2.1 Kinetic particle model of matter

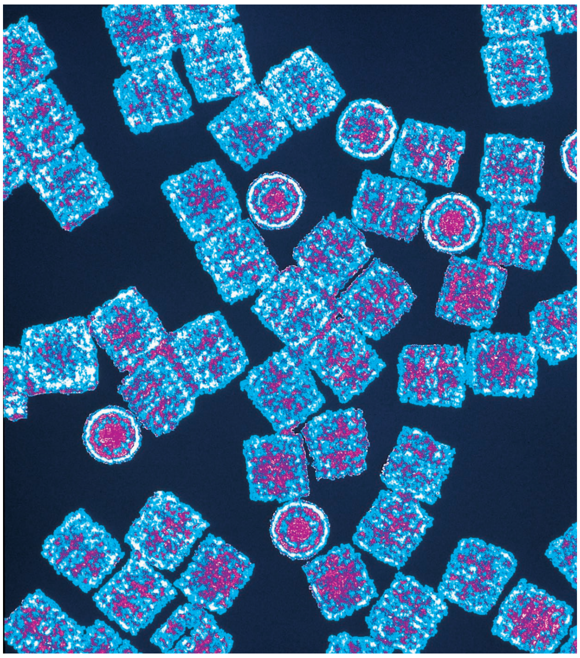
2.1.1 States of matter

FOCUS POINTS

- ★ Know the properties of solids, liquids and gases.
- ★ Understand that changes in state can occur and know the terms to describe these changes.

In this topic you will learn about the three states of matter: solids, liquids and gases. The particles in each are ordered differently and this leads to each state having different properties. You will find that solids have a high level of internal order, a liquid has less, and in a gas the particles have no order and move about randomly. The state of a material can be altered by heating or cooling. In a solid the bonds between particles break down on heating and it melts into a liquid; for example, ice melts into water. Boiling a liquid produces a gas with well separated particles; water turns into steam. The three states of matter can be represented in a particle diagram.

Matter is made up of tiny particles (atoms, **molecules**, ions and electrons) which are too small for us to see directly. But they can be 'seen' by scientific 'eyes'. One of these is the electron microscope. Figure 2.1.1 is a photograph taken with such an instrument, showing molecules of a protein. Molecules consist of even smaller particles called **atoms** and these are in continuous motion.



▲ **Figure 2.1.1** Protein molecules

Properties of solids, liquids and gases

Matter can exist in different states and each state has different characteristics.

Solids

Solids have a definite shape and volume and are not easily compressed. The particles in a solid are close together and in fixed positions.

When a force is applied to a solid the atoms move slightly further apart in the direction of the force and stretching occurs (see Topic 1.5.1). When a solid is heated (see Topic 2.2), the distance between atoms increases. If enough heat is supplied to the solid the atoms move even further apart and **melting** into a liquid occurs.

Liquids

Liquids have a definite volume but their shape depends on the container they are kept in. They are more easily compressed or stretched than solids and also expand more when heat is applied. The particles in a liquid are further apart than they are in a solid and have a less ordered structure. They are not fixed in position and can slide over each other when the liquid is poured. The liquid then takes on the shape of the new container.

When a liquid is cooled sufficiently, *solidification* occurs and it returns to the solid state. The density of a material in its solid state is usually higher than it is in its liquid state. When a liquid is heated, particles can escape from its surface by a process called **evaporation**. When sufficient heat is supplied to the liquid **boiling** occurs and the liquid turns into a gas.

Gases

Gases have no definite shape or volume as these depend on the dimensions of the container. The particles in a gas are much further apart than they are in a liquid and the density of a gas is much lower than that of a liquid. The particles have no ordered structure and are able to move about freely in a random manner. Gases are more easily compressed than solids or liquids and expand more when they are heated. When a gas is cooled sufficiently it will return to the liquid state in a process known as **condensation**.

Drops of water are formed when steam condenses on a cold window pane, for example.

Test yourself

1 Using what you know about the compressibility (squeezability) of the different states of matter, explain why
  a air is used to inflate tyres
  b steel is used to make railway lines.

2 Name the processes in which
  a a solid turns into a liquid
  b a liquid turns into a gas
  c a liquid turns into a solid
  d a gas turns into a liquid.

2.1.2 Particle model

FOCUS POINTS

★ Describe the particle structures of solids, liquids and gases and represent these states using particle diagrams.
★ Understand how temperature affects the movement of particles.
★ Understand the factors that affect the properties of solids, liquids and gases.
★ Understand the relationship between the kinetic energy of particles and temperature, including the concept of absolute zero.
★ Know how a change in pressure in a gas affects the motion and number of collisions of its particles.
★ Describe how a change in pressure of a gas affects the forces exerted by particles colliding with surfaces (force per unit area).
★ Describe Brownian motion and know that it is evidence for the kinetic particle model of matter.
★ Distinguish atoms or molecules from microscopic particles, and understand how these microscopic particles may be moved by collisions with much lighter molecules.

The properties of solids, liquids and gases can be related to the arrangement, separation and motion of the particles in each. In the previous section, you learnt about the properties of solids, liquids and gases. In this topic, you will learn that in a gas, the particles are well separated and in constant random motion, producing pressure on a container by their collisions with its surfaces. In a solid, the particles are closely arranged and firmly bound together, with a regular pattern in crystals. In a liquid the particles are further apart, with only local ordering between particles that have more freedom of movement than those in a solid. Although particles are too small to be seen with the unaided eye, their influence can be detected. When tiny particles in a fluid are observed under a microscope, they can be seen to move slightly in a random manner under the impact of collisions with many much lighter molecules. This effect is known as Brownian motion and provides evidence for the kinetic particle model of matter.

Particle model of matter

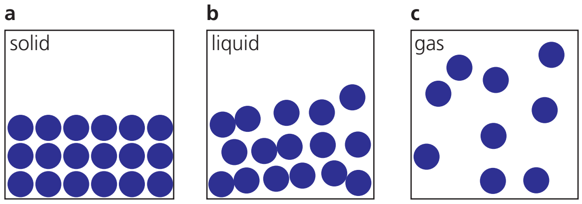
As well as being in continuous motion, particles (atoms, molecules, ions and electrons) also exert strong electric forces on one another when they are close together. The forces are both attractive and repulsive. The former hold particles together and the latter cause matter to resist compression.

The *particle model* can explain the existence of the solid, liquid and gaseous states.

Solids

Structure

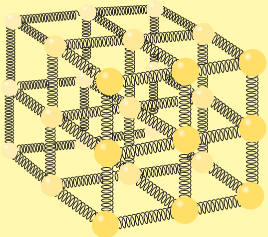
In solids the particles are close together and the attractive and repulsive forces between neighbouring molecules balance. Also, each particle vibrates about a fixed position. Particles in a solid can be arranged in a regular, repeating pattern like those formed by crystalline substances. Figure 2.1.2a represents the arrangement of particles in a solid.



▲ **Figure 2.1.2** Arrangements of particles in a solid, liquid and gas

Properties

We can imagine springs (Figure 2.1.3) representing the electric forces between particles that hold them together and determine the forces and distances between them. These forces enable the solid to keep a definite shape and volume, while still allowing the individual particles to vibrate backwards and forwards. Owing to the strong intermolecular forces, solids resist compression and expand very little when heated.



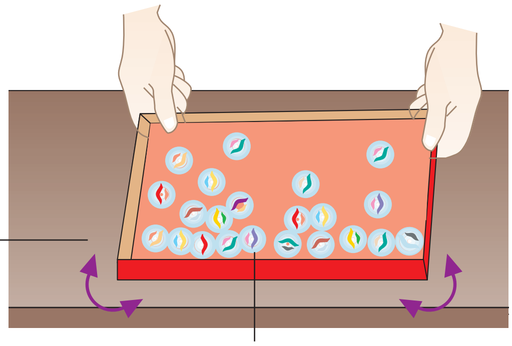
▲ **Figure 2.1.3** The electric forces between particles in a solid can be represented by springs.

Liquids

Structure

In liquids the particles are slightly further apart than in solids but still close enough together to have a definite volume (Figure 2.1.2b). As well as vibrating, they can at the same time move rapidly over short distances, slipping past each other in all directions.

A model to represent the liquid state can be made by covering about a third of a tilted tray with marbles ('particles') (Figure 2.1.4). It is then shaken back and forth and the motion of the marbles observed. The marbles are able to move around but most stay in the lower half of the tray, so the liquid has a fairly definite volume. A few energetic marbles escape from the 'liquid' into the space above. They represent particles that have evaporated from the liquid surface and become gas or vapour particles. The thinning out of the marbles near the liquid surface can also be seen.



▲ **Figure 2.1.4** A model of particle behaviour in a liquid

Properties

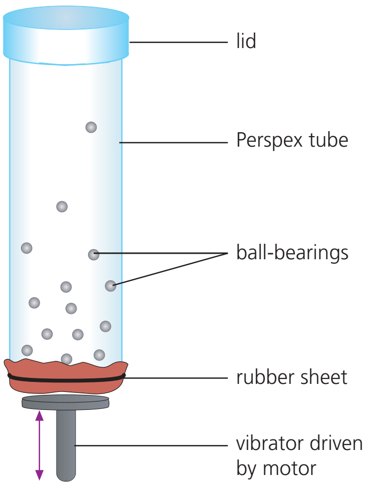
In a liquid the forces between particles are less than in a solid and so the distance between particles is greater. Liquids have a definite volume but individual particles can slide over each other and are never near another particle long enough to get trapped in a regular pattern. This allows liquids to flow and take on the shape of the vessel containing them. The forces between particles are strong enough that liquids are only slightly more easily compressed than solids. When heated, the particles move further apart, enabling liquids to expand more easily than solids. As the temperature increases some particles may have sufficient energy to escape from the surface of the liquid resulting in evaporation of the liquid.

Gases

Structure

The particles in gases are much further apart than in solids or liquids (about ten times; see Figure 2.1.2c) and so gases are much less dense and can be squeezed (compressed) into a smaller space. The particles dash around at very high speed (about 500 m/s for air molecules at 0°C) in all the space available. It is only during the brief spells when they collide with other particles or with the surfaces of the container that the particle forces act.

A model of a gas is shown in Figure 2.1.5. The faster the vibrator works, the more often the ball-bearings have collisions with the lid, the tube and with each other, representing a gas at a higher temperature. Adding more ball-bearings is like pumping more air into a tyre; it increases the pressure. If a polystyrene ball (1 cm diameter) is dropped into the tube, its irregular motion represents Brownian motion. Brownian motion provides evidence for the kinetic particle model of matter.



▲ **Figure 2.1.5** A model of particle behaviour in a gas

Properties

Owing to the high speed and the large distance between particles in a gas the interaction between them is small. Gases have no shape and their volume is determined by the volume of the container. They are easily compressed, and expand much more than solids or liquids when heated.

Temperature and kinetic energy

In a solid at room temperature, the particles vibrate about fixed positions. When heat is supplied to the solid and its temperature increases, the particles vibrate more strongly and the average kinetic energy of the particles increases. When the temperature is reduced, the average kinetic energy of the particles reduces, and eventually a temperature is reached where particle motion ceases and the kinetic energy of the particles is zero. We call this temperature **absolute zero** and it occurs at −273°C.

Pressure and kinetic energy

The particle model can explain the behaviour of gases.

Gas pressure

All the particles in a gas are in rapid random motion, with a wide range of speeds, and repeatedly hit and rebound from the surfaces of the container in huge numbers per second.

This causes a pressure on the surfaces of the container. When the temperature of the gas rises, so does the average speed and kinetic energy of the particles. Collisions with the surfaces of the container occur more frequently and so the pressure of the gas increases.

Force and gas pressure

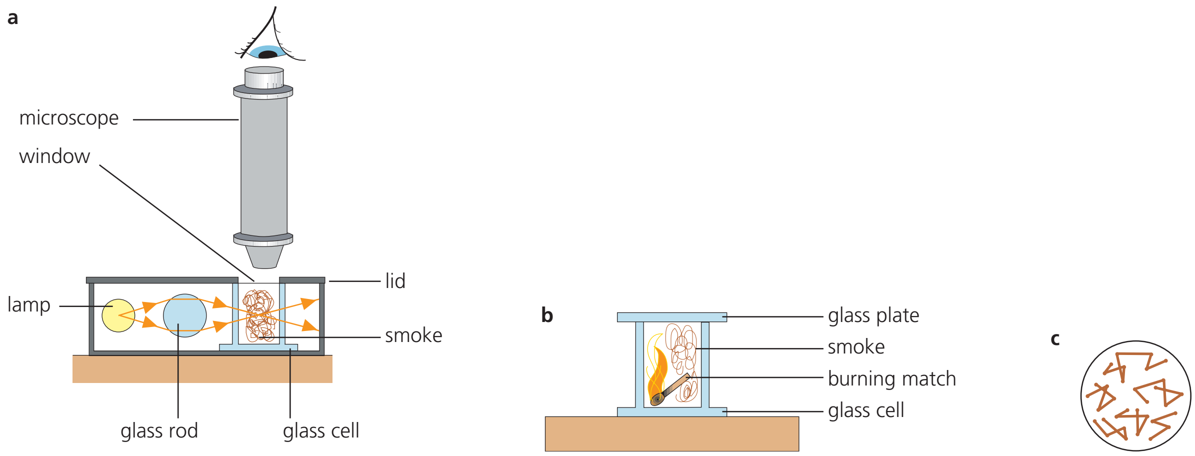
At each collision of a gas particle with a surface of the container, it undergoes a change of momentum which produces a force on the surface (see Topic 1.6). At a constant temperature the average force and hence the pressure exerted on the surface is constant, since pressure is force per unit area. When the temperature rises and the rate at which collisions with the surfaces of the container increases, so does the average force and hence the gas pressure.

Practical work

Brownian motion

For safe experiments/demonstrations related to this topic, please refer to the *Cambridge IGCSE Physics Practical Skills Workbook* that is also part of this series.

The apparatus is shown in Figure 2.1.6a. First fill the glass cell with smoke using a match (Figure 2.1.6b). Replace the lid on the apparatus and set it on the microscope platform. Connect the lamp to a 12 V supply; the glass rod acts as a lens and focuses light on the smoke.



▲ **Figure 2.1.6**

Carefully adjust the microscope until you see bright specks dancing around haphazardly (Figure 2.1.6c). The specks are smoke particles seen by reflected light; their random motion is called **Brownian motion** and is evidence for the kinetic particle model of matter. This motion is due to collisions between the microscopic particles in a suspension and the particles of the gas or liquid.

1 What are the specks of light in the glass cell of the Brownian motion experiment?
2 In a glass cell set up to show Brownian motion, describe how the specks of light move.

3 What do you think might cause microscopic particles to move in the way they do in a Brownian motion experiment?

Explanation of Brownian motion

The random motion of the microscopic smoke particles in the cell in Figure 2.1.6 is due to random molecular collisions of fast-moving air molecules in the cell. A smoke particle is massive compared with an air molecule, but if there are more high-speed molecules striking one side of it than the other at a given instant, the particle will move in the direction in which there is a net force. The imbalance, and hence the direction of the net force, changes rapidly in a random manner.

Test yourself

3 Explain the structure of
   a solids
   b liquids
   c gases.
   in terms of the particle model.
4 Explain what is meant by the term absolute zero.

5 Explain how smoke particles can be moved by air molecules in a Brownian motion experiment.

2.1.3 Gases and the absolute scale of temperature

FOCUS POINTS

★ Describe, in terms of particles, the effect of change of temperature or volume on the pressure of a fixed mass of gas.

★ Use the correct equation to calculate pressure and volume of a fixed mass of gas, and be able to represent this relationship graphically.

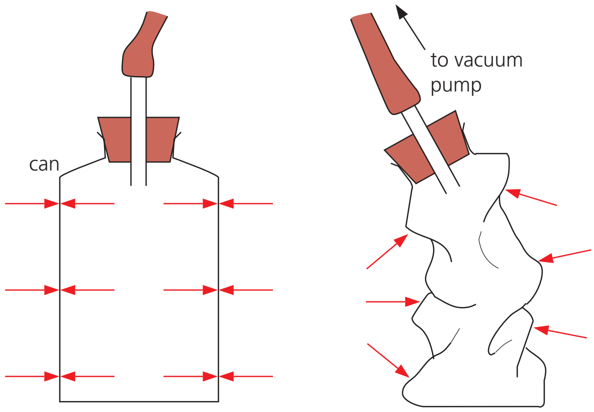
★ Convert temperatures between the Celsius and Kelvin temperature scales using the correct equation.

Gases show the simplest behaviour of the three states of matter and respond to changes of temperature or volume by a change of pressure. By keeping either volume or temperature constant in an experiment, their relationships with pressure can be determined and explained in terms of the kinetic particle model of matter. The properties of gases can be exploited for use in **thermometers** to measure temperature. You will be familiar with the Celsius scale of temperature for everyday measurements; the freezing temperature of water is set at 0°C and the boiling temperature of water at 100°C. In both the Kelvin and Celsius temperature scales, there are 100 degrees between the freezing temperature and boiling temperature of water, but the Kelvin scale starts from –273°C where the motion of particles ceases.

Pressure of a gas

The air forming the Earth's atmosphere stretches upwards a long way. Air has weight; the air in a normal room weighs about the same as you do, about 500 N. Because of its weight the atmosphere exerts a large pressure at sea level, about 100 000 N/m^2 = 10^5 Pa (or 100 kPa). This pressure acts equally in all directions.

A gas in a container exerts a pressure on the surfaces of the container. If air is removed from a can by a vacuum pump (Figure 2.1.7), the can collapses because the air pressure outside is greater than that inside. A space from which all the air has been removed is a **vacuum**. Alternatively, the pressure in a container can be increased, for example by pumping more gas into the can; a Bourdon gauge (Topic 1.8) is used for measuring gas pressures.



▲ **Figure 2.1.7** Atmospheric pressure collapses the evacuated can.

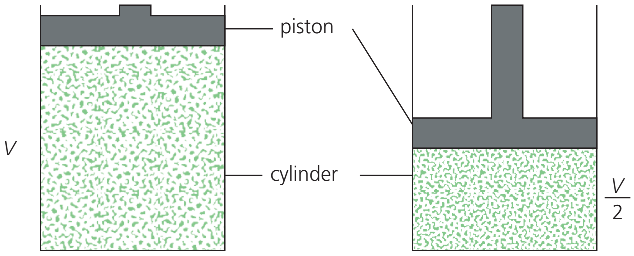
When a gas is heated, as air is in a jet engine, its pressure as well as its volume may change. To study the effect of temperature on these two quantities we must keep one fixed while the other is changed. When investigating relationships between properties only one **variable** should be changed at a time.

Effect on pressure of a change in temperature (constant volume)

When a gas is heated and its temperature rises, the average speed of its particles increases. If the volume of a fixed mass of gas stays constant, its pressure increases because there are more frequent and more violent collisions of the particles with the surfaces.

Effect on pressure of a change in volume (constant temperature)

If the volume of a fixed mass of gas is halved by halving the volume of the container (Figure 2.1.8), the number of particles per cm^3 will be doubled. There will be twice as many collisions per second with the surfaces, i.e. the pressure is doubled.



▲ **Figure 2.1.8** Halving the volume doubles the pressure.

Practical work

Effect on pressure of temperature (volume constant)

Safety

- The Bourdon gauge should be firmly clamped to prevent toppling.
- Eye protection must be worn.
- Take care with hot apparatus.

The apparatus is shown in Figure 2.1.9. The rubber tubing from the flask to the pressure gauge should be as short as possible. The flask must be in water almost to the top of its neck and be securely clamped to keep it off the bottom of the can. Heat can be supplied to the water by standing the can on a hot plate or on a tripod over a Bunsen burner.

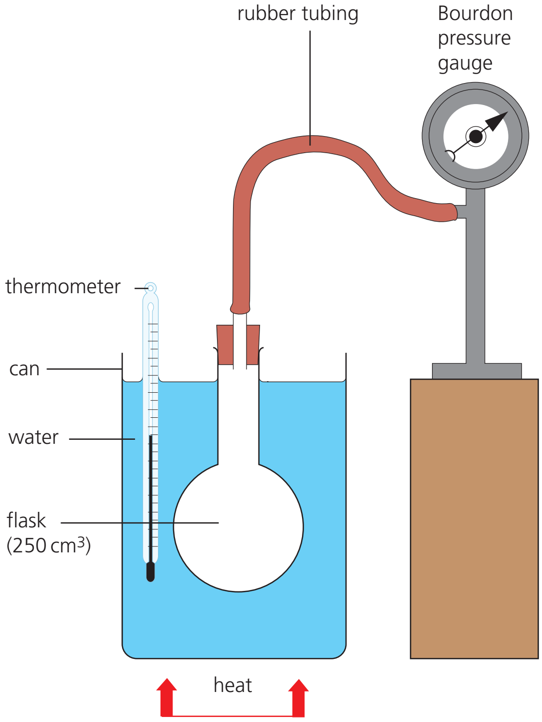
Record the pressure over a wide range of temperatures, but before taking a reading from the **thermometer**, stop heating, stir and allow time for the gauge reading to become steady; the air in the flask will then be at the temperature of the water. Take about six readings and tabulate the results.

Plot a graph of pressure on the y-axis and temperature on the x-axis.

4 **a** Name the independent variable in the experiment.
  b Name the dependent variable.

5 Why must the volume be kept constant in the experiment?

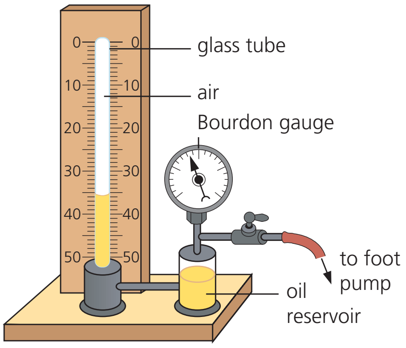
6 What precautions should you take to obtain accurate results in the experiment?



▲ **Figure 2.1.9**

Effect on volume of pressure (temperature constant)

Changes in the volume of a gas due to pressure changes can be studied using the apparatus in Figure 2.1.10. The volume V of air trapped in the glass tube is read off on the scale behind. The pressure is altered by pumping air from a foot pump into the space above the oil reservoir. This forces more oil into the glass tube and increases the pressure p on the air in it; p is measured by the Bourdon gauge. Take about six different measurements. Plot a graph of pressure versus volume as shown in Figure 2.1.11a.

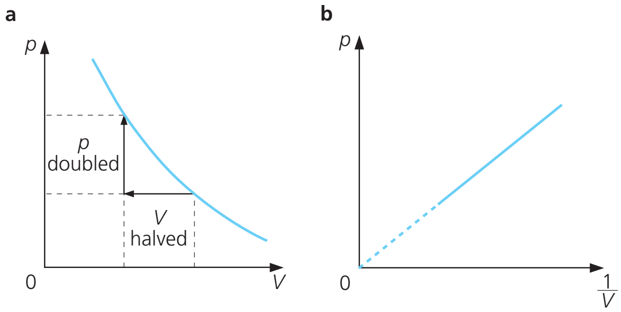


▲ **Figure 2.1.10**

7 **a** Name the independent variable in the experiment.

b Name the dependent variable.

8 A graph of pressure against 1/volume for the results of the experiment is shown in Figure 2.1.11b. Name the features of the graph which suggest that pressure is proportional to 1/volume.



▲ **Figure 2.1.11**

Variations in gas pressure with volume

The variation of the pressure of a fixed mass of gas with changes in volume (at constant temperature) is shown in Figure 2.1.11a. Close examination of the curve shows that if p is doubled, V is halved. That is, *p is inversely proportional to V*. In symbols

$$p \propto \frac{1}{V} \text{ or } p = \text{constant} \times \frac{1}{V}$$

$$\therefore \quad pV = \text{constant}$$

If several pairs of readings, p_1 and V_1, p_2 and V_2, etc. are taken, then it can be confirmed that

$$p_1V_1 = p_2V_2 = \text{constant}$$

This is Boyle's law, which is stated as follows:

> The pressure of a fixed mass of gas is inversely proportional to its volume if its temperature is kept constant.

Since p is inversely proportional to V, then p is directly proportional to $1/V$. A graph of p against $1/V$ is therefore a straight line through the origin (Figure 2.1.11b).

? Worked example

A certain quantity of gas has a volume of 40 cm^3 at a pressure of 1×10^5 Pa. Find its volume when the pressure is 2×10^5 Pa. Assume the temperature remains constant.

Using the equation pV = constant we have

$$p_1V_1 = p_2V_2$$

Rearranging the equation gives

$$V_2 = p_1 \times V_1/p_2$$
$$= 1 \times 10^5\,\text{Pa} \times 40\,\text{cm}^3/2 \times 10^5\,\text{Pa}$$
$$= 20\,\text{cm}^3$$

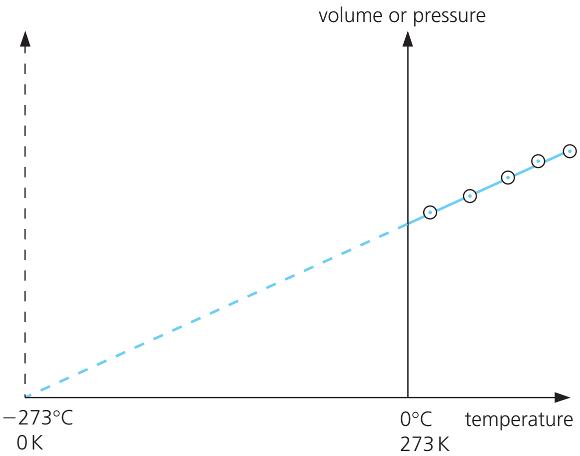
Now put this into practice

1 A fixed mass of gas has a volume of 9 cm^3 at a pressure of 1×10^5 Pa. Find its volume when the pressure is 3×10^5 Pa.

2 A certain quantity of gas has a volume of 40 cm^3 at a pressure of 2×10^5 Pa. Find its pressure when the volume is 20 cm^3.

Celsius and Kelvin temperature scales

The volume–temperature and pressure–temperature graphs for a gas are straight lines (Figure 2.1.12). They show that gases expand **linearly** with temperature as measured on a mercury thermometer, i.e. equal temperature increases cause equal volume or pressure increases.



▲ **Figure 2.1.12**

The graphs do not pass through the Celsius temperature origin (0°C). If graph lines are extrapolated backwards, they cut the temperature axis at about −273°C. This temperature is called absolute zero because we believe it is the lowest temperature possible. It is the zero of the *absolute* or *Kelvin scale of temperature*. At absolute zero molecular motion ceases and a substance has no internal energy.

Degrees on this scale are called **kelvins** and are denoted by K. They are exactly the same size as Celsius degrees. Since −273°C = 0 K, conversions from °C to K are made by adding 273. For example

$$0°\text{C} = 273\,\text{K}$$

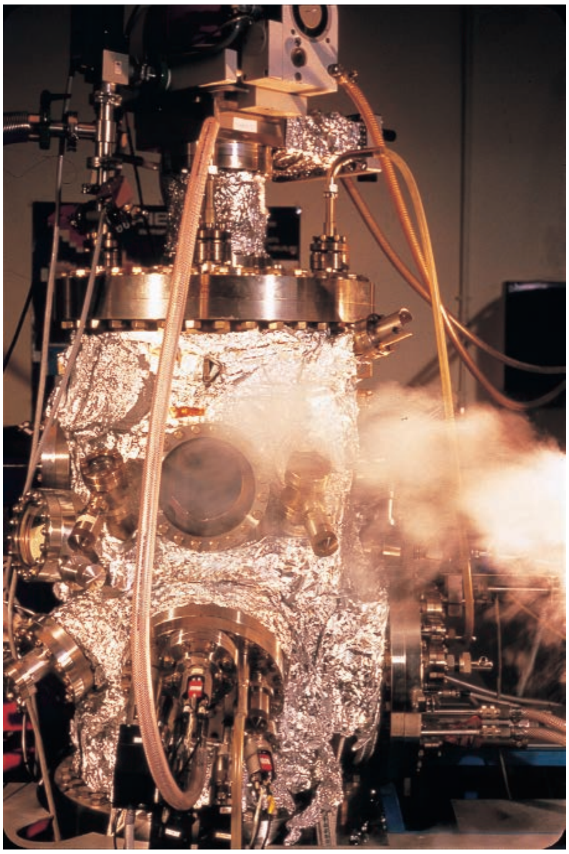
$$15°\text{C} = 273 + 15 = 288\,\text{K}$$

$$100°\text{C} = 273 + 100 = 373\,\text{K}$$

Kelvin or absolute temperatures are represented by the letter T, and if θ (Greek letter 'theta') stands for a **degrees Celsius** scale temperature then, in general,

$$T = 273 + \theta$$

Near absolute zero strange things occur. Liquid helium becomes a superfluid. It cannot be kept in an open vessel because it flows up the inside of the vessel, over the edge and down the outside. Some metals and compounds become superconductors of electricity and a **current**, once started in them, flows forever, without a battery. Figure 2.1.13 shows research equipment that is being used to create materials that are superconductors at very much higher temperatures, such as −23°C.



▲ **Figure 2.1.13** This equipment is being used to make films of complex composite materials that are superconducting at temperatures far above absolute zero.

Worked example

a Convert 27°C to K.
Substitute in the equation $T = 273 + \theta$ to give

$$T = 273 + 27 = 300\,\text{K}$$

b Convert 60 K to °C.
Rearrange the equation $T = 273 + \theta$ to give

$$\theta = T - 273 = 60 - 273 = -213°\text{C}$$

Now put this into practice

1 Convert 80°C to K.
2 Convert 100 K to °C.

Going further

Practical work

Effect on volume of temperature (pressure constant): Charles' law

Safety

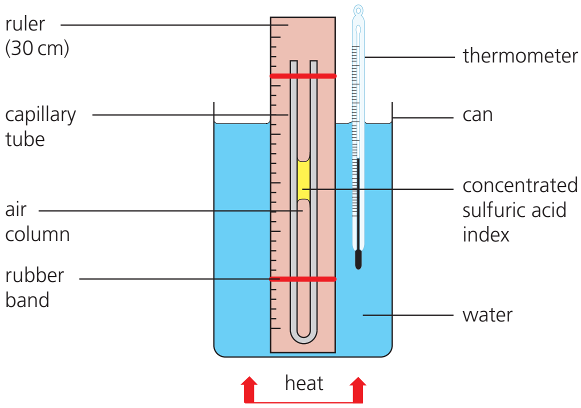
- Eye protection must be worn.
- Take care as concentrated sulfuric acid is highly corrosive. Do not touch it if any leaks out of the tube.

Arrange the apparatus as in Figure 2.1.14. The index of concentrated sulfuric acid traps the air column to be investigated and also dries it. Adjust the capillary tube so that the bottom of the air column is opposite a convenient mark on the ruler.

Note the length of the air column (between the lower end of the index and the sealed end of the capillary tube) at different temperatures but, before taking a reading, stop heating and stir well to make sure that the air has reached the temperature of the water. Put the results in a table.

Plot a graph of volume (in cm, since the length of the air column is a measure of it) on the y-axis and temperature (in °C) on the x-axis.

The pressure of (and on) the air column is constant and equals atmospheric pressure plus the pressure of the acid index.



▲ **Figure 2.1.14**

9 **a** Name the independent variable in the experiment.
b Name the dependent variable.

10 The results of the experiment are plotted in a graph of volume versus temperature and appear similar to those shown in Figure 2.1.12. What do the results indicate about the relationship between volume and temperature?

The gas laws

Using absolute temperatures, the gas laws can be stated in a convenient form for calculations.

Charles' law

In Figure 2.1.12 the volume–temperature graph passes through the origin if temperatures are measured on the Kelvin scale, that is, if we take 0 K as the origin. We can then say that the volume V is directly proportional to the absolute temperature T, i.e. doubling T doubles V, etc. Therefore

$$V \propto T \text{ or } V = \text{constant} \times T$$

or

$$\frac{V}{T} = \text{constant} \quad (1)$$

Charles' law may be stated as follows:

> The volume of a fixed mass of gas is directly proportional to its absolute temperature if the pressure is kept constant.

Pressure law

From Figure 2.1.12 we can say similarly for the pressure p that

$$p \propto T \text{ or } p = \text{constant} \times T$$

or

$$\frac{p}{T} = \text{constant} \quad (2)$$

The pressure law may be stated as follows:

> The pressure of a fixed mass of gas is directly proportional to its absolute temperature if the volume is kept constant.

Variations in gas pressure with volume

For a fixed mass of gas at constant temperature

$pV = \text{constant}$ (3)

Combining the laws

The three equations can be combined, giving

$$\frac{pV}{T} = \text{constant}$$

For cases in which p, V and T all change from, say, p_1, V_1 and T_1 to p_2, V_2 and T_2, then

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2} \quad (4)$$

Worked example

A bicycle pump contains 50 cm^3 of air at 17°C and at 1.0 atmosphere pressure (atm). Find the pressure when the air is compressed to 10 cm^3 and its temperature rises to 27°C.

We have

$p_1 = 1.0\,\text{atm}$ $\quad$ $p_2 = ?$

$V_1 = 50\,\text{cm}^3$ $\quad$ $V_2 = 10\,\text{cm}^3$

$T_1 = 273 + 17 = 290\,\text{K}$ $\quad$ $T_2 = 273 + 27 = 300\,\text{K}$

From equation (4) we get

$$p_2 = p_1 \times \frac{V_1}{V_2} \times \frac{T_2}{T_1} = 1 \times \frac{50}{10} \times \frac{300}{290} = 5.2\,\text{atm}$$

Note that: (i) all temperatures must be in K; (ii) any units can be used for p and V provided the same units are used on both sides of the equation; (iii) in some calculations the volume of the gas has to be found at standard temperature and pressure, or 's.t.p.'. This is temperature 0°C and pressure 1 atmosphere (1 atm = 10^5 Pa).

Now put this into practice

1 A fixed mass of gas has a volume of 9 cm^3 at a pressure of 1×10^5 Pa at 27°C. Find its pressure when the volume is compressed to 5 cm^3 and its temperature rises to 37°C.

2 A certain quantity of gas has a volume of 40 cm^3 at a pressure of 2.0×10^5 Pa at 27°C. Find its temperature when the volume is 30 cm^3 and the pressure is 3.2×10^5 Pa.

Test yourself

6 In terms of particle motion describe the effect on the pressure of a fixed mass of gas when the temperature rises but the volume is kept constant.

7 Describe the effect on the pressure of a fixed mass of gas if the volume is reduced but the temperature of the gas is kept constant.

8 a Why is −273°C chosen as the starting temperature for the Kelvin scale of temperature?

b How do the size of units on the Celsius and Kelvin scales of temperature compare?

Revision checklist

After studying Topic 2.1 you should know and understand:

- ✔ the different physical properties of solids, liquids and gases
- ✔ particle diagrams for the different states of matter
- ✔ the different particle structure of solids, liquids and gases
- ✔ how the particle model explains the physical properties of solids, liquids and gases.

After studying Topic 2.1 you should be able to:

- ✔ recall the terms describing changes in state of solids, liquids and gases
- ✔ explain temperature, absolute zero and change in pressure in terms of molecular motion
- ✔ describe and explain an experiment to show Brownian motion
- ✔ describe the effect on the pressure of a fixed mass of gas caused by a change in temperature (at constant volume) and a change of volume (at constant temperature)
- ✔ convert temperatures between the Celsius and Kelvin scales of temperature
- ✔ recall and use the equation pV = constant (for a fixed mass of gas at constant temperature).

Exam-style questions

1 Solids, liquids and gases are composed of particles. Which one of the following statements is *not* true?

A The particles in a solid vibrate about a fixed position.

B The particles in a liquid are arranged in a regular pattern.

C The particles in a gas exert negligibly small forces on each other, except during collisions.

D The densities of most liquids are about 1000 times greater than those of gases because liquid particles are much closer together than gas particles.

[Total: 1]

2 Sketch particle diagrams for

a a solid [2]

b a liquid [2]

c a gas. [2]

[Total: 6]

3 a Name the state of matter in which the particles are furthest apart. [1]

b Use the particle model of matter to explain how a gas exerts pressure on the surfaces of its container. [2]

c State and explain how the pressure changes when the temperature of the gas increases. [4]

[Total: 7]

4 Smoke particles and air exist in a sealed glass box. The box is illuminated, and the motion of the smoke particles is observed through a microscope.

a Describe the motion of the smoke particles. [1]

b Explain the reason the smoke particles move in this way. [4]

[Total: 5]

5 a The following statements refer to the pressure exerted by a gas in a container.
Write down whether each statement is *true* or *false*.

i Pressure is due to the particles of the gas bombarding the surfaces of the container. [1]

ii The pressure decreases if the gas is cooled at constant volume. [1]

iii The pressure increases if the volume of the container increases at constant temperature. [1]

b i Explain the significance of a temperature of –273°C in terms of particle motion. [2]

ii State the value of a temperature of –273°C on the Kelvin temperature scale. [1]

iii Calculate the value of a temperature of –200°C on the Kelvin scale of temperature. [1]

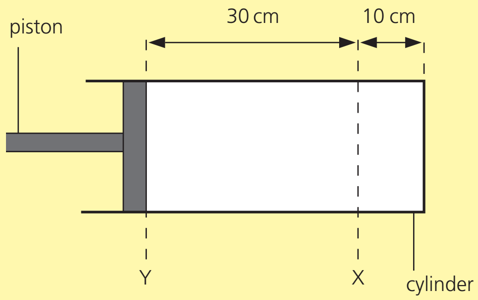
[Total: 7]

6 The piston in Figure 2.1.15 is pulled out of the cylinder from position X to position Y, without changing the temperature of the air enclosed. If the original pressure in the cylinder was 1.0×10^5 Pa, calculate

a the air pressure when the piston is at position Y [3]

b the air pressure when the piston is moved a further 10 cm to the left of position Y. [3]

[Total: 6]



▲ **Figure 2.1.15**

7 A certain quantity of gas has a volume of $30\,cm^3$ at a pressure of 1×10^5 Pa.
Assuming the temperature remains constant, calculate the volume of the gas when the pressure is

a 2×10^5 Pa [3]

b 5×10^5 Pa. [3]

[Total: 6]

Alternative to Practical

8 The variation in pressure of a fixed mass of gas is measured for different volumes.
The results obtained are listed in the following table:

Pressure/10^5 Pa	**Volume/cm^3**	**1/volume/cm^3**
24	1.0	
12	2.0	
8	3.0	
6	4.0	
4	6.0	

a Plot a graph of pressure against volume. [3]
b Work out values for 1/volume and enter them into the table. [1]
c Plot a graph of pressure against 1/volume. [3]
d Are the results in agreement with the equation $pV =$ constant? [2]

[Total: 9]