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PUBLISHING

ADVANCED Higher CHEMISTRY

BrightRED **Study Guide**

CfE

ADVANCED Higher

CHEMISTRY



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**NEW
EDITION**

INTRODUCTION

INTRODUCING ADVANCED HIGHER CHEMISTRY

COURSE STRUCTURE

The Advanced Higher Chemistry course is divided into four main areas of chemistry:

- Inorganic chemistry
- Physical chemistry
- Organic chemistry and instrumental analysis
- Researching chemistry

In the **Inorganic** section, you will discover how electromagnetic radiation is used in atomic spectroscopy to identify elements and your understanding of the concept of atomic structure will be extended by considering atomic orbitals and electronic configurations. You will learn, through valence shell electron pair repulsion theory, how to predict the shapes of molecules and ions. The physical and chemical properties of transition metals and their compounds are investigated.

In the **Physical** section your knowledge of chemical equilibria will be extended by considering the quantitative aspects of equilibria. You will also develop an understanding of the factors that influence the feasibility of chemical reactions. Your understanding of reaction rates and reaction mechanisms will be progressed by a study of reaction kinetics.

The **Organic chemistry and instrumental analysis** section will allow you to expand your knowledge and understanding of organic chemistry. You will study the structure and bonding in organic compounds and draw on this to explain their physical and chemical properties and to explain the origin of colour in some organic compounds. Key organic reaction types and mechanisms will be considered, which will allow you to devise ways of synthesising organic compounds from simpler molecules. You will also learn how elemental analysis and various spectroscopic techniques are used to verify chemical structures. This section concludes with a study of medicines and their interactions.

The **Researching chemistry** area gives you the opportunity to gain an understanding of stoichiometric calculations, to develop practical skills and to carry out research in chemistry. You will develop the key skills associated with a variety of practical techniques and by using this knowledge, along with an understanding of the basic concepts, you will be able to identify, research, plan and safely carry out a practical investigation of your choice. This section will also equip you with the scientific background and skills necessary to analyse scientific papers and to use them to make informed choices and decisions.

BENEFITS OF ADVANCED HIGHER CHEMISTRY

Advanced Higher Chemistry is a challenging, but rewarding, course. It has been devised to allow you to develop the ability to think analytically, creatively and independently, and to make reasoned evaluations. The course emphasises practical and experiential learning opportunities with a strong skills-based approach.

As well as providing an excellent grounding for the future study of chemistry and chemistry-related subjects, Advanced Higher Chemistry is highly regarded by employers.

EXTERNAL ASSESSMENT

At the end of the course you will be assessed externally by two components.

Component 1: Question paper – 110 marks (scaled to 120 marks, 75% of the total marks)

The duration of the question paper is 3 hours and it is divided into two sections:

- Section 1 is made up of 25 multiple-choice questions and is worth 25 marks
- Section 2 is made up of both restricted- and extended-response questions and is worth 85 marks

Marks are distributed, proportionally, across the inorganic, physical, organic chemistry and instrumental analysis and researching areas. Many of the marks will be awarded for applying knowledge and understanding of the course with the remaining marks being awarded for applying scientific enquiry and problem-solving skills. Section 2 also includes two open-ended questions with three marks allocated to each one. You will be able to recognise these questions by the phrase '**using your knowledge of chemistry**'. These questions will not directly assess the knowledge taught throughout the course, but instead, you are to use the knowledge you do have to suggest possible answers.

Component 2: Project report – 25 marks (scaled to 40 marks, 25% of the total marks)

As part of the course you will investigate/research an in-depth study of a chemistry topic, chosen by you in consultation with your teacher/lecturer. In general, the project will have the following format: planning; researching; investigating; collecting and analysing data; evaluation findings; and finally, producing a written scientific report, which will be submitted to the Scottish Qualifications Authority (SQA) for marking. You will find more information about the project on pages 98 to 101.

GRADING

The course assessment is graded A, B, C or D depending on how well you do in the written examination **and** the project report – in other words, your total mark out of 160 (scaled marks).

HOW THIS GUIDE WILL HELP YOU TO MEET THE CHALLENGES

The main aim of this Study Guide is to help you achieve success in the SQA Advanced Higher Chemistry examination by providing you with concise, but comprehensive, coverage of the areas of the course. Helpful hints and advice are provided in the **Don't forget** sections. The **Things to do and think about** sections provide questions to test your knowledge and understanding of the content and to help you extend your problem-solving skills. In a number of cases, the **Things to do and think about** section provides additional information to extend your knowledge of chemistry and to stimulate your interest in the subject. The **Online tests**, which consist of multiple-choice questions, are a useful tool to check your progress throughout the course and provide relevant feedback. The Study Guide also includes a section offering very useful advice on the production of the Project Report.

DON'T FORGET

The question paper will be set and marked by the SQA.

DON'T FORGET

A data booklet containing the relevant data and formulae will be provided for you in the exam.

DON'T FORGET

To gain a course award you will need to submit a project report for external marking and sit the written examination.

INORGANIC CHEMISTRY

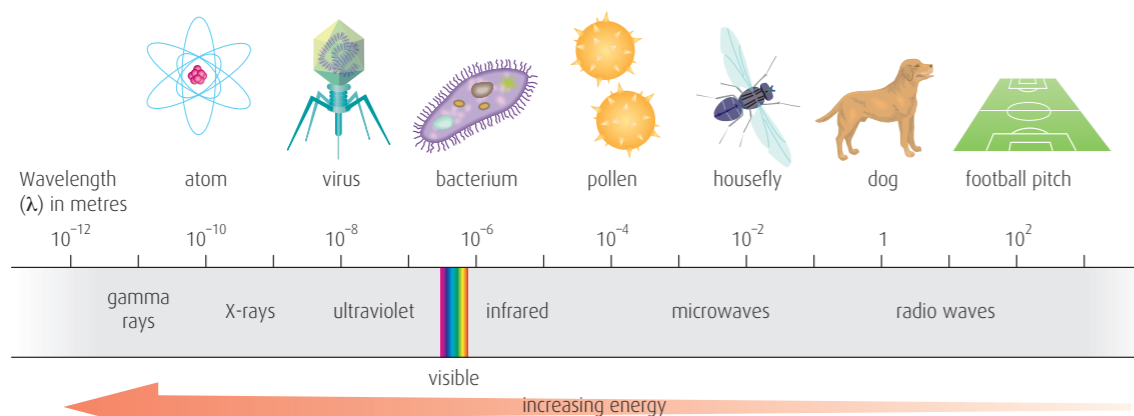
ELECTROMAGNETIC RADIATION AND ATOMIC SPECTRA 1

ELECTROMAGNETIC RADIATION

Chemical reactions take place when the reacting atoms, molecules or ions collide with each other. Therefore the outer electrons are involved when different substances react together and we need to understand the electronic structure of atoms to explain the chemical properties of the elements. Much of the information about the electronic structure of atoms and molecules is obtained using spectroscopic techniques based on different types of electromagnetic radiation.

Electromagnetic radiation includes visible light, microwaves, X-rays and television signals. Electromagnetic radiation can be considered as waves that travel in a vacuum at a constant speed of $3.00 \times 10^8 \text{ m s}^{-1}$ with wavelengths between 10^{-14} and 10^4 m .

Different types of electromagnetic radiation make up the electromagnetic spectrum. Visible light – the radiation that our eyes can detect – makes up only a small part of the electromagnetic spectrum.



The diagram shows some of the different types of radiation that make up the electromagnetic spectrum. At the high energy end of the spectrum, the waves are so tightly packed that they are closer together than the size of an atom, whereas at the low energy end the waves are further apart than the length of a football pitch.

WAVELENGTH, FREQUENCY AND VELOCITY OF ELECTROMAGNETIC RADIATION

As electromagnetic radiation may be described in terms of waves, it can be specified by its wavelength and/or its frequency.

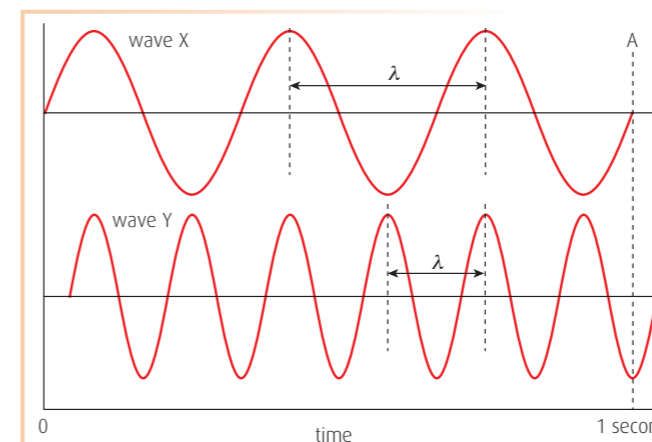
Wavelength is the distance between adjacent crests or high points of a wave. This distance can be measured in metres. However, in chemistry, the unit of wavelength most often used is the nanometre (nm). One nanometre is 10^{-9} m . The symbol for wavelength is the Greek letter lambda (λ).

Frequency is the number of wavelengths that pass a fixed point in one second. The symbol for frequency is f . Frequency is measured as $1/\text{time}$ and so has units of s^{-1} . This unit is also known as the Hertz (Hz).

All types of electromagnetic radiation travel at the same **velocity** in a vacuum. The velocity is $3.00 \times 10^8 \text{ m s}^{-1}$. This value is given the symbol, c , and it is assumed to be the constant velocity of electromagnetic radiation anywhere.

The relationship between frequency, velocity and wavelength is $f = \frac{c}{\lambda}$ or $c = f\lambda$.

contd



The wavelength of wave X has double the value of the wavelength of wave Y. As both waves travel at the same velocity ($c = 3 \times 10^8 \text{ m s}^{-1}$), then twice as many wavelengths of wave Y will pass position A every second compared to wave X. This means that the frequency of wave Y is twice that of wave X.

DON'T FORGET

The relationship between velocity, frequency and wavelength is $c = f\lambda$. You must be able to use this relationship in calculations.

VIDEO LINK

Watch the video clip on the electromagnetic spectrum at www.brightredbooks.net.

DON'T FORGET

You must be able to use the relationships given on this page.

ONLINE

Values of Planck's constant and Avogadro's constant are given on p. 22 of the SQA Data Booklet. The relationships $c = f\lambda$ and $E = hf$ are given on p. 4 of the SQA Data Booklet. The SQA Data Booklet can be downloaded from www.brightredbooks.net.

VIDEO LINK

Check out the video clip on the dual nature of electrons at www.brightredbooks.net.

ONLINE TEST

Head to www.brightredbooks.net and test yourself on this topic.

DUAL NATURE OF ELECTROMAGNETIC RADIATION: WAVES AND PARTICLES

Electromagnetic radiation can be absorbed or emitted. The absorption of ultraviolet radiation by our skin may cause sunburn. When we cook food in a microwave oven, the absorption of microwave radiation by the water in the food causes the water molecules to vibrate, generating heat that cooks the food. However, when electromagnetic radiation is absorbed or emitted by matter, it behaves more like a stream of particles than as a wave motion. These particles are called **photons** and so electromagnetic radiation can be considered both as a stream of photons and as waves with characteristic properties, such as wavelength (λ) and frequency (f). Therefore we say that electromagnetic radiation has a dual nature: wave motion and streams of photons.

Electromagnetic radiation that has a **short wavelength** and **high frequency**, such as gamma rays, is at the **high energy** end of the electromagnetic spectrum.

Radio waves and other radiation with a **long wavelength** and **low frequency** are at the **low energy** end of the electromagnetic spectrum.

When a photon is absorbed or emitted, energy is gained or lost by electrons within the substance. The photons in high frequency radiation transfer greater amounts of energy than photons in low frequency radiation.

This tells us that the energy, E , carried by a photon is related to its frequency. The relationship between energy and frequency is $E = hf$, where h is Planck's constant and has the value $6.63 \times 10^{-34} \text{ J s}$. Using this relationship, the energy is calculated in joules (J). In chemistry, energy values are normally expressed in units of kJ mol^{-1} . To convert from J to kJ mol^{-1} the number value must be divided by 1000. To obtain mol^{-1} in units of kJ mol^{-1} , the relationship changes to $E = Lhf$, where L is Avogadro's constant. L has the value $6.02 \times 10^{23} \text{ mol}^{-1}$.

Therefore $E = hf$ gives the energy value in J, $E = Lhf$ gives the energy in J mol^{-1} and $E = \frac{Lhf}{1000}$ gives the energy in kJ mol^{-1} .

When the energy is in units of kJ mol^{-1} , this is the energy associated with one mole of photons. Avogadro's constant is the number of formula units in one mole of a substance and so the number of photons in one mole of photons is 6.02×10^{23} photons.

It is often useful to relate energy, in kJ mol^{-1} , to wavelength. As $f = \frac{c}{\lambda}$, then $E = \frac{Lhc}{1000\lambda}$.

THINGS TO DO AND THINK ABOUT

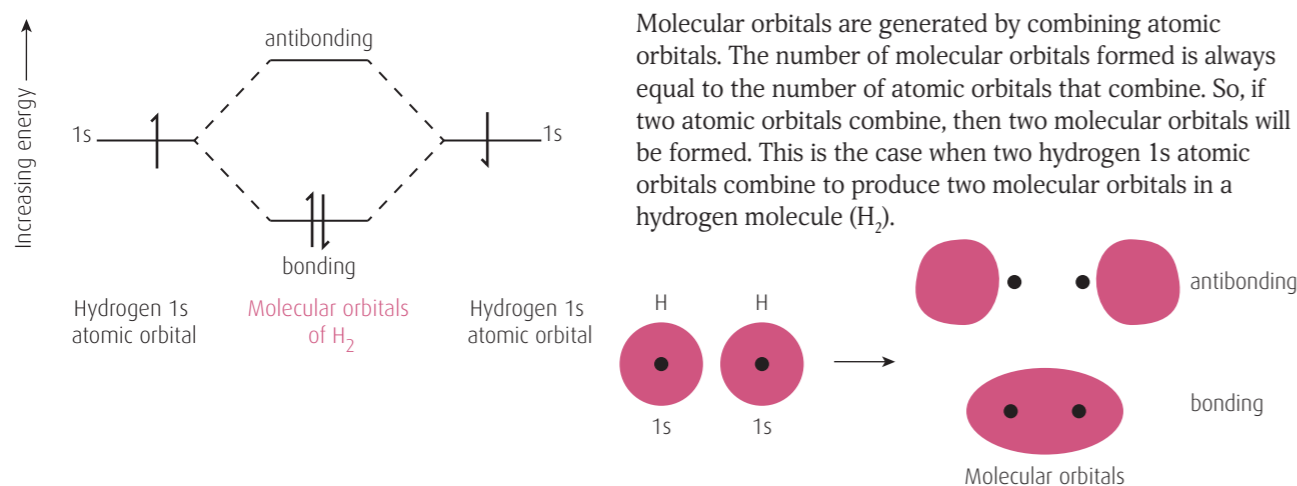
Velocity is measured in m s^{-1} , wavelength is measured in m and frequency is measured in s^{-1} .

When the units are substituted into the equation $c = \lambda f$, the value for c is given in m s^{-1} and the value for λf is also in m s^{-1} . However, in most chemistry calculations the wavelength is given in nm (10^{-9} m), so you must remember to convert the wavelength from nm into metres by dividing by 10^9 when you are using this equation.

MOLECULAR ORBITALS 1

FORMATION OF MOLECULAR ORBITALS

VSEPR (Valence Shell Electron Pair Repulsion) theory cannot explain the bonding in all compounds. In more complex molecules the bonding can be explained in terms of **molecular orbital theory**. The molecular orbital approach is based on the idea that, as electrons in **atoms** occupy **atomic orbitals**, electrons in **molecules** occupy **molecular orbitals**. Molecular orbitals have many of the same properties as atomic orbitals. They are populated by electrons, beginning with the orbital with the lowest energy and a molecular orbital is full when it contains two electrons of opposite spin.



The diagram on the left shows that one of the molecular orbitals is lower in energy than either of the two atomic orbitals that combined to produce it. This is called a **bonding molecular orbital**. The other molecular orbital is known as an **antibonding molecular orbital** and it is of higher energy than either of the atomic orbitals that combined to produce it. The H_2 molecule has only two electrons and both occupy the bonding molecular orbital; the antibonding molecular orbital is empty. The other diagram shows the shapes of the two molecular orbitals. You can see that the bonding molecular orbital embraces both nuclei, unlike the antibonding molecular orbital. In general, the attraction of the positively charged nuclei to the negatively charged electrons occupying the bonding molecular orbital is the basis of bonding between atoms.

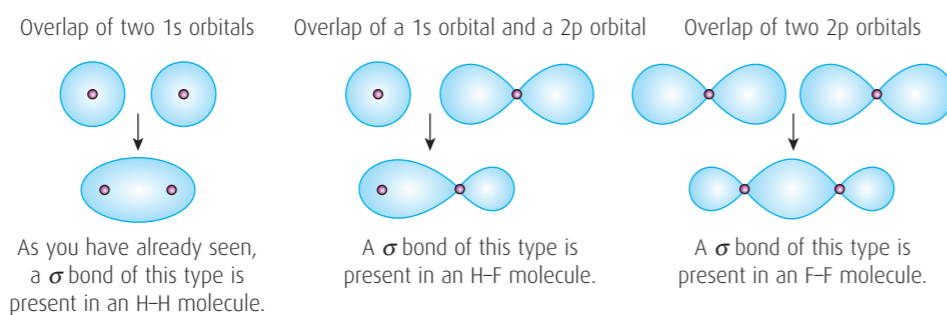
DON'T FORGET



When two atomic orbitals combine, two molecular orbitals (one bonding and the other antibonding) are formed.

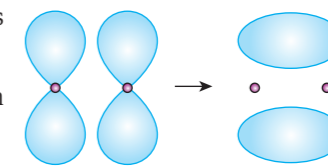
SIGMA AND PI BONDS

The formation of **bonding** molecular orbitals by an overlap of atomic orbitals applies not only to the 1s orbitals of hydrogen, but also to other atomic orbitals. When the atomic orbitals overlap along the axis of the bond, a covalent bond, called a **sigma (σ) bond**, results. This is normally referred to as **'end-on' overlap**. Some examples of the formation of σ bonds from overlapping atomic orbitals are shown in the diagrams.



contd

Consider now the overlap of two parallel p atomic orbitals that lie perpendicular to the axis of the bond:

Formation of a π bond.

The atomic orbitals overlap laterally or **'side-on'** and form a **pi (π) bond**.

π bonds arise when atoms form multiple bonds. The double bond in an oxygen molecule, for example, comprises one σ bond and one π bond, while the triple bond in a nitrogen molecule is made up of one σ bond and two π bonds. Side-on overlap of atomic orbitals is much less efficient than end-on overlap and, as a consequence, **π bonds are weaker than σ bonds**. This is borne out by the fact that a carbon-to-carbon double bond is not twice as strong as a carbon-to-carbon single bond (see p. 10 of the SQA Data Booklet).

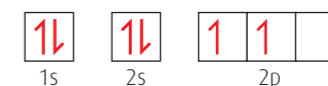
DON'T FORGET

Sigma (σ) bonds are formed by the end-on overlap of atomic orbitals and π bonds result from side-on overlap.

HYBRIDISATION

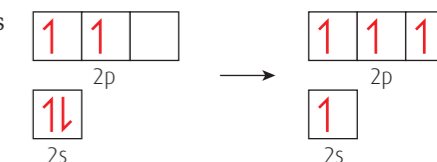
Carbon is the basis of all organic compounds and forms four covalent bonds. In many of these, the arrangement of the four bonds around the carbon atom is tetrahedral.

In its ground state, a carbon atom has the electronic configuration $1s^2 2s^2 2p^2$, which, in orbital box notation is:



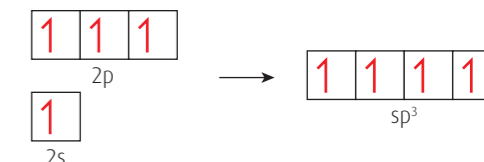
As you can see, carbon has two half-filled orbitals in the 2p subshell and, at first sight, it might have been expected to form two covalent bonds rather than the four. So why does carbon form four covalent bonds?

Carbon has one empty 2p orbital and so we can obtain more half-filled orbitals by promoting one of the paired 2s electrons into this empty 2p orbital:



The carbon atom now has four unpaired electrons and can form four bonds, but we still have not explained why these bonds adopt a tetrahedral arrangement. To do this, we introduce the concept of hybridisation.

Hybridisation is the process of mixing atomic orbitals within an atom to generate a set of new atomic orbitals called **hybrid orbitals**. In the case of a carbon atom, the **one** 2s orbital can mix with the **three** 2p orbitals to form **four** hybrid orbitals known as **sp^3 hybrid orbitals**.



The four sp^3 hybrid orbitals are degenerate and, as they are identical in shape, they will point towards the corners of a tetrahedron to minimise repulsion.

It is important to note that sp^3 hybridisation is not the only type of hybridisation shown by carbon (see p. 50), nor is hybridisation limited to carbon.

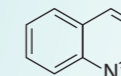
It is also important to appreciate that the number of hybrid orbitals formed is always equal to the number of atomic orbitals that were mixed.

DON'T FORGET

Hybridisation is the process of mixing atomic orbitals within an atom to form a set of degenerate hybrid orbitals.

THINGS TO DO AND THINK ABOUT

1 Quinoline has the following structure:



State the number of (a) σ bonds and (b) π bonds in a molecule of quinoline. (Hint: drawing the full structural formula of quinoline will help.)

2 In iodine heptafluoride, IF_7 , the iodine atom uses sp^3d^3 hybrid orbitals.

State the number and type of atomic orbitals that mix to form the set of sp^3d^3 hybrid orbitals.

VIDEO LINK

For an overview of σ bonding, π bonding and hybridisation, visit www.brightredbooks.net

ONLINE TEST

Test your knowledge of molecular orbitals 1 at www.brightredbooks.net

RESEARCHING CHEMISTRY

TECHNIQUES USED IN THE PREPARATION AND PURIFICATION OF COMPOUNDS 1

The techniques listed below are often used as part of the synthesis and/or analysis of compounds:

- refluxing
- recrystallisation
- vacuum filtration
- distillation
- solvent extraction/use of a separating funnel
- determination of percentage yield
- determination of melting point and mixed melting point
- use of thin-layer chromatography to assess product purity

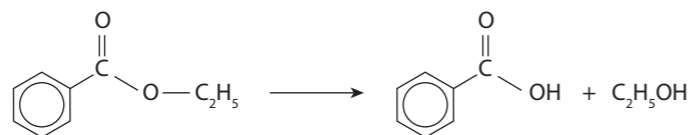
Most synthesis reactions will result in an impure product being formed as part of the reaction mixture. Impurities can include those present in the original starting materials (the reactants), unreacted reactants and the products formed in side reactions. It is usually necessary to remove the impurities from the desired product. There are a number of techniques that can be used to isolate and purify a desired product from a reaction mixture.

The pure products will often need to be analysed to either confirm their identity or to assess their purity.

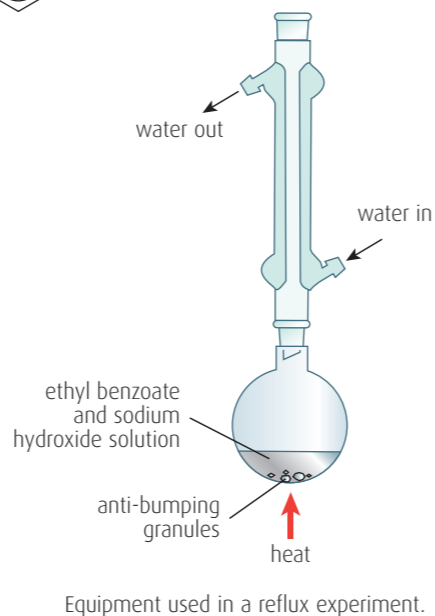
You may carry out all of these techniques during one experiment. An example that uses many of these techniques is the alkaline hydrolysis of the ester ethyl benzoate to produce benzoic acid.

REFLUXING

The alkaline hydrolysis of ethyl benzoate is carried out by **refluxing** a known, accurate mass of ethyl benzoate with sodium hydroxide solution. The overall equation for the reaction is:



Refluxing is a technique that allows substances to be heated for a prolonged period of time without the volatile reactants and/or products escaping into the atmosphere. The hydrolysis mixture is placed in a round-bottomed flask, along with some anti-bumping granules. When a reaction mixture is heated, there is a tendency for it to boil violently as large bubbles of superheated vapour suddenly erupt from the mixture. This is prevented by the addition of the anti-bumping granules. A condenser is placed in the mouth of the flask and connected to a cold-water tap (water goes in at the bottom and out at the top). The flask is then heated and the vapours produced are condensed back into liquids when they reach the cool condenser.



DON'T FORGET



Refluxing allows a reaction mixture to be heated for some time without any of the volatile substances escaping from the apparatus

VIDEO LINK



Watch the video clip showing reflux at www.brightredbooks.net

RECRYSTALLISATION

Recrystallisation is a technique used to purify an impure solid. You may have used this technique to purify an impure sample of benzoic acid.

The first step is to dissolve the impure solid in the minimum volume of an appropriate solvent. A small volume of hot solvent (water) is added to the impure solid (benzoic acid) and the mixture is heated. If the solid does not fully dissolve, more solvent is added. This process continues until all the solid has dissolved.

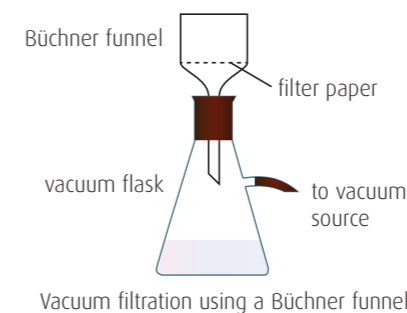
The solvent is chosen so that the desired product is readily soluble in it at high temperatures, but only sparingly soluble at lower temperatures so that crystals form as the hot mixture cools down. The solvent used to recrystallise benzoic acid is water.

Any insoluble impurities are removed by filtration. This is usually carried out as hot filtration. The filter funnel and conical flask used in the filtration are heated before use. This prevents the solvent mixture from cooling prematurely and forming crystals on both the filter paper and in the stem of the funnel.

The filtrate is now a hot saturated solution of the product and a dilute solution of impurities. As the solution cools down, the product crystallises out (it is less soluble at lower temperatures) and the impurities remain dissolved in the solvent. Once crystallisation is complete, the mixture is filtered.

VACUUM FILTRATION

Vacuum filtration involves carrying out filtration under reduced pressure and provides a faster method of separating a precipitate from a filtrate than traditional gravity filtration methods. A Büchner, Hirsch or sintered glass funnel can be used during vacuum filtration.



The pure recrystallised solid product collects on the filter paper. The filtrate contains a solution of soluble impurities. The solid product should now be washed with a small volume of cold solvent. This removes any soluble impurities that are mixed in with the pure solid.

The pure solid can be dried and weighed. A **percentage yield** can be calculated from its mass. The pure solid will often be subjected to analysis by **melting point** and **thin-layer chromatography** (see pp. 96–97).

THINGS TO DO AND THINK ABOUT

In a synthesis reaction, an impure sample of aspirin was prepared from 2-hydroxybenzoic acid and ethanoic anhydride. The reaction mixture was heated for approximately 10 minutes.

1. Suggest why reflux was not used during this reaction.
2. The impure aspirin sample was then purified by recrystallisation from ethanol. Describe the steps the chemist would need to take to purify the aspirin sample using this technique.
3. Ethanol was used as the solvent to recrystallise aspirin. Suggest why ethanol is a good choice of solvent.



VIDEO LINK

Check out the video clip showing recrystallisation at www.brightredbooks.net



VIDEO LINK

Head to www.brightredbooks.net for a video clip showing hot filtration.



DON'T FORGET

Recrystallisation is used to purify impure solids from a solvent in which the solid is soluble at high temperatures, but virtually insoluble at lower temperatures.



ONLINE

Watch the video clip of vacuum filtration at www.brightredbooks.net



ONLINE TEST

Test your knowledge of reflux, recrystallisation and vacuum filtration at www.brightredbooks.net

CfE ADVANCED Higher

CHEMISTRY

Archie Gibb, Dr David Hawley and Dr Shona Scheuerl

This BrightRED Study Guide is the ultimate companion to your CfE Advanced Higher Chemistry studies! Written by our trusted authors and experienced Chemistry teachers, Archie Gibb, Dr David Hawley and Dr Shona Scheuerl, this book is full-colour and packed with clear and accessible information, excellent examples, activities and advice. Inside, you will find:

- ▶ **All the essential course information, fully up-to-date with SQA course changes and additional new content**, arranged in easily digestible double-page topic spreads.
- ▶ **Detailed full-colour diagrams, illustrations and data boxes** to make sure all that study sticks!
- ▶ **Don't forget** pointers offering advice on the key facts to remember, and on how to avoid common mistakes.
- ▶ **Things to do and think about** sections encouraging the regular review of key points covered.
- ▶ **Digital Zone activities and tests** to supercharge your learning efforts online!
- ▶ **An index of key terms** to help when revising.

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