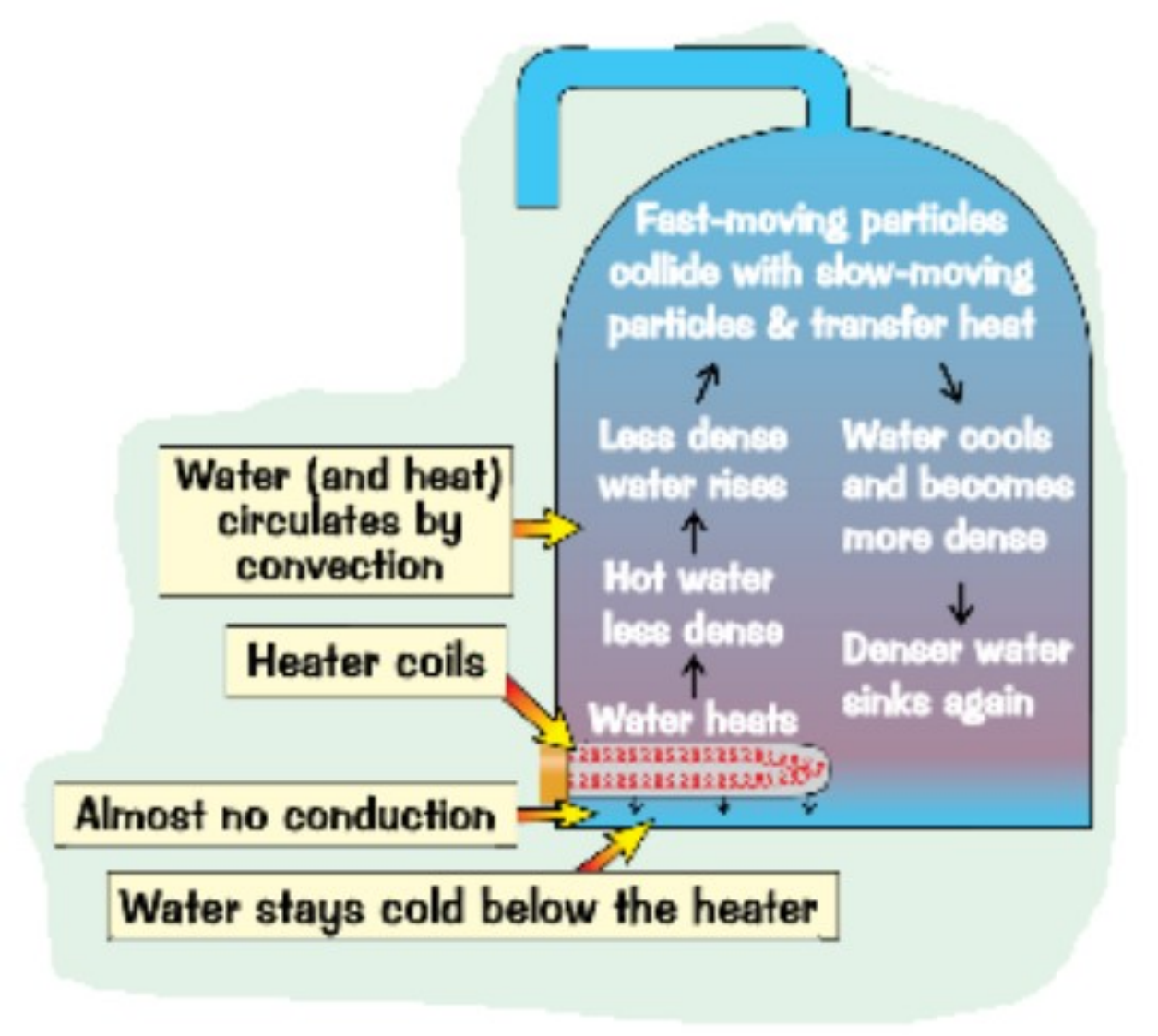
Convection

- Convection of heat – **liquids & gases only**
  - ✓ Convection simply **can't happen in solids because the particles can't move**.
- Convection occurs when the more energetic particles move from the hotter region to the cooler region – and transfer energy as they do.
- This is **how immersion heaters in kettle**, **hot water tanks**, and **convector heaters** work.

Convection


(2) The water begins to cool down, and warm water rises and pushes the cool water over
(3) As the water cools further, the molecules lose kinetic energy and move closer together. With increasing density, the cooler water sinks
(1) When heated, water molecules gain kinetic energy and move faster. They move further apart so the density of water decreases. The warm, less dense water rise above the cooler, more dense water
(4) The warm, less dense water rises and is replaced by cooler, denser water
Heat

The immersion heater



The immersion heater

Energy is transferred from the heater coils to the thermal energy store of the water by conduction.
The particles near the coils get more energy, so they start moving around faster. This means there's more distance between them, i.e. the water expands and becomes less dense. This reduction in density means that hotter water tends to rise above the denser, cooler water.

As the hot water rises, it displaces the colder water out of the way, making it sink towards the heater coils. This cold water is then heated by the coils with convection currents going up, round and down, circulating the energy through the water.

*Note: 1) convection is most efficient in roundish or squarish containers, because they allow the convection currents to work best. Shallow, wide containers or tall, thin ones just don't work quite so well. 2) Because the hot water rises (because of the lower density) you only get convection currents in the water above the heater. The water below it stays cold, there's almost no conduction.

Convection currents are all about changes in density.

THANK YOU

Section 2.3

Transfer of thermal energy

2.3.1 Conduction

2.3.2 Convection

2.3.3 Radiation

Thermal radiation

- **Thermal radiation** can also be called **infrared (IR) radiation**, and it consists purely of electromagnetic waves of a certain range of frequencies. It's next to the visible light in the **electromagnetic spectrum**.

  - ✓ All objects are continually emitting and absorbing infrared radiation.
  - ✓ An object that's hotter than its surroundings emits more radiation than it absorbs (as it cools down). And an object that's cooler than its surroundings absorbs more radiation than it emits (as it warms up).
  - ✓ For an object to be at a constant temperature, it needs to transfer energy away from the object at the same rate that it receives energy.
  - ✓ Infrared can be **emitted, absorbed, or reflected**.
  - ✓ Some colors and surfaces (textures) absorb and emit radiation better than others.

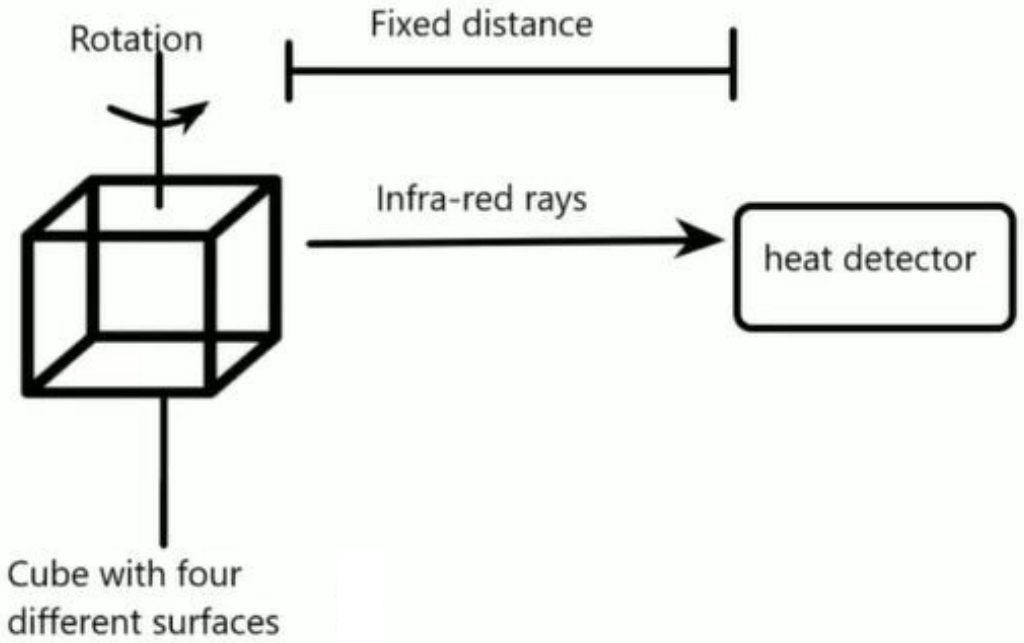
Thermal radiation – Emission experiment

Set-up & procedure

- A metal cube with is painted with 4 different types of surfaces: matt black, shiny black, white and silver
- The cube is filled with boiling water
- A heat detector is placed at a constant distance away from the cube i.e. 50cm
- The cube is rotated so that each side faces the heat detector in turn, and the readings are noted

Results (in order of emission levels)

- Matt black (highest) -> Shiny black -> White -> Silver (lowest)



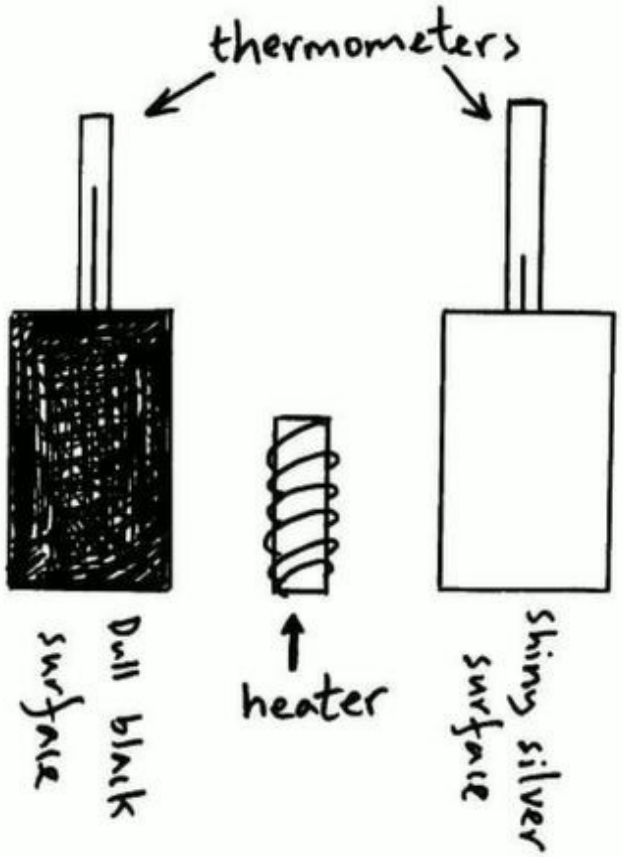
Thermal radiation – Absorption Experiment

Set-up & procedure

- A radiant heater is placed in the middle of two plates at equal distance away from the heater
- One plate is matt black and the other is silver
- A thermometer is placed on each plate and initial reads of the thermometers are recorded
- The heater is switched on and the temperatures of each of the plates are measured in equal intervals

Results:

- The temperature of the matt black plate will increase quicker than the silver
- Matt black surfaces are therefore better absorbers of radiation



Thermal radiation

Some colors and surfaces (textures) absorb and emit radiation better than others.

In order of emission levels:

Matt black (highest) > shiny black > white > silver (lowest)

In order of absorption levels:

Matt black (highest) > shiny black > white > silver (lowest)

A black surface is better at absorbing and emitting radiation than a shiny one. To reduce the energy transfers away from an object by thermal radiation, the object should be designed with a surface that is a poor emitter.

THANK YOU