Cambridge (CIE) IGCSE Physics

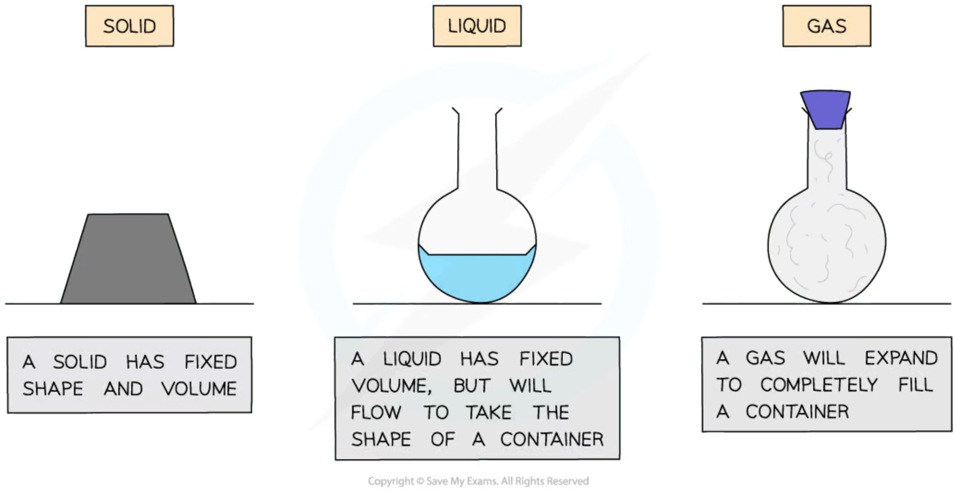
Your notes

Kinetic Particle Model of Matter

Contents

Properties of solids, liquids & gases

The three states of matter



The three states of matter in terms of shape and volume

Solids

- Solids have a definite shape and a definite volume
  - Solids cannot flow and are not compressible

Liquids

- Liquids have no definite shape but do have a definite volume
  - Liquids are able to flow to take the shape of a container but they are not compressible

Gases

- Gases have no definite shape and no fixed volume
  - Gases can flow to take the shape of their container and are highly compressible

Changes of state

When a substance changes state, the number of molecules in that substance doesn't change and so neither does its mass

- The only thing that changes is its **energy**
- Changes of state are physical changes and so they are **reversible**

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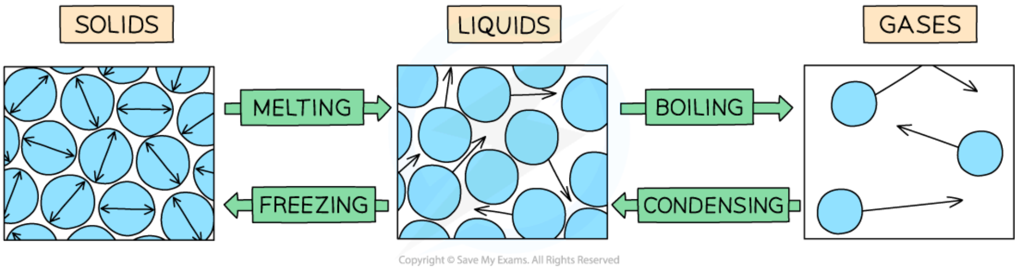
Melting & freezing

- Melting occurs when a solid turns into a liquid (e.g. ice to water)
- Freezing occurs when a liquid turns into a solid

Boiling & condensing

- Boiling occurs when a liquid turns into a gas
  - This is also called evaporating
- Condensing occurs when a gas turns into a liquid



You need to know these four processes only, and the states at which they start and end.

Examiner Tips and Tricks

It is very useful to think about water when learning the changes of state, because we are all used to the idea that solid water (ice) melts to become liquid water (water!) and boils to become gaseous water (water vapour).

However do remember that **all** substances undergo the same changes between the three states, but at different temperatures. So while water will help you to remember the names, don't refer to water in your answers unless it has been specified.

Arrangement & motion of particles

- All molecules and matter are in motion at room temperature
  - The motion and arrangement of particles must be known for each state of matter
- In a **solid**:
  - The molecules are very **close** together and arranged in a **regular** pattern
  - The molecules **vibrate** about fixed positions
- In a **liquid**:
  - The molecules are still **close** together (no gaps) but are no longer arranged in a regular pattern
  - The molecules are able to **slide past each other**
- In a **gas**:
  - The molecules are **widely separated** - about 10 times further apart in each direction
  - The molecules move about **randomly at high speeds**

Properties of states of matter

State	Solid	Liquid	Gas
Density	High	Medium	Low
Arrangement of particles	Regular pattern	Randomly arranged	Randomly arranged
Movement of particles	Vibrate around a fixed position	Move around each other	Move quickly in all directions
Energy of particles	Low energy	Greater energy	Highest energy

The forces & distances between molecules

Extended tier only

Intermolecular forces and motion of particles

- The **forces between molecules and matter** (or 'particles') affect the state of matter

- This is because the magnitude of the forces affects the **relative distances** and **motion** of the particles
- This affects the ability of the substance to
  - Change shape
  - Change volume
  - Flow
- The word **particles** can refer to:
  - Atoms
  - Molecules
  - Ions
  - Electrons

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Solids

- The molecules in a solid are held in place by **strong intermolecular** forces
  - They only **vibrate in position**
  - The **distance** between them is **fixed** and is very small
  - This gives the solid its **rigid shape** and **fixed volume**

Liquids

- The molecules in a liquid have enough **energy** to overcome the forces between them
- They are still held **close together**
  - The volume of the liquid is the same as the volume of the solid
- Molecules can **move around** (by sliding past each other)
  - This allows the liquid to **change shape** and **flow**

Gases

- The molecules in a gas have **more energy** and move **randomly** at **high speeds**
  - The molecules have **overcome** the forces holding them close together
- Because of the **large spaces** between the molecules
  - The gas can easily be **compressed** and is also able to **expand**
  - Gases **flow** freely

Worked Example

Two states of matter are described below. Identify each of the states of matter.

Substance 1

- molecules are spaced very far apart
- molecules move very quickly at random
- molecules move in a straight line

Substance 2

- molecules are quite closely packed together
- molecules move about at random
- molecules do not have fixed positions

Answer:

Substance 1

Step 1: Identify the distances between the molecules

- The molecules are spaced far apart
    - This can only describe a gas

Step 2: Identify the motion of the molecules

- The molecules move quickly, at random and in a straight line
    - This confirms that substance 1 is a gas

Substance 2

Step 1: Identify the distances between the molecules

- The molecules are closely packed
    - This could describe either a solid or a liquid

Step 2: Identify the motion of the molecules

- The molecules move at random and do not have fixed positions
    - This confirms that substance 2 is a liquid

Temperature & energy of particles

- As the **temperature** of a gas increases, so does the **average speed** of particles in the gas
    - At higher temperatures, the particles have more **kinetic energy**
- The amount of pressure that a gas exerts on its container is dependent on the temperature of the gas
    - This is because particles gain **kinetic energy** as their temperature increases
- Therefore, there must be a temperature at which the particles are **stationary**
    - This is the **lowest possible temperature**, as particles cannot travel any slower than 0 m/s
- The temperature at which all particles are stationary is called **absolute zero**

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- Absolute zero has a value of –273 °C

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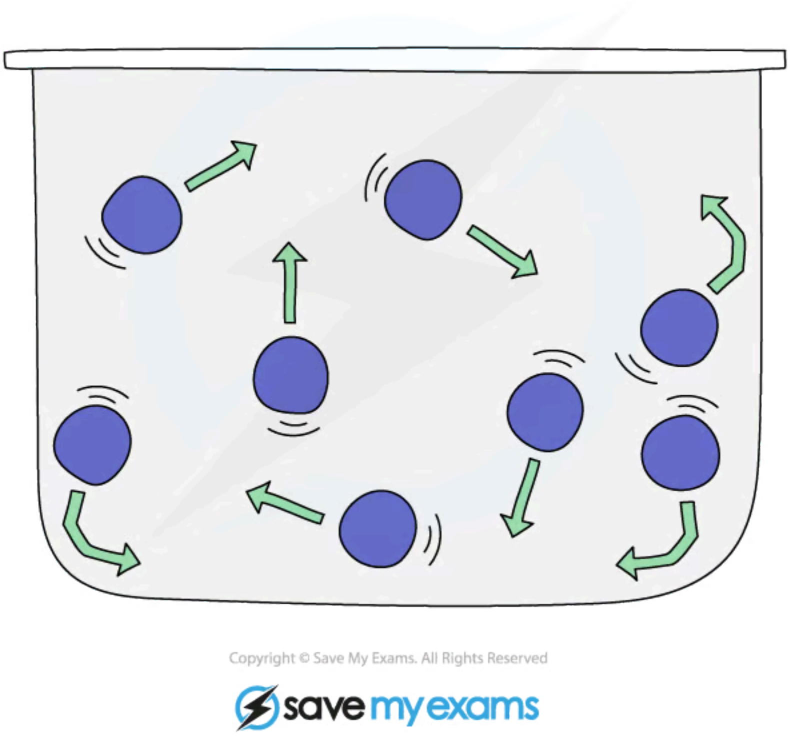
Motion of particles in a gas

- In the particle model, molecules in a gas are in constant **random** motion at high speeds
- Random motion means that the molecules are travelling in no specific path and undergo sudden changes in their motion if they collide:
  - With the walls of its container
  - With other molecules
- Pressure in a gas is caused by the collisions of particles with the walls of the container
- When the particles travel **faster** (e.g. at a higher temperature), they collide with walls **more frequently**
  - This means the gas exerts a **greater pressure**



Random motion of gas molecules in a container. Collisions with container walls creates pressure in the particle model

Pressure & force of particles in a gas

Extended tier only

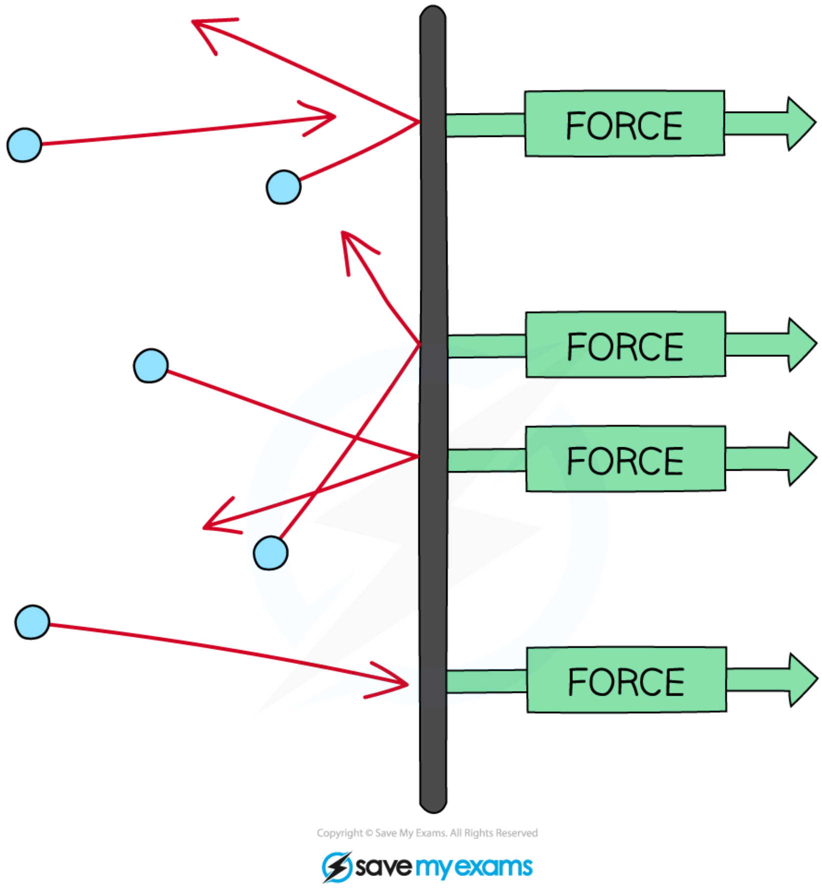
- Gases fill their container
- The pressure is defined as the **force per unit area**

$$p = \frac{F}{A}$$

- Where:
  - p = pressure in pascals Pa
  - F = force in newtons N
  - A = area in metres-squared m^2
- This equation and the particle model can be used to explain how particles exert pressure
- As the gas particles move about randomly they collide with the walls of their containers
- These collisions produce **force** at right angles to the wall of the gas container (or any surface)
  - Pressure is force per unit area, so the force of these collisions exerts a **pressure**
- When the particles move faster, they have **more frequent collisions** with the container walls and these exert a **greater force**
  - If the **force** exerted per unit area is greater and more frequent, the **pressure** exerted is also greater

Your notes

Your notes

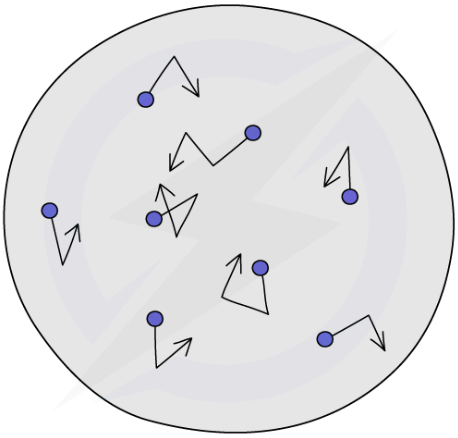


Gas molecules bouncing off the walls of a container exert a force perpendicular to the surface

Your notes

What is Brownian Motion?

- The **Kinetic Theory of Matter**, which simply says that **all matter is made up of tiny particles**, was discovered almost by accident
  - The Scottish scientist Robert Brown first described the random motion of pollen grains in water, which he saw under a microscope
  - This observation could not be explained at the time, but later it was realised that it shows that substances are made of particles which are in **constant motion** (hence 'kinetic')



Brownian Motion: the random motion of microscopic particles when observed through a microscope

- **Brownian motion** is the random movement of particles in a liquid or a gas produced by large numbers of **collisions** with smaller particles which are often too small to see
- When small particles (such as pollen or smoke) are suspended in a liquid or gas, they can be observed through a microscope moving around in a random, erratic fashion

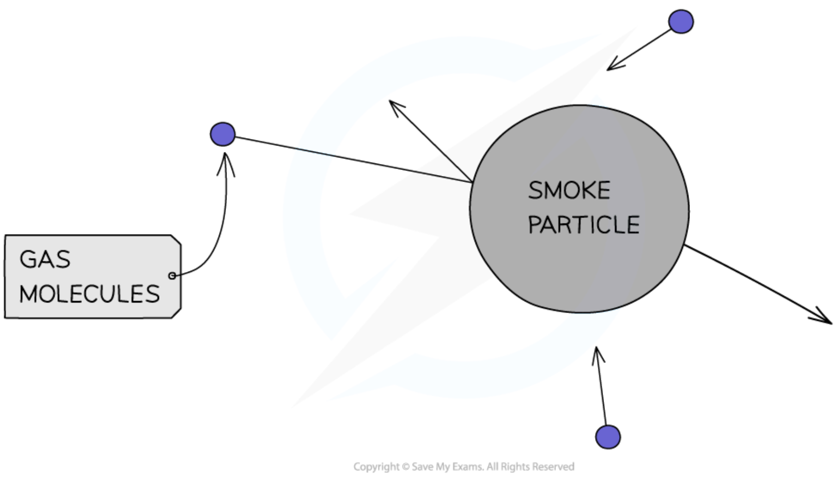
Explaining Brownian motion

Extended tier only

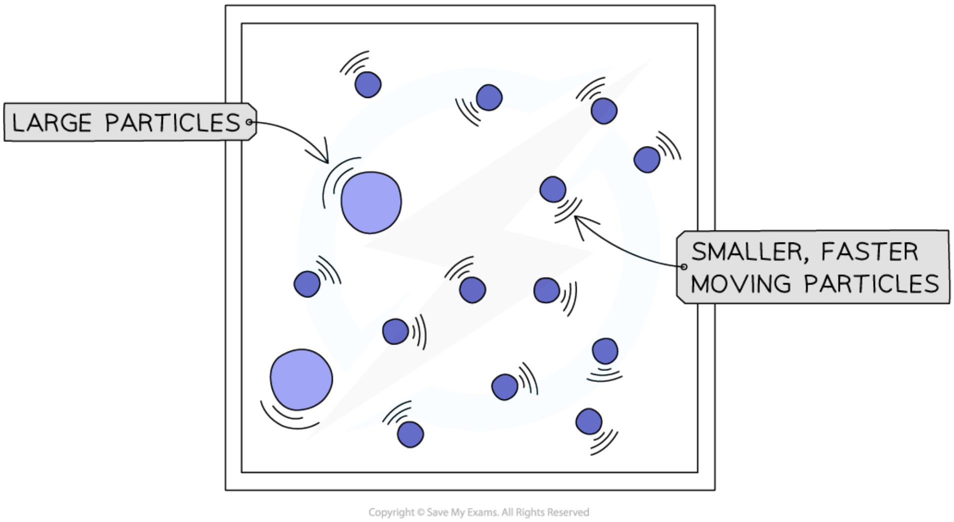
What is Brownian motion caused by?

- When observing Brownian Motion, even with a microscope, only the **microscopic particles** can be seen
  - The pollen or smoke particles are seen to move
  - Smaller **atoms and molecules**, of water or air, are still too small to be seen

- These **light, fast-moving atoms and molecules** collide with the larger microscopic particles
  - The collisions give the particles a little nudge, causing them to change their speed and directions randomly, each time they are struck by a molecule
- The presence of the light, fast moving atoms and molecules is **inferred** from the motion of the microscopic particles
  - Inferences such as this are an important part of scientific investigation



Light, fast-moving molecules collide with larger particles, giving them a little nudge



This not-to-scale diagram shows how the smaller, fast-moving particles (atoms and molecules) cause the larger, visible particles to move

Your notes

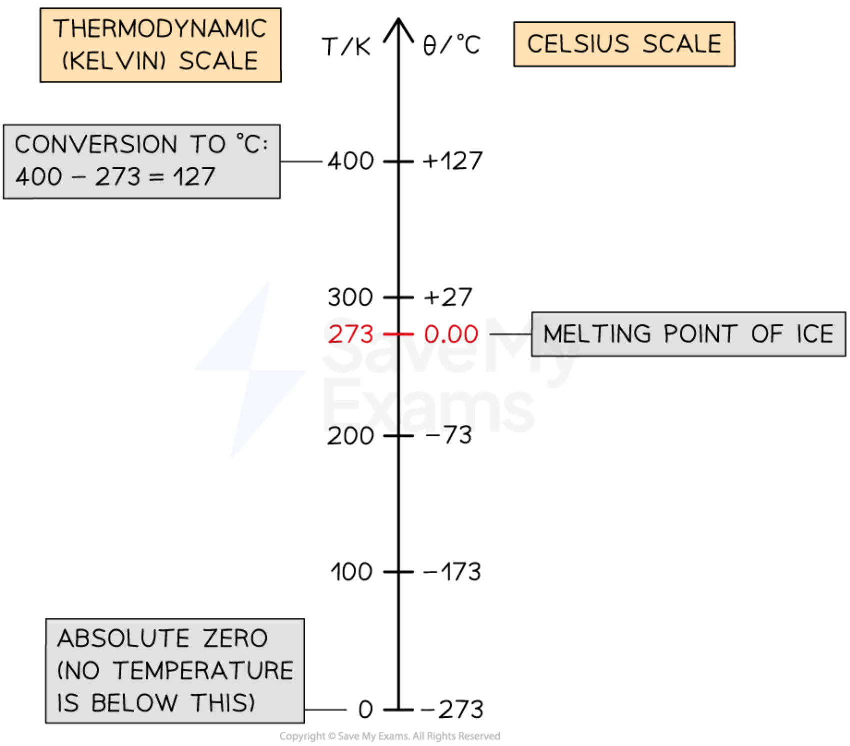
Absolute temperature

What is absolute temperature?

- Temperature measured in kelvin is called **absolute temperature**
- The **kelvin temperature scale** begins at **absolute zero**
  - **0 K is equal to -273 °C**
  - An increase of 1 K is the same change as an increase of 1 °C
- It is not possible to have a temperature **lower** than 0 K
- This means a temperature in kelvin will **never** have a negative value
- To convert between temperatures θ in the Celsius scale, and T in the Kelvin scale, use the following conversion:

$$\theta \,/\, ^\circ\mathrm{C} = T \,/\, \mathrm{K} - 273$$

$$T \,/\, \mathrm{K} = \theta \,/\, ^\circ\mathrm{C} + 273$$



Conversion chart relating the temperature on the Kelvin and Celsius scales

Your notes

Worked Example

Convert the following values between the Kelvin (absolute) and Celsius scales of temperature.

a) 0 K = _______ °C

b) 0 °C = _______ K

c) 20 °C = _______ K

Part (a)

Step 1: Choose whether to add or subtract 273 to the value

- The question is in kelvin therefore subtract 273 to convert to Celsius

Step 2: Do the calculation

- $0 - 273 = -273$

Step 3: Write the answer with units

- 0K = –273 °C

Part (b)

Step 1: Choose whether to add or subtract 273 to the value

- The question is in Celsius therefore add 273 to convert to kelvin

Step 2: Do the calculation

- $0 + 273 = 273$

Step 3: Write the answer with units

- 0 °C = 273 K

Part (c)

Step 1: Choose whether to add or subtract 273 to the value

- The question is in Celsius therefore add 273 to convert to kelvin

Step 2: Do the calculation

- $20 + 273 = 293$

Step 3: Write the answer with units

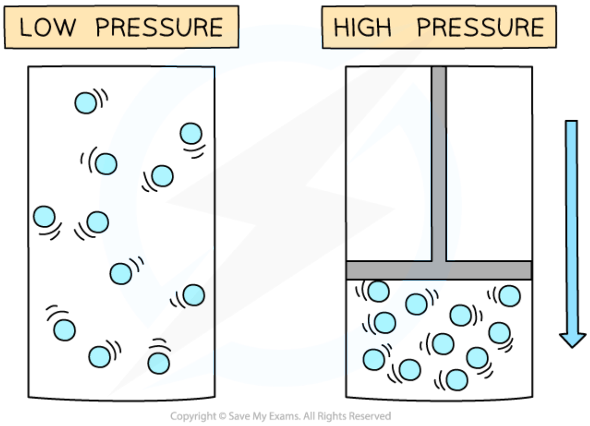
- 20 °C = 293 K

The gas laws

Pressure & volume (constant temperature)

- If the temperature of a gas remains **constant**, the pressure of the gas changes when it is:

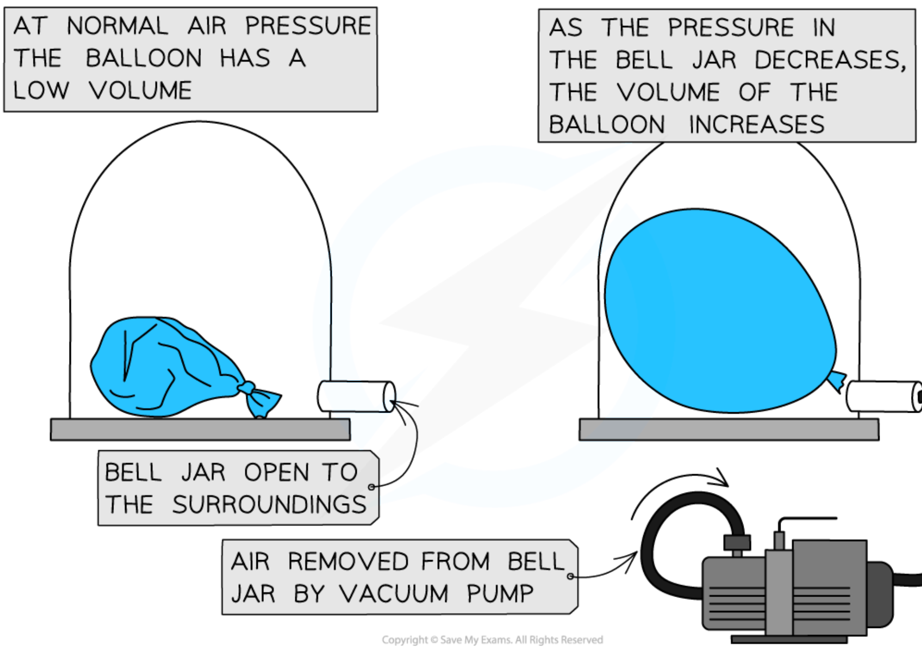
- **Compressed** – decreases the volume which **increases** the pressure
- **Expanded** – increases the volume which **decreases** the pressure



At constant temperature, changing the volume changes the pressure

- Similarly, a change in pressure can cause a change in volume
- A **vacuum pump** can be used to remove the air from a sealed container
- The diagram below shows the change in volume to a tied up balloon when the pressure of the air around it decreases:
  - The balloon is tied, so there are a **fixed number** of air particles within it
  - At **normal pressure**, the air pressure outside the balloon is **greater** than the air pressure inside the balloon
  - When **air is removed** from the bell jar, the air pressure outside the balloon is **less than** the air pressure inside the balloon
  - The **space between** the air particles in the balloon increases, so the **volume** of the balloon increases

Your notes



At constant temperature, changing the pressure changes the volume

- When a gas is compressed, the molecules will hit the walls of the container **more frequently**
  - This creates a larger overall **net force** on the walls, which increases the **pressure**

Pressure & temperature (constant volume)

- **Increasing temperature increases the pressure** of a gas which is kept at a **constant volume**
- The **average speed** of molecules increases when the temperature increases (and vice versa)
- As the gas heats up, the molecules will travel at a higher speed
  - They collide with the walls more often and with greater force, increasing the pressure
- Therefore, at a constant volume, an **increase** in temperature **increases** the pressure of a gas and vice versa
  - Diagram A shows molecules in the same volume collide with the walls of the container more as the temperature increases
  - Diagram B shows that since the temperature is directly proportional to the pressure (at constant volume), the graph is a straight line

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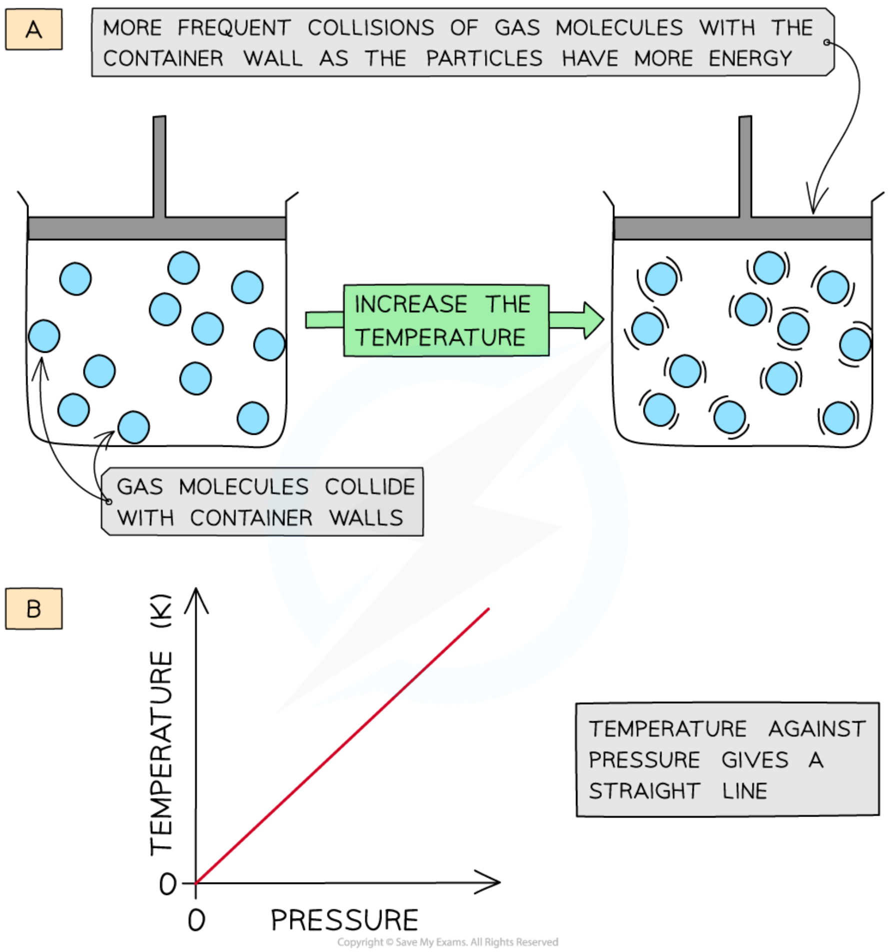


At constant volume, an increase in the temperature of the gas increases the pressure due to more collisions on the container walls

Boyle's Law

Extended tier only

Boyle's law

- If the temperature *T* of an ideal gas is constant, then **Boyle's Law** is given by:

$$p \propto \frac{1}{V}$$

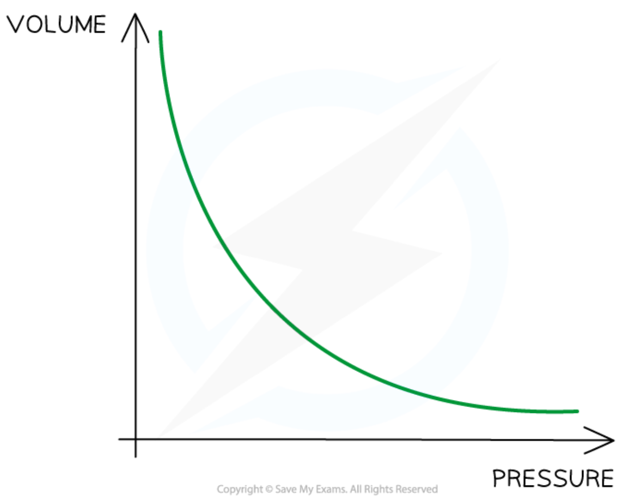
- This means the pressure is **inversely proportional** to the volume of a gas
- This can also be written as:

$$pV = \text{constant}$$

- The relationship between the pressure and volume for a fixed mass of gas at constant temperature can also be written as:

$$p_1V_1 = p_2V_2$$

- Where:
  - p_1 = initial pressure (Pa)
  - p_2 = final pressure (Pa)
  - V_1 = initial volume (m^3)
  - V_2 = final volume (m^3)
- Notice that volume and pressure are measured in m^3 and Pa respectively
  - In calculations if units are given in cm^3 or MPa this is a rare case where calculations can be done using the original units **as long as answers are reported in the same, original units and the final and initial units match**



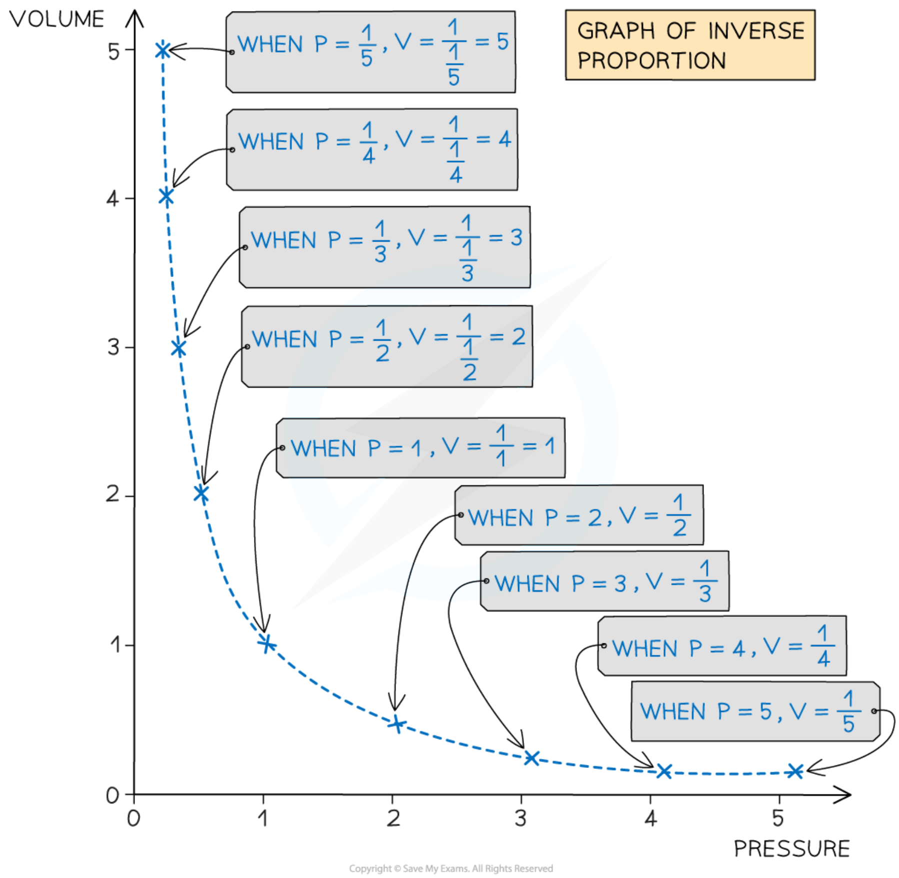
Boyle's Law graph: Pressure is inversely proportional to volume

Your notes

Examiner Tips and Tricks

It is an easy mistake to make to think that an **inversely proportional** graph will be a straight line sloping downwards. After all, a directly proportional graph is a straight line (through the origin) which slopes upwards!

The curve above which 'tends towards zero' (meaning the curve gets closer and closer but never touches the axis, or zero is an inversely proportional curve, as the graph below shows.


VOLUME
PRESSURE
GRAPH OF INVERSE PROPORTION
WHEN P = 1/5, V = 1/(1/5) = 5
WHEN P = 1/4, V = 1/(1/4) = 4
WHEN P = 1/3, V = 1/(1/3) = 3
WHEN P = 1/2, V = 1/(1/2) = 2
WHEN P = 1, V = 1/1 = 1
WHEN P = 2, V = 1/2
WHEN P = 3, V = 1/3
WHEN P = 4, V = 1/4
WHEN P = 5, V = 1/5
0
1
2
3
4
5
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