Production and uses of NPK fertilisers

4.10.4.2 · Using resources · revision notes

What NPK fertilisers are, how they are made from ammonia, mined potassium compounds and phosphate rock, and how industrial production compares with making the same salts in the laboratory. This is in GCSE Chemistry only, not in Combined Science. Expect recall of salt names, balanced equations, percentage by mass calculations and a 'compare' question on Paper 2.

Key facts

- NPK = nitrogen, phosphorus, potassium; fertilisers must be soluble
- $2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$ (ammonium sulfate)
- Phosphate rock + nitric acid → phosphoric acid + calcium nitrate
- Phosphate rock + phosphoric acid → calcium phosphate (triple superphosphate)
- Industry: continuous, large scale, concentrated; laboratory: batch, small scale, dilute
- $NH_3 + HNO_3 \rightarrow NH_4NO_3$ (ammonium nitrate)
- Potassium chloride and potassium sulfate are mined
- Phosphate rock + sulfuric acid → calcium sulfate + calcium phosphate (single superphosphate)
- % N by mass = (number of N atoms × 14) ÷ M_r × 100

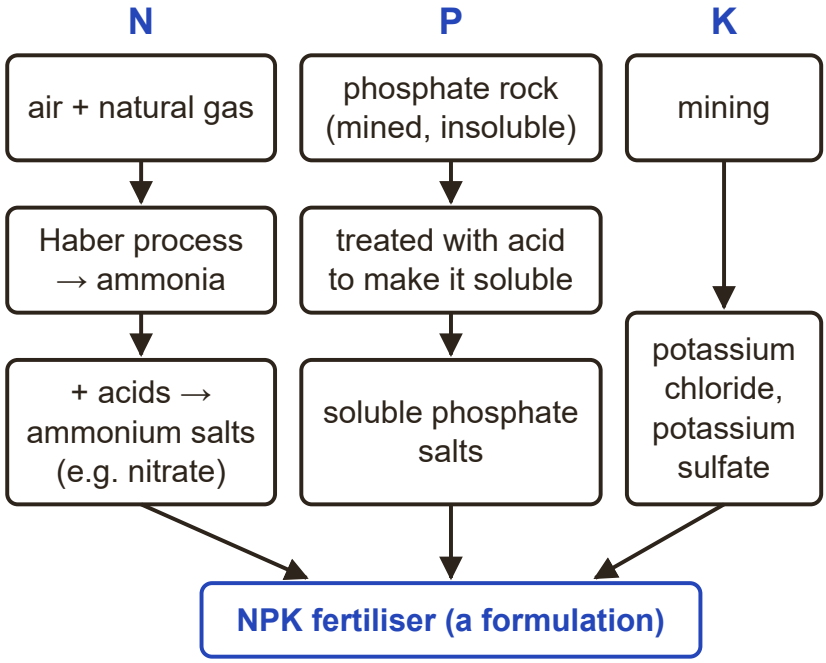
Notes

What NPK fertilisers are

- Compounds of **nitrogen (N)**, **phosphorus (P)** and **potassium (K)** are used as fertilisers to improve agricultural productivity. They replace elements removed from the soil by crops, so plants grow better and yields increase.
- **NPK fertilisers** contain compounds of all three elements. They are **formulations** of various salts containing appropriate percentages of the elements.
- Fertilisers must be **soluble in water** so that plants can absorb them through their roots.
- Industrial production uses a variety of raw materials in several **integrated processes**.
- Demand for fertilisers, and so for ammonia, has risen because the world population has grown and more food is needed.

Where the N, P and K come from

- **Nitrogen**: ammonia from the Haber process is used to manufacture **ammonium salts** and **nitric acid**.
- ammonia + nitric acid → ammonium nitrate: $NH_3 + HNO_3 \rightarrow NH_4NO_3$
- ammonia + sulfuric acid → ammonium sulfate: $2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$
- ammonia + phosphoric acid → ammonium phosphate (this supplies both N and P).
- **Potassium**: potassium chloride and potassium sulfate are obtained by **mining**.
- **Phosphorus**: **phosphate rock** is mined, but it cannot be used directly as a fertiliser because it is insoluble. It is treated with acid to produce soluble salts:
- phosphate rock + nitric acid → phosphoric acid + calcium nitrate
- phosphate rock + sulfuric acid → calcium sulfate + calcium phosphate (a mixture called single superphosphate)
- phosphate rock + phosphoric acid → calcium phosphate (called triple superphosphate)



The compounds must be soluble so that plants can absorb them.

Laboratory preparation and industrial production

- **Laboratory** (e.g. ammonium sulfate): titrate dilute ammonia solution with dilute sulfuric acid using an indicator, repeat with the same volumes but no indicator, then evaporate some water and leave the solution to crystallise. A few grams are made in a batch, from reactants bought ready-made.
- **Industry**: thousands of tonnes are made quickly in a **continuous** process using concentrated reactants. The ammonia and acid are made on site from raw materials (e.g. natural gas, air, sulfur), and the heat released by the reaction is used to evaporate the water.

How to answer each type of question

Identify the elements a fertiliser supplies

1 to 2 marks | Grade 5

1. Look at each formula for N, P and K.
2. Ammonium (NH_4) and nitrate (NO_3) supply N; phosphate (PO_4) supplies P; K supplies potassium.
3. Check that the mixture you choose contains all three elements.

Example. A gardener has three compounds: potassium nitrate, KNO_3; ammonium phosphate, $(NH_4)_3PO_4$; and ammonium nitrate, NH_4NO_3.
Which **two** compounds should be mixed to make an NPK fertiliser? Explain your answer. (2 marks)

Model answer. Potassium nitrate and ammonium phosphate (1). Potassium nitrate supplies K and N, and ammonium phosphate supplies N and P, so together they contain all three elements (1).

Name the products from phosphate rock or ammonia

1 to 4 marks | Grade 6

1. Learn the three phosphate rock reactions as a set.
2. Nitric acid is the odd one out: it gives an acid (phosphoric acid) as well as a salt (calcium nitrate).
3. For ammonium salts, the acid gives the name: nitric → nitrate, sulfuric → sulfate, phosphoric → phosphate.

Example. (a) Phosphate rock is treated with sulfuric acid. Name the **two** salts produced. (2 marks)
(b) Why is phosphate rock treated with an acid before it is used as a fertiliser? (1 mark)
(c) Name the salt formed when ammonia reacts with phosphoric acid. (1 mark)

Model answer.

(a) Calcium sulfate (1) and calcium phosphate (1)

(b) Phosphate rock is insoluble, so plants cannot absorb it; treating it with acid produces soluble salts (1)

(c) Ammonium phosphate (1)

Calculate the percentage of nitrogen by mass

2 to 4 marks | Grade 7

1. Work out M_r from the formula, multiplying everything inside a bracket by the number outside it.
2. Count the nitrogen atoms and multiply by 14.
3. Divide by M_r and multiply by 100.

Example. A farmer can buy ammonium nitrate, NH_4NO_3, or ammonium sulfate, $(NH_4)_2SO_4$.
Relative atomic masses (A_r): H = 1, N = 14, O = 16, S = 32
(a) Calculate the percentage by mass of nitrogen in ammonium sulfate. (3 marks)
(b) Ammonium nitrate contains 35% nitrogen by mass. Which fertiliser supplies more nitrogen per kilogram? (1 mark)

Model answer.

(a) $M_r = (2 \times 14) + (8 \times 1) + 32 + (4 \times 16) = 132$ (1); mass of nitrogen $= 2 \times 14 = 28$ (1); $28 \div 132 \times 100 = 21.2\%$ (1)
(b) Ammonium nitrate, because 35% is more than 21.2% (1)

Compare industrial and laboratory production

4 to 6 marks | Grade 8

1. Make matched comparisons: scale, batch or continuous, concentration, where the reactants come from, how the water is removed.
2. Write both sides of each point, using 'whereas'.
3. Where you can, give the reason for the industrial choice (e.g. continuous, to make large amounts cheaply).
4. Use any information given in the question.

Example. Ammonium nitrate can be made in a school laboratory and in a factory.
Compare the two methods. (4 marks)

Model answer. Any four matched comparisons, e.g.: the laboratory makes a few grams, whereas the factory makes thousands of tonnes (1); the laboratory uses a batch process, whereas the factory uses a continuous process (1); the laboratory uses dilute solutions, whereas the factory uses concentrated reactants (1); the laboratory buys ammonia solution and nitric acid, whereas the factory makes ammonia (by the Haber process) and nitric acid (from ammonia) on site from raw materials (1); in the laboratory the solution is heated with a Bunsen burner to evaporate water, whereas the factory uses the heat released by the reaction (1).

Don’t lose marks

- Writing 'ammonia nitrate' or 'ammonium nitrite'. The salt is ammonium nitrate.
- Ignoring the bracket in $(NH_4)_2SO_4$, so counting only one N or four H atoms.
- Saying phosphate rock can be spread on fields directly. It is insoluble, so it must be treated with acid first.

- Comparing laboratory and industrial methods with one-sided points such as 'industry is bigger'. Each comparison needs both sides.
- Saying potassium comes from ammonia or phosphate rock. Potassium chloride and potassium sulfate are mined.

More tips

Memory tricks

- N-P-K: Nitrogen, Phosphorus, and K for potassium (from its Latin name, kalium).
- Phosphate rock + nitric acid gives an acid AND a salt; the other two acids give only salts.
- S for sulfuric and single superphosphate; phosphoric acid gives triple superphosphate.
- Ammonia always gives an ammonium salt: nitric → ammonium nitrate, sulfuric → ammonium sulfate, phosphoric → ammonium phosphate.

Exam technique

- 'Compare' needs matched points using 'whereas' or 'but'; a list about only one method scores few marks.
- In percentage by mass questions show the M_r working, so you can earn method marks even if the final answer is wrong.
- When naming salts, write the full name: 'calcium phosphate', not just 'phosphate'.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 3 — **State why farmers use fertilisers**
Compounds of nitrogen, phosphorus and potassium improve agricultural productivity (bigger crop yields).

Grade 4 — **Explain what an NPK fertiliser is**
A formulation of salts containing appropriate percentages of nitrogen, phosphorus and potassium.

Grade 4 — **Name the sources of the three elements**
Nitrogen from ammonia; potassium from mined potassium chloride and potassium sulfate; phosphorus from mined phosphate rock.

Grade 5 — **Name ammonium salts made from ammonia**
With nitric acid, ammonium nitrate; with sulfuric acid, ammonium sulfate; with phosphoric acid, ammonium phosphate.

Grade 6 — **Name salts made from phosphate rock**
Nitric acid gives phosphoric acid and calcium nitrate; sulfuric acid gives calcium sulfate and calcium phosphate; phosphoric acid gives calcium phosphate.

Grade 7 — **Calculate percentage of nitrogen in a fertiliser**
Mass of nitrogen atoms in the formula ÷ M_r × 100, e.g. 35% in ammonium nitrate.

Grade 8 — **Compare industrial and laboratory production**
Industry: large scale, continuous, concentrated reactants made on site; laboratory: small scale, batch, dilute reactants, titration and crystallisation.

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