# MYP Chemistry

A concept-based approach

Years 4&5

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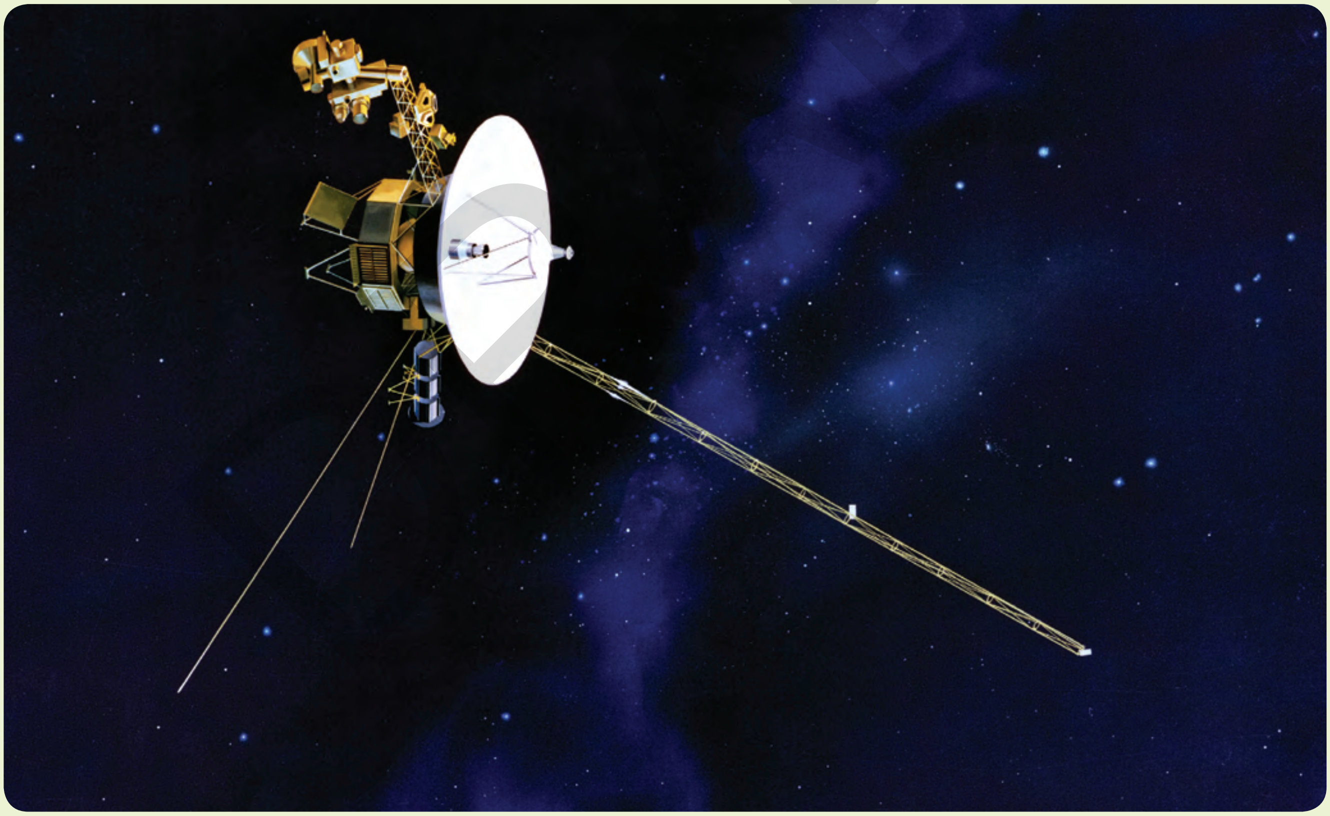
OXFORD

# 1 Balance

The ozone layer is found in the upper atmosphere, where it acts as a filter preventing over 95% of harmful UV radiation emitted from the Sun from reaching the Earth. Human interactions with the environment may result in the release of substances that can catalyse the breakdown of the ozone molecule. When the balance of the planet's resources and the environment is disrupted, the consequences are experienced globally. What happens when the balance between ozone production and ozone depletion is disturbed?

Fertilizers are easily solubilized in the soil, rapidly breaking down into ammonia. Soluble ammonia captured in rainwater can wash into aquatic environments resulting in an imbalance affecting the natural ecosystems and commercial aquaculture industries. This often results in the rapid growth of algae in ponds and streams. What is the impact of this increased amount of algae?

Camping and making a campfire are enjoyable recreational activities. When wood burns, is there an increase in disorder? Matter undergoes a change of state. Is matter still conserved? Can all matter in this combustion reaction be accounted for?



The first law of motion was proposed by Sir Isaac Newton in 1686. Regarded as the definition of inertia, it states that an object will remain at rest or keep moving in a straight line, unless the forces acting on the object become unbalanced due to an external force being applied. Voyager 2 is a deep space probe that was launched by NASA in 1977. It will maintain an approximate speed of 55,000 km $h^{-1}$ indefinitely unless the forces acting upon it become unbalanced. How has Newton's first law of motion helped us to explore the Universe that we live in?

**Key concepts:** Relationships

**Related concept:** Balance

**Global context:** Fairness and development

## Introduction

Systems within our universe are dynamic. They constantly undergo both internal and external changes, which require these systems to react and respond. Biological organisms rely on the process of homeostasis to regulate changes that occur within systems and maintain balance. Ecosystems are a dynamic environment of multiple components. Abiotic components include the physical surroundings such as sunlight, water and the soil in which the plants grow. Biotic components include the producers and consumers living within the ecosystem. All of these components contribute to maintaining the balance in conditions and relationships. Uncontrolled development applies external pressures on ecosystems, resulting in an imbalance.

Chemical and physical systems display characteristics that involve a balance in matter and energy, referred to as equilibrium. The control over the balance between reactants and products is essential in many industrial processes and synthetic reactions.

**Statement of inquiry:**

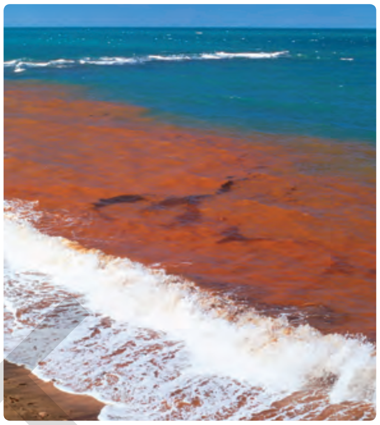
Imbalanced relationships affect finite resources, both locally and globally.

## Is there balance within the universe?

GENERAL

Systems within the universe fall into and out of balance constantly. Imbalanced relationships often have far-reaching effects, so our ability to understand the reasons why a system becomes unbalanced, and in turn rebalanced, is of fundamental importance. In our everyday lives, we too experience changes in balance.

- Biological systems undergo continual change, and to maintain balance is challenging. The diversity of ecosystems, organisms and micro-climates across our planet is immense; and marine environments are some of our planet's largest ecosystems.
- The relationship between organisms and their environments is a delicate balance.
- When excess amounts of nutrients enter a marine ecosystem as the result of increased industrial or agricultural runoff or natural changes in the amounts of available nutrients, this can have a significant and destructive impact.



Harmful algal blooms in marine ecosystems have a major impact within these environments causing an imbalance in the ecosystem. How is aquafarming affected by these occurrences? How might this be a threat to human health?

## What are examples of entropy in daily life?

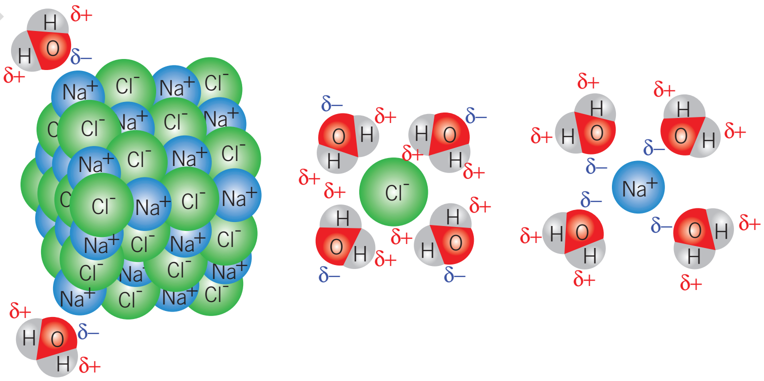
PHYSICAL

Entropy (S) is defined in chemistry as a measure of the distribution of total available energy between particles in a system. The conservation of energy is a fundamental principle of science. When a system has decreasing order and increasing disorder, it is said that its entropy is increasing. However, the total energy within the system remains balanced even when it is distributed in a different way.

With this definition of entropy in mind:

- Brainstorm in a small group within your class and identify systems that make up our daily life that have either increasing or decreasing entropy.
- Justify your choices with supporting arguments. When you have decided on your examples, collectively decide on an effective way to summarise your information so that it can be presented to the other members of the class.
- Remember that it is important to acknowledge other people's work by creating references and citations in your presentations.

Both languages and symbols are forms of communication that transcend




$NaCl(s) + H_2O(l) \rightarrow NaCl(aq)$
When you dissolve sodium chloride in water, the solid ionic compound breaks down into its ions. This change of state from a solid to a liquid is an example of an increase in entropy. The solid lattice structure of sodium chloride is broken down and the ions are free to move in the solution. The amount of disorder increases

ATL **Reflective skills**

## Develop new skills, techniques and strategies for effective learning

Knowledge, skills and understanding are the trilogy of learning. When you graduate from high school, you should aim to take with you knowledge, the skills necessary to acquire knowledge and an understanding of the concepts that you have studied.

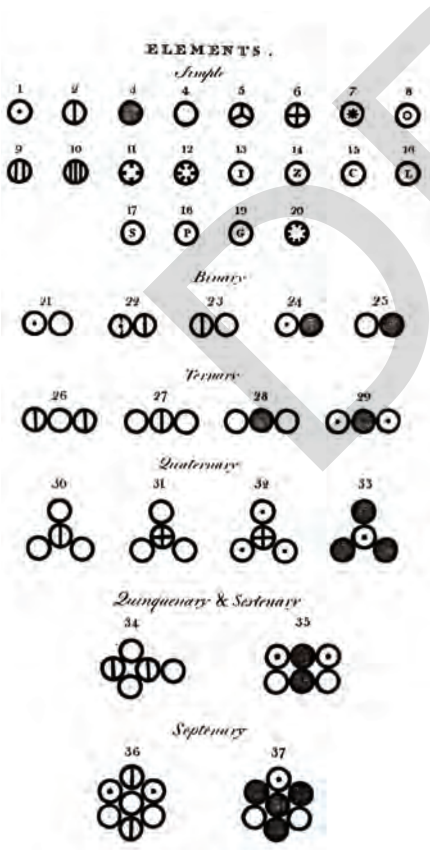
Knowledge consists of facts and figures that are ready for you to use. They are often easy to recall and many times are not open to debate. Examples of knowledge in chemistry include:

- The three main states of matter: solids, liquids and gases.
- The formulae of elements and compounds. For example, with oxygen, the element has the symbol O and the formula of the compound oxygen is $O_2$.
- In a chemical reaction, reactants are on the left-hand side of a chemical equation and products are on the right-hand side.
- Acids are corrosive and have a low pH.
- The main greenhouse gas is carbon dioxide with a chemical formula of $CO_2$.

Skills are the strategies you develop in order to acquire knowledge and build understanding. The Approaches to Learning skills that we will encounter through this book will help you develop the necessary skills to build your knowledge base and deepen your understanding of scientific concepts.

Understanding is your ability to use your skills and your knowledge, apply them to new contexts and advance your understanding of a concept. It is your understanding of the concepts that enables you to build your knowledge base.






QUANTITATIVE

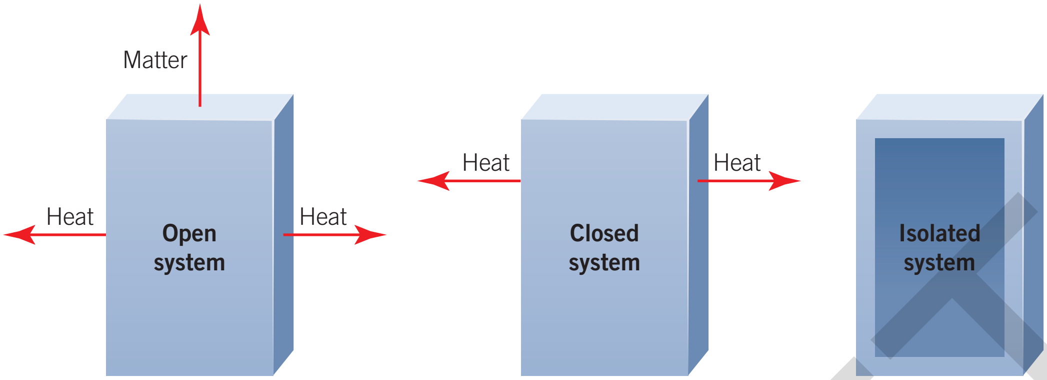
◀ John Dalton's symbolic and visual representations of the atom, published in 1808 in the *New System of Chemical Philosophy*

borders, allowing global citizens to communicate with each other. The scientific community uses elemental symbols, formulae and balanced chemical equations to communicate large amounts of information, enabling us to understand what elements and compounds are involved in a chemical reaction.

## What can a balanced chemical equation tell us about a reaction?

The study of chemical reactions focuses on substances that are undergoing change. A clear understanding of the energy changes occurring in a chemical reaction is also essential if we are to understand how the reaction occurs under a given set of conditions. The changing balance in energy between reactants and products needs to be understood.

Energy can neither be created nor destroyed, but is converted from one form of energy to another or transferred from one substance to another. The relationship that exists between a system, its surroundings and the universe is well understood.




The law of conservation of matter states that matter is neither created nor destroyed. Instead, in a chemical reaction, matter is changed from one form to another and can be accounted for at any given time.

All of the resources we use in chemical reactions are in finite supply, but some will be rarer in terms of natural abundance and more expensive. Most reactants in chemical processes are typically less expensive or less finite resources, and are said to be “in excess”. It is fundamentally important that we understand the stoichiometric amounts of the reactants required for a given reaction, so that a valuable finite resource is the limiting reactant. A limiting reactant determines the amount of product resulting from a chemical reaction. By designing a method that attempts to completely consume the entire limiting reagent in the reaction, we minimize wasting valuable resources.

▲ Chemists focus on the system when examining chemical reactions. Matter or energy can flow into and out of an open system altering the balance. This is the more common system being examined. In a closed system, energy can enter and leave the system but the amount of matter remains constant. In an isolated system, both matter and energy cannot enter or leave the system



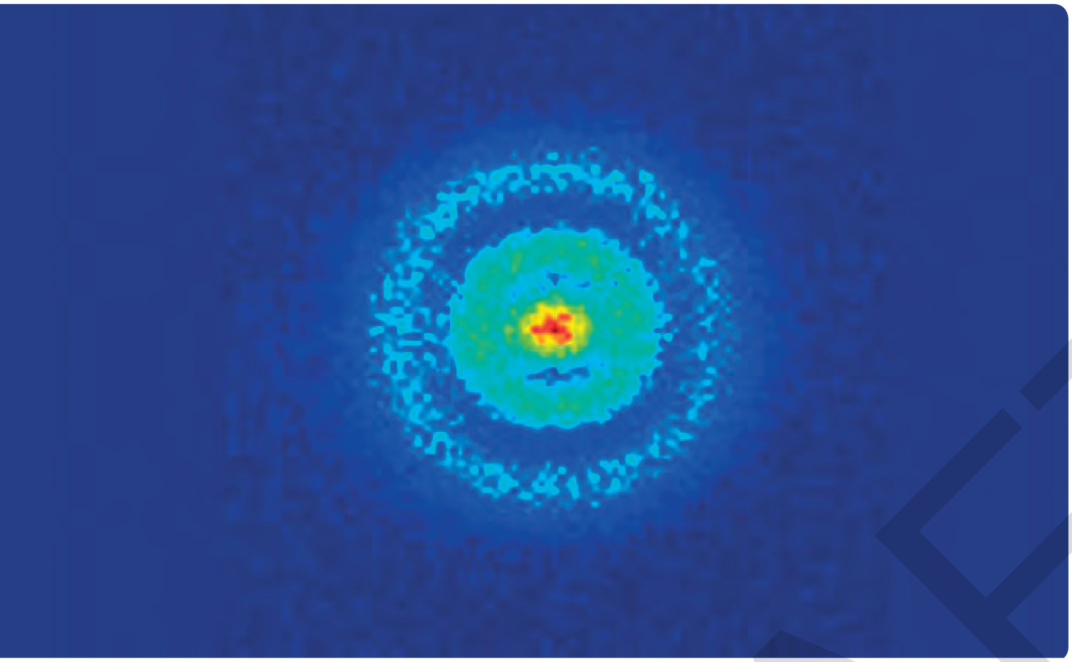
## ATL Thinking in context

As economic development throughout the world places demands on the planet’s finite resources, we can debate the consequences of connections between fairness and development and finite resources. Your task is to collect and analyse information that enables you to undertake informed discussion with your peers on the following questions:

1. What are some examples of finite resources that are closely managed in an attempt to ensure fair and equitable distribution?
2. Who decides on the distribution of resources within communities and between all living things?
3. What structures are in place within societies to monitor and protect the reserves of finite resources?
4. Should some societies be able to consume more finite resources than others?

QUANTITATIVE

# How do chemists manage finite resources in chemical reactions?



With a single proton, hydrogen is the simplest element that exists. This is the first image ever recorded of the orbital structure of a hydrogen atom. The instrument used to record the image is called a quantum microscope

Mathematics, the language of science, communicates that a balanced chemical equation is a proportional relationship between reactants and products. At the atomic level, individual atoms of elements are reacting with each other to form new compounds. How do we make sense of this at the macroscopic level?

The reactions between elements and compounds, and the chemical and physical properties of reactants and products are the focus of chemical research. Many different types of chemical reactions exist, such as combustion, single replacement, synthesis, decomposition and reduction-oxidation. In simple terms, a chemical reaction is a rearrangement of atoms, involving the making and breaking of bonds in the reactants and products. How then do we balance a chemical equation?

## Rules for balancing chemical equations

1. Balance the atoms of the metal element on the reactant and product side of the reaction first.
2. Balance the atoms of any element found in only one chemical formula on either side of the reaction.
3. Balance the atoms of any remaining elements, if required.
4. Check to see that there are the same number of atoms of each element on both sides of the chemical equation.

### Transition metal nomenclature

When metallic elements have more than one oxidation state, such as transition elements, Roman numerals are used to represent the oxidation number. For example, iron(III), copper(II), manganese(VII).

## Worked example

Metallic iron rusts in the presence of oxygen and water, losing three electrons to form the iron(III) cation. This is an oxidation reaction impacting steel and iron structures such as automobiles and bridges, causing hundreds of millions of dollars in damages each year.

$$\text{Iron} + \text{Oxygen} \rightarrow \text{Iron(III) oxide}$$

$$Fe(s) + O_2(g) \rightarrow Fe_2O_3(s)$$

**Step 1: Balance the atoms of the metal element on the reactant and product side of the reaction**

There is one iron atom on the reactant side and two iron atoms on the product side of the equation. Add a coefficient of 2 on the reactant side to the element iron: the metal element is balanced.

$$2Fe(s) + O_2(g) \rightarrow Fe_2O_3(s)$$

**Step 2: Balance the atoms of any element found in only one chemical formula on either side of the reaction**

In this case, there are no elements that are found in only one formula on either side of the reaction, so we can progress to step 3.

**Step 3: Balance the atoms of any remaining elements if required**

The only remaining element in this example that has not been balanced is oxygen. There are an even number of oxygen atoms on the reactant side and an odd number of oxygen atoms on the product side.

In mathematics, when adding fractions that have a different denominator, you calculate the lowest common denominator (LCD).

The LCD of 2 and 3 is 6. The number of atoms of oxygen on the reactant and product side must be 6. This change has imbalanced the iron atoms: there are now 4 atoms of iron on the product side.

$$2Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$$

**Step 4: Check to see that there are the same number of atoms for each element on both sides of the equation.**

As the previous step has imbalanced the number of iron atoms, double the coefficient for the iron atoms on the reactant side.

$$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$$



**1.** Fertilizers are produced by a reaction between an acid and ammonia. The following word equations summarize the formation of a variety of fertilizers. Write balanced chemical equations for these, including the states of matter for all reactants and products.

**a)** Ammonia + nitric acid → ammonium nitrate

**b)** Ammonia + sulfuric acid → ammonium sulfate

**c)** Ammonia + phosphoric acid → ammonium phosphate

**d)** Potassium hydroxide + nitric acid → potassium nitrate

2. The combustion of methane gas is an important source of energy. Methane is the most abundant compound in natural gas. Balance the chemical equation for the combustion of methane.

$CH_4(g) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$

3. Aluminium and iron are both common metals used in the manufacturing and construction industries. While iron is easily oxidized in the presence of water and oxygen, known as rusting, aluminium forms an oxide layer that prevents further oxidation. Balance the following chemical equations:

**a)** $Al(s) + O_2(g) \rightarrow Al_2O_3(s)$

**b)** $Fe(s) + O_2(g) \rightarrow Fe_2O_3(s)$



## Experiment

### Testing for the copper(II), iron(II) and iron(III) ions

There are two standard analytical tests for the presence of copper(II), iron(II) and iron(III) ions in a solution, one involving the addition of sodium hydroxide and the other the addition of ammonia solutions. The formation of insoluble metal hydroxides leads to the identification of these ions, as characteristic colour changes can be observed.

### Materials

- 0.5 mol $dm^{-3}$ copper(II) nitrate
- 0.5 mol $dm^{-3}$ iron(II) nitrate
- 0.5 mol $dm^{-3}$ iron(III) nitrate
- 1.0 mol $dm^{-3}$ ammonium nitrate
- 1.0 mol $dm^{-3}$ sodium hydroxide
- Test tubes and rack
- Dropping pipettes

### Method

1. Using a dropping pipette, transfer 3–5 $cm^3$ of 0.5 mol $dm^{-3}$ copper(II) nitrate solution into a test tube and observe the colour.
2. Then, using a different pipette, add 1.0 mol $dm^{-3}$ sodium hydroxide solution in a dropwise manner. Record your observations in the table below.
3. Continue adding the sodium hydroxide solution and observe any changes that are taking place. Record your observations.
4. Repeat steps 1–3 with fresh solutions of each of the metal ion solutions.
5. Repeat steps 1–3 with fresh solutions of each of the metal ion solutions and ammonium nitrate solution.

| Metal cation | Initial observations | Final observations (sodium hydroxide reaction) |
|---|---|---|
| $Cu^{2+}$ | | |
| $Fe^{2+}$ | | |
| $Fe^{3+}$ | | |

Create a similar table to record your observations when excess ammonium nitrate is use.

| | | |
|---|---|---|
| | | |
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ATL **Information literacy and communication skills**

## Green chemistry

In 1998, recognizing that our planet has a finite amount of resources and that the pace of industrialization and consumer-based economies was having a negative impact on the environment, Paul Anastas and John Warner developed a series of twelve guiding principles for chemical industries and manufacturing to follow when performing chemical synthesis and other chemical reactions. These principles are:

1. Prevent waste
2. Use of renewable feedstock
3. Atom economy
4. Reduce derivatives
5. Less hazardous waste
6. Catalysts
7. Design benign chemicals
8. Design for degradation
9. Benign solvents and auxiliaries
10. Real-time analysis for pollution prevention
11. Design for energy efficiency
12. Inherently benign chemistry for accident prevention

Anastas and Warner held the belief that there was a need for industry to reduce the amount of waste, both hazardous and non-hazardous, by devising methods that would create fewer unwanted products. Some of their proposed methods include: using less toxic solvents which could harm the environment, using renewable materials where possible (rather than diminishing the amount of finite resources)*, and using methodologies and building industrial infrastructure to prevent the loss of energy and recycle excess energy. Their initiatives have been embraced by many sectors of industry and governments alike, and in some countries the principles of green chemistry have been transformed into laws that govern the use of chemical technology.

Discuss the merits, and the large scale applicability, of green chemistry principles.

Research some examples of how green chemistry has been incorporated into existing industrial manufacturing systems to increase efficiency and decrease environmental effects. Some questions to consider include:

1. What are some characteristics of balanced industrial manufacturing systems?
2. How can imbalanced relationships produce both local and global effects?

*The law of conservation of matter states that matter can be neither created nor destroyed; however, non-renewable resources are considered to be finite as a consequence of the time required for them to form. As non-renewable resources are transformed into different compounds, the atoms are rearranged rather than lost. Discuss why some within the international community are concerned about the decrease in availability of non-renewable resources.



# What is a chemical equilibrium?

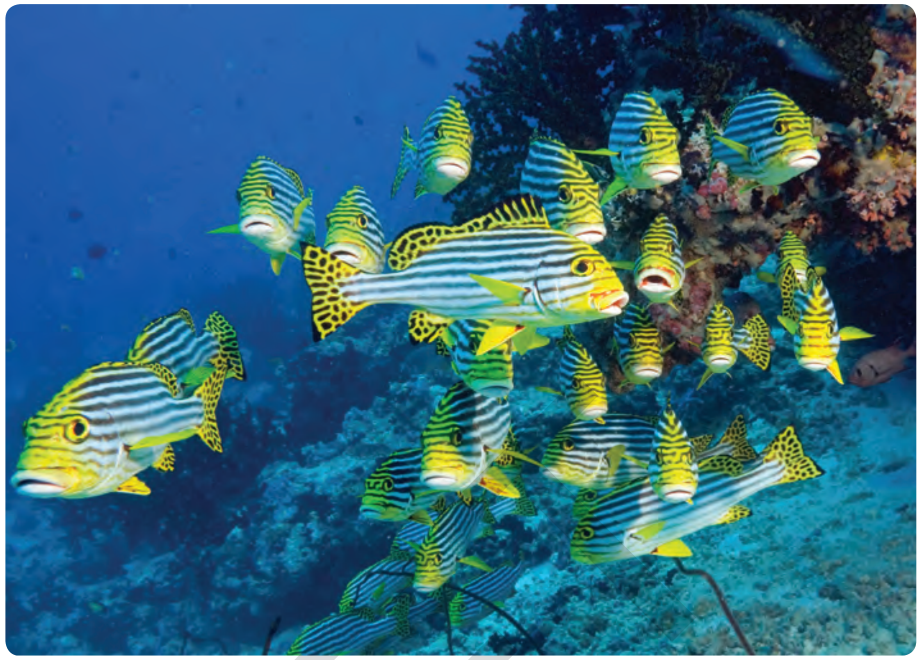
GENERAL

Many systems, including chemical reactions, exist in a state of equilibrium. An example of this is the hemoglobin-oxygen interaction: hemoglobin is the iron-containing protein in red blood cells, which is responsible for transporting oxygen to cells. Each hemoglobin molecule can carry up to four oxygen atoms, and the equilibrium reaction can be expressed as follows (where "Hb" represents hemoglobin):

$$Hb(aq) + 4O_2(g) \rightleftharpoons Hb(O_2)_4(aq)$$

This equilibrium is maintained as long as sufficient oxygen is supplied.

▶ Many fish have an organ called a swim bladder. This increases their ability to control buoyancy and therefore more easily maintain a preferred water depth without constantly swimming. These fish can be considered to be in equilibrium





### ATL Thinking in context

In some cases, social and economic development throughout the world has led to greater control of the planet's finite resources. We therefore can consider some possible connections to fairness and development with respect to these finite resources. With this in mind, discuss the following questions in small groups:

1. To what extent should scientists consider moral and ethical obligations when conducting their research?
2. When scientific research and discoveries have the potential to disrupt balance, to what extent are governments responsible for safeguarding society from this research and these discoveries?

GENERAL

## What impact did the Haber process have on our planet?

"Gaseous nitrogen combines with gaseous hydrogen in simple quantitative proportions to produce gaseous ammonia."

– Fritz Haber

German chemist Fritz Haber was awarded the Nobel Prize in Chemistry in 1918 for developing a method to synthetically fix nitrogen from the air. Before Haber's successful breakthrough, science had been unable to synthetically replicate this biological process.

Haber's discovery allowed for the large scale production of fertilizers that began during the Green Revolution and continues today. His process also

The large scale, industrial production of ammonia is an example of a once finite resource becoming much more easily controlled

provided Germany with a source of ammonia that was used for the production of explosives during World War I. The Green Revolution began in the mid-20th century, when advances in chemical fertilizers, synthetic pesticides and herbicides changed the face of agriculture forever. Advances in a new method of growing crops called high-crop yield improved the amount of food crops being produced and available to feed a growing global population. The Green Revolution, with the help of science and technology, continues today.

What do you envision when you hear the term "chemical equilibrium"? Perhaps you consider that a better understanding of a chemical reaction and the optimal conditions for it to occur will enable you to better control the reaction. Industrial chemists understand that in order to maximize their product yield, they have to analyse how reactions work and how efficiency within these reactions can be increased. This can often involve the manipulation of finite resources.

In economic terms, equilibrium occurs when supply and demand are equal. In a chemical system at equilibrium, the forward and reverse reaction rates are equal. No changes in the macroscopic properties of the reaction are observed when a system has reached equilibrium. The position of the equilibrium is dependent on the chemical reaction and the conditions under which it is taking place. Some chemical reactions favour the product side, while other chemical reactions favour the reactant side.

Equilibrium is linked to a stable balance where objects and systems are static (ie: no changes are occurring)

GENERAL

## How has industrial-scaled ammonia production impacted the global population?

At the beginning of the 20th century when the population of the world was 1.6 billion people, a shortage of synthetically produced fertilizers and a growing demand for increased food production encouraged Fritz Haber to develop a method that would enable the large scale production of ammonia. As ammonia is an essential component used to provide nitrogen for crop fertilizers, today the annual global production of ammonia stands at over 150 million tonnes and rising. Ammonia is mainly converted into other important compounds such as nitric acid, $HNO_3$, ammonium nitrate, $NH_4NO_3$, ammonium sulfate, $(NH_4)_2SO_4$, and urea, $NH_2CONH_2$.

The Haber process involves the reaction of 1 mol of nitrogen gas and 3 moles of hydrogen gas in the presence of a catalyst:

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92 \text{ kJ mol}^{-1}$$

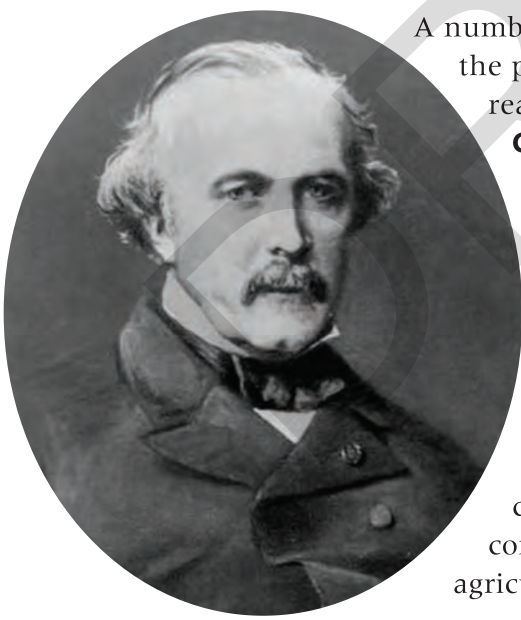
Haber's genius was to investigate and propose the ideal conditions under which the highest yield possible would be achieved in the shortest amount of time. He did this by determining the ideal temperature and pressure for the reaction.

GENERAL

## How do changes in reaction conditions affect an equilibrium system?

A number of very significant industrial processes, including the production of ethanol and ammonia, are reversible reactions and can be explained by the application of **Le Chatelier's principle.** This principle states that if a system in equilibrium is disturbed by changes in temperature, pressure, and/or concentration of the components, the system acts to oppose the change and rebalance the system.

This principle is named after Henry Louis Le Chatelier, a French chemist whose pioneering work opened the door to a better understanding of how equilibrium reactions behave. As we will see, this principle has critical implications for the production of ammonia (once considered a finite resource) and its use in large-scale agricultural applications.



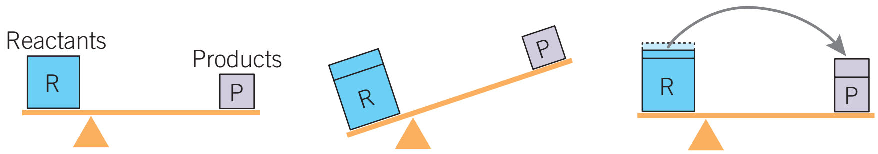
▲ In 1901, Le Chatelier unsuccessfully attempted nitrogen fixation in his laboratory, resulting in a massive explosion. The process was later perfected by Fritz Haber

According to Le Chatelier's principle, when a change is made to the conditions of a chemical equilibrium, the position of the equilibrium will readjust to minimise the change made. The balance between the forward and reverse reactions will shift to offset the change and return the system to equilibrium.

At equilibrium:

- The forward and reverse reactions are occurring at equal rates, meaning that the forward and reverse reactions continue to occur, but no overall changes are produced.
- The concentrations of reactants and products remain constant.
- Within the reactant/product mixture, there is no change in the observable (macroscopic) properties such as colour and density.

Gas molecules are normally far apart and moving at high velocities. By lowering the temperature and increasing the pressure of a closed system, gas molecules move closer to each other and eventually undergo a change of state from gas to liquid. This process is known as liquefaction.




This reaction is in equilibrium. The concentration of reactants is twice that of the products.

More reactants have been added. The equilibrium has been disturbed.

The equilibrium shifts to the right. Reactants are changed into products until the equilibrium is restored. The relative concentrations of reactants and products are the same as before.

## ATL Thinking in context

### Monocultures and food security

The use of synthetic fertilizers is a predominant global trend in agriculture. The Green Revolution allows, for the first time in mankind's history, for food production to be in excess of the increasing demand. However, the monocultures that dominate the agricultural landscape today are often viewed as unsustainable. While the productivity of annual food crops is of vital importance for feeding an ever growing world population, it can be argued that the prevalence of monocultures that dominate the global agricultural landscape is actually a threat to food security, the continuation of species and the conservation of natural resources throughout our planet.

According to the United Nations World Food Programme: "People are considered food secure when they have available access at all times to sufficient, safe, nutritious food to maintain a healthy and active life."

Research some of the threats posed by the monoculture model, considering both threats to food security and to the conservation of natural resources. Some questions you can consider include:

1. What are some characteristics of balanced agricultural systems with regard to crop selection and crop rotation?
2. What are some of the possible alternatives to monocultures?
3. How can imbalanced relationships produce both local and global effects?
4. How are imbalances in traditional weather patterns and climate trends affecting agricultural communities around the world?

GENERAL

# What changes will affect the equilibrium position in the Haber process?

## Concentration of reactants or products

According to Le Chatelier's principle, at a given temperature, the position of the equilibrium will change in response to a change in concentration of reactants or products. When industry collects ammonia by changing the pressure, thereby decreasing the concentration of ammonia present in the reaction vessel, the equilibrium will change to counteract this change.

An industrial ammonia production plant

Will the forward or backward reaction be favoured so that the concentration of ammonia increases, allowing the equilibrium position to return to its original position? How might we alter the concentration of nitrogen and hydrogen to favour the forward reaction and increase the amount of ammonia produced?

Chemists and chemical engineers who work at ammonia production facilities understand the principles of the Haber process and adjust reaction conditions to maximize yield and in turn profits.

## Pressure

The Haber process is an equilibrium system that involves only substances in the gaseous state. This means that the system will be affected by changes in applied pressure. In this reaction, the number of moles of gas on the reactant and product side is unequal. How many moles of gas are on the reactant side and how many are on the product side?

A change in pressure applied to the system will result in a shift in the equilibrium position, either favouring the forward or reverse reactions.

Consider the fact that 1 mol of a gas under standard conditions (temperature of 273 K and pressure of 1 atm) occupies 22.7 $dm^3$ of volume.

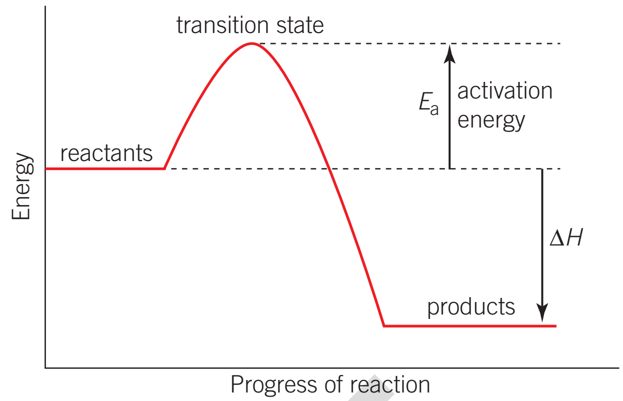
According to Le Chatelier's principle, an increase in pressure applied to the system will favour the side of the reaction with the least number of moles of a gas. For example, in the case of nitrogen gas reacting with hydrogen gas, the forward reaction is favoured and the yield increases:

$$N_2 + H_2 + H_2 + H_2 \rightleftharpoons NH_3 + NH_3$$

## Temperature

The production of ammonia is an **exothermic** process, where energy is released as heat into the surroundings during the reaction. The reverse reaction, which produces hydrogen and nitrogen gas, is therefore **endothermic**, and takes in energy from the surroundings. When the system is at equilibrium, the forward and reverse reactions occur at equal rates and there is no change in energy. Increasing the temperature of a reaction effectively adds additional reactant for an endothermic reaction, or product for an exothermic reaction. Therefore in the Haber process, increasing the temperature is adding to the ammonia side, so the reverse reaction is favoured to balance the equilibrium.

- What has happened to the yield when the temperature is increased?
- What is the advantage of increasing the temperature of the system?




▲ How does the total amount of energy contained in the reactants compare to the products? Which substances will be more energetically stable, reactants or products?

## Experiment

### Making fertilizer

**Safety**

- Wear eye protection
- Sulfuric acid is corrosive - avoid contact with the skin
- Ammonia is a corrosive gas to the respiratory system - perform the experiment in a well ventilated room or fume hood.

### Materials

- 1.0 mol $dm^{-3}$ sulfuric acid
- 1.0 mol $dm^{-3}$ ammonia solution
- 25 $cm^2$ measuring cylinder
- Porcelain evaporating basin
- Universal indicator paper
- Bunsen burner

### Method

1. Measure 20 $cm^2$ of 1.0 mol $dm^{-3}$ sulfuric acid with a measuring cylinder and transfer it into a porcelain evaporating basin. Place the basin on top of a wire gauze and tripod.
2. With a dropping pipette, slowly add small amounts of 1.0 mol $dm^{-3}$ ammonia solution to the basin until there is a constant smell of ammonia coming from the mixture.
3. After each small addition, check the pH of the solution by stirring the mixture with a glass stirring rod and placing a drop of the liquid onto a piece of universal indicator paper.
4. When the pH has moved above 7.0, sufficient ammonia has been added.
5. Over a moderate Bunsen burner flame, warm the solution until it has reduced in volume to about 20% of the original. Care should be taken not to allow the solution to be heated too strongly as the solution may spit.
6. When crystals begin to form in the basin, cool, filter and allow the crystals to dry.

### Questions

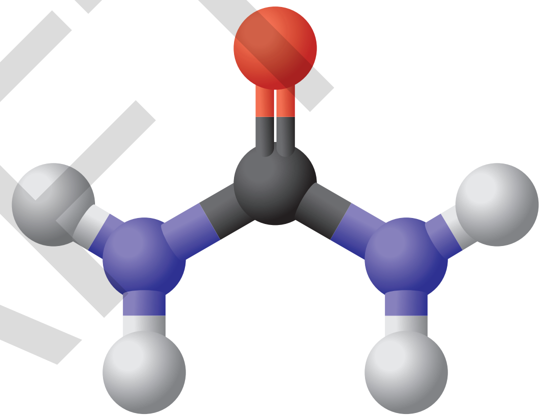
1. Write the word and balanced chemical equation for the reaction.
2. Which element found in the product is responsible for plant growth? Explain your answer.

## Research

1. What is the source of the reactants, nitrogen and hydrogen, used in the Haber process?
2. Write a balanced chemical equation for the production of hydrogen gas.

## Uses of nitrogen-containing chemicals

Gather information from a variety of sources about the main uses of the chemicals nitric acid, $HNO_3$, ammonium nitrate, $NH_4NO_3$, ammonium sulfate, $(NH_4)_2SO_4$ and urea, $NH_2CONH_2$. Structure the information as a summary and present it. Based on your research, share ideas with your peers, while answering the following question: Why must the total amount of ammonia production keep increasing each year?

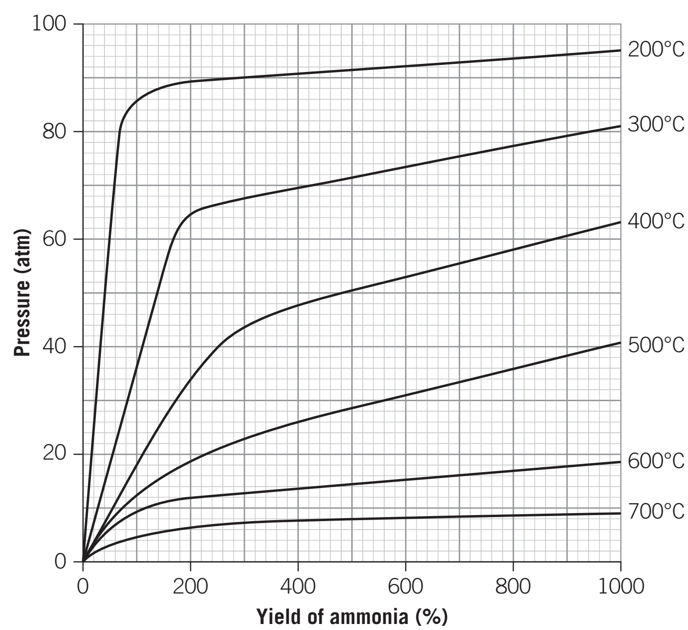


Urea is a commonly used component of fertilizers and an integral part of the agricultural industry



## Data-based question: Industrial reaction conditions for the production of ammonia

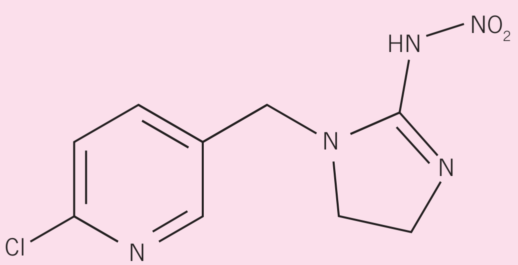
1. What temperature achieves the highest yield of ammonia? [1]
2. Describe how the yield changes as the pressure is increased. [1]
3. The ideal temperature used by Haber is approximately 450°C. Outline the reasons why a higher temperature would be used to increase production of ammonia instead of a lower temperature. [2]
4. A pressure of 200 atm is used during the process. Why does industry not use a much higher pressure to maximise yield? [2]
5. Explain with reference to the position of the equilibrium why increasing the pressure of this closed system favours the forward reaction. [2]



## ATL Thinking in context

### Fertilizers vs. pesticides, and CCD

Fertilizers and pesticides are both classes of synthetic compounds used in the agricultural industry; while fertilizers are typically nitrogen-based and applied to increase plant growth/yield, pesticides are applied to control insects considered to be crop pests. Imidacloprid is a pesticide belonging to the class of chemicals called neonicotinoids, which destroys insects by producing fatal effects within their central nervous system.




▲ Chemical structure of imidacloprid

Both fertilizers and pesticides have been documented to disrupt balance within environments. Of particular concern are recently documented links between honey bee exposure to imidacloprid and an increase in the rate of colony collapse disorder (CCD). In January 2013 the European Food Safety Authority stated that the use of imidacloprid presents an unacceptably high risk to honey bees and that the industry-sponsored scientific research and findings, upon which claims of safety have relied upon, may be flawed.

Research some of the current data related to colony collapse disorder (causes, effects, where it is occurring, solutions), and what the implications to our global food supply will be if pollinators continue to decrease in numbers on a large scale. Some questions to consider include:

1. Might pollinators be considered a finite resource? Why or why not?
2. What are some characteristics of balanced agricultural systems with regard to pollinators?
3. When scientific discoveries disrupt balance (for example, the design and application of imidacloprid), to what extent are governments responsible for safeguarding society from the harmful effects?
4. How are imbalances in the number of pollinators and beekeepers affecting agricultural communities around the world?
5. How can imbalanced relationships produce both local and global effects?



## Experiment

### Decomposition of ammonium chloride

**Safety**

- Wear eye protection
- Perform this reaction in a well ventilated area

**Materials**

- Solid ammonium chloride
- Bunsen burner and tongs
- Test tube

**Pre-investigation question**

How do you test for the presence of ammonia gas?

$NH_4Cl\ (s) \rightleftharpoons NH_3\ (g) + HCl\ (g)$

▲ The decomposition of ammonium chloride is an endothermic reaction which demonstrates the reversible nature of some chemical reactions

**Method**

1. Place 1–2 cm of ammonium chloride powder into the bottom of a dry test tube.
2. Light the Bunsen burner and slowly pass the test tube through a strong flame until you observe evidence that the reaction has started.

**Questions**

1. What do you observe when the test tube of ammonium chloride is heated?
2. A white solid is observed at the top of the test tube? Can you identify the substance?
3. Explain why this solid has re-formed away from the source of the reaction.

## Experiment

### Testing for the ammonium ion

**Safety**

- Wear eye protection
- Concentrated hydrochloric acid is corrosive - avoid contact with the skin
- Ammonia gas is a corrosive gas to the respiratory system - perform the experiment in a well ventilated room or fume hood.

**Materials**

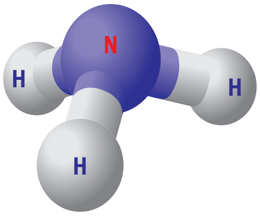
- 1 mol $dm^{-3}$ sodium hydroxide
- solid ammonium chloride salt
- 6 mol $dm^{-3}$ hydrochloric acid
- Red litmus paper
- Test tube and tube rack
- Dropping pipette
- Spatula
- Bunsen burner

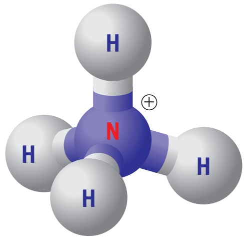
**Method**

1. Using a dropping pipette, transfer 2 $cm^3$ of 1 mol $dm^{-3}$ sodium hydroxide into a test tube.
2. Add 1 flat spatula of solid ammonium chloride salt.
3. Gently warm the contents of the test tube by passing it back and forth through a Bunsen burner flame.
4. Replace the test tube in the test tube rack and hold a piece of damp red litmus paper at the rim of the test tube. Record any observations.
5. Dip a stirring rod into concentrated hydrochloric acid (corrosive) and place the stirring rod at the tip of the test tube. What do you observe?

**Questions**

1. Name some other compounds that react with damp red litmus paper. What do they all have in common?
2. Construct a balanced chemical equation to describe the reaction that you observed when you heated the mixture.
3. Give the name and formula of the product of the reaction between ammonia and concentrated hydrochloric acid.



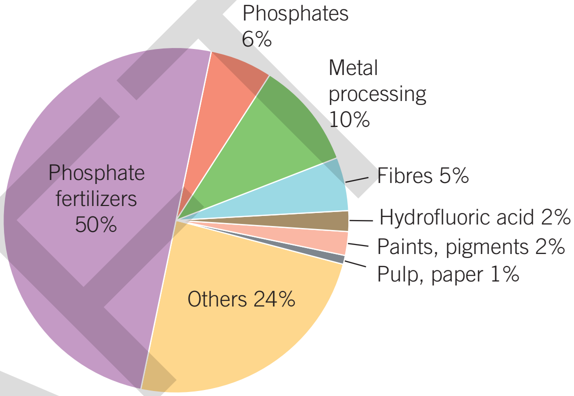




Ammonia gas ($NH_3$) is a noxious gas with a strong pungent smell. Ammonia is often confused with the ammonium ion

## How are equilibrium systems controlled in industrial processes?

GENERAL

Each year, the Contact process is used to produce over 200 million tonnes of sulfuric acid. Over 50% of total global production is used to manufacture phosphoric acid, $H_3PO_4$. Important products from the reactions of sulfuric acid and phosphoric acid include the fertilizers ammonium sulfate and ammonium phosphate. Sulfuric acid is used in many other processes including the manufacture of plastics, batteries and paints.




The uses of sulfuric acid

The Contact process is the conversion of sulfur dioxide into sulfur trioxide:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H° = -196\,kJ\,mol^{-1}$$

This process again utilises Le Chatelier's principle. The reactant side of this chemical reaction contains 3 moles of gases while the product side contains 2 moles of a gas. By raising the pressure of this system, the equilibrium will move to reduce the pressure and the forward reaction will be favoured. This will increase the yield of sulfur trioxide. Catalysts are also added to the reaction mixture to maximise the rate of production.

### The Ostwald process: nitric acid production

The Ostwald process is another industrial application of Le Chatelier's principle. This process is used for making nitric acid and involves the catalytic oxidation of ammonia (Haber process), as the first step.

Research the oxidation of ammonia through the Ostwald process, and respond to the following questions:

1. What is oxidation?
2. Explain the equilibrium process involved and the conditions used in this reaction.
3. What is nitric acid used for?
4. State the role of nitric acid in this industrial process. Give some other examples of catalysts being used in industrial processes.

# Summative assessment

**Statement of inquiry:**

Imbalanced relationships affect finite resources, both locally and globally.

## Introduction

When the large-scale chemical synthesis of ammonia began nearly a century ago, this once finite resource became much more easily controlled, and therefore much more accessible. At that time, few people would have foreseen the impact of large-scale manufacturing of ammonia on the global community. The Haber process allowed for the production and widespread use of fertilizers which improved crop yields, modernised agriculture and provided improved food security for billions of people. This, in turn, has contributed to shaping global economic, social and environmental landscapes.



### Le Chatelier's principle

Le Chatelier's principle states that if a system in equilibrium is disturbed by changes in temperature, pressure, and/or concentration of the components, the system will shift the position of the equilibrium to counteract the change and return the system to balance.

For each of the following chemical reactions, examine the reactants and products and their states of matter, and decide how the change in reaction conditions will affect the position of the equilibrium.

**1.** The Haber process describes the industrial production of ammonia gas on a large scale:

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H° = -92 \text{ kJ mol}^{-1}$$

Predict the effect of the following changes on the position of the equilibrium in the Haber process.

**a)** Nitrogen gas is added to the system at equilibrium.

**b)** Hydrogen gas is removed from the system at equilibrium.

**c)** The pressure of the system is decreased.

**d)** The temperature of the system is increased.

**2.** The decomposition of sulfur trioxide is an endothermic process:

$$2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g) \qquad \Delta H° = +196 \text{ kJ mol}^{-1}$$

Predict the effect of the following changes on the position of the equilibrium:

**a)** Sulfur trioxide gas is removed from the system at equilibrium.

**b)** Oxygen gas is removed from the system at equilibrium.

**c)** The pressure of the system is increased.

**d)** The temperature of the system is decreased.

**3.** The equilibrium that exists between nitrogen(IV) oxide and dinitrogen tetroxide can be monitored by observing the colour change with changing temperature:

$$2NO_2(g) \leftrightharpoons N_2O_4(g) \qquad \Delta H^\circ = -57\,kJ\,mol^{-1}$$

$NO_2$ is a brown coloured gas and $N_2O_4$ is colorless.

Predict the effect of the following changes on the position of the equilibrium. In each case deduce the colour observed before and after the changes described.

**a)** The temperature of the system is decreased.

**b)** The temperature of the system is increased.

**c)** The pressure of the system is increased.

## Exploring changes in equilibrium reactions

When the cobalt(II) chloride, a blue transition metal complex, is dissolved in water, it establishes an equilibrium with the pink coloured cobalt(II) hexahydrate ion. The forward reaction in this equilibrium is exothermic.

$[CoCl_4]^{2-}(s) + 6H_2O(l) \leftrightharpoons [Co(H_2O)_6]^{2+}(aq) + 4Cl^{-}(aq)$
$\Delta H^0 = -X\ kJ\ mol^{-1}$

**4.** Design an experiment that enables you to observe how the equilibrium of this system can be changed using the following materials: cobalt(II) chloride hexahydrate powder, 2 mol $dm^{-3}$ hydrochloric acid and distilled water.

Your design should include the following features:

- a method (including all apparatus) used to establish the initial equilibrium
- two different methods used to demonstrate how the equilibrium position can be altered
- an appropriate way of recording both quantitative and qualitative observations of the reactions you are performing
- details of the variables being controlled and evidence of an awareness of safety issues.

## Extension to your experiment

When you have shown your design to you teacher and your method is considered to be safe, perform the investigation and collect all the relevant quantitative and qualitative data. Next, interpret the data you collected, considering the following questions:

- In terms of Le Chatelier's principle, explain how you controlled and altered the position of the equilibrium.
- Evaluate the strengths and weaknesses of the investigation. Did you make any modifications to your method during the investigation?
- Suggest possible improvements to the method.
- Determine what possible extension to the investigation is possible.

## Impacts of the availability of fertilizers

***Choose one of the research tasks below and write a report as instructed.***

The Haber-Bosch process is considered by many to be one of the most important transformational technological developments of the modern age, with some of the most substantial unintended consequences.

A significant environmental effect of the widespread use of agricultural fertilizers on our planet is eutrophication: the accelerated growth of aquatic plants and algae in bodies of water that contain excess nutrients (namely, nitrogen and phosphorous) as a result of agricultural runoff. This increased presence of plants and algae depletes the levels of dissolved oxygen in the water, referred to as hypoxia, and often leads to areas of open water that are unable to sustain life (also known as "dead zones").

**5.** As a chemical hydrologist specializing in nutrient loss strategies, you are producing a community report on the health of local watersheds. Research the specific environmental impacts and scientifically viable prevention solutions related to agricultural runoff in a river of your choice. Your report can be written, visual, or a combination of the two, and must include:

- how the watershed has changed over the last 15-20 years
- current measures that are being implemented to restore health to the watershed
- a justified proposal for future measures that can be taken to reduce or eliminate nonpoint source pollutants.

Moreover, your report should also answer the following questions:

**a)** How can imbalanced relationships produce both local and global effects?

**b)** What are some of the consequences (moral, ethical, and/or environmental) of infinite resources becoming finite?

Another significant effect of the widespread use of agricultural fertilizers on our planet has been a skyrocketing 20th century global population, which increased from 1.6 billion to 6 billion. At the time of print nearly two decades into the 21st century, the global population is over 7.5 billion and continues to rise.

**or**

**6.** You are an ambassador with the United Nations Environment Programme working on the impacts of applied nitrogen in agriculture, and advocating for the UNEP proposed "20:20 for 2020" target. The target aims to improve the efficiency of nitrogen use by 20 percent and to reduce the overall use of nitrogen by 20 million tons each year up to 2020.

Write a report addressing the following points:

- how and why population models have changed over the past century
- current population forecasts for the next century
- implications of an ever-increasing global population
- a summary of proposed measures to reduce the application of nitrogen based fertilizers in agriculture.

Your report should also respond to the questions:

- How can imbalanced relationships produce both local and global effects?
- What are some of the consequences (moral, ethical, and/or environmental) of finite resources becoming infinite?