5.3 Rates of chemical reactions

Explosions are combustion reactions that occur in a fraction of a second. In contrast, the corrosion reaction that rusts a shipwreck may take years. Being able to control how fast chemical reactions occur is of great use in industry, medicine, at home and in science laboratories. Scientists can slow down unwanted reactions and speed up useful reactions for our benefit.

Fast and slow chemical reactions

The speed at which a chemical reaction proceeds is known as the **rate of reaction**. Some chemical reactions that proceed quickly are explosions and combustion reactions (Figure 5.3.1), when vinegar is mixed with bicarbonate of soda and the burning of gas in a Bunsen burner. These reactions are said to have a fast rate of reaction. Chemical reactions that proceed slowly are said to have a slow rate of reaction. Rusting, ripening and the fermentation of wine (Figure 5.3.2) are examples.

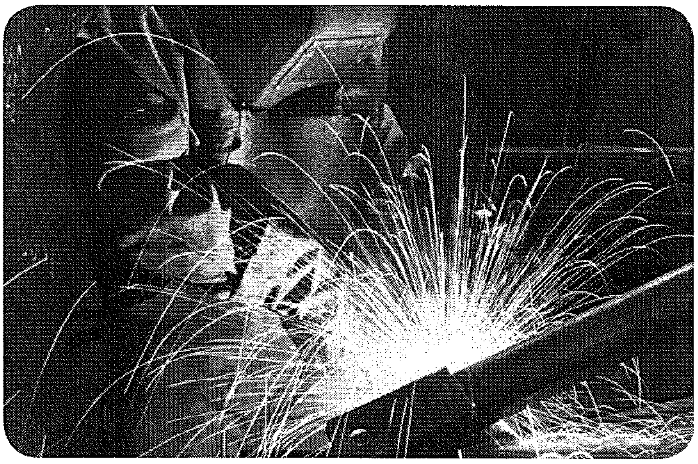

Figure 5.3.1 Welders use the rapid combustion of acetylene to produce the extremely hot flame required to weld and cut metals.

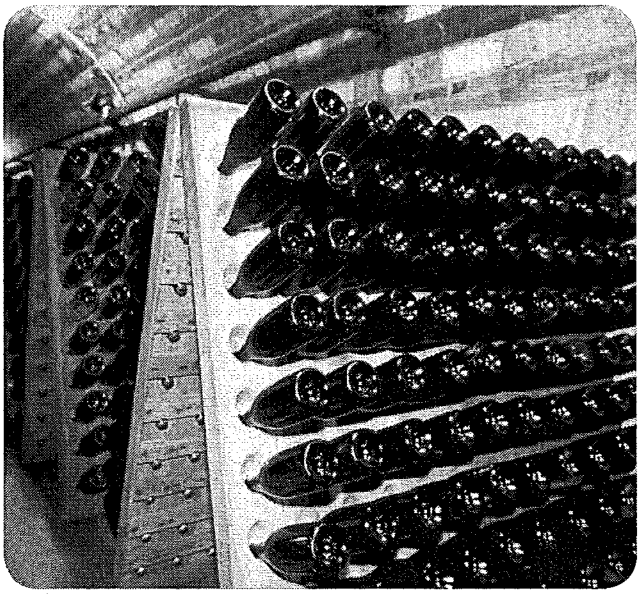

Figure 5.3.2 The slow chemical reactions that ferment wine and give it its flavour mean that it can take years before the wine is ready to drink.

Controlling the rate of chemical reactions

The rate of almost every reaction can be increased or decreased. For example, when you run a race and then breathe deeply, your heart pumps faster to speed up the rate of respiration. In contrast, the rate of respiration slows down when you're calm and relaxed. Scientists examine how each chemical reaction works to determine the best method for controlling its rate of reaction.

Factors that affect the rate of reaction are:

- temperature
- concentration of the reactants
- surface area (if the reactants are in lumps or fine powder)
- agitation (mixing and stirring)
- catalysts (chemical helpers).

By changing these variables, scientists can control how fast or slow a chemical reaction proceeds.

Temperature

Increasing the temperature will normally increase the rate of a chemical reaction. This occurs for two reasons.

First, increasing the temperature increases the speed of the particles in liquids and gases. As a result, particles collide more frequently, so more chemical reactions occur in a shorter amount of time.

Second, increasing the temperature gives the particles more energy. So, when the molecules collide, chemical bonds are more likely to break and the atoms in the reactants can rearrange more easily to form products.

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There are many reasons for using heat to increase the rate of a reaction. When you bake a batch of biscuits, you place it in the oven to increase the rate of chemical reactions that convert your dough into biscuits. However, you can't increase the temperature too much or the rate of reaction will be so fast that the biscuits will burn before they are cooked all the way through. This is what has happened in Figure 5.3.3.

Figure 5.3.3 Biscuits must be baked at the right temperature. If the temperature is too high, the reaction is so fast that they burn before they are cooked inside.

Sometimes you may want to decrease the rate of reaction by lowering the temperature. When you place a carton of milk in the fridge, it slows the rate of the chemical reaction that turns milk sour. Similarly, fruit farmers will transport their produce in refrigerated trucks to stop the fruit ripening before it gets to market.

SciFile

Putting life on hold

Through the process of in-vitro fertilisation (IVF), human egg cells can be fertilised and frozen for later use. Freezing the eggs stops the chemical reactions that cause the embryo to develop. Today, one in 33 births in Australia is the result of IVF. That's almost one in every classroom.

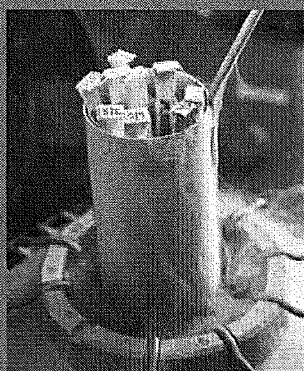

Figure 5.3.4 Frozen human eggs

Concentration

The term **concentration** refers to the amount of reactants present in a particular volume of liquid or gas during the reaction. For example, if you put 20 teaspoons of sugar in a litre of water, then the concentration of sugar is high. The solution is concentrated. However, if you put 1 teaspoon of sugar in a litre of water, then the concentration of sugar is low. The solution is dilute. Concentrated and dilute solutions are shown in Figure 5.3.5.

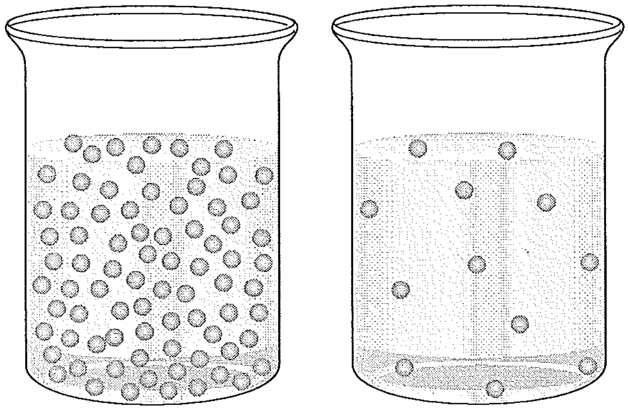

Figure 5.3.5 A concentrated solution has a large number of sugar molecules in the beaker of water. A dilute solution has very few sugar molecules in the same volume.

Increasing the concentration of the reactants will increase the rate of reaction. This is because the particles are more likely to collide and react when they are highly concentrated. Collisions between particles are necessary to allow the bonds to break and new bonds to form.

Increasing the concentration of reactants is a very common way of increasing the rate of reaction. You concentrate the reactants whenever you turn up the gas knob on a heater or stove like in Figure 5.3.6, add more wood to a fire, add more sugar to a breadmaker or drink 20 mL instead of 10 mL of antacid to relieve heartburn.

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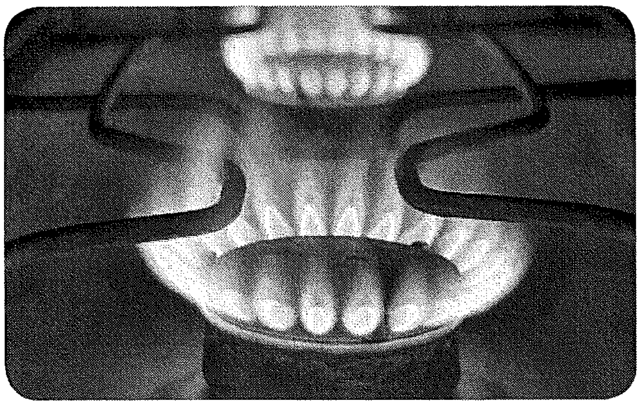

Figure 5.3.6 When you increase the flow of gas on a gas stove, you increase the concentration of reactants to produce a bigger flame and more heat.

It is also common to reduce the concentration of reactants in order to slow the rate of some reactions. When you place food in a zip-lock bag or air-tight container, you are limiting the concentration of oxygen and therefore limiting how quickly the food can go stale. A similar principle is used to protect some iron structures from rusting. Iron is often coated with paint to limit the amount of oxygen that can react with the surface to form iron(II) oxide (rust).

Agitation

Stirring reactants can also increase the rate of reaction. Stirring is known scientifically as **agitation.** Agitation ensures that the reactants are kept in contact, by removing build-up of products around the reactants. For example, if a solid piece of calcium carbonate is dropped into the bottom of a beaker of sulfuric acid, it will react with the acid to produce calcium sulfate, water and carbon dioxide gas. The word equation for this reaction is:

calcium carbonate + sulfuric acid → calcium sulfate + water + carbon dioxide

and the formula equation is:

$$CaCO_3(s) + H_2SO_4(aq) \rightarrow CaSO_4(aq) + H_2O(l) + CO_2(g)$$

Although the carbon dioxide bubbles off as a gas, the other products—calcium sulfate and water—build up around the calcium carbonate as shown in Figure 5.3.7. The products surround the calcium carbonate, which means less sulfuric acid contacts the calcium carbonate to react. Agitating the reaction flushes the products away from the calcium carbonate, and allows the sulfuric acid to attack the surface of the calcium carbonate. Magnetic stirrers (Figure 5.3.8) are used in the laboratory to constantly agitate reactions and ensure the maximum rate of reaction.

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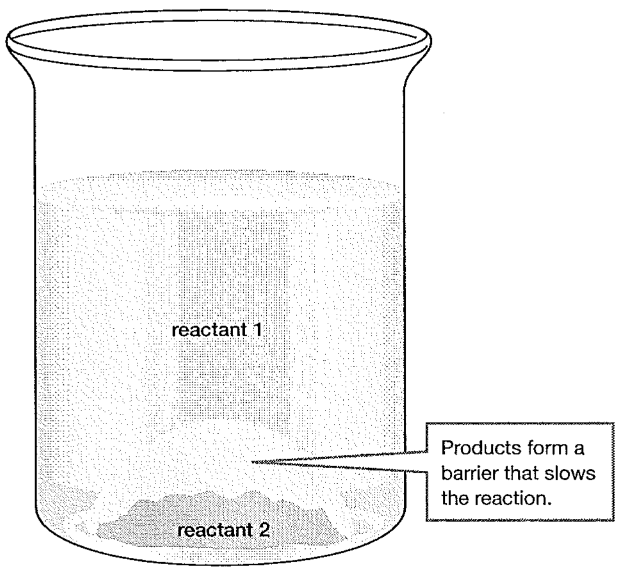

Figure 5.3.7 When a solid reacts with a liquid, the products build up around the solid, slowing down the rate of reaction. Agitation removes the build-up of products to maximise the rate of reaction.

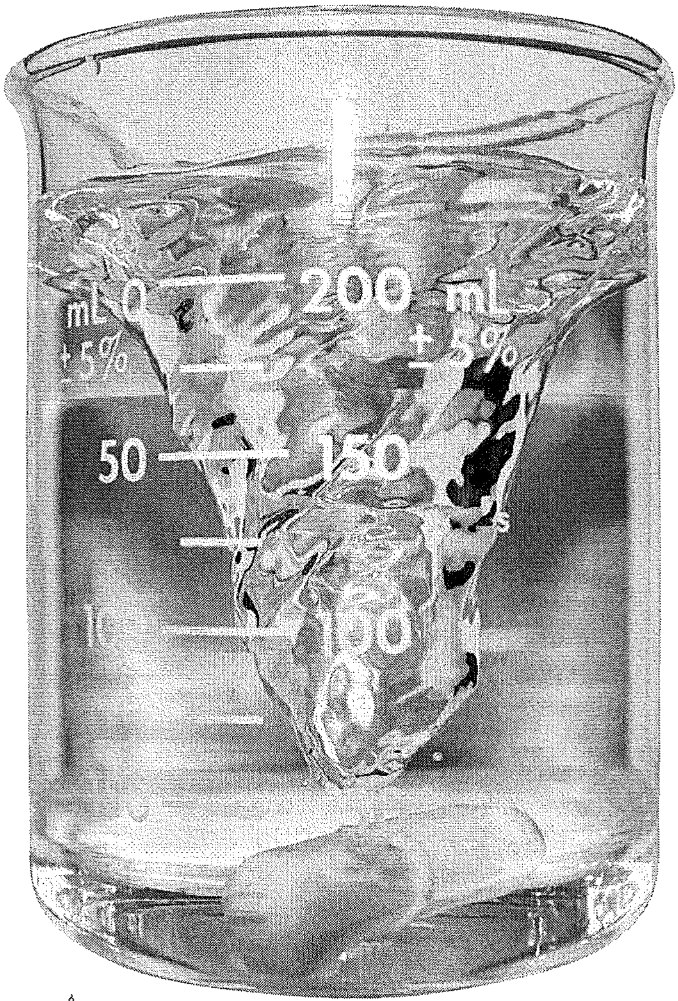

Figure 5.3.8 In the laboratory, scientists use magnetic stirrers to constantly agitate and ensure maximum rate of reaction.

Surface area of reactants

The rate of reaction between calcium carbonate and sulfuric acid can be increased further if the calcium carbonate is crushed into a powder rather than used as one solid piece. If the calcium carbonate is placed in the acid as a single, solid lump, the sulfuric acid can only react with the outside of the lump, as shown in Figure 5.3.9. However, if the lump is broken down into smaller pieces, then particles originally on the inside of the lump are now exposed and can react with the acid. This means more particles are reacting at the same time, so the reaction is faster. Dividing up solid reactants into smaller pieces creates a much larger surface in contact between the reactants.

Having a large surface area is important in the delivery of medicines in the form of capsules. The capsules contain powdered medicines so that when the capsule breaks apart in your stomach, the powdered medicines can be absorbed into your bloodstream more quickly.

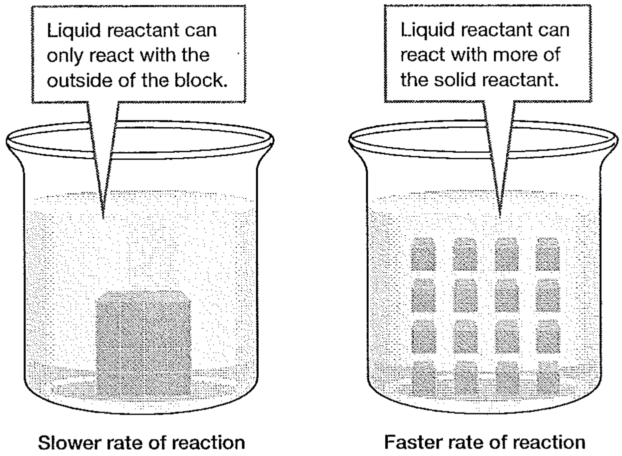

Figure 5.3.9 If the solid reactant is divided into smaller pieces, more of the solid is exposed to the liquid reactant and the rate of reaction is increased.

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Catalysts

Catalysts are chemicals that speed up reactions but are not consumed (used up) during the reaction. They can be considered 'chemical helpers' that help the reactants to form the products. Catalysts can do this in two ways:

- They reduce the amount of energy that is required to convert the reactants into products
- They make it easier for reactant molecules to collide and form products.

For example, a catalytic converter in a car exhaust system uses platinum metal as a catalyst to help convert the poisonous gas carbon monoxide (CO) into the less toxic carbon dioxide (CO_2). Normally, carbon monoxide and oxygen would not react fast enough to form carbon dioxide (Figure 5.3.10).

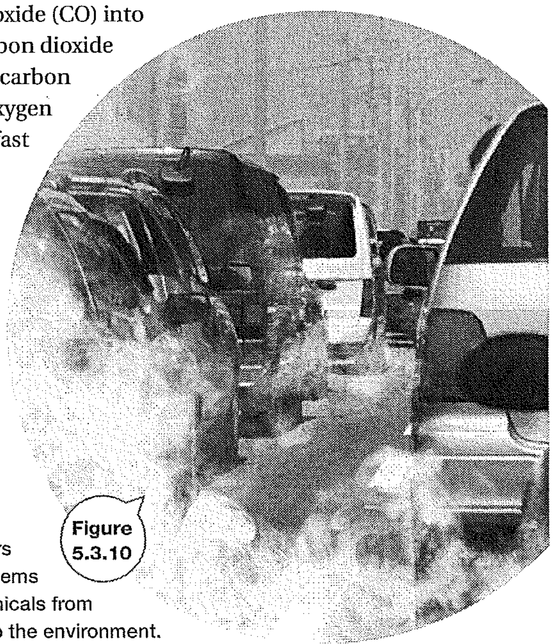

Figure 5.3.10 Catalytic converters in car exhaust systems prevent toxic chemicals from being released into the environment.