National 5 Chemistry

Unit 1 Chemical Changes & Structure

Part 1

Summary Notes

Topic 1

Rates of Reactions

Learning Outcomes

- Following the progress of a reaction through a change in mass or volume.
- Drawing and interpreting a graph to determine:
  - End-point of a reaction
  - Quantity of product
  - Quantity of reactant used
  - Effect of changing conditions
- Rate of reaction can be increased by the following:
  - Increasing the temperature
  - Increasing concentration of a reactant
  - Increasing surface area or decreasing particle size
  - Using a catalyst
- Catalysts are substances which speed up a chemical reaction but remain unchanged at the end of the reaction.
- Calculating average rate of reaction using rate = $\frac{\Delta \text{quantity}}{\Delta \text{time}}$
- Show that the rate of a reaction decreases over time through calculating the average rate.

Signs of Chemical Reactions

A chemical reaction takes place when substances react together and are changed into **new substances**. Many chemical reactions are accompanied by noticeable signs. Often a colour change is observed, a gas produced or a solid (precipitate) formed. In all chemical reactions an energy change occurs and a new substance is produced.

There are many chemical reactions that produce gases. Common gases produced are carbon dioxide, oxygen and hydrogen each of which has an identification test.

Gas	Identification Test
Carbon Dioxide	Turns lime water milky (cloudy)
Oxygen	Relights a glowing splint
Hydrogen	Burns with a “pop”

Reactions which release heat energy cause the temperature of the surroundings to increase and are called **exothermic** reactions. Reactions which absorb heat and cause the temperature of the surroundings to decrease are called **endothermic** reactions.

Rates of Chemical Reactions

Chemical reactions do not all occur at the same rate (speed). In the laboratory the reaction between an acid and alkali is instantaneous but the reaction between magnesium and dilute hydrochloric acid to form bubbles of gas takes place over minutes. Other reactions are very much slower and can take years.

Chemical Collisions

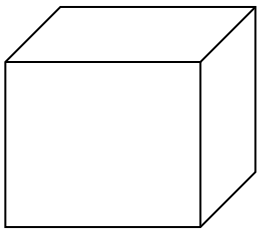
Before a chemical reaction can take place between two substances they must be brought into contact. This is necessary, because for a new substance (**product**) to be formed the starting particles (**reactants**) must collide with each other. The speed of a reaction can be changed by making changes to particle size (surface area), concentration and temperature of the reactants.

Particle Size/Surface Area

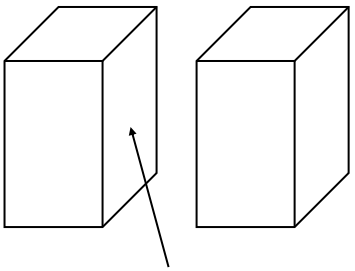
Particle size refers to the size of solid reactant particles in a reaction. Solid reactants may exist as one large piece or much smaller pieces even a powder. Consider the following diagram.

Rates of Chemical Reactions

One large particle
(Small surface area)



Two smaller particles
(Large surface area)

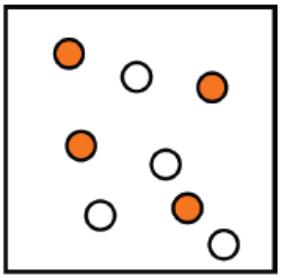


As the size of the pieces decreases new surface is exposed. The surface area is increased by breaking up lumps into chips or even grinding it into a powder. Overall a decrease in particle size increases the surface area and so the number of collisions increases causes an increase in the rate of reaction.

Concentration

The concentration of a solution is a measure of the number of particles present in a given volume of solution. In chemistry we measure concentration in terms of moles of solute per litre of solution written as **mol l^{-1}**. Consider the following diagram.

Low concentration (1 mol l^{-1})



High concentration (3 mol l^{-1})

An increase in concentration causes an increase in the number of collisions and therefore an increase in the rate of reaction.

Temperature

The temperature of substance is a measure of the **average kinetic energy** of particles. A substance at a higher temperature will contain particles which have more kinetic energy and are therefore moving around more. Particles which move around more are more likely to collide and therefore react therefore an increase in temperature causes an increase in the rate of reaction. In general the rate of reaction doubles with each 10°C rise in temperature.

Rates of Chemical Reactions

Catalysts

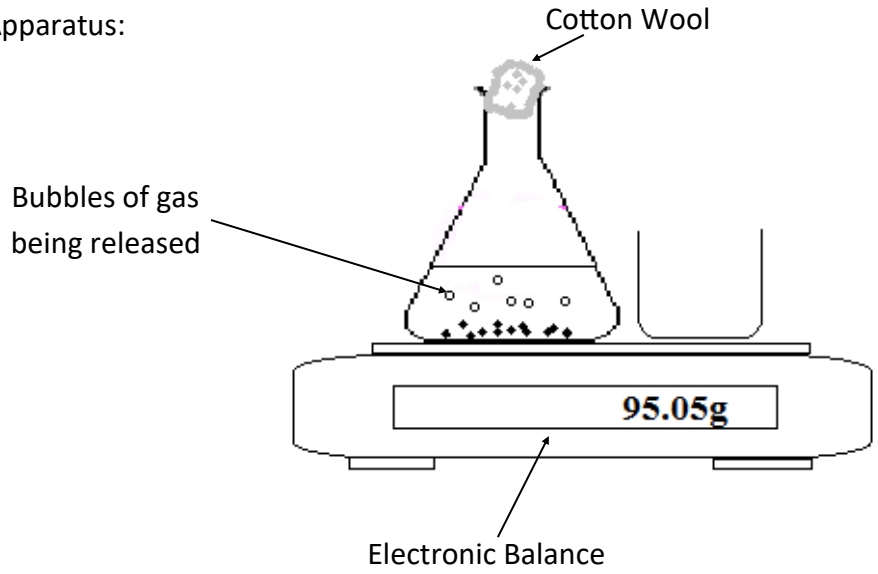
Catalysts are substances that can be used to increase the rate of a reaction. Different catalysts are required for different reactions. Catalysts are therefore said to be "reaction specific".

Catalysts provide an "easy route" from reactants to products but they are not used up during the course of a reaction and can be recovered unchanged at the end of the reaction. The mass of catalyst at the end of a reaction will therefore be the same as that at the start of the reaction.

Monitoring Mass Changes

In the reaction of marble chips and acid a gas is produced and therefore the mass of the apparatus will decrease as the reaction proceeds, this loss in mass can be measured.

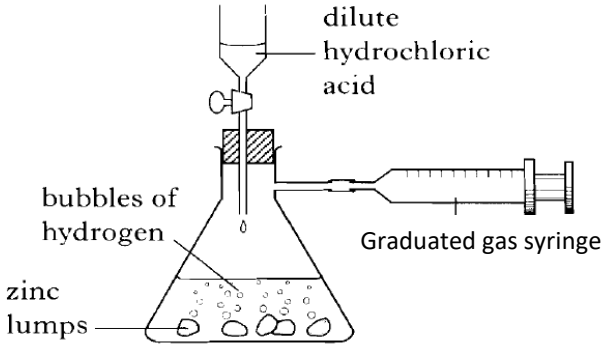
Mass loss Apparatus:

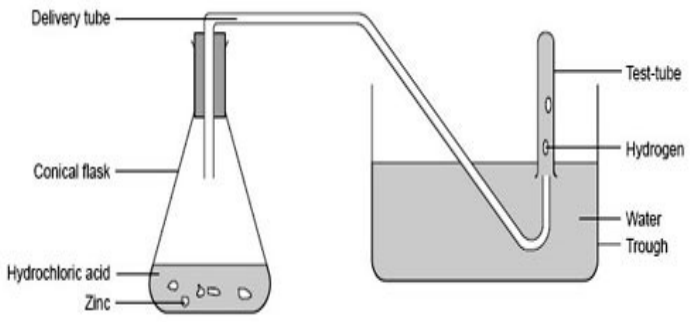


Monitoring Volume Changes

The volume of gas can be monitored when a reaction releases a gas.

Sample apparatus to measure volume of a gas produced using a syringe:





Alternatively the gas could be collected using downward displacement of water using a trough of water and measuring cylinder.

Rates of Chemical Reactions

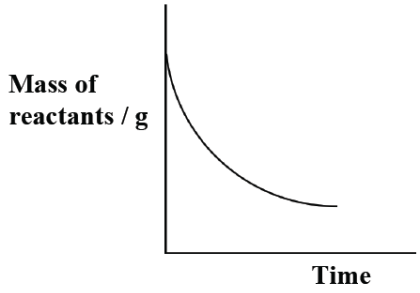
Measuring Rates of Reactions

As a reaction proceeds, reactants are being used up while products are being formed. The rate at which this happens can be followed by measuring the change in a "property" of a substance involved in the reaction over a period of time, e.g. the reaction of calcium carbonate with dilute acid.

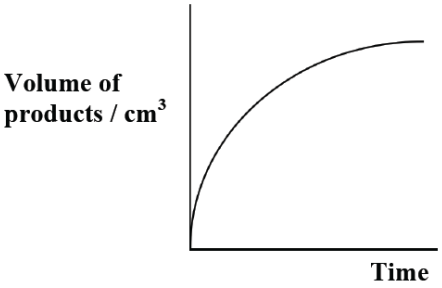
Calcium carbonate + Hydrochloric acid ⟶ Calcium Chloride + Water + Carbon dioxide

The change in mass (due to a gas being given off), volume of gas produced, concentration of acid or the pH of the acid can all be measured as the reaction proceeds. The speed of change directly relates to the speed of the reaction.

As this reaction proceeds the mass of the apparatus will decrease and this can be plotted to produce a graph e.g.

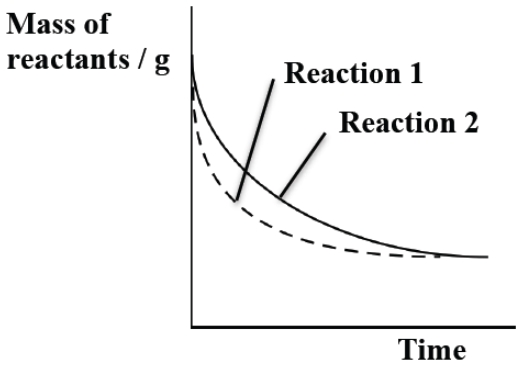


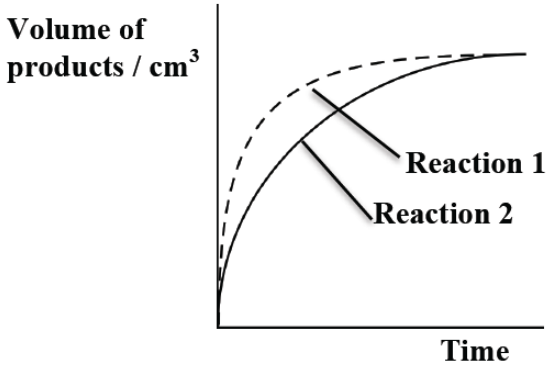
Alternatively as the volume of gas will increase as a reaction proceeds this could also be plotted e.g.



Special probes can be used to measure changes in concentration and also pH.

The rate of reaction is most rapid at the start and decreases as the reaction proceeds. The steeper the slope, the faster the rate of reaction, e.g. in the examples below, Reaction 1 is faster than Reaction 2.





The shorter the time for a particular change to take place, the faster the rate of reaction.

Rates of Chemical Reactions

Average Rate of Reaction

The **average rate** of reaction can be defined as a change in quantity (mass for example) divided by the time take for this change to occur i.e.

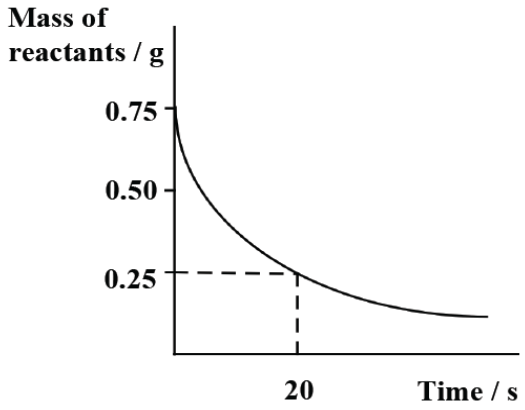
$$\text{Rate} = \frac{\Delta \text{ quantity}}{\Delta \text{ time}}$$

The units used for average rate depend on the measured change and the units of time used. For example if the change in mass was measured in grams and the time measured in minutes then the units of average rate would be grams per minute, written as g min^{-1}.

Example involving a change in mass

The average rate of reaction over the first 20s is:

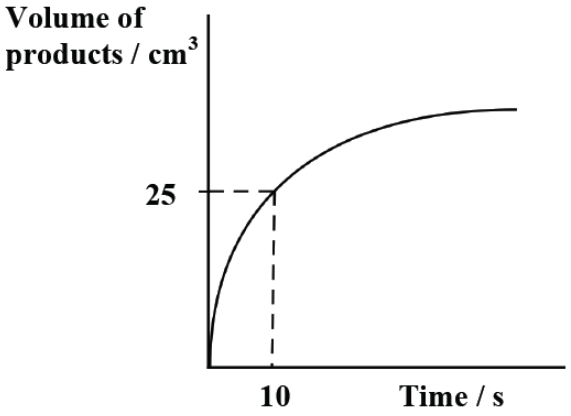
$$\text{Rate} = \frac{\Delta \text{ quantity}}{\Delta \text{ time}} = \frac{0.75 - 0.25}{20} = \frac{0.5}{20} = \mathbf{0.025\ g\ s^{-1}}$$



Example involving a change in volume

The average rate of reaction over the first 10s is

$$\text{Rate} = \frac{\Delta \text{ quantity}}{\Delta \text{ time}} = \frac{25 - 0}{10} = \mathbf{2.5\ cm^3\ s^{-1}}$$



Experiments can be repeated using the same quantity of reactants but under conditions where the rate is different. If the same quantity of reactants is used in different reactions then it can be expected that the same volume of gas will be produced or the same mass of gas will be released.

Topic Questions

Exercise 1

1. What is always produced whenever a chemical reaction takes place?
2. Which gas will relight a glowing splint?
3. List three signs which will suggest a chemical reaction has occurred.
4. What term is used to describe reactions which:
   a) absorb heat from the surroundings
   b) release heat to the surroundings?

5. Which of the following refer to a chemical reaction taking place?

A	Burning a piece of wood	**B**	Breaking glass
C	Sugar dissolving in tea	**D**	Frying an egg
E	Melting chocolate	**F**	Rotting of compost

6. Michael's teacher was demonstrating chemical reactions to the class. After the demonstration Michael wrote the following note in his class jotter.

   To begin with the teacher collected a container of chlorine gas and a piece of reddish copper metal. The piece of copper was then placed in the glass jar filled with chlorine gas. When the copper fell to the bottom of the glass jar it burst into flames and gave out a bright light. After the flame went out a green powder was lying at the bottom of the jar.

   From the note give **two** pieces of evidence which suggest a chemical reaction had taken place.

7. Copy and complete the following passage:

   'When a chemical reaction occurs reactant particles must _____ with each other. If the number of collisions increases then the speed of the reaction _____. By decreasing particle size the surface area _____ which in turn allows more collisions to occur and therefore the speed of the reaction _____. Powdered chalk will react _____ compared to lumps of chalk.'

Exercise 2

Explain each of the following statements in your jotter.

Refer to particle size, concentration, temperature and collisions where appropriate in your explanations.

1. Small sticks burn faster than a log.
2. Milk keeps longer in the fridge compared to sitting out in a kitchen.
3. Large potatoes cook slower than smaller potatoes.
4. Plants grow faster in a green house than in the open garden.
5. The blue flame on a Bunsen burner is hotter than the flame produced when the air hole is closed.

Exercise 3

The following data was recorded for an experiment.

Mass of gas produced/g	0	1·2	2·0	2·8	3·2	3·4	3·5	3·5
Time/s	0	10	20	30	40	50	60	70

1a) Calculate the average rate of reaction, in g s^{-1}, over the

i) first 10 seconds ii) first 20 seconds iii) first 40 seconds iv) first 60 seconds

b) Calculate the average rate of the reaction, in g s^{-1}, over the following time intervals

i) between 20 and 40 seconds ii) between 10 and 40 seconds.

2. During the first 10 seconds of a reaction the concentration of a reactant falls from 0·20 mol l^{-1} to 0·10 mol l^{-1}. What is the average rate, in mol l^{-1} s^{-1}, during the first 10 seconds?

A 0·20 B 0·10 C 0·02 D 0·01

3. During the first 20 seconds of a chemical reaction 5·0 cm^3 of gas were given off.
Calculate the average rate of reaction.

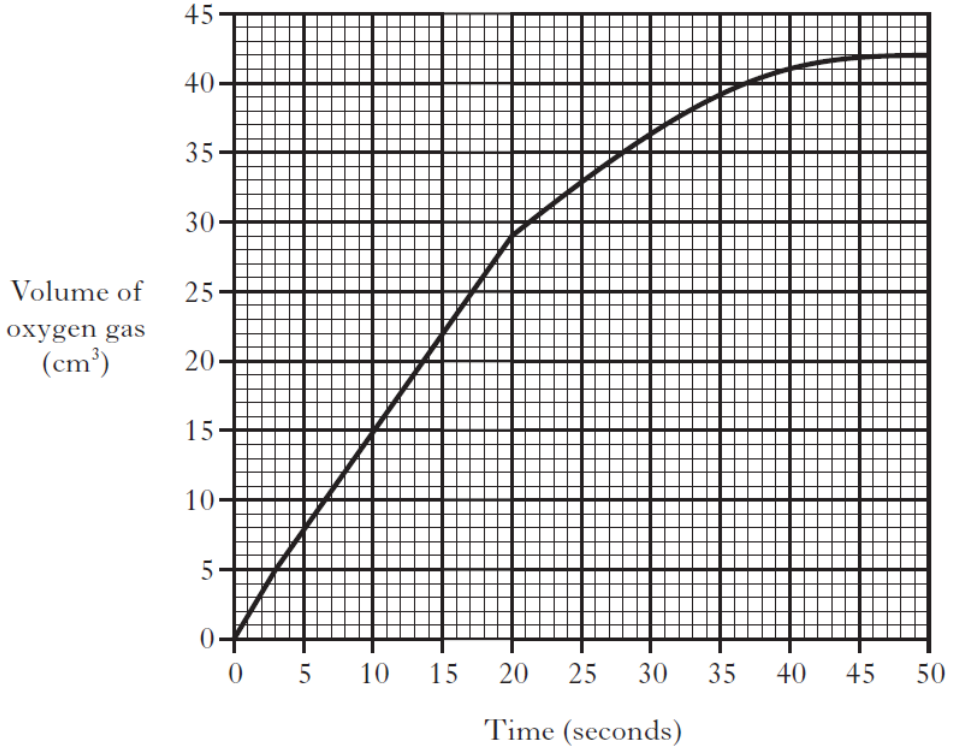
4. Which of the following pairs of reactants would produce hydrogen most **slowly**?

A Magnesium powder and 4 mol l^{-1} acid. **B** Magnesium ribbon and 2 mol l^{-1} acid.

C Magnesium powder and 2 mol l^{-1} acid. **D** Magnesium ribbon and 4 mol l^{-1} acid.

Exercise 4

1. The graph below was obtained for a reaction which produced oxygen gas.



Calculate the average rate of reaction between 0 and 20 seconds.

Using the graph calculate the average rate of reaction between:

a) 0 and 10 seconds b) 0 and 20 seconds c) 10 and 20 seconds

d) 0 and 40 seconds e) 20 and 40 seconds f) 25 and 35 seconds.

2. The table shows the volume of hydrogen gas produced over fifty seconds.

The table shows the volume of hydrogen gas produced over fifty seconds.

Time/s	Volume of gas/cm^3
0	0
10	20
20	40
30	55
40	65
50	72

a) Calculate the average rate of reaction between 0 and 20 seconds.

b) Calculate the average rate of reaction between 10 and 20 seconds.

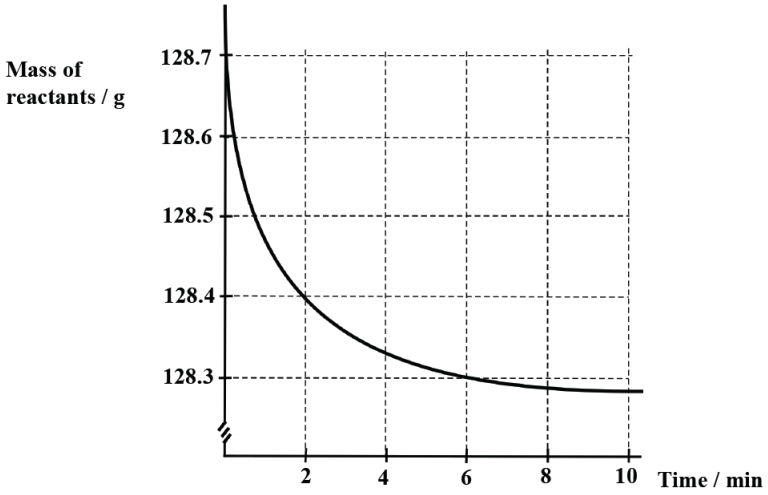
c) Calculate the average rate of reaction between 10 and 30 seconds.

d) Calculate the average rate of reaction between 10 and 40 seconds.

e) Calculate the average rate of reaction between 0 and 40 seconds.

f) Calculate the average rate of reaction between 0 and 50 seconds.

3. The graph below shows how the mass of reactants varies with time for a chemical reaction.



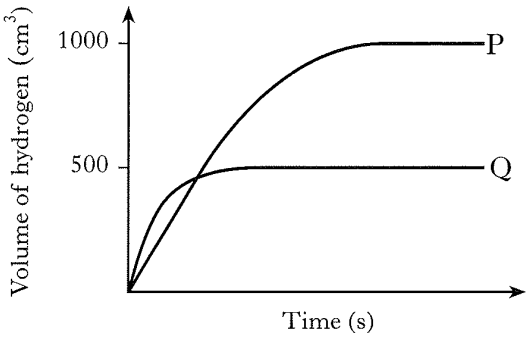
Calculate the average rate of reaction over the following periods:

a) 0 - 2 minutes

b) 0 - 6 minutes

c) 2 - 6 minutes

4. Graph P below shows the volume of hydrogen gas when 1·0 g of magnesium ribbon reacts with excess 2 mol l^{-1} hydrochloric acid.



Which of the following samples of magnesium would react with the acid to produce graph Q?

A 0·5 g of magnesium ribbon

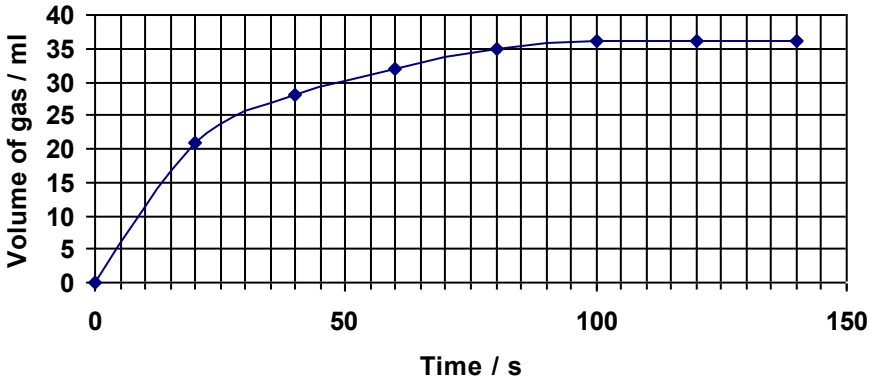
B 0·5 g of magnesium powder

C 1·0 g of magnesium powder

D 2·0 g of magnesium ribbon

Exercise 5

1. The graph below shows the volume of carbon dioxide gas given off against time when large lumps of marble are reacted with dilute hydrochloric acid solution.



a) How long does it take to produce 20 ml of carbon dioxide gas?

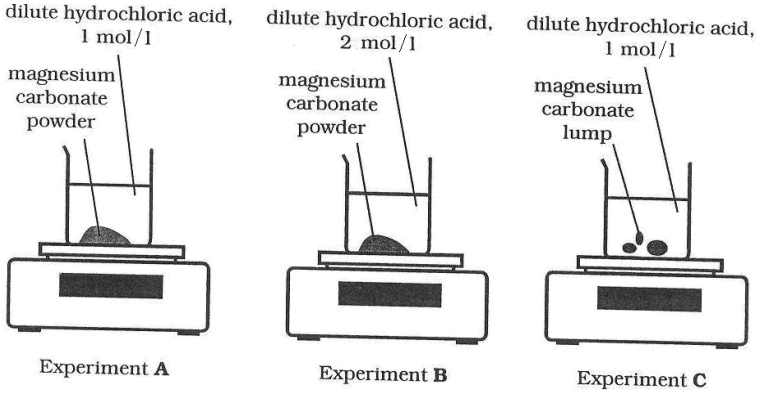
b) What volume of gas was formed after 50 seconds?

c) What was the total volume of gas given off in the reaction?

d) How long did it take to complete the reaction?

e) Add a dotted line to the graph above to show the graph obtained when small lumps of marble chips react with the dilute hydrochloric acid.

2. Pauline was studying rates of reaction. She set up three experiments in which magnesium carbonate was added to equal volumes of dilute hydrochloric acid. In each experiment, some magnesium carbonate remained unreacted.



a) List the experiments in order of increasing reaction rate.

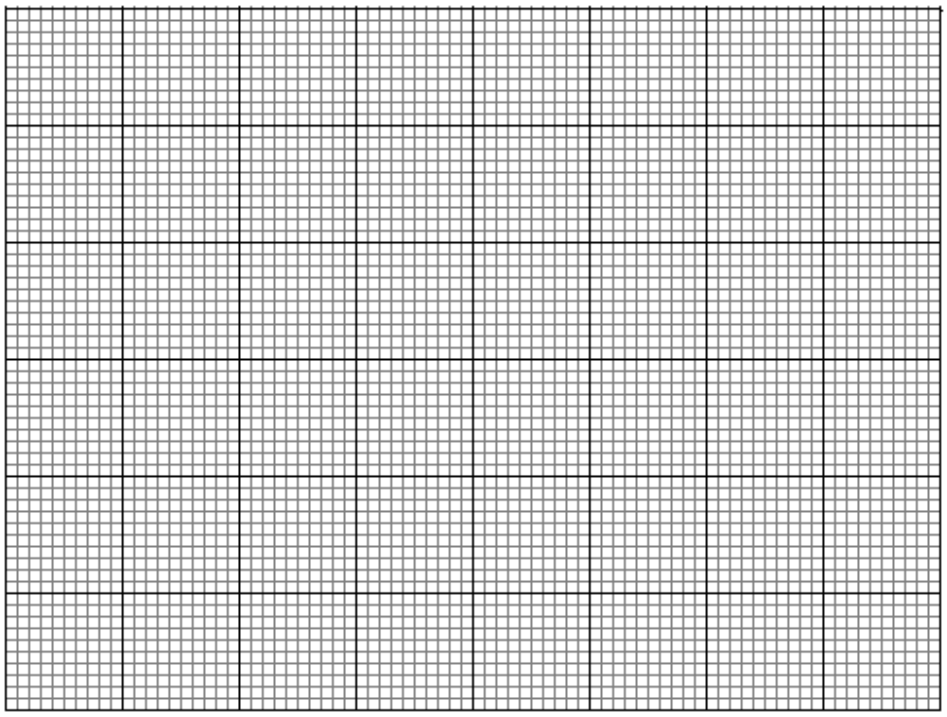
b) Pauline noted the balance readings and found that, at the end of all the experiments, the readings showed a decrease in mass. Why was the decrease in mass twice as much in experiment B as in experiment A?

3. When copper carbonate reacts with acid, carbon dioxide gas is given off.

The table shows the time taken for 100 cm^3 of gas to be produced when 1g samples of copper carbonate are added to acid, but two results are missing.

Acid concentration / %	20	40	60	80	100
Time / s		70	48	31	

a) Plot a line graph of acid concentration against time.

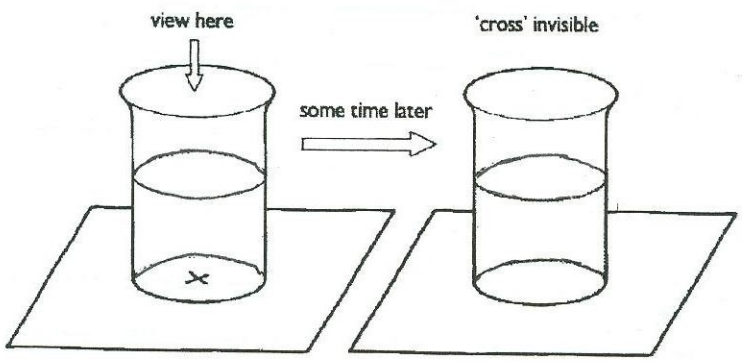


b) Use your graph to complete the results table

c) Draw a labelled diagram of the apparatus that could be used to carry out this reaction.

d) What happens to the speed of the reaction as the acid becomes more dilute?

4) The reaction between sodium thiosulfate solution and a dilute acid causes the mixture to become cloudy in appearance due to the formation of sulfur particles. A measure of how fast the reaction proceeds can be obtained by observing the time taken for a pencilled 'cross', on a piece of paper beneath a beaker containing the reaction mixture, to disappear from view.



The reaction was carried out at three different temperatures, in each case using 20ml of sodium thiosulfate solution and 5ml of dilute acid. Here are the results

Experiment	Temperature / °C	Time taken / s
1	10	208
2	20	104
3	30	52

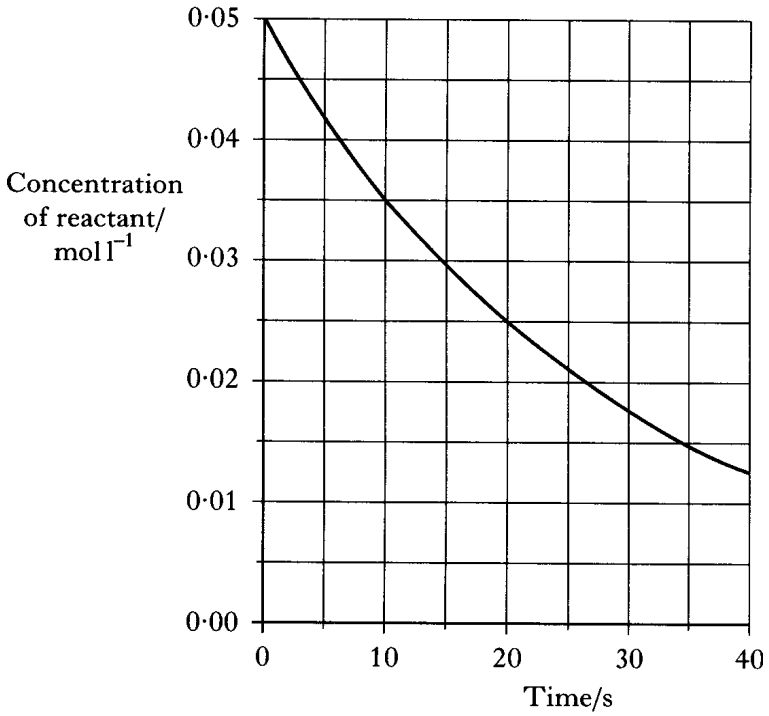
a) At what temperature is the reaction the slowest?

b) What effect does increasing the temperature have on the rate of reaction?

c) Predict the time taken for the cross to disappear from view if the experiment was carried out at 40°C

Exercise 6

1. The graph below shows the change in concentration of a reactant with time for a given chemical reaction



What is the average rate of this reaction in mol l^{-1} between 10 and 20 seconds?

A 1.0×10^{-2} **B** 1.0×10^{-3} **C** 1.5×10^{-2} **D** 1.5×10^{-3}

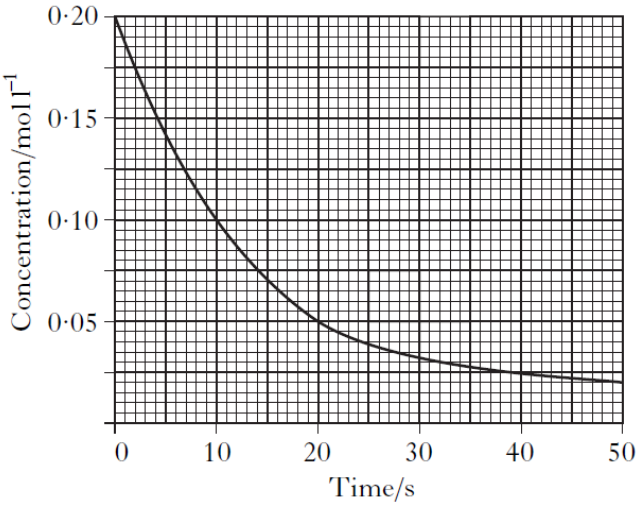
2. The following results were obtained in the reaction between marble chips and dilute hydrochloric acid

Time/minutes	0	2	4	6	8	10
Total volume of carbon dioxide produced/cm^3	0	52	68	78	82	84

What is the average rate of production of carbon dioxide, in $cm^3\ min^{-1}$, between 2 and 8 minutes?

A 5 **B** 26 **C** 30 **D** 41

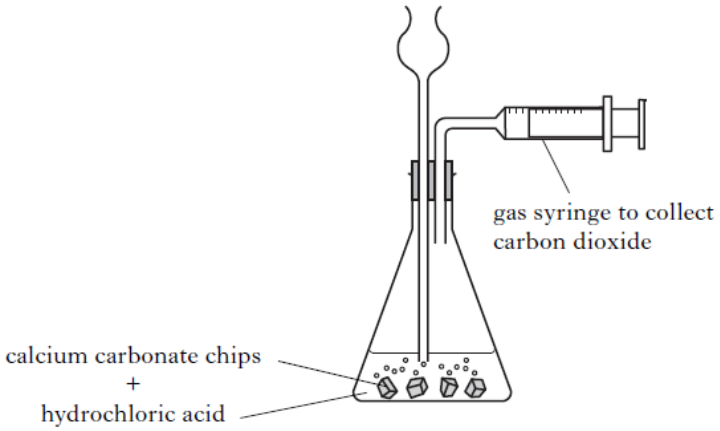
3. The graph shows the variation of concentration of a reactant with time as a reaction proceeds.



What is the average reaction rate during the first 20s?

A 0.0025 mol $l^{-1}\ s^{-1}$ **B** 0.005 moll$^{-1}\ s^{-1}$ **C** 0.0075 mol $l^{-1}\ s^{-1}$ **D** 0.015 mol– $l^{-1}\ s^{-1}$

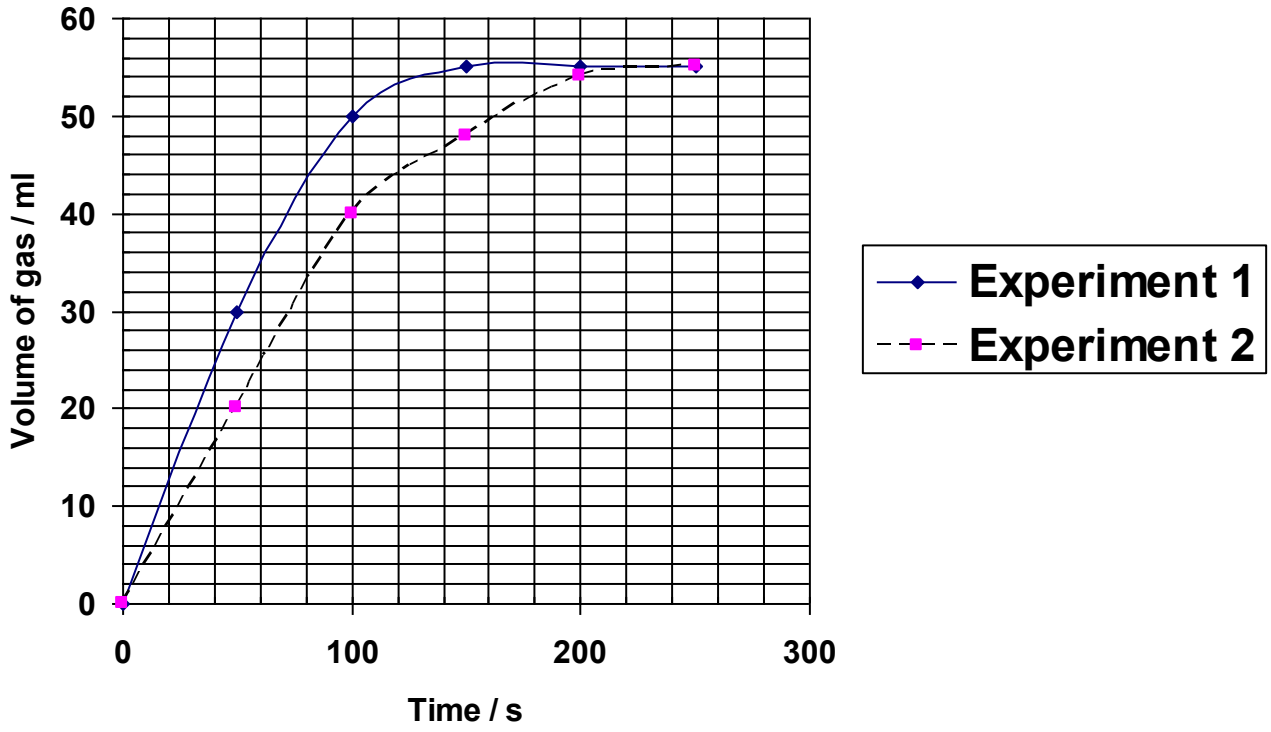
4. An experiment was carried out to determine the rate of the reaction between hydrochloric acid and calcium carbonate chips. The rate of this reaction was followed by measuring the volume of gas released over a certain time



a) Describe a different way of measuring volume in order to follow the rate of this reaction.

b) What other variable could be measured to follow the rate of this reaction?

5. Mary was investigating the reaction of marble chips with excess dilute hydrochloric acid. Her results for two experiments are shown below.



a) What volume of gas was produced in Experiment 1 during the first 80 s?

b) In the initial stages, the reaction in Experiment 2 was slower than in Experiment 1.

i) How can this be concluded from the graph?

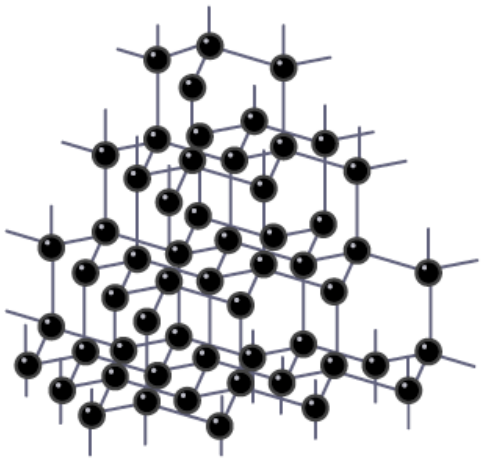
ii) Suggest two changes in conditions which could have resulted in the slower reaction.

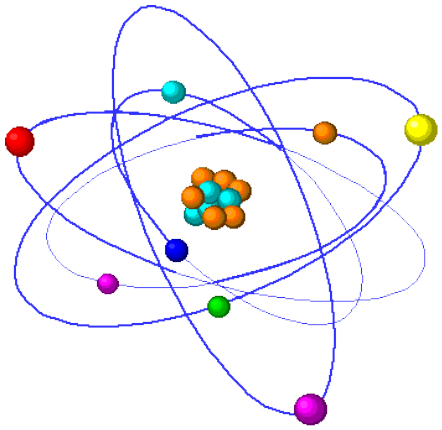
c) Mary used the same mass of marble chips in each experiment. How can this be concluded from the graph?

d) What is the final volume of gas produced in both reactions?

Topic 2

Atomic Structure and Bonding





Learning Outcomes

Periodic Table and Atoms

- Arrangement of elements in periodic table according to atomic number
- Determining if an element is a metal or non-metal according to its position in the periodic table.
- Groups are columns in the periodic table containing elements with the same number of outer electrons indicating the group number.
- Elements within a group share the same valency and have similar chemical properties due to the same number of outer electrons.
- Electron arrangements can be written from the first 20 elements.
- An atom has a nucleus, containing protons and neutrons, and electrons that orbit the nucleus.
- Protons have a 1+ charge, neutrons are neutral and electrons have a charge of 1-.
- Protons and neutrons have a mass of approximately 1 a.m.u and electrons in comparison have virtually no mass.
- The number of protons in an atom is given by the atomic number.
- In a neutral atom the number of electrons is equal to the number of protons.
- The mass number of an atom is equal to the number of protons added to the number of neutrons.
- Isotopes are defined as atoms with the same atomic number but different mass numbers (same number of protons and different number of neutrons).
- Nuclide notation is used to show the atomic number, mass number (and charge) of atoms (ions) from which the number of protons, neutrons and electrons can be determined.
- Most elements have two or more isotopes.
- The average atomic mass or relative atomic mass can be calculated for each element using the mass and proportion of each isotope present.

Covalent Bonding

- Covalent bond form between non-metal atoms.
- A covalent bond forms when two positive nuclei are held together by their common attraction for a shared pair of electrons.
- Diagrams can be drawn to show how outer electrons are shared to form the covalent bond(s) in a molecule.
- 7 elements exist as diatomic molecules through the formation of covalent bonds: H_2, N_2, O_2, F_2, Cl_2, Br_2, I_2.
- The shape of simple covalent molecules depends on the number of bonds and the orientation of these bonds around the central atom. These molecules can be described as linear, angular, trigonal pyramidal or tetrahedral.
- More than one bond can be formed between atoms leading to double and triple covalent bonds.
- Covalent substances can form either discrete molecular or giant network structures.

Covalent molecular substances:

- Have strong covalent bonds within the molecules and only weak attractions between the molecules
- Have low melting and boiling points as only weak forces of attraction between the molecules are broken when a substance changes state
- Do not conduct electricity because they do not have charged particles which are free to move
- Covalent molecular substances which are insoluble in water may dissolve in other solvents.

Covalent network structures:

- Have a network of strong covalent bonds within one giant structure
- Have very high melting and boiling points because the network of strong covalent bonds is not easily broken
- Do not dissolve
- In general, covalent network substances do not conduct electricity. This is because they do not have charged particles which are free to move.

Ionic compounds

- Ions are formed when atoms lose or gain electrons to obtain the stable electron arrangement of a noble gas.
- In general, metal atoms lose electrons forming positive ions and non-metal atoms gain electrons forming negative ions.
- Ion-electron equations can be written to show the formation of ions through loss or gain of electrons.
- Ionic bonds are the electrostatic attraction between positive and negative ions.
- Ionic compounds form lattice structures of oppositely charged ions with each positive ion surrounded by negative ions and each negative ion surrounded by positive ions.
- Ionic compounds have high melting and boiling points because strong ionic bonds must be broken in order to break up the lattice.
- Many ionic compounds are soluble in water. As they dissolve the lattice structure breaks up allowing water molecules to surround the separated ions.
- Ionic compounds conduct electricity only when molten or in solution as the lattice structure breaks up allowing the ions to be free to move.
- Conduction in ionic compounds can be explained by the movement of ions towards oppositely charged electrodes.

Atoms & Atomic Structure

Everything that exists is made up of very small particles called atoms. An element is a substance that is made up of atoms of only one kind. Each different atom has a number called the **atomic number**.

Elements are arranged in the Periodic Table in order of increasing atomic numbers.

Atomic Structure

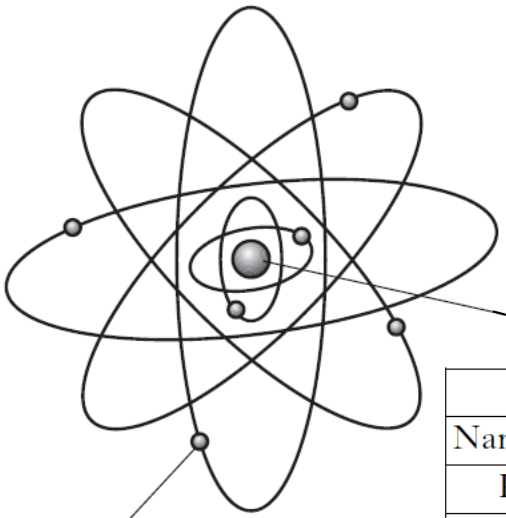
Atoms themselves consist of small particles (sub-atomic particles) called protons, neutrons and electrons.

Protons are found in the very small core at the centre of the atom. This core is called the nucleus and is very small compared to the rest of the atom. Protons have a positive charge and a mass of 1 atomic mass unit (amu).

Electrons move around outside the nucleus and have a negative charge which is opposite to that of the protons. Electrons have virtually no mass. Atoms are overall neutral since they will contain the same number of electrons as protons. This means that the total positive charge of the protons is equal to the total negative charge of the electrons, i.e. the positive and negative charges cancel out and so no overall charge.

Neutrons are also found inside the nucleus and have an atomic mass of 1 amu. Neutrons do not have a charge, i.e. they are neutral.

The Structure of an Atom



THE NUCLEUS	
Name of Particle	Relative mass
PROTON	1
NEUTRON	1

OUTSIDE THE NUCLEUS	
Name of Particle	Relative mass
ELECTRON	0

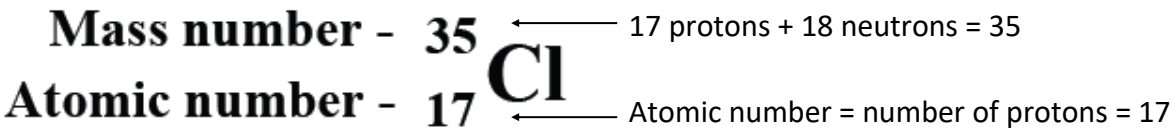
Atoms & Atomic Structure

Nuclide Notation

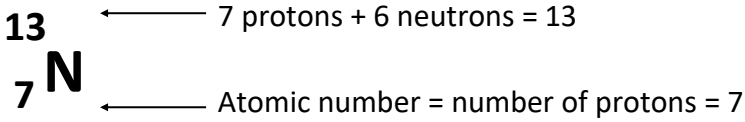
Nuclide notation is used to give the chemical symbol, atomic number and mass number of an atom. It is a shorthand way to list and show information about the nucleus of an atom.

The atomic number gives the number of protons in the nucleus of an atom and the mass number gives the number of protons plus the number of neutrons in the nucleus.

Example 1: A chlorine atom with 18 neutrons.



Example 2: A nitrogen atom with 6 neutrons.



Isotopes

Atoms of the same element always have the same number of protons (same atomic number). However, atoms of the same element can be different; they can have different numbers of neutrons. This means the mass number will be different.

Atoms which have the same atomic number but a different mass number are called **isotopes**. In other words isotopes have the same number of protons but a different number of neutrons.

Example: Isotopes of chlorine.

Chlorine exists as a mixture of 2 different chlorine atoms. One type of chlorine atom has 18 neutrons which another type of chlorine atom has 20 neutrons.

Chlorine 35: $^{35}_{17}Cl$

Chlorine 37: $^{37}_{17}Cl$

Both isotopes have the **same atomic number** but a **different mass number** since they both have 17 protons and a different number of neutrons.

Atoms & Atomic Structure

Relative Atomic Mass

Most elements exist as a mixture of isotopes, each with atoms of different mass. The relative proportions of each isotope will affect the relative atomic mass (RAM) of that particular element. The relative atomic mass of an element has a value between the mass numbers of the lightest and heaviest isotopes of the element. Its value is always closer to the most abundant (most common) isotope. The relative atomic mass is often not a whole number since it is an average mass of one atom of the element.

Example 1: Oxygen

The relative proportions of isotopes in oxygen are:

^{16}O	99.76%
^{17}O	0.037%
^{18}O	0.204%

Oxygen has a relative atomic mass of 16 since this isotope is the most abundant.

The **RAM** can also be worked out using the following calculation (*this would be given to you in an exam)*:

$$\frac{\text{(\% abundance isotope 1 x mass of isotope 1) + (\% abundance of isotope 2 x mass of isotope 2)}}{\text{100}}$$

Example 2: Chlorine

The relative proportions of isotopes in chlorine is:

^{35}Cl	75%
^{37}Cl	25%

Calculate the relative atomic mass of chlorine:

$$\frac{(75\% \times 35) + (25\% \times 37)}{100}$$

$$= \frac{3550}{100}$$

$$= 35.5$$

Atoms & Atomic Structure

Electron Arrangement

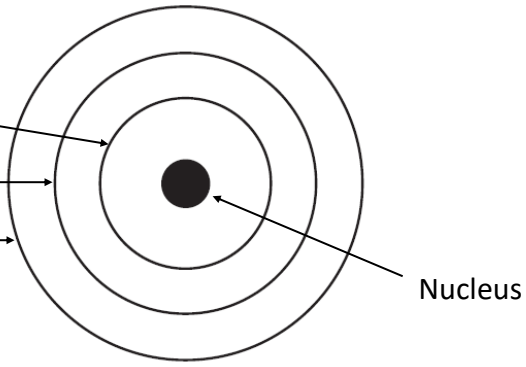
Most of an atom is empty space which electrons move through. The electrons are arranged within this empty space in a particular way.

Electrons are arranged in shells (energy levels) and there is a limit to the number of electrons each shell can hold.

The **first** shell (nearest the nucleus) can hold 2 electrons.

The **second** shell can hold up to 8 electrons.

The **third** shell can hold up to 8 electrons.



Electrons will occupy the shell which is nearest the nucleus before occupying the outer shells. In other words you don't start a new shell until the inner one is full. Electrons always fill on their own before pairing up.

The **valency number** of an element depends on the **Group** where the element is found in the Periodic Table and directly relates to the **number of bonds** the element can make.

Group	1	2	3	4	5	6	7	0
Valency	1	2	3	4	3	2	1	0

Ions

In some chemical reactions atoms lose or gain electrons to have a "**stable electron arrangement**". This means that the electrons in the outer shell can be lost to leave the outer shell full or stable. In general metal atoms will lose electrons to gain a stable electron arrangement while non-metal atoms will gain electrons to become stable.

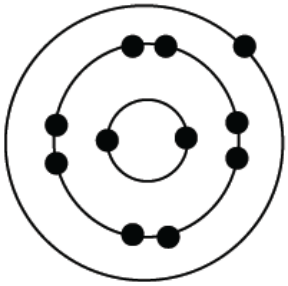
With the loss or gain of electrons atoms will no longer be electrically neutral and they have a charge; this means that an **ion** has been formed.

An atom which has lost electrons becomes an ion with a positive charge. (Metals)

An atom which has gained electrons becomes an ion with a negative charge. (Non-metals)

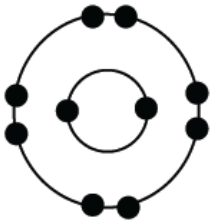
Example 1: The formation of a positive ion.

Sodium atoms have the electron arrangement 2, 8, 1. Sodium atoms lose 1 electron giving a stable electron arrangement of 2, 8. Since an electron (negative charge) has been lost the ion has an overall positive charge.



sodium atom
Na
2, 8, 1

sodium ion
Na^+
2, 8



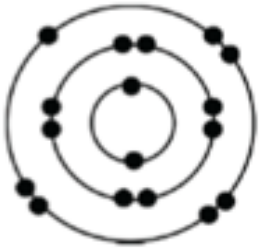
It is seen that the sodium ion is smaller but it is stable as the outer shell is full.

Sodium ion can be represented as: $^{23}_{11}Na^+$

The + sign shows the ion has an overall positive charge.

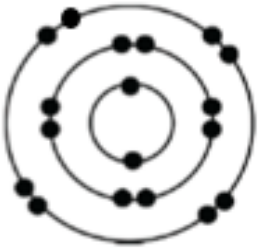
Example 2: The formation of a negative ion.

Chlorine atoms have an electron arrangement of 2,8,7. Chlorine atoms gain 1 electron giving a stable electron arrangement of 2,8,8. Since an electron (negative charge) has been gained the ion has an overall negative charge.



Chlorine atom
Cl
2,8,7

Chlorine Ion
Cl^-
2,8,8



Chlorine ion can be represented as: $^{35}_{17}Cl^-$

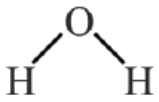
The - sign shows the ion has an overall negative charge.

Note: Use the data booklet to work out the electron arrangement and charge on an ion.

Covalent Bonding

Molecules

The join between atoms in an element or different atoms in a compound is called a **bond. Covalent** bonds are usually formed between non-metal elements. A covalent bond is a pair of electrons shared by two atoms. The shared pair of electrons holds the atoms together. A small group of atoms, in a fixed number. held together by covalent bonds is called a **molecule**.

E.g. A water molecule 

Since water contains 2 hydrogen atoms and 1 oxygen atom it has the chemical formula H_2O.

The chemical formula of a substance tells us which elements it is made from and also the number of atoms of each element in one molecule of the substance.

Diatomic Molecules

Molecules made up of only two atoms are called **diatomic** molecules, e.g. hydrogen chloride, HCl, (one carbon atom and one chlorine atom), and carbon monoxide, CO, (one carbon atom and one oxygen atom).

Diatomic Elements

Certain elements normally exist as diatomic molecules. Normally the formula of an uncombined element is just its symbol, for example, the formula of carbon is C. For the diatomic elements, however, the symbol is followed by a "2", for example, O_2, N_2, etc.

The full list of diatomic elements is hydrogen (H_2), nitrogen (N_2), oxygen (O_2), and the group 7 elements (F_2, Cl_2, Br_2, I_2). These can be simplified as the **HON7 or Magic 7** elements.

Examples

Diatomic molecule: H—Cl

Diatomic elements: H—H Cl—Cl O=O

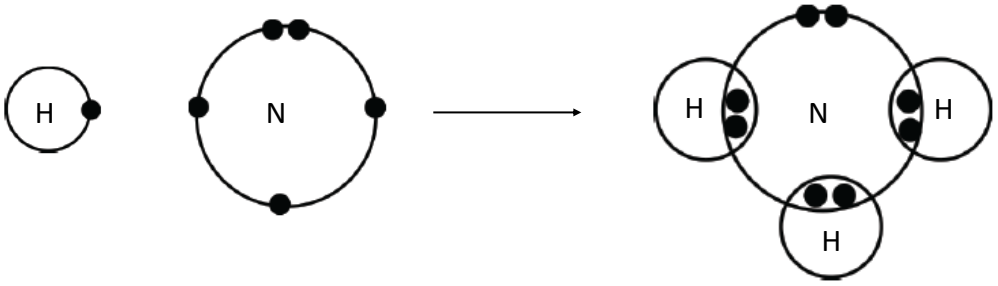
Covalent Bonding

Covalent bond form between non-metal atoms. A covalent bond forms when two positive nuclei are held together by their common attraction for a shared pair of electrons.

Covalent Bonding using Electron Shells

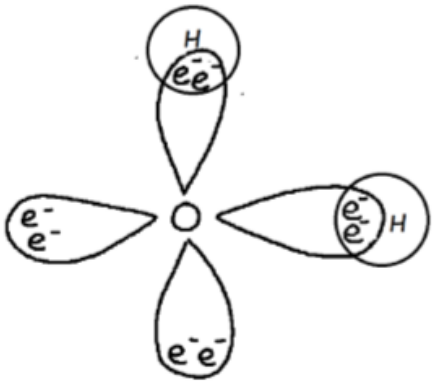
The noble gases have full outer energy levels and are therefore unreactive. When atoms form covalent bonds they share electrons in order to gain a full outer energy level. A target or petal diagram can be used to show the sharing of electron pairs which make up covalent bonds.

Example Target Diagram: **Nitrogen hydride (Ammonia), NH_3**



Hydrogen atom Nitrogen atom Nitrogen hydride molecule

Example Petal Diagram: **Water, H_2O**



***Important points:** Electrons can be drawn as dots, crosses or e^-.

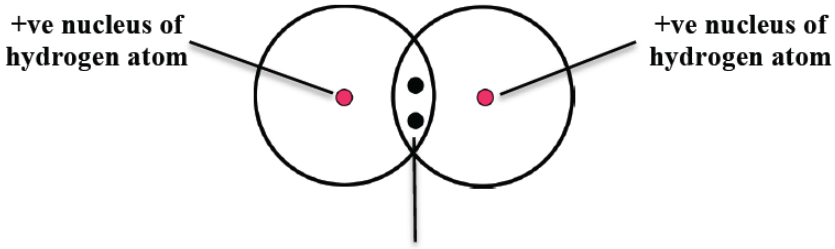
The bonded electrons must be within the overlap of orbitals.

Hydrogen is always drawn as a circle!

Covalent Bonding

What holds a Covalent Bond together?

The negatively charged electrons are attracted to both positively charged nuclei. A lot of energy is needed to break this force of attraction i.e. to break a covalent bond. This means covalent bonds are very strong.



+ve ⟷ -ve ⟷ +ve

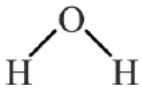
Shapes of Molecules

The chemical formula for covalent substance indicates the number of atoms of each element present but it gives no indication of the shape of a molecule. In some molecules the atoms are arranged in a straight line (called linear), e.g. hydrogen chloride.

Hydrogen chloride, a **linear** molecule: H—Cl

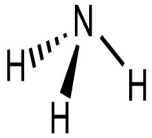
Water is an example of a flat molecule which is bent in shape.

Water, an **angular** molecule:



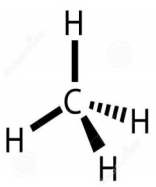
Nitrogen hydride (ammonia) is an example of a 3 dimensional molecule which is pyramidal in shape.

Ammonia, a **trigonal pyramidal** molecule:



Carbon hydride (methane) is also 3 dimensional and is tetrahedral in shape.

Methane, a **tetrahedral** molecule:



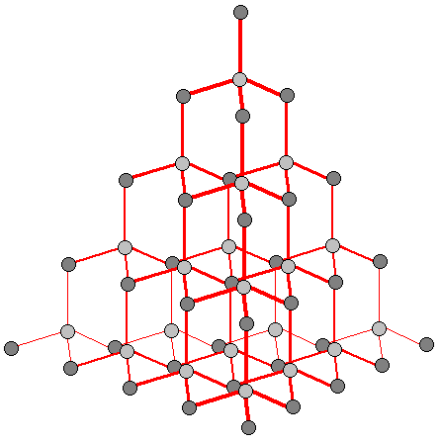
In general…

Number of atoms in molecule	Shape
2	Linear
3	Angular
4	Trigonal Pyramidal
5	Tetrahedral

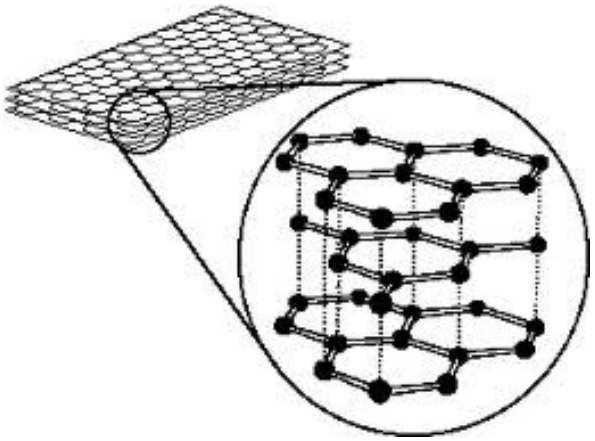
Covalent Bonding

Covalent Networks

Some covalent substances do not exist as molecules but instead exist as giant **covalent network** structures such as carbon, silicon, boron and silicon dioxide. Carbon exists in two forms—**diamond** and **graphite**.



Structure of Diamond

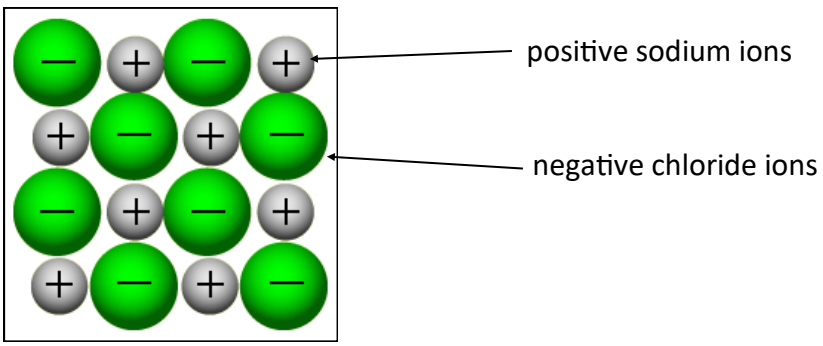


Structure of Graphite

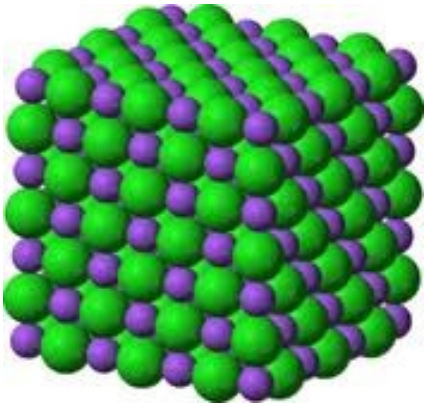
Ionic Bonding

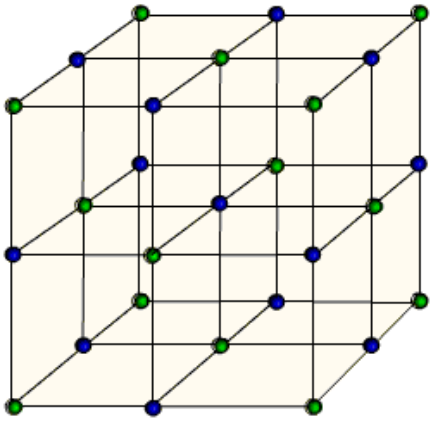
Ionic compounds contain both positively charged ions and negatively charged ions. Positive ions attract negative ions and the electrostatic force of attraction between oppositely charged ions is known as an **ionic bond**. The ions in an ionic compound are arranged in a pattern forming an **ionic lattice** structure. This arrangement will repeat in all directions.

Example: Sodium Chloride



Ionic Bonding





3 dimensional diagrams of the sodium chloride lattice.

Metal ions are positively charged and non-metal ions are negatively charged. Group 1 elements form ions with a charge of 1+ e.g. sodium ions Na^+ with an ion electron arrangement of 2, 8. Group 7 elements such as chlorine form ions with a charge of 1-, e.g. chloride ions Cl^- with an ion electron arrangement of 2, 8.

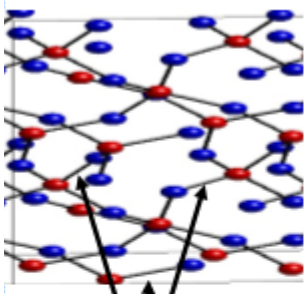
Melting and Boiling Point

Properties

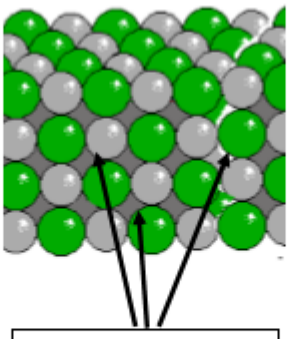
When a substance melts forces of attraction, that hold the substance together as a solid, get broken. Depending on the structure of the solid different forces of attraction are broken.

In a **covalent network** the solid particles consist of a **network of atoms held together by strong covalent bonds**. In an **ionic lattice** the solid particles consist of a **lattice of ions held together by strong ionic bonds**.

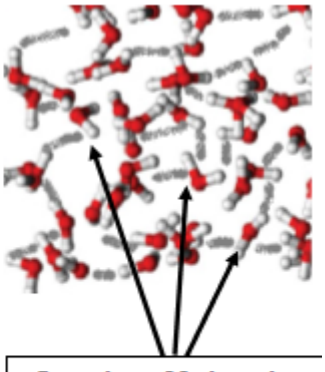
However in a solid consisting of **covalent molecules**, the atoms in the molecules are held together by strong covalent bonds but the **molecules are held together to form the solid by weak forces of attraction.**



Covalent Network
Strong covalent bonds between atoms



Ionic Lattice
Strong ionic bonds between ions



Covalent Molecular
Weak forces of attraction between molecules

Properties

The strength of these forces of attraction affect the melting point and boiling point. The **stronger the force the higher the melting point**. Pages 5 and 9 of your data book give the melting and boiling points of elements and selected compounds.

A low melting or boiling point means that only weak bonds / forces of attractions are being broken and a high melting point means that strong bonds are being broken.

Solubility

When a solid dissolves the forces of attraction that hold the particles together are broken. New forces of attraction between the particles and the solvent molecules occur.

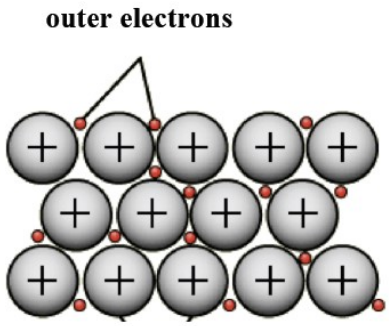
With solubility there are many exceptions to any rules but in general:

- **Ionic** compounds tend to be more **soluble in aqueous solvents**
- **Covalent molecules** tend to be more **soluble in non-aqueous solvents**
- **Covalent networks** are **insoluble in any solvent.**

Page 8 in your data book gives the solubility of various ionic compounds in water.

Electrical Conductivity

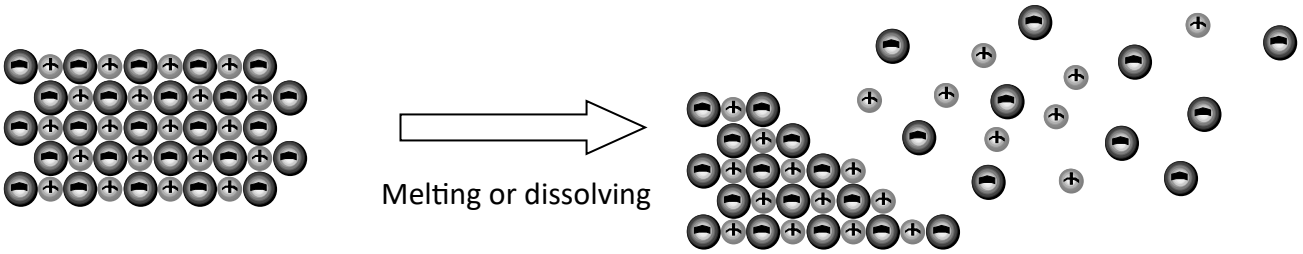
Electricity is a flow of charged particles. The charged particles which flow are either ions or electrons. In metals (and graphite) it is the outer electrons of atoms (delocalised electrons) which are able to move as shown in the diagram below.



There will be more notes on how to test for electrical conductivity of a substance in your practical jotter or work book.

Properties

Ionic substances will not conduct electricity as solids. This is due to the fact that ions are not free to move in a solid as they are arranged in an ionic lattice. When an ionic substance is dissolved in solution or molten the ionic lattice is broken down allowing the ions to move freely and so conduction occurs. The following diagram explains this.



ions in crystal lattice

- ions can't move
- ionic solid can't conduct

ions in solution or melt (molten/liquid)

- ions break away from lattice
- ions free to move around
- ionic solution or melt can conduct

Knowing the electrical conductivity of a substance allows you to be able to predict the type of bonding in a substance. The following rules can be used:

Rule 1: All metals conduct as solid or as a liquid.

Rule 2: All non-metals (except graphite) and covalent substances are electrical insulators (do not conduct).

Rule 3: Ionic substances do not conduct as solids but do conduct when molten or in solution.

Bonding Comparisons

Bonding Type	Melting Point (High, Med or Low)	Electrical Conductivity (Yes or No)	Solubility in water (Yes or No)
Covalent Molecular			
Covalent Network			
Ionic			

Topic Questions

Exercise 1

1. Elements are arranged in the periodic table. Explain what is meant by

   a) a group

   b) a period

2. a) Name the elements with each of the following atomic numbers.

i)	23	ii)	3	iii)	18	iv)	28	v)	55
vi)	17	vii)	19	viii)	10	ix)	9	x)	36

   b) From the list above, name the elements which are members of each of the following families.

i)	the halogens	ii)	the alkali metals
iii)	the transition metals	iv)	the noble gases

3. Write nuclide notation for the following atoms.

a)	A sulfur atom with mass number 32.	b)	A calcium atom with mass number 40.
c)	A hydrogen atom with 1 neutron.	d)	A helium atom with 2 neutrons.
e)	A potassium atom with 20 neutrons.	f)	An iron atom with 30 neutrons.

4. For each of the following atoms state the number of protons and the number of neutrons.

a) $^{18}_{8}O$ (b) $^{40}_{19}K$ (c) $^{23}_{11}Na$ (d) $^{24}_{12}Mg$ (e) $^{22}_{10}Ne$

5. Explain why atoms are electrically neutral overall.

6. For each atom in question 4 state the number of electrons present.

7. For each of the following atoms draw a diagram to show the electron arrangement.

a)	Helium	b)	Sodium	c)	Nitrogen	d)	Aluminium
e)	Fluorine	f)	Calcium	g)	Oxygen	h)	Hydrogen

Exercise 2

1a) Copy and complete the following table using your data booklet.

Element	Group	Electron Arrangement
Lithium		
Sodium		
Oxygen		
Sulfur		
Magnesium		
Calcium		

b) What is the relationship between the number of electrons in the outer shell of an atom and the group number?

2. Copy and complete the following table

Ion	Ion Symbol	Ion Electron Arrangement	Noble Gas with same Electron Arrangement
Sodium	Na^{+}	2, 8	Neon
Oxide			
Fluoride			
Magnesium			
Nitride			
	Al^{3+}		
	S^{2-}		
Calcium			

Exercise 3

1. Explain what is meant by the term isotope.

2. The grid shows information about some particles.

A $^{23}_{11}Na$	B $^{18}_{8}O$	C $^{40}_{19}K^{+}$
D $^{24}_{12}Mg^{2+}$	E $^{35}_{17}Cl^{-}$	F $^{16}_{8}O$

   a) Which box shows a particle with the electron arrangement 2, 8?

   b) Which box contains a particle which has 10 neutrons.

   c) Which two boxes contain particles that are isotopes?

   d) Which two boxes when compared have ions with the same electron arrangement?

3. The table below has information about some particles.

	Number of		
Particle	**protons**	**neutrons**	**electrons**
A	11	12	11
B	9	10	9
C	11	13	11
D	19	20	18
E	9	10	10

   a) Identify the particle which is a negative ion.

   b) Identify the **two** particles which are isotopes.

   c) Identify the particle which is a positive ion.

4. Use your data booklet and give the relative atomic mass of:

   a) Carbon b) Mercury c) Tin d) Lead

5. Iron has three isotopes with mass numbers 54, 55 and 57. The relative atomic mass of iron is 55·9. Explain which isotope must be the most abundant.

6. In a sample of oxygen there are two different types of oxygen atom: $^{16}_{8}O$ and $^{18}_{8}O$

   a) What term is used to describe these different types of oxygen a

   b) Copy and complete the following table for each type of oxygen atom.

Type of atom	Number of protons	Number of neutrons
$^{18}_{8}O$		
$^{16}_{8}O$		

7. Many chemical compounds contain ions.
   Which of the following compounds has **both** ions with the same electron arrangement as argon?

A strontium chloride	B lithium oxide	C calcium oxide
D barium fluoride	E sodium fluoride	F potassium chloride

Exercise 4

1. What is a covalent bond?
2. What is a molecule?
3. Explain what is meant by describing a molecule as "diatomic"?
4. . What information is given by a chemical formula?
5. Draw diagrams to show how the outer electrons are shared for each of the following molecules.

   a) Carbon hydride (CH_4)

   b) Carbon chloride (CCl_4)

   c) Phosphorus fluoride (PF_3)

   d) Sulfur hydride (SH_2)

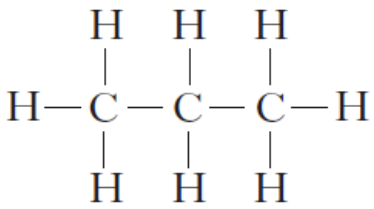
   e) Nitrogen fluoride (NF_3)

   f) Carbon dioxide (CO_2)

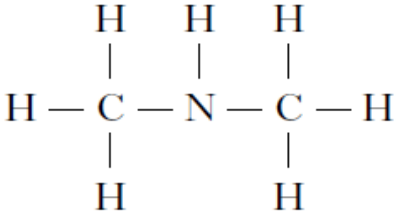
   g) Nitrogen (N_2)

6. Copy the diagram (structural formula) for each molecule below and write beside it the chemical formula.

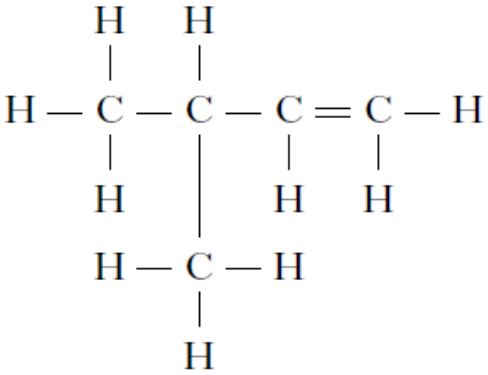
a)



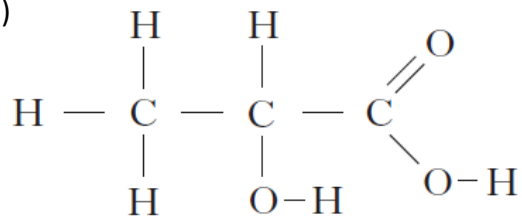
b)



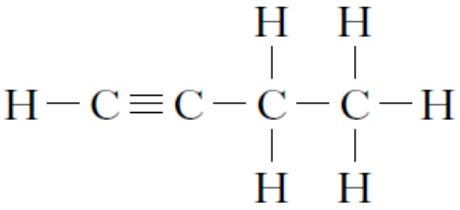
c)



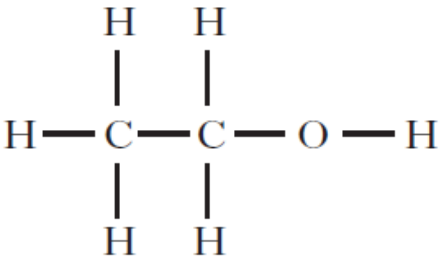
d)



e)



f)



Exercise 5

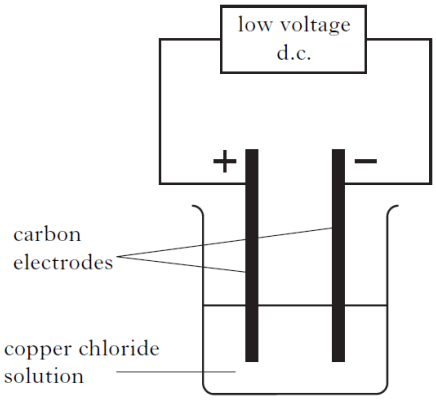
1. What type of elements are usually found in an ionic compound?
2. What is the arrangement of ions called where positive ions are surrounded by negative ions?
3. Explain clearly what is meant by an ionic bond.
4. For each of the following ions write the symbol including the charge.
   a) Potassium
   b) Oxide
   c) Chloride
   d) Magnesium
   e) Aluminium
   f) Nitride
   g) Lithium
5. Which of the following is a covalent substance?

   A Carbon dioxide B Calcium oxide C Sodium chloride D Copper fluoride

6. Which of the following is an ionic compound?

   A Sulfur dioxide B Carbon chloride C Methane D Sodium chloride

7. A student set up the following experiment to investigate electrical conductivity.



a) Carbon is unreactive and insoluble. Give another reason why it is suitable as electrodes.

b) The copper chloride solution was found to conduct.

i) What type of bonding must be present in copper chloride?

ii) Explain why this solution is able to conduct yet solid copper chloride will not conduct.

8. Solid potassium iodide does not conduct electricity because

A its ions are not free to move B it does not contain enough ions to carry a current

C it is a covalent substance D it contains no electrons.

Exercise 6

1. Take the following 4 headings in your jotter

Covalent Molecular Covalent Network Metals Ionic

Copy the following statements under the correct heading to summarise your understanding of bonding

Never conducts electricity.

Very high melting points due to the number of bonds which need to be broken.

Always conducts either as a solid or liquid.

Made from metal and non-metal elements.

Only weak forces exist between molecules.

Conducts when in solution since the ions are free to move.

Solids except mercury.

Insulators as solids but conducts when molten or in solution.

Contains delocalised electrons.

Non conductors except graphite.

High melting and boiling points.

Low melting and boiling points.

Giant rigid structure e.g. diamond.

Made from non-metals only.

Exercise 7

1. Complete the following:

   a) A horizontal row of elements is called a _____

   b) Elements which have similar chemical properties are in the same _____

   c) The family of very unreactive elements is called the _____ _____

   d) The _____ metals are very reactive metals stored under oil

   e) The _____ are the most reactive non-metals

   f) The _____ are very unreactive elements.

2. A compound which gives a lilac flame colour contains the element _____

   A compound which contains the element sodium gives a _____ flame colour.

3. Explain why atoms are neutral.

4. State what is meant by:

   a) Atomic number

   b) Mass number

5. Complete the following tables:

Particle	Mass (a.m.u.)	Charge	Location in atom
Proton			
Electron			
Neutron			

	$^{24}_{12}Mg$	$^{31}_{15}P$	$^{238}_{92}U$
Element name			
Number of protons			
Number of neutrons			
Number of electrons			

Atomic Number	Mass Number	Symbol	Protons	Number of Neutrons	Electrons
	5	He			
6				6	
			8	8	
	37	Cl			

Element	Atomic Number	Mass Number	Electrons	Number of Protons	Neutrons	Electron Arrangement
	2				2	
nitrogen		14				
					10	2,7
			12		12	
		40				2,8,8,2

6. An atom of sodium can be written as the nuclide notation: $^{23}_{11}Na$

Write the nuclide notation for each of the atoms below

a) An oxygen atom with 10 neutrons.

b) An atom, atomic number 6, with 7 neutrons.

c) An atom with 17 protons and 20 neutrons.

d) An atom of hydrogen, mass number 3.

Exercise 8

1. a) Draw two chlorine atoms showing their outer electrons.

   b) Draw a diagram of a chlorine molecule showing how the electrons are shared.

   c) What type of bond joins the atoms in a chlorine molecule?

   d) What do we call a molecule made up of two atoms?

   e) Name three other elements that exist as 2 atom molecules.

2. Write the electron arrangements for the following atoms:

   a) carbon b) phosphorus c) argon d) chlorine

3. Identify the compounds below that have covalent bonds between their atoms.

sodium chloride	hydrogen fluoride	lithium oxide
dinitrogen tetraoxide	sulphur dioxide	nitrogen trichloride
aluminium iodide	phosphorus oxide	calcium sulphide

4. Draw a diagram of the following molecules showing how the outer electrons are involved in bonding then name the shape of these molecules.

   a) hydrogen oxide (water) b) carbon hydride (methane)

5. A pupil was given a compound of a non-metal element X and hydrogen.

   Examination of the compound had shown that for every atom of X in the compound there were 3 atoms of hydrogen.

   a) What is the formula of the compound?

   b) Give two possible elements X might be.

   c) Draw a diagram of an atom of X showing the outer electron clouds (orbitals).

6. Here are six common elements from the Periodic Table:

A sodium	B chlorine	C magnesium
D potassium	E nitrogen	F oxygen

a) Atoms of which element (or elements) form ions with the same electron arrangement as argon atoms?

b) Which two elements will combine to form an ionic compound with the formula X_3Y_2?

c) Which element (or elements) form positive ions with the same electron arrangement as neon?