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| **C2.1 Structure and bonding** | | | | | | |
|  | **You should use your skills, knowledge and understanding to:**   * Write formulae for ionic compounds from given symbols and ionic charges. * Represent the electronic structure of the ions in sodium chloride, magnesium oxide and calcium chloride in the following form:     for sodium ion (Na+)   * Represent the covalent bonds in molecules such as water, ammonia, hydrogen, hydrogen chloride, methane and oxygen, and in giant structures such as diamond and silicon dioxide, in the following forms: |  | |  |  |  |
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|  | * **represent the bonding in metals in the following form (HT only):** |  | |  |  |  |
| **C2.1.1 Structure and bonding** | | | | | | |
|  | 1. Compounds are substances in which atoms of two or more elements are chemically combined (bonded together). | |  |  |  |  |
|  | 1. Chemical bonding involves either transferring or sharing electrons in the highest occupied energy levels (outer shells) of atoms in order to achieve the electronic structure of a noble gas with a full outer shell. | |  |  |  |  |
|  | 1. When atoms form chemical bonds by transferring electrons, they form ions. Atoms that lose electrons become positively charged ions. Atoms that gain electrons become negatively charged ions. Ions have the electronic structure of a noble gas (Group 0).   **You should be able to relate the charge on simple ions to the group number of the element in the periodic table e.g. Group 2 metals form 2+ ions by losing two electrons. Group 7 non-metals gain one electron to form 1- ions.** | |  |  |  |  |
|  | 1. The elements in Group 1 of the periodic table, the alkali metals, all react with non-metal elements to form ionic compounds in which the metal ion has a single positive charge e.g. Na+ | |  |  |  |  |
|  | 1. The elements in Group 7 of the periodic table, the halogens, all react with the alkali metals to form ionic compounds in which the halide ions have a single negative charge e.g. Cl- | |  |  |  |  |
|  | 1. An ionic compound is a giant structure of ions in a regular pattern. Ionic compounds are held together by strong electrostatic forces of attraction between oppositely charged ions. These forces act in all directions in the lattice and this is called ionic bonding.   **You should be familiar with the structure of sodium chloride and the properties of ionic compounds that can be explained by their structure.** | |  |  |  |  |
|  | 1. When atoms share pairs of electrons, they form covalent bonds. These bonds between atoms are strong. Some covalently bonded substances consist of simple molecules such as H2, Cl2, O2, HCl, H2O, NH3 and CH4. Others have giant covalent structures, such as diamond, graphite and silicon dioxide.   **You should know the bonding in the examples above, and should be able to recognise simple molecules and giant structures from diagrams that show their bonding.** |  | |  |  |  |
|  | 1. Metals consist of giant structures of metal ions arranged in a regular pattern held together by the electrostatic force of attraction between the metal ions and the sea of delocalised electrons. |  | |  |  |  |
|  | 1. **The electrons in the highest occupied energy levels (outer shell) of metal atoms are delocalised and so free to move through the whole structure. This corresponds to a structure of positive ions with delocalised electrons between the ions holding them together by strong electrostatic attractions. (HT only)** |  | |  |  |  |

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| **C2.2 How structure influences the properties and uses of substances** | | | | | | | | | | | |
|  | | Substances that have simple molecular, giant ionic and giant covalent structures have very different properties. Ionic, covalent and metallic bonds are strong. However, the forces between molecules are weaker, e.g. in carbon dioxide and iodine. Metals have many uses. When different metals are combined, alloys are formed. Shape memory alloys have a range of uses. There are different types of polymers with different uses. Nanomaterials have new properties because of their very small size.  **You should use your skills, knowledge and understanding to:**   * Relate the properties of substances to their uses. * Suggest the type of structure of a substance given its properties. * Evaluate developments and applications of new materials, e.g. nanomaterials, fullerenes and shape memory materials.   **You should be familiar with some examples of new materials.** |  | | |  | |  | |  | |
| **C2.2.1 Molecules** | | | | | | | | | | | |
|  | | 1. Substances that consist of simple molecules are gases, liquids or solids that have relatively low melting points and boiling points. | |  | |  | |  | |  | |
|  | | 1. Substances that consist of simple molecules have only weak forces (intermolecular forces) between the molecules. It is these intermolecular forces that are overcome when the substance melts or boils, not the covalent bonds.   **You need to be able to explain that intermolecular forces are weak in comparison with covalent bonds. (HT only)** | |  | |  | |  | |  | |
|  | | 1. Substances that consist of simple molecules do not conduct electricity because the molecules do not have an overall electric charge and have no delocalised electrons. | |  | |  | |  | |  | |
| **C2.2.2 Ionic compounds** | | | | | | | | | | | |
|  | | 1. Ionic compounds have regular structures (giant ionic lattices) in which there are strong electrostatic forces 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. | |  | |  | |  | |  | |
|  | | 1. When melted or dissolved in water, ionic compounds conduct electricity because the ions are free to move and carry the current. | |  | |  | |  | |  | |
| **C2.2.3 Covalent structures** | | | | | | | | | | | |
|  | | 1. Atoms that share electrons can also form giant structures. Diamond and graphite (forms of carbon) and silicon dioxide (silica) are examples of giant covalent structures (lattices) of atoms. All the atoms in these structures are linked to other atoms by strong covalent bonds and so they have very high melting points.   **You should be able to recognise other giant structures from diagrams showing their bonding.** |  | | |  | |  | |  | |
|  | | 1. In diamond, each carbon atom forms four covalent bonds with other carbon atoms in a giant covalent structure, so diamond is very hard. Diamond does not conduct electricity as it does not have delocalised electrons. |  | | |  | |  | |  | |
|  | | 1. In graphite, each carbon atom bonds to three others, forming layers. The layers are free to slide over each other because there are no covalent bonds between the layers and so graphite is soft and slippery.   **You should be able to explain the properties of graphite in terms of weak intermolecular forces between the layers (HT only).** |  | | |  | |  | |  | |
|  | | 1. In graphite, one electron from each carbon atom is delocalised. These delocalised electrons allow graphite to conduct heat and electricity.   **You should realise that graphite is similar to metals in that it has delocalised electrons. (HT only)** |  | | |  | |  | |  | |
|  | | 1. **Carbon can also form fullerenes with different numbers of carbon atoms. Fullerenes can be used for drug delivery into the body, in lubricants, as catalysts, and in nanotubes for reinforcing materials, e.g. in tennis rackets. (HT only)** |  | | |  | |  | |  | |
| **C2.2.4 Metals** | | | | | | | | | | | |
|  | | 1. Metals conduct heat and electricity because of the delocalised electrons in their structures that can move through the structure and carry a charge.   **You should know that conduction depends on the ability of electrons to move throughout the metal. (HT only)** |  | | |  | |  | |  | |
|  | | 1. The layers of atoms in metals are able to slide over each other and remain bonded because metallic bonding happens in all directions and so metals can be bent and shaped (malleable). |  | | |  | |  | |  | |
|  | 1. Alloys are usually made from a mixture of two or more different metals. The different sized atoms of the metals distort the layers in the structure, making it more difficult for them to slide over each other and so make alloys harder than pure metals. | | | |  | |  | |  | |  |
|  | 1. Shape memory alloys can return to their original shape after being deformed, e.g. Nitinol used in dental braces and spectacle frames. | | | |  | |  | |  | |  |
| **C2.2.5 Polymers** | | | | | | | | | | | |
|  | 1. The properties of polymers depend on what 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 using different catalysts and reaction conditions. | | | |  | |  | |  | |  |
|  | 1. Thermosoftening polymers consist of individual, tangled polymer chains with weak intermolecular forces between the chains. They can be melted and remoulded. 2. Thermosetting polymers consist of polymer chains with strong cross-links between the chains so that they do not melt when they are heated. 3. **You should be able to explain the properties of thermosoftening polymers in terms of intermolecular forces. (HT only)** | | | |  | |  | |  | |  |
| **C2.2.6 Nanoscience** | | | | | | | | | | | |
|  | 1. Nanoscience refers to structures that are 1–100nm in size, of the order of a few hundred atoms. Nanoparticles show different properties to the same materials in bulk and have a high surface area to volume ratio, which may lead to the development of new computers, new catalysts, new coatings, highly selective sensors, stronger and lighter construction materials, and new cosmetics such as sun tan creams and deodorants.   **You should know what is meant by nanoscience and nanoparticles and should consider some of the applications of these materials as well as their advantages and disadvantages.** | | | |  | |  | |  | |  |

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| **C2.3 Atomic structure, analysis and quantitative chemistry** | | | | | | |
|  | The relative masses of atoms can be used to calculate how much to react and how much we can produce, because no atoms are gained or lost in chemical reactions. There are various methods used to analyse these substances.  **You should use your skills, knowledge and understanding to:**   * Evaluate sustainable development issues relating the starting materials of an industrial process to the product yield and the energy requirements of the reactions involved. |  |  |  |  | |
| **C2.3.1 Atomic structure** | | | | | | |
|  | 1. Atoms can be represented as shown in this example and on The Periodic Table:   Mass number 23  Na  Atomic number 11 |  |  |  |  | |
|  | 1. The relative masses of protons, neutrons and electrons are:  |  |  |  | | --- | --- | --- | | **Name of particle** | **Mass** | **Charge** | | Proton | 1 | + | | Neutron | 1 | 0 | | Electron | Very small | - | |  |  |  |  | |
|  | 1. The total number of protons and neutrons in an atom is called its mass number. |  |  |  |  | |
|  | 1. Atoms of the same element can have different numbers of neutrons; these atoms are called isotopes of that element. |  |  |  |  | |
|  | 1. **The relative atomic mass of an element (Ar) compares the mass of atoms of the element with the 12C isotope. It is an average value for all the isotopes of the element. (HT only)** |  |  |  |  | |
|  | 1. 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.   **You are expected to use relative atomic masses in the calculations specified in the subject content.**  **You should be able to calculate the relative formula mass (*Mr*) of a compound from its formula.** |  |  |  |  | |
|  | 1. The relative formula mass of a substance, in grams, is known as one mole of that substance. |  |  |  |  | |
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| **C2.3.2 Analysing substances** | | | | | | |
|  | 1. Elements and compounds can be detected and identified using instrumental methods. Instrumental methods are accurate, sensitive, faster and can be automated and only need small sample sizes. |  |  |  |  | |
|  | 1. Chemical analysis can be used to identify additives in foods. Artificial colours can be detected and identified by paper chromatography. |  |  |  |  | |
|  | 1. Gas chromatography linked to mass spectroscopy (GC-MS) is an example of an instrumental method:  * Gas chromatography allows the separation of a mixture of compounds. * The time taken for a substance to travel through the column can be used to help identify the substance. (This is the retention time). * The output from the gas chromatography column can be linked to a mass spectrometer, which can be used to identify the substances leaving the end of the column. * **The mass spectrometer can also give the relative molecular mass of each of the substances separated in the column. (HT only)**   **You need only a basic understanding of how GC-MS works, limited to:**   * **Different substances, carried by a gas, travel through a column packed with a solid material at different speeds, so that they become separated.** * **The number of peaks on the output of a gas chromatograph shows the number of compounds present.** * **The position of the peaks on the output indicates the retention time.** * **A mass spectrometer can identify substances very quickly and accurately and can detect very small quantities.** * **The molecular mass is given by the molecular ion peak. (HT only)** |  |  |  |  | |
| **C2.3.3 Quantitative chemistry** | | | | | | |
|  | 1. The percentage of an element in a compound can be calculated from the relative mass of the element in the formula and the relative formula mass of the compound.   **You should be able to calculate the percentage of an element in a compound, given its formula.** |  |  |  |  | |
|  | 1. **The empirical formula of a compound can be calculated from the masses or percentages of the elements in a compound. (HT only)**   **You should be able to calculate empirical formulae. (HT only)** |  |  |  |  |
|  | 1. **The masses of reactants and products can be calculated from balanced symbol equations. (HT only)**   **You should be able to calculate the masses of individual products from a given mass of a reactant and the balanced symbol equation. (HT only)** |  |  |  |  |
|  | 1. Even though no atoms are gained or lost in a chemical reaction, it is not always possible to obtain the calculated amount of a product (100% yield) because:  * The reaction may not go to completion because it is a reversible reaction. * Some of the product may be lost when it is separated from the reaction mixture. * Some of the reactants may react in ways different from the expected reaction. |  |  |  |  |
|  | 1. **The amount of a product obtained is known as the yield. When compared with the maximum theoretical amount as a percentage, it is called the percentage yield.**   **You will be expected to calculate percentage yields of reactions. (HT only)** |  |  |  |  |
|  | 1. 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  For example:  ammonium chloride  ammonia + hydrogen chloride |  |  |  |  |

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| **C2.4 Rates of reaction** | | | | | |
|  | Being able to speed up or slow down chemical reactions is important in everyday life and in industry. Changes in temperature, concentration of solution, gas pressure, surface area of solids and the presence of catalysts all affect the rates of reactions. Catalysts can help to reduce the cost of some industrial processes.  **You should use your skills, knowledge and understanding to:**   * Interpret graphs showing the amount of product formed (or reactant used up) with time, in terms of the rate of the reaction. * Explain and evaluate the development, advantages and disadvantages of using catalysts in industrial processes. |  |  |  |  |
| **C2.4.1 Rates of reaction** | | | | | |
|  | 1. The rate of a chemical reaction can be found by measuring the amount of a reactant used or the amount of product formed over time:   Rate of reaction = amount of reactant used  time  Rate of reaction = amount of product formed  time |  |  |  |  |
|  | 1. Chemical reactions can only occur when reacting particles collide with each other and with sufficient energy. The minimum amount of energy particles must have to react is called the activation energy. |  |  |  |  |
|  | 1. Increasing the temperature increases the speed of the reacting particles so that they have more energy, move faster and collide more frequently. This increases the rate of reaction. |  |  |  |  |
|  | 1. Increasing the pressure of reacting gases increases the number of particles per volume and the frequency of collisions and so increases the rate of reaction. |  |  |  |  |
|  | 1. Increasing the concentration of reactants in solutions increases the number of particles per volume and frequency of collisions and so increases the rate of reaction. |  |  |  |  |
|  | 1. Increasing the surface area of solid reactants increases the number of reactant particles at the surface and frequency of collisions and so increases the rate of reaction. |  |  |  |  |
|  | 1. Catalysts change the rate of chemical reactions but are not used up during the reaction. Different reactions need different catalysts. |  |  |  |  |
|  | 1. Catalysts are important in increasing the rates of chemical reactions used in industrial processes to reduce costs. 2. Catalysts do this by reducing the activation energy so reactions can happen at lower temperatures. |  |  |  |  |
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| **C2.5 Exothermic and endothermic reactions** | | | | | |
|  | Chemical reactions involve energy transfers. Many chemical reactions involve the release of energy. For other chemical reactions to occur, energy must be supplied.  **You should use your skills, knowledge and understanding to:**   * Evaluate everyday uses of exothermic and endothermic reactions. |  |  |  |  |
| **C2.5.1 Energy transfer in chemical reactions** | | | | | |
|  | 1. When chemical reactions occur, energy is transferred to or from the surroundings. |  |  |  |  |
|  | 1. An exothermic reaction is one that transfers heat energy to the surroundings. Examples of exothermic reactions include combustion, many oxidation reactions and neutralisation. Everyday uses of exothermic reactions include self-heating cans (e.g. for coffee), burning of fuels and hand warmers. |  |  |  |  |
|  | 1. An endothermic reaction is one that takes in heat energy from the surroundings. Endothermic reactions include thermal decomposition. Some sports injury packs are based upon endothermic reactions. |  |  |  |  |
|  | 1. 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:    If 4J of energy are taken in by the forward reaction then 4J of energy are given out by the backward reaction. |  |  |  |  |

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| **C2.6 Acids, bases and salts** | | | | | |
|  | Soluble salts can be made from acids and insoluble salts can be made from solutions of ions. When acids and alkalis react the result is a neutralisation reaction.  **You should use your skills, knowledge and understanding to:**   * Select an appropriate method for making a salt, given appropriate information. |  |  |  |  |
| **C2.6.1 Making salts** | | | | | |
|  | 1. The state symbols in equations are (s) = solid, (l ) = liquid , (g) = gas and (aq) = aqueous. |  |  |  |  |
|  | 1. Soluble salts can be made from acids by reacting them with:  * Metals – not all metals are suitable; some are too reactive (Metals high in the reactivity series) and others are not reactive enough (Metals low in the reactivity series).   Zinc + Hydrochloric acid → Zinc chloride + Hydrogen   * Insoluble bases – the base is added to the acid until no more will react and the excess solid is filtered off.   Copper oxide + Nitric acid → Copper nitrate + Water   * Alkalis – an indicator can be used to show when the acid and alkali have completely reacted to produce a salt solution. * Sodium hydroxide + Sulfuric acid → Sodium sulphate + Water   **You should be able to suggest methods to make a named soluble salt.** |  |  |  |  |
|  | 1. Salt solutions can be crystallised to produce solid salts by evaporating the water. If a solid is used this is filtered off and then the water is evaporated to leave the salt. |  |  |  |  |
|  | 1. Insoluble salts can be made by mixing appropriate solutions of ions so that a precipitate is formed. Precipitation can be used to remove unwanted ions from solutions, for example in treating water for drinking or in treating effluent.   **You should be able to name the substances needed to make a named insoluble salt.** |  |  |  |  |
| **C2.6.2 Acids and bases** | | | | | |
|  | 1. Metal oxides and hydroxides are bases. Soluble hydroxides are called alkalis. |  |  |  |  |
|  | 1. 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, sulphuric acid produces sulfates). * The metal in the base or alkali. |  |  |  |  |
|  | 1. Ammonia dissolves in water to produce an alkaline solution. It is used to produce ammonium salts. Ammonium salts are important as fertilisers.   NH3 + H2O →NH4OH |  |  |  |  |
|  | 1. Hydrogen ions, H+ (aq), make solutions acidic and hydroxide ions, OH- (aq), make solutions alkaline. 2. The pH scale is a measure of the acidity or alkalinity of a solution.   **You should be familiar with the pH scale from 0 to 14, and that pH1 is a strong acid, pH 7 is a neutral solution and pH14 is a strong alkali.** |  |  |  |  |
|  | 1. In neutralisation reactions, hydrogen ions react with hydroxide ions to produce water. This reaction can be represented by the equation:   H+(aq) + OH–(aq) →H2O(l) |  |  |  |  |
| **C2.7 Electrolysis** | | | | | |
|  | Ionic compounds have many uses and can provide other substances. Electrolysis is used to produce alkalis and elements such as aluminium, chlorine and hydrogen. Oxidation–reduction reactions do not just involve oxygen.  **You should use your skills, knowledge and understanding to:**   * Predict the products of electrolysing solutions of ions. * Explain and evaluate processes that use the principles described in this unit, including the use of electroplating. |  |  |  |  |
| **C2.7.1 Electrolysis** | | | | | |
|  | 1. When an ionic substance is melted or dissolved in water, the ions are free to move about within the liquid or solution. |  |  |  |  |
|  | 1. Passing an electric current through ionic substances that are molten, for example lead bromide, or in solution breaks them down into elements. This process is called electrolysis and the substance that is broken down is called the electrolyte. |  |  |  |  |
|  | 1. During electrolysis, positively charged ions move to the negative electrode, and negatively charged ions move to the positive electrode. |  |  |  |  |
|  | 1. Electrolysis is used to electroplate objects. This may be for a variety of reasons and includes copper plating and silver plating. The object to be plated is the negative electrode. |  |  |  |  |
|  | 1. At the negative electrode, positively charged ions gain electrons (reduction) and at the positive electrode, negatively charged ions lose electrons (oxidation). |  |  |  |  |
|  | 1. If there is a mixture of ions, the products formed depend on the reactivity of the elements involved. Ions of elements that are high in the reactivity series will stay in solution whereas ions of elements lower in the reactivity series will gain or lose electrons to turn back into atoms/molecules and leave the solution. |  |  |  |  |
|  | 1. **Reactions at electrodes can be represented by half equations, for example: (HT only)**   **2Cl– 🡪 Cl2 + 2e–**  **or**  **2Cl– – 2e– 🡪 Cl2**  **You should be able to complete and balance half equations for the reactions occurring at the electrodes during electrolysis. (HT only)** |  |  |  |  |
|  | 1. Aluminium is manufactured by the electrolysis of a molten mixture of aluminium oxide and cryolite. Aluminium forms at the negative electrode and oxygen at the positive electrode. The positive electrode is made of carbon, which reacts with the oxygen to produce carbon dioxide.   **Liquid cryolite is used in this process to lower the temperature needed by dissolving the aluminium oxide. This saves energy on heating the electrolyte mixture.** |  |  |  |  |
|  | 1. The electrolysis of sodium chloride solution produces hydrogen and chlorine. Sodium hydroxide solution is also produced. These are important reagents for the chemical industry, e.g. sodium hydroxide for the production of soap and chlorine for the production of bleach and plastics, hydrogen as a fuel, to make margarine from vegetable oil and to make ammonia for fertilisers. 2. A membrane cell has a membrane to prevent the sodium hydroxide produced reacting with the chlorine produced. |  |  |  |  |