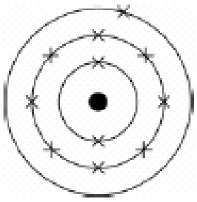
AQA Additional Science - Chemistry

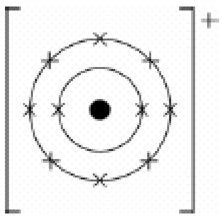
12.1 How do sub-atomic particles help us to understand the structure of substances?

Simple particle theory is developed in this unit to include atomic structure and bonding. The arrangement of electrons in atoms can be used to explain what happens when elements react and how atoms join together to form different types of substances.

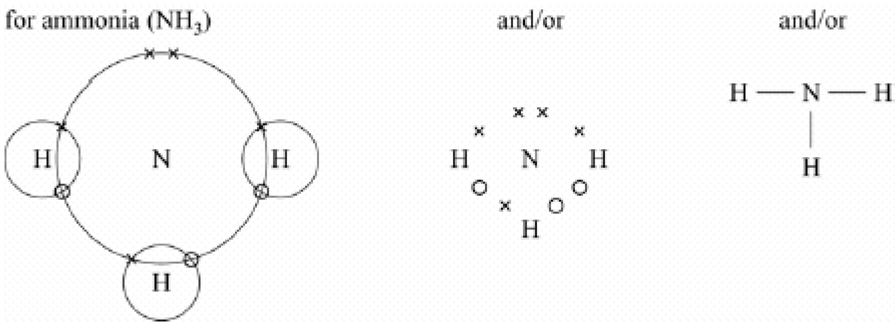
Represent the electronic structure of the first twenty elements of the periodic table in the following forms:

for sodium  and 2,8,1

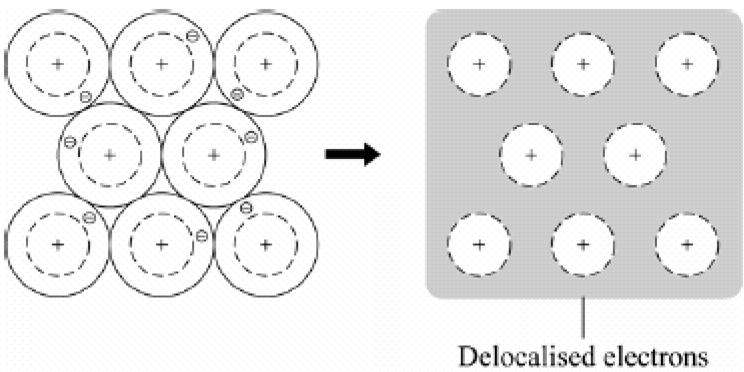
Represent the electronic structure of the ions in sodium chloride, magnesium oxide and calcium chloride in the following forms:

for sodium ion (Na^+)  and $[2,8]^+$

Represent the covalent bonds in molecules such as water, ammonia, hydrogen, hydrogen chloride, chlorine, methane and oxygen and in giant structures such as diamond and silicon dioxide in the following forms:



Represent the bonding in metals in the following form:



- Atoms have a small central nucleus made up of protons and neutrons around which there are electrons.
- The relative electrical charges are:

Name of particle	Charge
Proton	+1
Neutron	0
Electron	–1

- In an atom, the number of electrons is equal to the number of protons in the nucleus. Atoms have no overall electrical charge.
- All atoms of a particular element have the same number of protons. Atoms of different elements have different numbers of protons.
- The number of protons in an atom is called its atomic number (proton number). Atoms are arranged in the modern periodic table in order of their atomic number (proton number).
- Electrons occupy particular energy levels. Each electron in an atom is at a particular energy level (in a particular shell). The electrons in an atom occupy the lowest available energy levels (innermost available shells). (Though only energy levels are referred to throughout this specification, candidates may answer in terms of shells if they prefer.)
- Elements in the same group in the periodic table have the same number of electrons in the highest energy levels (outer electrons).
- Compounds are substances in which atoms of two, or more, elements are not just mixed together but chemically combined.
- Chemical bonding involves either transferring or sharing electrons in the highest occupied energy levels (shells) of atoms.
- 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).
- The elements in Group 1 of the periodic table, the alkali metals, have similar chemical properties. They all react with non-metal elements to form ionic compounds in which the metal ion has a single positive charge.
- The elements in Group 7 of the periodic table, the halogens, have similar chemical properties. They react with the alkali metals to form ionic compounds in which the halide ions have a single negative charge.
- An ionic compound is a giant structure of ions. Ionic compounds are held together by strong forces of attraction between oppositely charged ions. These forces act in all directions in the lattice and this is called ionic bonding.
- 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 H_2, Cl_2, O_2, HCl, H_2O and CH_4. Others have giant covalent structures (macromolecules), such as diamond and silicon dioxide.
- Metals consist of giant structures of atoms arranged in a regular pattern. 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 electrons between the ions holding them together by strong electrostatic attractions.

12.2 How do structures influence 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. The forces between molecules are weaker, e.g. in carbon dioxide and iodine.
- Nanomaterials have new properties because of their very small size.
- 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, smart materials.
- Substances that consist of simple molecules are gases, liquids or solids that have relatively low melting points and boiling points.
- Substances that consist of simple molecules 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.
- Substances that consist of simple molecules do not conduct electricity because the molecules do not have an overall electric charge.
- 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.
- When melted or dissolved in water, ionic compounds conduct electricity because the ions are free to move and carry the current.
- Atoms that share electrons can also form giant structures or macromolecules. 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.
- In diamond, each carbon atom forms four covalent bonds with other carbon atoms in a giant covalent structure, so diamond is very hard.
- In graphite, each carbon atom bonds to three others, forming layers. The layers are free to slide over each other and so graphite is soft and slippery.
- In graphite, one electron from each carbon atom is delocalised. These delocalised electrons allow graphite to conduct heat and electricity.
- Metals conduct heat and electricity because of the delocalised electrons in their structures.
- The layers of atoms in metals are able to slide over each other and so metals can be bent and shaped.
- Nanoscience refers to structures that are 1-100 nm 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 and stronger and lighter construction materials.

12.3 How much can we make and how much do we need to use?

- 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. In industrial processes, atom economy is important for sustainable development.
- Calculate chemical quantities involving formula mass (M*r*) and percentages of elements in compounds
- Calculate chemical quantities involving empirical formulae, reacting masses and percentage yield
- Calculate the atom economy for industrial processes and be able to evaluate sustainable development issues related to this economy.
- Atoms can be represented as shown:

Mass number 23
Na
Atomic Number 11

- The relative masses of protons, neutrons and electrons are:

Name of particle	Mass
Proton	1
Neutron	1
Electron	Very small

- The total number of protons and neutrons in an atom is called its mass number.

- Atoms of the same element can have different numbers of neutrons; these atoms are called isotopes of that element.
- The relative atomic mass of an element (A*r*) compares the mass of atoms of the element with the 12C isotope. It is an average value for the isotopes of the element.
- 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.
- The relative formula mass of a substance, in grams, is known as one mole of that substance.
- 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.
- The masses of reactants and products can be calculated from balanced symbol equations.
- 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 because:
    - The reaction may not go to completion because it is reversible
    - Some of the product may be lost when it is separated from the reaction mixture
    - Some of the reactants may react in ways different to the expected reaction.
- 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.
- The atom economy (atom utilisation) is a measure of the amount of starting materials that end up as useful products. It is important for sustainable development and for economical reasons to use reactions with high atom economy.
- 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:

$$\text{A} + \text{B} \rightleftharpoons \text{C} + \text{D}$$

For example:

$$\text{ammonium chloride} \rightleftharpoons \text{ammonia} + \text{hydrogen chloride}$$

- When a reversible reaction occurs in a closed system, equilibrium is reached when the reactions occur at exactly the same rate in each direction.
- The relative amounts of all the reacting substances at equilibrium depend on the conditions of the reaction.
- Although reversible reactions may not go to completion, they can still be used efficiently in continuous industrial processes, such as the Haber process that is used to manufacture ammonia.
- The raw materials for the Haber process are nitrogen and hydrogen. Nitrogen is obtained from the air and hydrogen may be obtained from natural gas or other sources.
- The purified gases are passed over a catalyst of iron at a high temperature (about 450 °C) and a high pressure (about 200 atmospheres). Some of the hydrogen and nitrogen reacts to form ammonia. The reaction is reversible so ammonia breaks down again into nitrogen and hydrogen:

$$\text{nitrogen} + \text{hydrogen} \rightleftharpoons \text{ammonia}$$

On cooling, the ammonia liquefies and is removed. The remaining hydrogen and nitrogen is re-cycled. The reaction conditions are chosen to produce a reasonable yield of ammonia quickly.

12.4 How can we control the rates of chemical reactions?

- Being able to speed up or slow down chemical reactions is important in everyday life and in industry. Changes in temperature, concentration of solutions, surface area of solids and the presence of catalysts all affect the rates of reactions.
- 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.

- 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:

$$\text{Rate of reaction} = \frac{\text{Amount of reactant used or amount of product formed}}{\text{Time}}$$

- The rate of a chemical reaction increases:
  - if the temperature increases
  - if the concentration of dissolved reactants or the pressure of gases increases
  - if solid reactants are in smaller pieces (greater surface area)
  - if a catalyst is used.
- 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.
- Increasing the temperature increases the speed of the reacting particles so that they collide more frequently and more energetically. This increases the rate of reaction.
- Increasing the concentration of reactants in solutions and increasing the pressure of reacting gases also increases the frequency of collisions and so increases the rate of reaction.
- Concentrations of solutions are given in moles per cubic decimetre (mol/dm3). Equal volumes of solutions of the same molar concentration contain the same number of moles of solute, i.e. the same number of particles.
- Equal volumes of gases at the same temperature and pressure contain the same number of molecules. (Candidates will not be expected to find concentrations of solutions or volumes of gases in this Unit.)
- Catalysts change the rate of chemical reactions but are not used up during the reaction. Different reactions need different catalysts.
- Catalysts are important in increasing the rates of chemical reactions used in industrial processes to reduce costs.

12.5 Do chemical reactions always release energy?

- Chemical reactions involve energy transfers. Many chemical reactions involve the release of energy. For other chemical reactions to occur, energy must be supplied. In industrial processes, energy requirements and emissions need to be considered both for economic reasons and for sustainable development.
- Describe the effects of changing the conditions of temperature and pressure on a given reaction or process
- Evaluate the conditions used in industrial processes in terms of energy requirements.
- When chemical reactions occur, energy is transferred to or from the surroundings.
- An exothermic reaction is one that transfers energy, often as heat, to the surroundings. Examples of exothermic reactions include combustion, many oxidation reactions and neutralisation.
- An endothermic reaction is one that takes in energy, often as heat, from the surroundings. Endothermic reactions include thermal decompositions.
- 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:

hydrated	endothermic	anhydrous		
copper sulfate	$\rightleftharpoons$	copper sulfate	+	water
(blue)	exothermic	(white)		

The reverse reaction can be used as a test for water.

- When a reversible reaction occurs in a closed system, equilibrium is reached when the reactions occur at exactly the same rate in each direction.

- The relative amounts of all the reacting substances at equilibrium depend on the conditions of the reaction.
- If the temperature is raised, the yield from the endothermic reaction increases and the yield from the exothermic reaction decreases.
- If the temperature is lowered, the yield from the endothermic reaction decreases and the yield from the exothermic reaction increases.
- In gaseous reactions, an increase in pressure will favour the reaction that produces the least number of molecules as shown by the symbol equation for that reaction.
- These factors, together with reaction rates, are important when determining the optimum conditions in industrial processes, including the Haber process.
- It is important for sustainable development as well as economic reasons to minimise energy requirements and energy wasted in industrial processes. Non-vigorous conditions mean less energy is used and less is released into the environment.

12.6 How can we use ions in solutions?

- Ionic compounds have many uses and can provide other substances. Electrolysis is used to produce alkalis and elements such as chlorine and hydrogen. Oxidation-reduction reactions do not just involve oxygen. Soluble salts can be made from acids and insoluble salts can be made from solutions of ions.
- Predict the products of electrolysing solutions of ions
- Suggest methods to make a named salt
- Explain and evaluate processes that use the principles described in this unit
- Complete and balance supplied half equations for the reactions occurring at the electrodes during electrolysis.
- The state symbols in equations are (s), (l), (g) and (aq).
- When an ionic substance is melted or dissolved in water, the ions are free to move about within the liquid or solution.
- Passing an electric current through ionic substances that are molten or in solution breaks them down into elements. This process is called electrolysis.
- During electrolysis, positively charged ions move to the negative electrode, and negatively charged ions move to the positive electrode.
- At the negative electrode, positively charged ions gain electrons (reduction) and at the positive electrode, negatively charged ions lose electrons (oxidation).
- If there is a mixture of ions, the products formed depend on the reactivity of the elements involved.
- Reactions at electrodes can be represented by half equations, for example: $2Cl^- \rightarrow Cl_2 + 2e^-$
- The electrolysis of sodium chloride solution produces hydrogen and chlorine. Sodium hydroxide solution is also produced. These are important reagents for the chemical industry.
- Copper can be purified by electrolysis using a positive electrode made of the impure copper and a negative electrode of pure copper in a solution containing copper ions.
- 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.
- Soluble salts can be made from acids by reacting them with:
    - Metals - not all metals are suitable, some are too reactive and others are not reactive enough
    - Insoluble bases – the base is added to the acid until no more will react and the excess solid is filtered off
    - Alkalis - an indicator can be used to show when the acid and alkali have completely reacted to produce a salt solution.

- Salt solutions can be crystallised to produce solid salt.
- Metal oxides and hydroxides are bases. Soluble hydroxides are called alkalis.
- 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 sulphates)
    - The metal in the base or alkali.
- Ammonia dissolves in water to produce an alkaline solution. It is used to produce ammonium salts. Ammonium salts are important as fertilisers.
- Hydrogen ions H^+ (aq) make solutions acidic and hydroxide ions OH^- (aq) make solutions alkaline. The pH scale is a measure of the acidity or alkalinity of a solution.
- In neutralisation reactions, hydrogen ions react with hydroxide ions to produce water. This reaction can be represented by the equation: $H^+ (aq) + OH^- (aq) \rightarrow H_2O (l)$.