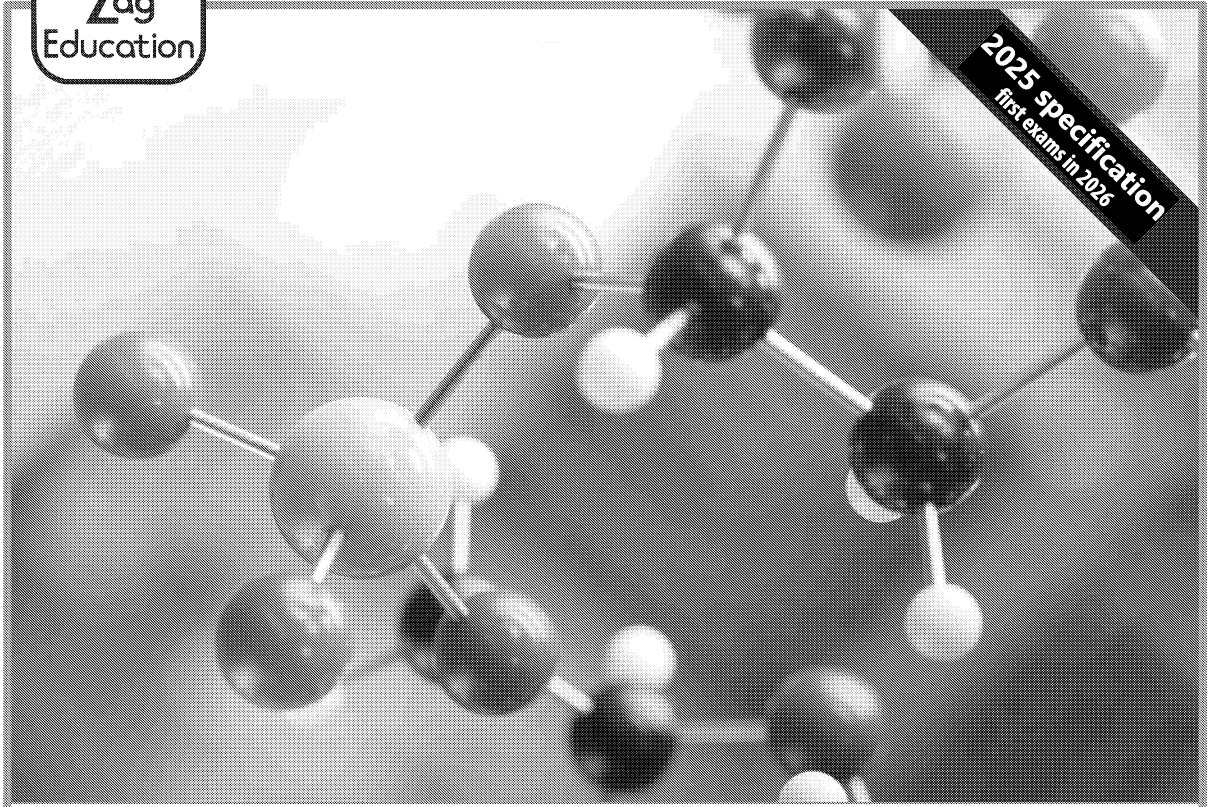
Science Level 3 | AAQ BTEC | 610/3965/2



Course Companion

for Pearson Level 3 AAQ BTEC National in Applied Science (Extended Certificate)

Unit 2 Principles and Applications of Chemistry

zigzageducation.co.uk

POD
12757

Contents

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Teacher's Introduction

Thank you for choosing this course companion which has been written specifically for the Level 3 BTEC National Extended Certificate in Applied Science (AAQ) qualification (first teaching from September 2025).
The theory notes and recap questions cover the essential knowledge and understanding prescribed in the BTEC Unit 2 specification.

About Unit 2: Principles and Applications of Chemistry

Unit 2 (60 GLH) is assessed using a 1 hour (50-mark) written examination, which is set and marked by Pearson. There are two opportunities for assessment each year – in January and in May/June.

Unit 2 is a mandatory unit and will be assessed in a variety of styles, such as: multiple-choice questions, calculations, short-answer questions and extended-response questions.

Remember!

Always check the exam board website for new information, including changes to the specification and sample assessment material.

Each of the five *learning aims* (A–E) is given its own section in the resource. These are as follows:

A. Atomic and electronic structure
B. Bonding and structure
C. Periodicity
D. Physical chemistry
E. Organic chemistry

Within each section there are student notes covering the specification content and structure. These aim to break down the content into manageable chunks, further supported with diagrams, images and examples of how to structure answers. Questions are interspersed throughout the guide to test and develop understanding. Suggested answers are included at the back of this resource.

NB the intention of these is to save the teacher time, rather than to offer a comprehensive set of definite answers. In some cases, there are equally valid alternative answers to those that have been given.

Best wishes and good luck to you and your students!

April 2025

A: Atomic and electronic s

A1.1 Features of the periodic table

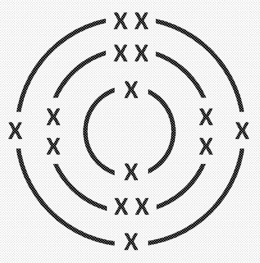
Key points covered

- Use of symbol, atomic number and mass number to determine numbers of subatomic particles
- Use of relative atomic mass to determine relative abundance of isotopes, and relative formula mass
- Use of groups an arrangement of e

The periodic table

The periodic table is a first point of reference for chemists everywhere. It can be found in almost all science laboratories across the world, from teaching classrooms to research labs. As of 2024, the periodic table consists of 118 elements arranged into **groups** and **periods** and ordered by increasing atomic number.

In your previous science studies you have learnt that the arrangements of electrons in an atom can be linked to its position within the periodic table. The number of electrons located in an atom's outer shell corresponds to the *group* you would find it in. The number of energy levels (shells) indicates the element's *period*.

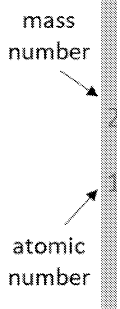


Example:
The sketch of the atom shown can help you de
periodic table and therefore its identity.

The atom shown has five electrons on its outer s
group 5. It has three shells in total, meaning it i
this element is phosphorus.

Each element on the periodic table is accompanied by select pieces of information:

- A chemical symbol
- The atomic (proton) number
- The mass number



Test your knowledge

- What period would you find sulfur in?
- What group would you find boron in?
- Use its position in the periodic table to sketch the arrangement of electrons

Discussion question: despite having one electron in its outer shell, hydrogen is r
the periodic table. Suggest why.

Subatomic particles

Atoms do not only consist of electrons. There are three subatomic particles which the atom: protons, neutrons and electrons. An atom is identified by the number o atoms of the same element will contain the *same number* of protons. Elements ar ascending order of protons, and this is shown as the **atomic number**.

Whilst all atoms of magnesium (atomic number 12) will contain 12 protons, and all atoms of sulfur (atomic number 16) contain 16 protons, the number of neutrons found in atoms of the same element can vary. Elements usually consist of a mixture of **isotopes**. The number of neutrons in an atom can be calculated by subtracting the atomic number from the mass number.

$^{23}_{11}\mathrm{Na}$

Example:
This atom of sodium has a mass number of 23 and an atomic nu
11 protons and 12 (23 – 11) neutrons in the nucleus of this ato

Atoms are electrically neutral due to an equal amount of positively charged proto and negatively charged electrons. **Ions** of an element will contain the same amou protons as the original atom, but a different number of electrons due to a loss or g during chemical reactions.

- **Cations** are positively charged ions. They have fewer electrons than protons, e.g. Ca^{2+} has two fewer electrons than protons.
- Anions are negatively charged ions. They have more electrons than protons, e.g. N^{3-} has three more electrons than protons.

Test your knowledge

- State the number of subato (protons, electrons and neu
- Describe the differences in t of oxygen-16 and oxygen-1

Discussion question: explain wh different physical properties but i

Relative atomic mass, A_r

The information given on the periodic table of elements includes a value for relativ atomic mass. This number is often a decimal number – this is due to the fact that i an *average* value of the mass of this element taking into account all isotopes of th element that exist and their relative abundances.

Relative atomic mass (RAM) is calculated using the following equation:

RAM = [(mass of isotope 1 × abundance of isotope 1) + (mass of isotope 2 ×
Total abundance

Example:
Chlorine exists naturally as two main isotopes: chlorine-35 (75.8 %) and chlorin
Calculate the relative atomic mass of chlorine.

RAM = [(mass of isotope 1 × abundance of isotope 1) + (mass of isotope 2 ×
Total abundance

RAM = [(35 × 75.8) + (37 × 24.2)] = 35.484 = 35.5 to 1
100

The value of an element's relative atomic mass gives some indication of the relativ that makes up the element. An element made from two main isotopes with a relat between the two individual masses suggests a 50 : 50 distribution of isotopes. If t to the mass value of one isotope than the other it suggests that this is the more n

Relative formula mass

Two or more different elements chemically bonded together form a compound. I
atoms within that compound are combined then you will have calculated the relat
substance, as shown below.

- K_2O = (A$_r$ K × 2) + A$_r$ O = (39.1 × 2) + 16.0 = 94.2
- $Mg(NO_3)_2$ = A$_r$ Mg + 2 × [A$_r$ N + (A$_r$ O × 3)] = 24.3 + 2 x [14.0 + (16.0 × 3)] = 14

Recap questions: Features of the periodic table

1 Sulfur is a mixture of four isotopes: ^{32}S, ^{33}S, ^{34}S and ^{36}S. Compare these iso
particles. (3 marks)

2 a) Determine the relative formula mass of ammonium carbonate, $(NH_4)_2$
b) A group 1 sulfate (Z_2SO_4) has a relative formula mass of 267.2. Deter
metal Z. ([illegible] marks)
c) An oxygenated hydrocarbon, $C_xH_yO_2$, is analysed via a mass spectromete
7[illegible] Determine the values of *x* and *y* in the chemical formula. (3 marks

3 A sample of potassium (atomic number = 19) was analysed in a mass spect
produced showed the following composition of isotopes:

Isotope	Abundance (%
^{39}K	93.20
^{40}K	0.07
^{41}K	6.73

a) Calculate the relative atomic mass of the potassium and give your ans
places. (2 marks)
b) Determine the number of each subatomic particle present in the ^{40}K a

4 Chlorine has a relative atomic mass of 35.5. Chlorine exists as two isotop
Explain what information the relative atomic mass gives you about the abu
isotopes. (2 marks)

A1.2 Electronic structure

Key points covered

- Use of shells, subshells and electronic orbitals in electronic structure
- Use of the rules around electronic filling in atoms
- Writing electronic notation and elec
- Use of blocks to d in atoms and ions

Electrons and shells

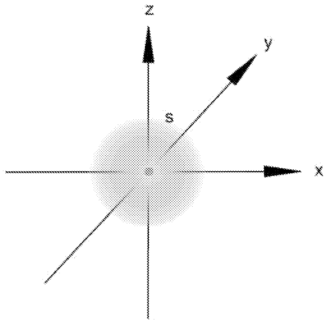
The nucleus of any atom is surrounded by shells of electrons. These shells can be regarded as energy levels, with the energy increasing as the shell number increases. Shells are made up of atomic **orbitals**. Orbitals can hold up to two electrons and can exist as different types: s, p, d and f. Within a shell, orbitals of the same type a grouped together as subshells.

Each shell can hold a designated amount of electrons as shown in the table.

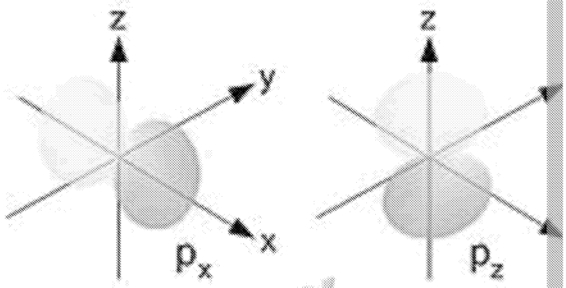
Shell number	Number of electron
1	2
2	8
3	18
4	32

Atomic orbitals

An atomic **orbital** is a region of space around the atom's nucleus that can hold up There are four different types of **orbital** and each one is a different shape. You sh **s orbital** and **p orbitals**.



s orbital



p orbitals

Each shell contains a specific arrangement of **orbitals** and within each shell **orbita** together as subshells. Whilst at first sounding confusing, it is easier to think of it a

Shell number	Which subshells are present?	Number of each orbital type				Numbe electrons i subsh
		s	p	d	f	
1	1s	1				2
2	2s + 2p	1	3			2 + 6
3	3s + 3p + 3d	1	3	5		2 + 6 +
4	4s + 4p + 4d + 4f	1	3	5	7	2 + 6 + 10

Filling of orbitals

Electrons are placed into orbitals following a set of specific rules.

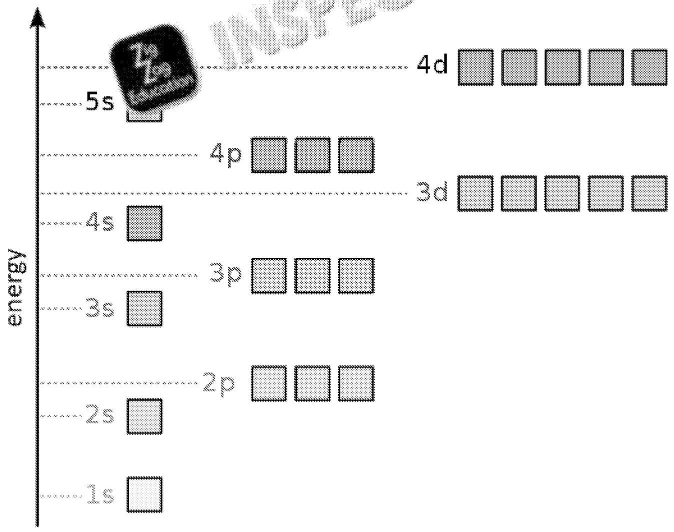
Test y

- Wh am fin
- Wh ele sec
- Wh of 4d

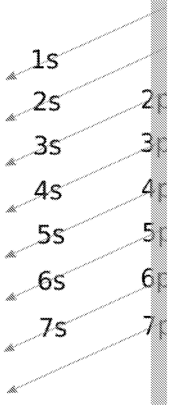
Aufbau principle

Shells are made up of subshells and each set of subshells within an energy level has a slightly different energy level. Each time a new subshell is added it is slightly higher in energy than any subshells that were previously present. For example, in the second energy level the new subshell introduced is the 2p and it is at a higher energy level than the 2s. The Aufbau principle states that orbitals will fill up in order of increasing energy.

- In the second energy level shell the order of filling is 2s, 2p
- In the third energy level shell the order of filling is 3s, 3p, 3d
- In the fourth energy level shell the order of filling is 4s, 4p, 4d, 4f



Arrangement of orbitals according to energy levels



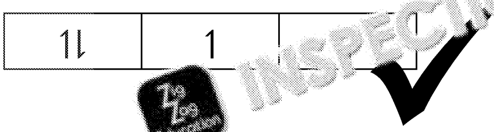
Order of f
based on

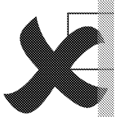
Due to the fact that the highest energy level subshell in the third shell overlaps wit subshell in the fourth energy level, you find that the 3d subshell is filled after the 4

Hund's law

Within a subshell the orbitals are all equivalent in energy. When placing electrons i subshell, Hund's law states that the orbitals must all be singly filled before any pai minimise the effect of any repulsive forces coming from paired electrons until abso

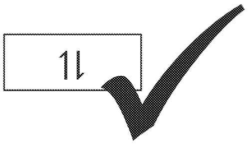
For example, when placing four electrons into the 2p subshell a single electron wo and $2p_z$ orbital before then pairing electrons in one of the orbitals.

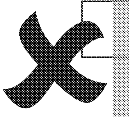




Pauli exclusion principle

Each orbital can hold a maximum of two electrons. Electrons have a property calle or down. Spin is shown by an arrow pointing either up ↑ or down ↓. Electrons are r two electrons in a closed space will repel each other. To help counteract the repuls charged electrons in an orbital they must have opposite spins.





Electronic configurations

You are expected to be able to write out electronic configurations for all atoms an and including krypton.

An atom of krypton has 36 electrons. The table below shows how these electrons

Energy level	1	2		3	
Subshell	1s	2s	2p	3s	3p
No. of electrons	2	2	6	2	6

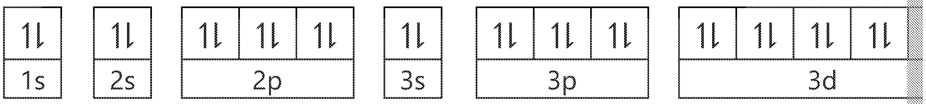
As dictated by the Aufbau principle, the 4s subshell is filled before the 3d due to b

This filling of subshells can be shown in two ways: s, p and d notation or electron-i

s, p and d notation of krypton's electronic configuration: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2$

It is worth noticing that although the 4s is filled first, it is written after 3d so that a can be written together.

Electron-in-box diagram of krypton's electronic configuration:



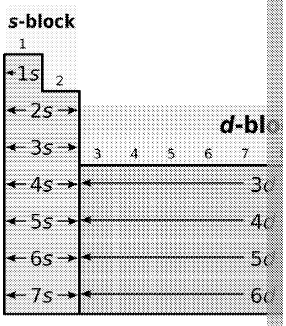
When forming ions the electrons are lost from the highest energy orbital first. For example, sodium atoms form Na^+ ions and oxygen atoms form O^{2-} ions as shown in the table on the right.

Species	Numbe electro
Na	11
Na^+	10
O	8
O^{2-}	10

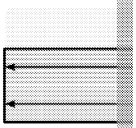
When creating ions from d-block elements, the electron is removed from the 4s before the 3d, despite being filled first. This is due to the fact that once filled, the energy of the 3d subshell drops below that of the 4s and it is the higher energy subshells that are emptied first.

Electronic configuration and the periodic table

The periodic table is divided into **blocks** as shown on the right:



The block an element is located in can be identified using the highest energy subshell.



- s-block elements have their highest energy electron in an s subshell
- p-block elements have their highest energy electron in a p subshell
- d-block elements have their highest energy electron in a d subshell

Recap questions: Electronic structure

1 The answer to each question below is a number.
  a) The number of electrons a 3p orbital can hold. (1 mark)
  b) The number of full shells in a krypton atom. (1 mark)
  c) The maximum amount of electrons in the 3d subshell. (1 mark)
  d) The number of unpaired electrons in a sulfur atom. (1 mark)
  e) The maximum number of electrons in the third energy level. (1 mark)

2 Draw out the electron-in-box diagram to show the electronic configuratio

3 Describe how the highest energy subshell is filled in an atom of sulfur. (4 m

A1.3 Ionisation energy

Key points covered

- Definitions and equations to represent ionisation energies of atoms
- Use of ionisation energies to support ideas of electronic structure
- Exploring trends i period and down a

Ionisation energy is a measure of how easily an atom loses an electron.
It can be represented in equation form as follows:

$X_{(g)} \rightarrow X^{+}_{(g)} + e^{-}$ where X would be replaced with the specified element

An atom will have multiple ionisation energies, the total of which will be equal to the total amount of electrons the atom consists of. Successive ionisation energies are defined in the same way as the first ionisation energy; however, you do need to be careful when identifying the species losing the electron. The number of the ionisation energy is the same as the charge formed on the resulting ion; for example, the third ionisation energy for an element will result in the 3+ ion being formed from a starting 2+ ion.

Test your kno

- Give the de ionisation e
- Give the eq ionisation e
- How many would ther

Example:

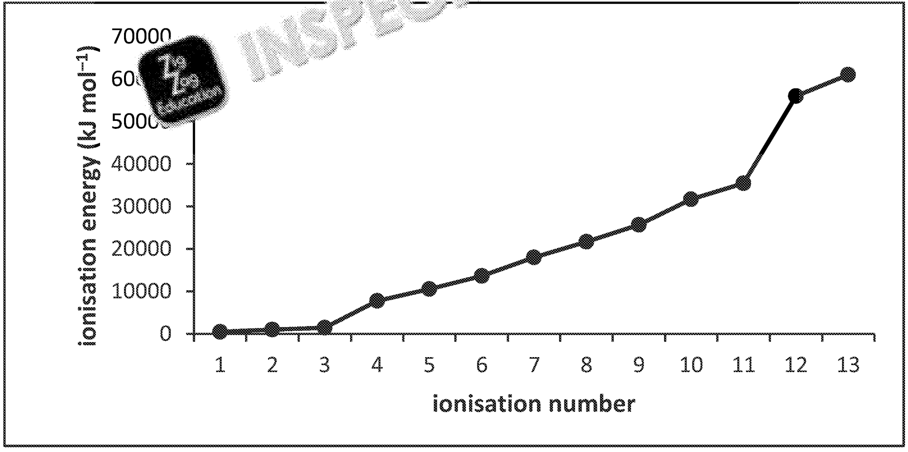
The equation representing the fourth ionisation energy for sodium would show 3+ ion. It would be written as: $Na^{3+}_{(g)} \rightarrow Na^{4+}_{(g)} + e^{-}$

Making predictions using ionisation energies

Looking at the successive ionisation energies an atom has can tell you a variety of pieces of information regarding the electronic structure of that atom.

Each time a successive electron is removed from an atom, the ionisation energy always increases. This is due to the nuclear attraction on any remaining electrons increasing and therefore more energy being required to remove subsequent electrons. By studying the trends in how the ionisation energy increases in value you can determine:

- The amount of electrons in the outer shell
- The number of shells an atom has
- The group of the periodic table an atom is in
- The identity of the atom



When analysing successive ionisation energies the key is to look for large jumps in energy values. Each large jump signifies a move into a new shell, with the electron i focus being closer to the nucleus and therefore more strongly attracted. The data shown on page 8 shows two such large jumps in ionisation energy, between ionisati 3 and 4 and then again between 11 and 12. This suggests that electrons 4 and 12 a being taken from new shells, closer to the nucleus and being held more tightly.

- Energy level 3 (the outer shell) contains three electrons
- Energy level 2 contains eight electrons
- Energy level 1 (closest to the nucleus) contains two electrons

All this evidence points to the atom being aluminium.

Factors affecting ionisation energy

Electrons are held in their shell due to attraction from the nucleus. There are three factors which affect the strength of the nuclear attraction and subsequently the ionisation energy.

Test your

Where wo
in energy i
energies o

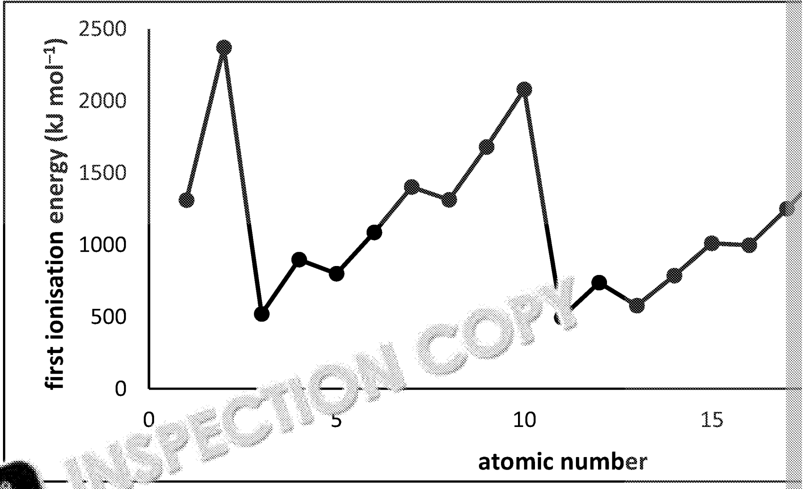
1. **Nuclear charge**
   As the number of protons in the nucleus increases, the strength of the nuclea therefore the greater the attraction between nucleus and electron.

2. **Number of shells**
   The larger the number of shells, the greater the distance between the nucleu nuclear attraction will be weaker with increasing distance.

3. **Shielding**
   The more shells of electrons there are, the greater the effect of shielding of th by the outer shell electrons from the inner shell electrons. Shielding reduces t attraction between the nucleus and outer electron.

Trends in ionisation energy

The graph below shows the ionisation energy for the first 21 elements on the peri can see that there are repeating patterns in ionisation energy as you go down a gr



Down a group

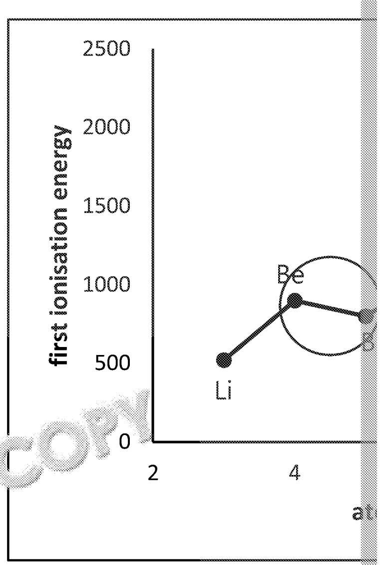
As you go down a group, the first ionisation energies decrease. Despite the nucle down the group this is outweighed by the increasing distance from the nucleus of increased shielding from inner shells.

Across a period

As you go across a period, the first ionisation energy will generally increase. Each proton in its nucleus, increasing its nuclear charge. The outer shell electron is plac therefore experiences the same level of shielding as the previous electron. This ca attraction and as a result the atomic radius decreases.

Subshells and first ionisation energies

Despite the general trend being an increase in ionisation energy as you go across a period, there are repeating patterns in the periodic table where anomalies seem to occur and ionisation energy falls. Considering period 2, these two anomalies can be observed between beryllium and boron and then between nitrogen and oxygen. Both of these can be explained by considering the subshells.



Comparing beryllium to boron

The outer electron in boron is located in the 2p subshell. This subshell is higher in energy than the 2s containing the outer electron of beryllium and therefore the electron requires less energy to remove.

Comparing nitrogen to oxygen

Both nitrogen and oxygen have their outer shell electron in the 2p subshell. Howe
are occupying singly filled orbitals. Oxygen's extra electron is placed into a half-fi
from the electron already in there which means oxygen's outer electron is lost mo

Recap questions: Ionisation energy

1 Write equations to represent the first two ionisation energies for oxygen, a
ionisation energies always increase. (4 marks)

2 The first six ionisation energies for a period 3 element are

Ionisation number	1	2	3	4
Energy (kJ/mol)	578	1817	2745	11 57

Suggest the identity of the element and give your reasoning. (3 marks)

3 a) Explain why the first ionisation energy of Al is lower than that of Mg. (
b) Explain why the first ionisation energy of S is lower than that of P. (2

B: Bonding and struct

B1.1 Metallic bonding and giant metallic

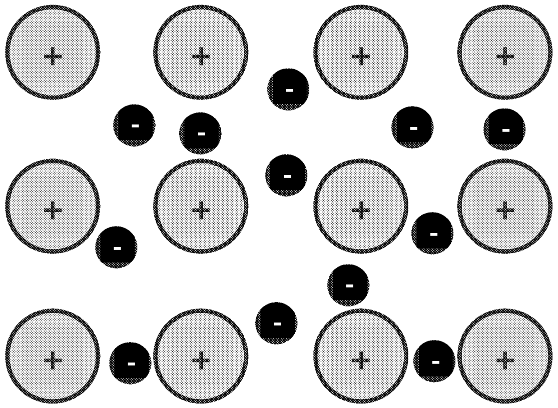
Key points covered

- Description of metallic bonding in terms of the species involved
- Diagrammatic metallic bondi

Metallic bonding is the strong electrostatic attraction between metal **cations** and a sea of **delocalised electrons**. The metal atoms are held together in a giant metallic lattice.

Each metal atom has given its outer shell electrons to a shared pool of electrons; these are known as delocalised. The resulting cations are held in position while the delocalised electrons are mobile and free to move through the structure.

In the metal shown, the 12 cations are balanced by the 12 delocalised electrons pr
In metals that form 2+ cations you would expect to see double the amount of delo
resulting in a stronger electrostatic attraction.



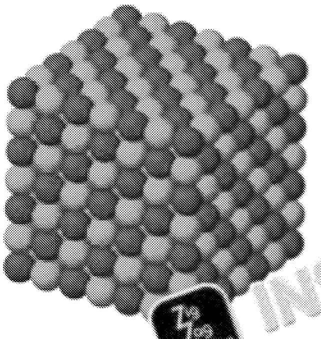
Test your knowledge

Use the idea of metallic bonding to explain why the bonding in aluminium meta
in sodium metal.

B1.2 Ionic bonding and giant ionic struct

! Key points covered

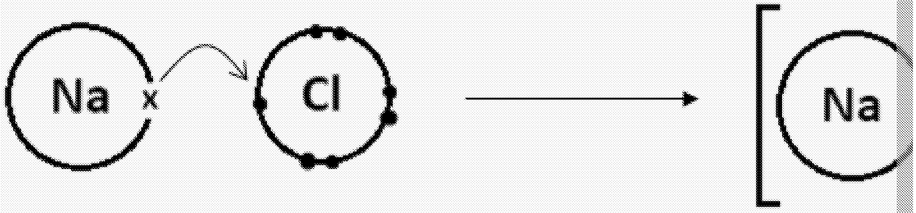
- Description of ionic bonding in terms of the species involved
- Diagrammatic ionic bonding



Ionic bonding is the strong **electrostatic attraction** between oppositely charged ions. Each ion attracts oppositely charged ions in all directions and as a result a giant ionic lattice is formed.

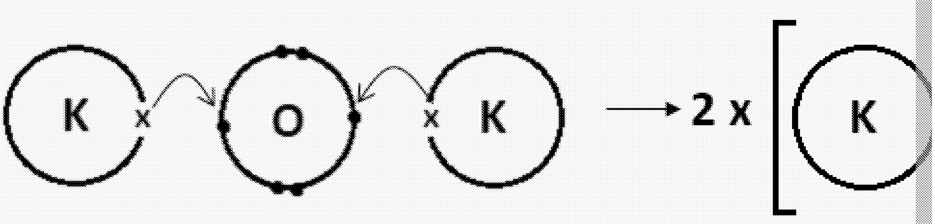
In most ionic compounds a metal atom transfers its o non-metal atom so both resulting ions have full outer as noble gas configuration.

Example 1 – Sodium chloride (NaCl)



A sodium atom contains one electron in its outer shell, whilst chlorine has seve electron to chlorine forming a positively charged sodium ion and a negatively c of each ion in the resulting giant ionic lattice is 1 : 1 (NaCl).

Example 2 – Potassium oxide (K_2O)



A potassium atom contains one electron in its outer shell, whilst oxygen has six electron to oxygen forming a positively charged potassium ion and a negatively of each ion in the resulting giant ionic lattice is 2 : 1 (K_2O).

Test your knowledge

- Use a dot-and-cross ionic bonding diagram to determine the chemical formula of aluminium oxide.
- Draw a giant ionic lattice to show the arrangement o in magnesium oxide.

B1.3 Covalent bonding and molecules

! Key points covered

- Definition of covalent bonding
- Using dot-and-cross diagrams to represent single, multiple and dative covalent bonds
- Recognising and d
covalent structure

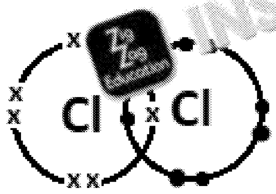
Covalent bonding is the strong electrostatic attraction between a shared pair of electrons and the nuclei of the bonded atoms. Covalent bonding tends to happen between atoms of non-metals to form molecules.

Covalent bonds can be single, **double**, **triple** or **dative**.

Dative covalent bo
electrons have both b
involved in the bond.

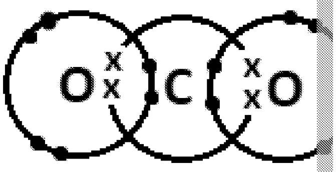
Double bond – two s

Triple bond – three s



Cl - Cl

Single bond



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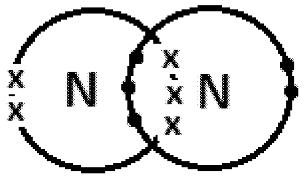
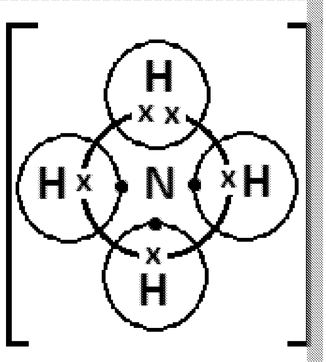


N ≡ N

Triple bond



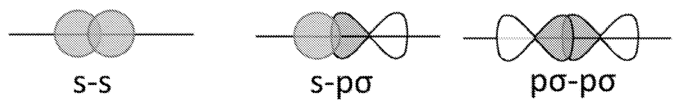
Dati

The strength of a covalent bond can be directly linked to its length; the longer the

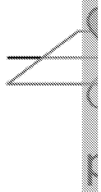
Bond type	Bond strength (kJ mol^{-1})	Bo
O–H	464	
C–C	348	
C–I	238	

In a covalent bond, the shared pair of electrons comes about due to an overlap of options for orbital overlap, and this results in two different types of covalent bonds.

Sigma (σ) bond
Formed by the overlap of one orbital from each atom in a bonding pair. The electron density is located directly between the nuclei of the two atoms.



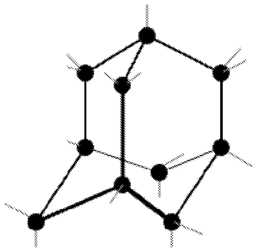
Pi (π) bond
Formed by the sidew
The electron density i
the plane of the bond



Allotropes of carbon

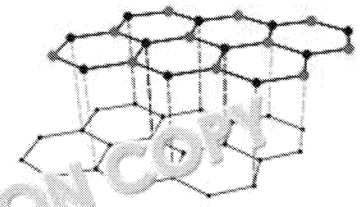
Most covalent molecules exist as simple substances where the individual molecules are held together by weak intermolecular forces. However, when carbon covalently bonds to itself, due to the four electrons it has in its outer shell, **giant covalent structures** can be formed.

Diamond



Each carbon atom forms four strong covalent bonds to neighbouring carbon atoms. The atoms arrange themselves in a tetrahedral structure with bond angles of 109.5°.

Graphite



Each carbon atom forms three strong covalent bonds and the final outer electron is added to a pool of delocalised electrons. The atoms are arranged in planar hexagonal layers with bond angles of 120°.

A s

Test your knowledge

Why do diatomic chlorine molecules contain single covalent bonds whe
oxygen molecules contain double covalent bonds?

Recap questions: Types of bonding

1 Describe the type of bonding found in aluminium chloride ($AlCl_3$). (4 marks
2 In metallic bonding, what forms the 'sea of electrons' that allows metals to
heat? (2 marks)
3 Describe how simple covalent bonding occurs in a molecule of water (H_2O
4 Compare the bonding in graphite and diamond. (3 marks)

B1.4 Physical properties of substances

! Key points covered

- Describing and explaining the melting points of metallic, ionic and covalent substances
- Describing and exp of metallic, ionic a

The physical properties of substances can be explained by looking at the structure

Melting points

Metallic

Most metals will have very high melting points. The melting point of a metal will d attraction between the cations and the sea of delocalised electrons. These are stro therefore high temperatures are needed to provide sufficient energy to overcome t

Ionic

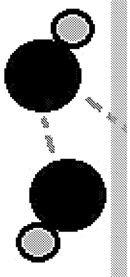
Almost all ionically bonded substances are solid at room temperature. This is due t is needed to break the many strong electrostatic attractions between the opposite be provided at lower temperatures. Ionic compounds will generally have high mel ionic bond is affected by:

- The charge of the ion
- The size of the ion

Ions that have a larger **charge density** (larger charge, small **ionic radius**) will form stronger electrostatic attractions, and therefore have a higher melting point than those with a small charge density. For example, KCl has a lower melting point than $CaCl_2$ due to potassium and calcium ions having a similar size but the calcium ion has a +2 charge and potassium only a +1 charge.

Simple covalent

When a simple covalent substance is melted or boiled it is not the strong covalent bonds between atoms that are required to be broken, but the weaker intermolecular forces that need to be overcome. The lower energy requirement of these weaker forces means that most simple covalent substances are liquid or gas at room temperature due to a low melting and boiling point.



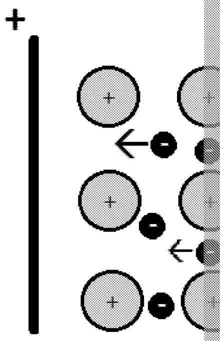
Giant covalent

Unlike simple molecular substances, giant covalent structures do not require inter during state change. In order to melt a giant covalent substance you would be req covalent bonds between the atoms. This would require large amounts of energy a such as diamond and graphite, have very high melting points.

Test your knowledge

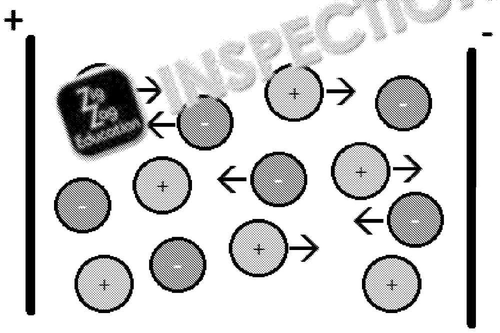
Compare and explain the relative melting points of magnesium oxide and ammo

Electrical conductivity



Metallic

All metals can conduct electricity in any state. When a voltage is applied to a metal the delocalised electrons will carry the charge through the substance as they move.



Ionic

In the solid state ioni
conduct electricity. T
fixed in position in th
no mobile charge car
However, if you melt
the giant ionic lattice
oppositely charged io
and free to move. N
and the substance be

Simple covalent

Due to the absence of charge carriers, simple covalent substances are unable to co

Giant covalent

The electrical conductivity of giant covalent structures varies depending on the sub
conduct electricity as all its outer shell electrons are involved in covalent bonding a
conducting electricity. However, in graphite and graphene there are three covalent
electron supplied by each carbon atom. This electron is free to move and carry an
substances electrical conductors.

? *Recap questions: Physical properties of substances*

1

Substance	Melting point / (°C)	Conductivity when solid
X	34	Poor
Y	[illegible]	Poor
Z	987	Good

Identify, with reasons, the type of bonding in substance X, Y and Z. (6 mar

2 Sodium has a melting point of 97.72 °C whereas magnesium melts at 650 °
bonding to explain the difference in these two melting points. (4 marks)

3

	Melting point (°C)	Conductivity at 25 °C
Aluminium oxide	2072	Poor

Use ideas of structure and bonding to help you explain the data in the abov

B1.5 Molecular shape

! ***Key points covered***

- Use of electron pair repulsion theory to determine the shape of molecules
- The names and an molecular shapes

Electron pair repulsion theory (VSEPR) is a model used in chemistry to help predic electrons in molecules. Electrons are negatively charged. When electrons are pai these pairs of electrons will repel one another.

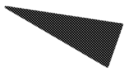
- There will be a central atom and the arrangement of electron regions aroun this atom will determine the shape of the molecule.
- Due to the repulsion of electron regions, they will arrange themselves as far ap as possible to try to minimise this repulsion.
- The number of electron **regions** and the combination of bonding and lone p will result in different shapes.

It can be hard to represent a three-dimensional shape on a two-dimensional shee series of wedges has been created to help chemists portray and visualise molecula

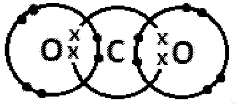
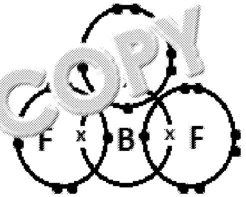
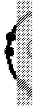
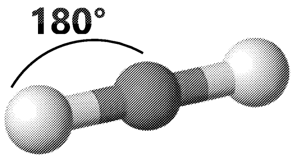
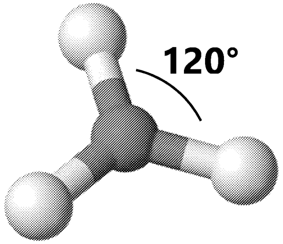
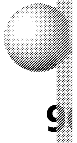
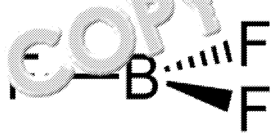
A solid line represents a bond that lies in the same plane as the paper

A dotted wedge represents a bond that goes into the plane of the paper

A solid wedge represents a bond that comes out of the plane of the paper



The following table shows the main shapes, their names and the bond angles associated with 2, 3, 5 and

Dot-and-cross diagram	 Carbon dioxide (CO_2)	 Boron trifluoride (BF_3)	 Phosp
Number [illegible] electron [illegible]	2	3	
Shape and bond angles			
Name of shape	$O=C=O$ Linear	 Trigonal planar	

Test your knowledge

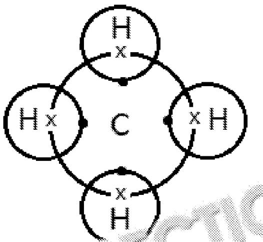
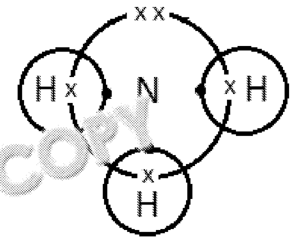
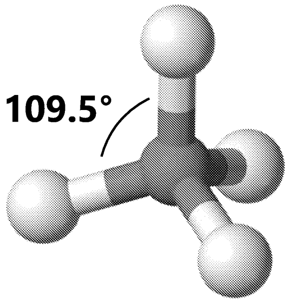
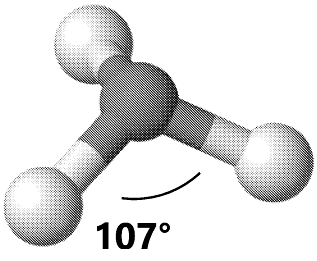
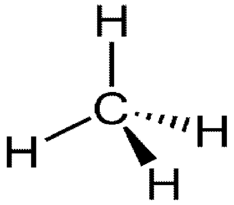
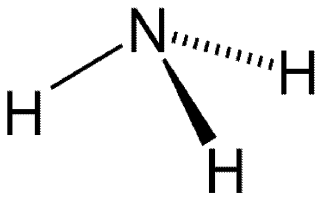
Use dot-and-cross diagrams to help you predict the shape and bond a

i) Sulfur trioxide (SO_3)

ii) Chlorine trifluoride, (ClF_3)

There is a great variety of molecules which contain four regions of electron densit these regions can be bonding pairs or lone pairs. As lone pairs sit closer to the ce and also take up more room, they will repel more strongly. Each additional lone p by approximately 2.5°.

The different combinations of lone pairs and bonding pairs result in a variety of m shown below.

Dot-and-cross diagram	 Methane (CH_4)	 Ammonia (NH_3)
Number of bonding pairs	4	3
Number of lone pairs	0	1
Shape and bond angles		
Name of shape	 Tetrahedral	 Pyramidal

Recap questions: Molecular shapes

1 For each molecule listed below you should
  - i) Give the bond angle
  - ii) Name the shape (10 marks)

  a) CH_4 b) CO_2 c) PF_3 d) H_2O e) SF_6

2 Explain why NH_3 is trigonal pyramidal whereas BF_3 is trigonal planar. (5 ma

3 Antimony chloride, $SbCl_3$, exists as simple covalent molecules.
  - a) Draw the dot-and-cross diagram for this molecule. (1 mark)
  - b) Name the shape of this molecule. (1 mark)
  - c) Give the bond angles in this molecule. (1 mark)
  - d) Explain why it has this shape. (2 marks)

B1.6 Electronegativity and polarity

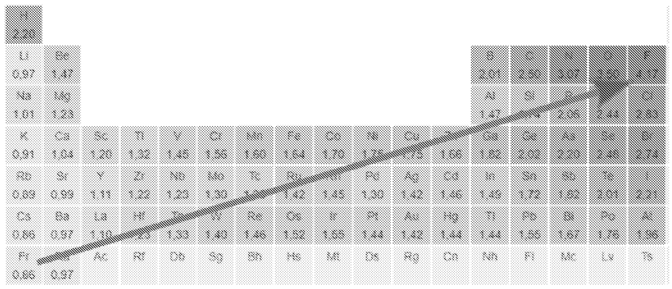
! Key points covered

- Definition of electronegativity
- Describing and explaining trends in electronegativity down a group and across a period
- Use of electronega and polarity of mo

Electronegativity

A covalent bond is formed due to the attraction of a shared pair of electrons and the nuclei of the bonded atoms. Up until now in your science studies the electron pair has been considered to be shared equally between the two bonded atoms, an this is true where the atoms are identical – for example, in H_2, Cl_2 and O_2.

In reality, when the bonded atoms are not the same, it is more likely that a shared pair of electrons will feel more attraction from one of the atoms in the bonded pai than the other. Atoms have different levels of attraction, or **electronegativity**, du to having different nuclear charges and **atomic radius**.



Measuring elec

Electronegativity is m
The larger the value, t
of that atom.

An atom's electroneg
in the periodic table.

- across a period
- up a group

Noble gases tend to have no value for electronegativity as they rarely form compounds.

Chlorine, fluorine, oxygen and nitrogen are the most electronegative elements due to their high nuclear charge and small atomic radius.

Group 1 metals are the least electronegative elements.

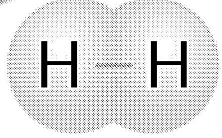
Test you

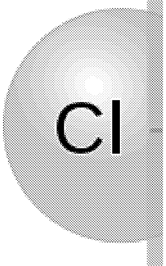
- Defin
- What acros
- What down

Bond polarity

Non-polar bonds

If the two bonded atoms have the same or similar electronegativity then the pair of electrons is shared equally and a non-polar bond is formed.

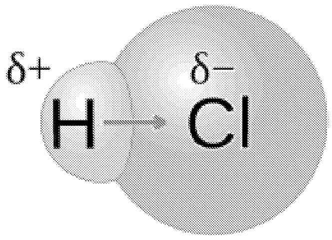


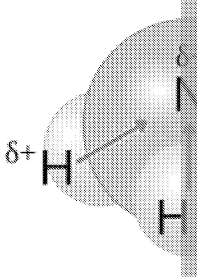


The molecules above both contain non-polar bonds. The bonded atoms are identi electronegativity, so the electron pair is equally shared. Carbon and hydrogen hav and as a result C–H bonds are also non-polar.

Polar bonds

A **polar bond** is formed when a bonded pair of electrons is not equally shared between the two bonding atoms due to differing electronegativities. The atom wi the greater electronegativity exerts a bigger force of attraction on the bonded electrons and will therefore experience a bigger proportion of negative charge.

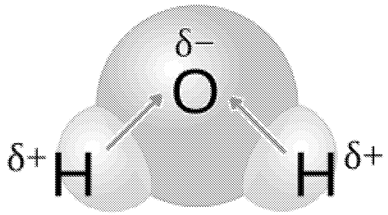




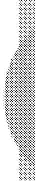
Each bond shown above is polarised [illegible] so [illegible]s a separation of charge. The δ s electronegative atom in the bond will have a partial positive charge, labelled as δ+, electronegativity will [illegible] partial negative charge, δ-. This separation of charges covalent bo[illegible] dipole does not change and is called a permanent dipole.

Polar molecules

If a molecule contains more than one **polar bond** the individual polar bonds can either work together to form one large overall dipole, or work against each other to cancel themselves out and leave the molecule with no dipole at all.



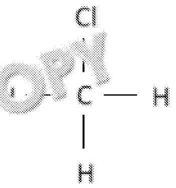
Water molecules contain two polar bonds. Th completely opposite directions to each other a other out. A water molecule is a polar molecul



Carbon dioxide molecules also contain two polar bonds. However, these bonds are acting in completely opposite directions to each other. The effect of the dipoles is cancelled out and, despite having polar bonds, carbon dioxide is not a polar molecule.

Recap questions: Electronegativity and polarity

1 Chlorine gas reacts with methane to form dichloromethane.



The Pauling value of each element in dichloromethane is shown below.

Element	Pauling value
Carbon	2.3
Hydrogen	2.1
Chlorine	3.0

Draw a 3D diagram, using dashes and wedges, to show the shape of dichlo to represent any polar bonds. (3 marks)

2 Explain whether dichloroethane is a polar molecule. (1 mark)

B1.7 Intermolecular forces

Key points covered

- Identification of the three main types of intermolecular force
- Explaining how the three main types of intermolecular bonds are formed
- Relative strength o intermolecular fo

Intermolecular forces are responsible for the physical properties of covalent molec point. There are forces of attraction between dipoles of neighbouring molecules a one of three categories:

1. London dispersion forces (temporary dipole-induced dipole forces)
2. Permanent dipole – permanent dipole forces
3. Hydrogen bonding

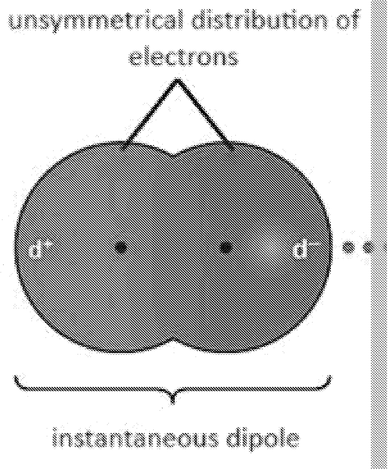
London dispersion forces

London dispersion forces are the weakest types of intermolecular force and exist b of polarity. They are an interaction between instantaneous and induced dipoles ir

Instantaneous-induced dipoles

Electrons are not static in atoms, but instead are continuously moving. This constant movement means that at any one moment there will be an uneven proportion of the electron cloud density on one of the atoms in a bonding pair, causing an ever-changing dipole. This is known as an instantaneous dipole.

The instantaneous dipole in one molecule causes a dipole to be induced in a neighbouring molecule, which then induces dipoles on other nearby molecules. These dipoles will then attract each other.



These attractions are only temporary and in the next moment will have disappeared and reformed in a different configuration.

The strength of a London force will depend on the number of electrons in the electron cloud. The larger the number of electrons, the larger the instantaneous dipole – induced dipole interaction and therefore the more energy is needed to overcome them. This will be observed as an increase in the boiling point.

Test y
Why d
haloge
the gro

Permanent dipole – permanent dipole forces

When a molecule contains a permanent dipole, the attraction between the two op dipole in neighbouring molecules forms an intermolecular force stronger than tha

$$\overset{\delta+}{\mathrm{H}}\!-\!\!-\!\overset{\delta-}{\mathrm{Cl}}\text{- - - -}\overset{\delta+}{\mathrm{H}}\!-\!\!-\!\overset{\delta-}{\mathrm{Cl}}$$

Test yo
What is a
dipole – p
interacti

It is important to remember that as well as having these permanent dipole – permanent dipole forces, polar molecules will also contain London dispersion forces.

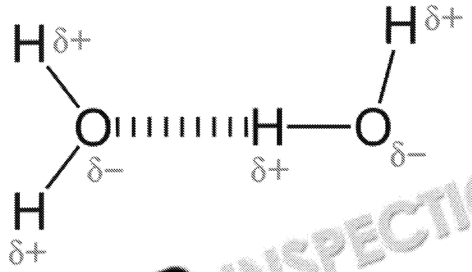
Hydrogen bonding

Hydrogen bonds are the strongest type of intermolecular attraction. A hydrogen b
permanent dipole – permanent dipole attraction formed between molecules which

i) A highly electronegative atom which contains a lone pair of electrons (nitroge

AND

ii) A hydrogen atom bonded to a highly electronegative atom (N–H, O–H or F–H



The hydrogen bond forms between th
the electronegative atom and the δ+ h
neighbouring molecule.

You represent hydrogen bonds using a
the geometry around the hydrogen bo

Recap questions: Intermolecular forces

1 The boiling points of three molecules are shown in the table below.

Molecule	Boiling poin
Chloromethane, CH_3Cl	-24
Fluorine, F_2	-188
Hydrogen fluoride, HF	20

Explain the difference in these boiling points. (5 marks)

2 Methanol, CH_3OH, is soluble in water as hydrogen bonds are able to form
Draw a diagram showing the hydrogen bond formed between these two m
partial charges and lone pairs. (2 marks)

B1.8 Hydrogen bonding and properties o

Key points covered

- Explaining how hydrogen bonding affects the properties of water

The hydrogen bonding in water gives rise to some anomalous (unusual) propertie

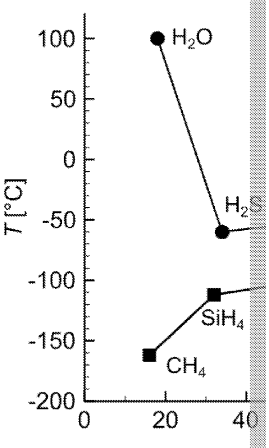
- Lower than expected density in the solid form
- Higher than expected melting and boiling points
- Higher than expected surface tension

Density

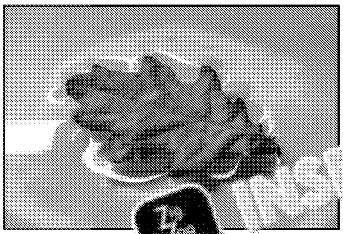
Solid water floats on top of liquid water. This is due to the abi water to form four hydrogen bonds per molecule – two fr the hydrogen atoms and one from each of the lone pairs of electrons on the oxygen atoms. The hydrogen bonds that are formed extend out from the molecule, holding the molecules i an open tetrahedral lattice with large holes in. When the ice n the water molecules are able to move closer together again. I structure that decrease the density of the solid form of water c

Melting and boiling point

If you were to consider the patterns and trends in boiling point of the hydrides, you would expect water to boil at -75 °C and be a gas at room temperature. But this is not the case; water boils at 100 °C, considerably higher than expected. The reason for this, again, is hydrogen bonding. Like all simple covalent substances, when you try to melt or boil water it is the intermolecular forces you need to overcome and break. And just like all molecules, water has London dispersion forces that require breaking. However, water also contains hydrogen bonding and this type of intermolecular force requires a large amount of additional energy to overcome. This results in a much higher than expected melting and boiling point.



Surface tension



Water droplets can be considered to be 'not wet' a on water! This phenomenon is due to the fact that placed under stress or tension. Water on the top s form hydrogen bonds to its neighbours, just like m water. However, molecules on the top surface of t neighbours with which to form hydrogen bonds, a top half. This means that the hydrogen bonds that water molecules are even stronger than normal, re

Recap questions: Hydrogen bonding and properties of water

1. What role does hydrogen bonding play in the density of water? (4 marks)
2. How does hydrogen bonding contribute to the high melting and boiling poi
3. What are the implications of water's high surface tension and how does hy property? (3 marks)

C: Periodicity

C1.1 Properties of period 3 elements

! ***Key points covered***

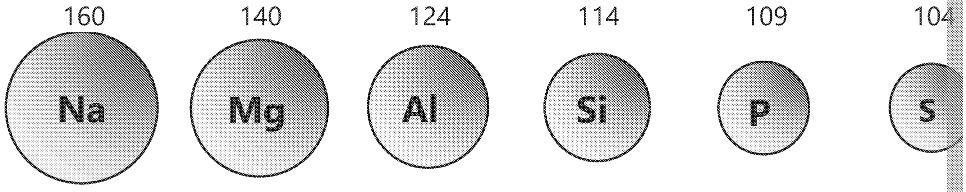
- Describe and explain how atomic radius and ionic radius change across period 3
- Describe and explain how melting point changes across period 3
- Describe and expla changes across pe

Periods are the horizontal rows across the periodic table. As you move across a period, from left to right, repeating patterns are observed in physical properties su as ionisation energy, structure and melting points. This is known as **periodicity**.

Atomic radius

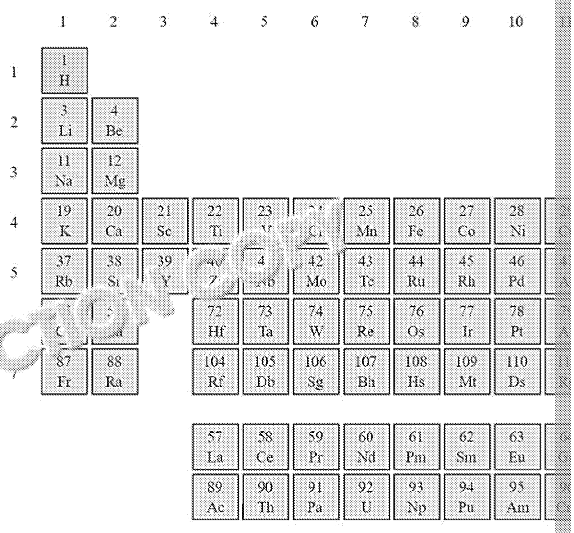
The atomic radius provides a useful indication of the size of an atom. This can be a are not solid objects. As you move from left to right across a period, the atomic ra

Atomic radius (pm)



As you go across a period, the atomic number – and, therefore, the number of pro resulting in a stronger nuclear charge. The extra electron that is also being added i This means the electrons are experiencing a stronger attraction towards the nucle

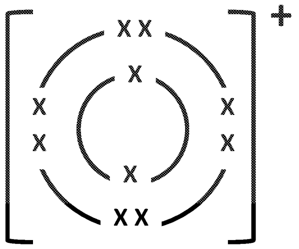
Ionic radius



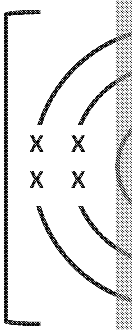
Ionic radius is similar to atomic radius; however, it measures the distance from the nucleus to the outer electron on a charged particle. As you go across period 3 the ionic radius decreases, with the exception of aluminium to phosphorus, where you see a large increase in radius.

Elements on the left-hand side of the periodic table, the metals, will lose electrons when they form ions and therefore be positively charged. The resulting ions are **isoelectronic**, however – each successive ion contains one extra This greater nuclear charge has a greater attraction on the electrons and pulls the to the nucleus, reducing the radius. Elements on the right-hand side of the periodi the non-metals, will gain electrons when they form ions and become negative ions. ions produced are again **isoelectronic** and each successive ion experiences a grea nuclear attraction due to increased proton number.

The large jump between positive and negative ions can be explained by considerin
the resulting ions.



Electronic structure of a positively charged ion in period 3



Electronic stru
charged

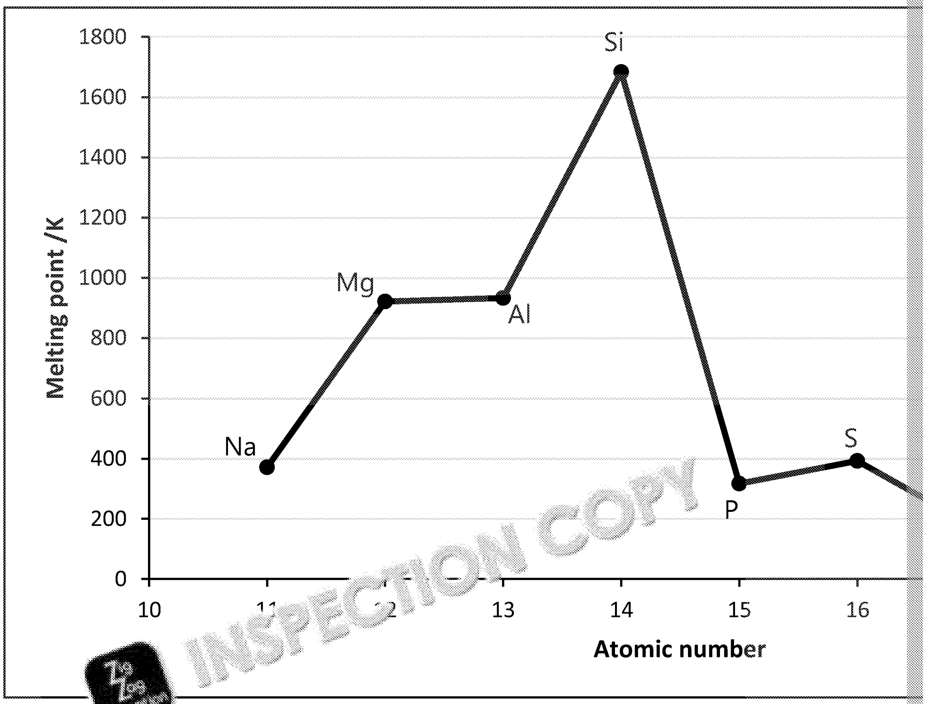
The negative ion contains an extra shell of electrons compared to the positively charged ion. This results in a large jump in ionic radius when the nature of the ion changes.

Test your knowledge

- Why do positively charged ion
radius than the atomic radius c
- Why do negatively charged io
than the atomic radius of the e

Melting point

The melting point of a substance is linked to the strength of the attractive forces h
The stronger the forces of attraction, the higher the amount of energy needed to b
higher melting point.



It is easier to understand the reasons behind this variation in melting points if you
sections, based on the type of bonding the element contains.

Sodium – Aluminium

As you move across the first three elements of period 3 there is an increase in mel are metals, containing metallic bonding, and therefore to make them melt you are electrostatic forces of attraction between the sea of delocalised electrons and pos

As you go from sodium to aluminium the amount of electrons donated to the sea increases, which also causes a greater charge on the positive metal ions. This resu which requires a larger amount of thermal energy to break.

Silicon

Silicon is a covalent molecule with a giant structure, similar to that of diamond. Th very high due to the fact that the forces between silicon atoms that require breaki

Phosphorus – Argon

The remaining elements in period 3 all consist of a simple covalent structure. Whe the intermolecular forces which are broken and not the covalent bonds between a only London forces, which are very weak and only require small amounts of therm

The strength of a London dispersion force is related to the amount of electrons co more electrons, the stronger the force. Sulfur exists as S_8 molecules, meaning it ha of phosphorus, P_4, and consequently a higher melting point. Chlorine is found as

Electrical conductivity

Electrical conductivity is the measure of a material's ability to carry an electrical cu the presence of mobile charged particles, such as electrons and ions (see section

As you go across period 3, the electrical conductivity of the elements initially incre group 4 and then stays almost negligible until group 8. This trend is explained by nature of each element.

Sodium	Magnesium	Aluminium	Silicon	Sulfur	Phospho
Metals Contain ionic bonding. As you go across the group, a further electron is donated to the sea of electrons, resulting in more electrons available to carry charge.			**Metalloid** Acts as a semi-conductor	**N** No charged p the el	

Recap questions: Properties of period 3 elements

1 Explain which element would have the smallest atomic radius in period 3. (

2 Describe and explain the trend in melting point for the first three elements

3 Explain the trend in the boiling points of phosphorus, chlorine and sulfur. (

C1.2 Oxidation numbers, oxidation and r

Key points covered

- Assign oxidation numbers for elements in compounds and ions
- Define oxidation and reduction
- Writ

A redox reaction is a reaction where both **oxidation** and **reduction** occur simultaneously. During this reaction one species will become oxidised (meaning it loses electrons) and a second species will be reduced (it gains electrons). When the redox reaction involves covalent compounds, **oxidation numbers** must be used in order to identify the oxidation and reduction processes.

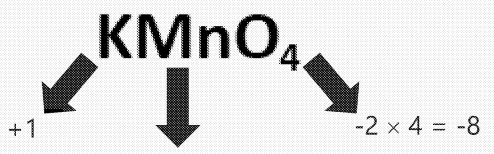
Oxidation numbers

In order to assign an oxidation number to a species, a series of rules must be applied.

1. Any element in its natural form will have an oxidation number of 0, e.g. Na, Al,
2. If an element is present as an ion, its oxidation number will be the same as th
3. Group 1, 2, 6 and 7 elements present in compounds will have oxidation ions ma ionic charges
4. Oxidation numbers of species in a compound will add to a total of 0
5. Oxidation numbers in a polyatomic ion will add to a total of the charge on th
6. The oxidation number of oxygen in a compound is always -2 (except when in a

Example 1: $KMnO_4$

- This is a compound – the oxidation numbers of all species must add up to a
- K is in group 1 of the periodic table, therefore in a compound it has an oxid
- O in a compound is always -2 (except when in a peroxide)
- Therefore Mn must have an oxidation number of +7



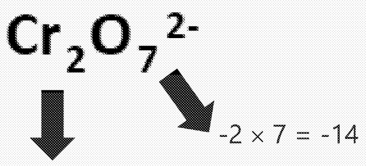
+1 (K) + *x* (Mn) -8 (O) = 0

x = +7

Oxidation numbers: K = +1, Mn = +7, O = -2

Example 2: $Cr_2O_7^{2-}$

- This is a polyatomic ion – the oxidation numbers of all species must add up
- O in a compound is always -2 (except when in a peroxide)
- Therefore Cr must have an oxidation number of +6



2*x* (Cr) + -14(O) = -2

2*x* = +12

x = +6

Oxidation numbers: Cr = +6, O = -2

Using oxidation numbers in naming

A characteristic property of transition metals is the ability to form ions with multip
When these ions then form compounds it is important to know which oxidation nu
order to correctly determine the chemical formula.

Roman numerals are used to show the oxidation number of an element and will b
of any compound containing that species.

Number	1	2	3	4	5
Roman numeral	I	II	III	IV	V

- **$KMnO_4$** – manganese can adopt multiple oxidation numbers. In this compound it is present in its +7 form. The systematic name is potassium manganate(VII).
- **CuO** – copper can adopt multiple oxidation numbers. In this compound it is present in its +2 form. The systematic name is copper(II) oxide.

Test your kn
Can you explai
oxidation num
compound, sp
exceptions or

Identifying oxidation and reduction

The terms oxidation and reduction were originally used to describe reactions invol

- A substance was said to be oxidised if it gained oxygen.
- A substance was said to be reduced if it lost oxygen.

The following equation shows both oxidation and reduction:

$$FeO + CO \rightarrow Fe + CO_2$$

- Iron(II) oxide has lost oxygen and has therefore been reduced.
- Carbon monoxide has gained oxygen and has been oxidised

Redox in terms of electron transfer

A further example of redox involves the loss and gain of electrons: **OILRIG**.
The reaction below does not involve any oxygen but does involve electron transfe

$$2Al + 3Cl_2 \rightarrow 2AlCl_3$$

- $AlCl_3$ is made up of positive aluminium ions, Al^{3+}, and negative chloride ions,
- Aluminium atoms have lost three electrons to become Al^{3+} and have therefo
- Chlorine atoms have gained one electron to become Cl^{-} and have therefore

Redox in terms of oxidation numbers

In order to determine which species has been oxidised and which species has bee
the oxidation number of the element must be determined in both the reactants an

- An increase in oxidation number between the reactant and the product indic
- A decrease in oxidation number between the reactant and the product indic

Take the following reaction:

$$2H_2 + O_2 \rightarrow 2H_2O$$

- Hydrogen starts with an oxidation number of 0 which has changed to +1 wh has increased; hydrogen was oxidised.
- Oxygen starts with an oxidation number of 0 which has changed to -2 when has decreased; oxygen was reduced.

A second, more complex example, including far more species would be:

$$2KMnO_4 + 3H_2O_2 \rightarrow 3O_2 + 2MnO_2 + 2KOH + 2H_2$$

Element	Oxidation number in reactant	Oxidation n
Potassium	+1	
Manganese	+7	
Oxygen	-2 (-1 in peroxide)	-2 (0 i
Hydrogen	+1	

- Oxygen starts with an oxidation number of -1 in H_2O_2 which has changed to 0 when in O_2. The oxidation number has increased; oxygen was oxidised.
- Manganese starts with an oxidation number of +7 which has changed to +4. The oxidation number has decreased; manganese was reduced.

Sp
in
ur
di
nu

Potassium and hydrogen are acting as **spectator ions**.

Disproportionation

In some chemical reactions an element is simultaneously oxidised and reduced to f
A chemical reaction like this is known as disproportionation. Here is an example o
involving chlorine:

$$3Cl_2 + 6OH^- \rightarrow 5Cl^- + ClO_3^- + 3H_2O$$

In this reaction:

- Some chlorine (Cl_2) is oxidised to chlorate ions (ClO_3^-) with a +5 oxidation state.
- Some chlorine (Cl_2) is reduced to chloride ions (Cl^-) with a -1 oxidation state.

Test your know

The following reac
$Ca + 2HCl \rightarrow CaCl$

Explain which spe
which species is b

Redox equations and half-equations

A redox equation gives the full, balanced equation for a redox reaction.

$$Mg + Zn^{2+} \rightarrow Mg^{2+} + Zn$$

This equation can be separated out to show the oxidation and reduction processes

Oxidation: $Mg \rightarrow Mg^{2+} + 2e^-$
Reduction: $Zn^{2+} + 2e^- \rightarrow Zn$

If any spectator ions are present they will not appear in the half-equations, as seen

$$Cu + 2AgNO_3 \rightarrow 2Ag + Cu(NO_3)_2$$

Oxidation: Copper's oxidation number changes from 0 to +2; $Cu \rightarrow Cu^{2+} + 2e^-$
Reduction: Silver's oxidation number changes from +1 to 0; $Ag^+ + e^- \rightarrow Ag$

Using half-equations to write redox equations

If you are provided with the equations that show the oxidation and reduction proc
can combine then to give the overall, full balanced equation by following these ste

1. Balance the electrons
2. Combine equations and cancel out the electrons
3. Cancel out any species that appear on both sides of the equation

Example:

A redox reaction occurs with the following oxidation and reduction processes:

$$Cr^{3+} + 8OH^- \rightarrow CrO_4^{2-} + 4H_2O + 3e^-$$
$$H_2O_2 + 2e^- \rightarrow 2OH^-$$

Use the half-equations to give the overall redox equation.

1. **Balance the electrons**
   There are three electrons in the top equation (oxidation) and only two elec (reduction). The oxidation equation needs to be multiplied by 2 and the re give six electrons in each equation.

   $$2Cr^{3+} + 16OH^- \rightarrow 2CrO_4^{2-} + 8H_2O + 6e^-$$
   $$3H_2O_2 + 6e^- \rightarrow 6OH^-$$

2. **Combine equations and cancel out the electrons**
   Combining all reactants from the oxidation and reduction processes gives: 2
   Combining all products from the oxidation and reduction processes gives: 2

   This gives the following equation:

   $$2Cr^{3+} + 16OH^- + 3H_2O_2 + 6e^- \rightarrow 2CrO_4^{2-} + 8H_2O + 6e$$

   The electrons can then be cancelled out to give:

   $$2Cr^{3+} + 16OH^- + 3H_2O_2 + \cancel{6e^-} \rightarrow 2CrO_4^{2-} + 8H_2O + \cancel{6e}$$
   $$2Cr^{3+} + 16OH^- + 3H_2O_2 \rightarrow 2CrO_4^{2-} + 8H_2O + 6O$$

3. **Cancel out any species that appear on both sides of the equation**
   There are hydroxide ions on both the reactant and product sides of the equat product can be cancelled out from the 16 on the reactant side, leaving only 1

   $$2Cr^{3+} + \cancel{16}OH^- + 3H_2O_2 \rightarrow 2CrO_4^{2-} + 8H_2O + \cancel{6}O$$
   $$2Cr^{3+} + 10OH^- + 3H_2O_2 \rightarrow 2CrO_4^{2-} + 8H_2O$$

   This gives the final redox equation as being:

   $$\mathbf{2Cr^{3+} + 10OH^- + 3H_2O_2 \rightarrow 2CrO_4^{2-} + 8H_2O}$$

? *Recap questions: Oxidation numbers, oxidation and reduction*

1 Determine the oxidation numbers of each element in the species below. (5

a) Na_2CO_3 b) Cr_2O_3 c) [illegible] d) MnO_4

2 Use oxidation numbers to determine what has been oxidised and what has following equations. (6 marks)

a) $3CuO + 2NH_3 \rightarrow 3Cu + 3H_2O + N_2$

b) $MnO_2 + 4HCl \rightarrow MnCl_2 + Cl_2 + 2H_2O$

c) $Mg + H_2SO_4 \rightarrow MgSO_4 + H_2$

3 Write half-equations for the following conversions and classify each change reduction. (10 marks)

a) $Na \rightarrow Na^+$ b) $Pb^{4+} \rightarrow Pb^{2+}$ c) $H_2 \rightarrow H^+$ d) $Br^- \rightarrow$

4 Combine the following half-equations to give the full, balanced redox equati

a) $MnO_4 + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$ and $Ce^{3+} \rightarrow Ce^{4+} + e^-$ (2 marks)

b) $H_2O_2 \rightarrow 2H^+ + O_2 + 2e^-$ and $MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$ (2 m

c) $C_2O_4^{2-} \rightarrow 2CO_2 + 2e^-$ and $FeO_4^{2-} + 8H^+ + 3e^- \rightarrow Fe^{3+} + 4H_2O$ (2 mar

C1.3 Reactions of period 3 elements

Key points covered

- Describe trends in the reaction of period 3 elements with oxygen
- Describe trends in the reaction of period 3 elements with water

Reactions with oxygen

The reaction of a substance with the oxygen found in air is known as **combustion** oxide. The table below outlines the characteristics of some period 3 elements whe balanced chemical equations for the reactions that occur.

Element	Observations
Sodium, Na	Burns vigorously with an orange flame to produce a white solid, sodium oxide.
Magnesium, Mg	Burns vigorously with a bright white light to produce a white solid, magnesium oxide.
Aluminium, Al	Aluminium powder will burn quickly in oxygen with a white flame to produce white aluminium oxide. Sheets of aluminium will also slowly react with oxygen in the absence of a flame, to produce a layer of aluminium oxide on the surface of the metal.
Phosphorus, P	Phosphorus will ignite spontaneously in oxygen and burn with a white flame, producing white smoke. In an excess of oxygen the main product is phosphorus(V) oxide, a white solid.
Sulfur, S	Requires gentle heating to burn with a pale blue flame. A colourless, toxic gas, sulfur dioxide, is formed.

Test your knowledge

Why does the reactivity of the period 3 metals decrease as you go across the gro energy in your answer.

Discussion question: a second oxide of phosphorus, phosphorus(III) oxide, is als phosphorus reacts with oxygen. What conditions do you think would be requirec be the formula of the oxide formed?

Reactions with water

Period 3 elements react with water to varying degrees; however, non-metals such as silicon and phosphorus do not react with water under normal conditions. The table overleaf outlines the characteristics of some period 3 elements when reacting with water, and balanced chemical equations for the reactions that occur.

Element	Observations
Sodium, Na	Will react with cold water in a highly **exothermic** reaction. Bubbles of hydrogen are generated and a colourless solution of sodium hydroxide.
Magnesium, Mg	Reacts much more slowly with cold water than sodium. Eventually the surface of the magnesium will become coated in bubbles of hydrogen gas and a thin layer of magnesium hydroxide is formed on the surface of the metal, causing the reaction to stop.
Aluminium, Al	Aluminium has very low reactivity with water due to the aluminium oxide coating and needs to lose three electrons. Aluminium powder will react with warm water slowly to produce aluminium hydroxide and hydrogen gas.

Reactions with chlorine

When we mix chlorine gas with elements from the third period of the periodic tab each element reacts uniquely. The products formed are known as chlorides. The table below outlines the characteristics of some period 3 elements when reacting with chlorine, and balanced chemical equations for the reactions that occur.

Element	Observations
Sodium, Na	Will burn easily in chlorine with an orange flame. The sodium chloride produced is a white solid.
Magnesium, Mg	Will burn easily in chlorine with a bright, white flame. The magnesium chloride produced is a white solid.
Aluminium, Al	Burns in a stream of dry chlorine to produce a pale yellow solid of aluminium chloride which quickly **sublimes** due to the high temperatures.
Silicon, Si	A colourless liquid, silicon tetrachloride, is formed which immediately vaporises due to the high temperatures.
Phosphorus, P	Will burn spontaneously in chlorine and form an off-white solid of phosphorus(V) chloride.

Recap questions: reactions of period 3 elements

1 Phosphorus reacts with oxygen to form phosphorus(V) oxide.
  a) What do you see happening as phosphorus burns? (2 marks)
  b) Write the balanced equation for phosphorus burning in oxygen. (2 ma

2 a) Name the two products formed when sodium reacts with water and showing this reaction. (3 marks)
  b) Explain why the reaction of aluminium with water is so slow and sugg increased. (2 marks)

3 Give the chemical formula of the chlorides formed when sodium, aluminiu with oxygen and state the oxidation numbers of the non-chlorine element

C1.4 Physical properties of period 3 oxid

Key points covered

- Describe the differences in melting point for the period 3 oxides and chlorides
- Describe the diffe of the period 3 ox

As seen in section B, the properties of a substance are related to the structure and can understand the trends in the properties of the period 3 oxides and chlorides, y particles within them are held together.

Period 3 oxide	Na_2O	MgO	Al_2O_3
Chemical bonding	Ionic	Ionic	Ionic
Structure	Giant ionic	Giant ionic	Giant ionic

Period 3 chloride	NaCl	$MgCl_2$	Al_2Cl_6
Chemical bonding	Ionic	Ionic	Covalent
Structure	Giant ionic	Giant ionic	Simple molecular

As you go across period 3, the bonding within the oxides and the chlorides becom the structure changes from giant ionic to simple molecular.

Physical properties of the period 3 oxides

Melting point

Period 3 oxide	Meting point °C
Na_2O	1132
MgO	2852
Al_2O_3	2072
P_4O_{10}	340
SO_2	-76

The metallic oxides are all ionic in nature. They have very high melting points due attractions between oppositely charged ions which require large amounts of energ

The remaining oxides are simple covalent substances. When melting they require v attractions to be overcome and this does not need as much energy.

Electrical conductivity

In solid form [illegible] of the period 3 oxides have free ions or delocalised electrons ava

However, if the metallic oxides are molten or dissolved in water, the ionic lattice will positively and negatively charged ions to move independently of each other, resulti

Physical properties of the period 3 chlorides

Melting point

Period 3 chloride	Meting point °C
NaCl	801
$MgCl_2$	714
Al_2Cl_6	sublimes
$SiCl_4$	-69
PCl_5	160

The melting points of sodium chloride and magnesium chloride are very high due t amount of energy needed to overcome the strong electrostatic attractions betwee

The melting points of the others are so much lower due to their covalent nature a requirement involved in having to overcome the weaker intermolecular attraction

Electrical conductivity

Both sodium and magnesium chloride have a giant ionic structure which means th electricity when solid as the ions are held firmly in position and unable to move. H aqueous the ions become mobile and are therefore free to carry an electrical charg

The other chlorides are unable to conduct in any state due to their covalent nature mobile electrons and so an electrical charge cannot be transferred.

? Recap questions: Physical properties of period 3 oxides and chl

1 The melting point of magnesium oxide is 2852 °C, whereas that of sodium Account for this large difference in melting point in terms of their bonding.

2 P_4O_{10} has a low melting point. Account for the low melting point in terms

3 Compare the electrical conductivity of magnesium chloride with phosphoru

C1.5 Acid-base behaviour of period 3 oxi and hydroxides

! Key points covered

- Explain how period 3 oxides and hydroxides act in water
- Describe whether a period 3 oxide acts as an acid or a base in chemical reactions
- Describe w as an acid o

When placed in water, period 3 oxides and hydroxides can act as either acids (donate H^+ ions and react with bases) or bases (accept H^+ ions and react with acids

The nature of the period 3 oxides is summarised below.

Period 3	Na_2O	MgO	Al_2O_3	
Acid/base nature	Basic	Basic	**Amphoteric**	

The reason behind the acidic/basic nature of the oxide is dependent on the way it i

Basic oxides

When sodium and magnesium oxide are placed in water the ions dissociate and th O^{2-} ions interact with the water molecules. This forms an alkaline solution which is

Period 3 oxide	Reaction with water	
Na_2O	The ionic lattice dissolves in water to form Na^+ and O^{2-} ions. The O^{2-} ions then react with water: $O^{2-} + H_2O \rightarrow 2\ OH^-$ Overall the process is $Na_2O + H_2O \rightarrow 2\ NaOH$	*e.g.* N Na Na
MgO	The ionic lattice dissolves in water to form Mg^{2+} and O^{2-} ions. The O^{2-} ions then react with water: $O^{2-} + H_2O \rightarrow 2\ OH^-$ Overall the process is $MgO + H_2O \rightarrow Mg(OH)_2$ The resulting solution is less alkaline than the one formed from sodium oxide as magnesium oxide has a lower solubility in water due to stronger electrostatic forces between the oppositely charged ions.	*e.g.* M M Mg(

Amphoteric oxides

Aluminium oxide is insoluble when placed in water as the electrostatic forces betw overcome. Aluminium oxide has the ability to react with both acids and hot, conce

Reaction with acid	Reaction wi
$Al_2O_3 + 6H^+ \rightarrow 2Al^{3+} + 3H_2O$ *e.g.* $Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$ $Al_2O_3 + 3H_2SO_4 \rightarrow 2Al_2(SO_4)_3 + 3H_2O$ $Al_2O_3 + 6HNO_3 \rightarrow 2Al(NO_3)_3 + 3H_2O$	$Al_2O_3 + 2OH^- + 3H_2$ *e.g.* $Al_2O_3 + 2NaOH + 3H_2$

Acidic oxides

The covalently bonded period 3 oxides all dissolve in water to produce acids whic when reacting with bases.

Period 3 oxide	Reaction with water	
P_4O_{10}	When put into water P_4O_{10} reacts violently to form phosphoric acid $P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$	P_4O or in its OH
SO_2	Sulfur dioxide dissolves when placed into water and forms sulfurous acid $SO_2 + H_2O \rightarrow H_2SO_3$ *A second oxide of sulfur, SO_3, also does similar when placed in water, except this time sulfuric acid is formed* $SO_3 + H_2O \rightarrow H_2SO_4$	S 2O

Other acidic oxides not previously met include silicon dioxide and various chlorine

Period 3	Reaction with water	
SiO_2	No reaction due to the giant covalent network structure adopted by silicon dioxide	SiO (the base
Cl_2O_7	When dissolved in water the very strong acid, perchloric acid, is formed $Cl_2O_7 + H_2O \rightarrow 2HClO_4$	OH
Cl_2O	When dissolved in water, the weak acid, hypochlorous acid, is partially formed $Cl_2O + H_2O \leftrightarrows 2HClO$	OH

Test your knowledge

What are the oxidation numbers of chlorine in each of the oxides give

Period 3 hydroxides

All three metallic period 3 hydroxides act as bases and will react with acids to form

$$\mathbf{NaOH_{(aq)} + H^+_{(aq)} \rightarrow Na^+_{(aq)} + H_2O_{(l)}}$$

e.g. $NaOH_{(aq)} + HCl_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$

$$\mathbf{Mg(OH)_{2(s)} + 2H^+_{(aq)} \rightarrow Mg^{2+}_{(aq)} + 2H_2O_{(l)}}$$

e.g. $Mg(OH)_{2(s)} + 2HCl_{(aq)} \rightarrow MgCl_{2(aq)} + 2H_2O_{(l)}$

$$\mathbf{Al(OH)_{3(s)} + 3H^+_{(aq)} \rightarrow Al^{3+}_{(s)} + 3H_2O_{(l)}}$$

e.g. $Al(OH)_{3(s)} + 3HCl_{(aq)} \rightarrow AlCl_{3(s)} + 3H_2O_{(l)}$

As with its oxide, aluminium hydroxide is amphoteric so when in the presence of a act as an acid:

$$\mathbf{Al(OH)_{3(s)} + NaOH_{(aq)} \rightarrow NaAl(OH)_{4(aq)}$$

? Recap questions [illegible]: Acid-base behaviour of period 3 oxides and hy

1 a) The oxides of the elements of the third period were added to water a formed recorded. What general trend in pH would be observed? (1 m

b) Which two of the oxides of the period 3 elements sodium to sulfur ar

2 a) Suggest a value for the pH of the solution formed when magnesium ox Give the formula of the compound formed which is responsible for th

b) Sulfur dioxide reacts readily with water. Suggest a value for the pH o give the formula of the compound which is responsible for the change

3 Aluminium hydroxide will react with both nitric acid and sodium hydroxide these reactions. (4 marks)

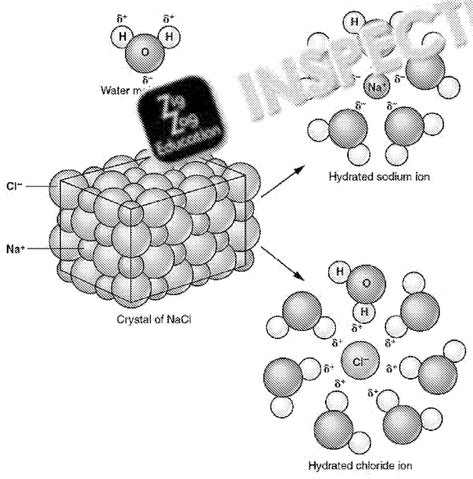
C1.6 Reaction of water and period 3 chlo

Key points covered

- Describe the interaction of period 3 chlorides with water
- State the pH of so chlorides in water

The reaction of a substance with water is known as hydrolysis. The period 3 chlori ways depending on their structure and bonding. As a result, the solutions formed

Period 3 chloride	NaCl	$MgCl_2$	Al_2Cl_6
pH of solution	7	6.5	3

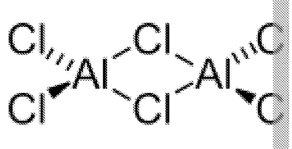


Sodium and magnesium c

When placed in water, both sodium chloride dissolve, rather than react. down and independent ions are for water molecules.

The higher charge of the magnesiu a small amount of the polar water m resulting in the slightly more acidic

Aluminium chloride



Aluminium chloride, Al_2Cl_6, exists as a **dimer**. When this substance is placed in water the dimer breaks down and produces hydrated Al^{3+} and Cl^- ions. As with magnesium chloride, the high charge on the positive aluminium ion causes a water molecule to lose an H^+ ion and make the solution acidic.

This H^+ ion is able to then react with the Cl^- ions to produce hydrogen chloride gas,

Silicon chloride

When reacting with water, silicon chloride again produces white fumes of hydroge chloride gas. A white **precipitate** of silicon dioxide is formed and some of the hydrogen chloride produced dissolves in the water to form a strongly acidic soluti

$$SiCl_{4(l)} + 2H_2O_{(l)} \rightarrow SiO_{2(s)} + 4HCl_{(g)}$$

Phosphorus chloride

PCl_5 is hydrolysed in wate [illegible] reaction to form two very acidic substances phosphoric [illegible]

$$PCl_{5(s)} + 4H_2O_{(l)} \rightarrow H_3PO_{4(aq)} + 5HCl_{(g)}$$

Recap questions: Reaction of water and period 3 chlorides

1. Describe the trend in pH of the solutions formed as a result of hydrolysis o period 3. (1 mark)
2. What observations are recorded when silicon chloride is placed in water? represents this reaction. (3 marks)
3. Name the two substances formed when phosphorus(V) chloride is placed i

C1.8 Predicting physical and chemical p

Key points covered

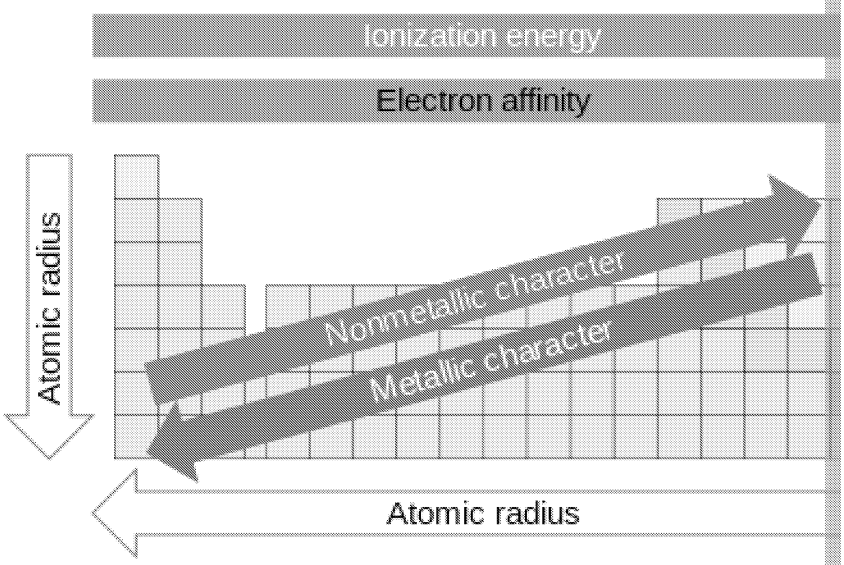
- Use of periodicity to predict physical properties of period 2 elements
- Use of periodicity t of period 2 eleme

Phy affe For e elec

Che a su

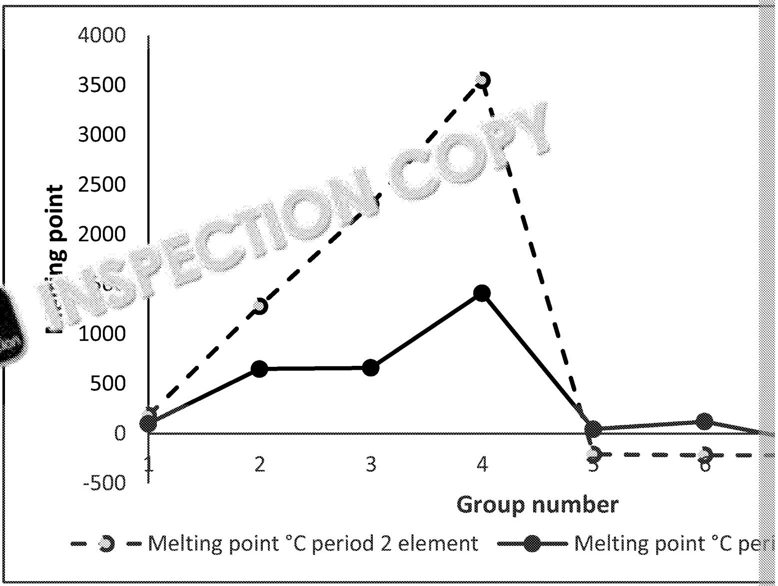
Periodicity is a useful tool that can be used by chemists to predict **physical** and **chemical properties** of other elements based on their location within the periodic table. As previously discussed, the periodic table arranges elements based on their electronic structure. All elements in the same group as each other will have similar electronic configurations, with the exception of an extra shell added as you progress down the group. All elements in the same period as each other will follow the same pattern in electronic configuration as the group before in a shell further from the nucleus.

The following properties can be predicted using periodicity: ionisation energy, ato metallic nature. The image below shows the trends followed by these properties i



Other properties of elements can also be predicted using the trends previously me
elements. Consider the data shown below in both tabulated and graphical form, f

Group number	1	2	3	4	5
Melting point °C period 2 element	181	1278	2300	3547	-2
Melting point °C period 3 element	98	649	660	1410	4



Despite the values between the period 2 elements and the equivalent period 3 ele
see that the trend for both periods is the same. As you move across the metallic e
rises, peaking at the group 4 giant covalent substance. The remaining elements i
in melting point due to their simple covalent nature.

Recap questions: Predicting physical and chemical properties

1 In period 2, which substance, out of the following pairs, would you expect
point, and why? (3 marks)
   a) lithium and carbon
   b) neon and beryllium
   c) lithium and beryllium

2 Rewrite the following list in order of decreasing electronegativity: fluorine
boron (B). (1 mark)

3 Based on the periodic trends for ionisation energy, which period 2 element
energy? Explain your answer. (4 marks)

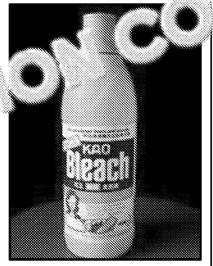
4 True or false? Nitrogen has a larger atomic radius than oxygen. Explain yo

C1.9 Uses of period 3 elements and com

! Key points covered

- Applications of period 3 elements
- Applications of pe

The table below outlines uses and applications of period 3 elements and their com exhaustive and there are many more uses out there.

Element	
Chlorine – disinfectant due to it ability to kill bacteria Argon – atmosphere for welding due to its inert nature 	Sodium oxide – glassmaking Magnesium oxide – fir materials Silicon dioxide – construction industry Phosphorus oxide – dr
Hydroxides	C
Sodium hydroxide – soap production Magnesium hydroxide – antacid due to its ability to neutralise acids Aluminium hydroxide – treat heartburn 	Sodium chloride – foo Magnesium chloride – dietary supplement Silicon chloride – chem

? Recap questions: Uses of period 3 elements and compounds

1 Stomach acid can be thought of as HCl. With the use of an equation, expla can be used as an antacid. (2 marks)

2 Silicon dioxide can be used in the construction industry due to its high mel Use structure and bonding to explain the reason for these two properties.

D: Physical chemist

D1.1 Moles

! Key points covered

- Use of the mole to calculate mass and relative formula mass of substances
- Use mole calculations to determine ratios of atoms in a compound and substances in a reaction
- Use of the mole t
- Use of moles to c chemical reaction

The mole

When chemists carry out chemical reactions the substances involved are usually m volume. However, chemistry is the study of atoms and therefore chemists need a convert the quantities of chemicals into the actual number of particles that have

Avogadro constant, N_A – a numerical value equivalent to 6.02×10^{23}. This is the amount of particles in one mole of a substance.

Due to the small size of atoms, huge amounts chemical reaction. The units used to measure moles, and one mole of a substance contains t of particles.

Carbon-12 is the standard for measuring atomic mass, and if you were to take the of carbon-12 you would find that they weigh a total of 12 g. This means it is very of any substance; it is the relative atomic mass of that element, expressed in gram

One mole of oxygen atoms, O, would have a mass of 16 g

One mole of magnesium atoms, Mg, would have a mass of 24 g

Two moles of oxygen atoms, O, would have a mass of (2 × 16) 32 g

Four moles of magnesium atoms, Mg, would have a mass of (4 × 24) 96 g

Test

- V c a
- H i

The idea of the mole gives us a way to take something that is too small to be seen and yet know exactly how many particles there are present; as long as you know which element you have and how much of this substance yo

Molar mass

Relative atomic mass can only be used in relation to elements. However, moles ca refer to anything, not just elements. **Molar mass** is a way of linking moles with m for any chemical substance. The molar mass of carbon is 12 g mol^{-1}, whereas the molar mass of carbon dioxide, CO_2, is 44 g mol^{-1} (12 + [2 × 16]).

Moles, molar mass and mass can be linked using the equation: $\text{moles} = \frac{\text{mass in g}}{\text{molar mass}}$

Test your knowledge

- What is the molar mass of BeO?
- Calculate the mass in grams of 0.125 moles of H_3PO_4

Empirical formula

Empirical formula is the simplest whole number ratio between the different elemen useful for chemical substances that are not molecular and exist in giant structures. millions of oppositely charged ions, with no set amount; the number of ions presen the size of the crystal studied. However, what will not change is the ratio between t

Empirical formula for substances can be calculated using one of two methods: thro analysis of percentage composition. Both methods involve the following steps:

Step 1 – calculate moles of each element using moles = $\frac{\text{mass in g}}{\text{molar mass}}$

Step 2 – divide by the smallest amount to find the simplest whole number ratio

Step 3 – write the empirical formula

Empirical formula using mass data *A student carried out an experiment where 0.6 g of calcium reacted with 1.05 g of chlorine. Use the given mass data to determine the empirical formula of the resulting compound.*	**Empirical formula us** *An organic chemical und found to have the followi carbon 40.00 %, hydroge Determine the empirical*
Step 1 – Moles of calcium = 0.6 ÷ 40 = 0.015 mol Moles of chlorine = 1.05 ÷ 35.5 = 0.03 mol **Step 2** – Moles of calcium is the smallest value Mol Ca = $\frac{0.015}{0.015}$ Mol Cl = $\frac{0.03}{0.03}$ 1 : 2 **Step 3** – Empirical formula = $CaCl_2$	Before following the ste the percentages given i the process as for mass **Step 1** – Moles of carbon = 40 ÷ Moles of hydrogen = 6. Moles of oxygen = 53.3 **Step 2** – Moles of carbon/oxyge Mol C = $\frac{3.33}{3.33}$ Mol H = $\frac{6}{3}$ 1 : 2 : 1 **Step 3** – Empirical formula = CH

Test your knowledge

Discussion question: if you were told the mass of substance used to give th in example 2, could you suggest a way to determine its molecular formula?

Balancing equations

Due to the **conservation of mass**, all chemical equations that are written must be balanced; this is to say they must have the same type and amount of atoms on the reactant side as there are on the product side. These atoms, however, will be arranged and bonded differently depending on the substance they are found in.

$$PCl_5 + 4\ H_2O \rightarrow H_3PO_4 + 5\ HCl$$

In the balanced equation above, the conservation of mass is illustrated

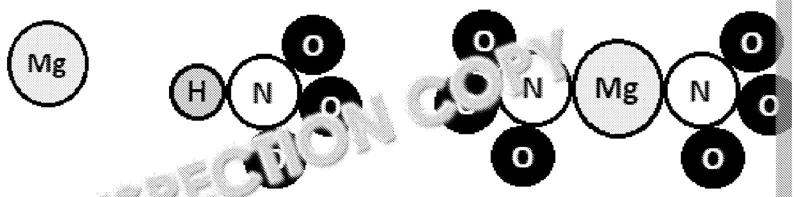
Number present on reactant side	Element	Number presen
1	P	1
5	Cl	5
8	H	8
4	O	4

Stoichiometric – the required relationship between substances in a balanced equation

When balancing equations you need to remember yo numbers in front of each species. These numbers ind relationship between the substances involved in the c the small, subscript numbers, you are changing the b molecules and therefore changing the nature of the c

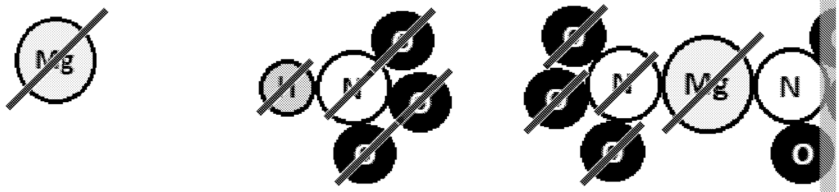
It is important that you consider the substances in their entirety, i.e. as compounds individual atoms. Drawing particle diagrams of the chemical formula can someti

$$Mg + HNO_3 \rightarrow Mg(NO_3) + H_2$$



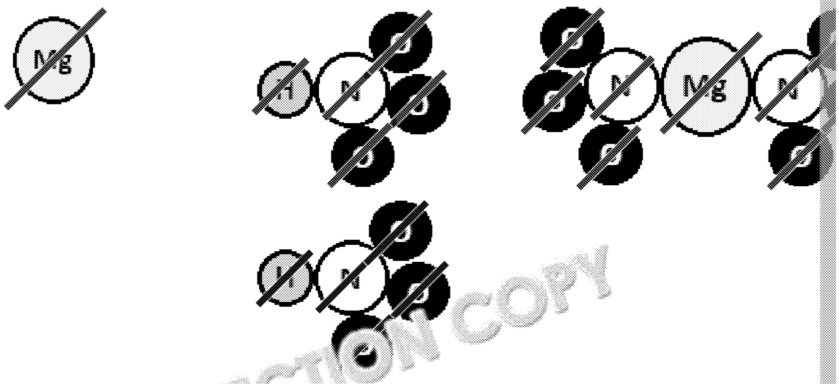
Once you are aware of how many atoms and what types you have on each side of cancelling out any that are accounted for on each side of the equation.

$$Mg + HNO_3 \rightarrow Mg(NO_3) + H_2$$



Once all existing atoms have been accounted for, you then add extra species to he the example above you can see that there is an absence on the reactant side of on and three oxygens. By introducing a second HNO_3 molecule you can address this

$$Mg + HNO_3 \rightarrow Mg(NO_3) + H_2$$



Now all atoms have cancelled each other out and there is no surplus on either side The last thing required is to add in the large numbers showing how many of each s balancing. Using the particle diagrams to help, you can see that only one of each s (HNO_3), was needed. Two nitric acid molecules were required. This equation woul

$$Mg + \mathbf{2}\,HNO_3 \rightarrow Mg(NO_3) + H_2$$

Test you

Balance th

- Na +
- Li + H

Gas volumes

In the previous section you saw that the number of moles of a substance can be r
mass. Whilst this works well for solids, in practice it is very hard to measure the m

Particle theory tells us that gas particles will spread out and fill all the space available to them in a container. As all gases will behave in this way, equal volumes of different gases will contain the same amount of molecules. This means that you indirectly have a method to count the number of molecules in your sample. We can refer to this standard as the **molar volume**.

Generally speaking, most chemical reactions are carried out under a standard set o
These are known as room temperature and pressure (RTP). Under these condition
a volume of 24 dm^3 (24 000 cm^3). At RTP the molar volume of gas is 24 dm^3 mol^{-1}

Converting between volumes of gas and moles

The volume of a gas and the number of moles it contains can be linked using the f

$$\text{moles} = \frac{\text{volume}}{\text{molar volume}}$$

Volume can be measured in either cm^3 or dm^3. When using this equation it is imp
quantities are in the same units.

$$1\ \text{dm}^3 = 1000\ \text{cm}^3$$

When converting from cm^3 to dm^3 you would divide the volume by 1000. If conve
dm^3 to cm^3, you multiply by 1000.

Example 1

How many moles of O_2 gas are present in 360 cm^3, measured at room tempera
(*molar volume is 24 dm^3 mol^{-1}*)

Before carrying out the calculation, convert both volumes into the same units.

$$360\ \text{cm}^3 \rightarrow \text{dm}^3 = \div 1000 \rightarrow 0.360\ \text{dm}^3$$

$$\text{Moles} = \frac{\text{volume}}{\text{molar volume}} = \frac{0.360}{24} = 0.015\ \text{moles}$$

Example 2

What volume, in cm^3, would be occupied by 1.25 moles of methane (CH_4) gas? (

Before carrying out the calculation, convert both volumes into the same units.

$$24\ \text{dm}^3 \rightarrow \text{cm}^3 = \times 1000 \rightarrow 24\ 000\ \text{cm}^3$$

$$\text{Volume} = \text{moles} \times \text{molar volume} = 1.25 \times 24\ 000 = 30\ 0$$

Test your knowledge

- How many moles are present in 56 cm^3 of nitrogen gas?
- What volume would be occupied by 2.5×10^{-3} moles of ethane gas?

Discussion question: if a set mass of solid is heated to vaporise it and the vo
is then measured, how could you determine the relative formula mass of the

Yield

The yield of a reaction is a description applied to how much desired product has b
specific types of yield you are expected to be familiar with:

- Theoretical yield – the expected mass of product, based on the mass of reac
- Actual yield – the mass of product physically obtained at the end of a reactio
- Percentage yield – a comparison between the theoretical yield and the actu

Theoretical yield

If you have a balanced equation and know how much starting reactant you are usi
amount of product you would expect to make.

$$2Mg + O_2 \rightarrow 2MgO$$

In the equation above, the molar relationship between the different substances – an
in – is given by the large coefficients. We can therefore see that for every two moles
moles of magnesium oxide will be produced. It is a 1 : 1 ratio between magnesium a

3 moles of magnesium makes 3 moles of magnesium o
0.125 moles of magnesium makes 0.125 moles of magnesi

The ratio between oxygen and magnesium oxide is 1 : 2.
This means that for every one mole of oxygen used, two moles of magnesium oxide will be produced.

2 moles of oxygen makes 4 moles of magnesium oxide
6 moles of oxygen makes 12 moles of magnesium oxide

As it is impossible to measure out chemicals using the value of moles, an initial conversion of mass in grams to moles is needed followed by converting the amount of moles made back into a mass once the ratio between the substances has been calculated.

Test your kn

2Na

Using the equa
number of mol

- Hydrogen
  water is u
- Sodium h
  moles of s

Example

$2Na + Cl_2 \rightarrow 2NaCl$

Calculate the theoretical yield of sodium chloride produced if 0.142 g of chlorine g

A_r: Na = 23 g mol^{-1}, Cl = 35.5 g mol^{-1}
M_r: NaCl = 58.5 g mol^{-1}

- **Step 1**: Convert mass of chlorine gas into moles
  Moles = $\frac{\text{mass}}{A_r} = \frac{0.142}{71}$ = 0.002 moles
- **Step 2**: Use the balanced equation to predict the moles of sodium chloride
  1 mole of Cl_2 makes 2 moles of NaCl
  0.002 moles of Cl_2 makes 0.004 moles of NaCl
- **Step 3**: Convert moles of sodium chloride into a mass
  Mass = moles × M_r = 0.004 × 58.5 = 0.234 g

Test your knowledge

$$P_4 + 10Cl_2 \rightarrow PCl_5$$

Using the above equation, calculate the theoretical yield of phosphorus(V) penta

- 6.2 g of phosphorus is used
- 2.1 g of chlorine is used

Percentage yield

The percentage yield for a reaction is calculated using the following equation:

$$\text{Percentage yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100$$

The closer to 100 % yield that is achieved, the more successful the reaction has be
for a 100 % yield to be obtained. This is due to:

- impurities in your starting reagents
- unexpected side reactions
- a reversible reaction occurring
- not removing all product from the reaction vessel

Example 1:
When magnesium and chlorine gas are reacted together it is expected you woul
chloride. The reaction itself [illegible] yielded 3.7 g. Calculate the percentage yield.

$$\text{Percentage yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100 = \frac{3.7}{5.4} \times 100 = 68.5\ \%$$

Example 2:
The reaction between aluminium and chlorine has a percentage yield of 76 %. Th
Calculate the amount of aluminium chloride actually obtained.

$$\text{Actual yield} = \frac{\text{percentage yield} \times \text{theoretical yield}}{100} = 7.14\ \text{g}$$

Recap questions: Moles

1 Give balanced equations for the following reactions. (4 marks)
  a) $Mg + HNO_3 \rightarrow Mg(NO_3)_2 + H_2$
  b) $CuCl_2 + NaOH \rightarrow Cu(OH)_2 + NaCl$
  c) sodium + oxygen → sodium oxide
  d) calcium + hydrochloric acid → calcium chloride + hydrogen

2 How many moles are there in each of the following? (4 marks)
  a) 72.0 g of Mg
  b) 4.00 kg of CuO
  c) 39.0 g of $Al(OH)_3$
  d) 20.0 g of $Cu(NO_3)_2$

3 a) What mass of iron is produced when 32 kg of iron(III) oxide is heated
  $Fe_2O_3(s) + 3\ CO(g) \rightarrow 2\ Fe(s) + 3\ CO_2(g)$ (3 marks)
  b) What mass of oxygen is needed to cause [illegible]02 g of ammonia to revert
  $4\ NH_3(g) + 3\ O_2(g) \rightarrow 2\ N_2(g) + 6\ H_2O(g)$ (3 marks)

4 Aluminium is extracted from aluminium oxide in the following reaction:

$$2\ Al_2O_3 \rightarrow 4\ Al + 3\ O_2$$

  a) Calculate the maximum theoretical mass of aluminium that can be mad
  [illegible] (3 marks)
  b) In [illegible] reaction, only 500 g of aluminium was made. Calculate the perc

5 a) 3.53 g of iron reacts with chlorine to form 10.24 g of iron chloride. Fi
  iron chloride. (5 marks)
  b) A compound contains 40.0 g of carbon, 6.7 g of hydrogen and 53.5 g of o
  formula of 180. Find both the empirical formula and the molecular formu

6 a) What volume of oxygen reacts with 100 cm^3 of but-1-ene?
  $C_4H_{8(g)} + 6\ O_{2(g)} \rightarrow 4\ CO_{2(g)} + 4\ H_2O_{(l)}$ (2 marks)
  b) 1 dm^3 of but-1-ene is reacted with 10 dm^3 of oxygen. What volume o
  end? (3 marks)

D1.2 Chemical kinetics

Key points covered

- Use of collision theory and activation energy to explain factors that affect rate of reaction
- Use of Maxwell–Boltzmann distribution curves to explain the effect of temperature, concentration and catalyst on rate of reaction
- Understanding of r
  and rate constants

Chemical reactions

The rate of a chemical reaction is considered to be the speed at which reactants a
formed. The average rate of a reaction can be calculated using:

$$\text{Rate (mol dm}^{-3}\text{ s}^{-1}) = \frac{\text{change in concentration (or reactant or product) (mol dm}^{-3})}{\text{Time (s)}}$$

In your previous science studies you will have been introduced to the fact that the
can have an effect on the rate of a chemical reaction:

- *Concentration* (or *pressure* if considering gaseous reactants) – the higher the concentration/pressure, the faster the rate
- *Temperature* – the higher the temperature, the faster the rate
- *Surface area* (for solid reactants) – the larger the surface area, the faster the ra
- ***Catalysts*** – the use of a **catalyst** will increase the rate

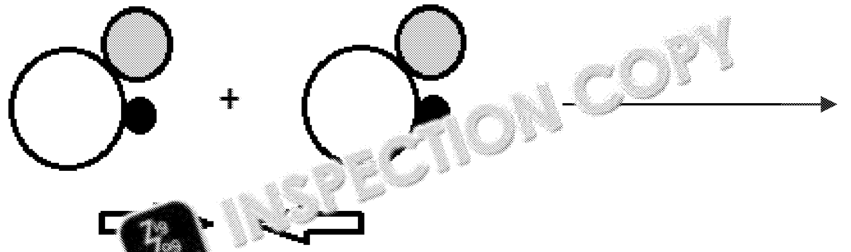
In order to explain the reasons behind each effect above you need to consider the
collision theory.

Collision theory

The chemical idea of collision theory states that in order for a reaction to occur the
into contact with each other and collide. Usually when particles collide, the collisio
particles simply bounce off each other but remain chemically unchanged. In order
to be successful a collision must fulfil two criteria:

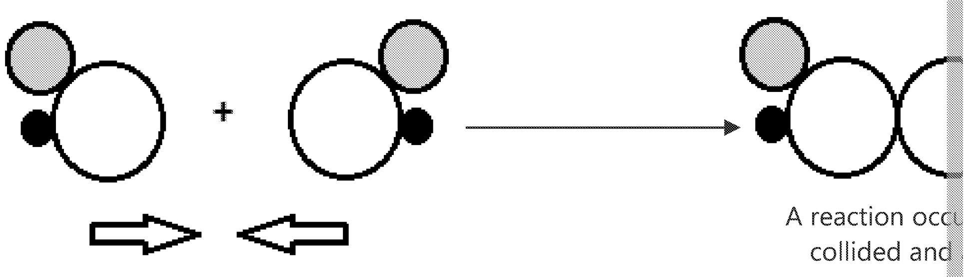
1. The particles collide with the correct orientation
2. The particles collide with sufficient energy to exceed the **activation energy**

Unsuccessful collision



No
two
ma

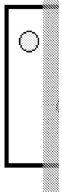
Successful collision



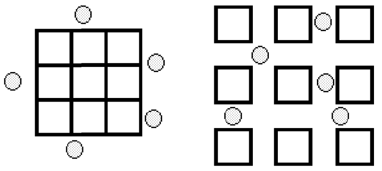
A reaction occ
collided and

Factors affecting rate of reaction and collision theo

Concentration



An increase in concentration of a solution results in a larger amount of particles in the same volume and therefore an increased frequency of collisions. As more collisions are now occurring per unit time, the probability of a successful collision increases and the rate of reaction increases.



Surface area

When a solid reactant is broken up into smalle surface area, and therefore the available spac increases. This means the frequency of collisi and the rate of reaction is faster.

Pressure

An increase in pressure means the particles present are now occupying a smaller volume and, as such, have an increased concentration. The increased rate of reaction is explained in exactly the same way as for concentration.

Temperature

When the temperature of a reaction is increased, the amount of kinetic energy the they move around the reaction faster. This will then increase the rate of reaction i

- The frequency of collisions increases.
- The probability of the energy of the collision meeting or exceeding the activa

Catalysts

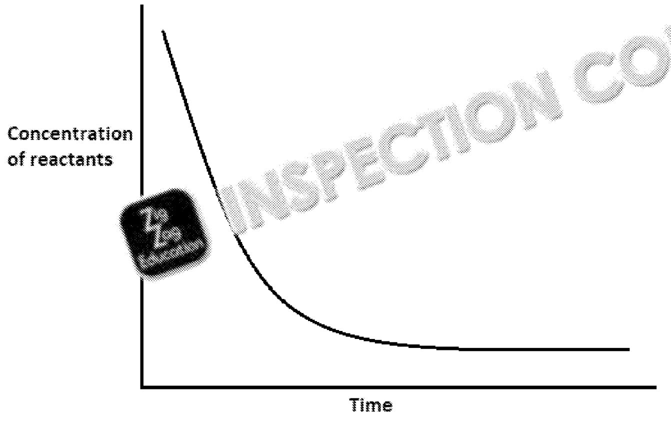
The addition of a catalyst to a chemical reaction will cause the rate of reaction to increase whilst the catalyst itself remains unchanged at the end. Catalysts are specific to their individual reaction and work by providing an alternative route with a lower activation energy.

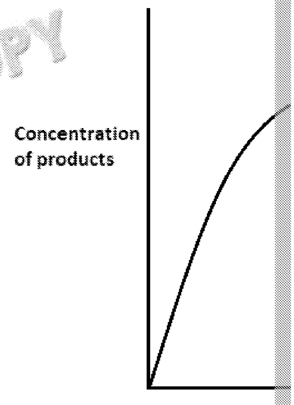
Test your know

1. State four fac rate of reactio
2. Use collision t factor affects

Concentration vs time graphs

The progress of a reaction can be followed by monitoring the decrease in reactant increase in products as a function of time. Graphical representation of this concen data gives a quick insight into how the rate of reaction changes as a reaction prog through its **gradient**. The steeper the **gradient**, the faster the rate.



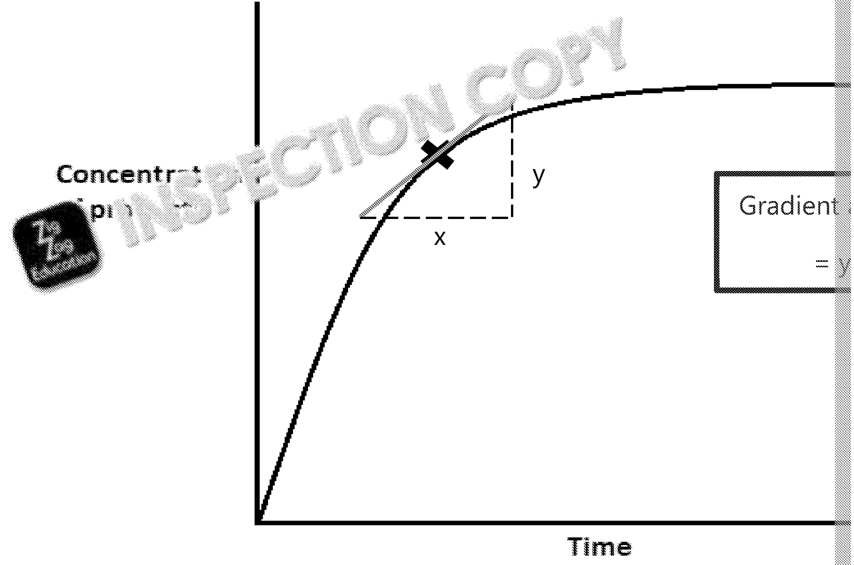


In both graphs you can see an initial high **gradient** as the rate of reaction is very f number of reactant particles present, colliding frequently and therefore a high pro occurring, resulting in a reaction.

As the reaction progresses the **gradient** decreases. This indicates the reaction is b reactant particles being converted into products and less frequent collisions occur

Eventually both graphs have a **gradient** of 0 showing that the reaction has stoppe been used up and no further collisions are taking place.

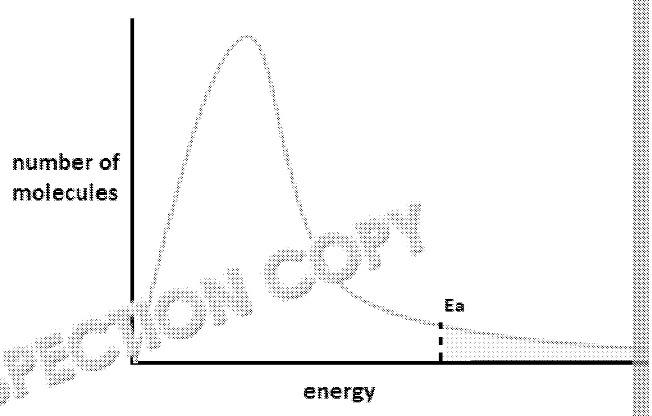
As well as giving an overall insight into how the rate of reaction is changing over ti are able to give information on the rate of a reaction at a given moment within the do this you need to draw a tangent on your graph at the point you want to know t this tangent to calculate the gradient.



Maxwell–Boltzmann distribution curves

The movement of molecules in a gas, liquid or solution is not uniform. Some mole with very low energy whilst others are moving very quickly with high energy. The n at close to the average speed and with average energy.

The spread of molecular energies in a gas sample is called the Maxwell–Boltzmann as follows:

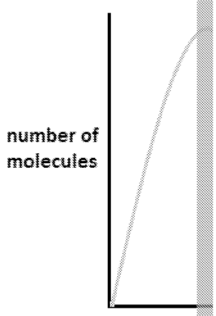


The Maxwell–Boltzmann distribution is marked with a line which represents the act reaction. The shaded area on the graph shows the amount of molecules which hav the activation energy.

The graph itself shows some features of the Maxwell–Boltzmann distribution:

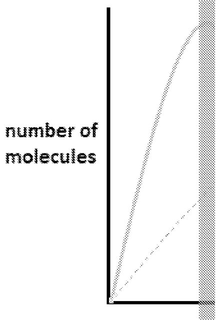
- The curve always starts at the origin (0,0). This is because there will be no mo zero energy.
- The curve will never meet the x-axis. This is because there is no maximum ene
- The area under the curve represents the total number of molecules in the sam

The Maxwell–Boltzmann distribution and catalysts



You have already seen that a catalyst increases the rate of reaction by providing an alternative route with a lower activation energy. In the presence of a catalyst the number of molecules with energy equal to or exceeding the activation energy will increase and the probability of a successful collision will increase.

The Maxwell–Boltzmann distribution and temperature



As temperature is increased the average amount of energy of the molecules in the reaction increases. This causes the distribution of energies on the Maxwell–Boltzmann distribution to shift. There will still be some molecules with low energy values, but far more molecules will be higher in energy than at the previous lower temperature. The curve on the graph will shift, the peak representing the average energy will move to the right-hand side, signifying the increase in average energy, but will also become slightly lower – the area under the curve must be the same as this represents the number of molecules in the reaction.

The amount of molecules with energy that is now equal to or exceeding the activa
resulting in an increased rate of reaction.

The Maxwell–Boltzmann distribution and concentration

Although an increase in concentration causes an increase in rate of reaction, the M
remains unaffected. This is due to the fact that the energy of the molecules and a
unaltered by the change in concentration.

Test your knowledge

1. What does the area under the curve on a Maxwell–Boltzmann distrib
2. Use a Maxwell–Boltzmann distribution to explain why an increase in t
   an increase in rate of reaction.

Rate equations

The rate equation for a chemical reaction is a way of expressing the mathematical r
rate and the concentration of the reactants involved. It will take the form:

$$\text{Rate of reaction} = k\,[A]^m\,[B]^n$$

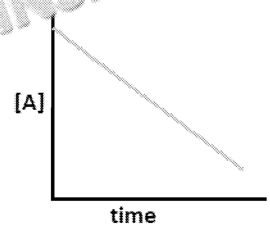
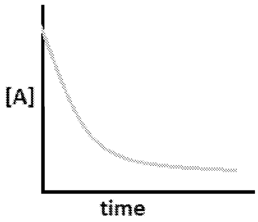
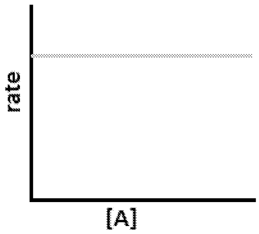
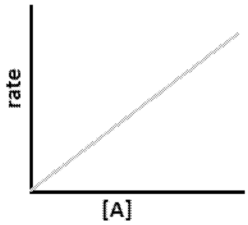
k represents the rate constant – a constant which links the concentration of the rea

[A] / [B] represents the concentration of the individual reactants

m / n represents the order of each individual reactant

Order of reaction

Changing the concentration of a reactant in a reaction will have an effect on the ra reactant is the measure of to what extent the reactant affects the rate of reaction a which the concentration will be raised to in the rate equation. Common orders are the reaction is the sum of all the individual orders.

Order of reaction	**Zero order**	**First order**
Effect of concentration change on rate	If changing the concentration of a reactant has no effect on the rate of reaction then we would say the order for that reactant is zero.	If changing the concentration results in an identical change in rate then we say the order for that reactant is first order, e.g. doubling the concentration results in doubling the rate
Mathematical relationship	Rate ∝ $[A]^0$	Rate ∝ $[A]^1$
Concentration vs time graph		
Rate vs concentration graph		

Orders from experimental data

The order for each reactant can only be determined experimentally and not from th reaction must be set up and then the initial rate measured and recorded as quickly then be repeated, modifying the concentration of one of the reactants and the new

Example:

The reaction between nitrogen dioxide and ozone takes place as follows:

$$2\ NO_2 + O_3 \rightarrow N_2O_5 + O_2$$

A series of reactions were carried out with various concentrations of reactants a were obtained.

Experiment no.	$[NO_2]$ / mol dm	$[O_3]$ / mol dm^{-3}
1	1×10^{-3}	2.5×10^{-3} ×2
2	1×10^{-3}	5.0×10^{-3}
[illegible]	2×10^{-3} ×2	5.0×10^{-3}

Looking at experiments 1 and 2:

The concentration of O_3 is doubled and this results in a doubling of rate.
O_3 is first order.

Looking at experiments 2 and 3:

The concentration of NO_2 is doubled and this results in a doubling of rate.
NO_2 is first order.

The rate equation is rate = k $[NO_2]$ $[O_3]$

Test your knowledge

Reaction number	$[CH_3COCH_3]$ / mol dm^{-3}	$[I_2]$ / mol dm^{-3}	$[H^+]$ / mol dm^{-3}
1	2	1.26	0.248
2	4	1.26	0.248
3	2	2.52	0.248
4	2	5.04	0.496

1. What is the order of reaction with respect to each reagent?
2. Write the rate equation for this reaction.

Determining the rate constant

As previously discussed, the rate constant can be considered as an exchange rate t converted into rate. It is possible to calculate the rate constant for a reaction if yo and orders with respect to each reactant.

Using the reaction between nitrogen dioxide and ozone and the data given in exp constant would be calculated as follows:

Step 1: rearrange the rate equation to make the rate constant, k, the subject:

$$\text{rate} = k\,[NO_2]\,[O_3] \rightarrow k = \frac{\text{rate}}{[NO_2]\,[O_3]}$$

Step 2: substitute in the data from the table for experiment 1 and solve:

$$k = \frac{\text{rate}}{[NO_2]\,[O_3]} = \frac{3.2 \times 10^{-8}}{1 \times 10^{-3} \times 2.5 \times 10^{-3}} = 1.28 \times$$

This value for the rate constant would have been the same regardless of the data s calculation. The rate constant is not affected by concentration, only by temperatu

Test your knowledge

Reaction number	$[CH_3COCH_3]$ / mol dm^{-3}	$[I_2]$ / mol dm^{-3}	$[H^+]$ / mol dm^{-3}
1	2	1.26	0.248
2	4	1.26	0.248
3	2	2.52	0.248
4	2	5.04	0.496

1. Use the data above to determine the rate constant for this set of data.

Determining units of the rate constant

The units of the rate constant depend on the overall order of the reaction itself an determined with each new rate constant calculated.

Units for the rate constant can be calculated by:

- Rearrange the rate equation to make k the subject
- Substitute in the required units; mol dm^{-3} s^{-1} for rate and mol dm^{-3} for conce
- Cancel out any necessary units and determine the overall units for k

For a zero order reaction:

Rate = k $[A]^0 \rightarrow$ k = rate

k = mol dm^{-3} s^{-1} units: mol dm^{-3} s^{-1}

For a first order reaction:

Rate = k $[A]^1 \rightarrow k = \frac{rate}{[A]^1}$

$k = \frac{\cancel{mol\ dm^{-3}}\ s^{-1}}{\cancel{mol\ dm^{-3}}}$ units: s^{-1}

For a second order reaction:

Rate = k $[A]^2 \rightarrow k = \frac{rate}{[A]^2}$

$k = \frac{\cancel{mol\ dm^{-3}}\ s^{-1}}{\cancel{mol\ dm^{-3}}\ mol\ dm^{-3}}$ units: $mol^{-1}\ dm^3\ s^{-1}$

Test your

What woul
following r
1. rate =
2. rate =
3. rate =
4. rate =

Rec[illegible]estions: Chemical kinetics

1 a) The following data is obtained when 50 cm³ of 0.10 mol dm^{-3} hydrochl
calcium carbonate chips at 20 °C: $CaCO_{3(s)} + 2HCl_{(aq)} \rightarrow CaCl_{2(aq)}$ + C

Time (s)	0	10	20	30	40	50
Volume of CO_2 (cm³)	0	30	45	54	59	60

Plot a graph to show this data and include a line of best fit. (3 marks)

b) Sketch and label lines for similar reactions done under the conditions s
- i) 50 cm³ of 0.10 mol dm^{-3} hydrochloric acid reacts with small calciu
at 40 °C (1 mark)
- ii) 50 cm³ of 0.10 mol dm^{-3} hydrochloric acid reacts with calcium ca
20 °C (1 mark)
- iii) 25 cm³ of 0.10 mol dm^{-3} hydrochloric acid reacts with small calciu
at 20 °C (2 marks)

c) Explain the reasons behind the new graph curves you have drawn in p

2 a) Sketch the Maxwell–Boltzmann distribution for a sample of particles i
Ensure you correctly label both axes. (4 marks)

b) On the same axis sketch a new distribution to show the same gas sam

c) Use a Maxwell–Boltzmann distribution to help explain how a catalyst c
reaction. (3 marks)

3 Sodium reacts with chlorine to form sodium chloride. 2 Na + $Cl_2 \rightarrow$ 2 Na
A series of experiments was carried out to determine the rate equation fo

Experiment Number	**[Na] (mol dm³)**	**[Cl_2] (mol dm³)**	**Initi**
1	0.2	0.3	
[illegible]	0.2	0.15	
3	0.1	0.6	
4	0.3	0.15	
5	0.1	0.3	

a) Determine and explain the order with respect to
- i) Na (2 marks)
- ii) Cl_2 (2 marks)

b) State the rate equation. (1 mark)

c) Determine the value of the rate constant. (3 marks)

d) Determine the units of the rate constant. (2 marks)

D1.3 Chemical energetics

Key points covered

- Use of enthalpy profile diagrams to explain exothermic and endothermic reactions
- Use of the terms standard conditions, enthalpy change of combustion, of formation and of reaction
- Use of Hess cycl changes indire

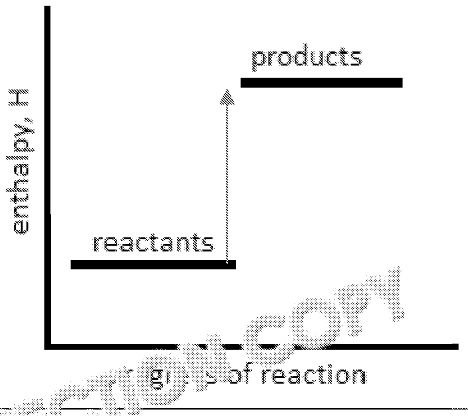
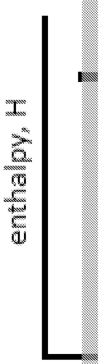
Enthalpy change

Enthalpy, H, can be considered as the amount of heat energy stored inside a **chemical system**. It is also sometimes thought of as the energy stored within the bonds of a chemical.

In a chemical reaction it is usually the case that the reactants and the products wil other. It is impossible to directly measure enthalpy, but you can measure enthalp done experimentally by monitoring the energy transfer between the **system** and th difference in these enthalpies is the enthalpy change. An enthalpy change can be e depending on whether the products have more or less enthalpy than the reactants.

If enthalpy change is positive, then heat energy has moved from the environment i reaction is described as endothermic.

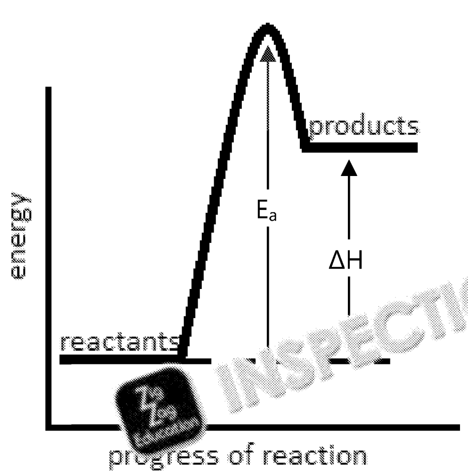
If enthalpy change is negative, then heat energy has moved from the **system** into t reaction is described as exothermic.

Type of enthalpy change	**Endothermic**	
Effect on environment	Surroundings lose energy and the external temperature decreases	Surroundi external t
Energy level diagram		
Examples	Photosynthesis, sports injury packs	Combusti

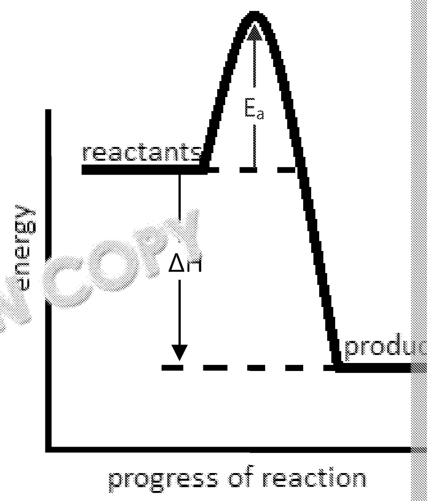
Reaction profile diagrams

These are graphs which show the changes in energy throughout the progress of a re
are able to determine the activation energy, enthalpy change and nature of the reac

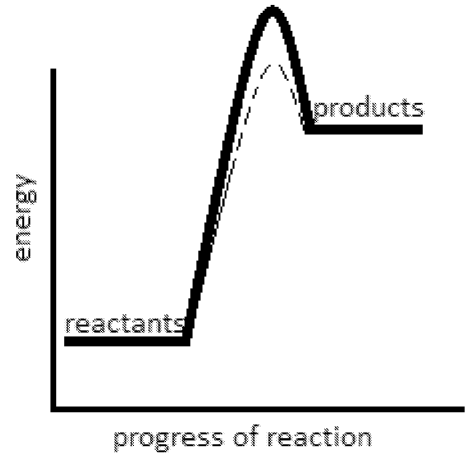
Endothermic



Exothermic



As previously covered, catalysts increase the rate of reaction by providing an altern
activation energy. This too can be shown on a reaction profile diagram as seen bel



The thinner, dotted line shows the energy changes for this reaction once a catalyst
change is the same, but the activation energy peak has been lowered.

Standard enthalpy changes

The enthalpy for a reaction will change slightly based on the conditions under which it is carried out. In order to ensure consistency, most enthalpy changes are quoted as the values obtained under **standard conditions**. When data that has been calculated using standard conditions is being given, it will be accompanied by a standard sign, **⦵.**

The conditions stated as standard conditions have been chosen as they are close t
laboratory. They are as follows:

- Standard temperature: 298 K (25 °C)
- Standard pressure: 1 atm
- Standard concentration: 1 mol dm^{-3}
- Standard state: the physical state you would find a state in at the conditions gi

Standard enthalpy change of formation

This is the enthalpy change when one mole of a substance is formed from its const conditions, with all substances in their standard states, $\Delta_f H^{\ominus}$.

According to this definition, the enthalpy of formation for any element must be 0 a

Balanced equations that show enthalpy of formation reactions for compounds will to ensure that only one mole of compound is formed as per the definition above.

$Ca_{(s)} + C_{(s)} + 1\frac{1}{2}O_{2(g)} \rightarrow CaCO_{3(s)}$ or $Fe_{(s)} + 1\frac{1}{2}Cl_{2}$

Enthalpy change of combustion

This is the enthalpy change when one mole of substance is completely burned in ex conditions, $\Delta_c H^{\ominus}$.

When any substance reacts in oxygen the products formed are known as oxides.

As with enthalpy of formation equations, balanced equations that show enthalpy o sometimes contain fractions to ensure it is only one mole of fuel being burned. Fo

$C_4H_{10} + 6\frac{1}{2}O_2 \rightarrow 4CO_2 + 5H_2O$ or $C_3H_7OH + 4\frac{1}{2}O_2$

Enthalpy change of reaction

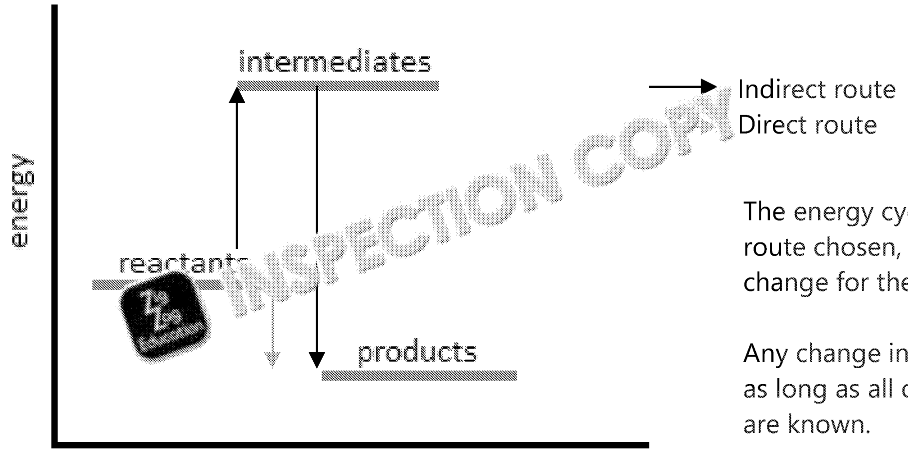
This is the enthalpy change when a chemical reaction occurs in the molar quantitie standard conditions, $\Delta_r H^{\ominus}$.

Enthalpy of reaction always refers to the specific reaction stated in the equation. T changes, the enthalpy value will too. For example:

$2H_2 + O_2 \rightarrow 2H_2O$ $\Delta_r H^{\ominus} = 570 \text{ kJ mol}^{-1}$ but $H_2 + \frac{1}{2}O_2 \rightarrow H_2O$

Hess's law

In some cases enthalpy changes can be determined directly from experimental dat that the enthalpy change cannot be determined experimentally and an energy cycl Hess's law is based on the conservation of energy and states that the overall enthal independent of the route taken, as long as the start and end points are the same. cycle.



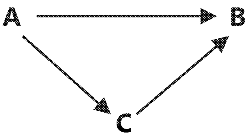
The energy cycle s route chosen, dire change for the ov

Any change in the as long as all othe are known.

Hess's law using combustion data

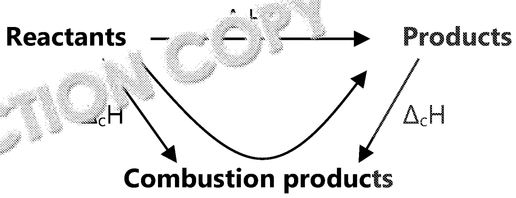
If you are provided with standard enthalpy change of combustion values you can u
enthalpy cycle for a given reaction.

Hess's law states that the enthalpy change is independent of the route taken.



For example, the energy change in going from A → B

When you are given combustion data to use, the enthalpy cycle you would draw ta



Using this cycle you can see that Δ_rH of the direct route is equivalent to Δ_cH of the

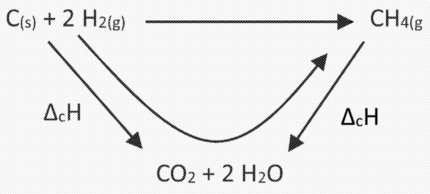
Δ_rH = [Σ Δ_cH of the reactants] – [Σ Δ_cH of the prod

Example:

Calculate the enthalpy change for the reaction shown using the standard enthal

$C_{(s)} + 2\ H_{2(g)} \rightarrow CH_{4(g)}$

	$C_{(s)}$	$H_{2(g)}$
Δ_cH / kJ mol^{-1}	-393	-286



Δ_rH = [Σ Δ_cH of the reactants] – [Σ
Δ_rH = [Δ_cH C + 2(Δ_cH H_2)] – [Δ_cH C
Δ_rH = [-393 + 2(-286)] – [-890]
Δ_rH = [-393 + -572] – [-890]
Δ_rH = -965 – -890
Δ_rH = -75 kJ mol^{-1}

Test your knowledge

1. Calculate the enthalpy for the reaction shown below using the given standard
   $2C + 3\ H_2 + ½\ O_2 \rightarrow C_2H_5OH$ Δ_cH $C_{(s)}$ = -393, $H_{2(g)}$ = -286, C_2H
2. Calculate the enthalpy of formation of pentane, $C_5H_{12(l)}$, using the enthalpies
   Δ_cH $H_{2(g)}$ -286; $C_{(s)}$ -393; $C_5H_{12(l)}$ -3509 kJ m

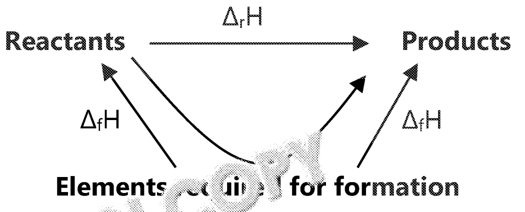
   HINT: *Begin by writing the equation that shows the enthalpy of for*

Hess's law using formation data

If you are provided with standard enthalpy change of formation values you can us cycle for a given reaction.

Hess's law states that the enthalpy change is independent of the route taken.

When you are given formation data to use, the enthalpy cycle you would draw tak



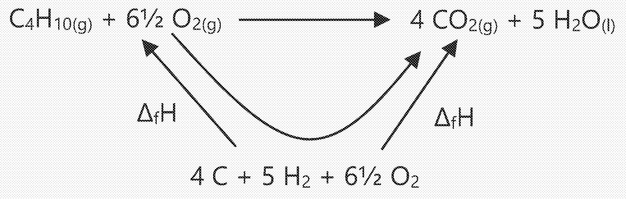
Using this cycle you can see that Δ_rH of the direct route is equivalent to $-\Delta_fH$ of th
This can be written mathematically as

Δ_rH = [Σ Δ_fH of the products] – [Σ Δ_fH of the react

Example:
Calculate the enthalpy change for the reaction shown using the standard enthal

$$C_4H_{10(g)} + 6½\ O_{2(g)} \rightarrow 4\ CO_{2(g)} + 5\ H_2O_{(l)}$$

	$C_4H_{10(g)}$	$CO_{2(g)}$	
Δ_fH / kJ mol^{-1}	-125	-393	



Δ_rH = [Σ Δ_fH of the prod
Δ_rH = [4(Δ_fH CO_2 + 5(Δ_cH
Δ_rH = [4(-393) + 5(-286)]
Δ_rH = [-1572 + -1430] – [
Δ_rH = -3002 – -125
Δ_rH = -2877 kJ mol^{-1}

Test your knowledge

1. Calculate the enthalpy change for the reactions shown below using the give of formation.
   a) $CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$ Δ_fH: CH_4 = -75, CO_2 = -393, H_2O
   b) $3\ Fe + 4\ H_2O \rightarrow 4\ H_2 + Fe_3O_4$ Δ_fH: H_2O = -242, Fe_3O_4 = -1117 k

Recap questions: Chemical energetics

1 a) Sketch an energy level diagram for this reaction:
$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$ ΔH = -890 kJ mol^{-1} (3 marks)
b) Draw a labelled arrow on your energy diagram to show the overall en
c) Draw a labelled arrow on your energy diagram to show the activation

2 a) Write an equation that represents the enthalpy of combustion for etha
b) Write an equation that represents the enthalpy of formation for sodiu

3 a) Calculate the enthalpy of combustion of propane, $C_3H_{8(g)}$, given the fo
Δ_fH $C_3H_{8(g)}$ = -104 kJ mol^{-1} Δ_fH $CO_{2(g)}$ = -394 kJ mol^{-1} Δ_fH H
b) Calculate the enthalpy of formation of propan-1-ol, $C_3H_7OH_{(l)}$, given t
Δ_cH $C_3H_7OH_{(l)}$ = -2010 kJ mol^{-1} Δ_cH $C_{(s)}$ = -394 kJ mol^{-1} Δ_cH

D1.4 Chemical equilibrium

Key points covered

- Definition and features of dynamic equilibrium
- Use of Le Chatelier's principle to predict the effect of changes to the position of equilibrium
- Calculation of equi concentrations or

Dynamic equilibrium

When a reversible reaction is occurring in a **closed system** you will reach a point where the rate of the forward reaction is equal to the rate of the backward reactio

Under these conditions on a large scale there appears to be no change to the over composition of the mixture. This is known as dynamic equilibrium. The concentrat will change at the beginning of the reaction, but only until equilibrium is reached.

Do not confuse this idea with the idea of concentrations of all substances being eq all equivalent to each other. The reactants may be dominant or there could be a la The relative amounts of reactants and products in a reaction can be described by st equilibrium. If equilibrium lies to the left then the reactants are dominant, wherea amounts of product if equilibrium lies to the right.

> **Le Chatelier's principle** – if a change is made to a system at equilibrium the position of equilibrium will shift to counteract the effect of this change

Le Chatelier's principle

Le Chatelier's principle can be used to pre conditions of a reaction will impact and ch Factors that can be considered using Le C concentration, pressure and temperature.

Concentration

Equilibrium will shift to counteract the effect of changing concentration in the follo

Change in concentration	Effect on equilibr
Increase in concentration of a reagent	Equilibrium will shift (left or right) to favour th reagent is used up
Decrease in concentration of a reagent	Equilibrium will shift (left or right) to favour th reagent is produced

Example: $N_{2(g)} + 3\,H_{2(g)} \rightleftharpoons 2\,NH_{3(g)}$

If the concentration of hydrogen is increased, equilibrium will shift to the right, reaction, to use up the hydrogen and counteract the increase in concentration.

If the concentration of ammonia is decreased, equilibrium will shift to the right, reaction, to produce more ammonia and counteract the decrease in concentrati

Test your knowledge

Chromate ions (CrO_4^{2-}) are yellow in colour. Dichromate ions ($Cr_2O_7^{2-}$) are orang takes place: $CrO_4^{2-} + 2H^+ \rightleftharpoons Cr_2O_7^{2-} + H_2O$ and is allowed to reach equilibrium.

a) If acid is added to an equilibrium mixture, will it become more yellow or mo Explain your answer.

b) If alkali is added to an equilibrium mixture, will it become more yellow or m Explain your answer.

Pressure

When considering the effect of pressure on a system at equilibrium, you are only c
Equilibrium will shift in the following ways:

Change in pressure	Effect on equilibri
Increase in pressure	Equilibrium will shift (left or right) to favour the amount of gas molecules are produced
Decrease in pressure	Equilibrium will shift (left or right) to favour the amount of gas molecules are produced

Example: $N_{2(g)} + 3\,H_{2(g)} \rightleftharpoons 2\,NH_{3(g)}$

If the pressure is increased, equilibrium will shift to the right, favouring the forward reaction, to produce the smaller amount of gas molecules and reduce the pressure.

If the pressure is decreased, equilibrium will shift to the left, favouring the backward reaction, to produce a greater amount of gas molecules and increase the pressure.

Test your knowledge

1. Sulfur trioxide is made b
$2\,SO_{2(g)} + O_{2(g)} \rightleftharpoons 2\,SO_3$
exothermic. Explain wh
sulfur trioxide if the pres
2. Iodine trichloride breaks
monochloride and chlor
$ICl_{3(g)} \rightleftharpoons ICl_{(g)} + Cl_{2(g)}$ T
endothermic. Explain w
of chlorine if the pressu

Temperature

Equilibrium will shift to counteract the effect of changing temperature in the following ways:

Change in temperature	Effect on equilibrium
Increase in temperature	Equilibrium will shift (left or right) to favour the reaction which is **endothermic**
Decrease in temperature	Equilibrium will shift (left or right) to favour the reaction which is **exothermic**

Example: $N_{2(g)} + 3\,H_{2(g)} \underset{endo}{\overset{exo}{\rightleftharpoons}} 2\,NH_{3(g)}$

If the temperature is increased, equilibrium will shift to the left, favouring the backward reaction, which is endothermic.

If the temperature is decreased, equilibrium will shift to the right, favouring the forward reaction, which is exothermic.

Test your knowledge

1. Sulfur trioxide is made b
$2\,SO_{2(g)} + O_{2(g)} \rightleftharpoons 2\,SO_3$
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endothermic. Explain w
of chlorine if the temper

Catalysts

Catalysts have no effect on the position of equilibrium. A catalyst is a substance w
reaction. Catalysts increase the rate of the forward reaction and backward reactio
although they cause equilibrium to be reached more quickly, the position of equili

The equilibrium constant

The exact position of equilibrium can be determined using the equilibrium consta
constant also gives a quick insight into the composition of the equilibrium mixture

- An equilibrium constant >1 indicates that the mixture contains a higher propo
- An equilibrium constant of 0 indicates that the mixture contains a 50 : 50 mi
- An equilibrium constant <1 indicates that the mixture contains a higher propo

The equilibrium constant, K_c

The equilibrium constant can be linked to the concentration of each substance in a equilibrium expression.

For a given reaction

$$aA + bB \rightleftharpoons cC + dD \qquad K_c = \frac{[C]^c\,[D]^d}{[A]^a\,[B]^b}$$

[ ] = concentration of named substance at equilibriu
a, b, c, d = moles of named substance according to the balanced c

Example:

Write the equilibrium expression for the following reaction. $N_{2(g)} + O_{2(g)} \rightleftharpoons 2NO_{(g)}$

$$K_c = \frac{[C]^c\,[D]^d}{[A]^a\,[B]^b} \qquad K_c = \frac{[NO_{(g)}]^2}{[N_{2(g)}]\,[O_{2(g)}]}$$

The equilibrium expression will only contain substances that can have a change
solids and liquids are excluded from the expression.

The equilibrium expression, K_p

When working with gases it can be very difficult to measure their concentration an with their pressures. As the square brackets present in the K_c equilibrium expressio equilibrium expression when referring to pressures will take a slightly different forn

For a given equation

$$aA_{(g)} + bB_{(g)} \rightleftharpoons cC_{(g)} + dD_{(g)} \qquad K_p = \frac{p(C)^c\,p(D)^d}{p(A)^a\,p(B)^b}$$

p = the equilibrium partial pressure of the named subs

As only gases are affected by pressure, all other states of matter are ignored when constructing K_p expressions.

Test your knowle

- Write the K_c equilibri
  the following rea
  a) $CH_{4(g)} + H_2C$
  b) $2\,NO_{2(g)} \rightleftharpoons N$

2. Write the K_p equi
   following reactio
   a) $PCl_{5(g)} \rightleftharpoons PC$
   b) $2\,O_{3(g)} \rightleftharpoons 3\,C$

Calculations using K_c

If you know the equilibrium concentrations of each substance in the reaction it is simply a case of substituting these into the equilibrium expression and then solving for K_c. As with rate constants, the units for K_c have to be determined in each individual case, using the indices laws.

Example:

Calculate K_c for the following reaction. Analysis of the mixture at equilibrium sh
$SO_2 = 0.058$, $O_2 = 0.343$ and $SO_3 = 0.230$ mol dm^{-3}.

$$2\,SO_{2(g)} + O_{2(g)} \rightleftharpoons 2\,SO_{3(g)}$$

Step 1: write the K_c expression

$$K_c = \frac{[SO_3]^2}{[SO_2]^2\,[O_2]}$$

Step 2: substitute in equilibrium concentrations and solve

$$K_c = \frac{0.230^2}{0.058^2 \times 0.343} = \frac{0.0529}{0.00115} = 46$$

Step 3: determine the units for K_c

$$K_c = \frac{\cancel{(mol\,dm^{-3})^2}}{\cancel{(mol\,dm^{-3})^2}\,mol\,dm^{-3}} = mol^{-1}dm^3$$

$K_c = 46\ mol^{-1}dm^3$

Sometimes, rather than an equilibrium concentration, the information you are given may refer to an amount of moles at equilibrium. In this case, before substituting your values in, you would need to determine the concentration using the equation: concentration = moles ÷ volume (dm^3)

It is also possible to determine the concentration of a substance at equilibrium if you are provided with the value for the equilibrium constant. In this scenario, you would begin by rearranging the K_c expression to make the concentration of the unknown the subject.

Test your kn

When PCl_5 is h
system the fol
PC

Analysis of the
to contain 0.05
PCl_3 and 0.5 m
determine the

Example:

In the following reaction: $H_{2(g)} + I_{2(g)} \rightleftharpoons 2\ HI_{(g)}$ Kc = 54.1

It was found, when analysed, that the equilibrium mixture of H_2 had a concentration of 4.80 mol dm^{-3} and HI a concentration of 3.53 mol dm^{-3}. Use this data to determine what the concentration of I_2 must have been.

Step 1: write the K_c expression

$$K_c = \frac{[HI]^2}{[H_2]\,[I_2]}$$

Step 2: rearrange to make $[I_2]$ the subject

$$[I_2] = \frac{[HI]^2}{[H_2]\,K_c}$$

Step 3: substitute in known values and solve

$$[I_2] = \frac{3.53^2}{4.80 \times 54.1} = \frac{12.46}{259.68} = 0.048 \text{ mol dm}^{-3}$$

The final type of K_c calculation, and the most challenging, is when you are supplie
regarding equilibrium concentrations. In this situation you would need to use the
determine the number of moles at concentration before using these value in the s
'RICE' table (shown below) is the easiest way to do this.

Example:

The reaction below was set up and allowed to reach equilibrium. 2 moles of CH
CH_3CH_2OH was used. The mixture was analysed at equilibrium and it was foun
$CH_3COOCH_2CH_3$ had been formed. Determine the K_c value.

$$CH_3COOH + CH_3CH_2OH \rightleftharpoons CH_3COOCH_2CH_3 + H_2O$$

	CH_3COOH	CH_3CH_2OH	CH_3CO
Ratio using the balanced equation	1	1	
Initial number of moles	2	1	There moles c present reacti
Change in concentration	- 0.845 The ratio from the equation shows that the change in moles will be the same, but will decrease as it is a reactant	- 0.845 The ratio from the equation shows that the change in moles will be the same, but will decrease as it is a reactant	+ 0
Equilibrium number of moles	2 – 0.845 = 1.155	1 – 0.845 = 0.155	0.

The equilibrium number of moles can now be used in the usual way.

Test your knowledge

When 4 moles of PCl_5 is heated in a 3 dm^3 closed system the following reaction o

$$PCl_{5(g)} \rightleftharpoons PCl_{3(g)} + Cl_{2(g)}$$

Analysis of the equilibrium mixture showed it to contain 2.4 moles of Cl_2. Use th
of K_c and its units.

Calculations involving K_p

When working with K_p, instead of concentration you are required to substitute into the reaction the **partial pressures** of the gases involved. This requires you to know the **mole fraction** of each gas.

Due to the fact that as long as the temperature and pressure is the same, the same volume of two different gases will contain the same number of moles, you can determine the mole fraction of a named gas using the following equation:

$$\text{mole fraction of gas X} = \frac{\text{number of moles of gas X}}{\text{total number of moles of gas in the mixture}}$$

The sum of all mole fractions in a mixture of gases must equal 1.

Example:

Earth's atmosphere is made up of 78 % nitrogen, 21 % oxygen and 1 % other ga
fraction of each gas present in the atmosphere.

$$N_2 = \frac{\text{number of moles of gas X}}{\text{total number of moles of gas in the mixture}} = \frac{78}{100} = 0.78$$

$$O_2 = \frac{\text{number of moles of gas X}}{\text{total number of moles of gas in the mixture}} = \frac{21}{100} = 0.21$$

$$\text{others} = \frac{\text{number of moles of gas X}}{\text{total number of moles of gas in the mixture}} = \frac{1}{100} = 0.01$$

Sum of mole fractions = 0.78 + 0.21 + 0.01 = 1.00

Once the mole fraction has been determined, the partial pressure of each gas can b
following equation:

partial pressure of gas X = mole fraction of gas X × total pressur

The sum of all partial pressures in a mixture of gas must equal the same as the ove

Example:

If a sample of Earth's atmosphere was placed under a pressure of 175 kPa, deter
each gas p[illegible]

N_2 = mole fraction of gas X × total pressure of the system = 0.78 × 175 = 136.5 k

O_2 = mole fraction of gas X × total pressure of the system = 0.21 × 175 = 36.75 k

others = mole fraction of gas X × total pressure of the system = 0.01 × 175 = 1.7

Sum of partial pressures = 136.5 + 36.75 + 1.75 = 175

These partial pressures could then be substituted into the K_p equilibrium expressi
determine the value of K_p.

Test your knowledge

$$2\ SO_{2(g)} + O_{2(g)} \rightleftharpoons 2\ SO_{3(g)}$$

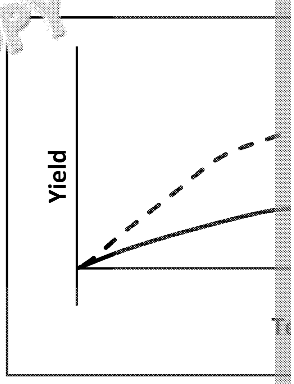
5 moles of SO_2 are combined with 4 moles of O_2 and allowed to reach equilibriu mixture showed that there was 1.5 moles of SO_3. The total pressure in the syster of K_p and its units.

***HINT:** Begin by determining the number of moles of each substance at equilibriu use these values to determine the mole fraction and partial*

Interpretation of yield graphs

Graphs showing the yield of reactions produced via different conditions can be interpreted to give information about the reaction itself. For example, in the graph shown here you can see that the higher the temperature the greater the yield.

From this you are able to infer that the reaction must be endothermic in the forward direction. This is due to higher temperatures causing equilibrium to shift to the right and yield increasing.



Finally, this graph also shows that the lower the pressure the higher the yield. Gra to ensure all possible information has been obtained from them.

? *Recap questions: Chemical equilibrium*

1. What is meant by the following terms?
   a) Dynamic equilibrium (1 mark)
   b) Closed system (1 mark)
2. Explain how the following changes affect the position of equilibrium:
   a) Increasing temperature (2 marks)
   b) Decreasing pressure (2 marks)
   c) Adding a catalyst (2 marks)
3. Hydrogen can be made via the following process: $CO_{(g)} + H_2O_{(g)} \rightleftharpoons CO_{2(g)}$ +
   a) If the temperature of this equilibrium was decreased, what would hap and why? (2 marks)
   b) If the pressure of this equilibrium was increased, what would happen t why? (2 marks)
4. For the equations given below, write the K_c equilibrium constant expressio
   a) $2SO_3 \rightleftharpoons 2SO_2 + O_2$ (2 marks)
   b) $PCl_3 + Cl_2 \rightleftharpoons PCl_5$ (2 marks)
5. 1.9 moles of hydrogen was reacted with 1.9 moles of iodine and then left t equilibrium mixture was sampled it was found to contain 3 moles of hydrog occurs: $H_{2(g)} + I_{2(g)} \rightleftharpoons 2\ HI_{(g)}$
   a) Determine the K_c expression for this reaction. (1 mark)
   b) Determine the equilibrium concentration of each chemical. (2 marks)
   c) Calculate the value for K_c and give its units. (3 marks)
6. For the equations given below write the K_p equilibrium constant expressio (assume all pressures are measured in Pa).
   a) $CO_{(g)} + 3\ H_{2(g)} \rightleftharpoons CH_{4(g)} + H_2O_{(g)}$ (2 marks)
   b) $2\ O_{3(g)} \rightleftharpoons 3\ O_{2(g)}$ (2 marks)
7. An equilibrium is set up between three gases, A, B and C, as follows: $2\ A_{(g)}$ there are 2.0 moles of A, 2.5 moles of B and 1.5 moles of C. The total pre value of K_p. (12 marks)

D1.5 Applications of chemical kinetics, e equilibrium in industry

! **Key points covered**

- Use of the idea of chemical compromise when determining ideal conditions for ch

Two important chemical industries which produce chemicals on a large scale are th process. As the aim of these industries is to produce the highest amount of produ important they carefully select the conditions they operate under carefully.

The Haber process

The Haber process provides the synthesis of ammonia, a highly valuable chemical u fertilisers, pharmaceuticals and explosives.

Ammonia is produced via a reversible reaction, combining nitrogen with hydrogen

$$N_{2(g)} + 3\ H_{2(g)} \rightleftharpoons 2\ NH_{3(g)}$$

Temperature

Due to Le Chatelier's principle, in order to produce the maximum yield of ammonia th be carried out at is as low as possible. This is due to the forward reaction being exoth low temperature results in equilibrium shifting to the right-hand side, favouring the fo

However, low temperature would result in a very low rate of reaction, due to the pa therefore very unlikely to be involved in a successful collision.

Therefore a compromise temperature of 450 °C is used to ensure a suitable yield o reasonable rate.

Pressure

Due to Le Chatelier's principle, in order to produce the maximum yield of ammonia t be carried out at is as high as possible. This is due to the forward reaction producing gas and therefore a high pressure results in equilibrium shifting to the right-hand sid

However, high pressures are very expensive and dangerous to create and maintain.

Therefore a compromise pressure of 200 atm is used to ensure a suitable yield of a reasonable rate and with good profits.

Catalyst

In order to increase overall rate of reaction an iron catalyst is added.

? ***Recap questions: Applications of chemical kinetics, energetics a***

1 The contact process is used to synthesise sulfuric acid via the following reac It is exothermic in the forward direction.
   a) Describe and explain the conditions required to ensure the highest yie
   b) 'Due to a high K_p value, a pressure of only 1 atm is used.' Explain this benefits of using a low pressure. (3 marks)
   c) Why is a compromise temperature of 450 °C used? (1 mark)
   d) The contact process uses vanadium(V) oxide as a catalyst.
      i. Explain what this does to the position of equilibrium. (1 mark)
      ii. Explain what this does to rate. (2 marks)

D1.6 Applications of green chemistry

Key points covered

- Use of atom economy when determining reaction routes
- Discussion of ideas industries are as g

Sustainable chemistry

The chemical industry is having to readjust its working practices to become more **sustainable**. We cannot continue to operate in a manner where resources are bei used up quicker than they can be replenished, and it is important to ensure we pre resources and the environment for future generations.

There are five main ways industry can consider when trying to adopt more greene

1. **Minimise waste by using high atom economy reactions.** Greener processe in chemistry aim to operate via reactions that have a high **atom economy**.
2. **Use as few chemicals as possible and don't use hazardous chemicals.** Dangerous chemicals in chemical processes are switched out for less risky alte products also need to be considered and should also be designed to be as ha
3. **Use renewable resources (i.e. from plants) whenever possible.** This allows materials and results in a more sustainable process.
4. **Use alternative energy resources such as solar energy, rather than non-re** fossil fuel consumption is beneficial in two main ways: it cuts down on the pro emissions and preserves a valuable resource for future generations.
5. **Ensure that any waste products are non-toxic and either recyclable or bi** products will be broken down by natural processes and this minimises the am further treatment after their production. Recycling any unwanted products wi

Calculating atom economy

Atom economy is calculated using the following equation:

$$\% \text{ atom economy} = \frac{\text{mass of desired products}}{\text{total mass of products}} \times 1$$

Example: the production of hydrogen by reacting methane with steam:

$CH_4 + H_2O \rightarrow 3\,H_2 + CO$

2 g mol^{-1} $\quad 28\text{ g mol}^{-1}$

Total mass of hydrogen produced = $3 \times 2\text{ g mol}^{-1} = 6\text{ g}$

Total mass of all products produced = 6 g (hydrogen) + 28 g (carbon monoxide)

6 g out of the 34 g of product produced is useful.

$$\% \text{ atom economy} = \frac{\text{mass of desired products}}{\text{total mass of products}} \times 100 = \frac{6}{34} \times 100 = 17.6\ \%$$

Test your knowledge

1. Calculate the atom economy when producing sodium through the electroly

   $2\,NaCl \rightarrow 2\,Na + Cl_2$

2. Calculate the atom economy when making oxygen from hydrogen peroxide.

   $2\,H_2O_2 \rightarrow 2\,H_2O + O_2$

Catalysts

The use of catalysts results in a faster reaction at lower temperatures and pressure economic benefits, in terms of lower energy costs, and environmental benefits, in t emissions due to lower consumption of fossil fuels.

Use of a catalyst can result in new routes being developed. These routes could inc economies and therefore less waste is produced.

Enzymes are ideal to use as catalysts. They produce very specific products and du operate around room temperature and low pressures, which again are all valuable greener procedures.

Recap questions: Applications of green chemistry

1 Explain how a catalyst can save money whilst reducing the environmental i proc (4 marks)

2 Ethanol can be produced via two alternative processes:

Process 1: Fermentation of glucose to produce ethanol: $C_6H_{12}O_{6(}$
Sugar or starch is dissolved in water and yeast is added. The mixture is th between 25 °C and 35 °C with the absence of oxygen for a few days.

Process 2: Hydration of ethane: $C_2H_{4(g)} + H_2O_{(g)} \rightarrow C_2H_5OH_{(g)}$
A mixture of ethene and steam is passed over a hot catalyst of phosphoric approximately 300 °C. The pressure used is 60 atm.

a) What is the atom economy of process 1? Give your answer to 3 s.f. (
b) Give **two** advantages of using process 1 over process 2. (2 marks)
c) Give **two** disadvantages of using process 1 over process 2. (3 marks)

E: Organic chemist

E1.1 Key terms

Key points covered

- Use of the terms saturated and unsaturated when describing hydrocarbons
- Defining key terms used in organic chemistry
- Giving general f homologous se

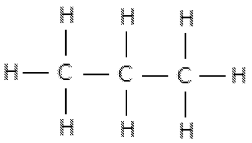
Organic chemistry

Organic chemistry is the study of carbon-based compounds. Carbon is a unique e stable bonds with other atoms, allowing for a vast diversity of molecules. These m ones like methane (CH_4), to complex structures like DNA, which carries your geneti

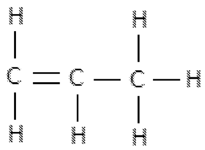
Carbon's ability to form four bonds makes it incredibly versatile. It can bond with c chains and rings, leading to an almost infinite variety of structures. This versatility i organic molecules.

Hydrocarbons

Hydrocarbons are organic compounds composed exclusively of hydrogen and carbon atoms. They form the simplest type of organic molecule and are the fundamental structures upon which more complex organic compounds are built. Hydrocarbons can be categorised into different types based on the types of bonds between the carbon atoms: alkanes, which have single bonds (**saturated** hydrocarbons); alkenes, which have at least one double bond; and alkynes, which have at least one triple bond.



Propane
Saturated alkane

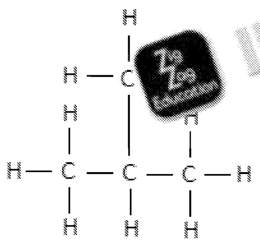


Propene
Unsaturated alkene

Hydrocarbons can be organised into different structures: straight chain, branched c Each type has unique characteristics based on the arrangement of carbon atoms wi

Straight chain hydrocarbons

These hydrocarbons consist of carbon atoms connected in a single, continuous chain. Each carbon atom, except for the ones at the ends, is bonded to two other carbon atoms, with hydrogen atoms filling the remaining available bonds. An example of a straight chain hydrocarbon is hexane (C_6H_{14}), where six carbon atoms form a linear sequence.



Branched chain hydrocarbons

In these hydrocarbons, the carbon chain has one or more b atoms attached to the main continuous chain. This branchi in the main chain forms a bond with another carbon atom, example, methylpropane (C_4H_{10}) is a branched chain hydro where three carbon atoms form the main chain and one ca atom branches off from the second carbon of the main cha

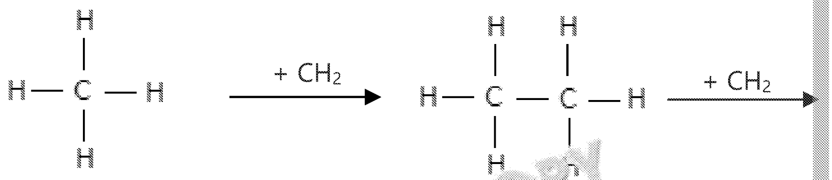
Cyclic hydrocarbons

These hydrocarbons have carbon atoms arranged in a ring or circle, with each carbon a bonded to two other carbon atoms to form a closed loop. A common cyclic hydrocarb cyclohexane (C_6H_{12}), which forms a six-membered ring.

Homologous series

A homologous series is a group of organic compounds that have the same **functional group** and differ from each other by a -CH_2 unit. This consistent difference results in predictable patterns in properties such as boiling point, melting point, and solubility.

The simplest homologous series is the alkanes.

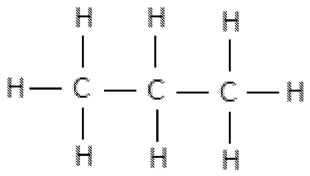
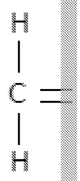
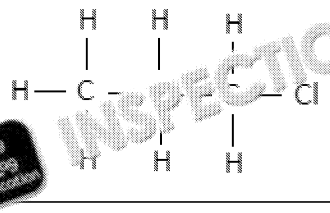
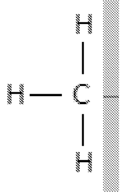


Methane (CH_4) Ethane (C_2H_6)

Functional groups

As well as hydrogen, carbon has the ability to bond to other elements such as oxyg **Functional groups** are specific groups of atoms within molecules that have charac They are the main deciding factor in the chemical behaviour of organic compound groups is important in organic chemistry because they allow chemists to predict th compounds can undergo. By identifying the functional groups in a molecule, you can infer the molecule's reactivity, solubility, and other key properties.

Some common functional groups include:

Alkane group (-C-C-): alkanes are the simplest type of hydrocarbons, consisting of only single bonds between carbon atoms	*Alkene group* (C=C): fo carbon–carbon double molecules more reactiv
	
Alkane (C_nH_{2n+2}) Propane	Alk
Halogenoalkanes (-X, where X is a **halogen**): halogenoalkanes contain a halogen atom (such as fluorine, chlorine, bromine, or iodine) bonded to a carbon chain	*Hydroxyl group* (-OH): f it makes molecules pola in water
	
Halogenoalkane ($C_nH_{2n+1}X$) Chloropropane	Alcoh

Each new homologous series has its own general formula. In organic chemistry, a g
describe the structure of an entire family of compounds using a simple, algebraic re
carbon (C) and hydrogen (H) atoms are in each molecule, and sometimes includes o
helps us understand and predict the structure and properties of different compoun

For example:

- Alkanes: alkanes are the simplest type of hydrocarbons, and their general fo
  number of carbon atoms. So, if n=3, the formula is C_3H_8, which is propane.
- Alkenes: alkenes have at least one double bond between carbon atoms, and
  For example, if n=2, the formula is C_2H_4, which is ethene.

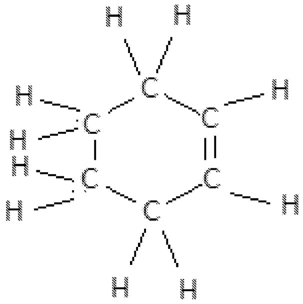
? *Recap questions: Key terms*

1 Define the term 'hydrocarbon'. (1 mark)

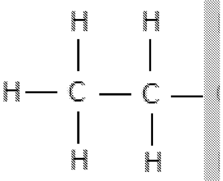
2 CH_2OH, C_2H_5OH and C_3H_7OH are all members of the same homologous
   a) [illegible] 'homologous series'. (2 marks)
   b) Name the functional group present in this group of compounds. (1 ma
   c) Use the general formula to predict the molecular formula of the fifth

3 Classify the following molecules as being:
   a) Saturated or unsaturated (4 marks)
   b) Straight chain, branched or cyclic (4 marks)

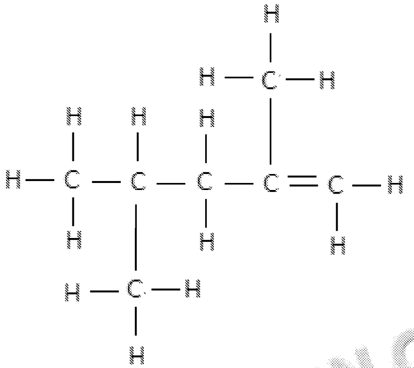
i)



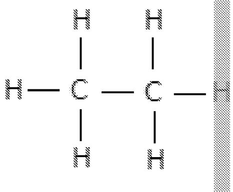
ii)



iii)



iv)



E1.2 Structure representations

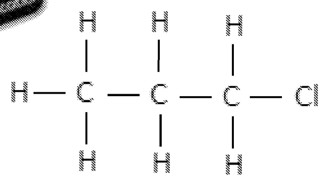
Key points covered

- Use of structural, skeletal and 3D diagrams of organic compounds

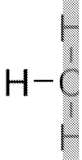
A variety of chemical formula types can be used in organic chemistry to show the stru molecular formula of a substance will tell you the type and number of atoms found i about how these atoms have been bonded and arranged. The purpose of the structu are to help inform you of the location of these atoms within the molecule and the sha

Full displayed structural formula

A displayed formula gives the most information about the structure of an organic co position and the bonds it has. For example, 1-chloropropane has the molecula formula can be seen below. Ethanol has the chemical formula C_2H_5OH. Its displaye

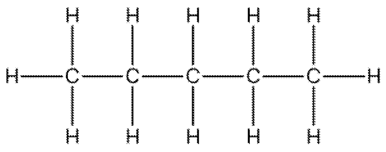


1-chloropropane

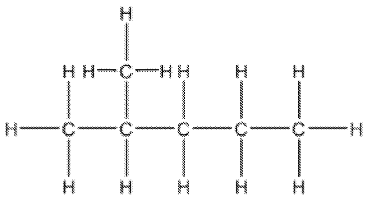


Condensed structural formula

In diagrams showing the condensed structural formula, less detail is shown. Every bonds are missing and instead you see the groups that have been bonded togeth structural formulae for a selection of organic compounds and their corresponding



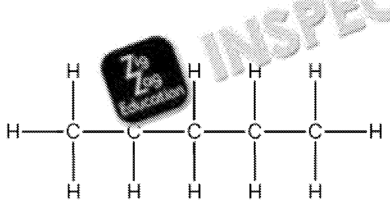
$CH_3CH_2CH_2CH_2CH_3$

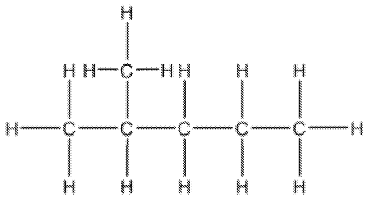


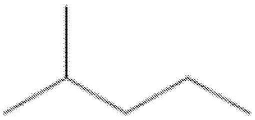
$CH_3CH(CH_3)CH_2CH_2CH_3$

Skeletal formula

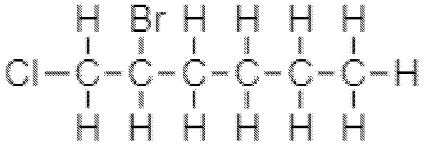
Skeletal formula is a simplified diagram of organic molecules which show only the to represent single covalent bonds between carbon atoms. There are no labels fo any bonds to hydrogen atoms are also absent

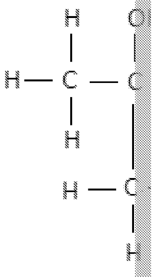


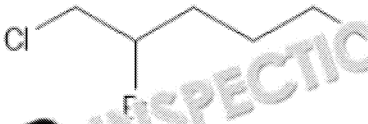


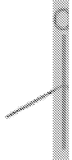


Any functional groups present in the molecule must also be shown in the skeletal









3D diagrams of organic molecules

Reminder

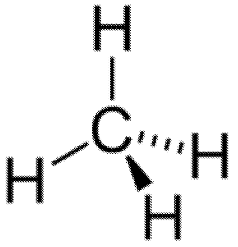
It can be hard to represent a three-dimensional shape on a two-dimensional shee
series of wedges has been created to help chemists portray and visualise molecula

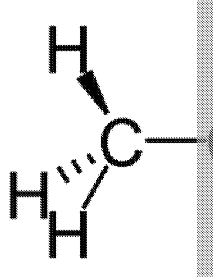
A solid line represents a bond that lies in the same plane as the paper.

A dotted wedge represents a bond that goes into the plane of the paper.

A solid wedge represents a bond that comes out of the plane of the paper.

Hydrocarbons adopt different shapes based on the number of bonds around the c
geometry to be adopted is tetrahedral, with bond angles of 109°.





However, in alkenes, the double bond between two carbons causes a trigonal plan
bond angles of 120°.

? *Recap questions: Structure representations*

1 a) Write out the full displayed structural formulae for the two hydrocarb
formula C_4H_{10} (2 marks)

b) Write out the condensed structural formulae for the two molecules. (

2 Draw the skeletal formula for the hydrocarbon with the molecular formul
the second carbon. (2 marks)

3 Draw the skeletal formula for the alcohol that is cyclic and contains five ca

4 Draw the full displayed structural formula for the halogenoalkane which ha
where the halogen is not on the end of the chain. (2 marks)

E1.3 Naming alkanes, alkenes, halogenoalk

Key points covered

- Use of IUPAC naming conventions to name key organic homologous series

IUPAC nomenclature

Due to carbon's ability to form up to four bonds per atom, in straight chain or cyclic are over 19 million known organic compounds in existence, many of which may con In order to ensure consistency and a common language when giving each of these has been drawn up and should be adhered to. The International Union of Pure and recognised authority with regard to chemical names, and they have devised a meth every possible organic compound has a name from which you are able to draw an u

Carbon chain length

All names in organic chemistry are based primarily on the main alkane found in the number of carbons in the longest chain, the appropriate stem can be selected.

Number of carbons	1	2	3	4
Stem to be used	Meth-	Eth-	Prop-	But-

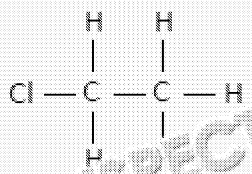
Functional groups

Once the stem of the name has been identified, any functional groups in the mole This is done in the form of either a prefix or suffix, as shown below.

Functional group	Nomenclature	Prefix/su
Alkane	-ane	Suffix
Alkene	-ene	Suffix
Halogenoalkane	Fluoro(alkane) Chloro(alkane) Bromo(alkane) Iodo(alkane)	Prefix
Alcohol	-anol	Suffix

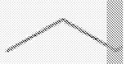
Example:

This molecule has two carbons in its longest chain (eth-). It also has the halogenoalkane functional group. Therefore its name is chloroethane.



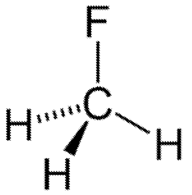
CH_2ClCH_3

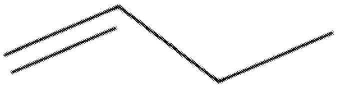
This molecule has six c (hex-). It also has the a Therefore its name is h

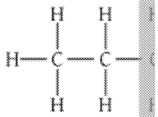


Test your knowledge

Name the following organic compounds:



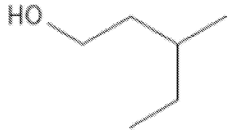




Branched alkanes

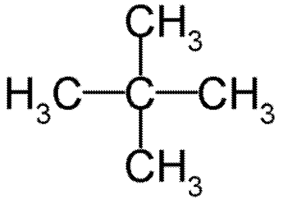
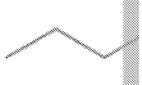
Any side chains within the alkane backbone can be identified by adding the suffix
These side chains are known as alkyl groups.

Example:

	
This is butanol with an ethyl group as a side chain. It would be called ethylbutanol	This is fluoropropane side chain. It methylflu

If there are multiple side chains on your molecule they should be named in alph
identical side chains then di- (for two) or tri- (for three) would be added in front

Example:

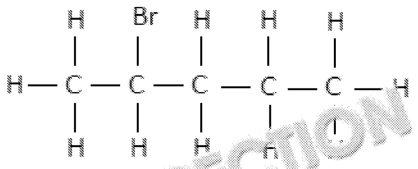
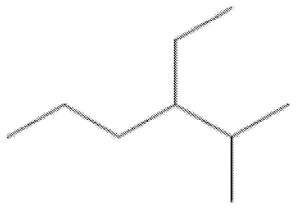
	
This is propane with two methyl group side chains. It would be called dimethylpropane.	This is hexanol with a chain. It would be ca

Locants

Side chains and functional groups should have their position indicated by giving th
found on. Carbons should always be numbered starting from the end that will give
molecule's name, even if this feels like you are working backwards.

Any adjacent numbers should be separated using a comma, and numbers should be se

Example:

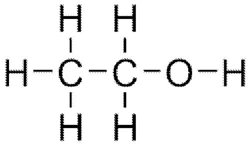
	
This is bromopentane with the bromine located on carbon 2. Its name is 2-bromopentane.	This is hexane with th carbon number 2 (num lowest number). I
	CH_3–C
This would be called 3-ethyl-2-methylhexane.	This is 2,2-d

Recap questions: Naming alkanes, alkenes, halogenoalkanes an

1 Draw the following organic molecules. (4 marks)

a) 3-methylhexane
b) Pentan-3-ol
c) Trichlorofluoromethane
d) Pent-1-ene

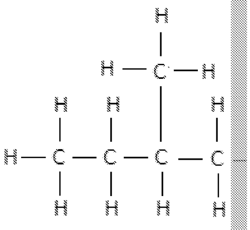
2 Name the following organic molecules. (4 marks)

a) 

$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ H & - & C & - & C & - & O - H \\ & & | & & | & & \\ & & H & & H & & \end{array}$$

c) CH_3CH_2Br

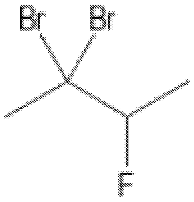
b) CH_3CH_2CH [illegible]

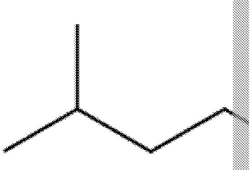
d) 

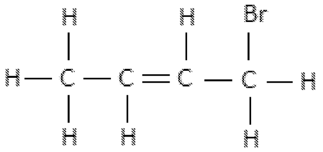
3 Draw the following organic molecules. (4 marks)

a) 2,3-dimethylpentane
b) 2,3-dimethylpent-3-ene
c) 3-bromo-3-fluoro-2-methylhexane
d) 2-methylpropan-2-ol

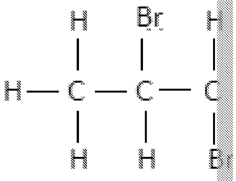
4 Name the following organic molecules. (4 marks)

a) 

c) 

b) 

$$\begin{array}{ccccccccc} & & H & & H & & H & & Br \\ & & | & & | & & | & & | \\ H & - & C & - & C & = & C & - & C - H \\ & & | & & | & & & & | \\ & & H & & H & & & & H \end{array}$$

d) 

E1.4 Isomerism

Key points covered

- Defining types of isomerism present in organic compounds
- Identifying isom organic compou

Isomerism

In organic chemistry there can be many molecules with the same molecular formul are arranged will differ from molecule to molecule. Compounds with the same mo arrangements of atoms are called **isomers**.

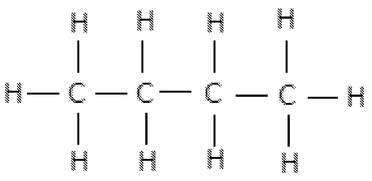
There is a variety of types of isomerism. In this applied science course the focus is stereoisomerism.

Structural isomerism

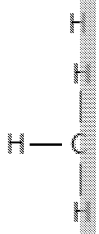
Structural isomers are defined as being compounds with the same molecular formul

Branched alkanes

Structural isomerism is exhibited repeatedly in the alkane homologous series. If yo formula C_4H_{10} there are two possible structures that can be drawn:



Butane

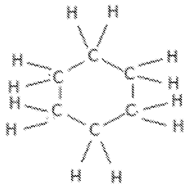


Me

Test your knowledge

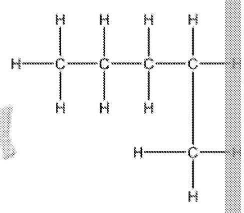
Justify if each pair of molecules are isomers of each other.

a)



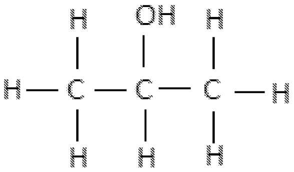
and

b)

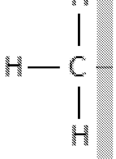


Positioning of the functional group

In functional groups containing compounds, such as alkenes, halogenoalkanes and can be placed in different positions along the carbon chain. The molecular formul following two structures:



Propan-2-ol



P

Stereoisomerism

Test your know
How many isome
molecular formul
full displayed for
name them all?

Stereoisomers are defined as being compounds with the same molecular formula but different arrangements of atoms in space. This differs from the previous discussed structural isomers as the connectivity of the atoms is identical in both isomers, it is simply the orientation of the atoms in respect of each other that differs.

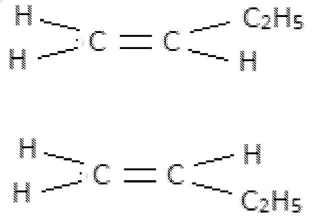
Stereoisomerism in alkenes

The double bond in an alkene is formed from one σ bond and one π bond. The π
position and restricts any rotation around that bond. This causes any atoms bond
in fixed positions relative to each other.

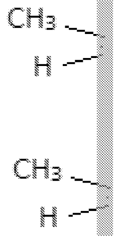
E/Z isomerism

In order to display E/Z isomerism a molecule must satisfy two criteria:

1. It must contain a C=C
2. Different groups bonded to each carbon in the double bond

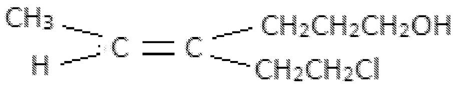


But-1-ene does not show E/Z isomerism as the two groups bonded to the left-hand carbon in the double bond are identical. This means both versions of the alkene are identical.



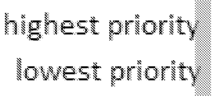
But-2-ene does sho
attached to each ca
different; a hydrog

If these criteria are met then two isomers of the alkene will be formed: the E isome
determine the correct name the priority of the bonded groups has to be determin
decided based upon its atomic number; the higher the atomic number, the higher
bonded to the carbons are initially identical you need to find the first point of diffe
priority from this point.

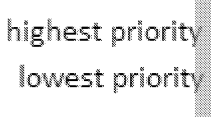


The groups attached to the right-han
initially identical. However, after the f
group has a third CH_2 bonded, the at
the bottom group has a Cl attached, v
17. The bottom group is the higher p

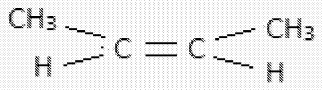
- If the groups with the highest priority are on the same side of the double bond, the compound is the Z isomer.



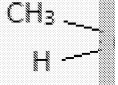
- If the groups with the highest priority are on opposite sides of the double bond, the compound is the E isomer.



Example:



The methyl group on each carbon is the higher priority group and these are located on the same side of the double bond. This is Z-but-2-ene.



The methyl group on e
group and these are l
the double bo

Cis/trans isomerism

Test your kn

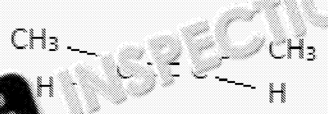
Would pent-1-
What about pe
any stereoisom
these two com

This is a very specific type of E/Z isomerism. For a compound to show cis/trans isomerism it would need to meet the same two requirements as for E/Z isomerism (it must contain a C=C, different groups bonded to each carbon in the double bond). However, additionally, to satisfy the criteria for cis/trans isomerism one of the bonded groups on each of the double bond must be the same.

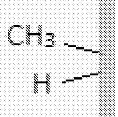
When these criteria are met, then

- the Z isomer will be known as the **cis** isomer
- the E isomer will be known as the **trans** isomer

Example:



The methyl groups on each carbon are located on the same side of the double bond.
This is cis-but-2-ene.

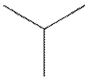


The methyl groups
on the opposite
This is

Recap questions: Isomerism

1 Define the terms
   a) structural isomers (1 mark)
   b) stereoisomers (1 mark)

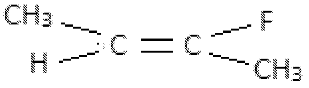
2 Identify which type of isomerism is present in the pairs of isomers shown b
   a)



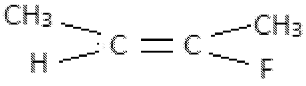
and

(1 mark)

   b)



and



(1 mark)

3 Draw and name all isomers with the chemical formula C_6H_{14}. (10 marks)

4 Draw the following alkenes and decide if they will show stereoisomerism.
   a) 2-methylpent-2-ene (2 marks)
   b) hex-3-ene (2 marks)
   c) 2,3-dichlorobut-2-ene (2 marks)

5 Draw the stereoisomers of butan-2-ol and correctly name each one. (4

6 State which type of isomerism, if any, the following molecules could display
   a) [illegible]
   b) [illegible]
   c) C_4H_{10}

E1.5 Sigma and pi molecular orbitals

Key points covered

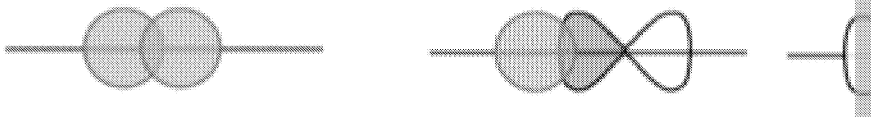
- Describing the formation of sigma molecular orbitals
- Describing the for

Bonding in carbon

Carbon has four valence shell electrons, which means it has the ability to form four covalent bonds with other atoms in order to obtain a full and stable outer shell. As discussed previously, the electrons in an atom exist in orbitals; for carbon, the outer shell electrons are found in the 2s and 2p orbitals ($1s^2\ 2s^2\ 2p^2$). To form a covalent bond these orbitals must overlap to form a combined orbital called the molecular orbital. Dependent on the form this overlap takes, two types of covalent bonds can be formed: σ (sigma) or **π (pi)** bonds.

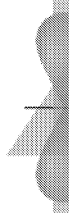
σ (sigma) bonds

σ bonds can be formed from either s or p orbitals and involve the end-to-end overla diagram below shows end-to-end overlap between two s orbitals, an s orbital and a p



The shared electron density that occurs as a result of this overlap is shared betwee two nuclei. σ bonds are the strongest type of covalent bond and are often commo

π (pi) bonds



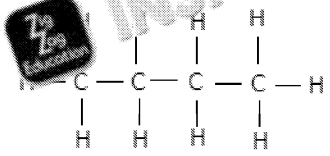
π bonds are formed by p orbitals and involve the sideways overlap of two that are adjacent. The diagram (right) shows the overlap between the two lobes of neighbouring p orbitals, which lie above and below the plane of the nuclei.

One **π bond** is represented as two clouds of electron density. This means that a double covalent bond is made up of one **σ bond** and one **π bond**.

Recap questions: Sigma and pi molecular orbitals

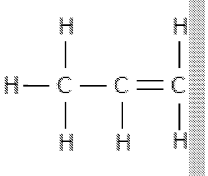
1. a) Draw the molecular orbital that results when an s orbital is involved i p orbital. (1 mark)
   b) Name the type of covalent bond that is formed. (1 mark)
2. a) Draw the molecular orbital formed in a pi bond. (1 mark)
   b) Which orbitals must overlap to form a pi bond? (1 mark)
3. How does a sigma bond differ from a pi bond? (2 marks)
4. Identify how many…
   a) sigma bonds   b) pi bonds   … are in each of these compou

i.

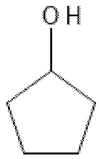


(2 marks)

ii.

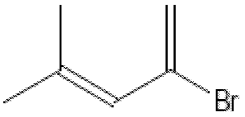


iii.



(2 marks)

iv.



E1.6 Changes in boiling point

Key points covered

- Explaining differences in boiling point due to chain length
- Explaining differenc

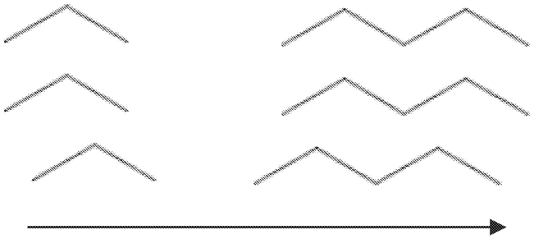
Alkanes are obtained from crude oil via the process of fractional distillation. Oil ref mixture of hydrocarbons as each alkane has a different boiling point. In order to ca to boil you need to break the intermolecular forces that hold the molecules togeth through London forces; the stronger the London forces, the higher the boiling poi

Boiling point and chain length

As the length of the hydrocarbon chain increases, boiling point increases as shown

Alkane	methane	ethane	propane	butane	pentane	hexane
Boiling point /°C	[illegible]	-89	-42	-1	36	69

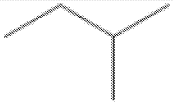
The longer the alkane chain, the larger the surface area of the molecule. This resul occurring between the molecules and therefore greater London forces which woul



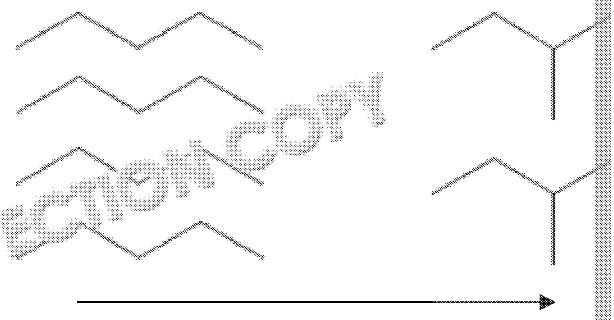
Shorter chain length
Less surface area contact
Weaker London forces

Boiling point and chain branching

As the level of branching in the hydrocarbon chain increases, boiling point decreas

Alkane		
Boiling point /°C	36	28

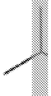
The branches on the alkane chains prevent the molecules from approaching each c contact. They also reduce the surface area of the alkane and this results in less surf factors result in weaker London forces which require less energy to break.



Less branching
More surface area contact
Stronger London forces

Recap questions: Changes in boiling point

1 Rank the following alkanes in order of boiling point, from highest to lowest.

a)  b)  c) 

2 Explain the reason behind your order in question 1. (4 marks)

E1.7 Reactions of organic compounds

! Key points covered

- Describe the reaction conditions required for a range of organic conversions
- Predict the produc organic conversio

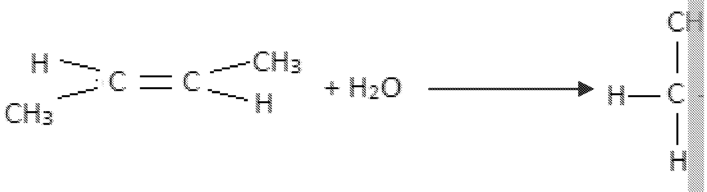
Organic compounds can undergo a variety of reactions due to the varying properti Understanding these reactions is vital for knowing how different molecules are for knowledge is fundamental in areas such as pharmaceuticals, materials science, and

Organic reactions are the backbone of organic chemistry, enabling the synthesis a compounds. These reactions can be grouped into several types, each with its own mechanisms.

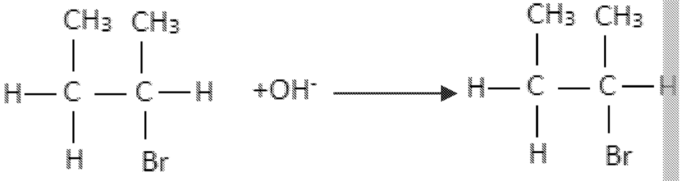
Types of organic reactions

Organic reactions are typically categorised based on the changes occurring in the main categories include:

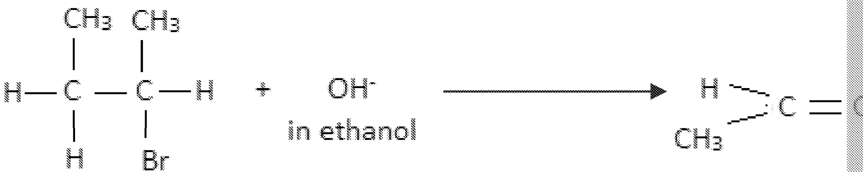
Addition reactions: where two reactants combine to form one product.



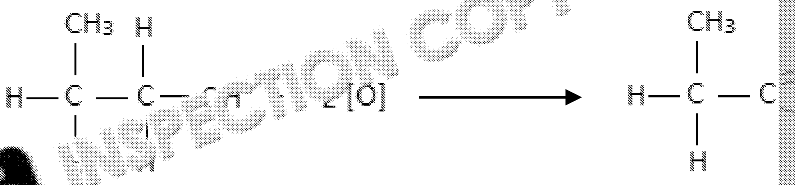
Substitution reactions: involving the replacement of an atom or group in a molec



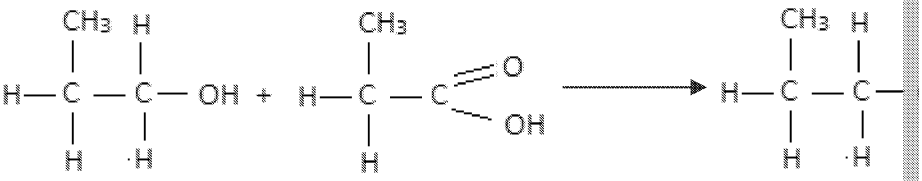
Elimination reactions: where atoms or small groups of atoms are removed from a



Oxidation reactions: where a molecule loses electrons or gains oxygen, altering it



Condensation reactions: where two molecules combine to form a larger molecule molecule like water.



Addition reactions

Addition reactions are common in unsaturated compounds such as alkenes. Due t present in alkenes there is a high area of electron density that is very susceptible t species. In an addition reaction the carbon–carbon double bond is broken and ea bond. There is a variety of addition reactions that alkenes can undergo.

Hydrogenation

Hydrogenation is the addition of hydrogen (H_2) to a double bond, converting alke requires a catalyst, such as platinum (Pt) or nickel (Ni) and heat, 423 K. Ethene wil catalyst at 423 K to form ethane.

Halogenation

Halogenation involves the addition of halogens (Cl_2, Br_2) to alkenes to form dihaloge at room temperature and requires no special conditions. Ethene will react with bro

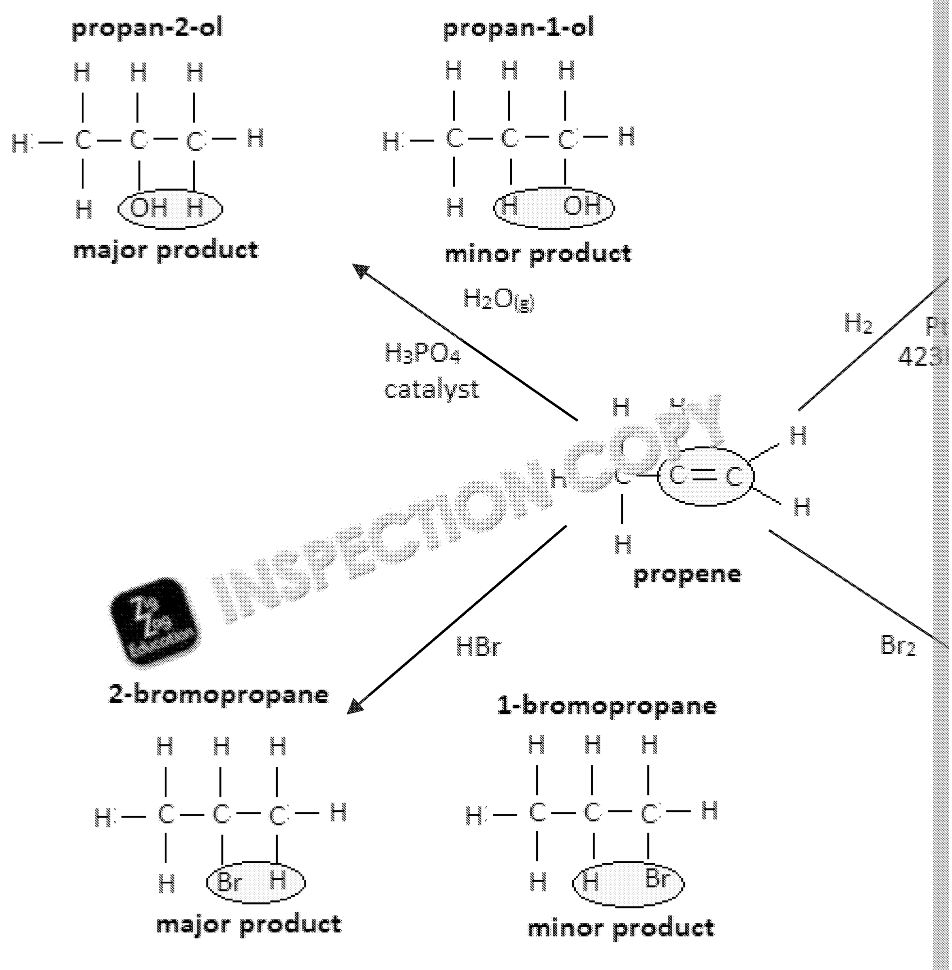
Reaction with hydrogen halides

The addition of hydrogen halides (HCl, HBr) to alkenes produces halogenoalkanes. unsymmetrical alkene then there are two possible products that can be formed. T Markovnikov's rule. The dominant product is that where the hydrogen atom from the carbon with the greater number of hydrogen atoms, and the halogen attaches hydrogen atoms (see diagram below). Ethene reacts with hydrogen bromide to fo

Hydration

Hydration involves the addition of water, in the form of steam (H_2O), to alkenes to needed for this reaction in the form of phosphoric acid (H_3PO_4). This reaction also taking place on unsymmetrical alkenes. Ethene reacts with water in the presence o

Each of these reaction types is represented visually in the diagram below, using pr



Test your knowledge

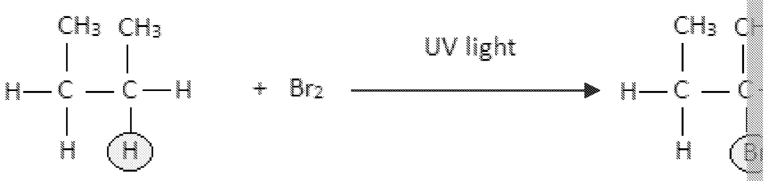
1. Draw the full structural formulae of three different alkenes which would fo reacted with hydrogen at 423 K in the presence of a Pt catalyst.
2. Draw the two structural isomers formed when pent-2-ene reacts with HBr.
3. Explain why there are two products formed when pent-1-ene reacts with H H_3PO_4 catalyst. Which product will be the major product? Why?

Substitution reactions

Substitution reactions are a key type of reaction in organic chemistry. In a substitu of atoms in a molecule is replaced by another atom or group. Substitution reactio chemical 'swap' where one part of a molecule is exchanged for another. For examp bromine atom attached, we might replace the bromine with a different group, like a changes the molecule into a new compound with different properties. These react wide variety of organic compounds and are commonly used in both laboratory and

Substitution reactions of alkanes to form halogenoalkanes

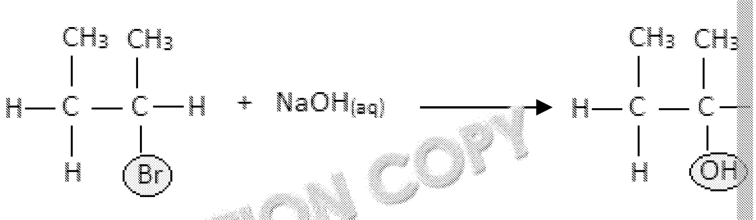
Due to their low reactivity, in order to make an alkane react a large amount of ene needed. This energy is given to the reaction in the form of UV light. UV light will c bond between two halogen atoms to break and form a **radical** which is then able t is then able to proceed to substitute itself for one of the hydrogen atoms in the alk chain. This reaction is uncontrollable; you are unable to control where or how man substitutions occur.



Substitution reactions of halogenoalkanes to form alcohols

Nucleophile – a molecule or atom that is attracted to positive charge. Usually a species with a negative charge or lone pair of electrons.

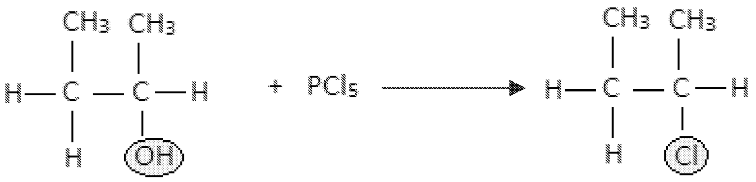
Halogenoalkanes are far more reactive than alkan halogen causing an uneven distribution of charge that is bonded to the halogen having a δ+ charge **nucleophiles**. The reaction of a halogenoalkane v results in the formation of an alcohol where the h



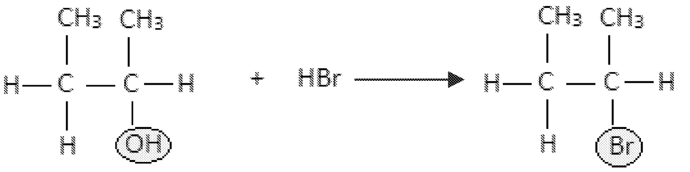
Substitution reactions of alcohols to form halogenoalkanes

The conversion of an alcohol to a halogenoalkane, known as halogenation, requires which halogen atom you intend to substitute for the hydroxyl group.

In order to chlorinate the ring you can add phosphorus(V) chloride, PCl_5. This causes a which gives off hot, steamy fumes of HCl. Due to the vigorous nature of the reaction, r



Bromination of an alcohol simply requires the addition of HBr.



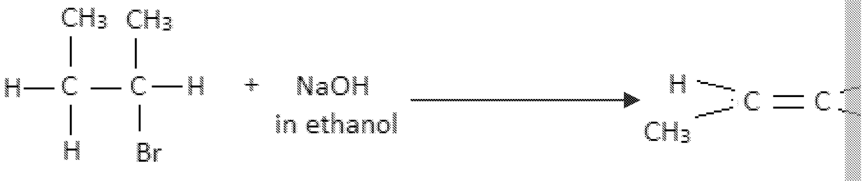
Test your knowledge

1. Write the equation to show the reaction between propan-2-ol and PCl_5.
2. Why is UV light required for the substitution reactions of alkanes?
3. What conditions would be needed to convert 2-chlorobutane into butan-2-
4. What addition inorganic product is formed when an alcohol reacts with HB

Elimination reactions

Elimination reactions of halogenoalkanes to form alkenes

In this reaction a small molecule, HX (where X is the halogen present), is removed f halogenoalkane to form a C–C double bond. This is achieved by heating the halog with **ethanolic** sodium hydroxide. The reaction conditions are very important; if a sodium hydroxide is used then substitution, as described above, would occur.



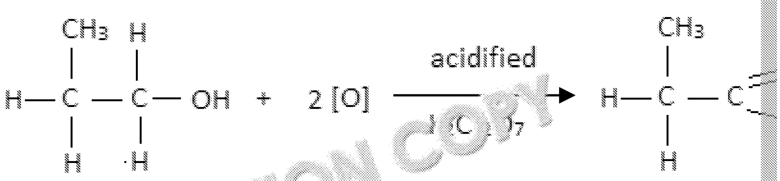
Oxidation reactions

Oxidation of primary alcohols to carboxylic acids

Carboxylic acid – a molecule containing the -COOH functional group

Aldehyde – a molecule containing the -CHO functional group

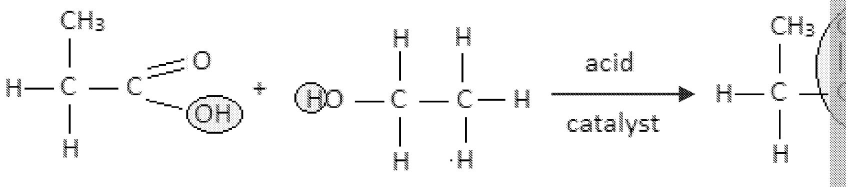
In organic chemistry, oxidation reactions are processes where a molecule gains oxygen or loses hydrogen. The oxidation of primary alcohols to carboxylic acids is important reaction in organic chemistry. Usi **oxidising agents** like potassium dichromate i acidic conditions, primary alcohols can be full passing through an **aldehyde** stage. The oxid conversion is acidified potassium dichromate, takes place the oxidising agent changes colou



Condensation reactions

Condensation reactions to form esters

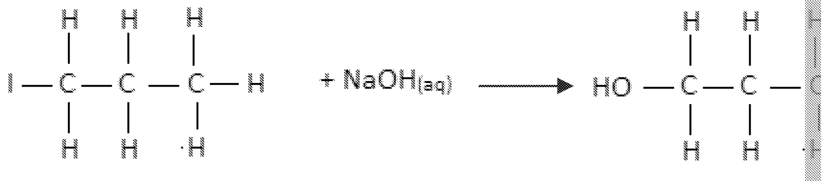
Esterification is a key reaction in organic chemistry that produces esters from alcoh reaction is catalysed by an acid, such as sulfuric acid, and requires heating. Esters h everyday products such as fragrances and flavourings.



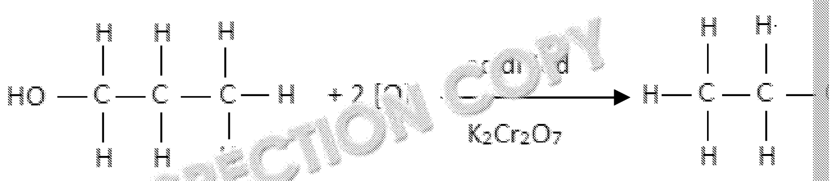
Recap questions: Reactions of organic compounds

1 Classify the following conversions as either: addition, substitution, eliminati

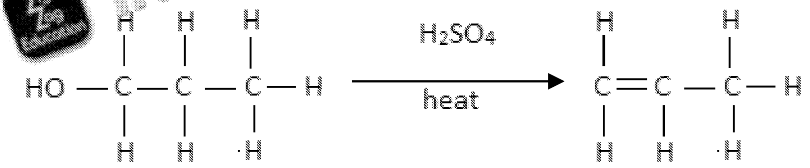
a)



b)

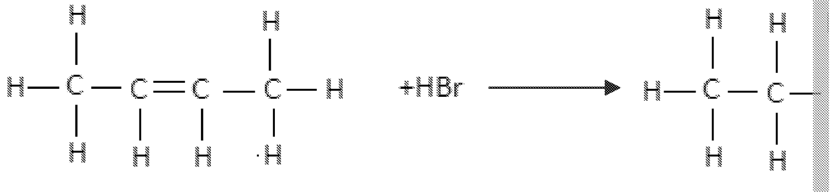


c)



(

d)

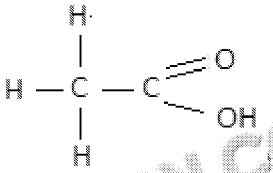


2 State the reactants and conditions needed for the following conversions.

a) pent-2-ene to pentan-1-ol (2 marks)
b) 2-chlorobutane to butan-2-ol (2 marks)
c) ethanol to ethene (2 marks)
d) but-1-ene to butane (3 marks)
e. propane to 2-chloropropane (2 marks)

3 Predict the structure of the **major** organic product formed in the followin

a) butan-1-ol heated with acidified potassium dichromate (1 mark)



b) propan-2-ol and [illegible] heated with sulfuric acid (1 m
c) ethene and hydrogen at 423 K with a nickel catalyst (1 mark)
d) pent-1-ene and steam with H_3PO_4 (1 mark)

E1.8 Reactions of commercial importanc

! Key points covered

- Predict the products formed from a range of important organic conversions
- Write equations to industrial conversi

Organic chemicals have a wide range of uses, but are particularly desired in the medical, agricultural and material industries. **Polymers** are used in the synthesis of modern materials such as plastic and rubber. Short chain hydrocarbons, such as methane and ethane, are vital for use as fuels in heating and cooking. Many different organic substances are the starting material for drug synthesis in the pharmaceutical industry.

Combustion

Combustion is a chemical process that occurs when a substance, typically a fuel, reacts releasing energy in the form of heat and light. This exothermic reaction is vital to many technologies, from everyday heating and cooking to industrial energy production and

There are two main types of combustion that can occur: complete and incomplete:

- **Complete combustion**: occurs when there is enough oxygen (excess) for the fuel to react completely, producing carbon dioxide and water.
- **Incomplete combustion**: happens when there is insufficient oxygen, leading to the production of **carbon monoxide** alongside water.

Example:

Complete combustion of propane

Propane + Oxygen → Carbon dioxide + Water

$C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$

Incomplete combustion of hexanol

Hexanol + Oxygen → Carbon monoxide + Water

$C_6H_{13}OH + 6\ O_2 \rightarrow 6\ CO + 7\ H_2O$

Test your knowled

Write out the balance

a) complete combus

b) complete combus

c) incomplete comb

d) incomplete comb

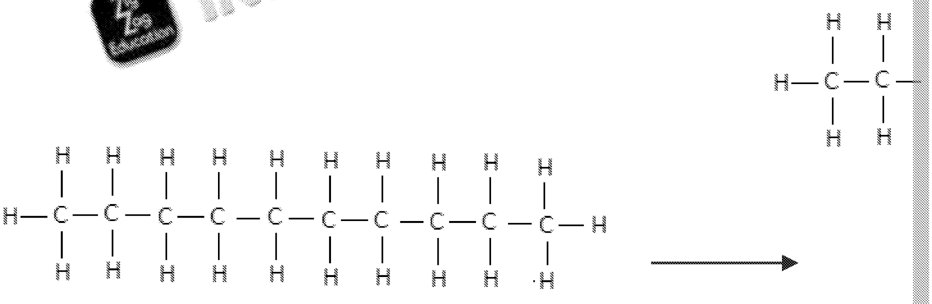
Cracking

Volatility – the ability of a substance to evaporate at standard temperatures

Viscosity – a measure of a substance's resistance to flow

Short chain hydrocarbons are more useful and equivalents. This is due to their higher flammab lower **viscosity** making them ideal substances composition of crude oil favours long chain alk needed to convert these alkanes into shorter ch

Thermal decomposition is used in order to address this supply and demand issue. alkanes and converts them into more useful, short chain alkanes and alkenes.



decane

Cracking can occur in one of two ways:

- **Thermal cracking**: this requires very high temperatures of approximately 1000 °C alongside high pressures of approximately 70 atm.
- **Catalytic cracking**: this reaction operates at lower temperatures and pressures but requires a catalyst such as aluminium oxide.

Test your kno

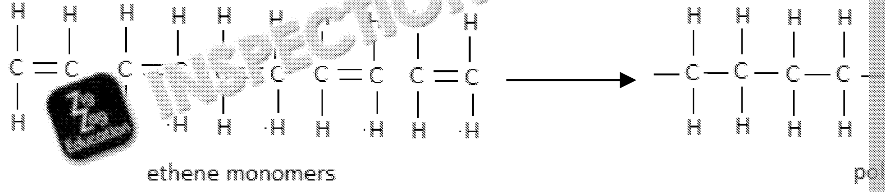
Complete the b
for the followin
a) $C_8H_{18} \rightarrow C_2$
b) ____ $\rightarrow C_6H$
c) $C_{16}H_{34} \rightarrow$ _
d) $C_{20}H_{42} \rightarrow C$

Addition polymerisation

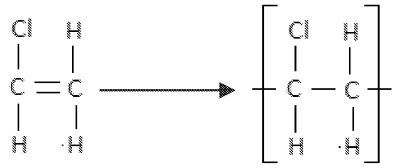
Monomer – a molecule that can react with similar molecules to form a long, repeating chain

Addition polymerisation is a type of polymerisation in wh
without the loss of any small molecules to form a polyme

This process involves the opening of a double bond in th
link together in a chain. The monomers involved in addit



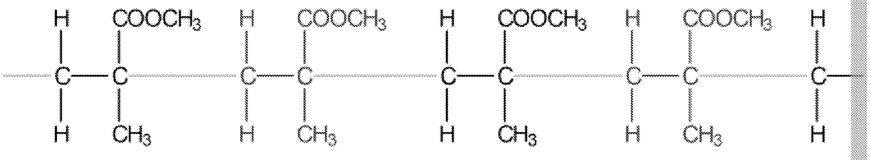
As well as showing the structural formula of the polymer, you can also show the re
is simply the monomer, with its double bond broken ready to join with a second m



Polymers are also known as plastics. Addition polymerisation is extremely importa
able to produce a wide variety of plastics, based on the monomers that began the
are essential in everyday life, such as polyethene, used in packaging (like plastic ba
household products, and polystyrene, used for products like disposable cutlery an

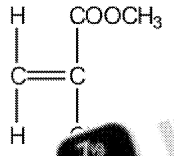
Test your knowledge

1. Acrylic is a polymer with the following structure:



Draw the monomer that forms acrylic.

2. The monomer used to form superglue has the following structure:



Draw the polymer chain formed from this monomer. The chain

Condensation polymerisation

Condensation polymerisation is an alternative method of polymerisation that invol
monomers, joining together to form large molecules called polymers. During this
water (H_2O) or methanol (CH_3OH) are released as by-products. This is different fro
where monomers simply add together without releasing any by-products.

Condensation polymerisation is important because it helps produce many useful ma
lives, such as polyesters which are used in making plastic bottles, food packaging, an
polyamides (e.g. Nylon): used in making textiles, ropes, and fishing nets because of it

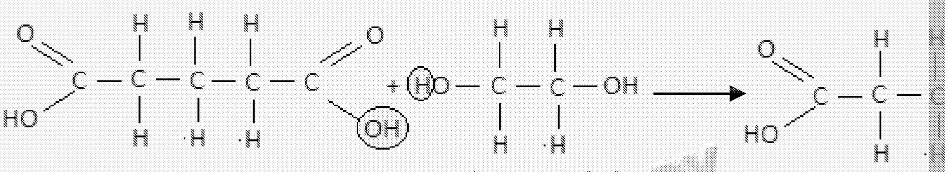
Formation of polyesters

A polyester is formed when a **dicarboxylic acid** reacts with a **diol**. There is a loss of water and the two monomers are then bonded together by an ester link.

Dicarboxylic acid –
-COOH functional gr

Diol – an organic m
group at either end o

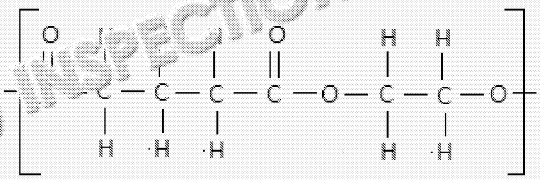
Example:



pentandioic acid

ethane-1,2-dio

Repeating unit =

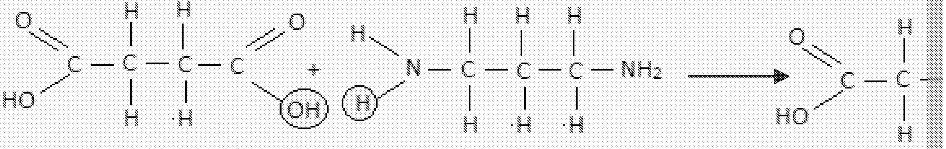


Formation of polyamides

A polyamide is formed when a dicarboxylic acid reacts with a **diamine**. There is a loss of water and the two monomers are then bonded together by an amide link.

Di
cc
ei

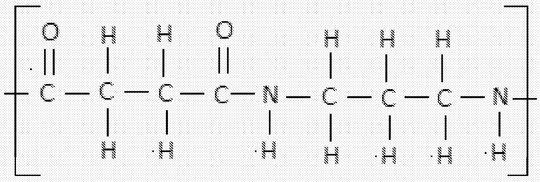
Example:



butandioic acid

1,3-diaminopropane

Repeating unit =



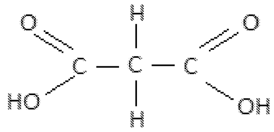
? *Recap questions: Reactions of commercial importance*

1 a) Write the balanced chemical equation for the reaction of propan-2-ol i
oxygen. (2 marks)
b) [illegible] h[illegible] the products formed would be different if there was a limi
[illegible]. (2 marks)

2 Explain why there is a need for cracking alkanes. (3 marks)

3 One of the products produced in cracking can be used in a further commercia
functional group present in this product and then describe the subsequent rea

4 Draw the products formed as a result of the reaction between buntan-1,4-



(2 marks)

E1.9 Combustion, CFCs, polymers and al

! Key points covered

- Description of the benefits provided by a variety of organic reactions and chemicals
- Description of the organic reactions a

Organic reactions are key for many industries, helping to make progress in medicin and protecting the environment. They allow us to create complex medicines, impr and pesticides, and develop new materials like plastics and biofuels. Organic chem biotechnology, perfumes, flavours, dyes, and new medical treatments. However, sc problems for the environment and our health. Using certain solvents can pollute t Many organic reactions produce hazardous waste that needs careful disposal to av Some processes use a lot of energy, leading to high carbon emissions, and toxic ch cyanides can be dangerous to both people and nature. Some organic compounds meaning they don't break down easily and can build up in the environment, causin these issues, we need to keep developing greener, more sustainable chemical proc

	Benefits	
Combustion	Provides large amounts of energy quickly, reliably and relatively cheaply.	Production of carbon greenhouse gas. Production of carbon incomplete combustic Consumption of fossil renewable resource.
Halogenoalkanes (CFCs)	Non-flammable and non-toxic so good for use as refrigerants and propellants.	Collect in the upper at energy, break down a
Polymers (plastics)	The wide range of monomers means that a wide variety of polymers can be made with different properties.	Consumption of fossil renewable resource. Polymers are non-bio for hundreds of years
Alcohol	Used as an alternative fuel in cars which can be considered carbon-neutral and therefore cleaner burning.	Consumption of fossil non-renewable resour starting material. Use of large areas of l growing crops for foo produce alcohol.

? Recap questions: combustion, CFCs, polymers and alcohol

1 What are some industries that benefit from organic reactions, and how do

2 What are some environmental and health problems caused by organic reac

3 List **three** benefits and **three** problems associated with the combustion o

4 Why are halogenoalkanes (CFCs) useful, and what environmental issue do t

5 State **one** benefit and **two** problems associated with the use of polymers. (

E1.10 Solutions to environmental proble

Key points covered

- Discussion of ways to overcome environmental problems caused by a variety of o

Combustion

As one of the major uses of combustion is in energy generati overcome the environmental impact is to invest and research Renewable energy resources such as solar, wind and hydroele large amounts of energy, whilst conserving a vital finite resou

CFCs

CFCs were initially developed due to their low toxicity and fla However, upon reaching the upper atmosphere they break d chlorine radicals which break down the ozone layer. Alternatives have been develo HFCs (hydrofluorocarbons). These are of equally low flammability and have low to however, they lack chlorine atoms within them and so will not cause ozone depleti

Polymers

Recycling polymers helps reduce landfill waste. Recycling also conserves resource from crude oil products. However, recycling is labour-intensive because polymers indicated by recycling symbols and numbers on the product. Mixed polymers can complicating recycling. For example, PVC contains toxic chlorine, which can be rel

Some polymers derived from crude oil or natural gas are difficult to recycle. They significant energy in their chains and can be incinerated to generate power, simila coal-fired power stations. However, burning releases carbon dioxide, contributing global warming, and other toxic by-products like hydrogen chloride from PVC.

Bioplastics are made from renewable resources such as plant starch, cellulose, plan and proteins. They provide a sustainable alternative to traditional polymers, which derived from finite resources like crude oil. Bioplastics can be decomposed by microorganisms, resulting in by-products like carbon dioxide, water, and other org polyamides, which can be broken down by hydrolysis reactions, are biodegradable over polyalkenes, which do not easily degrade.

Photodegradable polymers have bonds that weaken when exposed to light, leadin oil-based, but additives that absorb light can be included to encourage degradati

Alcohol

The production of alcohol can be made more sustainable by ensuring sustainable f obtain the crops used for alcohol production. Practices such as organic farming a minimise the environmental impact of this process.

? Recap questions: Solutions to environmental problems

1 What are **three** renewable energy resources that can be used to produce reduce pollution? (3 marks)
2 Why were CFCs initially developed, and what environmental harm do they
3 How do HFCs differ from CFCs in terms of environmental impact? (3 mar
4 What are the benefits and challenges of recycling polymers? (5 marks)
5 How can the production of alcohol be made more sustainable? (3 marks)

Answers for Recap Que

A: Atomic and electronic structure

Features of the periodic table

1. Similarities: same number of protons, 16 (1) same number of electrons, 16 (1)
   Differences: different number of neutrons: ^{32}S, 16; ^{33}S, 17; ^{34}S, 18; ^{36}S, 20 (1)
2. a) [14.0 + (1.0 × 4)] × 2 + [12.0 + (16.0 × 3)] (1)
   = 96 (1)
   b) HSO_4 = 32.0 + (16.0 × 4) = 96 (1)
   267.2 – 96 = 171.2 (1)
   RAM of group 1 element = 85.6 = Rubidium Rb (1)
   c) O_2 = 32.0; 74 – 32 = 42 (1)
   42 ÷ 12 = 3.5 which means 3 carbons; these will have a mass of 36 so the va
   32 + 36 = 68 which is a value of 6 away from the M_r so therefore 6 hydrogen
3. a) RAM = [(39 × 93.20) + (40 × 0.07) + (41 × 6.73)] (1)
   100
   = [illegible] = 39.14 (1)
   b) 1 mark for each correct row in the table:

Isotope	Protons	Neutrons
^{40}K	19	21
$^{41}K^+$	19	22

4. Chlorine-35 is the most abundant isotope (1 mark) as the relative atomic mass is c

Electronic structure

1. a) 2 (1) b) 3 (1) c) 10 (1) d) 2 (1) e) 18 (
2.

1s	2s	2p			3s	4p			3d				
↿⇂	↿⇂	↿⇂	↿⇂	↿⇂	↿⇂	↿⇂	↿⇂	↿⇂	↿	↿	↿	↿	

   Correct number of electrons (1)
   Correct filling order (1)
   Correct spin (1)
3. The highest subshell is the 3p subshell (1)
   It contains 4 electrons (1)
   The $3p_x$, $3p_y$ and $3p_z$ are first singly filled (1)
   The final electron is then placed in a 3p orbital with opposite spin to the electron a

Ionisation energy

1. $O_{(g)} \rightarrow O^+_{(g)} + e^-$ (1)
   $O^+_{(g)} \rightarrow O^{2+}_{(g)} + e^-$ (1)
   The nuclear attraction on the remaining electrons is higher (1) and more energy is
2. Aluminium (1); there is a large increase between the third and fourth ionisation en
   electron must be being taken from a new shell, closer to the nucleus (1)
3. a) Because the outer electron is being taken from the 2p subshell (1) which is hi
   subshell where Mg's outer electron is removed from (1)
   b) Because the outer electron is being taken from a fully occupied orbital (1) an
   electrons already in the orbital (1)

B: Bonding and structure

Types of bonding

1. The bonding is ionic bonding (1); a strong electrostatic attraction (1) between Al^{3}
2. Each metal atom delocalises (1) its outer shell electrons (1)
3. There is a shared pair of electrons between each hydrogen and the oxygen atom (
   electron (1)
4. Both substances have a giant covalent structure (1). In diamond, each carbon ato
   bonds (1). In graphite, each carbon atom makes three single covalent bonds and

Physical properties of substances

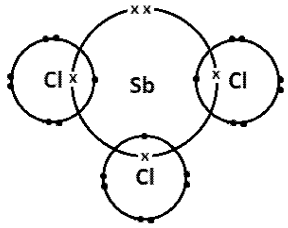
1. X – simple covalent bonding (1); it has a very low melting point due to weak inter conduct electricity due to a lack of charged particles (1)
   Y – giant ionic lattice (1); high melting point due to strong electrostatic attractions and can only conduct when liquid as ions are immobile when in solid form (1)
   Z – giant metallic lattice (1); high melting point due to strong electrostatic attracti of delocalised electrons; can conduct electricity in any form as electrons (in sea of and carry the charge through the substance (1)
2. Both substances contain metallic bonding (1); when melted you need to overcome between the sea of electrons and the positive metal ions (1); as magnesium ions h 1+ charge of sodium (1) the electrostatic attraction is stronger and more energy is
3. Ionic bonding (1); strong electrostatic forces of attraction between oppositely cha amounts of energy to overcome (1); at 25 °C it is solid and unable to conduct elec lattice and unable to move (1); at 3000 °C the substance has melted (1); now the io charge, so electricity is conducted (1)

Molecular shape

1.

	Bond angle / ° (1 mark each)	Shape (1 mark each)
a) C[illegible]	109.5	Tetrahedral
b) CO_2	180	Linear
c) PF_3	107	Pyramidal
d) H_2O	104.5	Non-linear
e) SF_6	90	Octahedral

2. NH_3 has 4 areas of electron density (1); 3 bonding pairs and 1 lone pair (1); where density (1); all bonding pairs (1); lone pairs repel more than bonding pairs (1)
3. a)

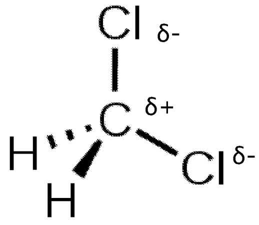


(1)

   b) Pyramidal (1)
   c) 107° (1)
   d) It has 3 bonding pairs and 1 lone pair (1); electron pairs repel each other as m

Electronegativity and polarity

1.

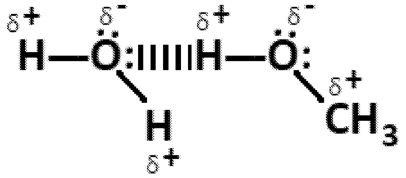


1 mark for correct shape, then 1 mark for correct dipole on each C–Cl bond

2. It is polar as there is an asymmetrical distribution of charge (1)

Intermolecular forces

1. Each substance has simple covalent bonding and this means the boiling point depe intermolecular forces (1). Fluorine has the lowest boiling point as it only contains L these are the weakest intermolecular force (1); chloromethane has permanent dipol intermolecular forces (1); hydrogen fluoride contains the strongest intermolecular f
2.



1 mark for all dipoles and lone pairs correctly shown, 1 mark for correct hydrogen

Hydrogen bonding and properties of water

1. Water has a smaller density when solid than when liquid (1). Hydrogen bonds be molecules further apart than normal when solid (1), meaning less mass per unit vo
2. When water boils, hydrogen bonding must be overcome (1); this is the strongest requires lots of energy (1); there are 2 hydrogen bonds formed per water molecul
3. High surface tension allows objects such as insects to walk on water (1); the wate water are able to form hydrogen bonds to fewer molecules than internal molecul exist are extremely strong (1)

C: Periodicity

Properties of period 3 elements

1. Argon (1); across the period there are more protons (1) but the outer electrons ar stronger nuclear pull pulling the electrons closer to the nucleus (1)
2. All melting points will be high as strong metallic bonding (1) Al > Mg > Na (1) as f attractions get stronger (1) due to higher charge on metal ions (1) and more deloc
3. Melting point is observed as chlorine < phosphorus < sulfur (1); these elements e will all have low melting points as simple molecular substances (1) with weak Lon increase as number of electrons increases and therefore strength of London fo

Oxidation numbers, oxidation and reduction

1. a) Na +1, C +4, O -2 (1)
   b) Cr +3, O -2 (1)
   c) Cr +6, O -2 (1)
   d) Mn +6, O -2 (1)
   e) Mn +7, O -2 (1)
2. a) Oxidised: N, -3 → 0 (1)
   Reduced: Cu, +2 → 0 (1)
   b) Oxidised: Cl, -1 → 0 (1)
   Reduced: Mn, +4 → +2 (1)
   c) Oxidised: Mg, 0 → +2 (1)
   Reduced: H, +1 → 0 (1)
3. a) $Na \rightarrow Na^+ + e^-$ (1) oxidation (1)
   b) $Pb^{4+} + 2e^- \rightarrow Pb^{2+}$ (1) reduction (1)
   c) $H_2 \rightarrow 2H^+ + 2e^-$ (1) oxidation (1)
   d) $2Br^- \rightarrow Br_2 + 2e^-$ (1) oxidation (1)
   e) $2Hg^{2+} + 2e^- \rightarrow Hg_2^{2+}$ (1) reduction (1)
4. a) $5Ce^{3+} + MnO_4^- + 8H^+ \rightarrow Mn^{2+} + 4H_2O + 5Ce^{4+}$ (1 mark for correct species, 1 r
   b) $2MnO_4^- + 6H^+ + 5H_2O_2 \rightarrow 2Mn^{2+} + 8H_2O + 5O_2$ (1 mark for correct species, 1
   c) $2FeO_4^{2-} + 16H^+ + 3C_2O_4^{2-} \rightarrow 2Fe^{3+} + 8H_2O + 6CO_2$ (1 mark for correct specie

Reaction of period 3 elements

1. a) Yellow flame (1) giving white smoke (1)
   b) $P_4 + 5O_2 \rightarrow P_4O_{10}$; correct formula for phosphorus(V) oxide (1) Correctly bala
2. a) Sodium hydroxide (1) and hydrogen (1); $2Na + 2H_2O \rightarrow 2NaOH + H_2$ (1)
   b) A coating of protective aluminium oxide is present (1) the water must be wa
3. NaCl (1) Na = +1 (1); Al_2Cl_6 (1) Al = +3 (1); $SiCl_4$ (1) Si = +4 (1); PCl_5 (1) P = +5 (1)

Physical properties of period 3 oxides and chlorides

1. Magnesium oxide has stronger ionic bonding (than sodium oxide) (1) due to the b magnesium ions (compared to sodium ions) (1)
2. P_4O_{10} is simple molecular (1) with weak induced dipole–dipole forces OR little ene induced dipole–dipole forces (1)
3. Magnesium chloride can conduct when molten or dissolved (1) as the ions are fre phosphorus chloride can never conduct (1) as it has no free ions or electrons (1)

Acid-base behaviour of period 3 oxides and hydroxides

1. a) The pH generally decreases / becomes more acidic (1 mark)
   b) The oxides of aluminium and silicon (1)
2. a) The pH is 9–11 inc. (1) due to the formation of $Mg(OH)_2$ (1)
   b) pH 2–3 (1) due to the formation of H_2SO_3 (1)
3. $Al(OH)_{3(s)} + 3HCl_{(aq)} \rightarrow AlCl_{3(s)} + 3H_2O_{(l)}$; correct formula for all species (1); correct b
   $Al(OH)_{3(s)} + NaOH_{(aq)} \rightarrow NaAl(OH)_{4(aq)}$; correct formula for all species (1); correct ba

Reaction of water and period 3 chlorides

1. pH decreases / acidity increases (1)
2. A white precipitate is formed (1); white fumes given off (1); $SiCl_{4(l)} + 2H_2O_{(l)} \rightarrow SiO$
3. Hydrochloric acid (1); phosphoric acid (1)

Predicting physical and chemical properties

1. a) Carbon; group 4 so therefore has a giant covalent structure (1)
   b) Beryllium; has a giant metallic structure (1)
   c) Beryllium; stronger electrostatic attractions as higher number of delocalised
2. fluorine > sulfur > phosphorus > boron (1)
3. Neon (1); ionisation energy is the amount of energy needed to remove an electro strongest nuclear attraction so requires the most energy (1); all period 2 atoms ha shell so atomic radius remains similar for all (1)
4. True (1); there are more protons in the oxygen nucleus [illegible] but the extra electron previous electrons (1); the nucleus has greater attraction to the oxygen electron

Uses of period 3 elements and compounds

1. $Al(OH)_3$ [illegible] Cl → [illegible] $+ 3H_2O$ (1); the acid is neutralised to salt and water (1)
2. High melting point: large numbers of strong covalent bonds to overcome (1)
   Strength: giant covalent structure is very strong (1)

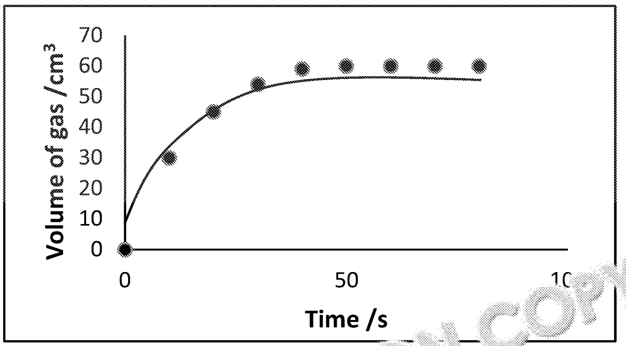
D: Physical chemistry

Moles

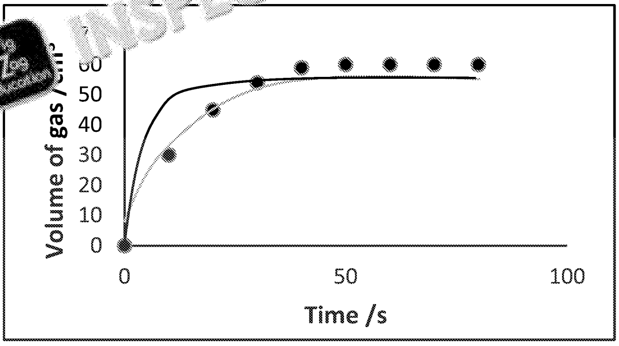
1. a) $Mg + 2\ HNO_3 \rightarrow Mg(NO_3)_2 + H_2$ (1)
   b) $CuCl_2 + 2\ NaOH \rightarrow Cu(OH)_2 + 2\ NaCl$ (1)
   c) $4\ Na + O_2 \rightarrow 2\ Na_2O$ (1)
   d) $Ca + 2\ HCl \rightarrow CaCl_2 + H_2$ (1)
2. a) 72 ÷ 24 = 2.96 (1)
   b) 50.3 (1)
   c) 0.5 (1)
   d) 0.107 (1)
3. a) Moles of Fe_2O_3 = 32 000 ÷ 159.6 = 200.5 mol (1)
      1 mole of Fe_2O_3 forms 2 moles of Fe ∴ moles of Fe = 2 × 200.5 = 401.0 mol (
      Mass of Fe = moles × M_r = 401.0 × 55.8 = 22 400 g (3 s.f.) (1)
   b) Moles of NH_3 = 102 ÷ 17 = 6.00 mol (1)
      4 moles of NH_3 reacts with 3 moles of O_2 ∴ moles of O_2 = 6.00 × ¾ = 4.50 m
      Mass of O_2 = moles × M_r = 4.50 × 32.0 = 144 g (3 s.f.) (1)
4. a) Moles of Al_2O_3 = 1000 ÷ 102 = 9.8 mol (1)
      2 moles of Al_2O_3 produces 4 moles of Al ∴ moles of Al = 9.8 × 2 = 19.61 mo
      Mass of Al = moles × M_r = 19.61 × 27 = 529 g (3 s.f.) (1)
   b) Percentage yield = (500 ÷ 529) × 100 = 94.5 % (1)
5. a) Moles of iron = 3.53 ÷ 56 = 0.063 (1)
      Mass of chlorine = 10.24 – 3.53 = 6.71 g (1)
      Moles of chlorine = 6.71 ÷ 35.5 = 0.189 (1)
      Ratio = 1 Fe : 3 Cl (1)
      Formula = $FeCl_3$ (1)
   b) Moles of carbon [illegible] 3.33 (1)
      Moles of hydrogen = 6.7 ÷ 1 = 6.7 (1)
      Moles of oxygen = 53.5 ÷ 16 = 3.34 (1)
      Ratio = [illegible] C : 2 H : 1 O (1)
      Empirical formula = CH_2O (1)
      M_r of empirical formula unit = 30 (1)
      Molecular formula = $C_6H_{12}O_6$ (1)
6. a) Ratio: 1 C_4H_8 : 6 O_2 (1)
      6 × 100 = 600 cm^3 O_2 needed (1)
   b) Ratio: 1 C_4H_8 : 6 O_2 (1)
      6 dm^3 of O_2 is used up (1)
      4 dm^3 of O_2 is left over (1)

Chemical kinetics

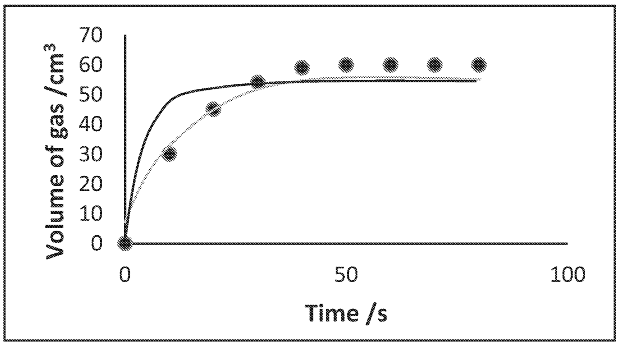
1. a) Labels on axes with units (1)
   Points correctly plotted (1)
   Smooth curve of best fit drawn (1)



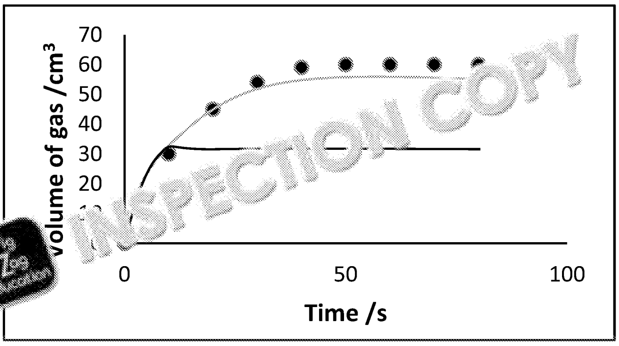
   b) i) Curves with a steeper gradient (1)
   Finishes and starts at same volume as original line (1)



   ii. Curves with a steeper gradient (1)
   Finishes and starts at same volume as original line (1)

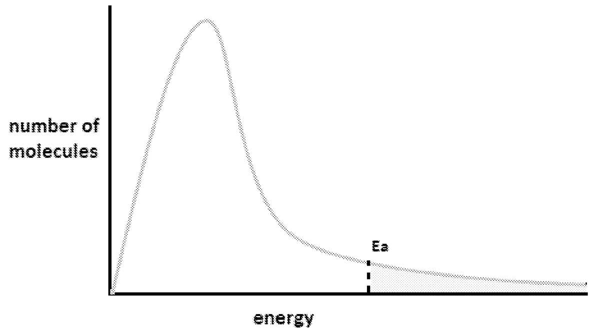


   iii. Curves with the same gradient (1)
   Finishes at a volume 50 % less than original line (1)



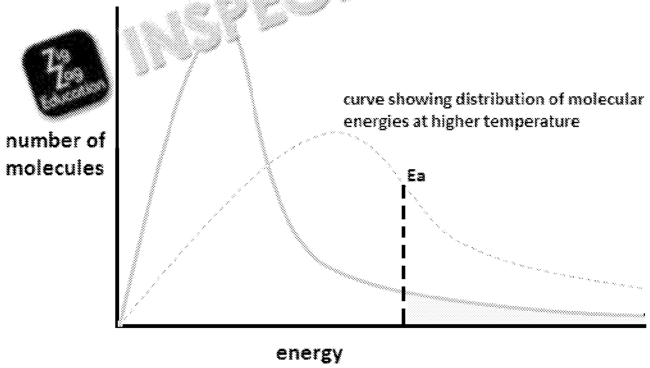
   c) The higher temperature increases rate (1) because the particles have more ki
   frequently and are more likely to reach the activation energy (1). The powde
   surface area and so faster rate (1) meaning collisions will occur more freque
   will result in the same initial rate (1) as there are the same number of particle
   the smaller number of particles present (1) means there is also a lower amou

2. a)



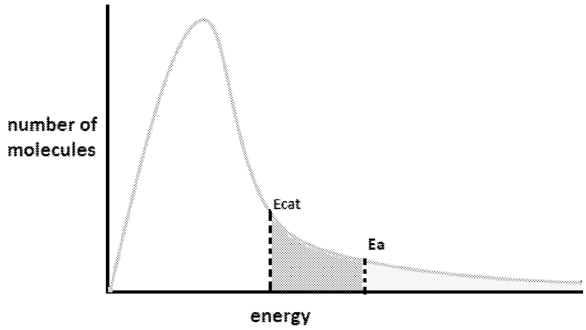
y-axis labelled correctly (1)
x-axis labelled correctly (1)
Line correct shape (1)
Line starting at 0,0 and never crosses the x-axis (1)

b)



Peak of curve shifted to the right (1)
Peak of curve at a lower height than previously (1)

c)



Curve showing Ea for catalysed and uncatalysed reaction (1)
Explanation stating that a catalyst lowers activation energy by providing an
more collisions will be successful (1)

3. a) i) Na: order = 0 (1) in reactions 1 and 5 the concentration of Na is halved,
ii) Cl_2: order = 2 (1) in reactions 1 and 3 the concentration of Cl_2 is double

b) rate = k $[Cl_2]^2$ (1)

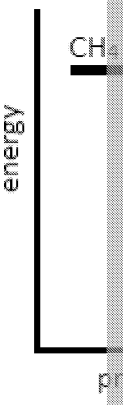
c) $k = \frac{\text{rate}}{[Cl_2]^2}$ (1)

Appropriate substitution using any row of data (1)
k = [illegible]77777777) (1)

d) $k = \frac{\text{mol dm}^{-3}\text{ s}^{-1}}{(\text{mol dm}^{-3})^2}$ (1)

$k = \text{mol}^{-1}\text{ dm}^{3}\text{ s}^{-1}$ (1)

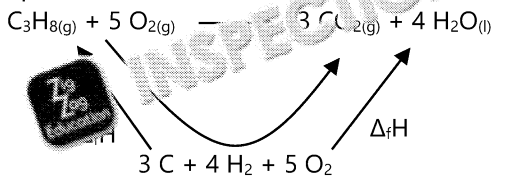
Chemical energetics



1. a) Products lower than reactants (1)
   Both axes correctly labelled (1)
   Reactants and products labelled with chemicals (1)
   b) See diagram (1)
   c) See diagram (1)

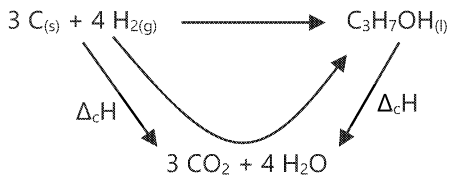
2. a) $C_2H_5OH_{(l)} + 3\ O_{2(g)} \rightarrow 2\ CO_{2(g)} + 3\ H_2O_{(g)}$
   Species correct (1) balancing correct (1)
   b) $Na_{(s)} + ½\ F_{2(g)} \rightarrow NaF_{(s)}$
   Species correct (1) balancing correct (1)

3. a)



Δ_rH = [Σ Δ_fH of the products
Δ_rH = [3(Δ_fH CO_2 + 4(Δ_cH H
Δ_rH = [3(-394) + 4(-286)] – [
Δ_rH = [-1182 + -1144] – [-1
Δ_rH = -2326 – -104
Δ_rH = -2222 kJ mol^{-1} (1)

   b)



Δ_rH = [Σ Δ_cH of the reacta
Δ_rH = [3(Δ_cH C) + 4(Δ_cH H
Δ_rH = [3(-394) + 4(-286)] –
Δ_rH = [-1182 + -1144] – [-2
Δ_rH = -2326 – -2010
Δ_rH = -316 kJ mol^{-1} (1)

Chemical equilibrium

1. a) Dynamic equilibrium: when the forward reaction and backward reaction are p
   closed system (1)
   b) Closed system: where nothing can enter or leave the reaction (1)
2. a) Equilibrium will shift in the direction of the endothermic reaction (1) to oppos
   temperature back down again (1)
   b) Equilibrium will shift in the direction of the reaction that produces the most a
   oppose the change and increase pressure (1)
   c) No effect on the position of equilibrium (1); just causes it to reach equilibriu
3. a) Equilibrium would shift to the right (1) as this is the exothermic reaction (1)
   b) Equilibrium would be unaffected (1) as there is the same number of gaseous
4. a) $K_c = \frac{[SO_2]^2\,[O_2]}{[SO_3]^2}$ (1) units = $\frac{(mol\ dm^{-3})^3}{(mol\ dm^{-3})^2}$ = $\boldsymbol{mol\ dm^{-3}}$ (1)
   b) $K_c = \frac{[PCl_5]}{[Cl_2][PCl_3]}$ (1) units = $\frac{(mol\ dm^{-3})}{(mol\ dm^{-3})(mol\ dm^{-3})}$ = $mol^{-1}\ dm^3$ (1)
5. a) $K_c = \frac{[HI]^2}{[H_2]\ [I_2]}$ (1)
   b) equilibrium [illegible] H_2 = 0.4 (1), equilibrium moles of I_2 = 0.4 (1)
   c) K[illegible]) = [illegible]6.5 (1) no units (1)
   0.4[illegible]
6. a) $K_p = \frac{p(CH_4)\ p(H_2O)}{p(CO)\ p(H_2)^3}$ (1) Units = Pa^{-2} (1)
   b) $K_p = \frac{p(O_2)^3}{p(O_3)^2}$ (1) Units = Pa (1)
7. equilibrium moles of A = 2 (1), equilibrium moles of B = 2.5 (1), equilibrium moles
   Mole fraction of A = 2/6 (1), Mole fraction of B = 2.5/6 (1), Mole fraction of C = 1.5
   Partial pressure of A = 166.7 (1), partial pressure of B = 208.3 (1), partial pressure c
   $K_p = \frac{p(C)^2}{p(A)^2\ p(B)}$ (1) = 0.0027 (1) Units = kPa^{-1} (1)

Applications of chemical kinetics, energetics and equilibriu

1. a) Low temperature (1): equilibrium will shift to the right-hand side to favour th
   High pressure (1): equilibrium will shift to the right-hand side to favour the side
   b) A high K_p value means the position of equilibrium sits far to the side of the p
   safer (1) and less expensive (1).
   c) To increase rate (1)
   d) i. No effect on position of equilibrium (1)
      ii. Increases rate (1), provides an alternative route with a lower activation e

Applications of green chemistry

1. Allows a reaction to occur at lower temperatures (1); this reduces the need to bur
   in lower fuel costs (1) and lower production of greenhouse gases (1)
2. a) % atom economy = (M_r useful products ÷ M_r total products) × 100
   M_r useful products = 92 (1)
   M_r total products = 180 (1)
   (92 ÷ 180) × 100 = 51.1% (1)
   b) Uses a renewable resource (1); carried out at lower temperatures / lower fuel
   c) A[illegible] fr[illegible] very slow (1); poor atom economy (1); production of carbon di

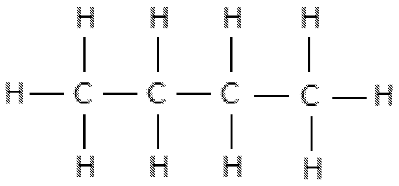
E: Organic chemistry

Key terms

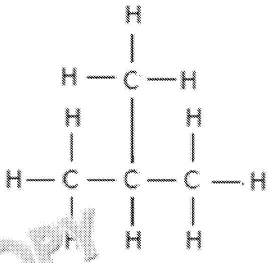
1. A compound made of only carbon and hydrogen atoms (1)
2. a) A series of compounds with the same functional group (1) but differing by a
   b) Alcohol (1)
   c) General formula: $C_nH_{2n+1}OH$ (1); fifth member = $C_5H_{11}OH$ (1)
3. a) i. Unsaturated (1)
   ii. Saturated (1)
   iii. Unsaturated (1)
   iv. Saturated (1)
   b) i. Cyclic (1)
   ii. Branched (1)
   iii. Branched (1)
   iv. Straight chain (1)

Structure representations

1. a)



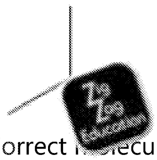
(1)



(1)

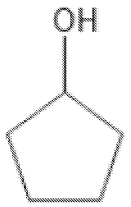
   b) $CH_3CH_2CH_2CH_3$ (1); $CH_3CH(CH_3)CH_3$ (1)

2.



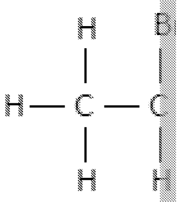
Correct molecule (1); represented skeletally (1)

3.



Correct molecule (1); represented skeletally (1)

4.

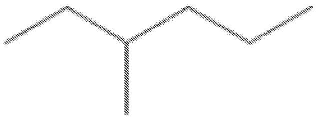


Correct molecul
formula (1) *Allow*

Naming alkanes, alkenes, halogenoalkanes and alcohols

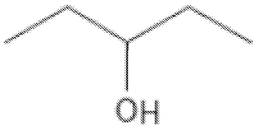
1. (Accept any type of structural representation as long as the molecule is correct)

a)



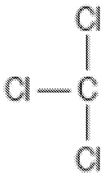
(1)

b)



(1)

c)

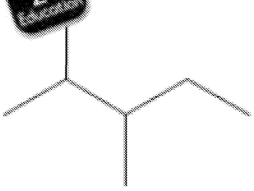


d)

2. a) Ethanol (1)
   b) But-1-ene (1)
   c) Bromoethane (1)
   d) 2-methylbutane (1)

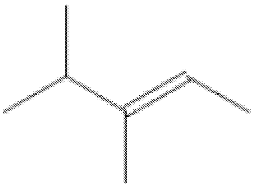
3. (Accept any type of structural representation as long as the molecule is correct)

a)



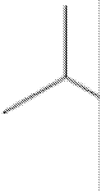
(1)

b)

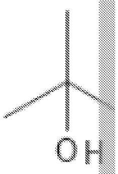


(1)

c)



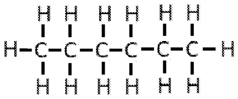
d)



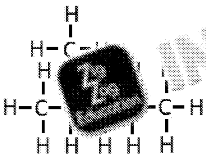
4. a) 2,2-dibromo-3-fluorobutane (1)
   b) 1-bromobut-2-ene (1)
   c) 3-methylbutan-1-ol (1)
   d) 2,3-dibromobutane (1)

Isomerism

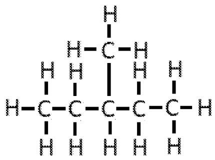
1. a) Compounds with the same molecular formula but different structural formul
   b) Compounds with the same structural formula but different arrangements of
2. a) Structural isomerism (1)
   b) Stereoisomerism (1)
3. Allow any structural representation. (1) for each correct structure; (1) for each co



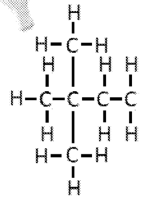
HEXANE

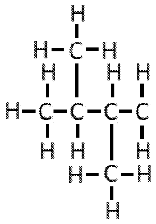


2-METHYLPENTANE

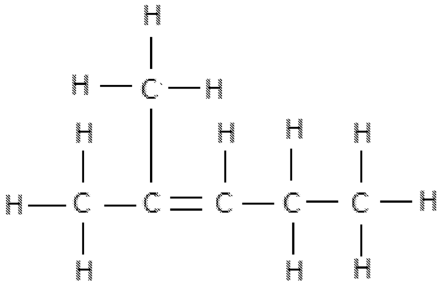


3-METHYLPENTANE



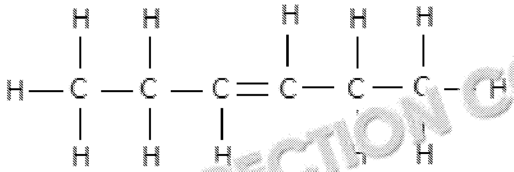


4. a)



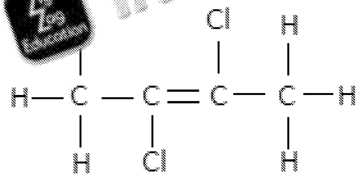
(1); No stereoisomerism (1)

b)



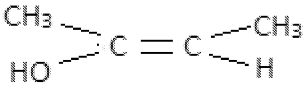
(1); Stereoisomerism (1)

c)

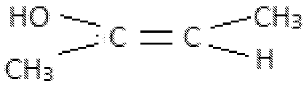


(1); Stereoisomerism (1)

5.



(1); E-but-2-en-2-ol or cis-but-2-en-2-ol (1)

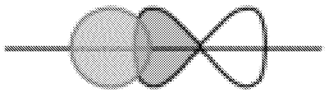


(1); Z-but-2-en-2-ol or trans-but-2-en-2-ol (1)

6. a) No isomerism (1)
   b) Stereoisomerism and structural isomerism (1)
   c) Structural isomerism (1)

Sigma and pi molecular orbitals

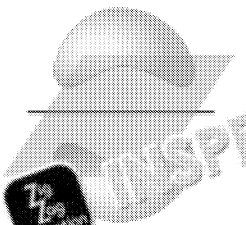
1. a)



(1)

   b) Sigma bond (1)

2. a)



(1)

   b) p orbitals (1)

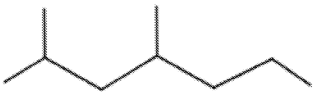
3. Sigma bond has end-to-end overlap of orbitals whereas pi bond is sideways overl
Sigma bond has shared electron density between the nuclei whereas pi bond has
the plane of the nuclei (1)

4. a) i. 13 (1) ii. 8 (1) iii. 16 (1) iv. 15 (1)
   b) i. 0 (1) ii. 1 (1) iii. 0 (1) iv. 2 (1)

Changes in boiling point

1. From highest to lowest:

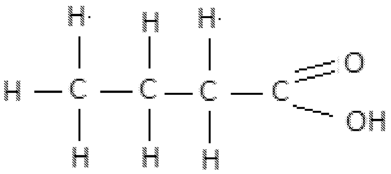
(all three corre



2. The boiling point depends on the strength of the intermolecular/London forces (1
higher the boiling point (1). Molecule b) has the longest chain and no branching,
and London forces are great (1). Molecule a) has the shortest chain and therefore
weakest London forces (1).

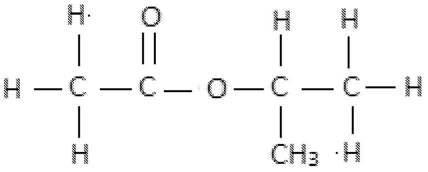
Reactions of organic compounds

1. a) Substitution (1)
   b) Oxidation (1)
   c) Elimination (1)
   d) Addition (1)
2. a) $H_2O_{(g)}$/steam (1), H_3PO_4 (1)
   b) NaOH (1), aqueous (1)
   c) H_2SO_4 (1), heat (1)
   d) H_2 (1), 423 K (1), Ni/Pt catalyst (1)
   e) Cl_2 (1), UV light (1)
3. a)



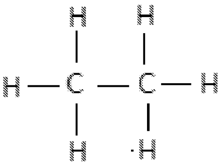
(1 mark for functional group)

   b)



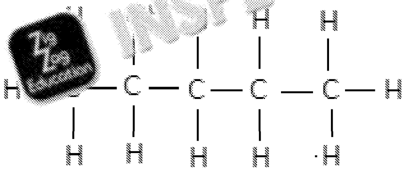
(1)

   c)



(1)

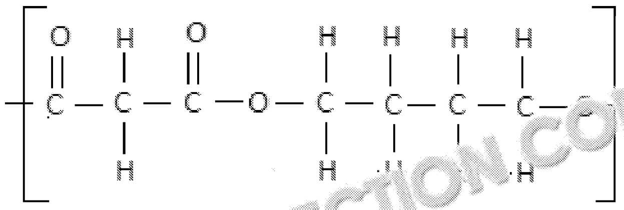
   d)



(1)

Reactions of commercial importance

1. a) $C_3H_7OH + 4.5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$ (1 mark for correct products) (1 mark for
   b) Incomplete combustion would occur (1); carbon monoxide / carbon (soot) w carbon dioxide (1)
2. Short chain alkanes are more valuable/useful than long chains (1); the supply of s the demand (1); long chain alkanes are broken down to produce more – shorter c
3. Alkene (1); undergoes addition polymerisation (1); the double bond breaks (1) an chain (1)
4. A polymer containing the following repeating unit:



(1); H_2O (1)

Combus[illegible] CFCs, polymers and alcohol

1. Any thre[illegible]m (1 mark each):
   Medicine, farming, materials, biotechnology, perfumes
2. Any three from (1 mark each):
   Using certain solvents can pollute the air; Many organic reactions produce hazard consumption leading to high carbon emissions; Use of toxic chemicals like heavy pollutants that don't break down easily
3. Benefits: Provides large amounts of energy quickly (1), reliably (1), and relatively c
   Problems: Production of carbon dioxide, a greenhouse gas (1); Production of carb combustion (1); Consumption of non-renewable fossil fuels (1)
4. Useful because they are non-flammable and non-toxic (1); Good for use as refrige environmental issue by destroying the ozone layer when they collect in the upper
5. Benefits: Wide range of monomers allows a variety of polymers with different pro
   Problems: Consumption of non-renewable fossil fuels (1); Non-biodegradable, lea

Solutions to environmental problems

1. Solar energy (1); Wind energy (1); Hydroelectric energy (1)
2. Initially developed due to low toxicity and flammability (1); Cause environmental h upper atmosphere to form chlorine radicals (1); These chlorine radicals break dow
3. HFCs have low flammability and toxicity like CFCs (1); HFCs lack chlorine atoms (1) depletion (1)
4. Benefits: Reduces landfill waste (1); Conserves resources, especially crude oil prod
   Challenges: Labour-intensive due to the need for sorting by type (1); Mixed polym materials (1); Toxic by-products, like hydrogen chloride from PVC, may be release
5. Using sustainable farming methods (1); Practices such as organic farming (1); Cro