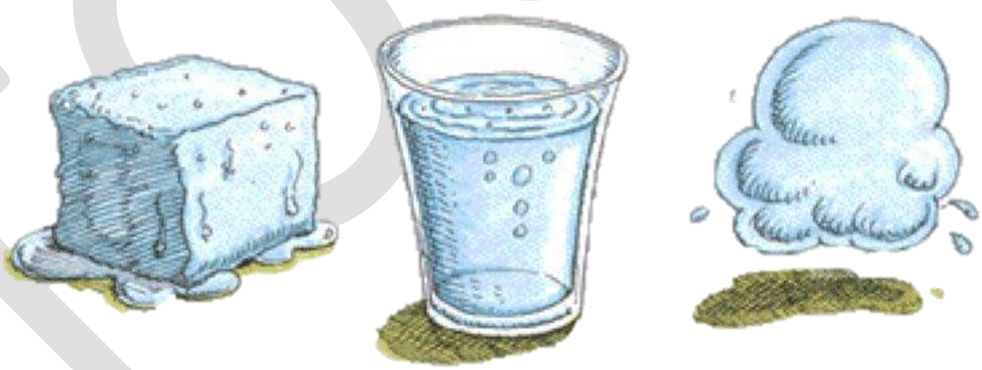
Cambridge AS Chemistry

(Code: 9701)

Chapter 5
States of matter



States of matter

Gases have no fixed shape or volume. Gas particles:

- are far apart, therefore gases can be compressed
- are randomly arranged
- can move freely from place to place, in all directions.

Liquids take the shape of the container they occupy. Liquid particles:

- are close together, so liquids have a fixed volume and can only be compressed slightly
- are arranged fairly randomly
- have limited movement from place to place, in all directions.

Solids have a fixed shape and volume. Solid particles:

- are touching each other, so solids cannot be compressed
- are usually in a regular arrangement
- cannot change positions with each other – they can only vibrate.

Five types of structure are found in elements and compounds:

- simple atomic, e.g. argon
- simple molecular, e.g. carbon dioxide
- giant ionic, e.g. sodium chloride
- giant metallic, e.g. iron
- giant molecular, e.g. silicon(IV) oxide.

The gaseous state

The kinetic theory of gases

The idea that molecules in gases are in constant movement is called the kinetic theory of gases. This theory makes certain assumptions:

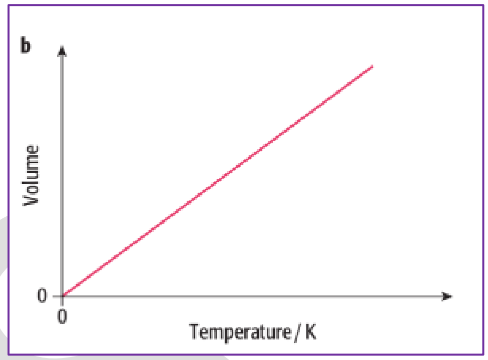
- the gas molecules move rapidly and randomly
- the distance between the gas molecules is much greater than the diameter of the molecules so the volume of the molecules is negligible
- there are no forces of attraction or repulsion between the molecules
- all collisions between particles are elastic – this means no kinetic energy is lost in collisions (kinetic energy is the energy associated with moving particles)
- the temperature of the gas is related to the average kinetic energy of the molecules.

A theoretical gas that fits this description is called an ideal gas. The gases we encounter are called real gases. Noble gases with small atoms, such as helium and neon, approach ideal gas behaviour. This is because the intermolecular forces are so small.

Ideal gases

The volume that a gas occupies depends on:

- its pressure; we measure pressure in pascals, Pa
- its temperature; we measure temperatures of gases in kelvin, K.



The kelvin temperature equals the Celsius temperature plus 273.

We say that the volume is inversely proportional to the pressure.

An ideal gas will have a volume that varies exactly in proportion to its temperature and exactly in inverse proportion to its pressure.

Limitations of the ideal gas laws

Real gases do not always obey the kinetic theory in two ways:

- there is not zero attraction between the molecules
- we cannot ignore the volume of the molecules themselves.

These differences are especially noticeable at very high pressures and very low temperatures. Under these conditions:

- the molecules are close to each other
- the volume of the molecules is not negligible compared with the volume of the container
- there are van der Waals' or dipole–dipole forces of attraction between the molecules
- attractive forces pull the molecules towards each other and away from the walls of the container
- the pressure is lower than expected for an ideal gas
- the effective volume of the gas is smaller than expected for an ideal gas.

The general gas equation

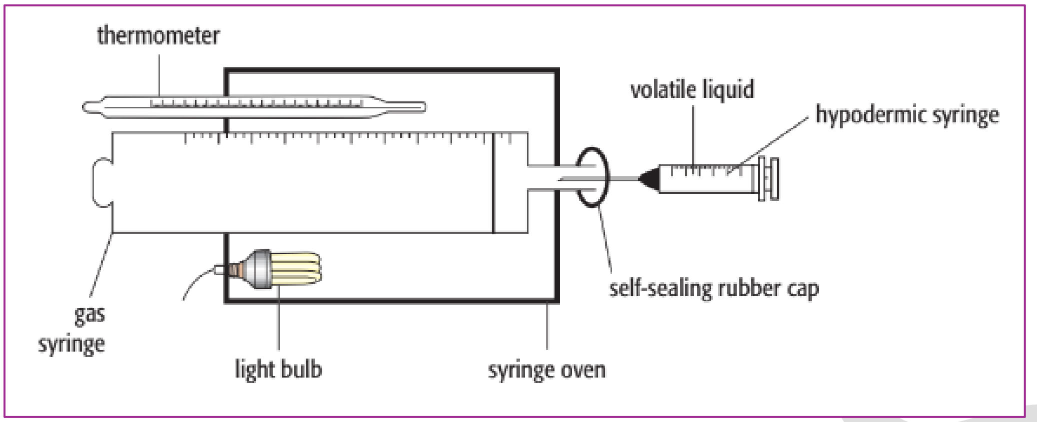
$$\boxed{pV = nRT}$$

Calculating relative molecular masses

This method can also be applied to find the relative molecular mass of a volatile liquid.

The volume of vapour produced is:
final gas syringe volume – initial gas syringe volume

The mass used in the calculation is:
initial mass of hypodermic syringe + liquid –final mass of hypodermic syringe + liquid



The liquid state

The behaviour of liquids

When we heat a solid:

- the energy transferred to the solid makes the particles vibrate more vigorously
- the forces of attraction between the particles weaken
- the solid changes to a liquid when its temperature is sufficiently high.

We call this change of state melting.

When we cool a liquid, the particles:

- lose kinetic energy so they do not move around so readily
- experience increasing forces of attraction
- stop sliding past each other when the temperature is sufficiently low; the liquid solidifies.

We call this change of state freezing.

Vaporisation and vapour pressure

When we heat a liquid:

- the energy transferred to the liquid makes the particle move faster
- the forces of attraction between the particles weaken
- the particles with most energy are the first to escape from the forces holding them together in the liquid
- the liquid evaporates – this happens at a temperature below the boiling point
- the forces weaken enough for all the particles to become completely free from each other; they move fast and randomly and they spread out
- the liquid boils; this happens at the boiling point.

This change from the liquid state to the gas state is called vaporisation. The energy required to change one mole of liquid to one mole of gas is called the enthalpy chang of vaporisation.
When we cool a vapour, the particles:

- lose kinetic energy so the molecules move around less quickly
- experience increasing forces of attraction

- move more slowly and become closer together when the temperature is sufficiently low; the gas liquefies.

We call this change of state condensation.

At equilibrium the concentration of water molecules in the vapour remains constant. the pressure exerted by a vapour in equilibrium with its liquid is called its vapour pressure. Vapour pressure will increase when the temperature increases because:

- the gas particles have more kinetic energy
- the gas particles move faster, so are able to overcome intermolecular forces of attraction more easily.

The temperature at which the vapour pressure is equal to the atmospheric pressure is the boiling point of the liquid.

The solid state

Ionic lattices

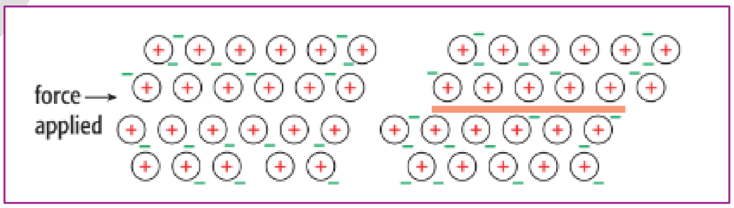
Ionic lattices have a three-dimensional arrangement of alternating positive and negative ions. Compounds with ionic lattices are sometimes called giant ionic structures.

The properties of ionic compounds reflect their structure as well as their bonding.

- They are hard. It takes a lot of energy to scratch the surface because of the strong attractive forces keeping the ions together.
- They are brittle. Ionic crystals may split apart when hit in the same direction as the layers of ions.
- They have high melting points and high boiling points.
- Many of them are soluble in water.
- They only conduct electricity when molten or in solution

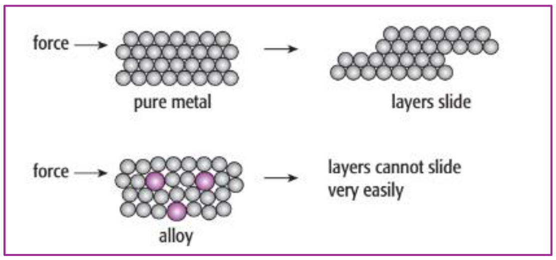
Metallic lattices

metals are malleable (they can be hammered into different shapes) and ductile (they can be drawn into wires). The high tensile strength and hardness of most metals is also due to the strong attractive forces between the metal ions and the delocalised electrons.



Alloys and their properties

An alloy is a mixture of two or more metals or a metal with a non-metal. Brass is an alloy of copper (70%) with zinc (30%).



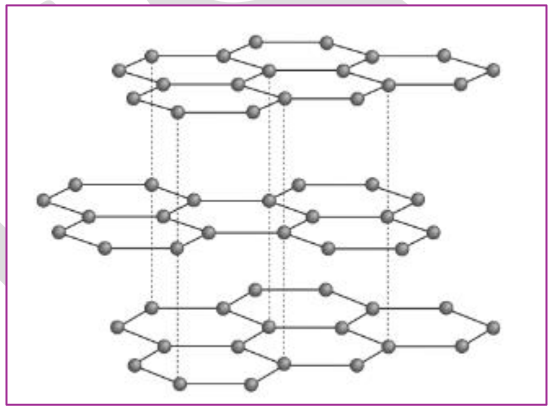
Simple molecular lattices

Substances with a simple molecular structure, such as iodine, can also form crystalsIce also forms a crystalline lattice. Ice and water have peculiar properties because of hydrogen bonding

Giant molecular structures

Some covalently bonded structures have a three- dimensional network of covalent bonds throughout the whole structure. We call these structures giant molecular structures or giant covalent structures. Different crystalline or molecular forms of the same element are called allotropes.

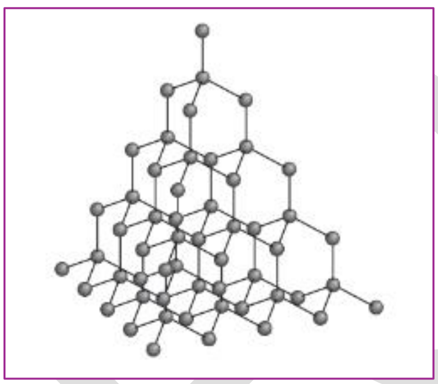
Graphite



The properties of graphite are related to its structure.

- High melting and boiling points
- Softness: graphite is easily scratched. The layers readily flake off. This ‘flakiness’ is why graphite is used in pencil ‘leads’ and feels slippery.
- Good conductor of electricity

Diamond

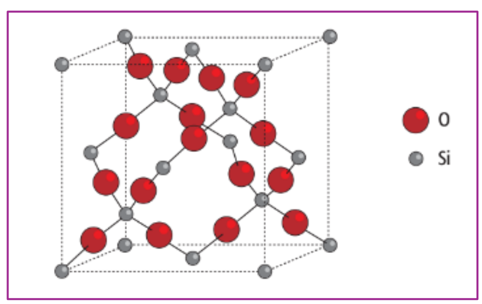


The properties of diamond are related to its structure.

- High melting and boiling points
- Hardness
- Does not conduct electricity or heat

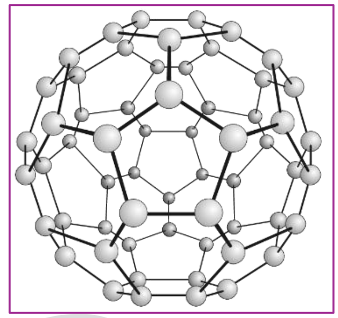
Silicon(IV) oxide

It forms hard, colourless crystals with high melting and boiling points and it does not conduct electricity. Sand is largely silicon(IV)oxide.



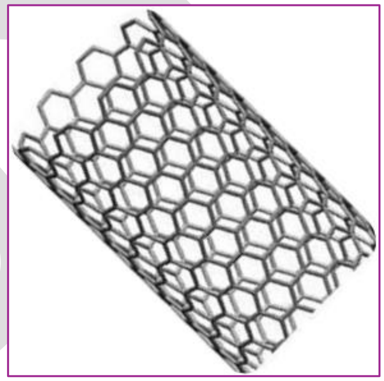
Carbon nanoparticles

Fullerenes



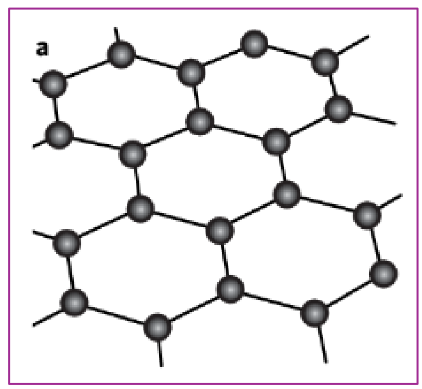
Fullerenes are allotropes of carbon in the form of hollow. They are similar in structure to graphite, in that each carbon atom is bonded to three other carbon atoms. The first fullerene discovered was called buckminsterfullerene, C_{60}.

A second type of fullerene is a class of molecules described as nanotubes. Nanotubes have characteristic properties:



- They have high electrical conductivity along the long axis of the cylinder. This is because, like graphite, some of the electrons are delocalised and are able to move along the cylinder when a voltage is applied.
- They have a very high tensile strength when a force is applied along the long axis of the cylinder. They can be up to 100 times stronger than steel of the same thickness.
- They have very high melting points (typically about 3500°C). This is because there is strong covalent bonding throughout the structure.

Graphene



Graphene is a single isolated layer of graphite. Graphene has some of the properties of graphite, but they are more exaggerated. For example:

- Graphene is the most chemically reactive form of carbon. Single sheets of graphene burn at very low temperatures and are much more reactive than graphite.
- Graphene is extremely strong for its mass.
- For a given amount of material, graphene conducts electricity and heat much better than graphite.

Conserving materials

Recycling materials

Recycling has several advantages:

- it saves energy (this helps tackle global warming, as we burn less fossil fuel)
- it conserves supplies of the ore
- landfill sites do not get filled up as fast and there is less waste
- it is cheaper than extracting the metal from the ore.

Copper

Recycling copper is important because:

- less energy is needed to recycle copper than is needed to transport copper ore to the smelting plant and extract copper from it
- less energy is needed to extract and refine the recycled copper so that it is pure enough to be electrolysed.

Aluminium

Purifying and remoulding aluminium is much cheape than extracting aluminium from bauxite ore. Savings are made because:

- it is not necessary to extract the aluminium ore from the ground or to transport it to the smelting plant; these processes require energy
- the treatment of bauxite to make pure aluminium oxide for electrolysis does not need to be carried out
- the aluminium scrap needs less energy to melt it, compared with melting aluminium oxide
- the expensive electrolysis of aluminium oxide does not need to be carried out

EXCERSISE

1. When used for cutting or welding, ethyne is transported in cylinders which contain the gas under pressure. A typical cylinder has a volume of 76 dm3 and contains ethyne gas at 1515 kPa pressure at a temperature of 25 °C. Use the general gas equation, pV = nRT, to calculate the amount, in moles, of ethyne in this cylinder.

2.
   a. At sea level and a temperature of 20°C an inflated bicycle tyre contains 710cm3 of air at an internal pressure of 6 × 105 Pa. Use the general gas equation PV = nRT to calculate the amount, in moles, of air in the tyre at sea level.
   b. The same bicycle, with its tyres inflated at sea level as described in (a) above, is placed in the luggage hold of an airliner. At a height of 10 000m, the temperature in the luggage hold is 5°C and the air pressure is 2.8 × 104 Pa.

3. The kinetic theory of gases is used to explain the large scale (macroscopic) properties of gases by considering how individual molecules behave.
   a. State two basic assumptions of the kinetic theory as applied to an ideal gas.
   b. State two conditions under which the behaviour of a real gas approaches that of an ideal gas.
   c. Place the following gases in decreasing order of ideal behaviour,

      ammonia, neon, nitrogen

   most ideal .... least ideal Explain your answer.

d. By using the kinetic-molecular model, explain why a liquid eventually becomes a gas as the temperature is increased.

4. CO_2 does not behave as an ideal gas.
   a. State all the basic assumptions of the kinetic theory as applied to an ideal gas.
   b. Suggest one reason why CO2 does not behave as an ideal gas.

5. Which of the following least resembles an ideal gas?
   A. ammonia
   B. helium
   C. hydrogen
   D. trichloromethane

6. The density of ice is 1.00 g cm^{-3}. What is the volume of steam produced when 1.00 cm^3 of ice is heated to 323 °C (596 K) at a pressure of one atmosphere (101 kPa)? [1 mol of a gas occupies 24.0 dm^3 at 25 °C (298 K) and one atmosphere.]
   A. 0.267 dm^3
   B. 1.33 dm^3
   C. 2.67 dm^3
   D. 48.0 dm^3

7. Use of the Data Booklet is relevant to this question. The gas laws can be summarised in the ideal gas equation.

$$pV = Nrt$$

0.96 g of oxygen gas is contained in a glass vessel of volume 7000 cm3 at a temperature of 30 °C. What is the pressure in the vessel?

   A. 1.1 kPa
   B. 2.1 kPa
   C. 10.8 kPa
   D. 21.6 kPa

8. Which gas is likely to deviate most from ideal gas behaviour?
   A. HCl
   B. He
   C. CH_4
   D. N_2

9. Which of the following would behave most like an ideal gas at room temperature?
   A. carbon dioxide
   B. helium
   C. hydrogen
   D. nitrogen

10. 8 Flask X contains 5 dm3 of helium at 12 kPa pressure and flask Y contains 10 dm3 of neon at 6 kPa pressure. If the flasks are connected at constant temperature, what is the final pressure?
    A. 8 kPa
    B. 9 kPa
    C. 10 kPa
    D. 11 kPa

11. An ideal gas obeys the gas laws under all conditions of temperature and pressure. Which of the following are true for an ideal gas?
    A. The molecules have negligible volume.
    B. There are no forces of attraction between molecules.
    C. The molecules have an average kinetic energy which is proportional to its absolute temperature.

12. When a sample of a gas is compressed at constant temperature from 1500 kPa to 6000 kPa, its volume changes from 76.0 cm3 to 20.5 cm3. Which statements are possible explanations for this behaviour?
    A. The gas behaves non-ideally.
    B. The gas partially liquefies.
    C. Gas is adsorbed on to the vessel wall

13. What are assumptions of the kinetic theory of gases and hence of the ideal gas equation, PV = nRT ?
    A. Molecules move without interacting with one another except for collisions.
    B. Intermolecular forces are negligible.
    C. Intermolecular distances are much greater than the molecular size.