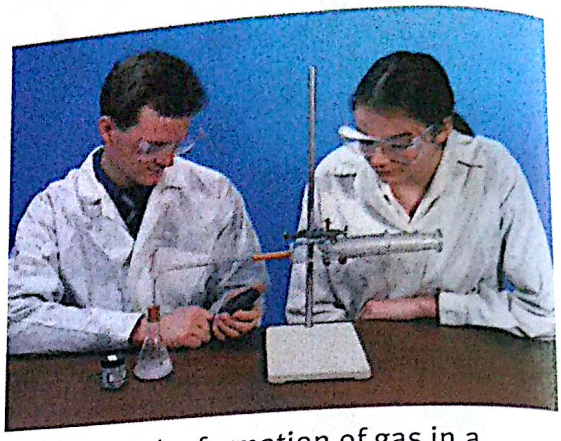
8.1 Measuring the rate of reaction

The rate at which a reaction takes place can be measured by working out how much of one of the products has been made in a given time, or how much of a reactant is used up in a given time.

For example, when you add a piece of magnesium ribbon to hydrochloric acid, hydrogen gas is given off.

Question

1 Write the word equation for the reaction of magnesium with hydrochloric acid.

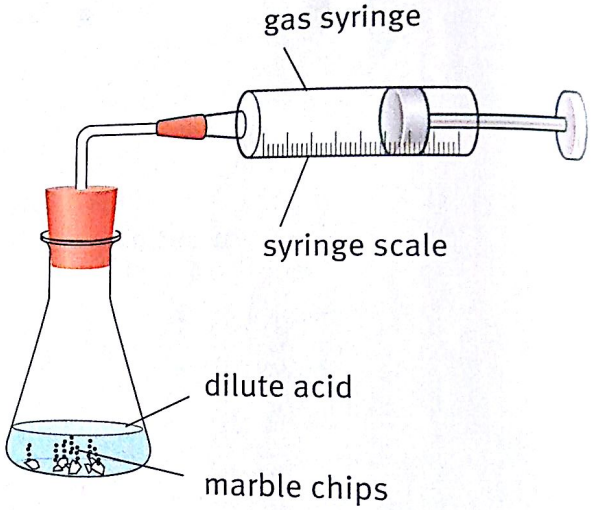


Measuring the formation of gas in a reaction.

How can you measure how quickly the reaction is taking place?

It is difficult to measure how quickly the reactants are used up or how quickly the magnesium chloride is formed. The easiest way is to measure how quickly the hydrogen gas is produced. You can measure the volume of gas produced in a particular length of time.

To collect the gas you can attach a syringe to the top of the flask so that no hydrogen can escape. You can use the scale on the syringe to measure the volume of gas produced at different times during the reaction.



The table below shows results obtained using this apparatus.

Time / s	Total volume of hydrogen gas produced / cm^3
0	0
30	10
60	20
90	26
120	40
150	48
180	54
210	60
240	64
270	66
300	66
330	66

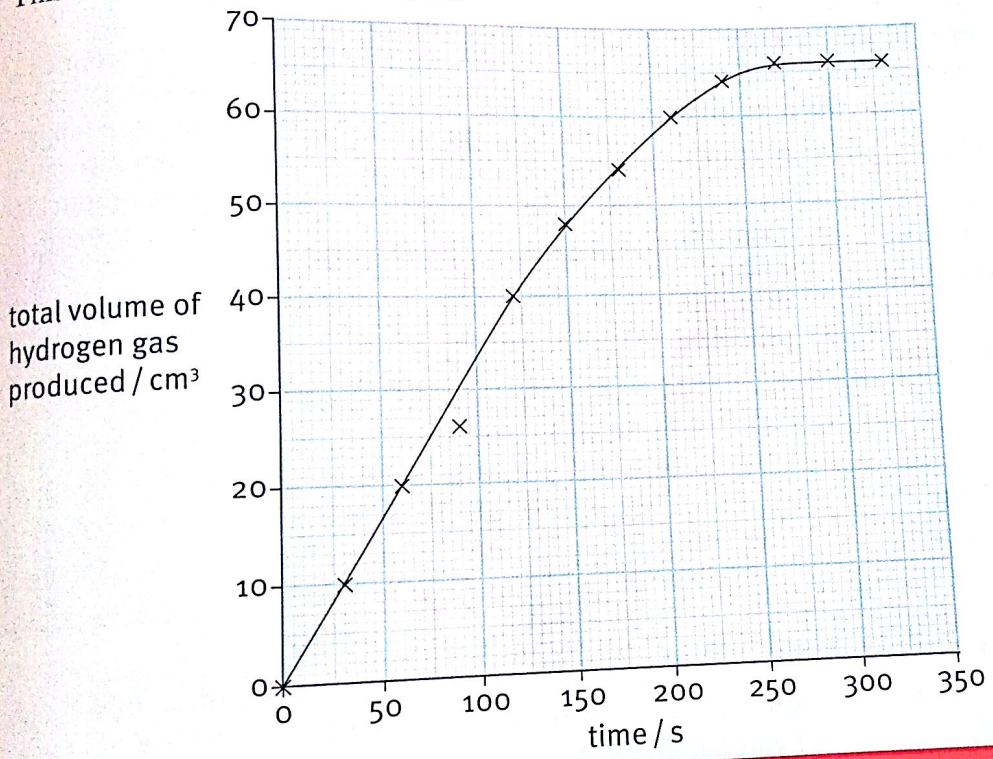
Questions

2 How can you tell from the results table that the reaction has finished at 270 seconds?

3 Suggest what might happen to the experiment if you used a lot more magnesium and acid, so that more than 100 cm^3 of hydrogen gas was formed. What could be done to reduce the risk of an accident if more than 100 cm^3 of hydrogen was produced?

When a graph of the results is plotted, it is easier to see the pattern that they make.

The graph shows that one of the results does not fit (correspond with) the pattern. This is called an anomalous result.



Questions

4 Which of the results is anomalous? Explain how you identified the anomalous result, and say what you would expect the result to be.

5 If you did this experiment and produced an anomalous result, what would you do about it? How would this help you to decide if the result really was anomalous?

Summary

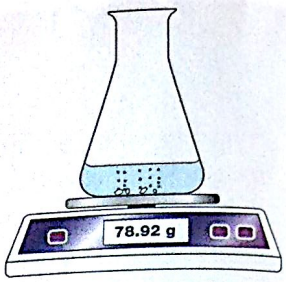
- The rate of a reaction can be measured by the amount of product made in a given time or amount of reactant used.
- If a gas is made in a reaction, measuring the volume of the gas produced in a given time is often the best way to measure the rate of the reaction.

8.2 Changes in the rate of reaction

If you measure the rate of reaction, you find that the rate changes as the reaction proceeds. For example, in a reaction between calcium carbonate and hydrochloric acid, lots of bubbles of carbon dioxide gas are given off at the start of the reaction. As the reaction continues, fewer and fewer bubbles are produced. This shows that the reaction has slowed down.

Question

1 Write the word equation for the reaction of calcium carbonate with hydrochloric acid.



Measuring the rate of a reaction by finding the loss in mass.

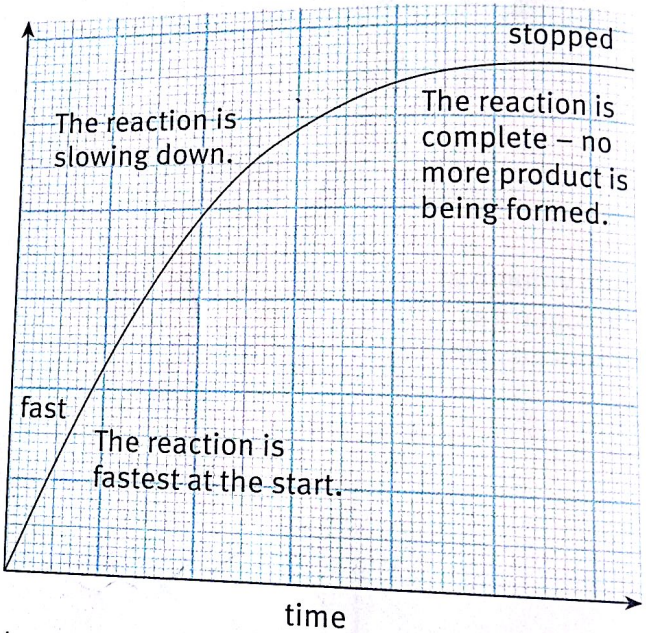
As carbon dioxide gas is lost from the flask, the mass of the flask and contents decreases. If you measure the mass of the flask every 30 seconds, you find that the mass decreases quickly at first. But as the reaction continues, the mass decreases more and more slowly.

Using the graph

The graph can be used to measure the rate of reaction at any given time. The slope or gradient of the line tells you how quickly the reaction is taking place.

The steeper the slope, the faster the reaction.

The line is steepest at the start of the reaction. This is when the reaction is fastest. As the slope of the line becomes less steep, the reaction is slowing down. When the line levels out it shows that no more carbon dioxide is being lost. This means that the reaction has ended.



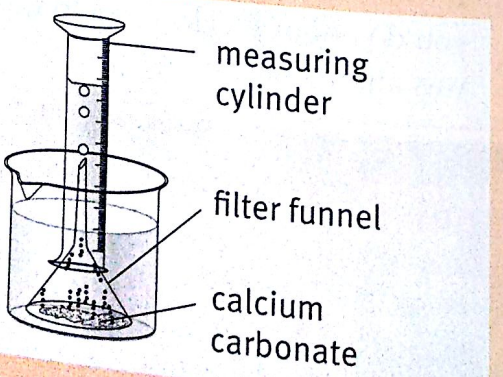
This graph shows the results of an investigation into the rate of reaction between calcium carbonate and hydrochloric acid.

Activity 8.2

Measuring the rate of reaction

SE

In this activity you are going to measure the rate of reaction between calcium carbonate and hydrochloric acid. You could do this by measuring the mass of carbon dioxide lost, using a top pan balance as in the diagram at the top of this page. Or you could collect the carbon dioxide and measure the volume produced either using a gas syringe, as shown on page **104**, or using a funnel and measuring cylinder filled with water, as shown here.



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1 Prepare a table for your results.
2 Assemble your equipment and put the calcium carbonate into the flask.
3 Add the hydrochloric acid; start the timer and measure the initial mass or volume.
4 After 30 seconds measure again. Repeat this every thirty seconds, until you have three readings that are the same.

Questions

A1 Plot a graph of your results and describe how the rate of reaction changes over time.
A2 What problems did you find when you carried out this reaction? How might these have affected your results?
A3 How could you improve the reliability of your results?

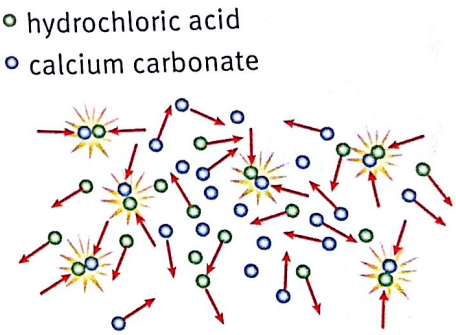
Why does the rate of reaction change?

We can use the ideas about particle theory that you learnt about in Stages **7** and **8** to answer this question.

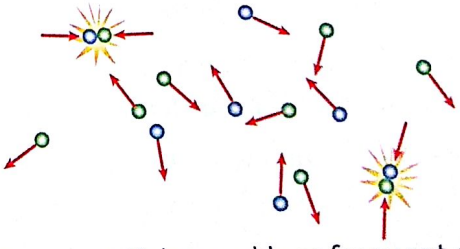
For a chemical reaction to take place, the particles of the reactants involved have to collide with each other with enough energy to react together. At the start of a reaction there are lots of particles that have not reacted. **Collisions** happen frequently. This means that a lot of carbon dioxide is formed in the first 30 second period.

As the particles react, the number that have not reacted gets lower and lower. The chance of two unreacted particles colliding with each other decreases. This means that less carbon dioxide is formed in the later 30 second periods. This means that the rate of reaction is slower.

Eventually, all the particles have reacted. There are no more collisions that result in the production of carbon dioxide gas. The reaction has finished.



Many particles and frequent collisions.



Fewer particles and less frequent collisions.

Summary

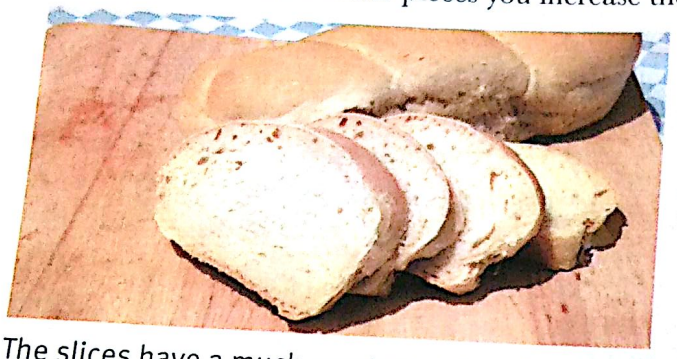
- The rate of a reaction changes with time.
- The slope of the graph of the results is a measure of the rate of reaction.
- The more collisions between particles of reactants there are in a given time, the faster the reaction.

8.3 Surface area and the rate of reaction

When you burnt magnesium ribbon in a Bunsen flame it reacted very quickly, with a white flame. But if you place a large piece of magnesium in the Bunsen flame it does not burn. If you place magnesium powder in the Bunsen flame it burns faster than the ribbon.

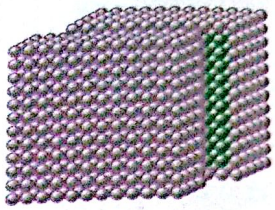
Why does this happen? Think about what is happening as the magnesium reacts with oxygen in the air. Only the magnesium atoms on the surface can make contact with the oxygen. In the block of magnesium, most of the atoms are inside the block, away from the oxygen. In the magnesium ribbon, most of the atoms are on the surface and react. Magnesium powder has an even larger total **surface area** and, because it has the most atoms available to react, the reaction is quicker.

Small pieces of solids always react faster than larger pieces. Each time you cut a solid into smaller pieces you increase the total surface area.

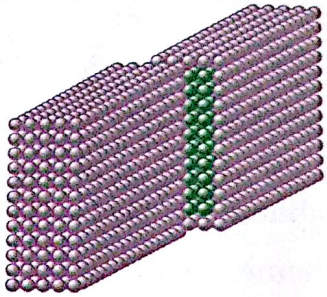


The slices have a much greater total surface area than the whole loaf.

- atom at the surface
- atom inside



Only the magnesium atoms on the surface can react with oxygen in the air.



In magnesium ribbon, more of the atoms are on the surface and can react with oxygen in the air.

Activity 8.3A
Burning iron

You are going to compare what happens when you heat an iron nail, iron wool and iron filings in air. Remember to record your observations for each.

1. Grip the nail firmly with tongs and hold it in the flame of a Bunsen burner.
2. Hold the iron wool in tongs and hold it in the flame of a Bunsen burner.
3. Use the end of a spatula to gently sprinkle a few iron filings into a Bunsen flame.

Questions

A1 Compare the reactions of these three forms of iron.

A2 What effect does increasing the total surface area have on the rate of reaction?

A3 Explain the reasons for the change in reaction rate.

Activity 8.3B

The effect of surface area on the rate of reaction

In this activity you are going to investigate the effect of changing the size of pieces of calcium carbonate (marble chips) in the reaction with hydrochloric acid.

You could use any of the methods shown in topic **8.1** and topic **8.2** on pages **104–107** for measuring the rate of reaction. You are going to do the experiment twice, using different sizes of calcium carbonate chips. Whichever method you use, carry out the same one for the two experiments.

Answer these questions before you start the experiment.

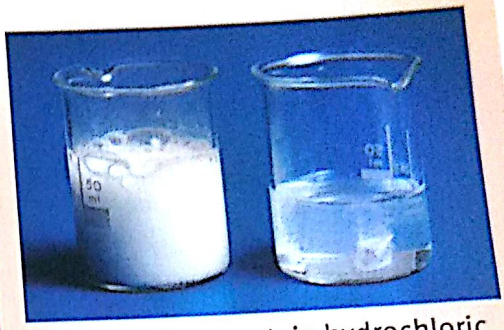
Questions

A4 Which reaction do you predict will be the fastest?

A5 The size of the pieces of calcium carbonate will be changed but the total mass of the pieces will be kept the same. Why is it also important to keep the volume, type and concentration of the acid the same?

A6 What are the dependent and independent variables?

A7 Read what you are going to do, and construct a results table.



These beakers contain hydrochloric acid reacting with calcium carbonate. You will probably be able to use flasks instead of beakers in your experiment.

1. Add 5 g of large marble chips to a measured volume of hydrochloric acid in a conical flask.
2. Start the timer and read the volume or mass every 30 seconds, until you have at least three readings that are the same. Record your results carefully.
3. Repeat, but this time use 5 g of smaller chips.
4. Plot both sets of results on one graph.

Questions

A8 Which line on your graph is steeper?

A9 Which size of marble chip reacts more quickly?

A10 What happens to the rate of reaction as the total surface area increases?

A11 What do you predict would happen if you repeated the experiment using powdered calcium carbonate?

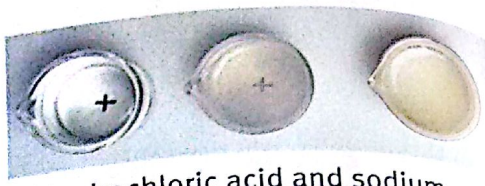
Summary

- When a solid lump is cut into pieces, its total surface area increases.
- An increase in the total surface area gives an increase in the rate of reaction.
- The rate of reaction increases because the reaction can only take place with the particles on the surface of the solid.

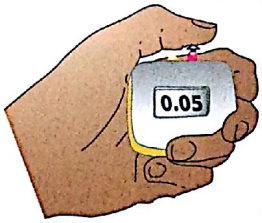
8.4 Temperature and the rate of reaction

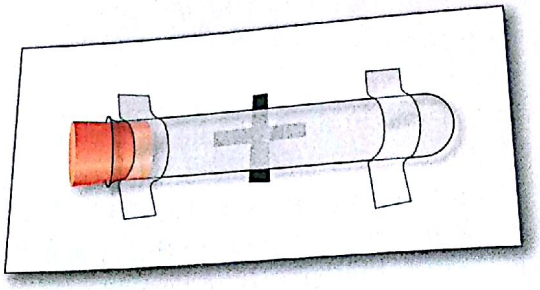
You are going to investigate how temperature affects the rate of reaction between hydrochloric acid and a salt called sodium thiosulfate. This reaction is a good one to use, because there is an especially easy way to measure its rate.

If you mix hydrochloric acid with a solution of sodium thiosulfate, the mixture becomes cloudy. This is because sulfur is produced. Sulfur is insoluble in water, so it forms a **precipitate**. You can time how long it takes for enough sulfur to be formed to make it impossible to see through the liquid.



As hydrochloric acid and sodium thiosulfate react together, sulfur is formed. The sulfur makes the liquid cloudy.





Activity 8.4A

The effect of temperature on the rate of reaction – trial run

SE

You are going to measure the rate of the reaction between sodium thiosulfate and hydrochloric acid at different temperatures. Before you do this you will need to carry out a **trial run**. A trial run means you will carry out a practice experiment to make sure you can do the experiment safely and effectively. You can then be prepared and overcome any problems you find.

Safety: Make sure the room is well ventilated, because sulfur dioxide gas will be produced. Place any reacted solutions into a container with some solid sodium hydrogencarbonate for your teacher to remove later. This will react with the sulfur dioxide.

1. Mark a dark line or a cross on a piece of paper.
2. Place 10 cm^3 of sodium thiosulfate solution in a test tube.
3. Add 1 cm^3 hydrochloric acid and put the stopper into the test tube.
4. Place the test tube horizontally on the paper over the dark cross. (You can hold it in place with some sticky tape or tack adhesive). Time how long it takes for the line to disappear.

Question

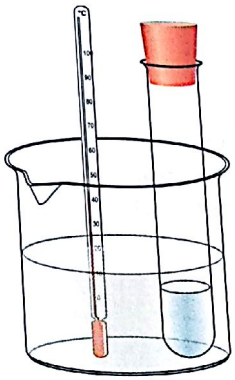
A1 What information did your trial run give you?

Activity 8.4B

The effect of temperature on the rate of reaction – preliminary work

The next step is to do some preliminary work to decide which temperatures you will use. To change the temperature of the sodium thiosulfate solution, warm it in a suitable water bath before adding the acid. Make sure there is a stopper in the tube while it is warming.

Discuss in your group how you will do this preliminary work. When you have made your plan discuss it with your teacher.



Questions

A2 Describe what you have decided to do as your preliminary work.
A3 How will this help you with your final investigation?
A4 Write the outline plan for your investigation, including a results table.

Activity 8.4C

The effect of temperature on the rate of reaction – investigation

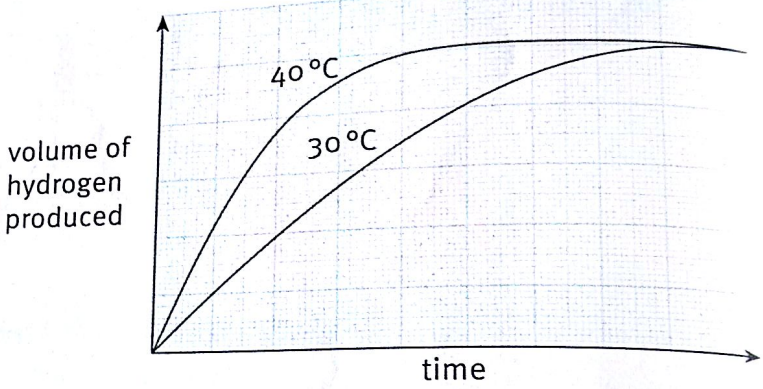
SE When your teacher has checked your plan, you can carry out your investigation.

Questions

A5 How did you make sure this was a fair test?
A6 Plot a graph of your results.
A7 Describe the relationship between the temperature and the rate of reaction.

Here is a graph of some typical results for the rate of the reaction between marble chips and hydrochloric acid. This was carried out as in the previous topic.

You can see from the graph that you do not get any more of the product (carbon dioxide gas) at the higher temperature. You get the same volume of gas, but in less time.

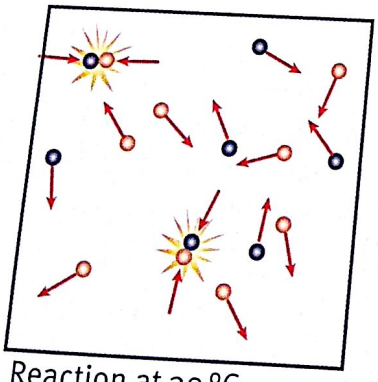


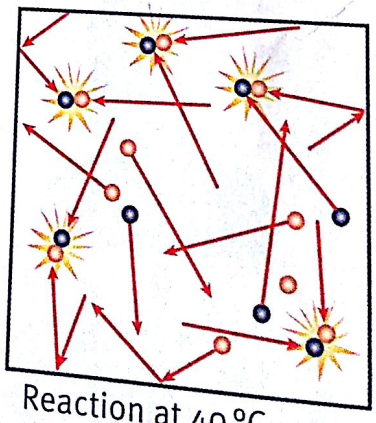
Questions

A+I 1 How can you tell which line shows the faster reaction?
A+I 2 If you did the same experiment at 50 °C what would the line on the graph be like?

Explaining the effect of temperature

Particles move all the time. When the temperature of the reaction is increased the particles move faster. They collide more often, and with more energy.


Reaction at 30 °C.


Reaction at 40 °C.

Summary

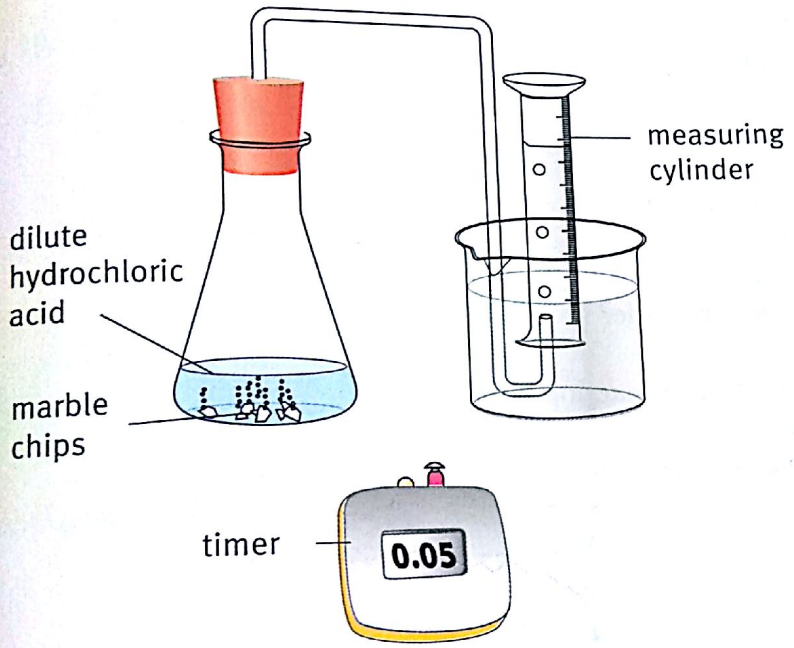
- As the temperature is increased the rate of reaction increases.
- When particles have more energy they move faster, and collide more often and with greater energy.

If you carried out an experiment with marble chips and hydrochloric acid, using the same size and same mass of chips, the same temperature but different concentrations of the acid, what would you expect to happen?

Activity 8.5A

Planning an investigation into the effect of concentration

In this experiment you will change the concentration of the acid used. Instead of measuring the volume of carbon dioxide produced every 30 seconds, you will use a slightly different method of measuring the rate of the reaction – timing how long it takes to collect 25 cm^3 of carbon dioxide in the measuring cylinder.



Discuss in your group how you will carry out this investigation. Things to be considered are:

- Which factors will you keep the same?
- What mass of marble chips will you use?
- What volume of acid will you use?
- Which concentrations of acid will you use?
- What safety precautions should you take?
- Do you need to do a trial run or some preliminary work?
- If so what do you want to find out?
- Do you need to repeat any of your readings?

When you have planned your investigation show it to your teacher.

Activity 8.5B

Carrying out an investigation into the effect of concentration

1 Make up your concentrations of acid. You can do this by diluting the acid you have been given. Make up 50 cm^3 each time. Use the following table to help you.

Solution	Acid / cm^3	Water / cm^3	
A	10	40	least concentrated
B	20	30	↓
C	30	20	
D	40	10	
E	50	0	most concentrated

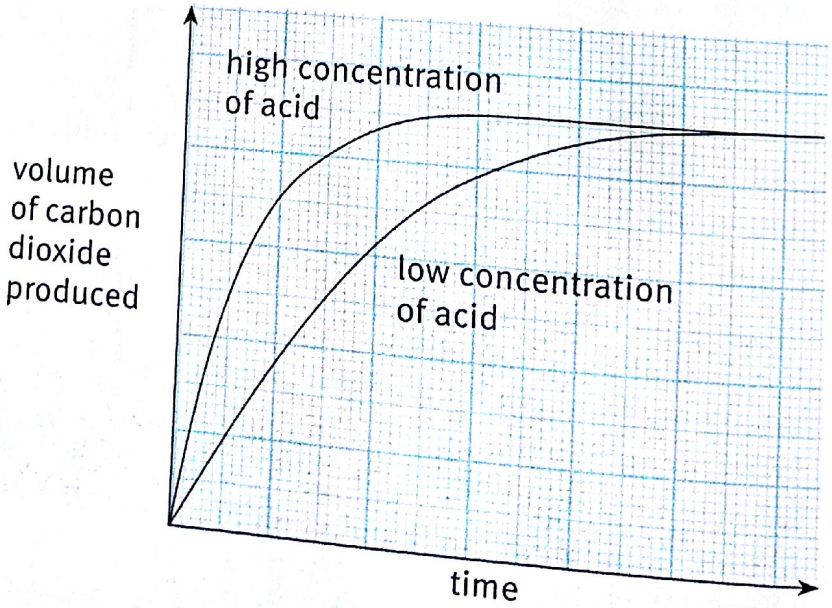
2 Set up the apparatus as in the diagram.
3 Weigh out the marble chips and place them in the flask.
4 Add the acid and time how long it takes to collect 25 cm^3 of carbon dioxide.
5 Repeat with the different concentrations of acid.

Questions

A1 How did you make sure this was a fair test?
A2 How did you make sure the results were reliable?
A3 Plot a graph of your results.
A4 Which concentration of acid gave the fastest reaction?
A5 Describe the pattern in your results.

Here is a graph of some typical results for the rate of reaction between marble chips and dilute hydrochloric acid. In this experiment the volume of carbon dioxide has been measured every 10 seconds.

You can see from the graph that you do not get any more of the product (carbon dioxide gas) at the higher concentration. You get the same volume of gas, but more quickly.



Questions

1 How can you tell which line on the graph shows the faster reaction?
2 If you did the same experiment with even less concentrated acid what would the line on the graph be like?

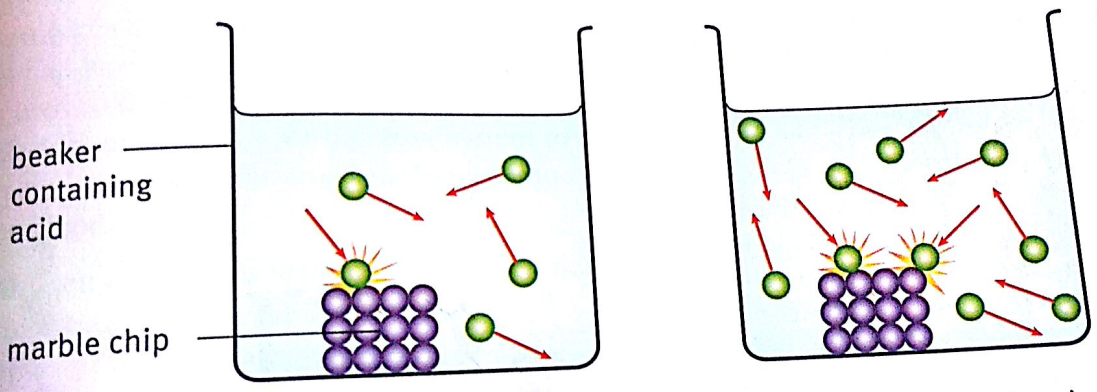
Explaining the effect of concentration

Again, we can use particle theory to help explain these results.

The higher the concentration of hydrochloric acid, the more hydrochloric acid particles there are in a given amount of space. This means that there will be more frequent collisions between hydrochloric acid particles and calcium carbonate particles.

hydrochloric acid particle

marble particle



Reaction in dilute acid.

Reaction in acid that is twice as concentrated.

Summary

- As the concentration of reactants is increased, the rate of reaction is increased.
- When there are more particles in a given volume they are more likely to collide with each other.

8.6 Catalysts

When chemical manufacturers make their products, they want to make them as quickly and as cheaply as they can. You have seen that to speed up a reaction you could increase the temperature, concentration or surface area. You could increase all three.

But manufacturers have to balance the costs of the process against the increase in speed of the reaction. Increasing the temperature can be very expensive because energy costs are high. Increasing the concentration can also be expensive. Increasing the surface area may involve a process of crushing solids, which could add to the cost.

Many cars have catalytic converters fitted to their exhaust systems. These have catalysts inside that speed up reactions that help to get rid of harmful gases produced in the engine.

Activity 8.6

Using a catalyst to speed up a reaction

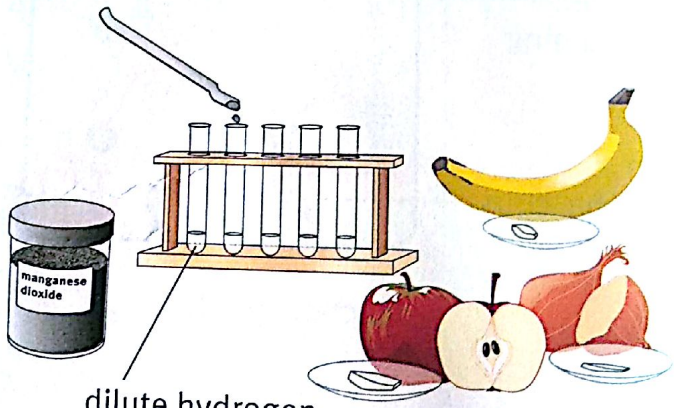
SE

In this activity, you will look at a different way of speeding up a reaction.

Hydrogen peroxide is a colourless liquid. It can decompose (break apart) to produce water and oxygen.

hydrogen peroxide → water + oxygen

You can tell when this reaction is happening because you will see bubbles of oxygen.



dilute hydrogen peroxide

1. Place a small volume (no more than 5 cm^3) of dilute hydrogen peroxide in two test tubes.
2. Leave one test tube with hydrogen peroxide only. This is for you to use as a comparison. It is a control.
3. Add a small amount of manganese oxide to the other test tube. Record your observations.
4. Put the same volume of dilute hydrogen peroxide into four or five other test tubes. Add small pieces of fruit, vegetables and /or meat to each one. Record your observations.
5. Recover the manganese oxide from your second test tube. (Think about how you can do this. **Hint**: manganese oxide is insoluble in water.) Add this manganese oxide to another tube of hydrogen peroxide. Record your observations.

Questions

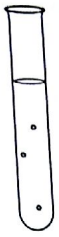
A1 Which of the items that you added caused the reaction to be quickest? How could you tell?

A2 Did the manganese oxide work for a second time after you had recovered it?

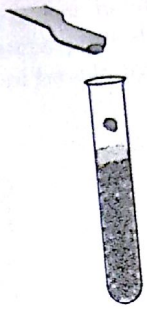
Using catalysts

The manganese dioxide made the reaction happen faster than if the hydrogen peroxide was just left on its own. But at the end of the reaction, the manganese dioxide was still there. A substance that speeds up a reaction, but remains unchanged at the end of the reaction, is called a **catalyst**.

Catalysts are often used to speed up reactions in industrial processes. The same catalyst can be used over and over again. This is usually much cheaper than increasing the temperature.



Bubbles of oxygen gas are given off as the hydrogen peroxide breaks down slowly on its own.



When manganese oxide is added the breakdown of hydrogen peroxide happens much faster.

Enzymes

You learnt about **enzymes** when you studied digestion. Enzymes are **biological catalysts**. Enzymes help to speed up most of the reactions that happen in your body. For example, enzymes are used to speed up the breakdown of the molecules of food in your digestive system so that you can use absorb the small molecules into your blood.

Hydrogen peroxide is formed as a waste product in many reactions in the cells of plants and animals. It is poisonous and if it is not broken down to harmless water and oxygen quickly, it will kill living cells. All living cells have an enzyme, called **catalase**, which speeds up the breakdown of hydrogen peroxide. That is why all the fruits, vegetables and meat you added in your experiment broke down the hydrogen peroxide very quickly.

Some washing powders contain enzymes. They are called biological washing powders. They help to break down stains, such as food and blood.

Questions

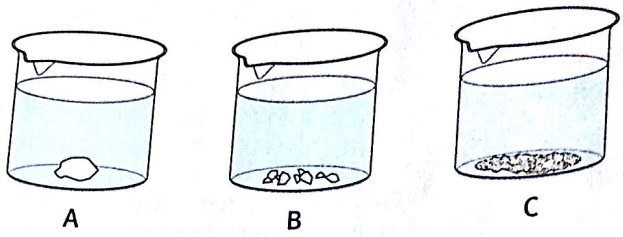
1 What is another name for a biological catalyst?
2 What sort of washing powder has a catalyst in it?
3 Why do cars have catalytic converters fitted to them?

Summary

- A catalyst is a substance which speeds up a chemical reaction.
- A catalyst is not changed in the reaction and can be recovered and re-used.

Unit 8 End of unit questions

8.1 The chemical name for marble is calcium carbonate. In the experiment shown below, equal masses of marble lumps, small marble chips and powdered marble were placed into equal volumes of dilute hydrochloric acid.



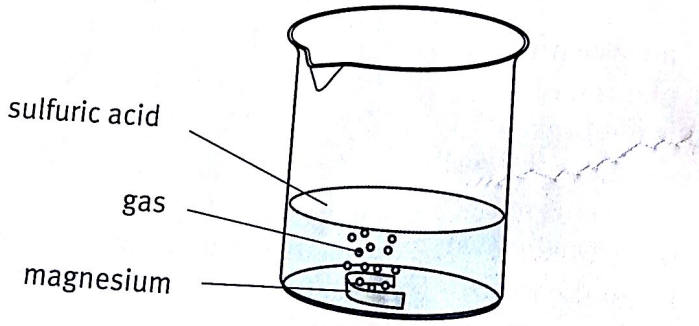
a In which beaker will the reaction be fastest? [1]

b Explain why you think this. [3]

c When the reaction between the calcium carbonate and dilute acid occurs, carbon dioxide gas is given off. How would you test for this gas and what would tell you that the test is positive? [2]

d What is the name of the salt formed in this reaction? [1]

8.2 Samuel was investigating the reaction below. He placed 4 g of magnesium ribbon into a beaker of dilute sulfuric acid. He timed how long it took for the magnesium to 'disappear'. It took 45 seconds.



a Write the word equation for the reaction between magnesium and sulfuric acid. [2]

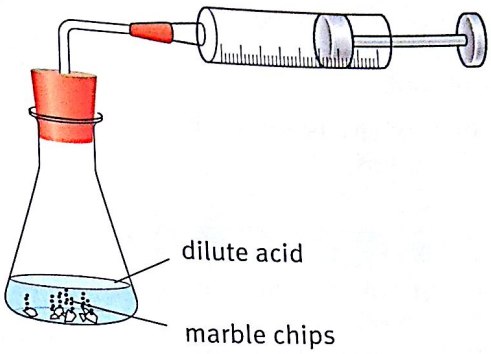
b How would you test for the gas given off in this reaction? (Remember to give the result you would get if the test was positive.) [2]

c Which of the following would result in the magnesium ribbon 'disappearing' in less than 45 seconds?

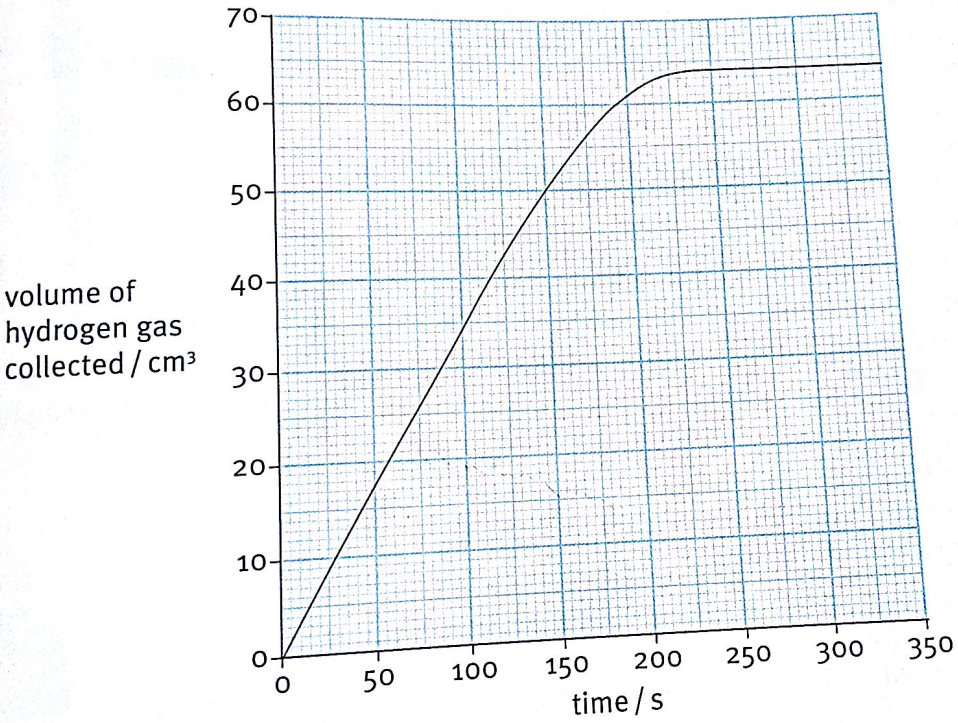
- warming the acid
- using 2 g magnesium ribbon
- stirring the mixture
- adding water to the acid

[2]

8.3 Bahula investigates the rate of reaction between magnesium and dilute hydrochloric acid.



She measures how much gas is given off every 30 seconds. The graph shows her results.



a How long does it take to collect 30 cm³ of the gas? [1]

b How long does it take for the reaction to finish? [1]

c Describe how the rate of reaction changes over the period that the reaction is taking place. [3]

d Predict what would happen to the rate of the reaction if Bahula increased the temperature of the acid. [1]

e Explain your answer to **d** using particle theory. [3]