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Editor: Morton Jenkins

Chapter 5 Atomic structure and the Periodic Table, compounds and patterns in reactions

By the end of this Chapter you should:

- know that elements are made up of atoms that have a small central nucleus made up of protons and neutrons;
- understand that most of the mass is concentrated in the positive nucleus, which is surrounded by light, negatively charged electrons;
- know that the electrons occupy energy levels (orbits or shells) around the nucleus;
- understand the terms 'mass number' and 'atomic number';
- know the maximum number of electrons that each orbit or energy level can hold;
- know the arrangement of the elements in the Periodic Table of elements;
- understand the formation of compounds;
- understand some chemistry of the elements in Groups 1 and 7 of the Periodic Table;
- know how to write simple chemical equations;
- know how to test for hydrogen and carbon dioxide;
- know how to test for chlorides and iodides;
- understand that elements are the basic building blocks of all substances and cannot be broken into anything simpler by chemical means;
- know that Mendeleev constructed the first periodic table by arranging the elements in order of relative atomic mass and leaving gaps for elements not discovered at that time;
- know that the modern Periodic Table arranges the elements in order of their atomic numbers;
- know that columns in the Periodic Table are called groups and rows are called periods;
- know the chemistry of the elements in two groups in the Periodic Table.

Atomic structure

The structure of atoms

Elements are the basic building blocks of matter. Elements cannot be broken into anything simpler by chemical means. Each element has its own symbol. We now know that elements are made up of **atoms**. The English chemist John Dalton (see Figure 5.1) put forward the first successful atomic theory at the beginning of the nineteenth century. He used it to explain observed facts about the behaviour of substances. This is how science works. Theories explain the observed facts.

Since then our knowledge has steadily grown. We now know that atoms are made up of even simpler particles.

- Each atom contains a small positively charged central region called the **nucleus**.

Figure 5.1 John Dalton put forward the first theory of atomic structure.

Did you know?

John Dalton suffered from colour blindness, which is sometimes called Daltonism.

Atomic structure:
www.chemguide.co.uk

General chemistry websites:
www.rsc.org
www.bbc.co.uk/schools
chemistry.about.com
www.sciencemuseum.org.uk
www.chemicalelements.com
www.schoolscience.co.uk

- The nucleus contains nearly all the mass of the atom.
- Light, negatively charged **electrons** surround the nucleus (see Figure 5.2) and are attracted to it. (Positive attracts negative.)

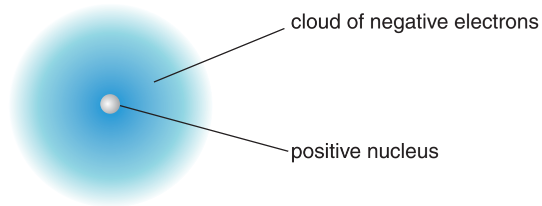

Figure 5.2 Model of the structure of the atom

The nucleus is made up of two types of particle: the **proton** and the **neutron**. The mass of the positive proton is 0.000 000 000 000 000 000 000 001 7 g, which is very small. The mass of a neutron is the same as that of the proton, but it has no electrical charge. For convenience, we can call the mass of a proton 1 unit and its charge +1, and describe the other particles relative to these values.

Table 5.1 Relative masses and charges of fundamental particles

Particle	Relative mass	Relative charge
Proton	1	+1
Neutron	1	0
Electron	Negligible	–1

Protons, neutrons and electrons (see Table 5.1) are called fundamental particles. The number of protons in the nucleus of an atom is called the **atomic number**. Each element has its own atomic number. For example, hydrogen has the atomic number 1. Lithium has the atomic number 3. Chlorine has the atomic number 17.

The number of protons plus the number of neutrons is called the **mass number**. The mass number and atomic number for an atom of sodium, Na, can be written as shown in Figure 5.3.

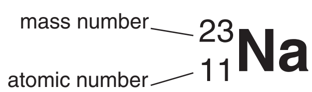

Figure 5.3 Mass number and atomic number of sodium

An atom is electrically neutral because **the number of electrons surrounding the nucleus equals the number of protons in the nucleus**. Where the number of electrons does not equal the number of protons, the particle is no longer an atom. It is called an **ion**, and it has an electrical charge.

Activity

Plan experiments to show how the rate of a chemical reaction is affected by:

- changes in concentration
- changes in temperature
- changes in the surface area of solid reactants.

Your plan should include:

- the apparatus you would use
- the reactants
- the precise way you would carry out the experiments
- how you would present the results of your experiments.

How reactions take place

A chemical reaction can occur when reacting molecules, atoms or ions encounter or collide with one another. Not every collision results in chemical reaction, but when the collision has enough energy for bonds to break and be reformed, then a reaction takes place. Such successful collisions are a small fraction of the total collisions taking place in a given time.

The easiest reactions to visualise are those that take place in the gaseous state. The molecules of a gas are in constant random motion, colliding with themselves and the walls of the containing vessel. Figure 6.9 represents the gaseous reaction shown in Figure 6.8.

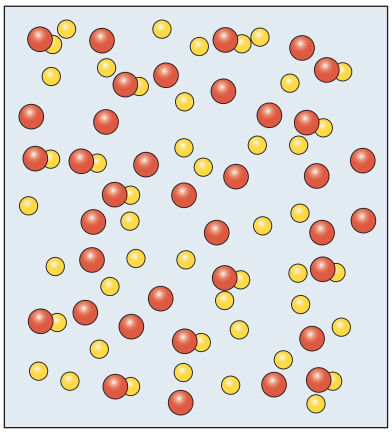

Figure 6.9 Moving gas particles collide frequently.

Figure 6.8 Molecules react when they collide.

Ionic reactions in solution take place very quickly when ions of opposite charge come together. Solid ionic compounds, which react in solution, often show no reaction in the solid state.

Factors affecting the rate of a chemical reaction

The physical state of the reactants

The greater the surface area, the faster the reaction! Finely divided solids react more quickly than lumps of a solid. The reason is that in the finely divided or powder form, the surface area exposed to reaction is greater. This means that more collisions between the reactants can take place in a given time, so there are more successful collisions and the reaction takes place more quickly.

The increase in surface area when a material is finely divided is shown in Figure 6.10. Work out what the total surface area would be if the original cube were divided in this way five times.

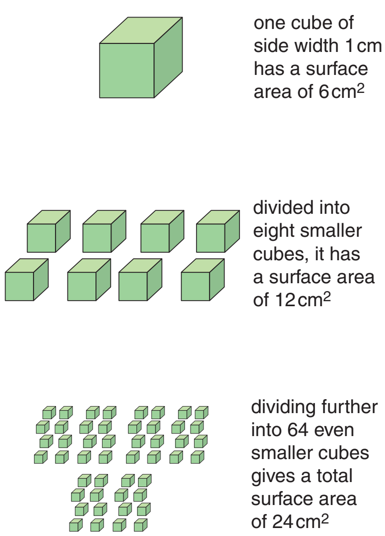

Figure 6.10 Division of a cube increases its surface area.

In flour mills there is a risk of explosions. Flour is made of starch, which can be burnt. When fine flour particles are mixed with air, a very large surface area is exposed to the oxygen in the air. There have been many cases of sparks setting off a combustion reaction, which then proceeds explosively.

Many solids show no reaction in the solid state but react in solution. This applies to ionic compounds in particular. In solution, the ions are free to move and interact.

The concentration of the reactants

The greater the concentration, the greater the rate of reaction! When the concentration of a reactant is increased, there are more particles in a given volume. Therefore there are more collisions per unit time, and more successful collisions, so the rate of the reaction increases.

When magnesium ribbon reacts with hydrochloric acid, the following reaction takes place.

magnesium metal + hydrochloric acid → magnesium chloride + hydrogen

$$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$$

H

Did you know?

Cooking involves chemical reactions. Vegetables cook faster in a pressure cooker because water boils at above 100 °C under pressure.

Practical work

The rates of chemical reactions

You are given some 3 cm lengths of magnesium ribbon and some dilute hydrochloric acid. Devise an experiment to investigate how the rate of this reaction varies with the concentration of the hydrochloric acid. Your plan should include the equipment you would use, and how you would record your results.

The effect of an increase in temperature

The higher the temperature, the greater the rate of a chemical reaction! The particles in gases and liquids are in constant motion. The average energy of the particles depends on the temperature; the greater the temperature, the greater the average energy of the particles.

Not all particles have the same energy. Only a fraction of the particles have sufficient energy to react. As the temperature increases, the number of particles with sufficient energy to react increases, and there are more successful collisions and the reaction goes more quickly. For many reactions, a 10 °C rise in temperature doubles the rate of reaction.

Practical work

1. It is easy to study rates of reaction at home. Measure the time taken for an indigestion tablet to dissolve in
   - **a** a glass of cold water
   - **b** a glass of hot water.
2. Compare these times with those taken for a powdered tablet to dissolve. (No one in the household should drink any of these solutions.)

Catalysts

Catalysts are substances that speed up a chemical reaction but remain chemically unchanged at the end of the reaction. Many catalysts work only for one particular reaction.

A solution of hydrogen peroxide decomposes rapidly into water and oxygen when in contact with manganese(IV) oxide.

Note that the manganese(IV) oxide catalyst does not appear in the equation.

hydrogen peroxide solution → water + oxygen

$$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$$

H

In living systems, biological catalysts are produced by cells and are called **enzymes**. The enzymes produced by yeast are used in the brewing and baking industries. Enzymes from yeast change

Did you know?

Catalysts are used extensively in industry. Catalysts are used in the manufacture of ammonia, sulfuric acid, margarine, polythene and a host of other important chemicals.

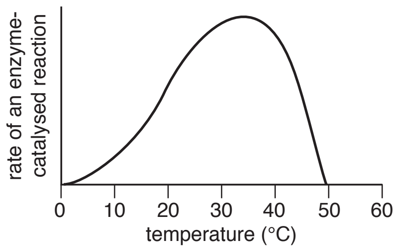

Figure 6.11 At what temperature does the enzyme work best in this enzyme-catalysed reaction?

Did you know?

Biological washing powders and liquids contain enzymes. Why are these detergents used in low-temperature washes?

carbohydrates into alcohol (ethanol) and carbon dioxide. Bubbles of carbon dioxide make the dough rise. In the dairy industry, the enzyme called rennin (or chymosin), which is found in rennet, is used to produce curds from the milk. This is the first stage in cheese-making.

When enzyme-catalysed reactions are heated, the reaction rate increases at first, but then decreases because enzymes are destroyed at higher temperatures (see Figure 6.11).

Catalysts are very important in industry, and there is a constant search for new and improved catalysts. Catalysts allow reactions to proceed at a good rate at a lower temperature and hence they save energy.

Some catalysts allow products to be created from renewable resources, for example fuel produced from renewable vegetable matter. Catalysts often enable a product to be formed in fewer stages. The important production of **biodiesel** from renewable resources (see Figure 6.12) uses a catalyst in one of its stages.

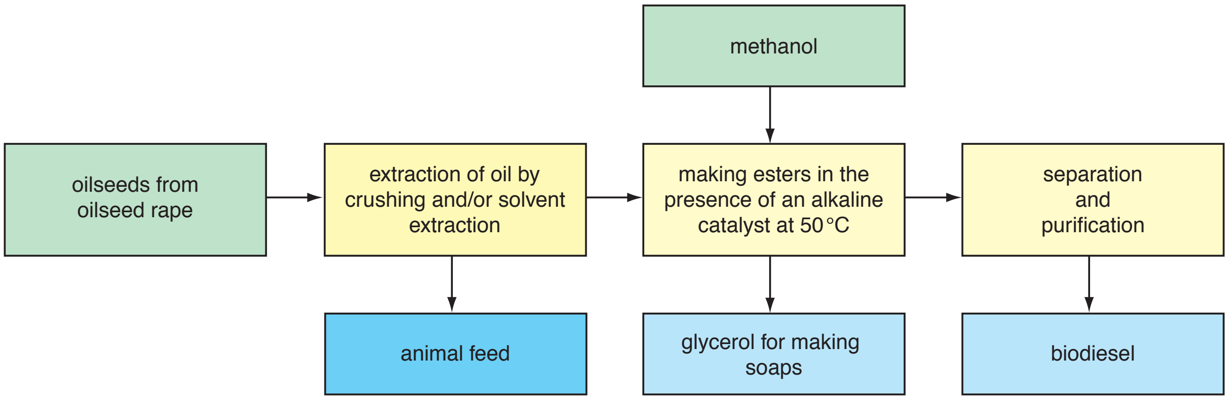

Figure 6.12 The reaction that produces biodiesel from vegetable oil needs a catalyst.

Nanoparticles

A nanometre (nm) is 1.0×10^{-9} m, or 0.000 000 001 m.

Scientists have recently developed small particles of nanometre size. When reduced to this size, particles often display new and different properties to the same substance in bulk form.

One new advance in this area has been the production of silver particles on a nanoscale. These particles have been found to have antibacterial, antifungal and antiviral properties. It is thought that they work through the production of silver ions. It is hoped that they may be effective against MRSA (methicillin-resistant *Staphylococcus aureus*). This infection is antibiotic-resistant and is commonly acquired in hospital. It can be fatal.

Nano-sized silver particles are currently being used in the linings of refrigerators to make them self-sterilising.

One firm is reported to have produced a device for treating urinary infections by inserting a biodegradable plastic device covered with nano-sized silver particles into the urinary tract.

Nanoscience is a new science, and there are concerns about its applications. Since a substance in the nano form has different properties from the same substance in the bulk form, care must be exercised. Nanoparticles may pass through the skin and have adverse biological effects. Since nanoparticles are so small, they may be easily dispersed into the environment. Much that is written is speculation, and research is continuing to determine what dangers really exist.

Nanoscience:
www.wellcome.ac.uk/bigpicture

Did you know?

Nanoparticles have different properties from larger masses of the same material, possibly because each particle is only a few hundred atoms. Gold particles are totally inactive until they are less than about 8 nm in diameter, but nano-sized gold particles are used as catalysts.

Fossil fuels and combustion

Figure 6.13 Cefn Coed Colliery, Wales, 1930: then the deepest anthracite mine in the world.

There are three forms of fossil fuel: coal, oil and natural gas. The three were formed many hundreds of millions of years ago.

- **Coal**: Coal is made up of carbon, hydrogen, oxygen, nitrogen and varying amounts of sulfur. There are three main types of coal: anthracite, bituminous coal and lignite. Coal was formed from the decay of prehistoric plant material, under the influence of heat and pressure. Evidence of the plant origin can often be found as fossils in coal strata (see Figure 6.13).
- **Oil**: Petroleum formation occurred in several steps. There was a lot of organic matter from organisms such as plankton, bacteria, small animals and algae. This organic matter was buried quickly before oxidation took place. Chemical reactions under heat and pressure slowly transformed the organic material into the hydrocarbons found in petroleum (see Figure 6.14).
- **Natural gas**: This was formed via the same processes as petroleum, but it could also seep through porous rock and collect in pockets in the Earth's crust. It mainly consists of methane (CH_4).

Figure 6.14 Texaco Oil Refinery, Pembroke, Wales

As all three fossil fuels were formed hundreds of millions of years ago, they are **finite resources**, and already supplies are dwindling in various parts of the world.

Fractional distillation of crude oil

Petroleum or crude oil is a complicated mixture of hydrocarbons. Hydrocarbons are compounds containing carbon and hydrogen only. For useful materials to be obtained from crude oil, the oil must be subjected to several processes. The first of these is **fractional distillation**. This involves separating the complex mixture of hydrocarbons in crude oil into simpler mixtures of hydrocarbons (fractions), depending upon their boiling points (see Figure 6.15).

Fractional distillation:
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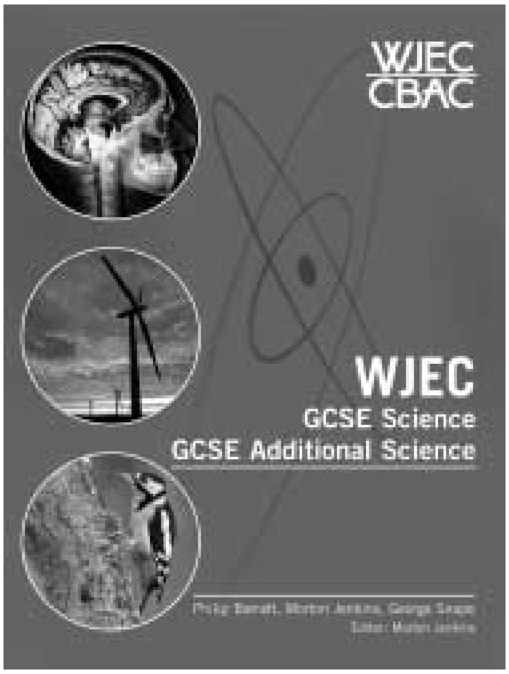

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