4.6 The rate and extent of chemical change

Chemical reactions can occur at vastly different rates. Whilst the reactivity of chemicals is a significant factor in how fast chemical reactions proceed, there are many variables that can be manipulated in order to speed them up or slow them down. Chemical reactions may also be reversible and therefore the effect of different variables needs to be established in order to identify how to maximise the yield of desired product. Understanding energy changes that accompany chemical reactions is important for this process. In industry, chemists and chemical engineers determine the effect of different variables on reaction rate and yield of product. Whilst there may be compromises to be made, they carry out optimisation processes to ensure that enough product is produced within a sufficient time, and in an energy-efficient way.



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****4.6.1 Rate of reaction

4.6.1.1 Calculating rates of reactions

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| **Content** |  |  |  |  | **Key opportunities for skills** |
|  |  |  |  |  | **development** |
|  |  |  |  |
| The rate of a chemical reaction can be found by measuring the | MS 1a |
| quantity of a reactant used or the quantity of product formed over | Recognise and use |
| time: |  |  |  |  |
|  |  |  |  | expressions in decimal |
|  |  |  |  |  |
| *mean rate o f reaction* | = | *quantit y o f reactant used* |  |  | form. |
| *time taken* |
|  |  | MS 1c |
| *mean rate o f reaction* | = | *quantit y o f product f ormed* |  |
|  | Use ratios, fractions and |
| *time taken* |
|  |  |
| The quantity of reactant or product can be measured by the mass in | percentages. |
| grams or by a volume in cm3. | MS 1 d |
| The units of rate of reaction may be given as g/s or cm3/s. | Make estimates of the |
| For the Higher Tier, students are also required to use quantity of | results of simple |
| calculations. |
| reactants in terms of moles and units for rate of reaction in mol/s. |
|  |
| Students should be able to: |  |  |  | MS 4a |
|  |  |  |  |
| • calculate the mean rate of a reaction from given information | Translate information |
| between graphical and |
| about the quantity of a reactant used or the quantity of a product |
| numeric form. |
| formed and the time taken |
|  |
| • draw, and interpret, graphs showing the quantity of product | MS 4b |
| formed or quantity of reactant used up against time | Drawing and interpreting |
| • draw tangents to the curves on these graphs and use the slope |
| appropriate graphs from |
| of the tangent as a measure of the rate of reaction |
| data to determine rate of |
| • (HT only) calculate the gradient of a tangent to the curve on |
| reaction. |
| these graphs as a measure of rate of reaction at a specific time. |
| MS 4c |
|  |  |  |  |  |
|  |  |  |  |  | Plot two variables from |
|  |  |  |  |  | experimental or other data. |
|  |  |  |  |  | MS 4d |
|  |  |  |  |  | Determine the slope and |
|  |  |  |  |  | intercept of a linear graph. |
|  |  |  |  |  | MS 4e |
|  |  |  |  |  | Draw and use the slope of a |
|  |  |  |  |  | tangent to a curve as a |
|  |  |  |  |  | measure of rate of change. |
|  |  |  |  |  |  |



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4.6.1.2 Factors which affect the rates of chemical reactions

|  |  |
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| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Factors which affect the rates of chemical reactions include: the |  |
| concentrations of reactants in solution, the pressure of reacting |  |
| gases, the surface area of solid reactants, the temperature and the |  |
| presence of catalysts. |  |
|  |  |
| Students should be able to recall how changing these factors | This topic offers |
| affects the rate of chemical reactions. | opportunities for practical |
|  | work and investigations in |
|  | addition to required |
|  | practical 5. |
|  |  |

**Required practical 5:** investigate how changes in concentration affect the rates of reactions by amethod involving measuring the volume of a gas produced and a method involving a change in colour or turbidity.

This should be an investigation involving developing a hypothesis.

AT skills covered by this practical activity: 1, 3, 5 and 6.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in [Key opportunities for skills development](#page106) (page 106).

4.6.1.3 Collision theory and activation energy



|  |  |  |
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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
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Collision theory explains how various factors affect rates of reactions. According to this theory, chemical reactions can occur only when reacting particles collide with each other and with sufficient energy. The minimum amount of energy that particles must have to react is called the activation energy.

Increasing the concentration of reactants in solution, the pressure of reacting gases, and the surface area of solid reactants increases the frequency of collisions and so increases the rate of reaction.

Increasing the temperature increases the frequency of collisions and makes the collisions more energetic, and so increases the rate of reaction.



|  |  |
| --- | --- |
| Students should be able to : | WS 1.2 |

* predict and explain using collision theory the effects of changing conditions of concentration, pressure and temperature on the rate of a reaction



|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| • predict and explain the effects of changes in the size of pieces of | MS 5c |
| a reacting solid in terms of surface area to volume ratio | MS 1c |
| • use simple ideas about proportionality when using collision |
|  |
| theory to explain the effect of a factor on the rate of a reaction. |  |
|  |  |

4.6.1.4 Catalysts



|  |  |  |
| --- | --- | --- |
| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
|  |  |  |
| Catalysts change the rate of chemical reactions but are not used up |  | AT 5 |
| during the reaction. Different reactions need different catalysts. |  | An opportunity to |
| Enzymes act as catalysts in biological systems. |  |
|  | investigate the catalytic |
|  |  |
| Catalysts increase the rate of reaction by providing a different |  | effect of adding different |
| pathway for the reaction that has a lower activation energy. |  | metal salts to a reaction |
| A reaction profile for a catalysed reaction can be drawn in the |  | such as the decomposition |
|  | of hydrogen peroxide. |
| following form: |  |
|  |  |



Students should be able to identify catalysts in reactions from their effect on the rate of reaction and because they are not included in the chemical equation for the reaction.

Students should be able to explain catalytic action in terms of activation energy.

Students do not need to know the names of catalysts other than those specified in the subject content.



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4.6.2 Reversible reactions and dynamic equilibrium

4.6.2.1 Reversible reactions



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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
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In some chemical reactions, the products of the reaction can react to produce the original reactants. Such reactions are called reversible reactions and are represented:

*A* + *B  C* + *D*

The direction of reversible reactions can be changed by changing the conditions.

For example:



4.6.2.2 Energy changes and reversible reactions



|  |  |  |
| --- | --- | --- |
| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
|  |  |  |

If a reversible reaction is exothermic in one direction, it is endothermic in the opposite direction. The same amount of energy is transferred in each case. For example:



4.6.2.3 Equilibrium

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| When a reversible reaction occurs in apparatus which prevents the | WS 1.2 |
| escape of reactants and products, equilibrium is reached when the |  |
| forward and reverse reactions occur at exactly the same rate. |  |
|  |  |



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****4.6.2.4 The effect of changing conditions on equilibrium (HT only)

|  |  |
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| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| The relative amounts of all the reactants and products at equilibrium |  |
| depend on the conditions of the reaction. |  |
| If a system is at equilibrium and a change is made to any of the |  |
| conditions, then the system responds to counteract the change. |  |
| The effects of changing conditions on a system at equilibrium can |  |
| be predicted using Le Chatelier’s Principle. |  |
| Students should be able to make qualitative predictions about the |  |
| effect of changes on systems at equilibrium when given appropriate |  |
| information. |  |
|  |  |

4.6.2.5 The effect of changing concentration (HT only)

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| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| If the concentration of one of the reactants or products is changed, |  |
| the system is no longer at equilibrium and the concentrations of all |  |
| the substances will change until equilibrium is reached again. |  |
| If the concentration of a reactant is increased, more products will be |  |
| formed until equilibrium is reached again. |  |
| If the concentration of a product is decreased, more reactants will |  |
| react until equilibrium is reached again. |  |
| Students should be able to interpret appropriate given data to |  |
| predict the effect of a change in concentration of a reactant or |  |
| product on given reactions at equilibrium. |  |
|  |  |



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4.6.2.6 The effect of temperature changes on equilibrium (HT only)



|  |  |  |
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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
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If the temperature of a system at equilibrium is increased:

* the relative amount of products at equilibrium increases for an endothermic reaction
* the relative amount of products at equilibrium decreases for an exothermic reaction.

If the temperature of a system at equilibrium is decreased:

* the relative amount of products at equilibrium decreases for an endothermic reaction
* the relative amount of products at equilibrium increases for an exothermic reaction.

Students should be able to interpret appropriate given data to predict the effect of a change in temperature on given reactions at equilibrium.

4.6.2.7 The effect of pressure changes on equilibrium (HT only)



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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
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For gaseous reactions at equilibrium:

* an increase in pressure causes the equilibrium position to shift towards the side with the smaller number of molecules as shown by the symbol equation for that reaction
* a decrease in pressure causes the equilibrium position to shift towards the side with the larger number of molecules as shown by the symbol equation for that reaction.

Students should be able to interpret appropriate given data to predict the effect of pressure changes on given reactions at equilibrium.

4.7 Organic chemistry

The chemistry of carbon compounds is so important that it forms a separate branch of chemistry. A great variety of carbon compounds is possible because carbon atoms can form chains and rings linked by C-C bonds. This branch of chemistry gets its name from the fact that the main sources of organic compounds are living, or once-living materials from plants and animals. These sources include fossil fuels which are a major source of feedstock for the petrochemical industry. Chemists are able to take organic molecules and modify them in many ways to make new and useful materials such as polymers, pharmaceuticals, perfumes and flavourings, dyes and detergents.



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****4.7.1 Carbon compounds as fuels and feedstock

4.7.1.1 Crude oil, hydrocarbons and alkanes



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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
|  |  |  |
| Crude oil is a finite resource found in rocks. Crude oil is the remains |  | WS 1.2 |
| of an ancient biomass consisting mainly of plankton that was buried |  | Make models of alkane |
| in mud. |  | molecules using the |
|  |  |
| Crude oil is a mixture of a very large number of compounds. Most of |  | molecular modelling kits. |
| the compounds in crude oil are hydrocarbons, which are molecules |  |  |
| made up of hydrogen and carbon atoms only. |  |  |
| Most of the hydrocarbons in crude oil are hydrocarbons called |  |  |
| alkanes. The general formula for the homologous series of alkanes |  |  |
| is CnH2n+2 |  |  |
| The first four members of the alkanes are methane, ethane, |  |  |
| propane and butane. |  |  |
| Alkane molecules can be represented in the following forms: |  |  |
| C2H6 or |  |  |



Students should be able to recognise substances as alkanes given their formulae in these forms.

Students do not need to know the names of specific alkanes other than methane, ethane, propane and butane.



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4.7.1.2 Fractional distillation and petrochemicals

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| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| The many hydrocarbons in crude oil may be separated into | WS 1.2 |
| fractions, each of which contains molecules with a similar number of |  |
| carbon atoms, by fractional distillation. |  |
| The fractions can be processed to produce fuels and feedstock for |  |
| the petrochemical industry. |  |
| Many of the fuels on which we depend for our modern lifestyle, |  |
| such as petrol, diesel oil, kerosene, heavy fuel oil and liquefied |  |
| petroleum gases, are produced from crude oil. |  |
| Many useful materials on which modern life depends are produced |  |
| by the petrochemical industry, such as solvents, lubricants, |  |
| polymers, detergents. |  |
| The vast array of natural and synthetic carbon compounds occur |  |
| due to the ability of carbon atoms to form families of similar |  |
| compounds. |  |
| Students should be able to explain how fractional distillation works |  |
| in terms of evaporation and condensation. |  |
| Knowledge of the names of other specific fractions or fuels is not |  |
| required. |  |
|  |  |

4.7.1.3 Properties of hydrocarbons

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  |  | **development** |
|  |  |
| Some properties of hydrocarbons depend on the size of their | WS 1.2, 4.1 |
| molecules, including boiling point, viscosity and flammability. These | Investigate the properties of |
| properties influence how hydrocarbons are used as fuels. |
| different hydrocarbons. |
| Students should be able to recall how boiling point, viscosity and |
|  |
| flammability change with increasing molecular size. |  |
| The combustion of hydrocarbon fuels releases energy. During |  |
| combustion, the carbon and hydrogen in the fuels are oxidised. The |  |
| complete combustion of a hydrocarbon produces carbon dioxide |  |
| and water. |  |
| Students should be able to write balanced equations for the |  |
| complete combustion of hydrocarbons with a given formula. |  |
| Knowledge of trends in properties of hydrocarbons is limited to: |  |
| • | boiling points |  |
| • | viscosity |  |
| • | flammability. |  |
|  |  |  |



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****4.7.1.4 Cracking and alkenes

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| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Hydrocarbons can be broken down (cracked) to produce smaller, | WS 1.2 |
| more useful molecules. |  |
| Cracking can be done by various methods including catalytic |  |
| cracking and steam cracking. |  |
| Students should be able to describe in general terms the conditions |  |
| used for catalytic cracking and steam cracking. |  |
| The products of cracking include alkanes and another type of |  |
| hydrocarbon called alkenes. |  |
| Alkenes are more reactive than alkanes and react with bromine |  |
| water, which is used as a test for alkenes. |  |
| Students should be able to recall the colour change when bromine |  |
| water reacts with an alkene. |  |
| There is a high demand for fuels with small molecules and so some |  |
| of the products of cracking are useful as fuels. |  |
| Alkenes are used to produce polymers and as starting materials for |  |
| the production of many other chemicals. |  |
| Students should be able to balance chemical equations as |  |
| examples of cracking given the formulae of the reactants and |  |
| products. |  |
| Students should be able to give examples to illustrate the |  |
| usefulness of cracking. They should also be able to explain how |  |
| modern life depends on the uses of hydrocarbons. |  |
| (For Combined Science: Trilogy and Synergy students do not need |  |
| to know the formulae or names of individual alkenes.) |  |
|  |  |



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4.7.2 Reactions of alkenes and alcohols (chemistry only)

4.7.2.1 Structure and formulae of alkenes



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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
|  |  |  |
| Alkenes are hydrocarbons with a double carbon-carbon bond. The |  | WS 1.2 |
| general formula for the homologous series of alkenes is CnH2n |  | Recognise substances that |
| Alkene molecules are unsaturated because they contain two fewer |  | are alkenes from their |
| hydrogen atoms than the alkane with the same number of carbon |  | names or from given |
| atoms. |  | formulae in these forms. |
| The first four members of the homologous series of alkenes are |  | MS 5b |
| ethene, propene, butene and pentene. |  | Visualise and represent 2D |
|  |  |
| Alkene molecules can be represented in the following forms: |  | and 3D forms including two- |
| C3H6 |  | dimensional representations |
|  | of 3D objects. |
| or |  |  |



Students do not need to know the names of individual alkenes other than ethene, propene, butene and pentene.

4.7.2.2 Reactions of alkenes

|  |  |  |
| --- | --- | --- |
| **Content** | **Key opportunities for skills** |  |
|  | **development** |  |
|  |  |  |
| Alkenes are hydrocarbons with the functional group C=C. |  |  |
| It is the generality of reactions of functional groups that determine |  |  |
| the reactions of organic compounds. |  |  |
| Alkenes react with oxygen in combustion reactions in the same way |  |  |
| as other hydrocarbons, but they tend to burn in air with smoky |  |  |
| flames because of incomplete combustion. |  |  |
| Alkenes react with hydrogen, water and the halogens, by the |  |  |
| addition of atoms across the carbon-carbon double bond so that the |  |  |
| double bond becomes a single carbon-carbon bond. |  |  |
|  |  |  |
| Students should be able to: | WS 1.2 |  |
| • describe the reactions and conditions for the addition of |  |  |
| hydrogen, water and halogens to alkenes |  |  |
| • draw fully displayed structural formulae of the first four members |  |  |
| of the alkenes and the products of their addition reactions with |  |  |
| hydrogen, water, chlorine, bromine and iodine. |  |  |
|  |  |  |
|  |  |  |

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****4.7.2.3 Alcohols



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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
|  |  |  |
| Alcohols contain the functional group –OH. |  | AT 2, 5, 6 |
| Methanol, ethanol, propanol and butanol are the first four members |  | Opportunities when |
| of a homologous series of alcohols. |  | investigating reactions of |
| Alcohols can be represented in the following forms: |  | alcohols. |
|  |  |
| CH3CH2OH |  |  |
| or |  |  |



Students should be able to:

* describe what happens when any of the first four alcohols react with sodium, burn in air, are added to water, react with an oxidising agent
* recall the main uses of these alcohols.

Aqueous solutions of ethanol are produced when sugar solutions are fermented using yeast.

Students should know the conditions used for fermentation of sugar using yeast.

Students should be able to recognise alcohols from their names or from given formulae.

Students do not need to know the names of individual alcohols other than methanol, ethanol, propanol and butanol.

Students are not expected to write balanced chemical equations for the reactions of alcohols other than for combustion reactions.



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4.7.2.4 Carboxylic acids



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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
|  |  |  |
| Carboxylic acids have the functional group –COOH. |  | AT 2, 5, 6 |
| The first four members of a homologous series of carboxylic acids |  | Opportunities within |
| are methanoic acid, ethanoic acid, propanoic acid and butanoic |  | investigation of the |
| acid. |  | reactions of carboxylic |
| The structures of carboxylic acids can be represented in the |  | acids. |
|  |  |
| following forms: |  |  |
| CH3COOH |  |  |
| or |  |  |



Students should be able to:

* describe what happens when any of the first four carboxylic acids react with carbonates, dissolve in water, react with alcohols
* (HT only) explain why carboxylic acids are weak acids in terms of ionisation and pH (see [Strong and weak acids (HT only)](#page48) (page 48)).

Students should be able to recognise carboxylic acids from their names or from given formulae.

Students do not need to know the names of individual carboxylic acids other than methanoic acid, ethanoic acid, propanoic acid and butanoic acid.

Students are not expected to write balanced chemical equations for the reactions of carboxylic acids.

Students do not need to know the names of esters other than ethyl ethanoate.



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****4.7.3 Synthetic and naturally occurring polymers (chemistry only)

4.7.3.1 Addition polymerisation



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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
|  |  |  |
| Alkenes can be used to make polymers such as poly(ethene) and |  | WS 1.2 |
| poly(propene) by addition polymerisation. |  | Use models to represent |
|  |  |
| In addition polymerisation reactions, many small molecules |  | addition polymerisation. |
| (monomers) join together to form very large molecules (polymers). |  |  |
| For example: |  |  |



|  |  |
| --- | --- |
| In addition polymers the repeating unit has the same atoms as the |  |
| monomer because no other molecule is formed in the reaction. |  |
|  |  |
| Students should be able to: | MS 5b |
| • recognise addition polymers and monomers from diagrams in | Visualise and represent 2D |
| the forms shown and from the presence of the functional group | and 3D forms including two- |
| C=C in the monomers | dimensional representations |
| • draw diagrams to represent the formation of a polymer from a | of 3D objects. |
| given alkene monomer |  |
| • relate the repeating unit to the monomer. |  |



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4.7.3.2 Condensation polymerisation (HT only)

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| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Condensation polymerisation involves monomers with two | WS 1.2 |
| functional groups. When these types of monomers react they join | Use models to represent |
| together, usually losing small molecules such as water, and so the |
| condensation |
| reactions are called condensation reactions. |
| polymerisation. |
| The simplest polymers are produced from two different monomers |
|  |
| with two of the same functional groups on each monomer. |  |
| For example: |  |
| ethane diol |  |
| and |  |
| hexanedioic acid |  |
| polymerise to produce a polyester: |  |
|  |  |
| Students should be able to explain the basic principles of | MS 5b |
| condensation polymerisation by reference to the functional groups | Visualise and represent 2D |
| in the monomers and the repeating units in the polymers. |
|  | and 3D forms including two- |
|  | dimensional representations |
|  | of 3D objects. |
| 4.7.3.3 Amino acids (HT only) |  |
|  |
|  |  |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Amino acids have two different functional groups in a molecule. |  |
| Amino acids react by condensation polymerisation to produce |  |
| polypeptides. |  |
| For example: glycine is H2NCH2COOH and polymerises to produce |  |
| the polypeptide |  |
| (-HNCH2COO-)n and n H2O |  |
| Different amino acids can be combined in the same chain to |  |
| produce proteins. |  |
|  |  |



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****4.7.3.4 DNA (deoxyribonucleic acid) and other naturally occurring polymers



|  |  |  |
| --- | --- | --- |
| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
|  |  |  |

DNA (deoxyribonucleic acid) is a large molecule essential for life. DNA encodes genetic instructions for the development and functioning of living organisms and viruses.

Most DNA molecules are two polymer chains, made from four different monomers called nucleotides, in the form of a double helix. Other naturally occurring polymers important for life include proteins, starch and cellulose.

Students should be able to name the types of monomers from which these naturally occurring polymers are made.

4.8 Chemical analysis

Analysts have developed a range of qualitative tests to detect specific chemicals. The tests are based on reactions that produce a gas with distinctive properties, or a colour change or an insoluble solid that appears as a precipitate.

Instrumental methods provide fast, sensitive and accurate means of analysing chemicals, and are particularly useful when the amount of chemical being analysed is small. Forensic scientists and drug control scientists rely on such instrumental methods in their work.

4.8.1 Purity, formulations and chromatography

4.8.1.1 Pure substances

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| In chemistry, a pure substance is a single element or compound, | WS 2.2, 4.1 |
| not mixed with any other substance. |  |
| Pure elements and compounds melt and boil at specific |  |
| temperatures. Melting point and boiling point data can be used to |  |
| distinguish pure substances from mixtures. |  |
| In everyday language, a pure substance can mean a substance |  |
| that has had nothing added to it, so it is unadulterated and in its |  |
| natural state, eg pure milk. |  |
| Students should be able to use melting point and boiling point data |  |
| to distinguish pure from impure substances. |  |
|  |  |



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4.8.1.2 Formulations

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| A formulation is a mixture that has been designed as a useful | WS 1.4, 2.2 |
| product. Many products are complex mixtures in which each |  |
| chemical has a particular purpose. Formulations are made by |  |
| mixing the components in carefully measured quantities to ensure |  |
| that the product has the required properties. Formulations include |  |
| fuels, cleaning agents, paints, medicines, alloys, fertilisers and |  |
| foods. |  |
| Students should be able to identify formulations given appropriate |  |
| information. |  |
| Students do not need to know the names of components in |  |
| proprietary products. |  |
|  |  |

4.8.1.3 Chromatography



|  |  |  |
| --- | --- | --- |
| **Content** |  | **Key opportunities for skills** |
|  |  |  |  |  | **development** |
|  |  |  |  |
| Chromatography can be used to separate mixtures and can give |  | WS 2.2, 3.1, 2, 3 |
| information to help identify substances. Chromatography involves a |  | MS 1a |
| stationary phase and a mobile phase. Separation depends on the |  |
|  |  |
| distribution of substances between the phases. |  | Recognise and use |
| The ratio of the distance moved by a compound (centre of spot from |  | expressions in decimal |
| origin) to the distance moved by the solvent can be expressed as its |  | form. |
| Rf | value: |  | MS 1c |
| *R f* | = | *distance moved b y solvent* |  | Use ratios, fractions and |
|  |  | *d istance moved b y substance* |  |  |  |
| Different compounds have different Rf values in different solvents, |  | percentages. |
|  | MS 1d |
| which can be used to help identify the compounds. The compounds |  |
| in a mixture may separate into different spots depending on the |  | Make estimates of the |
| solvent but a pure compound will produce a single spot in all |  | results of simple |
| solvents. |  | calculations. |

Students should be able to:

* explain how paper chromatography separates mixtures
* suggest how chromatographic methods can be used for distinguishing pure substances from impure substances
* interpret chromatograms and determine Rf values from chromatograms
* provide answers to an appropriate number of significant figures. MS 2a



**Required practical 6:** investigate how paper chromatography can be used to separate and tell thedifference between coloured substances. Students should calculate Rf values.

AT skills covered by this practical activity: 1 and 4.



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****This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in [Key opportunities for skills development](#page107) (page 107).

4.8.2 Identification of common gases

4.8.2.1 Test for hydrogen

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| The test for hydrogen uses a burning splint held at the open end of |  |
| a test tube of the gas. Hydrogen burns rapidly with a pop sound. |  |
|  |  |

4.8.2.2 Test for oxygen

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| The test for oxygen uses a glowing splint inserted into a test tube of |  |
| the gas. The splint relights in oxygen. |  |
|  |  |

4.8.2.3 Test for carbon dioxide

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| The test for carbon dioxide uses an aqueous solution of calcium |  |
| hydroxide (lime water). When carbon dioxide is shaken with or |  |
| bubbled through limewater the limewater turns milky (cloudy). |  |
|  |  |

4.8.2.4 Test for chlorine

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| The test for chlorine uses litmus paper. When damp litmus paper is |  |
| put into chlorine gas the litmus paper is bleached and turns white. |  |
|  |  |



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4.8.3 Identification of ions by chemical and spectroscopic means (chemistry only)

4.8.3.1 Flame tests

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Flame tests can be used to identify some metal ions (cations). | AT 8 |
| Lithium, sodium, potassium, calcium and copper compounds | An opportunity to |
| produce distinctive colours in flame tests: |
| investigate flame colours. |
| • lithium compounds result in a crimson flame |
|  |
| • sodium compounds result in a yellow flame |  |
| • potassium compounds result in a lilac flame |  |
| • calcium compounds result in an orange-red flame |  |
| • copper compounds result in a green flame. |  |
| If a sample containing a mixture of ions is used some flame colours |  |
| can be masked. |  |
|  |  |
| Students should be able to identify species from the results of the | WS 2.2 |
| tests in 4.8.3.1 to 4.8.3.5. |  |
| Flame colours of other metal ions are not required knowledge. |  |
|  |  |

4.8.3.2 Metal hydroxides

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Sodium hydroxide solution can be used to identify some metal ions | AT 8 |
| (cations). | An opportunity to make |
|  |
| Solutions of aluminium, calcium and magnesium ions form white | precipitates of metal |
| precipitates when sodium hydroxide solution is added but only the | hydroxides. |
| aluminium hydroxide precipitate dissolves in excess sodium |  |
| hydroxide solution. |  |
| Solutions of copper(II), iron(II) and iron(III) ions form coloured |  |
| precipitates when sodium hydroxide solution is added. |  |
| Copper(II) forms a blue precipitate, iron(II) a green precipitate and |  |
| iron(III) a brown precipitate. |  |
|  |  |
| Students should be able to write balanced equations for the | WS 2.2 |
| reactions to produce the insoluble hydroxides. |  |
| Students are not expected to write equations for the production of |  |
| sodium aluminate. |  |
|  |  |



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****4.8.3.3 Carbonates

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Carbonates react with dilute acids to form carbon dioxide gas. |  |
| Carbon dioxide can be identified with limewater. |  |
|  |  |

4.8.3.4 Halides

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Halide ions in solution produce precipitates with silver nitrate |  |
| solution in the presence of dilute nitric acid. Silver chloride is white, |  |
| silver bromide is cream and silver iodide is yellow. |  |
|  |  |

4.8.3.5 Sulfates

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Sulfate ions in solution produce a white precipitate with barium |  |
| chloride solution in the presence of dilute hydrochloric acid. |  |
|  |  |

**Required practical 7:** Use of chemical tests to identify the ions in unknown single ioniccompounds covering the ions from sections [Flame tests](#page73) (page 73) to [Sulfates](#page74) (page 74).

AT skills covered by this practical activity: 1 and 8.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in [Key opportunities for skills development](#page107) (page 107).

4.8.3.6 Instrumental methods



|  |  |  |
| --- | --- | --- |
| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
|  |  |  |

Elements and compounds can be detected and identified using instrumental methods. Instrumental methods are accurate, sensitive and rapid.

Students should be able to state advantages of instrumental methods compared with the chemical tests in this specification.



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4.8.3.7 Flame emission spectroscopy

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Flame emission spectroscopy is an example of an instrumental | AT 8 |
| method used to analyse metal ions in solutions. | An opportunity to observe |
|  |
| The sample is put into a flame and the light given out is passed | flame spectra using a hand- |
| through a spectroscope. The output is a line spectrum that can be | held spectroscope. |
| analysed to identify the metal ions in the solution and measure their |  |
| concentrations. |  |
|  |  |
| Students should be able to interpret an instrumental result given | WS 3.6 |
| appropriate data in chart or tabular form, when accompanied by a | MS 4a |
| reference set in the same form, limited to flame emission |
|  |
| spectroscopy. |  |
|  |  |

4.9 Chemistry of the atmosphere

The Earth’s atmosphere is dynamic and forever changing. The causes of these changes are sometimes man-made and sometimes part of many natural cycles. Scientists use very complex software to predict weather and climate change as there are many variables that can influence this. The problems caused by increased levels of air pollutants require scientists and engineers to develop solutions that help to reduce the impact of human activity.

4.9.1 The composition and evolution of the Earth's atmosphere

4.9.1.1 The proportions of different gases in the atmosphere

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| For 200 million years, the proportions of different gases in the | MS 1c |
| atmosphere have been much the same as they are today: | To use ratios, fractions and |
|  |
| • about four-fifths (approximately 80%) nitrogen | percentages. |
| • about one-fifth (approximately 20%) oxygen |  |
| • small proportions of various other gases, including carbon |  |
| dioxide, water vapour and noble gases. |  |
|  |  |



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****4.9.1.2 The Earth's early atmosphere

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Theories about what was in the Earth’s early atmosphere and how | WS 1.1, 1.2, 1.3, 3.5, 3.6, |
| the atmosphere was formed have changed and developed over | 4.1 |
| time. Evidence for the early atmosphere is limited because of the |  |
| time scale of 4.6 billion years. |  |
| One theory suggests that during the first billion years of the Earth’s |  |
| existence there was intense volcanic activity that released gases |  |
| that formed the early atmosphere and water vapour that condensed |  |
| to form the oceans. At the start of this period the Earth’s |  |
| atmosphere may have been like the atmospheres of Mars and |  |
| Venus today, consisting of mainly carbon dioxide with little or no |  |
| oxygen gas. |  |
| Volcanoes also produced nitrogen which gradually built up in the |  |
| atmosphere and there may have been small proportions of methane |  |
| and ammonia. |  |
| When the oceans formed carbon dioxide dissolved in the water and |  |
| carbonates were precipitated producing sediments, reducing the |  |
| amount of carbon dioxide in the atmosphere. No knowledge of other |  |
| theories is required. |  |
| Students should be able to, given appropriate information, interpret |  |
| evidence and evaluate different theories about the Earth’s early |  |
| atmosphere. |  |
|  |  |

4.9.1.3 How oxygen increased

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Algae and plants produced the oxygen that is now in the | WS 1.2 |
| atmosphere by photosynthesis, which can be represented by the | An opportunity to show that |
| equation: |
| aquatic plants produce |
|  |
|  | oxygen in daylight. |
| Algae first produced oxygen about 2.7 billion years ago and soon |  |
| after this oxygen appeared in the atmosphere. Over the next billion |  |
| years plants evolved and the percentage of oxygen gradually |  |
| increased to a level that enabled animals to evolve. |  |
|  |  |



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4.9.1.4 How carbon dioxide decreased



|  |  |  |
| --- | --- | --- |
| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
|  |  |  |

Algae and plants decreased the percentage of carbon dioxide in the atmosphere by photosynthesis.

Carbon dioxide was also decreased by the formation of sedimentary rocks and fossil fuels that contain carbon.



|  |  |
| --- | --- |
| Students should be able to: | WS 1.2, 4.1 |

* describe the main changes in the atmosphere over time and some of the likely causes of these changes
* describe and explain the formation of deposits of limestone, coal, crude oil and natural gas.

4.9.2 Carbon dioxide and methane as greenhouse gases

4.9.2.1 Greenhouse gases

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Greenhouse gases in the atmosphere maintain temperatures on | WS 1.2 |
| Earth high enough to support life. Water vapour, carbon dioxide and |  |
| methane are greenhouse gases. |  |
| Students should be able to describe the greenhouse effect in terms |  |
| of the interaction of short and long wavelength radiation with matter. |  |
|  |  |



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****4.9.2.2 Human activities which contribute to an increase in greenhouse gases in the atmosphere



|  |  |  |
| --- | --- | --- |
| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
|  |  |  |

Some human activities increase the amounts of greenhouse gases in the atmosphere. These include:

* carbon dioxide
* methane

Students should be able to recall two human activities that increase the amounts of each of the greenhouse gases carbon dioxide and methane.

Based on peer-reviewed evidence, many scientists believe that human activities will cause the temperature of the Earth’s atmosphere to increase at the surface and that this will result in global climate change.

However, it is difficult to model such complex systems as global climate change. This leads to simplified models, speculation and opinions presented in the media that may be based on only parts of the evidence and which may be biased.



|  |  |
| --- | --- |
| Students should be able to: | WS 1.2, 1.3, 1.6 |

* evaluate the quality of evidence in a report about global climate change given appropriate information
* describe uncertainties in the evidence base
* recognise the importance of peer review of results and of communicating results to a wide range of audiences.

4.9.2.3 Global climate change



|  |  |  |
| --- | --- | --- |
| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
|  |  |  |
| An increase in average global temperature is a major cause of |  | WS 1.5 |
| climate change. |  |  |
| There are several potential effects of global climate change. |  |  |
| Students should be able to: |  |  |

* describe briefly four potential effects of global climate change
* discuss the scale, risk and environmental implications of global climate change.



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4.9.2.4 The carbon footprint and its reduction

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| The carbon footprint is the total amount of carbon dioxide and other | WS 1.3 |
| greenhouse gases emitted over the full life cycle of a product, |  |
| service or event. |  |
| The carbon footprint can be reduced by reducing emissions of |  |
| carbon dioxide and methane. |  |
| Students should be able to: |  |
| • describe actions to reduce emissions of carbon dioxide and |  |
| methane |  |
| • give reasons why actions may be limited. |  |
|  |  |

4.9.3 Common atmospheric pollutants and their sources

4.9.3.1 Atmospheric pollutants from fuels

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| The combustion of fuels is a major source of atmospheric |  |
| pollutants. |  |
| Most fuels, including coal, contain carbon and/or hydrogen and may |  |
| also contain some sulfur. |  |
| The gases released into the atmosphere when a fuel is burned may |  |
| include carbon dioxide, water vapour, carbon monoxide, sulfur |  |
| dioxide and oxides of nitrogen. Solid particles and unburned |  |
| hydrocarbons may also be released that form particulates in the |  |
| atmosphere. |  |
| Students should be able to: |  |
| • describe how carbon monoxide, soot (carbon particles), sulfur |  |
| dioxide and oxides of nitrogen are produced by burning fuels |  |
|  |  |
| • predict the products of combustion of a fuel given appropriate | WS 1.2 |
| information about the composition of the fuel and the conditions |  |
| in which it is used. |  |
|  |  |



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****4.9.3.2 Properties and effects of atmospheric pollutants

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Carbon monoxide is a toxic gas. It is colourless and odourless and |  |
| so is not easily detected. |  |
| Sulfur dioxide and oxides of nitrogen cause respiratory problems in |  |
| humans and cause acid rain. |  |
| Particulates cause global dimming and health problems for humans. |  |
|  |  |
| Students should be able to describe and explain the problems | WS 1.4 |
| caused by increased amounts of these pollutants in the air. |  |
|  |  |

4.10 Using resources

Industries use the Earth’s natural resources to manufacture useful products. In order to operate sustainably, chemists seek to minimise the use of limited resources, use of energy, waste and environmental impact in the manufacture of these products. Chemists also aim to develop ways of disposing of products at the end of their useful life in ways that ensure that materials and stored energy are utilised. Pollution, disposal of waste products and changing land use has a significant effect on the environment, and environmental chemists study how human activity has affected the Earth’s natural cycles, and how damaging effects can be minimised.



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4.10.1 Using the Earth's resources and obtaining potable water

4.10.1.1 Using the Earth's resources and sustainable development



|  |  |  |
| --- | --- | --- |
| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
|  |  |  |

Humans use the Earth’s resources to provide warmth, shelter, food and transport.

Natural resources, supplemented by agriculture, provide food, timber, clothing and fuels.

Finite resources from the Earth, oceans and atmosphere are processed to provide energy and materials.

Chemistry plays an important role in improving agricultural and industrial processes to provide new products and in sustainable development, which is development that meets the needs of current generations without compromising the ability of future generations to meet their own needs.

Students should be able to:

* state examples of natural products that are supplemented or replaced by agricultural and synthetic products
* distinguish between finite and renewable resources given appropriate information.

Students should be able to:



|  |  |
| --- | --- |
| • extract and interpret information about resources from charts, | WS 3.2 |
| graphs and tables | MS 2c, 4a |
|  |
|  |  |
| • use orders of magnitude to evaluate the significance of data. | MS 2h |
|  | Translate information |
|  | between graphical and |
|  | numeric form. |



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****4.10.1.2 Potable water



|  |  |  |
| --- | --- | --- |
| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
|  |  |  |

Water of appropriate quality is essential for life. For humans, drinking water should have sufficiently low levels of dissolved salts and microbes. Water that is safe to drink is called potable water. Potable water is not pure water in the chemical sense because it contains dissolved substances.

The methods used to produce potable water depend on available supplies of water and local conditions.

In the United Kingdom (UK), rain provides water with low levels of dissolved substances (fresh water) that collects in the ground and in lakes and rivers, and most potable water is produced by:

* choosing an appropriate source of fresh water
* passing the water through filter beds
* sterilising.

Sterilising agents used for potable water include chlorine, ozone or ultraviolet light.

If supplies of fresh water are limited, desalination of salty water or sea water may be required. Desalination can be done by distillation or by processes that use membranes such as reverse osmosis. These processes require large amounts of energy.

Students should be able to:

* distinguish between potable water and pure water
* describe the differences in treatment of ground water and salty water
* give reasons for the steps used to produce potable water.

**Required practical 8:** analysis and purification of water samples from different sources, includingpH, dissolved solids and distillation.

AT skills covered by this practical activity: 2, 3 and 4.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in [Key opportunities and skills development](#page107) (page 107).



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4.10.1.3 Waste water treatment



|  |  |  |
| --- | --- | --- |
| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
|  |  |  |

Urban lifestyles and industrial processes produce large amounts of waste water that require treatment before being released into the environment. Sewage and agricultural waste water require removal of organic matter and harmful microbes. Industrial waste water may require removal of organic matter and harmful chemicals.

Sewage treatment includes:

* screening and grit removal
* sedimentation to produce sewage sludge and effluent
* anaerobic digestion of sewage sludge
* aerobic biological treatment of effluent.

Students should be able to comment on the relative ease of obtaining potable water from waste, ground and salt water.

4.10.1.4 Alternative methods of extracting metals (HT only)



|  |  |  |
| --- | --- | --- |
| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
|  |  |  |

The Earth’s resources of metal ores are limited.

Copper ores are becoming scarce and new ways of extracting copper from low-grade ores include phytomining, and bioleaching. These methods avoid traditional mining methods of digging, moving and disposing of large amounts of rock.

Phytomining uses plants to absorb metal compounds. The plants are harvested and then burned to produce ash that contains metal compounds.

Bioleaching uses bacteria to produce leachate solutions that contain metal compounds.

The metal compounds can be processed to obtain the metal. For example, copper can be obtained from solutions of copper compounds by displacement using scrap iron or by electrolysis.

Students should be able to evaluate alternative biological methods of metal extraction, given appropriate information.



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****4.10.2 Life cycle assessment and recycling

4.10.2.1 Life cycle assessment

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Life cycle assessments (LCAs) are carried out to assess the | WS 1.3, 4, 5 |
| environmental impact of products in each of these stages: | LCAs should be done as a |
|  |
| • extracting and processing raw materials | comparison of the impact |
| • manufacturing and packaging | on the environment of the |
| • use and operation during its lifetime | stages in the life of a |
| • disposal at the end of its useful life, including transport and | product, and only quantified |
| where data is readily |
| distribution at each stage. |
| available for energy, water, |
| Use of water, resources, energy sources and production of some |
| resources and wastes. |
| wastes can be fairly easily quantified. Allocating numerical values to | Interpret LCAs of materials |
| pollutant effects is less straightforward and requires value | or products given |
| judgements, so LCA is not a purely objective process. |
| appropriate information. |
| Selective or abbreviated LCAs can be devised to evaluate a product |
| MS 1a |
| but these can be misused to reach pre-determined conclusions, eg |  |
| in support of claims for advertising purposes. | Recognise and use |
| Students should be able to carry out simple comparative LCAs for | expressions in decimal |
| form. |
| shopping bags made from plastic and paper. |
|  |
|  | MS 1c |
|  | Use ratios, fractions and |
|  | percentages. |
|  | MS 1d |
|  | Make estimates of the |
|  | results of simple |
|  | calculations. |
|  | MS 2a |
|  | Use an appropriate number |
|  | of significant figures. |
|  | MS 4a |
|  | Translate information |
|  | between graphical and |
|  | numeric form. |
|  |  |



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4.10.2.2 Ways of reducing the use of resources

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| The reduction in use, reuse and recycling of materials by end users |  |
| reduces the use of limited resources, use of energy sources, waste |  |
| and environmental impacts. |  |
| Metals, glass, building materials, clay ceramics and most plastics |  |
| are produced from limited raw materials. Much of the energy for the |  |
| processes comes from limited resources. Obtaining raw materials |  |
| from the Earth by quarrying and mining causes environmental |  |
| impacts. |  |
| Some products, such as glass bottles, can be reused. Glass bottles |  |
| can be crushed and melted to make different glass products. Other |  |
| products cannot be reused and so are recycled for a different use. |  |
| Metals can be recycled by melting and recasting or reforming into |  |
| different products. The amount of separation required for recycling |  |
| depends on the material and the properties required of the final |  |
| product. For example, some scrap steel can be added to iron from a |  |
| blast furnace to reduce the amount of iron that needs to be |  |
| extracted from iron ore. |  |
| Students should be able to evaluate ways of reducing the use of |  |
| limited resources, given appropriate information. |  |
|  |  |

4.10.3 Using materials (chemistry only)

4.10.3.1 Corrosion and its prevention

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Corrosion is the destruction of materials by chemical reactions with |  |
| substances in the environment. Rusting is an example of corrosion. |  |
| Both air and water are necessary for iron to rust. |  |
| Corrosion can be prevented by applying a coating that acts as a |  |
| barrier, such as greasing, painting or electroplating. Aluminium has |  |
| an oxide coating that protects the metal from further corrosion. |  |
| Some coatings are reactive and contain a more reactive metal to |  |
| provide sacrificial protection, eg zinc is used to galvanise iron. |  |
|  |  |
| Students should be able to: | WS 2.2, 7, 3.5 |
| • describe experiments and interpret results to show that both air | Investigate the conditions |
| and water are necessary for rusting | for rusting. |
| • explain sacrificial protection in terms of relative reactivity. |  |
|  |  |



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****4.10.3.2 Alloys as useful materials

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Most metals in everyday use are alloys. |  |
| Bronze is an alloy of copper and tin. Brass is an alloy of copper and |  |
| zinc. |  |
| Gold used as jewellery is usually an alloy with silver, copper and |  |
| zinc. The proportion of gold in the alloy is measured in carats. 24 |  |
| carat being 100% (pure gold), and 18 carat being 75% gold. |  |
| Steels are alloys of iron that contain specific amounts of carbon and |  |
| other metals. High carbon steel is strong but brittle. Low carbon |  |
| steel is softer and more easily shaped. Steels containing chromium |  |
| and nickel (stainless steels) are hard and resistant to corrosion. |  |
| Aluminium alloys are low density. |  |
|  |  |
| Students should be able to: | MS 1a |
| • recall a use of each of the alloys specified | Recognise and use |
| • interpret and evaluate the composition and uses of alloys other | expressions in decimal |
| than those specified given appropriate information. | form. |
|  | MS 1c |
|  | Use ratios, fractions and |
|  | percentages. |
|  |  |



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4.10.3.3 Ceramics, polymers and composites

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Most of the glass we use is soda-lime glass, made by heating a |  |
| mixture of sand, sodium carbonate and limestone. Borosilicate |  |
| glass, made from sand and boron trioxide, melts at higher |  |
| temperatures than soda-lime glass. |  |
| Clay ceramics, including pottery and bricks, are made by shaping |  |
| wet clay and then heating in a furnace. |  |
| The properties of polymers depend on what monomers they are |  |
| made from and the conditions under which they are made. For |  |
| example, low density (LD) and high density (HD) poly(ethene) are |  |
| produced from ethene. |  |
| Thermosoftening polymers melt when they are heated. |  |
| Thermosetting polymers do not melt when they are heated. |  |
| Students should be able to: |  |
| • explain how low density and high density poly(ethene) are both |  |
| produced from ethene |  |
| • explain the difference between thermosoftening and |  |
| thermosetting polymers in terms of their structures. |  |
| Most composites are made of two materials, a matrix or binder |  |
| surrounding and binding together fibres or fragments of the other |  |
| material, which is called the reinforcement. |  |
| Students should be able to recall some examples of composites. |  |
|  |  |
| Students should be able to, given appropriate information: | WS 1.4, 3.5, 3.8 |
| • compare quantitatively the physical properties of glass and clay | Compare the properties of |
| ceramics, polymers, composites and metals | thermosetting and |
| • explain how the properties of materials are related to their uses | thermosoftening polymers. |
| and select appropriate materials. |  |
|  |  |



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****4.10.4 The Haber process and the use of NPK fertilisers (chemistry only)

4.10.4.1 The Haber process



|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Content** |  |  |  |  |  | **Key opportunities for skills** |
|  |  |  |  |  |  |  | **development** |
|  |  |  |  |  |  |  |
| The Haber process is used to manufacture ammonia, which can be |  | MS 1a |
| used to produce nitrogen-based fertilisers. |  | Recognise and use |
|  |  |  |  |  |  |  |
| The raw materials for the Haber process are nitrogen and |  | expressions in decimal |
| hydrogen. |  |  |  |  |  | form. |
| Students should be able to recall a source for the nitrogen and a |  | MS 1c |
| source for the hydrogen used in the Haber process. |  | Use ratios, fractions and |
|  |  |  |  |  |  |  |
| The purified gases are passed over a catalyst of iron at a high |  | percentages. |
| temperature (about 450°C) and a high pressure (about 200 |  |  |
| atmospheres). Some of the hydrogen and nitrogen reacts to form |  |  |
| ammonia. The reaction is reversible so some of the ammonia |  |  |
| produced breaks down into nitrogen and hydrogen: |  |  |
| *nitrogen* + *h yd rogen* | *ammonia* |  |  |
| On cooling, the ammonia liquefies and is removed. The remaining |  |  |
| hydrogen and nitrogen are recycled. |  |  |
|  |  |  |
| (HT only) Students should be able to: |  | MS 1a |
| • interpret graphs of reaction conditions versus rate |  | Recognise and use |
|  |  |  |  |  |  |  | expressions in decimal |
|  |  |  |  |  |  |  | form. |
|  |  |  |  |  |  |  | MS 1c |
|  |  |  |  |  |  |  | Use ratios, fractions and |
|  |  |  |  |  |  |  | percentages. |
|  |  |  |
| • apply the principles of dynamic equilibrium in [Reversible](#page59) |  | WS 3.5, 3.8 |
|  |  |  |  |  |  |  |
|  | [reactions and dynamic equilibrium](#page59) (page 59) to the Haber |  |  |
|  | process |  |  |  |  |  |  |



* explain the trade-off between rate of production and position of equilibrium
* explain how the commercially used conditions for the Haber process are related to the availability and cost of raw materials and energy supplies, control of equilibrium position and rate.



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4.10.4.2 Production and uses of NPK fertilisers

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Compounds of nitrogen, phosphorus and potassium are used as | AT 4 |
| fertilisers to improve agricultural productivity. NPK fertilisers contain | Prepare an ammonium salt. |
| compounds of all three elements. |
|  |
| Industrial production of NPK fertilisers can be achieved using a |  |
| variety of raw materials in several integrated processes. NPK |  |
| fertilisers are formulations of various salts containing appropriate |  |
| percentages of the elements. |  |
| Ammonia can be used to manufacture ammonium salts and nitric |  |
| acid. |  |
| Potassium chloride, potassium sulfate and phosphate rock are |  |
| obtained by mining, but phosphate rock cannot be used directly as |  |
| a fertiliser. |  |
| Phosphate rock is treated with nitric acid or sulfuric acid to produce |  |
| soluble salts that can be used as fertilisers. |  |
| Students should be able to: |  |
| • recall the names of the salts produced when phosphate rock is |  |
| treated with nitric acid, sulfuric acid and phosphoric acid |  |
| • compare the industrial production of fertilisers with laboratory |  |
| preparations of the same compounds, given appropriate |  |
| information. |  |
|  |  |