4.1 Atomic structure and the periodic table

The periodic table provides chemists with a structured organisation of the known chemical elements from which they can make sense of their physical and chemical properties. The historical development of the periodic table and models of atomic structure provide good examples of how scientific ideas and explanations develop over time as new evidence emerges. The arrangement of elements in the modern periodic table can be explained in terms of atomic structure which provides evidence for the model of a nuclear atom with electrons in energy levels

**17**

****4.1.1 A simple model of the atom, symbols, relative atomic mass, electronic charge and isotopes

4.1.1.1 Atoms, elements and compounds



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| --- | --- | --- |
| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
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All substances are made of atoms. An atom is the smallest part of an element that can exist.

Atoms of each element are represented by a chemical symbol, eg O represents an atom of oxygen, Na represents an atom of sodium.

There are about 100 different elements. Elements are shown in the periodic table.

Compounds are formed from elements by chemical reactions. Chemical reactions always involve the formation of one or more new substances, and often involve a detectable energy change. Compounds contain two or more elements chemically combined in fixed proportions and can be represented by formulae using the symbols of the atoms from which they were formed. Compounds can only be separated into elements by chemical reactions.

Chemical reactions can be represented by word equations or equations using symbols and formulae.

Students will be supplied with a periodic table for the exam and should be able to:

* use the names and symbols of the first 20 elements in the periodic table, the elements in Groups 1 and 7, and other elements in this specification
* name compounds of these elements from given formulae or symbol equations
* write word equations for the reactions in this specification
* write formulae and balanced chemical equations for the reactions in this specification.

(HT only) write balanced half equations and ionic equations where appropriate.



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4.1.1.2 Mixtures

|  |  |
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| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| A mixture consists of two or more elements or compounds not | WS 2.2, 2.3 |
| chemically combined together. The chemical properties of each | AT 4 |
| substance in the mixture are unchanged. |
| Safe use of a range of |
| Mixtures can be separated by physical processes such as filtration, |
| equipment to separate |
| crystallisation, simple distillation, fractional distillation and |
| chemical mixtures. |
| chromatography. These physical processes do not involve chemical |
| reactions and no new substances are made. |  |
| Students should be able to: |  |
| • describe, explain and give examples of the specified processes |  |
| of separation |  |
| • suggest suitable separation and purification techniques for |  |
| mixtures when given appropriate information. |  |
|  |  |

4.1.1.3 The development of the model of the atom (common content with physics)

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| New experimental evidence may lead to a scientific model being | WS 1.1, 1.6 |
| changed or replaced. | This historical context |
|  |
| Before the discovery of the electron, atoms were thought to be tiny | provides an opportunity for |
| spheres that could not be divided. | students to show an |
| The discovery of the electron led to the plum pudding model of the | understanding of why and |
| describe how scientific |
| atom. The plum pudding model suggested that the atom is a ball of |
| methods and theories |
| positive charge with negative electrons embedded in it. |
| develop over time. |
| The results from the alpha particle scattering experiment led to the |
| WS1.2 |
| conclusion that the mass of an atom was concentrated at the centre |
| (nucleus) and that the nucleus was charged. This nuclear model |  |
| replaced the plum pudding model. |  |
| Niels Bohr adapted the nuclear model by suggesting that electrons |  |
| orbit the nucleus at specific distances. The theoretical calculations |  |
| of Bohr agreed with experimental observations. |  |
| Later experiments led to the idea that the positive charge of any |  |
| nucleus could be subdivided into a whole number of smaller |  |
| particles, each particle having the same amount of positive charge. |  |
| The name proton was given to these particles. |  |
| The experimental work of James Chadwick provided the evidence |  |
| to show the existence of neutrons within the nucleus. This was |  |
| about 20 years after the nucleus became an accepted scientific |  |
| idea. |  |
| Students should be able to describe: |  |
|  |  |



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| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| • why the new evidence from the scattering experiment led to a | WS 1.1 |
| change in the atomic model |  |
|  |  |
| • the difference between the plum pudding model of the atom and | WS 1.2 |
| the nuclear model of the atom. |  |
|  |  |
| Details of experimental work supporting the Bohr model are not |  |
| required. |  |
| Details of Chadwick’s experimental work are not required. |  |
|  |  |

4.1.1.4 Relative electrical charges of subatomic particles



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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
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| The relative electrical charges of the particles in atoms are: |  |  |



|  |  |
| --- | --- |
| In an atom, the number of electrons is equal to the number of |  |
| protons in the nucleus. Atoms have no overall electrical charge. |  |
| The number of protons in an atom of an element is its atomic |  |
| number. All atoms of a particular element have the same number of |  |
| protons. Atoms of different elements have different numbers of |  |
| protons. |  |
| Students should be able to use the nuclear model to describe | WS 1.2 |
| atoms. |  |



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4.1.1.5 Size and mass of atoms



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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
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| Atoms are very small, having a radius of about 0.1 nm (1 x 10-10 m). WS 4.3, 4 |
| The radius of a nucleus is less than 1/10 000 of that of the atom |  | Use SI units and the prefix |
| (about 1 x 10-14 m). |  | nano. |
| Almost all of the mass of an atom is in the nucleus. |  | MS 1b |
| The relative masses of protons, neutrons and electrons are: |  | Recognise expressions in |
|  |  | standard form. |



The sum of the protons and neutrons in an atom is its mass number.

Atoms of the same element can have different numbers of neutrons; these atoms are called isotopes of that element.

Atoms can be represented as shown in this example:



Students should be able to calculate the numbers of protons, neutrons and electrons in an atom or ion, given its atomic number and mass number.



Students should be able to relate size and scale of atoms to objects MS 1d in the physical world.

4.1.1.6 Relative atomic mass

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| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| The relative atomic mass of an element is an average value that |  |
| takes account of the abundance of the isotopes of the element. |  |
| Students should be able to calculate the relative atomic mass of an |  |
| element given the percentage abundance of its isotopes. |  |
|  |  |



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****4.1.1.7 Electronic structure

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| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| The electrons in an atom occupy the lowest available energy levels | WS 1.2 |
| (innermost available shells). The electronic structure of an atom can | Students should be able to |
| be represented by numbers or by a diagram. For example, the | represent the electronic |
| electronic structure of sodium is 2,8,1 or |
| structures of the first twenty |
|  |
|  | elements of the periodic |
|  | table in both forms. |
|  | MS 5b |
|  | Visualise and represent 2D |
|  | and 3D forms including two- |
| showing two electrons in the lowest energy level, eight in the | dimensional representations |
| of 3D objects. |
| second energy level and one in the third energy level. |  |
| Students may answer questions in terms of either energy levels or |  |
| shells. |  |
|  |  |



4.1.2 The periodic table

4.1.2.1 The periodic table

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| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| The elements in the periodic table are arranged in order of atomic |  |
| (proton) number and so that elements with similar properties are in |  |
| columns, known as groups. The table is called a periodic table |  |
| because similar properties occur at regular intervals. |  |
| Elements in the same group in the periodic table have the same |  |
| number of electrons in their outer shell (outer electrons) and this |  |
| gives them similar chemical properties. |  |
|  |  |
| Students should be able to: | WS 1.2 |
| • explain how the position of an element in the periodic table is |  |
| related to the arrangement of electrons in its atoms and hence to |  |
| its atomic number |  |
| • predict possible reactions and probable reactivity of elements |  |
| from their positions in the periodic table. |  |
|  |  |



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4.1.2.2 Development of the periodic table

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| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Before the discovery of protons, neutrons and electrons, scientists | WS 1.1, 1.6 |
| attempted to classify the elements by arranging them in order of | Explain how testing a |
| their atomic weights. |
| prediction can support or |
|  |
| The early periodic tables were incomplete and some elements were | refute a new scientific idea. |
| placed in inappropriate groups if the strict order of atomic weights |  |
| was followed. |  |
| Mendeleev overcame some of the problems by leaving gaps for |  |
| elements that he thought had not been discovered and in some |  |
| places changed the order based on atomic weights. |  |
| Elements with properties predicted by Mendeleev were discovered |  |
| and filled the gaps. Knowledge of isotopes made it possible to |  |
| explain why the order based on atomic weights was not always |  |
| correct. |  |
| Students should be able to describe these steps in the development |  |
| of the periodic table. |  |
|  |  |

4.1.2.3 Metals and non-metals

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| **Content** | **Key opportunities for skills** |
|  |  |  |  |  |  |  |  |  | **development** |
|  |  |  |  |  |  |  |  |  |  |
| Elements that react to form positive ions are metals. |  |
| Elements that do not form positive ions are non-metals. |  |
| The majority of elements are metals. Metals are found to the left |  |
| and towards the bottom of the periodic table. Non-metals are found |  |
| towards the right and top of the periodic table. |  |
| Students should be able to: |  |
| • explain the differences between metals and non-metals on the |  |
| basis of their characteristic physical and chemical properties. |  |
| This links to [Group 0](#page24) (page 24), [Group 1](#page24) (page 24), [Group 7](#page25) |  |
|  |  |  |  |  |  |  |  |  |  |
| (page 25) and [Bonding, structure and the properties of matter](#page26) |  |
| (page 26) |  |  |  |
| • explain how the atomic structure of metals and non-metals |  |
| relates to their position in the periodic table |  |
| • explain how the reactions of elements are related to the |  |
| arrangement of electrons in their atoms and hence to their |  |
| atomic number. |  |
|  |  |  |  |  |  |  |  |  |  |



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****4.1.2.4 Group 0



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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
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The elements in Group 0 of the periodic table are called the noble gases. They are unreactive and do not easily form molecules because their atoms have stable arrangements of electrons. The noble gases have eight electrons in their outer shell, except for helium, which has only two electrons.

The boiling points of the noble gases increase with increasing relative atomic mass (going down the group).



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

* explain how properties of the elements in Group 0 depend on the outer shell of electrons of the atoms
* predict properties from given trends down the group.

4.1.2.5 Group 1



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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
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The elements in Group 1 of the periodic table are known as the alkali metals and have characteristic properties because of the single electron in their outer shell.

Students should be able to describe the reactions of the first three alkali metals with oxygen, chlorine and water.

In Group 1, the reactivity of the elements increases going down the group.



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

* explain how properties of the elements in Group 1 depend on the outer shell of electrons of the atoms
* predict properties from given trends down the group.



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4.1.2.6 Group 7



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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
|  |  |  |
| The elements in Group 7 of the periodic table are known as the |  | AT 6 |
| halogens and have similar reactions because they all have seven |  | Offers an opportunity within |
| electrons in their outer shell. The halogens are non-metals and |  |
|  | displacement reactions of |
| consist of molecules made of pairs of atoms. |  |
|  | halogens. |
| Students should be able to describe the nature of the compounds |  |
|  |  |
| formed when chlorine, bromine and iodine react with metals and |  |  |
| non-metals. |  |  |
| In Group 7, the further down the group an element is the higher its |  |  |
| relative molecular mass, melting point and boiling point. |  |  |
| In Group 7, the reactivity of the elements decreases going down the |  |  |
| group. |  |  |
| A more reactive halogen can displace a less reactive halogen from |  |  |
| an aqueous solution of its salt. |  |  |
|  |  |  |
| Students should be able to: |  | WS 1.2 |

* explain how properties of the elements in Group 7 depend on the outer shell of electrons of the atoms
* predict properties from given trends down the group.

4.1.3 Properties of transition metals (chemistry only)

4.1.3.1 Comparison with Group 1 elements



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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
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The transition elements are metals with similar properties which are different from those of the elements in Group 1.

Students should be able to describe the difference compared with Group 1 in melting points, densities, strength, hardness and reactivity with oxygen, water and halogens.

Students should be able to exemplify these general properties by reference to Cr, Mn, Fe, Co, Ni, Cu.



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****4.1.3.2 Typical properties



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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
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Many transition elements have ions with different charges, form coloured compounds and are useful as catalysts.

Students should be able to exemplify these general properties by reference to compounds of Cr, Mn, Fe, Co, Ni, Cu.

4.2 Bonding, structure, and the properties of matter

Chemists use theories of structure and bonding to explain the physical and chemical properties of materials. Analysis of structures shows that atoms can be arranged in a variety of ways, some of which are molecular while others are giant structures. Theories of bonding explain how atoms are held together in these structures. Scientists use this knowledge of structure and bonding to engineer new materials with desirable properties. The properties of these materials may offer new applications in a range of different technologies.

4.2.1 Chemical bonds, ionic, covalent and metallic

4.2.1.1 Chemical bonds



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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
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There are three types of strong chemical bonds: ionic, covalent and metallic. For ionic bonding the particles are oppositely charged ions. For covalent bonding the particles are atoms which share pairs of electrons. For metallic bonding the particles are atoms which share delocalised electrons.

Ionic bonding occurs in compounds formed from metals combined with non-metals.

Covalent bonding occurs in most non-metallic elements and in compounds of non-metals.

Metallic bonding occurs in metallic elements and alloys.

Students should be able to explain chemical bonding in terms of electrostatic forces and the transfer or sharing of electrons.



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4.2.1.2 Ionic bonding



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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
|  |  |  |
| When a metal atom reacts with a non-metal atom electrons in the |  | MS 5b |
| outer shell of the metal atom are transferred. Metal atoms lose |  | Visualise and represent 2D |
| electrons to become positively charged ions. Non-metal atoms gain |  |
|  | and 3D forms including two- |
| electrons to become negatively charged ions. The ions produced by |  |
|  | dimensional representations |
| metals in Groups 1 and 2 and by non-metals in Groups 6 and 7 |  | of 3D objects. |
| have the electronic structure of a noble gas (Group 0). |  |
|  |  |
| The electron transfer during the formation of an ionic compound can |  |  |
| be represented by a dot and cross diagram, eg for sodium chloride |  |  |



|  |  |
| --- | --- |
| Students should be able to draw dot and cross diagrams for ionic | WS 1.2 |
| compounds formed by metals in Groups 1 and 2 with non-metals in |  |
| Groups 6 and 7. |  |
| The charge on the ions produced by metals in Groups 1 and 2 and |  |
| by non-metals in Groups 6 and 7 relates to the group number of the |  |
| element in the periodic table. |  |
| Students should be able to work out the charge on the ions of |  |
| metals and non-metals from the group number of the element, |  |
| limited to the metals in Groups 1 and 2, and non-metals in Groups 6 |  |
| and 7. |  |

4.2.1.3 Ionic compounds

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| --- | --- | --- |
| **Content** | **Key opportunities for skills** |  |
|  | **development** |  |
|  |  |  |
| An ionic compound is a giant structure of ions. Ionic compounds are | MS 5b |  |
| held together by strong electrostatic forces of attraction between | Visualise and represent 2D |  |
| oppositely charged ions. These forces act in all directions in the |  |
| and 3D forms including two- |  |
| lattice and this is called ionic bonding. |  |
| dimensional representations |  |
|  |  |
| The structure of sodium chloride can be represented in the following | of 3D objects. |  |
| forms: |  |  |
|  |  |  |
|  |  |  |



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| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Students should be able to: | WS 1.2 |
| • deduce that a compound is ionic from a diagram of its structure | MS 4a |
| in one of the specified forms | MS 1a, 1c |
| • describe the limitations of using dot and cross, ball and stick, two |
| and three-dimensional diagrams to represent a giant ionic |  |
| structure |  |
| • work out the empirical formula of an ionic compound from a |  |
| given model or diagram that shows the ions in the structure. |  |
| Students should be familiar with the structure of sodium chloride but |  |
| do not need to know the structures of other ionic compounds. |  |
|  |  |



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4.2.1.4 Covalent bonding



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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
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| When atoms share pairs of electrons, they form covalent bonds. |  | WS 1.2 |
| These bonds between atoms are strong. |  | Recognise substances as |
|  |  |
| Covalently bonded substances may consist of small molecules. |  | small molecules, polymers |
| Students should be able to recognise common substances that |  | or giant structures from |
|  | diagrams showing their |
| consist of small molecules from their chemical formula. |  |
|  | bonding. |
| Some covalently bonded substances have very large molecules, |  |
|  |  |
| such as polymers. |  |  |
| Some covalently bonded substances have giant covalent |  |  |
| structures, such as diamond and silicon dioxide. |  |  |
| The covalent bonds in molecules and giant structures can be |  |  |
| represented in the following forms: |  |  |



Polymers can be represented in the form:



where n is a large number.



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| --- | --- | --- |
| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
|  |  |  |
| Students should be able to: |  | MS 5b |

* draw dot and cross diagrams for the molecules of hydrogen, chlorine, oxygen, nitrogen, hydrogen chloride, water, ammonia and methane
* represent the covalent bonds in small molecules, in the repeating units of polymers and in part of giant covalent structures, using a line to represent a single bond
* describe the limitations of using dot and cross, ball and stick, two and three-dimensional diagrams to represent molecules or giant structures
* deduce the molecular formula of a substance from a given model or diagram in these forms showing the atoms and bonds in the molecule.

4.2.1.5 Metallic bonding

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| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Metals consist of giant structures of atoms arranged in a regular | WS 1.2 |
| pattern. | Recognise substances as |
|  |
| The electrons in the outer shell of metal atoms are delocalised and | metallic giant structures |
| so are free to move through the whole structure. The sharing of | from diagrams showing |
| delocalised electrons gives rise to strong metallic bonds. The | their bonding. |
| bonding in metals may be represented in the following form: | MS 5b |
|  |
|  | Visualise and represent 2D |
|  | and 3D forms including two- |
|  | dimensional representations |
|  | of 3D objects. |
|  |  |



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4.2.2 How bonding and structure are related to the properties of substances

4.2.2.1 The three states of matter



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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
|  |  |  |
| The three states of matter are solid, liquid and gas. Melting and |  | MS 5b |
| freezing take place at the melting point, boiling and condensing |  | Visualise and represent 2D |
| take place at the boiling point. |  |
|  | and 3D forms including two- |
|  |  |
| The three states of matter can be represented by a simple model. In |  | dimensional representations |
| this model, particles are represented by small solid spheres. |  | of 3D objects. |
| Particle theory can help to explain melting, boiling, freezing and |  |  |
| condensing. |  |  |



The amount of energy needed to change state from solid to liquid and from liquid to gas depends on the strength of the forces between the particles of the substance. The nature of the particles involved depends on the type of bonding and the structure of the substance. The stronger the forces between the particles the higher the melting point and boiling point of the substance.

(HT only) Limitations of the simple model above include that in the model there are no forces, that all particles are represented as spheres and that the spheres are solid.



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

* predict the states of substances at different temperatures given appropriate data
* explain the different temperatures at which changes of state occur in terms of energy transfers and types of bonding
* recognise that atoms themselves do not have the bulk properties of materials
* (HT only) explain the limitations of the particle theory in relation to changes of state when particles are represented by solid inelastic spheres which have no forces between them.



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****4.2.2.2 State symbols

|  |  |
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| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| In chemical equations, the three states of matter are shown as (s), |  |
| (l) and (g), with (aq) for aqueous solutions. |  |
| Students should be able to include appropriate state symbols in |  |
| chemical equations for the reactions in this specification. |  |
|  |  |

4.2.2.3 Properties of ionic compounds

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Ionic compounds have regular structures (giant ionic lattices) in |  |
| which there are strong electrostatic forces of attraction in all |  |
| directions between oppositely charged ions. |  |
| These compounds have high melting points and high boiling points |  |
| because of the large amounts of energy needed to break the many |  |
| strong bonds. |  |
| When melted or dissolved in water, ionic compounds conduct |  |
| electricity because the ions are free to move and so charge can |  |
| flow. |  |
| Knowledge of the structures of specific ionic compounds other than |  |
| sodium chloride is not required. |  |
|  |  |

4.2.2.4 Properties of small molecules

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Substances that consist of small molecules are usually gases or | WS 1.2 |
| liquids that have relatively low melting points and boiling points. |  |
| These substances have only weak forces between the molecules |  |
| (intermolecular forces). It is these intermolecular forces that are |  |
| overcome, not the covalent bonds, when the substance melts or |  |
| boils. |  |
| The intermolecular forces increase with the size of the molecules, |  |
| so larger molecules have higher melting and boiling points. |  |
| These substances do not conduct electricity because the molecules |  |
| do not have an overall electric charge. |  |
| Students should be able to use the idea that intermolecular forces |  |
| are weak compared with covalent bonds to explain the bulk |  |
| properties of molecular substances. |  |
|  |  |



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4.2.2.5 Polymers

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Polymers have very large molecules. The atoms in the polymer |  |
| molecules are linked to other atoms by strong covalent bonds. The |  |
| intermolecular forces between polymer molecules are relatively |  |
| strong and so these substances are solids at room temperature. |  |
| Students should be able to recognise polymers from diagrams |  |
| showing their bonding and structure. |  |
|  |  |

4.2.2.6 Giant covalent structures

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Substances that consist of giant covalent structures are solids with | MS 5b |
| very high melting points. All of the atoms in these structures are | Visualise and represent 2D |
| linked to other atoms by strong covalent bonds. These bonds must |
| and 3D forms including two- |
| be overcome to melt or boil these substances. Diamond and |
| dimensional representations |
| graphite (forms of carbon) and silicon dioxide (silica) are examples |
| of 3D objects. |
| of giant covalent structures. |
| WS 1.2 |
| Students should be able to recognise giant covalent structures from |
| diagrams showing their bonding and structure. |  |
|  |  |

4.2.2.7 Properties of metals and alloys

|  |  |  |
| --- | --- | --- |
| **Content** | **Key opportunities for skills** |  |
|  | **development** |  |
|  |  |  |
| Metals have giant structures of atoms with strong metallic bonding. |  |  |
| This means that most metals have high melting and boiling points. |  |  |
| In pure metals, atoms are arranged in layers, which allows metals |  |  |
| to be bent and shaped. Pure metals are too soft for many uses and |  |  |
| so are mixed with other metals to make alloys which are harder. |  |  |
|  |  |  |
| Students should be able to explain why alloys are harder than pure | WS 1.2 |  |
| metals in terms of distortion of the layers of atoms in the structure of |  |
| a pure metal. |  |  |
| 4.2.2.8 Metals as conductors |  |  |
|  |  |  |
| **Content** | **Key opportunities for skills** |  |
|  | **development** |  |
|  |  |  |
| Metals are good conductors of electricity because the delocalised |  |  |
| electrons in the metal carry electrical charge through the metal. |  |  |
| Metals are good conductors of thermal energy because energy is |  |  |
| transferred by the delocalised electrons. |  |  |
|  |  |  |
|  |  |  |

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****4.2.3 Structure and bonding of carbon

4.2.3.1 Diamond

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| In diamond, each carbon atom forms four covalent bonds with other | MS 5b |
| carbon atoms in a giant covalent structure, so diamond is very hard, | Visualise and represent 2D |
| has a very high melting point and does not conduct electricity. | and 3D forms including two- |
|  |
|  | dimensional representations |
|  | of 3D objects. |
|  |  |
| Students should be able to explain the properties of diamond in | WS 1.2 |
| terms of its structure and bonding. |  |
|  |  |

4.2.3.2 Graphite

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| In graphite, each carbon atom forms three covalent bonds with | WS 1.2 |
| three other carbon atoms, forming layers of hexagonal rings which |  |
| have no covalent bonds between the layers. |  |
| In graphite, one electron from each carbon atom is delocalised. |  |
| Students should be able to explain the properties of graphite in |  |
| terms of its structure and bonding. |  |
| Students should know that graphite is similar to metals in that it has |  |
| delocalised electrons. |  |
|  |  |



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4.2.3.3 Graphene and fullerenes

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| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Graphene is a single layer of graphite and has properties that make | WS 1.2, 1.4 |
| it useful in electronics and composites. | MS 5b |
| Students should be able to explain the properties of graphene in |
| Visualise and represent 2D |
| terms of its structure and bonding. |
| and 3D forms including two- |
|  |
| Fullerenes are molecules of carbon atoms with hollow shapes. The | dimensional representations |
| structure of fullerenes is based on hexagonal rings of carbon atoms | of 3D objects. |
| but they may also contain rings with five or seven carbon atoms. |  |
| The first fullerene to be discovered was Buckminsterfullerene (C60) |  |
| which has a spherical shape. |  |
| Carbon nanotubes are cylindrical fullerenes with very high length to |  |
| diameter ratios. Their properties make them useful for |  |
| nanotechnology, electronics and materials. |  |
| Students should be able to: |  |
| • recognise graphene and fullerenes from diagrams and |  |
| descriptions of their bonding and structure |  |
| • give examples of the uses of fullerenes, including carbon |  |
| nanotubes. |  |
|  |  |

4.2.4 Bulk and surface properties of matter including nanoparticles (chemistry only)

4.2.4.1 Sizes of particles and their properties

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Nanoscience refers to structures that are 1–100 nm in size, of the | WS 1.2, 1.4, 4.1, 4.2, 4.3 |
| order of a few hundred atoms. Nanoparticles, are smaller than fine | 4.4, 4.5 |
| particles (PM2.5), which have diameters between 100 and 2500 nm | MS 2h |
| (1 x 10-7 m and 2.5 x 10-6 m). Coarse particles (PM10) have | Make order of magnitude |
| diameters between 1 x 10-5 m and 2.5 x 10-6 m. Coarse particles |
| are often referred to as dust. | calculations. |
| As the side of cube decreases by a factor of 10 the surface area to | MS 5c |
| volume ratio increases by a factor of 10. | Calculate areas of triangles |
|  |
| Nanoparticles may have properties different from those for the | and rectangles, surface |
| same materials in bulk because of their high surface area to | areas and volumes of cubes. |
| volume ratio. It may also mean that smaller quantities are needed |  |
| to be effective than for materials with normal particle sizes. |  |
|  |  |



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|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Students should be able to compare ‘nano’ dimensions to typical | MS 1b |
| dimensions of atoms and molecules. | Recognise and use |
|  |
|  | expressions in standard |
|  | form. |
|  | MS 1c |
|  | Use ratios, fractions and |
|  | percentages. |
|  | MS 1d |
|  | Make estimates of the |
|  | results of simple |
|  | calculations. |
|  |  |

4.2.4.2 Uses of nanoparticles



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

Nanoparticles have many applications in medicine, in electronics, in cosmetics and sun creams, as deodorants, and as catalysts. New applications for nanoparticulate materials are an important area of research.

Students should consider advantages and disadvantages of the applications of these nanoparticulate materials, but do not need to know specific examples or properties other than those specified.



|  |  |
| --- | --- |
| Students should be able to: | WS 1.3, 1.4, 1.5 |

* given appropriate information, evaluate the use of nanoparticles for a specified purpose
* explain that there are possible risks associated with the use of nanoparticles.

4.3 Quantitative chemistry

Chemists use quantitative analysis to determine the formulae of compounds and the equations for reactions. Given this information, analysts can then use quantitative methods to determine the purity of chemical samples and to monitor the yield from chemical reactions.

Chemical reactions can be classified in various ways. Identifying different types of chemical reaction allows chemists to make sense of how different chemicals react together, to establish patterns and to make predictions about the behaviour of other chemicals. Chemical equations provide a means of representing chemical reactions and are a key way for chemists to communicate chemical ideas.



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4.3.1 Chemical measurements, conservation of mass and the quantitative interpretation of chemical equations

4.3.1.1 Conservation of mass and balanced chemical equations

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| The law of conservation of mass states that no atoms are lost or | WS 1.2 |
| made during a chemical reaction so the mass of the products |  |
| equals the mass of the reactants. |  |
| This means that chemical reactions can be represented by symbol |  |
| equations which are balanced in terms of the numbers of atoms of |  |
| each element involved on both sides of the equation. |  |
| Students should understand the use of the multipliers in equations |  |
| in normal script before a formula and in subscript within a formula. |  |
|  |  |

4.3.1.2 Relative formula mass

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| The relative formula mass (*M*r) of a compound is the sum of the |  |
| relative atomic masses of the atoms in the numbers shown in the |  |
| formula. |  |
| In a balanced chemical equation, the sum of the relative formula |  |
| masses of the reactants in the quantities shown equals the sum of |  |
| the relative formula masses of the products in the quantities shown. |  |
|  |  |

4.3.1.3 Mass changes when a reactant or product is a gas

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Some reactions may appear to involve a change in mass but this | AT 1, 2 ,6 |
| can usually be explained because a reactant or product is a gas | Opportunities within |
| and its mass has not been taken into account. For example: when a |
| investigation of mass |
| metal reacts with oxygen the mass of the oxide produced is greater | changes using various |
| than the mass of the metal or in thermal decompositions of metal |
| apparatus. |
| carbonates carbon dioxide is produced and escapes into the |
|  |
| atmosphere leaving the metal oxide as the only solid product. |  |
| Students should be able to explain any observed changes in mass |  |
| in non-enclosed systems during a chemical reaction given the |  |
| balanced symbol equation for the reaction and explain these |  |
| changes in terms of the particle model. |  |
|  |  |



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****4.3.1.4 Chemical measurements



|  |  |  |
| --- | --- | --- |
| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
|  |  |  |
| Whenever a measurement is made there is always some |  | WS 3.4 |
| uncertainty about the result obtained. |  |  |
| Students should be able to: |  |  |

* represent the distribution of results and make estimations of uncertainty
* use the range of a set of measurements about the mean as a measure of uncertainty.

4.3.2 Use of amount of substance in relation to masses of pure substances

4.3.2.1 Moles (HT only)

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Chemical amounts are measured in moles. The symbol for the unit | WS 4.1, 4.2, 4.3, 4.5, 4.6 |
| mole is mol. | MS 1a |
| The mass of one mole of a substance in grams is numerically equal |
| Recognise and use |
| to its relative formula mass. | expressions in decimal |
|  |
| One mole of a substance contains the same number of the stated | form. |
| particles, atoms, molecules or ions as one mole of any other | MS 1b |
| substance. |
| Recognise and use |
| The number of atoms, molecules or ions in a mole of a given |
| expressions in standard |
| substance is the Avogadro constant. The value of the Avogadro |
| form. |
| constant is 6.02 x 1023 per mole. |
| MS 2a |
| Students should understand that the measurement of amounts in |
|  |
| moles can apply to atoms, molecules, ions, electrons, formulae and | Use an appropriate number |
| equations, for example that in one mole of carbon (C) the number of | of significant figures. |
| atoms is the same as the number of molecules in one mole of | MS 3a |
| carbon dioxide (CO2). |
| Understand and use the |
|  |
|  | symbols: =, <, <<, >>, >, ∝, |
|  | ~ |
|  | MS 3b |
|  | Change the subject of an |
|  | equation. |
|  |  |
| Students should be able to use the relative formula mass of a | MS 1c |
| substance to calculate the number of moles in a given mass of that |  |
| substance and vice versa. |  |
|  |  |



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4.3.2.2 Amounts of substances in equations (HT only)

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| The masses of reactants and products can be calculated from | MS 1a |
| balanced symbol equations. | Recognise and use |
|  |
| Chemical equations can be interpreted in terms of moles. For | expressions in decimal |
| example: | form. |
| Mg + 2HCIMgCI2 + H2 | MS 1c |
| shows that one mole of magnesium reacts with two moles of | Use ratios, fractions and |
| percentages. |
| hydrochloric acid to produce one mole of magnesium chloride and |
| one mole of hydrogen gas. | MS 3b |
| Students should be able to: | Change the subject of an |
| • calculate the masses of substances shown in a balanced symbol | equation. |
| equation | MS 3c |
| • calculate the masses of reactants and products from the | Substitute numerical values |
| balanced symbol equation and the mass of a given reactant or |
| into algebraic equations |
| product. |
| using appropriate units for |
|  |
|  | physical quantities. |
|  |  |



4.3.2.3 Using moles to balance equations (HT only)

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| The balancing numbers in a symbol equation can be calculated | MS 3b |
| from the masses of reactants and products by converting the | Change the subject of an |
| masses in grams to amounts in moles and converting the numbers |
| equation. |
| of moles to simple whole number ratios. |
| MS 3c |
| Students should be able to balance an equation given the masses |
|  |
| of reactants and products. | Substitute numerical values |
| Students should be able to change the subject of a mathematical | into algebraic equations |
| using appropriate units for |
| equation. |
| physical quantities. |
|  |
|  |  |



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****4.3.2.4 Limiting reactants (HT only)

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| In a chemical reaction involving two reactants, it is common to use | WS 4.1 |
| an excess of one of the reactants to ensure that all of the other |  |
| reactant is used. The reactant that is completely used up is called |  |
| the limiting reactant because it limits the amount of products. |  |
| Students should be able to explain the effect of a limiting quantity of |  |
| a reactant on the amount of products it is possible to obtain in terms |  |
| of amounts in moles or masses in grams. |  |
|  |  |

4.3.2.5 Concentration of solutions

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Many chemical reactions take place in solutions. The concentration | MS 1c |
| of a solution can be measured in mass per given volume of | Use ratios, fractions and |
| solution, eg grams per dm3 (g/dm3). |
| percentages. |
| Students should be able to: |
| MS 3b |
| • calculate the mass of solute in a given volume of solution of |
| Change the subject of an |
| known concentration in terms of mass per given volume of |
| equation. |
| solution |
|  |
| • (HT only) explain how the mass of a solute and the volume of a |  |
| solution is related to the concentration of the solution. |  |
|  |  |



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4.3.3 Yield and atom economy of chemical reactions (chemistry only)

4.3.3.1 Percentage yield

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  |  |  | **development** |
|  |  |  |  |
| Even though no atoms are gained or lost in a chemical reaction, it is | WS 4.2, 4.6 |
| not always possible to obtain the calculated amount of a product | MS 1a |
| because: |
| Recognise and use |
| • the reaction may not go to completion because it is reversible |
| expressions in decimal |
| • some of the product may be lost when it is separated from the |
| form. |
| reaction mixture |
| MS 1c |
| • some of the reactants may react in ways different to the |
| expected reaction. | Use ratios, fractions and |
| The amount of a product obtained is known as the yield. When | percentages. |
| compared with the maximum theoretical amount as a percentage, it | MS 2a |
| is called the percentage yield. | Use an appropriate number |
| % *Y ield* = | *M ass o f prod uct actuall y mad e* |
|  |
|  | × 100 | of significant figures. |
| *M aximum theoretical mass o f prod uct* |
| Students should be able to: | MS 3b |
| • calculate the percentage yield of a product from the actual yield | Change the subject of an |
| of a reaction | equation. |
| • (HT only) calculate the theoretical mass of a product from a |  |
| given mass of reactant and the balanced equation for the |  |
| reaction. |  |
|  |  |  |  |

4.3.3.2 Atom economy

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  |  |  | **development** |
|  |  |  |  |
| The atom economy (atom utilisation) is a measure of the amount of | WS 4.2, 4.6 |
| starting materials that end up as useful products. It is important for | MS 1a |
| sustainable development and for economic reasons to use |
| Recognise and use |
| reactions with high atom economy. |
| The percentage atom economy of a reaction is calculated using the | expressions in decimal |
| form. |
| balanced equation for the reaction as follows: |
| MS 1c |
|  | *Relative f ormula mass o f d esired prod uct f rom equation* |
|  |  | × 100 |  |
|  | *Sum o f relative f ormula masses o f all reactants f rom equation* | Use ratios, fractions and |
| Students should be able to: |
| percentages. |
| • calculate the atom economy of a reaction to form a desired | MS 3b |
|  | product from the balanced equation | Change the subject of an |
| • (HT only) explain why a particular reaction pathway is chosen to |
| equation. |
|  | produce a specified product given appropriate data such as atom |
|  | economy (if not calculated), yield, rate, equilibrium position and |  |
|  | usefulness of by-products. |  |
|  |  |  |  |



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****4.3.4 Using concentrations of solutions in mol/dm3 (chemistry only)

(HT only)

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| The concentration of a solution can be measured in mol/dm3. | WS 4.2, 4.3, 4.6 |
| The amount in moles of solute or the mass in grams of solute in a | MS 1a |
| given volume of solution can be calculated from its concentration in | Recognise and use |
| mol/dm3. |
| expressions in decimal |
|  |
| If the volumes of two solutions that react completely are known and | form. |
| the concentration of one solution is known, the concentration of the | MS 1c |
| other solution can be calculated. |
| Use ratios, fractions and |
| Students should be able to explain how the concentration of a |
| percentages. |
| solution in mol/dm3 is related to the mass of the solute and the |
| MS 3b |
| volume of the solution. |
|  | Change the subject of an |
|  | equation. |
|  | MS 3c |
|  | Substitute numerical values |
|  | into algebraic equations |
|  | using appropriate units for |
|  | physical quantities. |
|  | AT 1, 3, 8 |
|  | Opportunities within |
|  | titrations including to |
|  | determine concentrations of |
|  | strong acids and alkalis. |
|  |  |



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4.3.5 Use of amount of substance in relation to volumes of gases (chemistry only) (HT only)

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Equal amounts in moles of gases occupy the same volume under | WS 1.2, 4.1, 4.2, 4.3, 4.6 |
| the same conditions of temperature and pressure. | MS 1a |
| The volume of one mole of any gas at room temperature and |
| Recognise and use |
| pressure (20oC and 1 atmosphere pressure) is 24 dm3. |
| expressions in decimal |
|  |
| The volumes of gaseous reactants and products can be calculated | form. |
| from the balanced equation for the reaction. | MS 1c |
| Students should be able to: |
| Use ratios, fractions and |
|  |
| • calculate the volume of a gas at room temperature and pressure | percentages. |
| from its mass and relative formula mass | MS 3b |
| • calculate volumes of gaseous reactants and products from a |
| Change the subject of an |
| balanced equation and a given volume of a gaseous reactant or |
| product | equation. |
| • change the subject of a mathematical equation. | MS 3c |
|  | Substitute numerical values |
|  | into algebraic equations |
|  | using appropriate units for |
|  | physical quantities. |
|  |  |

4.4 Chemical changes

Understanding of chemical changes began when people began experimenting with chemical reactions in a systematic way and organizing their results logically. Knowing about these different chemical changes meant that scientists could begin to predict exactly what new substances would be formed and use this knowledge to develop a wide range of different materials and processes. It also helped biochemists to understand the complex reactions that take place in living organisms. The extraction of important resources from the earth makes use of the way that some elements and compounds react with each other and how easily they can be ‘pulled apart’.

4.4.1 Reactivity of metals

4.4.1.1 Metal oxides



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

Metals react with oxygen to produce metal oxides. The reactions are oxidation reactions because the metals gain oxygen.

Students should be able to explain reduction and oxidation in terms of loss or gain of oxygen.



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****4.4.1.2 The reactivity series

|  |  |
| --- | --- |
| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| When metals react with other substances the metal atoms form | AT 6 |
| positive ions. The reactivity of a metal is related to its tendency to | Mixing of reagents to |
| form positive ions. Metals can be arranged in order of their reactivity |
| in a reactivity series. The metals potassium, sodium, lithium, | explore chemical changes |
| and/or products. |
| calcium, magnesium, zinc, iron and copper can be put in order of |
|  |
| their reactivity from their reactions with water and dilute acids. |  |
| The non-metals hydrogen and carbon are often included in the |  |
| reactivity series. |  |
| A more reactive metal can displace a less reactive metal from a |  |
| compound. |  |
| Students should be able to: |  |
| • recall and describe the reactions, if any, of potassium, sodium, |  |
| lithium, calcium, magnesium, zinc, iron and copper with water or |  |
| dilute acids and where appropriate, to place these metals in |  |
| order of reactivity |  |
| • explain how the reactivity of metals with water or dilute acids is |  |
| related to the tendency of the metal to form its positive ion |  |
| • deduce an order of reactivity of metals based on experimental |  |
| results. |  |
| The reactions of metals with water and acids are limited to room |  |
| temperature and do not include reactions with steam. |  |
|  |  |



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4.4.1.3 Extraction of metals and reduction



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

Unreactive metals such as gold are found in the Earth as the metal itself but most metals are found as compounds that require chemical reactions to extract the metal.

Metals less reactive than carbon can be extracted from their oxides by reduction with carbon.

Reduction involves the loss of oxygen.

Knowledge and understanding are limited to the reduction of oxides using carbon.

Knowledge of the details of processes used in the extraction of metals is not required.

Students should be able to:

* interpret or evaluate specific metal extraction processes when given appropriate information
* identify the substances which are oxidised or reduced in terms of gain or loss of oxygen.

4.4.1.4 Oxidation and reduction in terms of electrons (HT only)



|  |  |  |
| --- | --- | --- |
| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
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Oxidation is the loss of electrons and reduction is the gain of electrons.

Student should be able to:

* write ionic equations for displacement reactions
* identify in a given reaction, symbol equation or half equation which species are oxidised and which are reduced.



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****4.4.2 Reactions of acids

4.4.2.1 Reactions of acids with metals

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| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Acids react with some metals to produce salts and hydrogen. |  |
| (HT only) Students should be able to: |  |
| • explain in terms of gain or loss of electrons, that these are redox |  |
| reactions |  |
| • identify which species are oxidised and which are reduced in |  |
| given chemical equations. |  |
| Knowledge of reactions limited to those of magnesium, zinc and |  |
| iron with hydrochloric and sulfuric acids. |  |
|  |  |

4.4.2.2 Neutralisation of acids and salt production

|  |  |
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| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Acids are neutralised by alkalis (eg soluble metal hydroxides) and |  |
| bases (eg insoluble metal hydroxides and metal oxides) to produce |  |
| salts and water, and by metal carbonates to produce salts, water |  |
| and carbon dioxide. |  |
| The particular salt produced in any reaction between an acid and a |  |
| base or alkali depends on: |  |
| • the acid used (hydrochloric acid produces chlorides, nitric acid |  |
| produces nitrates, sulfuric acid produces sulfates) |  |
| • the positive ions in the base, alkali or carbonate. |  |
| Students should be able to: |  |
| • predict products from given reactants |  |
| • use the formulae of common ions to deduce the formulae of |  |
| salts. |  |
|  |  |



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4.4.2.3 Soluble salts



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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
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Soluble salts can be made from acids by reacting them with solid insoluble substances, such as metals, metal oxides, hydroxides or carbonates. The solid is added to the acid until no more reacts and the excess solid is filtered off to produce a solution of the salt.

Salt solutions can be crystallised to produce solid salts.

Students should be able to describe how to make pure, dry samples of named soluble salts from information provided.

**Required practical 1:** preparation of a pure, dry sample of a soluble salt from an insoluble oxideor carbonate using a Bunsen burner to heat dilute acid and a water bath or electric heater to evaporate the solution.

AT skills covered by this practical activity: 2, 3, 4 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](#page103) (page 103).

4.4.2.4 The pH scale and neutralisation



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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
|  |  |  |
| Acids produce hydrogen ions (H+) in aqueous solutions. |  | AT 3 |
| Aqueous solutions of alkalis contain hydroxide ions (OH–). |  | This is an opportunity to |
| The pH scale, from 0 to 14, is a measure of the acidity or alkalinity |  | investigate pH changes |
|  | when a strong acid |
| of a solution, and can be measured using universal indicator or a |  |
|  | neutralises a strong alkali. |
| pH probe. |  |
|  |  |
| A solution with pH 7 is neutral. Aqueous solutions of acids have pH |  |  |
| values of less than 7 and aqueous solutions of alkalis have pH |  |  |
| values greater than 7. |  |  |
| In neutralisation reactions between an acid and an alkali, hydrogen |  |  |
| ions react with hydroxide ions to produce water. |  |  |
| This reaction can be represented by the equation: |  |  |



Students should be able to:

* describe the use of universal indicator or a wide range indicator to measure the approximate pH of a solution
* use the pH scale to identify acidic or alkaline solutions.



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****4.4.2.5 Titrations (chemistry only)



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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
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The volumes of acid and alkali solutions that react with each other can be measured by titration using a suitable indicator.

Students should be able to:

* describe how to carry out titrations using strong acids and strong alkalis only (sulfuric, hydrochloric and nitric acids only) to find the reacting volumes accurately
* (HT Only) calculate the chemical quantities in titrations involving concentrations in mol/dm3 and in g/dm3.

**Required practical 2:** (chemistry only) determination of the reacting volumes of solutions of astrong acid and a strong alkali by titration.

(HT only) determination of the concentration of one of the solutions in mol/dm3 and g/dm3 from the reacting volumes and the known concentration of the other solution.

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 and skills development](#page104) (page 104).

4.4.2.6 Strong and weak acids (HT only)

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| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| A strong acid is completely ionised in aqueous solution. Examples | AT 8 |
| of strong acids are hydrochloric, nitric and sulfuric acids. | An opportunity to measure |
|  |
| A weak acid is only partially ionised in aqueous solution. Examples | the pH of different acids at |
| of weak acids are ethanoic, citric and carbonic acids. | different concentrations. |
| For a given concentration of aqueous solutions, the stronger an |  |
| acid, the lower the pH. |  |
| As the pH decreases by one unit, the hydrogen ion concentration of |  |
| the solution increases by a factor of 10. |  |
| Students should be able to: |  |
| • use and explain the terms dilute and concentrated (in terms of |  |
| amount of substance), and weak and strong (in terms of the |  |
| degree of ionisation) in relation to acids |  |
|  |  |
| • describe neutrality and relative acidity in terms of the effect on | MS 2h |
| hydrogen ion concentration and the numerical value of pH | Make order of magnitude |
| (whole numbers only). |
| calculations. |
|  |
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4.4.3 Electrolysis

4.4.3.1 The process of electrolysis

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| **Content** | **Key opportunities for skills** |
|  | **development** |
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| When an ionic compound is melted or dissolved in water, the ions |  |
| are free to move about within the liquid or solution. These liquids |  |
| and solutions are able to conduct electricity and are called |  |
| electrolytes. |  |
| Passing an electric current through electrolytes causes the ions to |  |
| move to the electrodes. Positively charged ions move to the |  |
| negative electrode (the cathode), and negatively charged ions move |  |
| to the positive electrode (the anode). Ions are discharged at the |  |
| electrodes producing elements. This process is called electrolysis. |  |
| (HT only) Throughout Section 4.4.3 Higher Tier students should be |  |
| able to write half equations for the reactions occurring at the |  |
| electrodes during electrolysis, and may be required to complete and |  |
| balance supplied half equations. |  |
|  |  |

4.4.3.2 Electrolysis of molten ionic compounds

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| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| When a simple ionic compound (eg lead bromide) is electrolysed in | A safer alternative for |
| the molten state using inert electrodes, the metal (lead) is produced | practical work is anhydrous |
| at the cathode and the non-metal (bromine) is produced at the | zinc chloride. |
| anode. |  |
| Students should be able to predict the products of the electrolysis of |  |
| binary ionic compounds in the molten state. |  |
|  |  |



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****4.4.3.3 Using electrolysis to extract metals

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| **Content** | **Key opportunities for skills** |
|  | **development** |
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| Metals can be extracted from molten compounds using electrolysis. |  |
| Electrolysis is used if the metal is too reactive to be extracted by |  |
| reduction with carbon or if the metal reacts with carbon. Large |  |
| amounts of energy are used in the extraction process to melt the |  |
| compounds and to produce the electrical current. |  |
| Aluminium is manufactured by the electrolysis of a molten mixture |  |
| of aluminium oxide and cryolite using carbon as the positive |  |
| electrode (anode). |  |
| Students should be able to: |  |
| • explain why a mixture is used as the electrolyte |  |
| • explain why the positive electrode must be continually replaced. |  |
|  |  |

4.4.3.4 Electrolysis of aqueous solutions

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| **Content** | **Key opportunities for skills** |
|  | **development** |
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| The ions discharged when an aqueous solution is electrolysed |  |
| using inert electrodes depend on the relative reactivity of the |  |
| elements involved. |  |
| At the negative electrode (cathode), hydrogen is produced if the |  |
| metal is more reactive than hydrogen. |  |
| At the positive electrode (anode), oxygen is produced unless the |  |
| solution contains halide ions when the halogen is produced. |  |
| This happens because in the aqueous solution water molecules |  |
| break down producing hydrogen ions and hydroxide ions that are |  |
| discharged. |  |
|  |  |
| Students should be able to predict the products of the electrolysis of | WS 1.2 |
| aqueous solutions containing a single ionic compound. |  |
|  |  |

**Required practical 3:** investigate what happens when aqueous solutions are electrolysed usinginert electrodes. This should be an investigation involving developing a hypothesis.

AT skills covered by this practical activity: 3, 7 and 8.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in [Key opportunities and skills development](#page104) (page 104).



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4.4.3.5 Representation of reactions at electrodes as half equations (HT only)



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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
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During electrolysis, at the cathode (negative electrode), positively charged ions gain electrons and so the reactions are reductions.

At the anode (positive electrode), negatively charged ions lose electrons and so the reactions are oxidations.

Reactions at electrodes can be represented by half equations, for example:

2H+ + 2e- → H2

and

4OH- → O2 + 2H2O + 4e-

or

4OH- – 4e- → O2 + 2H2O

4.5 Energy changes

Energy changes are an important part of chemical reactions. The interaction of particles often involves transfers of energy due to the breaking and formation of bonds. Reactions in which energy is released to the surroundings are exothermic reactions, while those that take in thermal energy are endothermic. These interactions between particles can produce heating or cooling effects that are used in a range of everyday applications. Some interactions between ions in an electrolyte result in the production of electricity. Cells and batteries use these chemical reactions to provide electricity. Electricity can also be used to decompose ionic substances and is a useful means of producing elements that are too expensive to extract any other way.



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****4.5.1 Exothermic and endothermic reactions

4.5.1.1 Energy transfer during exothermic and endothermic reactions



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| **Content** |  | **Key opportunities for skills** |
|  |  | **development** |
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| Energy is conserved in chemical reactions. The amount of energy in |  | AT 5 |
| the universe at the end of a chemical reaction is the same as before |  | An opportunity to measure |
| the reaction takes place. If a reaction transfers energy to the |  |
|  | temperature changes when |
| surroundings the product molecules must have less energy than the |  |
|  | substances react or |
| reactants, by the amount transferred. |  |
|  | dissolve in water. |
| An exothermic reaction is one that transfers energy to the |  |
|  |  |
| surroundings so the temperature of the surroundings increases. |  |  |
| Exothermic reactions include combustion, many oxidation reactions |  |  |
| and neutralisation. |  |  |
| Everyday uses of exothermic reactions include self-heating cans |  |  |
| and hand warmers. |  |  |
| An endothermic reaction is one that takes in energy from the |  |  |
| surroundings so the temperature of the surroundings decreases. |  |  |
| Endothermic reactions include thermal decompositions and the |  |  |
| reaction of citric acid and sodium hydrogencarbonate. Some sports |  |  |
| injury packs are based on endothermic reactions. |  |  |
| Students should be able to: |  |  |

* distinguish between exothermic and endothermic reactions on the basis of the temperature change of the surroundings
* evaluate uses and applications of exothermic and endothermic reactions given appropriate information.

Limited to measurement of temperature change. Calculation of energy changes or ΔH is not required.

**Required practical 4:** investigate the variables that affect temperature changes in reactingsolutions such as, eg acid plus metals, acid plus carbonates, neutralisations, displacement of metals.

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 and skills development](#page105) (page 105).



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4.5.1.2 Reaction profiles

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| **Content** | **Key opportunities for skills** |
|  | **development** |
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| 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. |  |
| Reaction profiles can be used to show the relative energies of |  |
| reactants and products, the activation energy and the overall |  |
| energy change of a reaction. |  |
|  |  |
| Students should be able to: |  |
| • draw simple reaction profiles (energy level diagrams) for |  |
| exothermic and endothermic reactions showing the relative |  |
| energies of reactants and products, the activation energy and |  |
| the overall energy change, with a curved line to show the energy |  |
| as the reaction proceeds |  |
| • use reaction profiles to identify reactions as exothermic or |  |
| endothermic |  |
| • explain that the activation energy is the energy needed for a |  |
| reaction to occur |  |
|  |  |

4.5.1.3 The energy change of reactions (HT only)

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| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| During a chemical reaction: |  |
| • energy must be supplied to break bonds in the reactants |  |
| • energy is released when bonds in the products are formed. |  |
| The energy needed to break bonds and the energy released when |  |
| bonds are formed can be calculated from bond energies. |  |
| The difference between the sum of the energy needed to break |  |
| bonds in the reactants and the sum of the energy released when |  |
| bonds in the products are formed is the overall energy change of |  |
| the reaction. |  |
| In an exothermic reaction, the energy released from forming new |  |
| bonds is greater than the energy needed to break existing bonds. |  |
| In an endothermic reaction, the energy needed to break existing |  |
| bonds is greater than the energy released from forming new bonds. |  |
|  |  |
| Students should be able to calculate the energy transferred in | MS 1a |
| chemical reactions using bond energies supplied. |  |
|  |  |



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****4.5.2 Chemical cells and fuel cells (chemistry only)

4.5.2.1 Cells and batteries

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| **Content** | **Key opportunities for skills** |
|  | **development** |
|  |  |
| Cells contain chemicals which react to produce electricity. | AT6 |
| The voltage produced by a cell is dependent upon a number of | Safe and careful use of |
| factors including the type of electrode and electrolyte. | liquids. |
| A simple cell can be made by connecting two different metals in |  |
| contact with an electrolyte. |  |
| Batteries consist of two or more cells connected together in series |  |
| to provide a greater voltage. |  |
| In non-rechargeable cells and batteries the chemical reactions stop |  |
| when one of the reactants has been used up. Alkaline batteries are |  |
| non-rechargeable. |  |
| Rechargeable cells and batteries can be recharged because the |  |
| chemical reactions are reversed when an external electrical current |  |
| is supplied. |  |
| Students should be able to interpret data for relative reactivity of |  |
| different metals and evaluate the use of cells. |  |
| Students do not need to know details of cells and batteries other |  |
| than those specified. |  |
|  |  |

4.5.2.2 Fuel cells

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| **Content** | **Key opportunities for skills** |
|  | **development** |
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| Fuel cells are supplied by an external source of fuel (eg hydrogen) |  |
| and oxygen or air. The fuel is oxidised electrochemically within the |  |
| fuel cell to produce a potential difference. |  |
| The overall reaction in a hydrogen fuel cell involves the oxidation of |  |
| hydrogen to produce water. |  |
| Hydrogen fuel cells offer a potential alternative to rechargeable cells |  |
| and batteries. |  |
| Students should be able to: |  |
| • evaluate the use of hydrogen fuel cells in comparison with |  |
| rechargeable cells and batteries |  |
| • (HT only) write the half equations for the electrode reactions in |  |
| the hydrogen fuel cell. |  |