PUPIL RESEARCHER INITIATIVE

Feed the World

Setting the Scene

You will be working as a member of a university chemistry department research team. The World Food Commission (WFC) has issued a press release asking scientists to help set up an educational programme for use in developing countries. You will carry out research into fertilisers. You will use your findings to help you produce a leaflet for either farmers or teachers in these countries

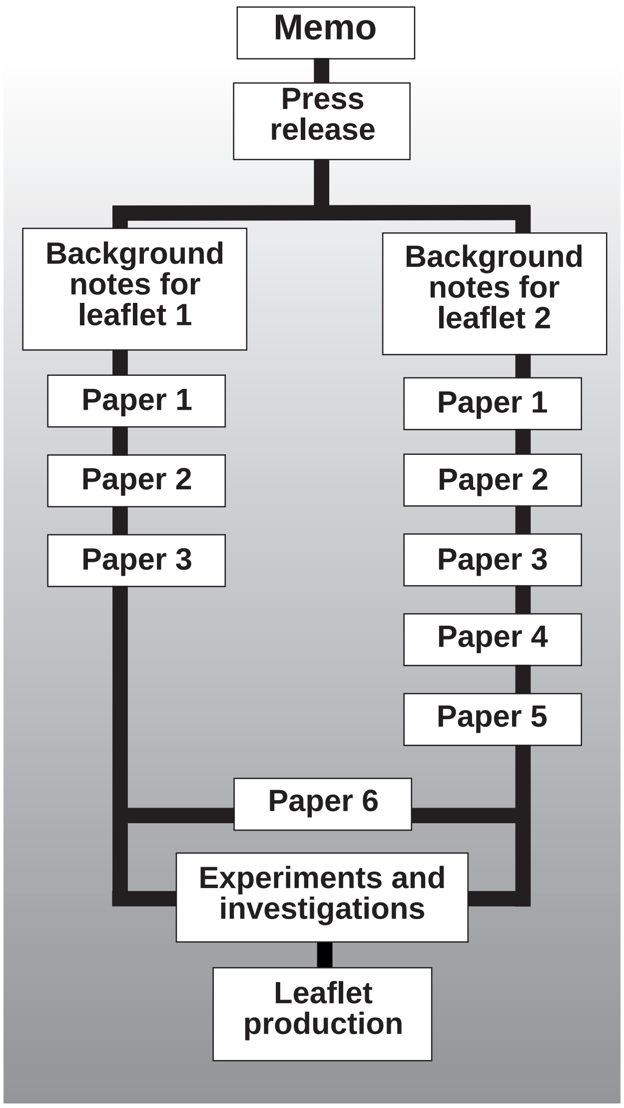
Pupil Research Brief

Study Guide

Syllabus Targets *Science you will learn about in this Brief*

- ❏ air is almost 80% nitrogen
- ❏ nitrogen can be used to manufacture several important chemicals, including nitrogen-based fertilisers
- ❏ nitrogen-based fertilisers are important in agriculture for increasing the yield of crops
- ❏ ammonia is manufactured in the Haber process
- ❏ ammonium nitrate fertiliser is made by the neutralisation reaction between ammonia and nitric acid
- ❏ materials are returned to the environment either in waste or when living things die and decay
- ❏ materials decay because they are broken down (digested) by microbes
- ❏ the constant cycling of nitrogen is called the nitrogen cycle. In the nitrogen cycle green plants absorb nitrogen in nitrates from the soil. Plants use these nitrates to make proteins
- ❏ nitrifying bacteria convert ammonia compounds to nitrates

Route through the Brief



Outcome Checklist

You will produce a leaflet for farmers or teachers in a developing country. A memo and a set of notes guide you through the Brief. You should make sure you produce the following items as you work through the Brief.

Notes for Leaflet 1

❏ a leaflet for farmers

Paper 1 and 2

❏ notes to help you write your leaflet

Paper 5

❏ notes on the experiment

Paper 6

❏ an investigation report

Notes for Leaflet 2

❏ a leaflet for teachers

Paper 1, 2 and 3

❏ notes to help you write your leaflet

Paper 4 and 5

❏ notes on the experiments

Paper 6

❏ an investigation report

Central University

Memo

From: Professor Indira Khapoor

To: Research Teams

Subject: Fertilisers: education programme for developing countries

Date:

Please read the copy of a press release from the World Food Commission (WFC), which I've attached to this memo. The WFC is asking scientists from across the world to help set up an educational programme for use in a number of developing countries where it has support programmes working at the moment. I think that some of the work we do here could be relevant. The press release says that any Research Department interested in helping should contact the Commission. I have done so, and they have suggested how we can help.

We have been asked to produce two educational leaflets covering the same topics but aimed at two different audiences. They should explain: **what fertilisers are, why they should be used, and how they work**. The first leaflet should be aimed at farmers, many of whom have little scientific knowledge. The second should be aimed at teachers who work with young people, quite a few of whom will become farmers themselves. Research teams from other universities will be producing other leaflets, covering such topics as technical information about different types of fertiliser, when to use them, and possible problems associated with their use.

I would like you and your research team to have a go at producing the two leaflets. You could divide the team into two groups who could produce one leaflet each. I have put together some background material, together with some of my own notes, which should help you with the task. Where we refer to practical work (outlined in Papers 4 and 5), you should carry it out yourselves first to check that all the instructions make sense, and secondly that useful results can be obtained.

Documents attached

1. World Food Commission Press Release

2. my two sets of notes on how to proceed with each leaflet

3. Background Papers 1,2 and 5 for Leaflet 1, Background Papers 1-5 for Leaflet 2. Background Paper 6 is available if you need it.

Press Release...

World Food Commission

The need for food

Each day in many parts of the world, people are dying due to lack of food. In some countries people exist on a repetitive diet of rice or bread. Some people can grow enough vegetables and keep enough animals to have a healthy, satisfying diet. In richer countries people often demand exotic food which is relatively cheap to buy and easy to prepare.

How can we reconcile these situations? It is possible to transport food from those with more than enough to those with insufficient, but how many people are willing to reduce their standard of living for people that they will never meet? The best alternative is to provide anyone who needs it with the means to grow enough food for a healthy, satisfying diet.

In trying to address these issues, the WFC is asking the world's scientists to help set up an education programme for use in a number of developing countries. We would like ideas for educational programmes and materials which could be used by local teachers to help educate school pupils, college students on agricultural courses and farmers. We would also like to see materials produced which could be sent directly to farmers. The main topic for the education programme is the use of fertilisers to increase crop yields.

We would like any Research Department who is interested in contributing to this programme to get in touch with the Commission. We will discuss how you can help, and give you a target to achieve.

WFC Fertilisers Project

Notes for Leaflet 1

Target Audience: farmers with little scientific knowledge.

Aim: to explain how nitrogen-based fertilisers can increase crop yield.

Format: the leaflet should fit onto two sides of A4. The paper could be folded to produce a small booklet, with four sides. Use diagrams where they help to get the information across.

You will need to cover the following topics.

1. The nitrogen cycle
(See Paper 1, or any appropriate science text book). The important points to get across here are:

- how plants take nitrogen from the soil
- what plants use the nitrogen for
- natural ways that nitrogen is returned to the soil

You should also mention how farmers can help this natural process by using either manure or compost from unused parts of the crop.

2. How nitrogen-based fertilisers are made
(See Paper 2, or any appropriate science text book). The important points to get across here are:

- why ammonia is used to make fertilisers
- how ammonia is made (very briefly -don't use any chemical formulae - they are not needed)
- how fertilisers can be used to put back the nitrogen which is used by plants for healthy growth and removed when they are taken out of the soil (you will need to research this)
- how fertilisers can be made (see Paper 5) - try it yourself

3. What happens when plants are grown with and without nitrogen-based fertiliser?
You will need to plan an investigation into what happens to plants growing with and without nitrogen.

If you have problems getting started on this, I have a paper (Paper 6) which might help you.

Finish off with a short summary which explains how important it is to put back nitrogen into the soil (using natural or chemical fertilisers), and how this could improve crop yield.

WFC Fertilisers Project

Notes for Leaflet 2

Target Audience: Teachers.

Aim: to provide teachers with a summary of the information they could use in teaching about the value of using fertilisers to increase crop yield, and to explain how nitrogen-based fertilisers are produced.

Format: the leaflet should fit onto four sides of A4. The sheets could be folded to produce a smaller booklet, with eight sides. Use diagrams where they help to get the information across.

You will need to include the following topics.

1. The nitrogen cycle
(See Paper 1 or any appropriate science text book).This section should cover:

- the importance of nitrogen in living things
- a summary of the natural nitrogen cycle. (This could be in the form of a glossary, or as notes written on a large diagram of the nitrogen cycle)

2. Making ammonia using the Haber Process (Papers 2 and 3). This should include:

- a flowchart showing the process, labelled to show the sources of the reactants (where we get them from) and the chemical reactions taking place
- an account of the conditions necessary for an optimum yield of ammonia. A glossary of terms would be useful here. Decide on which words need to be explained - a good starting point would be some of the words in italics on Paper 3

3. Current research into new ways to fix nitrogen and make ammonia (Papers 1,2 and 3)

Use this to explain how researchers have found ways to fix nitrogen and produce ammonia at normal temperatures and pressures.

Suggestions for practical work
I think it would be good to suggest a couple of experiments or investigations for the teachers to use. I have included two different methods for making ammonium nitrate (Papers 4 and 5). Try them out, and decide on which one to include.
I would also suggest you:

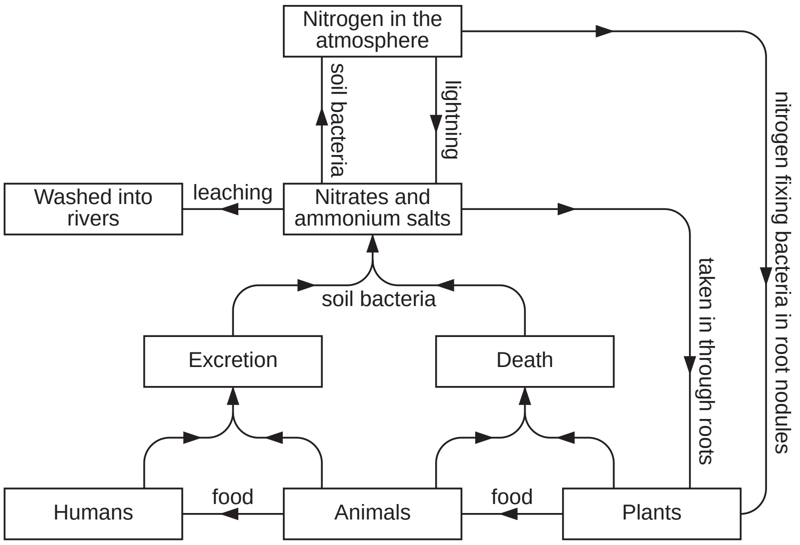
- plan and carry out an investigation into the effects of growing plants with and without nitrogen
- investigate plant growth with varying amounts of nitrogen

If you have problems getting started on this, I have a paper (Paper 6)which might help you. If you have time, you could also investigate what happens when plants are deprived of other minerals. Include a list of the minerals which are needed by plants for healthy growth and what the mineral does inside the plant. This could be a chart. Use a science text book to help you with this.

The Struggle for Nitrogen

Paper 1

Apart from water, which makes up 65% of the body, humans are mostly made up of chemicals called *proteins:* 18% of our bodies are proteins, including parts of muscles, bones, organs (like the kidneys and the brain), blood and hair, as well as important chemicals like *hormones* and *enzymes.* Proteins are long-chain molecules, containing thousands of atoms and are made up of smaller molecules, called *amino acid*s, joined end to end. All amino acids contain the element nitrogen. Nitrogen makes up 78% of the atmosphere, but the human body has no way of changing it into amino acids. The only way we can build up amino acids is through our food; by eating plants, or animals that eat plants. Only plants can use nitrogen to make chemicals which can be changed into amino acids. The way that nitrogen moves between the atmosphere, plants and animals is shown in the *nitrogen cycle* diagram below.



The nitrogen cycle

Nitrogen from the atmosphere (together with water and oxygen) is changed by lightning into soluble nitrates and ammonium salts, which can be taken in by plant roots. Some leguminous plants (peas, beans, and clover) have special *bacteria* in swellings (nodules) in their roots, which can change nitrogen into ammonia (*nitrogen fixation*). Biological nitrogen fixation in bacteria is carried out by an enzyme called *nitrogenase.* Researchers are currently trying to understand the role of nitrogenase in the fixation of nitrogen. They are attempting to recreate the reaction under laboratory conditions so that ultimately they may use it industrially to manufacture ammonia more efficiently and more cheaply. Plants, and the animals that eat them, change ammonium salts, nitrates and ammonia into amino acids and proteins. When living things die or excrete (expel waste), bacteria change their residues back into nitrates and ammonium salts, while other bacteria change these chemicals back into nitrogen gas.

The natural nitrogen cycle has two problems:

1 nitrates and ammonium salts are being *leached* into rivers and not replaced;
2 it cannot produce enough plants to satisfy the demands of the expanding human population.

Scientists have to work out how best to put nitrogen back into the nitrogen cycle.

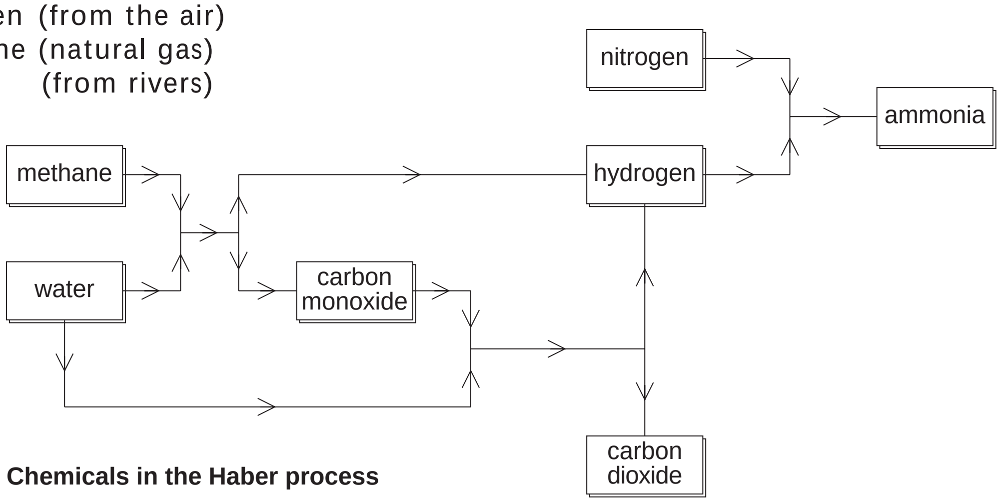
Ammonia Synthesis

Paper 2

Fertilisers containing nitrogen are made from *ammonia,* NH_3. The search to make ammonia from its elements, nitrogen and hydrogen, was finally ended in 1908, when the German scientist *Fritz Haber* found a way of reacting nitrogen gas with hydrogen gas directly.

The process has been refined over the years until, with the aid of *catalysts* and suitable conditions of *temperature* and *pressure,* ammonia is now manufactured on a large scale from three common substances:

- nitrogen (from the air)
- methane (natural gas)
- water (from rivers)



Chemicals in the Haber process

After sulphur is removed, methane is reacted with steam to form carbon monoxide and hydrogen:

$$CH_4\,(g) + H_2O\,(g) \longrightarrow CO\,(g) + 3H_2\,(g)$$

methane, water, carbon monoxide, hydrogen

The carbon monoxide is reacted with more steam to form carbon dioxide and hydrogen:

$$CO\,(g) + H_2O\,(g) \longrightarrow CO_2\,(g) + H_2\,(g)$$

carbon monoxide, water, carbon dioxide, hydrogen

The carbon dioxide is removed, then the hydrogen is reacted with nitrogen to make ammonia:

$$N_2\,(g) + 3H_2\,(g) \longrightarrow 2NH_3\,(g)$$

nitrogen, hydrogen, ammonia

Since all these reactions are *reversible* (go in both directions at the same time), it is important that the conditions of temperature and pressure are carefully chosen, together with a catalyst (a substance that speeds up a reaction, but does not itself change).

Current research suggests that it may be possible to produce a suitable electrolytic method for converting atmospheric nitrogen into ammonia at normal pressures. This will probably never replace the Haber process for large scale production of ammonia, but it could supply irrigation channels with ammonia using cheap sources of electricity such as wind, tidal or solar power.

How far, how fast?

Paper 3

In many chemical reactions, not all of the *reactants* (what you start off with) react to form the *product* (what you end up with). These reactions are reversible, which means that they are moving in both directions at once. For example, in the ammonia synthesis:

$$N_2\,(g) + 3H_2\,(g) \longrightarrow 2NH_3\,(g)$$

Nitrogen and hydrogen are reacting to form ammonia, and at the same time ammonia is breaking down to form nitrogen and hydrogen. Eventually, these reactions settle down until the forward reaction (left to right) and the backward reaction (right to left) are happening at the same rate (speed). This is called *equilibrium.*

The position of equilibrium can be changed: if it moves to the right, more ammonia is made; if to the left, less ammonia is made. A movement to the right is obviously needed in industry. These changes can be made by changing the *conditions* (temperature, pressure or concentration). Most reactions are either *exothermic* (heat is given out) or *endothermic* (heat is taken in). These reactions will obviously cause a change of temperature. The ammonia synthesis is exothermic: as ammonia is made, the reaction gets hotter.

Reactions involving gases cause changes in pressure: if more molecules of gas are produced than react, the pressure increases. In the ammonia synthesis, the pressure decreases ($1N_2$ and $3H_2$ [4 molecules] form $2NH_3$ [2 molecules]).

In an equilibrium reaction: *if the conditions are changed, the equilibrium moves to reverse the change*.

The ammonia synthesis can be summarised as follows:

$N_2\,(g) + 3H_2\,(g)$	$\longrightarrow$	$2NH_3\,(g)$
lower temperature		higher temperature
higher pressure		lower pressure

If the *temperature is raised*, the equilibrium moves to lower the temperature, and so *less ammonia* is made.

If the *pressure is raised*, the equilibrium moves to lower the pressure, and so *more ammonia* is made.

So the best conditions for a high yield of ammonia are a *low temperature* and a *high pressure*.

Many chemical reactions take place comparatively slowly. In industry, it is not only important to get a high yield, but to get it quickly, so the *rate of the reaction* must be increased. One of the ways to increase the rate of the ammonia synthesis is to raise the temperature, but unfortunately this also lowers the yield. A compromise is used, with a moderate temperature.
Another way of increasing the rate of a reaction is to use a *catalyst.* This has no effect on the position of equilibrium, and so no effect on the yield.

The actual conditions for the ammonia synthesis are:

- moderate temperature (~450°C)

- high pressure (200 atmospheres)

- catalyst (iron).

How far, how fast?

Paper 3 continued

The industrial process thus requires a great deal of energy.

Biological nitrogen fixation in bacteria is carried out by an enzyme called nitrogenase. This consists of two proteins, one containing the metal iron (Fe) and the other containing the metals molybdenum (Mo) and iron.

The advantage of biological nitrogen fixation over the Haber process is that it takes place at normal temperature and pressure. This means the process uses less energy.

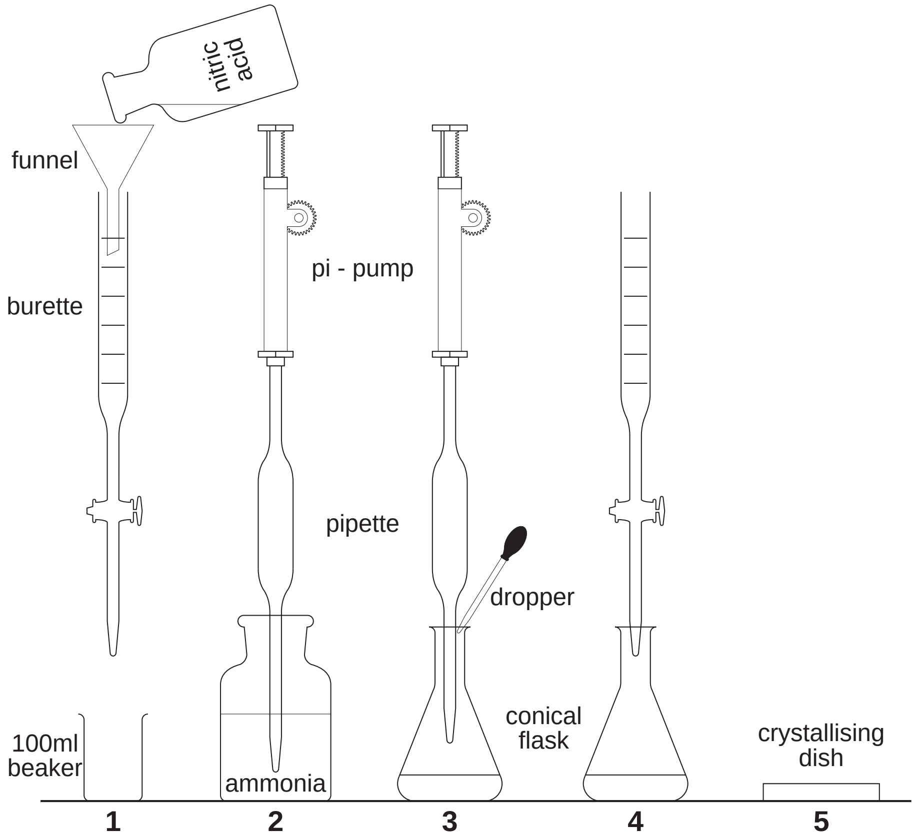
Research analysis shows that the nitrogen molecule becomes attached to the molybdenum/iron protein, allowing it to be reduced to ammonia. Energy for the process is generated by reactions of a chemical also found in human cells, called *ATP*.

Research groups in England, Russia and the USA have used solutions of compounds of the metals vanadium (V) and molybdenum to change nitrogen (N_2) to hydrazene (N_2H_2) and ammonia (NH_3).

Making Ammonium Nitrate

Paper 4

method 1



Wear eye protection!

1 Set up a burette on a stand, with a $100cm^3$ beaker under the tap. Using a small funnel, carefully fill the burette up to the zero mark with dilute nitric acid. Run a little acid into the beaker until the tube below the tap has no air in it. Refill the burette to the zero mark.

2 Using a pi-pump or similar pipette filler, carefully fill a pipette to the mark with dilute ammonia solution.

3 a) Transfer the ammonia to a conical flask.
b) Add 5-10 drops of indicator solution.

4 Carefully add the nitric acid from the burette to the flask, swirling the liquid gently, until the indicator starts to change colour. Continue swirling, adding the acid a drop at a time, until the indicator changes colour *with one drop*. Make a careful note of the volume of acid added.

5 Repeat steps 1 to 3a but do not *add the indicator solution*. Add the same volume of nitric acid that you used before. Pour some of the solution into a crystallising dish and leave it to crystallise.

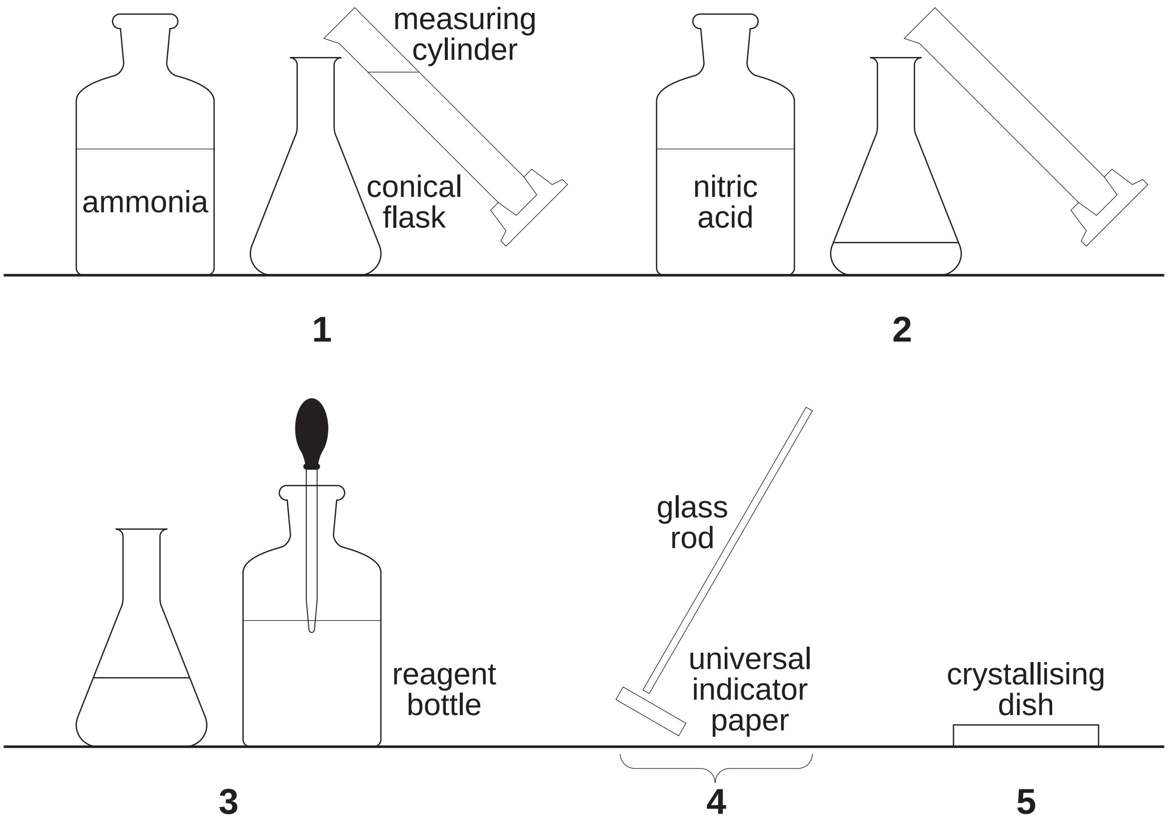
$$NH_3\,(aq) + HNO_3\,(aq) \longrightarrow NH_4NO_3\,(aq)$$

ammonia solution — nitric acid — ammonium nitrate

Making Ammonium Nitrate

Paper 5

method



Wear eye protection!

1 Using a measuring cylinder, put $10cm^3$ of ammonia solution into a conical flask.

2 Using a second measuring cylinder, add $10cm^3$ of dilute nitric acid to the ammonia in the flask. Stir the flask with a glass rod and test the solution by using the rod to put a drop onto a piece of universal indicator paper.

3 If the solution is acid, add a drop of ammonia solution using a dropper, if the solution is alkaline, add a drop of nitric acid using a dropper. Stir and test the solution with a glass rod and universal indicator paper.

4 Continue steps 3 and 4 until the solution is neutral (green, or you get a colour change with one drop.)

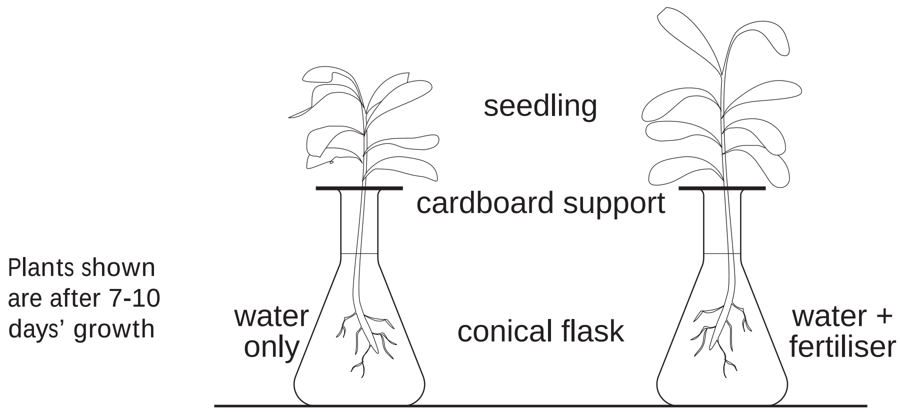
5 Pour some of the solution into a crystallising dish and leave it to crystallise.

$$NH_3\,(aq) + HNO_3\,(aq) \longrightarrow NH_4NO_3\,(aq)$$

ammonia solution + nitric acid → ammonium nitrate

Fertiliser and Plant Growth

Paper 6



1. Dissolve around 4g of fertiliser in 100cm^3 of distilled water and pour it into a 100cm^3 conical flask.

2. Put 100cm^3 of distilled water into a second conical flask.

3. Take two identically sized seedlings (wheat, barley or broad bean) and put each through a hole in a piece of cardboard, so that the leaves are supported.

4. Put one seedling into the water and the other into the fertiliser solution, so that the roots are under the liquid.

5. Leave the seedlings for 2-3 weeks, topping up with distilled water if necessary so that the roots remain under water. It may be necessary to blow air from an aquarium aerator or a straw into the liquid from time to time to make sure that the roots get enough oxygen.

6. Note any differences in growth over this period of time.

The experiment above outlines a method to investigate what happens when plants are grown with and without fertiliser. The fertiliser used in this experiment actually contained more than just nitrogen (it also included phosphorus and potassium, as well as nine other minerals needed for healthy plant growth). You will need to plan that investigation differently to enable you to carry out your task to show the effect of growing plants with and without nitrogen.

You could also investigate the effect of using various amounts of nitrogen.

You should then be able to describe in the leaflet current research we are carrying out to show what happens when plants grow without nitrogen, or with insufficient nitrogen.