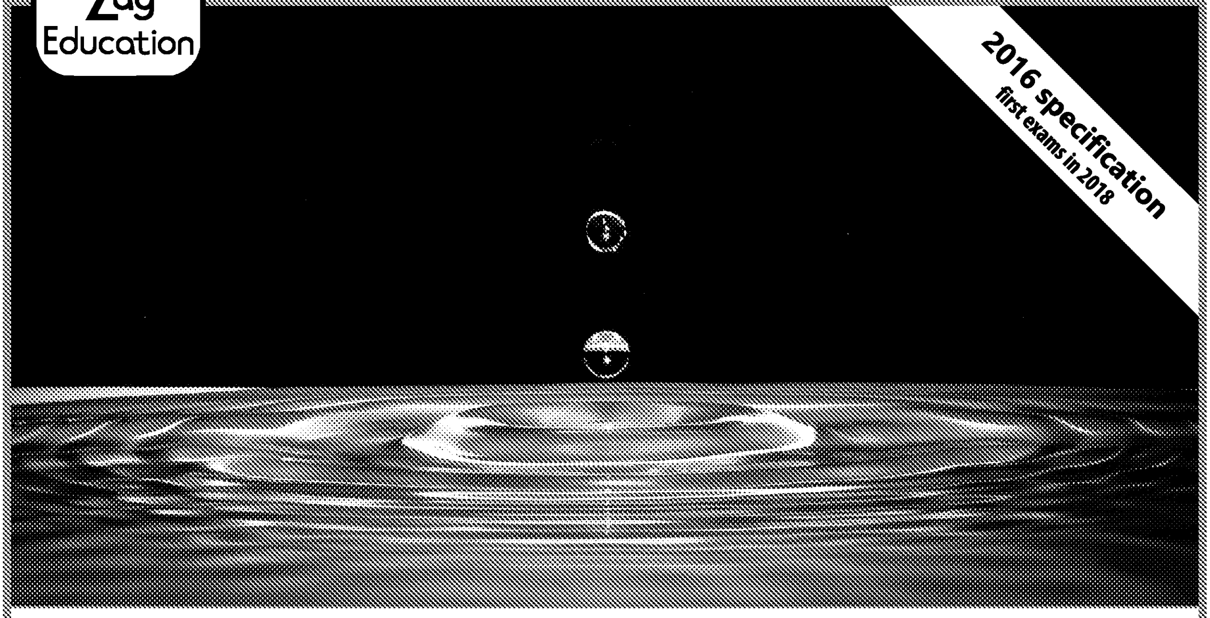
Chemistry

GCSE (9–1) | AQA | 8462



2016 specification
first exams in 2018

Stretch and Challenge Articles

for GCSE AQA Chemistry

Pack 2 (Topics 6–10)

zigzageducation.co.uk

POD 11583

Contents

Teacher's Introduction

Welcome! These Stretch and Challenge Articles are designed to complement the 2016 (9–1) GCSE AQA Chemistry specification for Paper 2 (topics 6–10). This pack contains 14 articles covering key areas of interest to any student chemist – each article is designed to not only stretch a student's understanding of chemistry but to also give the student a wider appreciation of how chemistry has been and is being used to solve big problems in our societies. Some articles give some historic context of some innovations in chemistry and others give a more forward-looking perspective on current issues.

For each article, the following activities are included:

- Comprehension questions to check the reader's understanding and engagement
- Discussion questions to encourage deeper thinking about and engagement in the wider impact of chemistry in our societies
- Extension questions to encourage students' further research and independent learning

Also included for each article:

- Keyword identification to ensure important concepts and context are recognised and understood
- Indicative content for all activities

Each article has a direct link to the specification, which is given on the specification information page, but also goes beyond the specification giving historical context and recent developments.

The articles are between 500 and 1000 words each, and are expected to take a student approximately 15 minutes to read. The comprehension questions are expected to be short, while discussion questions should be given more time and can be used in a whole-class activity. The activities are structured so that all students are able to access them and it is suggested that where the activities are teacher-led small-group discussions are encouraged.

Extension tasks can be used as homework or to encourage independent learning.

We hope you enjoy these resources.

A web page containing all the links listed in the Further Reading sections in this resource is conveniently provided on ZigZag Education's website at ***zzed.uk/11583***

You may find this helpful for accessing the websites rather than typing in each URL.

May 2022

Specification Information

Article	Topic
The importance of catalytic converters	Rates of reactions
Element number 6	Hydrocarbons
Should ethanol still be classified as a green fuel?	Alcohols
The gift and the curse of plastics	Polymers
What is in your tap water?	Qualitative analysis
A dance between sources and sinks	Earth and atmospheric science
The consequences of combustion	Fuels
Sweet crude oil	Fuels
The issue with acid rain is…	Earth and atmospheric science
Water treatment around the world	Potable water
Are we running out of copper?	Alternative methods of extracting metals
The life of a drink can	Life cycle assessment
Alchemy and alloys	Alloys as useful materials
When life gives you nitrogen and hydrogen, make ammonia…	Le Chatelier's principle

The importance of catalytic conv

Keywords

Adsorb – When a substance attaches to the surface of an object, substance or
Catalytic converter – A device containing a metal catalyst fitted to a vehicle's pollutant gases to less harmful gases by oxidation and reduction reactions
Oxidised – A chemical reaction where oxygen is added to or hydrogen remove
Redox reaction – A chemical reaction where both oxidation and reduction hav
Reduction – A chemical reaction where oxygen is removed from or hydrogen
Smog – A mixture of smoke (pollutant gases) and fog usually formed in highly populated areas

'Only twenty of ten on Monday morning and already the sky was a fla taut to its combustible edges as far as the eye c

- Helena Maria Viramontes

On 26th July 1943, residents of Los Angeles, California, woke to a thick fog which b also reduced their visibility to only a few metres. This was during World War II an they had been attacked with chemical weapons.

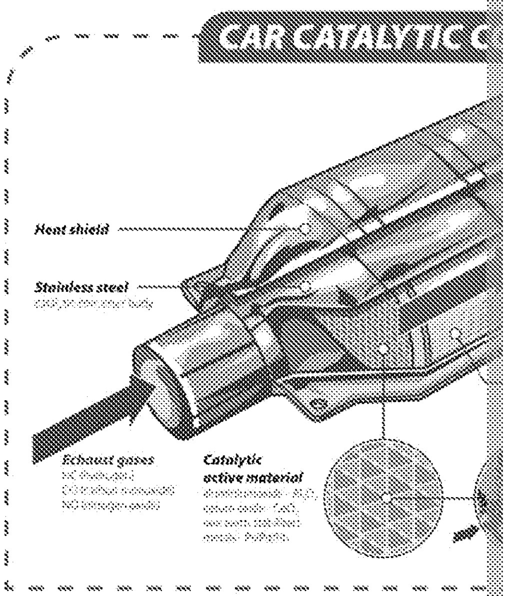
On 5th December 1952 during a cold spell there was a similar occurrence in Londo hospitalised and as many as 12,000 deaths are linked to this event, which lasted fo similar incidents in cities such as Beijing, Delhi, Mexico City and Tehran.

What was this strange occurrence?

The incidents above were later linked to what is now known as **smog**. Think of sm and fog. Smog is formed from a mixture of gases produced from the combustion factories. It has a higher probability of being formed in densely populated and in

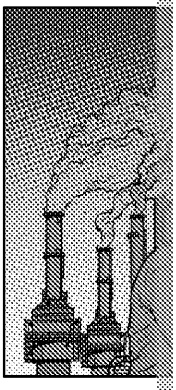
Introducing – The catalytic converter

In 1973 the first production-ready catalytic converter was made. This followed years of laws being passed to reduce air pollution. A **catalytic converter** is a device designed to convert toxic and pollutant gases from a vehicle's exhaust to less harmful gases. All modern vehicles are now fitted with catalytic converters to ensure their exhaust gases legally meet emission standards. The converters are built to minimise the release of carbon monoxide (CO), nitrogen oxides (NO_x) and unburnt hydrocarbon fuels such as Octane (C_8H_{18}) through a series of very quick chemical reactions. In must occur in the few seconds before the gases escape from the vehicle's exhaust



The inside of the converter contains a honeycomb/mesh-like structure made from platinum, rhodium or palladium. These metals catalyse a series of oxidation and r pollutants into less harmful gases. The honeycomb structure provides a very high gases to react as they flow quickly through the converter. The gases are, therefor surface of the precious metal where they undergo oxidation or reduction reaction

Conversions



Carbon monoxide displaces oxygen from red blood cells and deprives the heart, brain and other important organs of oxygen. This can result in unconsciousness, organ failure and death. In the catalytic converter, carbon monoxide reacts with oxygen and is **oxidised** to carbon dioxide.

Nitrogen oxides which accelerate the formation of acid rain undergo **reduction**; they lose oxygen to form the inert and non-polluting nitrogen gas.

Unburnt hydrocarbon fuel, which could lead to the formation of smog, is oxidised by reactions with oxygen to form carbon dioxide and water. The reactions in the converter are all examples of **redox reactions**, a combination of reduction and oxidisation.

It's not all good

The catalytic converter is best described as a device that causes more good than h
The use of rare and expensive metals as the catalyst increases their demand, extra
processes release pollutant gases such as carbon dioxide and sulfur dioxide, which
The use of precious metals in these devices also makes them a target for theft, esp
is easier to get under the vehicle to cut out the converter. In 2019 the estimates w
£1,300/ounce, while rhodium goes for £4,000/ounce.

Catalytic converters only work effectively after they heat up to temperatures above
car heats up harmful gases are being released. During the redox reactions, carbon
released from both the oxidation of carbon monoxide and unburnt hydrocarbons.
as the complete combustion of hydrocarbon fuel would have produced the same t

After years of use the catalyst becomes coated with different substances and is no
converter may need to be changed. The disposal of the old converter adds to our

Do the advantages outweigh the disadvantages? What is your view?

Comprehension questions

1. Explain why smog is most likely to form in some cities and not others. (2
2. Octane is a hydrocarbon commonly found in petrol. Write the word equa in a catalytic converter. (1 mark)
3. Describe the effect of a named exhaust gas on the body. (2 marks)
4. Explain why catalytic converters are prone to theft. (2 marks)

Discussion questions

1. Explain how the design of the catalytic converter makes it very effective fo
2. Discuss the advantages and disadvantages of using catalytic converters. (

Extension

1. Write word equations for the combustion of carbon monoxide and nitrog
2. Write balanced symbol equations for the combustion of each of the follo the passage: carbon monoxide, nitrogen monoxide, octane. (4 marks)
3. The catalytic converter does not reduce the quantity of a major pollutant statement and the effect of the pollutant gas on the environment. (2 mark

Independent task

Create a PowerPoint slide highlighting the benefits and disadvantages of elec
friendly solution to the use of fossil fuels in vehicles.

Further reading

Electric cars are thought to be a great option as an energy source for current
What are the pros and cons?

Suggested sources
https://www.theguardian.com/environment/blog/2012/oct/05/electric-cars-emissi
https://www.edfenergy.com/electric-cars/batteries
https://www.energysage.com/electric-vehicles/101/pros-and-cons-electric-cars/

Element number 6

Keywords

Allotropes – Different physical forms of the same element
Catenation – When an element bonds with other atoms to form stable chains
Isomerism – Molecules having the same molecular formula but different struc
Molecular formula – A formula showing the number of atoms of different ele
Synthesise – To make/produce a product or substance

Carbon is without doubt one of the most important elements in the periodic table. Life as we know it would not exist without this amazing element. Only 0.025 % of Earth's crust is made of carbon, but carbon is still considered the king of all eleme the periodic table.

Carbon the element

The first unusual fact about carbon is that in its pure form it can exist as different **allotropes**, such as diamond, graphite, graphene and various fullerenes. Carbon is however, found naturally as either coal, diamond or graphite. Carbon's importanc increased due to the continued research and development in nanotechnology. Gr super material due to its highly valuable physical properties, such as unusually hig

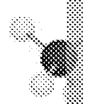
Due to the wide variety in the different forms of carbon, the element has a wide ra drill bits, electrodes, touchscreens, medical implants, filters, pencils, aeroplanes, res

Carbon is life

Carbon is the key element found in the molecules of all organisms and, therefore, pharmaceutical, food and agricultural industries is unmatched. Important biologic carbohydrates, lipids, enzymes, hormones and countless others are all carbon-bas and that of other organisms rely on carbon as the key element; every organ, tissue based molecules.

Why is carbon so special?

Carbon has some unique properties which allows it to form an unusually high number of different molecules. One such property is its ability to **catenate**. Catenation is the ability of atoms of an element to form stable molecules in the form of rings and chains. Octane and hexane are straight chain molecules while cyclohexane is cyclic (a ring structure).



Carbon is fairly unique in its ability to catenate, with a few other elements such as sulfur and phosphorus. Carbon is able to form extra strong bonds in its molecules, which increases their stability and likelihood to be produced from various reactions. A comparison of the bond energies of C–C and P–P bonds, for example, shows that C–C bonds require more energy to break, and, therefore, molecules containing carbon C–C bonds are more likely to exist as they are more stable than molecules containing P–P bonds.

From the table below it is seen that carbon has the highest single and double bon
bonds are the strongest in Figure 1. Carbon atoms can, therefore, successfully bo
double C=C and even triple C≡C bonds. The molecules of carbon are very stable
common reactions such as oxidation.

Bond	Bond Energy JK/mol
O–O	140
S–S	215
P–P	215
C–C	345
O=O	498
C=C	611

Figure 1

Carbon, therefore, forms a vast number of stable molecules and structures with ex
bonding. The molecular formulas, names and structural formulas of three hydroca

CH_4 **C_2H_6**

Methane ***Ethane***

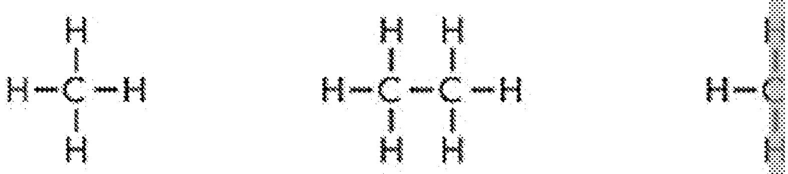
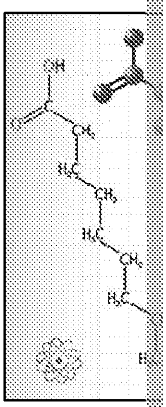


Figure 2

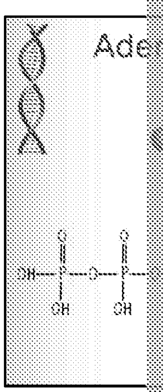
More complex molecules



The molecules shown above are relatively small compared to the vast number of other carbon-based molecules. To the right is an example of a more complex carbon-based molecule, a fatty acid called stearic acid.

The ability of carbon to form these types of structures is also helped by the fact that carbon, being a group 4 element, is able to form four covalent bonds (tetravalency) with either itself or other elements. Take some time to examine the molecules in Figures 2 and 3 – every carbon atom is bonded four times, the hydrogen atoms are not shown in the ball-and-stick 3D model.

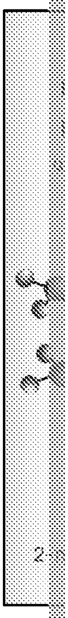
Carbon frequently bonds with elements such as oxygen, hydrogen, sulfur, phosphorus and nitrogen, and this vastly increases the variety and complexity of carbon-based molecules.



The molecule shown to the right is ATP, a key biological molecule responsible for carrying and releasing energy in the cells of organisms. The molecule has three rings (to reduce the complexity of the diagram some hydrogens are not shown).

Isomerism

Carbon chemistry is full of examples of **isomerism**. Isomerism results from atoms of the same elements being able to bond in different sequences, thereby producing different molecules from the same starting elements. Isomers have the same number of atoms of each element but a different sequence of bonding.



The four isomers of butene, **molecular formula** C_4H_8, more commonly known as butylene, are shown to the right. All four compounds have the same number of carbon and hydrogen atoms; however, on close examination we see the attachment of the atoms – the location of double bond and the spatial arrangement differs within each molecule.

Carbon's unusual properties has resulted in it being able to form an almost limitless number of compounds, and new carbon-based molecules are still being discovered and **synthesised**.

An astonishing fact is that carbon forms more compounds than all the other elements – how special is that?

Comprehension questions

1. Name three allotropes of carbon and their uses. (3 marks)
2. One of the four isomers of butane is branched – state its name. (1 mark)
3. A molecule of caffeine is shown to the right – state its molecular formula.

Discussion questions

1. Explain why molecules having carbon to carbon bonds, C–C, are less react phosphorus and sulfur bonds. (2 marks)
2. Explain why carbon is able to form a large number of different compound as phosphorus. (3 marks)

Extension

1. Explain what isomerism is, then draw a molecule of butane and then one of butane. (3 marks)

Independent task

Carbon chemistry is full of isomerism – research and create a resource explaini isomerism: chain, functional and positional. You should give examples of com and draw the displayed formula of the relevant molecules.

Further reading

The wonderful world of carbon

Suggested sources

https://edu.rsc.org/infographics/allotropes-of-carbon/4012885.article
https://www.theburningofrome.com/advices/why-is-carbon-so-important-in-organ
https://chem.libretexts.org/Bookshelves/Environmental_Chemistry/Green_Chemistry
ustainability_(Manahan)/06%3A_he_Wonderful_World_of_Carbon-_Organic_Chemis

Should ethanol still be classified as a g

Keywords

Alcohol – An organic molecule containing the hydroxyl (OH) group

Anaerobic – An environment where there is a lack of or insufficient oxygen

Biofuel – A fuel created from plant materials

Combustion – A chemical reaction where a substance is burnt in oxygen, usua

Fermentation – A reaction used to convert plant material (glucose) into ethan anaerobic conditions

Green fuel – A fuel whose production and uses does not contribute to any net

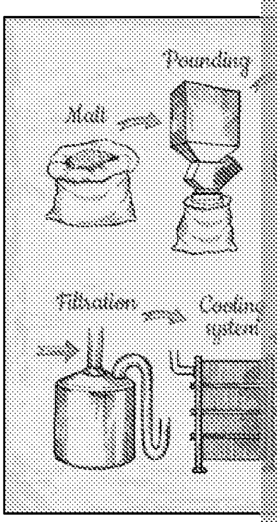
Hydrocarbon – A molecule containing only carbon and hydrogen atoms

Hydroxyl – The OH group

It's not alcohol, it's ethanol

You may have seen adverts for alcoholic beverages at some point, but what we refer to as alcohol is actually a compound called ethanol. Ethanol itself belongs to a larger group of compounds called **alcohols**. Other examples of alcohols are methanol, propanol, butanol and pentanol, and there are so many others. Alcohols all have at least one hydroxyl, OH, group. All alcohols are toxic to some extent; methanol, the alcohol with the smallest molecule, is extremely toxic. If ingested it can result in headaches, vomiting and even blindness. Ethanol, on the other hand, is mildly toxic in small quantities – this is what gives a person a 'buzz' or an intoxicating effect.

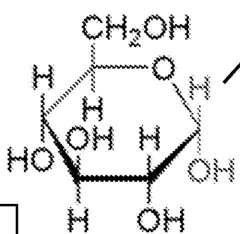
It's all about zymase



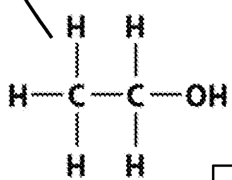
Ethanolic beverages are produced by the **fermentation** of plant material rich in sugars – plants such as corn, beets, sugar cane and even potatoes are used. Fermentation is only effective if a single cellular organism yeast is added to the plant mixture under **anaerobic** conditions. The yeast releases an enzyme called zymase.

Zymase catalyses the breakdown of the cyclic structure of glucose into two straight chain ethanol molecules – both compounds contain **hydroxyl** groups. Ethanol has one hydroxyl group and glucose has five hydroxyl groups, as shown on the structural formulas below. Carbon dioxide is given off as a by-product of this reaction.

$$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2 + \text{heat}$$



Glucose



Ethan

Fermentation produces a maximum of 15 % ethanol before the zymase becomes d
alcohol production to beverages which had a maximum of 15 % alcohol, but if fer
by distillation this allowed the ethanol to be separated and concentrated due to it
volatility compared to the other components of the fermented mixture. This resul
beverages with very high alcohol content.

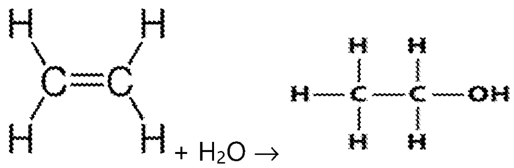
Beverage	Alcohol content %
Whisky	40–68
Gin	38–80
Vodka	35–90
Rum	38–80

Ethanol as a biofuel

In the early 1800s the use of ethanol as a fuel was first experimented with by famo
Otto – he used ethanol as fuel for early combustion engines. Ethanol was at this ti
such as lamps and lighters as it burned with a clean blue flame. Another positive a
does not release sulfur dioxide and nitrogen oxides, which are atmospheric pollut
viewed by some as a fuel for the future and a leading candidate to replace **hydro**
diesel. The idea of ethanol being used as a fuel was based mostly on the fact it co
renewable source, crops, and as a result ethanol is classified as a **biofuel**. This is i
such as gasoline and kerosene, which are fractionally distilled from crude oil, whic

Hydrate me

An alternative method to produce ethanol is the **hydration** of hydrocarbon ethen



The hydration produces only ethanol and, therefore, has a 100 % atom economy, w
compared to fermentation. However, ethene is obtained from the cracking of cru
whole point of using ethanol is to reduce our use of crude oil, which is a finite res

The downside

The production of ethanol by fermentation, its transportation and its combustion a
this is enough of a disadvantage for some people to claim it is misleading to class
1970s the production of ethanol as a biofuel has increased more than fivefold – in
on ethanol only or a blend of ethanol and gasoline (petrol) called gasohol. The id
'saviour of fuels' has, however, not been globally accepted, especially in countries w
agricultural-based economy. Currently in the UK our petrol contains 5 % ethanol
within the next few years.

With the rise of the rechargeable electric car due to companies such as Tesla, and a
technology by companies such as Toyota, ethanol has lost some of its visibility as t

Is there still a place for ethanol as a biofuel in our future? You decide.

Comprehension questions

1. Explain why it is more accurate to call alcoholic beverages ethanolic bevera
2. Ethanol is the only alcohol that is consumed – explain why this is the case.
3. Explain why vodka, gin and rum cannot be produced by fermentation only
4. A student discovers a liquid in the laboratory labelled ethanal. She is not s and suspects it should have been labelled ethanol instead. She tests the li in a spirit lamp, and the liquid burns with a smoky orange flame. Explain w should make from this observation. (2 marks)

Discussion questions

1. Should we continue to classify ethanol as a green fuel? (3 marks)
2. Compare the production of ethanol by fermentation and by hydration. (3 m
3. Explain why the production of ethanol and its use as a biofuel is popular in the USA but not in most countries around the world. (2 marks)

Extension

1. Calculate the atom economy for the production of ethanol by fermentation
2. Explain which process has a more favourable atom economy. (1 mark)

Independent task

Write a letter highlighting the main concerns we should have if ethanol were to a large scale.

Further reading

Fuel cells are thought to be another great option as an energy source for curren Research what a fuel cell is and how it generates energy, then explain why fuel c used commercially on a large scale.

Suggested sources
https://www.energy.gov/eere/fuelcells/fuel-cells

The gift and the curse of plast

Keywords

Alkenes – A group of hydrocarbons containing carbon to carbon double bond production of some types of polymers

Biodegradable – A material that will decompose naturally by different agents

Physical properties – Different features of characteristics of a material, e.g. solu

Polymers – A material made by joining small repeating units, called monomer

Since the start of the twentieth century, plastics have been both a gift and a curse. The dominance of plastics started after World War I when production of plastics increased from 2.3 million tonnes in 1950 to 448 million tonnes by 2015. Production is expected to double by 2050.

Fantastic plastic?

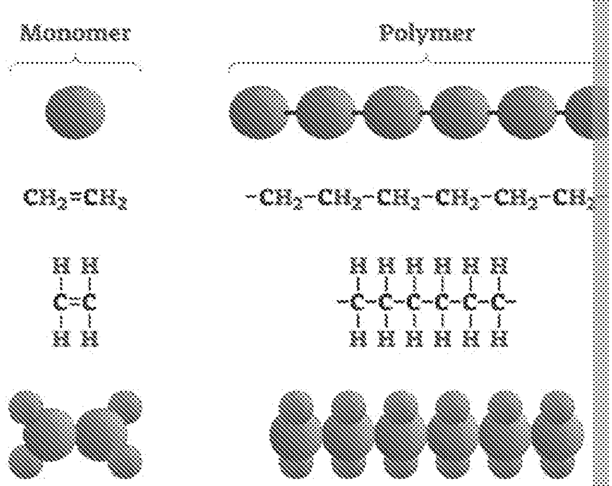
What exactly is plastic? Plastics are a group of man-made **polymers** which can be deformed without breaking. The majority of plastics are used for various types of packaging, construction and automobiles. Most plastics are made from **alkenes** obtained from the cracking of large hydrocarbons obtained from crude oil.

The production of plastics is greater than all other materials due to various **physical** have a wide range of uses. Additionally, plastics are very cheap to produce compar properties of a plastic can be changed using different mixtures of raw materials and production. The result is that there are many different types of plastics with many d of plastics are: heat-resistant, durable, chemical resistant, electrical insulators and st

Over and over again

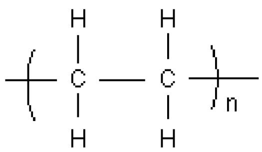
Polyethene is the most widely produced polymer in the world; it is used for packa and pipes). More than 100 million tonnes of polyethene was produced annually i of the total plastics market.

Polyethene is an example of an addition polymer. Polyethenes are usually made fro alkenes. Polyethene is made by the polymerisation of ethene, C_2H_4; during this proc single bond and the ethene molecule adds to itself over and over again to produce



Ethene | *Three repeat units of polyeth*

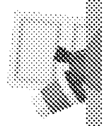
During polymerisation there is not a specific number of ethene molecules involved
formula for the polymer. Polymers are represented using a shortened form called
used to show that the formula shown is repeated n times.



Polyethene

Gift or curse?

Plastics are man-made and as a result they are not **biodegradable**. Decomposers and environmental conditions are not able to easily break down plastic items when they are discarded as waste. Some examples of how long it takes for a plastic material to decompose are:

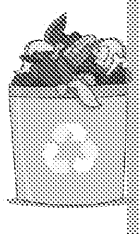


Plastic bags	10–20 years
Plastic bottles	450 years
Plastic nappies	550 years
Plastic straws	200 years

Millions of animals are killed each year by plastics when they ingest plastic waste.
discarded on land, but a lot of it finds its way into waterways, and eventually ocea
and in many cases starvation due to animals mistaking plastic items for food.

Over the last two decades we have gained a better understanding of how plastic w
the globe and now even into our food and water supply. When plastics are discar
sun, wind, rain and cold break it down into very small microplastic particles, invisib
These particles have made their way into the water cycle and microplastics have b
of Earth. Microplastics can be found in the air, water and even our food supply –
escape them.

The solution to the pollution



There are many ways we can tackle the problems associated with plastics. These include: enacting laws, proper waste management, recycling and choosing alternative materials.

There is also another solution, using biodegradable plastics. Biodegradable plastics have been successfully made from renewable and naturally occurring materials such as starches, acids, and plant material such as cellulose and lignin. Currently
biodegradable plastics do not have the same wide range of properties and uses a
still more expensive to produce. The use of plant-based raw materials reduces the
crops. Bioplastics still need considerable time to decompose and many are not co

Some countries, such as Italy, have banned the use of non-biodegradable plastics,
applied taxes to make them more expensive than biodegradable plastic; however,
plastics across the world continues to increase.

There is some hope that eventually the use of biodegradable plastics will be great
plastics. If this does not happen, in another 50 years there will be more plastic tha

What can you do to help?

Comprehension questions

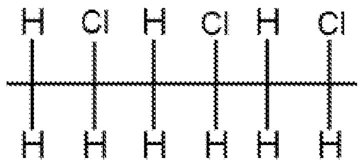
1. Describe three physical properties of plastics. (3 marks)
2. Explain why the use of plastic has increased significantly from the 1950s.
3. Explain how plastics might end up in our food supply. (2 marks)

Discussion questions

1. Describe how you and your household can help to minimise plastic waste
2. Compare biodegradable and non-biodegradable plastics and explain why used more widely. (4 marks)

Extension

1. Explain how the polymer shown to the right is produced. (2 marks)
2. Using ethene as the example, explain what happens to alkene molecules when they form polymers such as polyethene. (2 marks)
3. PVC is a widely used polymer; it is used to make water pipes. Explain why PVC is suitable for this use. (3 marks)



Independent task

Write a letter to your local MP to suggest strategies countries such as the UK s countries to reduce their use of plastic.

Further reading

The uses of a material are dependent on its physical properties. Compare the p polymer materials Kevlar and polystryrene.

Suggested sources
https://www.popsci.com/science/article/2012-11/science-behind-4-greatest-polym

What is in your tap water?

Keywords

Aqueous – A phase of matter occurring when a substance dissolves in water
Heavy metals – Metals with a relatively high density and atomic mass
Insoluble – A material that does not dissolve in a given solvent
Ion – A positively or negatively charged particle formed when an atom loses o
Precipitate – A solid that forms after two liquids are mixed together
Qualitative test – A procedure done to determine what is present in a sample
Transition metal – A metal found in the middle (d block) of the periodic table

Although over 70 % of Earth's surface is covered with water, less than 1 % of all w without undergoing some form of treatment. Safe drinking water should be colou free from any suspended or dissolved solids, especially **heavy metals**. It should a microorganisms and pathogens.

Do you drink water from the tap in your home? If you don't drink tap water, do y wash your fruits, vegetables and meat?

Testing your drinking water

If you are concerned about water from your tap there are simple tests you can do at home without any chemicals or equipment.

- Examine the colour – good-quality water should be colourless and transparent.
- Leave the water to stand in a glass for a few hours. Do you notice any sediments forming at the bottom of the glass?
- Shake or stir the water vigorously. Is there any odour being given off?

These tests, however, are not comprehensive enough to identify key dissolved ions that might be present in a water sample.

If a water sample is coloured in any way then a transition metal **ion** such as Co^{2+}, Cr^{3+}, Fe^{2+}, Fe^{3+} or Cu^{2+} may be present. The colour from these ions is due to the fact that **transition metal** ions form coloured complexes with water molecules. Non-transitional metal ions such as Ba^{2+}, Al^{3+} and Mg^{2+} do not form coloured solutions and may be present in colourless water samples.

Lead

Historically the element lead has always been a huge concern for persons living in water pipes were made from lead. It was not until the early 1970s that the use of l concern, when lead was linked to neurological diseases and brain damage. Althou metal, over time and at different temperatures the pipes eventually react to releas The possibility of lead entering the water supply was not considered an issue as m hard water sources which contain dissolved carbonate ions, CO_3^{2-}, and scientists i quantities of lead ions that would enter the water supply would combine with **aqu** **insoluble** lead carbonate, which would deposit as solid coating the inside of the p taps. Since the 1970s the use of lead water pipes has been completely phased ou before then the lead pipes might not have been replaced.

Qualitative testing

To ensure that water being considered for drinking meets the minimum standards, chemical testing is done at various stages before it reaches your home. **Qualitative** tests are carried out to determine what is present and then quantitative tests measure how much of a known substance is present.

The simplest qualitative tests rely on precipitation reactions or the production of gases from solutions. The observations from qualitative tests can give us clues that help us to identify various ions.

Sodium hydroxide is very widely used in qualitative testing – the reason behind this is the hydroxides of many metals are insoluble in water and they form precipitates with distinct colours. For example, if iron(II) ions are present in a water sample then a green **precipitate** forms due to the reaction of the hydroxide ions and iron(II) ions. The ionic equation is

$$Fe^{2+}_{(aq)} + OH^{-}_{(aq)} \rightarrow Fe(OH)_{2(s)}$$

Green

Cheap and simple water testing kits can be purchased online to carry out the tests However, these types of test do not always give reliable or accurate results. In som contaminant ions is too low for any precipitate or gas to form, or a combination of might disguise each other's colours, leading to false positives and incorrect conclu important then instrument methods such as flame ionisation spectroscopy and gas options. These techniques only require very small samples; they are very accurate extremely expensive.

Could we actually run out of drinking water?

The answer is yes, the United Nations World Water Development Report estimates that over 6 billion people, or a projected 57 % of the global population, will suffer from lack of access to suitable quality water for at least one month out of each ye

Of course the total amount of water on Earth will be exactly the same, but it is the quality of the water that is decreasing – you should be able to figure out why.

Comprehension questions

1. Describe some of the characteristics of water which is suitable for drinking
2. Explain how simple qualitative tests work, with the help of an ionic equati aluminium hydroxide, $Al(OH)_{3\ (s)}$. (3 marks)

Discussion questions

1. Explain the dangers associated with using lead water pipes and why in the was not a huge concern even for some scientists. Include an ionic equatio
2. Should we be concerned about water scarcity? Give reasons why this is li future. (4 marks)

Extension

The World Health Organization's guideline for lead is that the concentration i
10 µg/L and concentrations between 10 and 50 µg/L are suitable for bathing a
In a village in Bangladesh a water sample from a well was found to have a co
(µg/L = 1 microgram per litre).

1. Explain what this water should be used for based on the WHO's standar
2. The average male drinks 2.7 litres of water per day. Determine, using a c the average male in Bangladesh consumes in a week. (2 marks)

Independent task

Where exactly does the drinking water in your home come from? How is it tr
Do some research and create a summary in the format of your choice.

Further reading

Improper agricultural practices and livestock farming are blamed among othe
contributors to our worsening water crisis. Using the example of South Afric
of water in 2018, discuss to what extent this statement is true and how South

Suggested sources

https://www.worldvision.org/clean-water-news-stories/global-water-crisis-facts
https://www.unwater.org/water-facts/scarcity/
https://www.who.int/news-room/fact-sheets/detail/arsenic
https://www.nature.com/articles/s41545-019-0039-9

A dance between sources and si

Keywords

Atmosphere – A layer of gases surrounding Earth's crust

Catalyst – A substance that speeds up a chemical reaction without being used

Degasification – The process where a gas dissolved in a liquid leaves the liqui

Ozone – A gas found in high concentration in the upper atmosphere which ab the UV radiation from the Sun

ppm – A unit used to measure the concentration of substances in small quanti

Precipitation – A reaction where a solid is produced from mixing two liquids

Sink – A process that removes a pollutant gas from the atmosphere

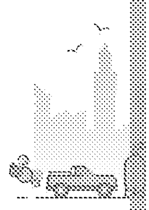
Source – A process that releases a pollutant gas into the atmosphere

There is a careful balance of gases in our atmosphere; the composition of these gases constant for hundreds of years and has helped to sustain life on Earth. In our atmosp and movement of molecules as gases enter and leave the **atmosphere** through differ

A sink is any process or chemical reaction that removes a gas from the atmosphere a reaction which releases the gas into the atmosphere. Sources and sinks have existed in harmony with each other through various material cycles to keep the composition

CO_2 concerns

Over the last century, and certainly in the last decade, we have become increasingly concerned about carbon dioxide emissions. The carbon dioxide content in air in 2021 was 419 **ppm** compared to 280 ppm just under 300 years ago. Carbon dioxide currently accounts for more than 65 % of all greenhouse gases in the atmosphere.

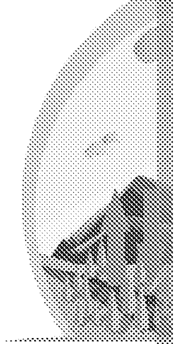


The main biotic process releasing carbon dioxide into the atmosphere is respiration, and the main biotic sink is photosynthesis. These biotic processes are accompanied by abiotic processes, atmospheric carbon dioxide released from the combustion of fossil fue used as a building material. The main abiotic sink for carbon dioxide is from disso the form of rainfall and in waterbodies. Carbon dioxide dissolves in natural water along with other gases helps to make rainwater naturally acidic, with a pH of abou

$$H_2O + CO_2 \rightarrow H_2CO_3$$

Degasification

Carbon dioxide also dissolves in waterbodies such as rivers, lakes and oceans, with oceans of course playing the biggest role. The ocean is a major sink for many atmospheric gases. The ability of waterbodies to absorb carbon dioxide depends on their temperature and acidity. The solubility of gases decreases as the temperature of a waterbody increases. As global temperatures continue to trend upward we expect less carbon dioxide to dissolve in oceans and lakes, and at some point we expect that the carbon dioxide already dissolved will start being released by **degasification**, in the same way that a fizzy drink releases its carbon dioxide and goes flat more quickly on a warm day.



$$H_2CO_3 \rightarrow H_2O + CO_2$$

As more carbon dioxide, sulfur dioxide and nitrous oxides are released, their comb
increase in the acidity in natural water resources, and this decreases the ability of w
acidic atmospheric gases. Higher acidity in soil and oceans also speeds up the rea
and rocks such as limestone, marble and dolomite, which are carbonates.

$$CaMg(CO_3)_2 + 4H^+ \rightarrow Ca^{2+} + Mg^{2+} + H_2O$$

Dolomite rock	Acidity	Calcium ion	Magnesium ion	Wate

These reactions also become additional sources of carbon dioxide to the atmosph
increased urbanisation and industrialisation, resulting in the removal of natural ve
abiotic sink for carbon dioxide, photosynthesis.

The net effect is carbon dioxide molecules are now spending longer periods in the at
carbon dioxide molecules now spending 20–100 years in the atmosphere. It is very d
carbon dioxide sinks and stores to effectively manage continued increases in carbon
temperatures rise.

Methane

Methane is a more powerful greenhouse gas than carbon dioxide as each molecule is able to absorb more UV radiation and then release it as heat in the atmosphere. Methane is naturally released from marshes and ponds, and animals.

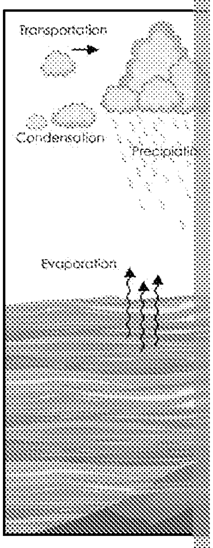
In the past 30 years methane released by human activities has far exceeded the release from natural sources. Cattle farming, rice fields, landfills and drilling for hydrocarbons have all surpassed the natural methane sources. Rice and beef production is responsible for most methane emissions. Unlike carbon dioxide, methane molecules spend only around 12 years in the atmosphere, before being removed by the reaction with hydroxyl radicals found i
methane sink. Increased large-scale food production could further change the ex

Triple trouble

Nitrogen oxides, such as nitrous oxide, are also powerful greenhouse gases. Natura
nitrogen and ammonia by soil microbes. The overuse of fertilisers in large-scale far
and this results in increased output of nitrogen oxides by soil microbes. Nitrous oxi
combustion of fossil fuels. The atmospheric lifetime of nitrous oxide is around 114 y
diffuses all the way to the upper atmosphere and the only major sink is its reaction w
ozone depletion. This depletion is made more severe by the fact that the role of ni
but instead a **catalyst.** In the equations below, nitrous oxide molecules are regener
broken down. One molecule of nitrous oxide is responsible for the destruction of co

$$N_2O + O\ (excited) \rightarrow 2NO$$
$$NO + O_3 \leftrightarrow NO_2 + O_2$$

The threat from nitrous oxide is considerable as it contributes to global warming, acid rain and ozone depletion.



Water

Water is by far the most powerful and the most abundant greenhouse gas in the atmosphere. Its ability to absorb and release infrared radiation is greater than either methane or carbon dioxide. The water vapour in air is, however, carefully regulated by the fast-paced water cycle with many abiotic and biotic components. The result is that water molecules spend as little as hours and only as long as days in the atmosphere. As a result the atmospheric impact of water on global warming is very low compared to other gases.

Sources vs sinks

The examples on the previous page demonstrate how human activities easily disru sources and sinks in our atmosphere. Without creating additional sinks to remove their quantities will continue to increase and their impact at some point may beco We all have a part to play – what will you do?

Comprehension questions

1. State two processes that remove carbon dioxide from the atmosphere. (1 m
2. Give the reasons why there is little concern about increased levels of water va
3. Write a symbol equation showing how acidity in soil or rainwater reacts with li

Discussion questions

1. Describe how the use of fertilisers is impacting on the atmosphere. (2 ma
2. Explain how the ability of waterbodies to help regulate carbon dioxide co increased carbon dioxide concentration in the atmosphere. (4 marks)
3. Compare the impact of carbon dioxide and nitrous oxide on the environm

Extension

1. Explain how eating beef contributes to global warming. (3 marks)
2. The carbon dioxide content of atmosphere changed from 280 to 419 ppm in percentage increase in the carbon dioxide concentration. (2 marks)
3. At 22 °C, 24 dm^3 of air contains 6.02×10^{23} particles. Calculate the number o 24 dm^3 of air, given the concentration is 419 ppm. (2 marks)

Independent task

Which countries have been significantly affected by climate change over the la Create a report highlighting how a country of your choice has been impacted b affected in the future.

Further reading

Is the eating of beef really a big contributor to global warming?

Suggested sources

https://www.theguardian.com/environment/2021/oct/27/whats-the-beef-with-cow
https://www.nytimes.com/2019/10/01/upshot/beef-health-climate-impact.html

The consequences of combusti

Keywords

Correlation – An observed relationship between two variables

Crude oil – A naturally found mixture of hydrocarbons formed by the decomp organic material over millions of years

Exothermic – A chemical reaction that releases heat

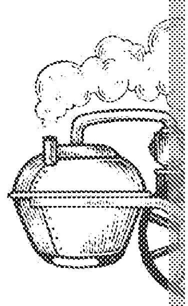
Incomplete combustion – A combustion reaction where there is insufficient o incompletely burnt

Internal combustion engine – A heat engine where fuels are burnt with oxyge to release vast amounts of energy

As far back as the era of *Homo erectus*, 2 million years ago, our ancestors discovered a source. The discovery of controlled fire was in fact the discovery of combustion. The r for two purposes – heating and cooking – but this changed with the discovery and use bronze, which led to the development of metal extraction procedures which all involve fuels significantly increased during this period, known as the Bronze Age. The use of s dominated; however, in the eighth century the first liquid fuel – **crude oil** (petroleum) –

Coal power

Around 1790 the first steam engines were developed and the combustion of coal was used to boil water to provide energy for machines and vehicles. The use of coal was expanded to power ships, street lights and locomotives. In the late 1800s a new type of engine was developed – the **internal combustion engine**, which developed into today's modern engines which use hydrocarbon derivatives of petroleum as fuel.



It's all about the O_2

Combustion in simple terms means burning, but in more accurate terms combust with oxygen, releasing heat. Fuels are only suitable for wide-scale uses if their co **exothermic**. Most of the fuels used around the world are hydrocarbons or even c The products vary slightly depending on the quantities of oxygen available during

Complete combustion

Where sufficient oxygen is available, complete combustion occurs, producing carb

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + \text{energy}$$

In limited oxygen – for example, in a faulty boiler or even a fireplace – **incomplete** This produces carbon monoxide, water, and in some cases unburnt carbon (soot).

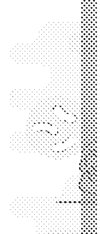
Some oxygen: Incomplete combustion

$$CH_4 + 1.5O_2 \rightarrow CO + 2H_2O$$

Little oxygen: Incomplete combustion

$$CH_4 + O_2 \rightarrow C + 2H_2O$$

Carbon dioxide has no immediate impact on our health, but carbon monoxide, CO particularly dangerous, especially in unventilated spaces and highly populated and Carbon monoxide forms a stronger and more stable bond with haemoglobin in our red blood cells than oxygen does. When inhaled it therefore displaces oxygen from our red blood cells and can lead to dizziness, unconsciousness and suffocation. Unburnt carbon particles are respiratory irritants and long-term exposure contributes to respiratory diseases. Quantities of sulfur dioxide and nitrogen oxides are also produced during the combustion of impure fossil fuels – these gases are known to contribute to the formation of acid rain.



Early warning signs

In Europe, as early as the eighteenth century there were signs of deforestation du coal as fuel. Increasingly in highly populated cities such as London air quality dec respiratory problems increased, especially during long periods of cold weather. In made severely ill with estimates of 4000 to 8000 deaths due to air pollution linked in London.

Even bigger problems

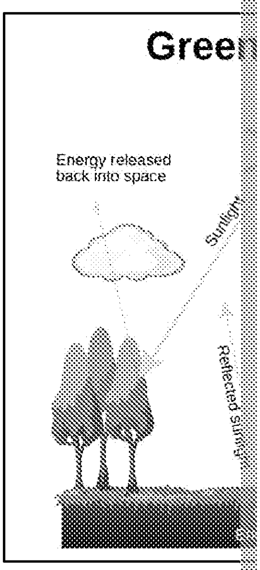
Since the 1950s the average global surface temperature has risen between 1.0 and 1.5 °C. This is a very small number but when compared to the temperature rise from 1850 to 1950, 0.2 °C, then it becomes more significant. During the last decade the number of extreme weather events has increased significantly. In the last year alone we have had the following:

Frequent wildfires: Turkey, Greece, Australia and California
Stronger hurricanes: Caribbean and United States
Longer droughts: California, Central America, South Africa
Unusual flooding: UK, Houston, Germany

Cause or coincidence?

Is there really a link between the combustion of fossils fuels and climate change? S but some political leaders say this is not the case as in our history Earth has warmed really a connection between rising temperatures, climate change and the combustio in carbon dioxide, a known greenhouse gas. A greenhouse gas is a molecule which bending of its covalent bonds, is able to absorb and store thermal infrared radiation

The most powerful greenhouse gases are water, carbon dioxide, methane and nitrogen dioxide. All except methane are produced during the combustion of fossil fuels. So why do we highlight carbon dioxide in most discussions? Water molecules spend only a few days in the atmosphere and nitrogen dioxide is produced in much smaller quantities than carbon dioxide during combustion. The impact of these gases on global temperatures is, therefore, small compared to the impact of carbon dioxide. Carbon dioxide molecules spend a much longer time in the air as the rate of photosynthesis, the main process that removes carbon dioxide from the air, is too slow to balance the increasing release of carbon dioxide from combustion.



$$6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

Photosynthesis

Data from weather stations, ice cores, tree rings and other measurements show a between carbon dioxide levels in the atmosphere and global temperatures. Corre cause, and that is enough for some persons to doubt the science. It is also in the companies to dismiss the science and the rising global temperatures as being nat

Comprehension questions

1. State two fuels mentioned in the article. (2 marks)
2. Explain what a greenhouse gas is. (3 marks)
3. Describe two consequences of global warming. (2 marks)

Discussion questions

1. Explain why carbon dioxide is thought to have a bigger impact on global wa greenhouse gases. (2 marks)
2. Explain how incomplete combustion can impact on a person's health. (2 ma

Extension

1. Compare and contrast incomplete and complete combustion – use equations
2. Coal is an allotrope of carbon. Write balanced equations to show the comple of coal. (3 marks)

Independent task

Is there sufficient evidence to show a link between carbon dioxide levels in the a temperatures? Find data from two sources you consider reliable and explain wh (The data shown should be in the form of a table or graph and you should nam you think it is a reliable source.)

Further reading

Is climate change real?

Suggested sources
https://climate.nasa.gov/evidence/
https://www.wwf.org.uk/updates/10-myths-about-climate-change

Sweet crude oil

Keywords

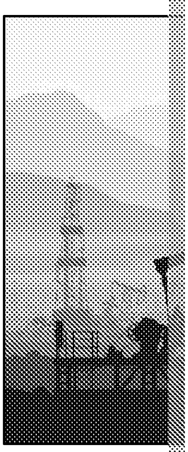
Cracking – The process of splitting large hydrocarbon molecules into smaller mole

Fractional distillation – A process where components of a mixture are separa points. It involves vaporising, condensing and collecting the components at di

Fractions – A mixture of hydrocarbons having similar boiling points, propertie fractional distillation of crude oil.

Hydrocarbon – A molecule containing only carbon and hydrogen

Oil refining – The process by which crude oil and other fuels are treated and con



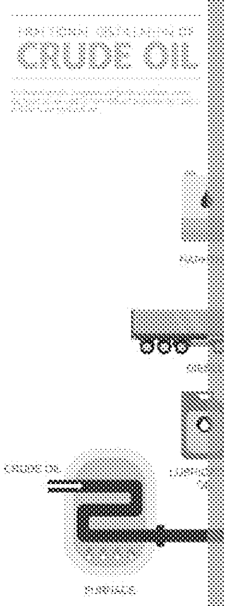
Crude oil, otherwise known as petroleum, is usually a thick black, brown or even yellow liquid obtained by drilling underground or undersea. Crude oil is a mixture of mainly **hydrocarbons**, molecules containing only the elements hydrogen and carbon, formed from the decomposition of compressed organic matter over time. Crude oil also contains sulfur. Hydrocarbons have made crude oil one of the most valuable substances in modern history due to their many uses.

First things first

Crude oil when drilled from the ground is relatively thick, does not ignite easily and is totally useless as is. The word 'crude' means unrefined or raw. **Oil refining** converts crude oil into useful products. The first oil refineries were built around 1853, and today the world's largest oil refineries are found in India, Venezuela, South Korea and the United Arab Emirates. They produce more than 6 million barrels of oil every day.

What do fractions have to do with it?

Crude oil deposits consist of random amounts and types of hydrocarbons, and, therefore, it is not profitable to try to separate every single hydrocarbon. Instead crude oil is separated into what are called **fractions**. A fraction is a group of hydrocarbons of similar size and whose boiling points and properties are close enough to be used together for specific purposes.



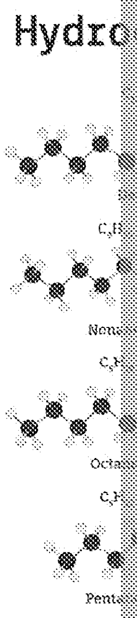
Fractional distillation is used to separate the fractions of crude oil based on their different boiling points. This is done in a fractionating column. Crude oil is pumped in and heated to over 300 °C at the bottom of the tower. The different fractions boil and as they rise up the column they experience cooler temperatures as they get further from the heat source.

The fractions rise until each reaches a temperature lower than its boiling point, and at this point the fraction condenses and can be collected for use. This process allows fractions to separate from one another.

The most widely used fraction in the world is petrol – it contains hydrocarbons having 5 to 10 carbons and it condenses and is collected near to the top of the fractionating column at around 60–89 °C.

Other fractions, such as diesel and kerosene, condense at different levels as their hydrocarbon molecules have different sizes and boiling points from petrol.

Counting your carbs



The quantity of petrol obtained from the fractional distillation of crude oil is far less than the global demand, and as a result an important process in oil refining is to split larger hydrocarbon molecules into smaller molecules that can be used as petrol – this is known as **cracking**. Cracking splits larger hydrocarbon molecules into smaller hydrocarbon molecules which are in higher demand and that can be used as petrol. The process also produces a type of hydrocarbon called alkenes, which are used to manufacture polymers such as plastics.

$$C_{14}H_{30} \rightarrow C_8H_{18} + C_6H_{12}$$

tetradecane octane hexene

Sweetening the deal

Crude oil also contains sulfur as an impurity, usually less than 0.5 %, but this varies depending on where the crude oil is found. Crude oil with sulfur content less than 0.5 % is known as sweet oil and over 0.5 % is known as sour oil. Petrol and all the other fractions obtained from crude oil therefore also contain sulfur. The combustion of hydrocarbons with sulfur is the main contributor to the formation of **acid rain**, which is a huge atmospheric pollutant. T removed by mixing the petrol with hydrogen in the presence of a catalyst, where t sulfur, forming hydrogen sulfide. This process is known as desulfurisation or hydro

At what cost do we continue to use petrol?

It is very rare that all the sulfur is removed, and, therefore, petrol will almost certai of this impurity. The combustion of petrol also releases significant quantities of ca greenhouse gas. About 2.353 kilograms of carbon dioxide (CO_2) are released per l about 1.525 kilograms of CO_2 per litre when a biofuel such as ethanol is burned.

Petrol, however, continues to be in high demand. It is a very energy-dense fuel, w fuels such as ethanol. Petrol fuel releases 34.8 MJ/l of energy, compared to bioeth Petrol continues to be the most economical fuel and still the fuel of choice around to consider the cost to our environment.

Comprehension questions

1. State the names of the two types of hydrocarbons commonly mentione
2. Explain why crude oil is considered valuable but not very useful before i
3. State the names of the three main processes involved in the refining of
4. The UK uses approximately 1.6 million barrels of oil daily. Given that one b litres, determine the mass of carbon dioxide released daily from the combu

Discussion questions

1. Describe how sour crude oil is converted to sweet crude oil and explain
2. Compare the use of biofuels such as ethanol with that of fossil fuels suc

Extension

1. Explain why cracking is an important step in the refining of crude oil. W how the hydrocarbon undecane, $C_{11}H_{24}$, is cracked to produce octane a
2. Explain how fractional distillation works and explain why kerosene, diese collected at different levels up the fractionating column. (3 marks)

Independent task

How has fossil fuel usage changed over the last 30 years in the UK? Resea
on a PowerPoint slide or poster.

Further reading

Scientists have projected that crude oil resources will run out in the next 50
article, 'Imagining a world without crude oil'.

Suggested sources
https://www.washingtonpost.com/opinions/imagining-a-world-without-oil/2011/04

The issue with acid rain is...

Keywords

Catalyse – Use a substance which does not change during a reaction and can b
chemical reaction

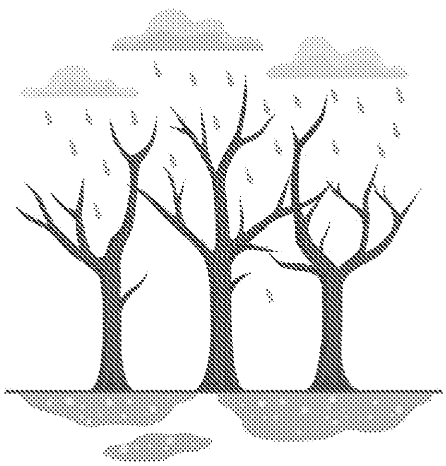
Combustion – Burning substance in oxygen to release heat

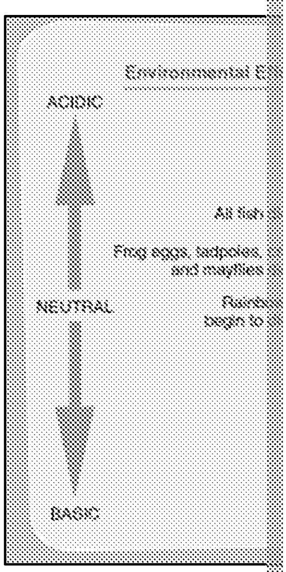
Crude oil – A liquid fossil fuel made up of a mixture of hydrocarbons

Fossil fuel – A set of hydrocarbon fuels formed by compression of the plant m

pH – A value used to express how acidic or alkaline a solution is; it ranges from

Waxy cuticle – A protective layer found on the surface of leaves





It stripped the leaves off trees and destroyed forests in Europe, it killed all life in s crops and affected food supply in parts of China, it has damaged important monu

Dead lakes

In the 1970s at a lake in Killarney Provincial Park in Canada it was noticed that obj seen falling clearly all the way down to the bottom of the lake. The waters of the l calm. This was an example of a 'dead lake', and investigations later showed that a The Killarney Park Lake is just one example of a dead lake. It strangely had a very than 100 times what it should normally be, 6.5.

Double trouble

Since the Industrial Revolution, coal, natural gas and **crude oil** have been used to these **fossil fuels** all contain sulfur. Crude oil generally has sulfur content below 0 3 %. It is very expensive to remove sulfur from fuels and generally they are burnt

During the combustion of fossil fuels, the sulfur impurities react to produce sulfur into the air where it reacts with more oxygen to form sulfur trioxide, SO_3. Sulfur tr atmospheric water to form sulfuric acid. To make matters worse, the high temper **combustion** of fossil are enough to break the very strong nitrogen–nitrogen triple inert nitrogen gas, found in air, to react with oxygen to form nitrogen oxides such Nitrogen dioxide, for example, dissolves in water to produce nitric acid, HNO_3. Ni much more dangerous role. They catalyse the formation of sulfur trioxide and thi of the more damaging sulfuric acid.

The presence of both sulfur and nitrogen oxides in the atmosphere has resulted in t amounts of acidic rain, fog and snow, which also acidifies waterbodies such as lakes a bit misleading as in fact the problem is an acidification of all forms of atmospheric

Side effects

The main industries contributing to the formation of acid rain are: electricity generation, animal agriculture, factories, and motor vehicles.

Acid rain produces no known direct health impact, and, therefore, the average person is unaware of its effects.

Highly acidic rain reacts with limestone and marble structures, as the sulfuric acid reacts with calcium carbonate, discolouring and corroding the structures.

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

Metal structures such as bridges are also corroded due to chemical reactions with the acids. Acidic rain has a huge impact on the pH of soil – plants grow best in slightly acidic soils and a decrease in soil pH significantly affects the health of plants. At low pH values, necessary mineral ions magnesium are pushed out of the soil beyond the root zones and reach of plants. acidity can be identified by a yellowing of their veins and stunted growth. The aci the protective **waxy cuticle** of plants, leading to excessive water loss and death o considerably impacts on farming and our food supply.

Acidified waterbodies lead to the death of organisms, which disrupts the food cha fishes and other large aquatic organisms. This has led to some of the 'dead lakes'

How the battle was won...

Acid rain was such a huge problem in the 1970s that the USA started accusing Ca their border to acidify lakes in the USA, and this led to tension between the two c great distances through the atmosphere, not only from city to city but also across thought to have contributed 16 % of acid deposits in Norway and is blamed for th lakes. The polluting effects of acid rain are, therefore, a global problem, not a loc

The obvious solution to reduce acid rain has been to reduce the use and combust done through various regulations, policies and international agreements being en use of fossil fuels.

Factories which burn fossil fuels to generate energy for their operations are also l of the acidic gases before their waste gases are released into the atmosphere. Th gases through chemicals, such as powdered calcium carbonate, which will react w nitrogen oxides.

In some cases powdered bases such as calcium oxide have been spread from aer neutralise excess acidity and to protect wildlife.

The fight against acid rain has been fairly successful over the last 40 years and the in the release of sulfur dioxide globally. However, we have been less successful in nitrogen oxides. This is due to the fact that the formation of nitrogen oxides is al fertilisers, and this problem now requires a completely different approach.

We may have won one battle but we are still fighting the war against acid rain.

How can you help?

Comprehension questions

1. State which two gases are important for the formation of acid rain. (1 ma
2. Describe three of the effects of acid rain. (3 marks)
3. Write an equation for the production of sulfuric acid from sulfur trioxide ((2 marks)

Discussion questions

1. Explain why it is important for countries to work together to solve the p
2. Acid rain has no impact on our health. Explain how we are affected indi

Extension

1. Explain why nitrogen gas is not normally reactive but is able to react du fossil fuels. (2 marks)
2. Starting with sulfur, write three symbol equations showing step by step h sulfur. (4 marks)
3. Compare the roles of sulfur dioxide and nitrogen dioxide in the formatio

Independent task

Which countries are the largest contributors to the release of gases linked wi top five polluters in the world, and give data to support your findings.

Further reading

Are we winning the battle with acid rain?

Suggested sources
https://deepoceanfacts.com/effects-of-acid-rain-on-ocean
https://blog.arcadia.com/15-key-facts-and-statistics-about-acid-rain

Water treatment around the wo

Keywords

Adsorb – Attach to the surface of a material

Chlorination – The addition of chlorine compounds to drinking water to kill pa

Desalination – The process of removing salt or minerals from salty (saline) wat

Filtration – The removal of solid particles from a liquid mixture using a filter

Potable – Suitable for drinking

20th April 2018 was known as Zero Day in South Africa. It was the day when the over 59 million population was expected to run out of water. This prediction followed three years of below average rainfall and extended drought. The remaining water supply was shut down and all citizens were required to collect water daily from water centres. Luckily, with changes in habit and consistent water management the disaster was avoided – for now.

As far back as civilisations existed we have always depended on access to water. The earliest populations across the world used various methods, including: digging water channels in the ground, using hollow tree trucks, bamboo and many others, to transport water from various sources (springs, lakes, rainwater) to their communities. In fact, communities were built at and relocated to locations where there was suitable access to water.

The Romans built dams in rivers, causing lakes to form, and huge aqueducts that transported water for miles – these structures can still be seen today.

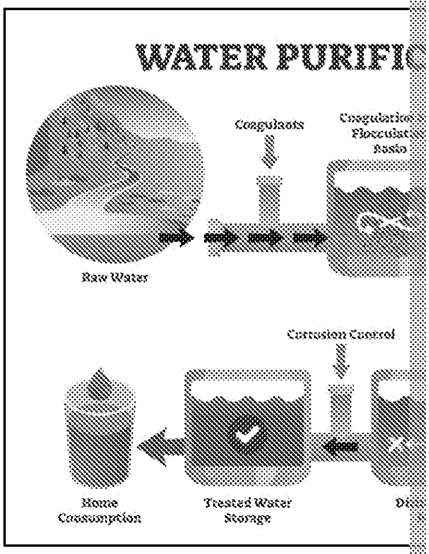
Despite the building of water systems, highly unhygienic conditions existed, and this resulted in the large-scale spread of diseases such as cholera and typhoid in various populations throughout history.

Quality not quantity

Potable water should be free from pathogens, organic waste, chemicals such as metal ions, acids, alkalis, pesticides and fertilisers, and also free from radioactiv

Surface water is usually found as oceans, lakes, ponds, streams and rivers. Water waterbodies called aquifers. Water covers some 70 % of Earth's surface; of this an and only 2.8 % fresh. Not all of this fresh water is easily accessible or immediately This means as little as 1 % of water on Earth's surface is fit for drinking or domesti generally referred to as raw water.

As far back as the early 1800s, **filtration** of water through sand and charcoal was being used as a form of water treatment. The fine loose sand particles have the ability to stop large solid materials from passing through, while charcoal is able to **adsorb** very fine suspended particles and remove them from water flowing over or through it.



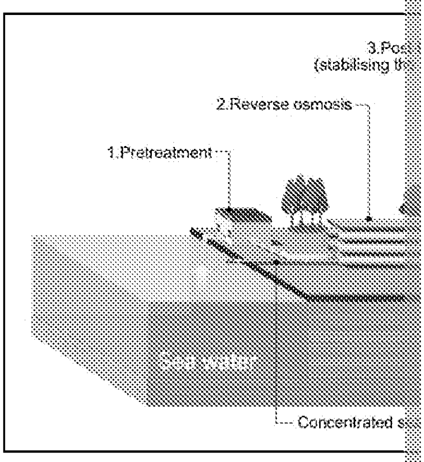
Charcoal filters are still used today – they are commonly found in fish tanks. However, more advanced filtration systems now exist, and these are much more effective.

Filtration, however, did not halt the transmission of diseases, as pathogens easily p microscopic size. It was not until the 1900s that water disinfection was used as an of water for drinking. Chlorine was used as the disinfectant and this was hailed as is highly effective at killing microorganisms (and, therefore, pathogens).

It was, however, quickly discovered that the incidence of respiratory illness increas water treatment. There was much concern over the dangers of chlorine as it beca was. The use of chlorine, however, continued, but instead of the element being us chlorine, such as sodium hypochlorite, are now being used, but even now there ar compounds have a long-term effect on our health.

Stick with me

Chemical treatment was later expanded to include the addition of chemicals to ca as alum (hydrated aluminium sulfate) were added to water to allow very fine parti to stick together and form larger particles which can be trapped by filters or settle tanks – this is known as coagulation. Once these large particles form, the water is particles to sink and settle to the bottom – this is known as sedimentation.



In the UK, most of our domestic water comes from the treatment of underground and surface water resources. To increase water supply, rainwater is also diverted into rivers and lakes to be collected, stored, screened and then chemically treated. In London, the River Thames is a major water source, providing more than 65 % of London's drinking water, with the rain coming from surface and underground reservoirs.

Saudi Arabia has one of the largest daily rates of water consumption and is also the largest country in the world without running surface water. The country gets over 60 % of its water from the **desalination** of ocean wate separation of water from minerals and salts. This is an energy-intensive process inv lot of heat. The energy consumption of desalination makes desalinated water more from surface or underground sources. However, these resources are not always ava

Water treatment varies from country to country and place to place depending on being treated, but generally the processes mentioned here are used at almost eve

The question is, with growing populations how can we conserve and make best us resources, H_2O?

Comprehension questions

1. Raw water can be obtained from rivers and lakes. State two other sources the world. (2 marks)
2. Describe the role of filtration in water treatment. (2 marks)
3. Explain why natural water sources need to be treated before drinking. (2

Discussion questions

1. Describe the relative advantages and disadvantages of using chlorine in w
2. Describe the role of chemicals in water treatment. (4 marks)

Extension

1. Compare drinking water treatment in London and Saudi Arabia. (6 marks
2. Explain why desalination is the main form of water treatment in Saudi Ara

Independent task

Countries with heavily populated cities, such as South Africa and the UK, are at drinking water. Suggest some steps that can be taken to prevent this.

Further reading

Improper agricultural practices and livestock farming are blamed among other contributors to our worsening water crisis. Using the example of South Africa, water in 2018, discuss to what extent this statement is true and how South Afri

Suggested sources
https://www.worldvision.org/clean-water-news-stories/global-water-crisis-facts
https://www.who.int/news-room/fact-sheets/detail/arsenic

Are we are running out of copp

Keywords

Acid rain – Polluting rain caused by the increased acidification of natural rain b
Concentrate – A mixture produced with high concentration of a substance
Ductility – The ability of a material to be stretched and drawn into wires witho
Electrorefining – A process using electricity to purify a substance by electrolys
Malleability – The ability of a material to be moulded, hammered or bent into d
Ore – A rock containing enough quantities of a metal for it to be economical t
Oxidation – A chemical reaction where oxygen is added to or hydrogen remo

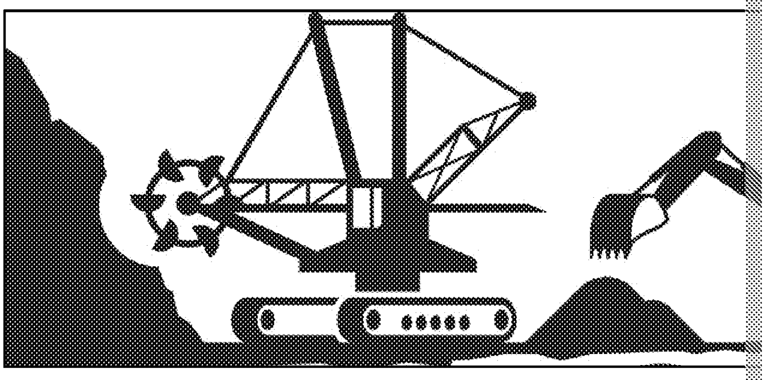
The world-famous Statue of Liberty, found in New York, is made of copper sheets around 2.4 mm thick hammered together. Copper is a reddish-orange solid yet the Statue of Liberty is a light green colour due to the oxidation of the metal to green copper oxide, which over the years has formed a protective layer preventing further **oxidation** of the metal.

As far back as 8000 BC copper was being extracted by humans – the metal was used to make coins, jewellery, statues, various tools, musical instruments and so much more. Thousands of years later copper was melted and mixed with other metals such as zinc to produce the alloy bronze.

Most of the world's copper is used in building construction, telecommunications, heating and cooling systems, consumer electronics and auto car contains about 40 pounds of copper; however, modern electric and hybrid veh 100 pounds of the metal due to their larger number of electrical components. Co usage is due to its high **malleability**, **ductility**, corrosion resistance, and electrical

Copper extraction

Copper is one of the few metals which can be found in Earth's crust in its native fo very small quantities in rock and soil. The proportion of copper in Earth's crust is 50 ppm (parts per million). Copper is more likely to be found in and extracted fro chalcopyrite ($CuFeS_2$), chalcocite (Cu_2S), covellite (CuS), and bornite (Cu_5FeS_4).



Rocks of these ores usually contain less than 1 % copper, and, therefore, the first s concentrate the ore to 10–15 %, which makes extraction more economically viable this step is sometimes sold by mining companies to copper-refining companies.

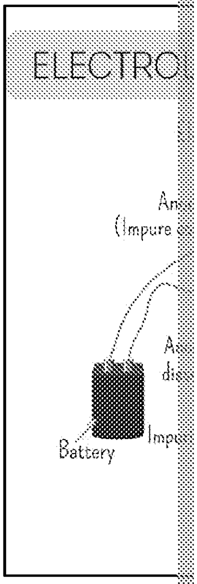
The next step is usually to remove quantities of iron, which is very often found in c copper sulfide, which is then roasted to produce copper oxide. Sulfur dioxide is a

$$2\ Cu_2S + 3\ O_2 \rightarrow 2\ Cu_2O + 2\ SO_2$$

Sulfur dioxide is known to contribute to **acid rain**; however, it can be captured du produce sulfuric acid.

Further heating of copper oxide produces copper and oxygen

$$2\ Cu_2O \rightarrow 4\ Cu + O_2$$



Copper produced at this stage is still impure, usually containing small quantities of other metals such as iron, zinc, silver and gold. The impure copper is purified by **electrorefining**. During this process, impure copper is made the anode of an electrolytic cell and previously purified copper the cathode. During the process, copper ions leave the impure anode, enter the electrolyte and then deposit on the pure copper cathode.

$$Cu \rightarrow Cu^{2+} + 2\ e^-$$

At the end of the process, the anode decomposes into a sludge of impurities and all the copper deposits on the cathode as pure copper.

$$Cu^{2+} + 2\ e^- \rightarrow Cu$$

The cathode is then removed as pure copper, which is transported to be processed for various uses.

EIA

Chile, Peru, China and Zambia are some of the world's largest copper producers, a some of the world's largest copper mines. In these countries we find many high-v High value means it is profitable to extract and purify the metal from an ore. The of resources; these include expensive equipment, chemicals, fuel and electricity. V feasibility study is always done before any extraction begins. This includes an env as copper extraction is highly disruptive to the environment. In many cases it is si beneficial to extract copper from a discovered deposit.

What are the options?

Known copper reserves are being depleted at an increasingly high rate as global d annually. Copper supply is estimated to increase by 1–2 % annually, and this mea annually than ever before and reserves are being used up.

One obvious solution is to recycle copper. Copper is similar to aluminium in the f infinitely without any change in its properties. The recycling of copper is, howeve if the metal was previously mixed with other substances or contaminates. Recycli involves electrorefining, which is an expensive and energy-intensive process which but generates significant greenhouse gases. Around half of Europe's copper is ob

Bioleaching is an option to traditional copper extraction methods – this involves u copper and sulfur in the ores. The advantages are that copper can be extracted fr is released, both mining and mining costs are significantly reduced and it is overa companies. This process is, however, highly inefficient and takes several months, produced from the electrorefining of concentrates.

In 2020 worldwide copper reserves were estimated to be 870 million metric tonne was an estimated 22.4 metric tonnes, compared to 17.8 metric tonnes in 1999. Ho reserves last with global demand for copper increasing year after year? You do th

Comprehension questions

1. Explain how the Statue of Liberty has been able to resist corrosion. (2 ma
2. State two ways that copper reserves can be conserved. (2 marks)
3. Explain what high-grade ores are. (1 mark)

Discussion questions

1. Describe three benefits of using bioleaching to extract copper sulfide. (3 m
2. Explain how the extraction of copper contributes to the formation of acid r

Extension

1. Explain how impure copper is produced from copper sulfide – use an equ
2. Describe how copper is purified by electrorefining. (3 marks)
3. Using data in the article, estimate the year we will use up all copper reserv (Assume the demand for copper stays the same as 2020 and no new copp

Independent task

What are some good alternatives to the use of copper? Name three materials t copper in the future. Give reasons why you think each material is a good optio

Further reading

Is this the end of copper?

Suggested sources
https://www.webro.com/alternatives-to-copper-cable/
https://www.reuters.com/article/us-copper-substitution-idUSTRE6BM1M020101223

The life of a drink can

Keywords

Bauxite – A red rock/ore containing significant quantities of aluminium, makin

Electrolysis – A chemical reaction produced by passing significant amounts of aqueous substance

Gibbsite – A rock/ore containing significant quantities of aluminium, making it

Ore – A rock containing sufficient quantities of a metal that it can be extracted

Smelting – The process of using heat to melt an ore to extract a metal

Over 135 815 198 685 aluminium cans consumed so far this yea

At some point you may have had a drink from a can. Each household in the UK uses around 340 aluminium drink cans per year. More than 180 billion beverage cans are manufactured globally per year. When this article was being written in September 2021 over 135 billion cans had already been consumed.

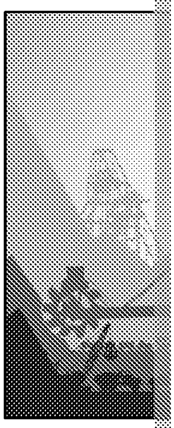
Have you ever wondered what resources are used to make a beverage can, the resources used to get it on a supermarket shelf and the resources it requires after it leaves your hand?

Aluminium – the metal of choice

Any modern can of drink or juice is most likely to have been made from the metal the case – the earliest beverage cans were made in the 1930s from metals such as preferred metal at the time. One of the major issues at the time was that the acid resulted in some oxidation of the tin or iron. This of course changed the flavour o health issue. The reaction between acid and metal meant that after a month or so and this reduced the product's shelf life. It was not until the 1960s that aluminium the manufacturing of beverage cans due to its low reactivity and non-toxicity. Ov produced in the USA and Europe are now made from aluminium.

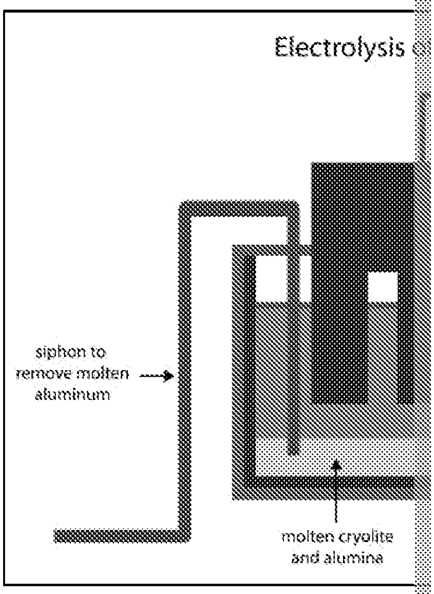
Aluminium is the most abundant metal in Earth's crust, but it is almost never foun **ores** such as **gibbsite** and bauxite. Bauxite looks nothing like shiny metallic alum rock or clay. The life of a modern drink can begins with the extraction of aluminiu as deposits in Earth's crust.

Mining



The first stage in the manufacturing of the drink can is to clear many hectares of land, removing all of the topsoil and digging out huge quantities of bauxite ore. This is a highly disruptive process and produces massive amounts of dust and waste, displacement of wildlife and destruction of habitats. The energy costs are huge as large quantities of hydrocarbons, usually diesel or fuel oil, are burnt to fuel the large vehicles and machinery used in the mining and transportation of bauxite.

Electrolysis



Mined bauxite is usually then transported to a **smelting** plant where it is reacted with caustic sodium hydroxide to produce aluminium oxide, which is then melted with cryolite mineral at around 1000 °C. The resulting molten mixture then undergoes **electrolysis** in an iron or steel tank lined with graphite to produce pure molten aluminium, which is formed into huge blocks called Ingots.

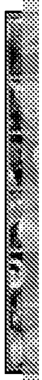
This process is very energy-intensive and usually huge amounts of coal are burnt as fuel to supply the energy needs of the smelting plant. This includes generating massive amounts of electricity.

Each year more than 66 billion tonnes of resources are extracted from Earth's crus
One tonne of aluminium is produced from four tonnes of bauxite; the remaining w
held in huge mud ponds to be treated before it is let out into the environment. T
concentration of heavy metals ions such as arsenic and is also highly alkaline. The
mud lakes affecting nearby water resources as these substances seep through the

The can

Not all of a beverage can is made from pure aluminium – metals such as magnesi
places such as the lid of the can to increase the strength. The materials undergo c
and printing to produce a finished can. In some cases, the cans are then packaged
company, where they are filled and sealed before being transported to their point

After use



The impact of an aluminium can does not stop after you use it. Resources are used to firstly collect and transport the cans to municipal waste. In countries where aluminium is recycled the cans are then usually cut into small pieces. Many countries, such as the USA, Germany and the UK, export this valuable aluminium scrap. Seventy-five per cent of aluminium cans in the UK are recycled; the scrap is cleaned and melted to 650–850 °C to produce aluminium. Recycling uses only 5 % of the energy needed to produce a new can. One of the amazing properties of aluminium is that recycling has no impact on its properties, and this means aluminium can be recycled infinitely.

Interesting data

Over 80 billion tonnes of resources are extracted from Earth each year to produce
much as 2 % of the world's energy, which might seem small but this means we are
resources just to make beverage cans. Recycling reduces energy consumption, gr
need for the mining of bauxite.

Or we could just stop drinking from cans?

Comprehension questions

1. State two properties of aluminium which make it suitable to make drinkin
2. Explain why iron and tin are no longer the main metals used to make beve

Discussion questions

1. Explain how the manufacturing of drink cans contributes to the release o
2. Describe three processes involved in the manufacturing of drink cans fro

Extension

1. Explain why we should recycle aluminium instead of extracting it. (6 mar
2. Explain why metals are used in the manufacturing of aluminium cans. (2

Independent task

Create a poster to educate people on how important it is to recycle and to red

Further reading

Is the impact of using aluminium cans all that great?

Suggested sources
https://www.theworldcounts.com/challenges/consumption/foods-and-beverages/a

Alchemy and alloys

Keywords

Alloy – A mixture of metals with smaller quantities of non-metals

Biocompatibility – A material's compatibility with living tissue

Lattice – A three-dimensional structure made of particles connected in a fixed

Machinability – The ability of a metal to be cut and used for various purposes

Nanotechnology – Technology on a very small scale

Oxidation – A chemical reaction where oxygen adds to a substance

Shape memory alloy – An alloy which changes its shape when heated or cool original shape once it returns to original temperature

'You are an alchemist, make gold of that.'
– William Shakespeare

The first **alloy** to be used on a wide scale was bronze. Its discovery led to what is (3300 BC to 1200 BC). During this period, copper was melted and mixed with vario arsenic. Bronze alloys were used to make tools, armour, weapons, sculptures, mus The metals used were extracted and then mixed together at high temperatures. N experimenting with the addition of other materials. Interestingly, as the science o was linked to magic, witchcraft and sorcery.

3D magic

Alloying in 2021 is just as magical as it appeared in the Bronze Age, but the techn able to print metallic objects and alloys to our exact specifications. This process, c lasers to scan, melt and fuse together metal powder particles to print alloyed obje This process is done in a build chamber filled with a noble gas such as argon to pr the metals. 3D printing is precise enough to build the components of small medi

Superalloys

Metals have always played an important role in construction and the manufacturi devices. Metals are usually strong, hard, malleable and ductile, and are good ther high melting points. Strictly speaking, this is not true of all metals; group 1 and g are soft, weak materials with relatively low melting points. Despite the fact that m properties, many metals are reactive and will corrode due to their reaction with ox environment, and this greatly limits their uses.

Superalloys are alloys made to withstand very high temperatures and forces, while re These alloys have enhanced properties which make them highly suitable for various is their ability to be made into a variety of shapes without losing their strength and d uses, including the manufacturing of medical implants, prosthetics, turbines, engines

The shape shifter

Nitinol contains 50 % nickel and 50 % titanium, and is a good example of a supera Most alloys of nickel are unique in their ability to change shape based on the tem They are referred to as **shape memory alloys**, and will assume a specific shape at particular temperature. These alloys assume specific shapes at specific temperatu therefore, do not randomly deform when heated or cooled to extreme temperatu This property makes the alloys very useful for making components of devices that withstand temperature changes with distorting irregularly. Nitinol is used to man engine parts for rockets and aircrafts, and also turbines for generators and power strong but also super elastic. This results in its many medical uses, including: den artery stents and joining bone fractures and even intestinal tissue.

Titanium alchemy

Titanium is a non-toxic, low weight, strong, shiny metal with a high melting point and low thermal and electrical conductivity. Titanium is more than twice as strong as aluminium but only 60 % heavier. Pure titanium reacts quickly with oxygen and quickly forms a thin 1–4 nm layer of titanium oxide, TiO_2, which coats the metal and protects it from further oxidation. This makes titanium very resistant to corrosion, and alloys of titanium are known for their high durability. During the production of titanium alloys the reaction with oxygen is prevented by mixing the materials in a vacuum.

Alloys of titanium have great **machinability** and a wide variety of uses. The significant improvement in 3D printing technology and the metal's **biocompatibility** have increased the suitability of these alloys for manufacturing small medical transplant devices and prosthetics. These alloys are also used to ma repair, bone sockets, dental implants, pacemakers and much more.

Nanotech

The increased amount of research and development spent on superalloys is largely industry. Materials used in this industry must be able to withstand very high pressu without deteriorating. The truth is even superalloys have weaknesses – defects that during the manufacturing reduce their ability to withstand thermal and **tensile** stres These defects can be seen using electron microscopes and **nanotechnology** makes individual atoms to create an almost perfect atomic **lattice**, although this is currentl

Nanotechnology is improving rapidly – maybe in the next decade we can expect t

Comprehension questions

1. Describe how bronze was produced around 1100 BC. (2 marks)
2. Write the balanced equation for the production of titanium oxide from tit
3. Nitinol is used to manufacture the parts for jet engines and turbines. Stat make it suitable for these uses. (2 marks)

Discussion questions

1. Explain how nanotechnology will further improve the development of allo
2. Describe and explain the medical uses of alloys of titanium. (2 marks)
3. Compare the properties of metals and alloys, referring to examples given

Extension

1. Titanium is a highly reactive metal but also corrosion-resistant. Explain w
2. Describe two technologies which have helped with the development and
3. Explain why the machinability and malleability of alloys is important. (2 m

Independent task

Create a poster to highlight how alloys of nickel and titanium are being used i

Further reading

Alloys and the future

Suggested sources

https://www.fanaticalfuturist.com/2021/10/ai-is-designing-new-alloys-to-order-at-
https://www.sciencedirect.com/topics/chemistry/superalloys

When life gives you nitrogen and hydrogen,

Keywords

Ammonia – A covalent compound, NH3, produced by the Haber process and u ammonium sulfate. It is also known for its alkaline properties.

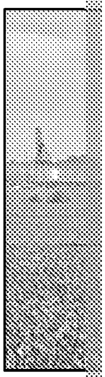
Closed system – A chemical system where substance (reactant or product) is a

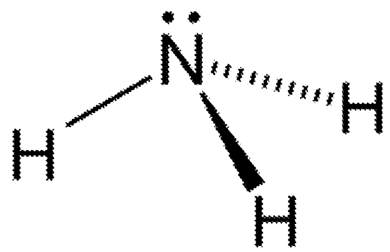
Dynamic equilibrium – A chemical system where the rates of forward and bac resulting in no net change in the quantities of reactants or products

Haber process – An industrial process used to produce ammonia from hydrog presence of iron catalyst

Le Chatelier's principle – A principle used to explain and predict how chemica changes in different conditions such as temperature, pressure and concentratio

In the nineteenth century, as populations grew there was an increasingly heavy demand for food, and large-scale farming started to grow rapidly. At the time farmers knew fertilisers could be manufactured using a compound called **ammonia**, NH_3; however, they did not know how to manufacture ammonia efficiently and on a large scale.





In 1901 French scientist Henry Le Chatelier came very close; however, one day air in a huge explosion in his laboratory which almost killed one of his technicians.

It was not until 1909 that German scientist Fritz Haber successfully converted gase liquid ammonia. This process is considered one of the most important discoveries

At the time Haber was, however, unable to produce ammonia in the large quantiti purchased from him by a German company, BASF, where Carl Bosch worked on it.

If at first you don't succeed, try and try again...

Bosch tried hundreds of different conditions, changing the temperature and press different catalysts, but he struggled. For years he was not able to produce ammo He assumed at higher temperatures he would get more ammonia, but instead he quantities of ammonia were produced when he increased temperatures. Bosch ev conditions were: 400–500 °C, 200 atm and using iron as a catalyst, but even under able to convert 20 % of the nitrogen and hydrogen to ammonia. In 1913, the first finally opened by BASF in Germany using these conditions; the process was called

The balancing act

We now understand that the problems Bosch faced trying to increase the yield of formation of a **dynamic equilibrium**. During the production of ammonia, nitroge pumped into a sealed container and the molecules bond, forming ammonia mole

As the ammonia molecules build up in the container with nowhere to go, they star and nitrogen molecules. The result is that there is both a forward and reverse/bac same time, and at some point the rate at which ammonia is being formed and the become equal, and, therefore, the quantity of ammonia (yield) remains constant. T chemical equilibrium. A dynamic equilibrium is reached when there is a balance be reaction. This only happens in a **closed system** and when conditions of temperatu

Le Chatelier later came up with an explanation of how chemical systems in equilib
these conditions. **Le Chatelier's principle** states that when a system in equilibriu
condition then the equilibrium mixture will shift to counteract the change. In its s
a chemical reaction is at equilibrium and you increase the temperature, for examp
decrease the temperature to restore the balance. The opposite happens if the ter

Our understanding of Le Chatelier's principle helps chemical engineers to decide t
for chemical reactions in various industries.

An efficient industrial reaction is one which produces a satisfactory yield of produ
cheaply as possible. This means the conditions used are actually a compromise b
and the cost. High temperatures may favour a faster reaction but mean additiona
a lower yield, and this is true in the case of the Haber process. Moderate tempera
well as a catalyst to ensure the process is as cheap and fast as possible but there i

It is not all good though…

Today over 150 million tonnes of ammonia are produced every year; it is one of the most highly produced chemicals in the world. The production process uses a lot of energy, which is mainly obtained from the burning of natural gas. The hydrogen used in the process is obtained from the cracking of natural gas and nitrogen obtained from the fractional distillation of air.

The contribution of the Haber process to our global food security is very important, and without it farmers might not be able to feed even as much as a half of the world's 7 billion population. However, the reliance of the process on fossil fuels and the overuse of fertilisers are huge global issues impacting negatively on communities and our environment.

The overuse of fertilisers is wide-scale across the globe, and this has led to great l
contamination of water resources.

Maybe we should find a new Haber process?

Comprehension questions

1. The production of ammonia is sometimes called the Haber–Bosch proces
   scientists contributed to the process. (2 marks)
2. Explain how a dynamic equilibrium is reached during the Haber process.
3. Write a word equation and then a balanced symbol equation for the Habe
4. Write a word equation and then a balanced symbol equation for the back
   Haber process. (2 marks)

Discussion questions

1. Describe the conditions used to produce ammonia and explain why they a
   of ammonia is only about 20 %. (2 marks)
2. The Haber process is described as one of the most important discoveries
   Discuss the advantages and disadvantages of the process. (4 marks)

Extension

1. Explain why Le Chatelier's principle is important in chemical industries. (2 m
2. Ammonia is used to produce the fertiliser ammonium sulfate by reacting it
   The sulfuric acid is produced by the reaction of sulfur trioxide with water.
   Write balanced symbol equations for these reactions. (4 marks)

Independent task

Ammonia is used to produce ammonium-based fertilisers such as ammonium s
these fertilisers? Can we reduce our dependence on the Haber process in the
three types of fertilisers that could be used on a wide scale instead of those p

Further reading

Are there alternatives to the Haber process?

Suggested sources
https://catalyst-magazine.org/articles/de-carbonising-ammonia-alternatives-to-th
https://cen.acs.org/environment/green-chemistry/Tackling-sustainable-fertilizer-p
alternative/96/web/2018/05

Answers

The importance of catalytic converters

Comprehension questions

1. Smog is a combination of smoke and fog. It is more likely to be formed in densely p hydrocarbons are being burned (1) as fuels in vehicles or factories. It is also more li formed on a regular basis (1).
2. Octane + oxygen → carbon dioxide + water (1)
3. Carbon monoxide (1) is able to displace oxygen from haemoglobin in our red blood c oxygen being transported to important organs such as the brain and heart and can unconsciousness (1), organ failure (1) and death (1).
4. They are made with very precious and expensive metals (1) such as platinum or rho good price.

Discussion questions

1. **Any two from:**
   The honeycomb structure provides a very high surface area (1) for the pollutant gas (1) before being released into the environment. The structure is also made from a
2. **Any six points from below (three advantages and three disadvantages):**
   Advantages
   Catalytic converters are an important way to decrease the pollution caused by the c vehicles. They convert pollutant gases such as carbon monoxide, nitrogen oxides a harmful gases (1). They are very important in reducing atmospheric pollution.

   Disadvantages
   The use of converters increases the demand for rare metals (1) and this results in m (1) and these processes damage habitats and landscapes, and release pollutant gas
   The metals used in the converters result in them being a target for thieves. (1)
   Catalytic converters have to be changed after years of use and the disposal increase
   The converters do not reduce the amount of carbon dioxide or sulfur dioxide being pollutant gases (1).

Extension

1. Carbon monoxide + oxygen → carbon dioxide (1)
   Nitrogen monoxide → nitrogen + oxygen (1)
2. $2CO + O_2 \rightarrow 2CO_2$ (1)
   $2NO \rightarrow N_2 + O_2$ (1)
   $C_8H_{18} + 12.5\ O_2 \rightarrow 8CO_2 + 9H_2O$ **or** $2C_8H_{18} + 25\ O_2 \rightarrow 16CO_2 + 18H_2O$ (1) (balanced 1)
3. **Any two from:**
   The catalytic converter does not reduce the quantity of carbon dioxide released int remaining hydrocarbons and oxidises carbon monoxide to carbon dioxide. It theref of carbon dioxide to be released (1) from the combustion of the fossil fuels burnt in
   Carbon dioxide is a greenhouse gas and its release from the combustion of fossil fu greenhouse effect which is linked to global warming and climate change (1).

Element number 6

Comprehension questions

1. Diamond – jewellery, cutting instruments, drill bits (1)
   Graphite – lubricant, electrical conductors (1)
   Graphene – aircraft and rocket parts, engines (1)

2. 2-methyl propene (1)

3. Molecular formula – $C_8H_{12}N_3O$ (1)

Discussion questions

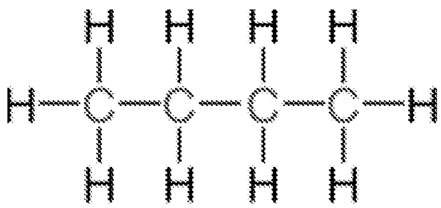
1. C–C bonds are stronger than P–P or S–S bonds (1). This means the bonds are more makes molecules with C–C bonds much less reactive.

2. **Any three from:**
   - Carbon atoms are able to form four bonds (tetravalent) (1)
   - Carbon molecules are able to exist as isomers (1)
   - Carbon is able to form stable single, double or triple bonds with other carbon
   - Carbon is able to form stable molecules with chains and rings (1)

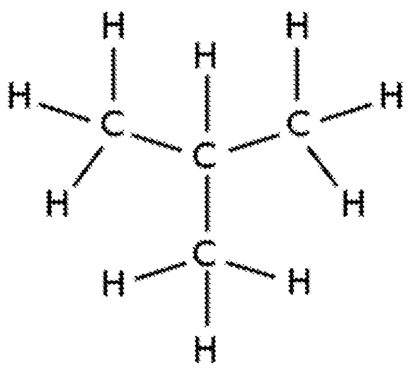
Extension

1. Isomerism is the existence of molecules with the same molecular formula but differ

   Butane (1)



   Isomers (iso-butane) (1)



Should ethanol still be classified as a green fuel?

Comprehension questions

1. Alcohols are a group of compounds/molecules having similar properties. Ethanol is alcoholic beverages and which is suitable for human consumption (1).

2. **Any one from:**
   All alcohols are toxic when ingested (1). Ethanol is the only alcohol which is mildly very small quantities (1). Consuming other alcohols such as methanol can lead to s vomiting and blindness. (1)

3. **Any two from:**
   Alcoholic beverages are produced by fermentation, which is catalysed by the enzym yeast (1). The enzyme becomes denatured once the ethanol concentration reaches to concentrate the ethanol to the higher percentages which are found in vodka, gin percentages much higher than 15 %.

4. The liquid is not ethanol as it does not burn with a clean blue flame (1). It is not an correct as the ending of the name ethanal is not correct for an alcohol (1).

Discussion questions

1. This is undecided to some extent. Arguments for and against can be justified and a
   Arguments for / pros/ advantages:
   - Ethanol produced from a renewable source: crops which can be grown over an
   - Ethanol production does not release other harmful gases such as sulfur dioxide

   Arguments against / cons / disadvantages:
   - Combustion of ethanol releases carbon dioxide, which is a major greenhouse g
   - The production of ethanol by fermentation also releases carbon dioxide. (1)
   - Transportation of raw materials, farming and other processes involved all contri
   - The growing of crops to produce ethanol reduces availability of agricultural lan contribute to higher food prices (1) if ethanol is produced on a very large scale.

2. **Any three from:**
   Fermentation uses a renewable source (1): crops / plant materials / such as corn (1 obtained from crude oil (1), which is non-renewable.
   Hydration produces pure / 100 % ethanol but fermentation produces only 15 % eth distilled and then filtered to get pure ethanol.

3. Ethanol is produced from the fermentation of plant materials from crops such as co grown in very large quantities in the USA and Brazil respectively. Many countries e or have strong agricultural industries. (1)

Extension

1. Atom economy = ((2 × 46) / 180) × 100 = 51 % for fermentation (1)
   Atom economy = 46 / (18 + 28) × 100 = 100 % for hydration (1)

2. Hydration has a 100 % atom economy, which is more viable. 100 % means all of the ra to the useful product / ethanol. There is <u>no other product or waste</u>, and this is perfect

The gift and the curse of plastics

Comprehension questions

1. **Any three from:**
   Plastics are usually: strong for their weight (1), good insulators of electricity (1), hea
   chemical resistant (1)

2. **Any two from:**
   The use of plastics increased as they are cheap to produce (1) and their physical pro
   Also you can make different types of plastics with different uses by changing the ra

3. **Any two from:**
   Plastics do not biodegrade easily. When left in the environment, the wind, rain and
   plastic to form microscopic pieces (1) which end up in our water supply (1) and are
   entering our food chain.

Discussion questions

1. **Any three from:**
   Households can:
   - Reuse (1) plastic containers, use for different purposes or reuse for same purp
   - Reduce the number of plastic bags, containers or items purchased (1 – specific
   - Find and use alternatives, paper, wood or ceramic materials (1 – specific exam
   - Check labels and buy biodegradable plastics (1)
   - Consistently make sure plastic waste is sorted for recycling (1)

2. **Any four from (must include at least one point for each):**
   Non-biodegradable
   - Made from alkenes obtained from crude oil (1)
   - Very cheap to produce compared to biodegradable plastics (1)
   - Do not break down in environment or take many years, adding to solid waste p
   - Have a wider range of useful properties than biodegradable plastics (1)

   Biodegradable
   - Made from natural occurring materials such as starches and organic acids (1)
   - Break down by decomposers and conditions in the environment (1)
   - Some of the raw materials come from plants which would have been used for c
   - Supply also uses valuable farmland (1)

Extension

1. The polymer is produced from the addition polymerisation (1) of ethene (1)
2. During the formation of polyethene from ethene one of the C=C bonds breaks (1) and
3. PVC is useful to make water pipes as it is insoluble (1) and unreactive within water (

What is in your tap water?

Comprehension questions

1. **Any two from:**
   Water suitable for drinking is: colourless/transparent (1), free from odour (1) and c
   chemicals or suspended particles (1)

2. Qualitative tests work based on precipitation reactions (1), where two dissolved ion
   salt (1), e.g. $Al^{3+}_{(aq)} + OH^{-}_{(aq)} \rightarrow Al(OH)_{3\,(s)}$ (1)

Discussion questions

1. Lead is linked to diseases of the central nervous system, including the brain (1)
   Lead pipes were argued to be safe as:
   - Only small quantities of lead would dissolve as lead is very insoluble (1)
   - Any dissolved lead ions would react with carbonate ions, forming a solid coati
   - $Pb^{2+}_{(aq)} + CO_3{}^{2-}_{(aq)} \rightarrow PbCO_{3(s)}$ (1)

2. **Any four from:**
   Natural water resources are being polluted by human activities (1) such as industri
   farming, increased urbanisation (1)
   The demand for potable and domestic water will continue to increase (1) as popula
   Increasingly changes in climate are resulting in longer droughts in some parts of the

Extension

1. The water is not fit for drinking as the lead concentration is higher than 10 µg/L (1).
   and sanitation as the concentration is less than 50 µg/L (1).

2. Mass = concentration × volume
   = 15 × (2.7 × 7) = 283.5 (1) µg (1)

A dance between sources and sinks

Comprehension questions

1. **Any two for 1 mark:**
   Photosynthesis, dissolving in surface water, dissolving in precipitation

2. **Any two from:**
   Water vapour molecules only spend a short time (1) in the atmosphere due to the f
   They spend as little as hours or days compared to other gases which spend years (1

3. $2H^+ + CaCO_3 \rightarrow Ca^{2+} + H_20 + CO_2$
   (1 mark – all formulas correct) (1 mark – balanced equation)

Discussion questions

1. Fertilisers are a source of nitrates. The overuse of fertilisers puts more nitrates in t absorb (1). Nitrates are denitrified by soil microbes to release nitrogen oxides (1).

2. **Any four from:**
   Carbon dioxide from the atmosphere naturally dissolves in ocean water (1). It is a r
   As more carbon dioxide dissolves in the oceans and the concentration increases, les
   Higher concentration of carbon dioxide in the air results in higher global temperatu
   carbon dioxide becomes less soluble (1) and the ocean will also experience some de

2. Both carbon dioxide and nitrogen oxides contribute to acid rain and global warming the breakdown of ozone (1) in the upper atmosphere.

Extension

1. **Any three from:**
   The demand for beef results in increased large-scale cattle farming, cattle release s the atmosphere (1)
   Methane is one of the most powerful greenhouse gases (1) and contributes signific a methane molecule spends more than 10 years in the atmosphere (1)

2. Percentage change in carbon dioxide = $\frac{419 - 280}{280}$= 50 % (2)

3. 419 particles in every 1 000 000 particles of air (1)
   $\frac{419 \times 6.02 \times 10^{23}}{1\ 000\ 000}$ = 2.52×10^{20} particles of air (1)

The consequences of combustion

Comprehension questions

1. **Any two from:**
   Coal (1), petroleum / crude oil (1), wood (1), charcoal (1), octane (1)

2. **Any three from:**
   - A gas whose molecules absorb infrared radiation for the bending and stretchin
   - The infrared radiation is stored and released as thermal energy (1)
   - Greenhouse gases trap infrared radiation from the Sun and contribute to the w

3. Climate change – changes in regular weather patterns and increased frequency of r
   Specific examples (1) – stronger and more frequent hurricanes/storms, longer drou
   forest fires, more frequent flooding, any other relevant example

Discussion questions

1. Greenhouse gases such as nitrogen dioxide, water or methane are either (1)
   - released in the atmosphere in much smaller quantities or
   - their molecules spend much less time in the atmosphere (1)

2. Soot – is a respiratory irritant, can trigger conditions such as asthma and other resp
   Carbon monoxide – leads to headaches and dizziness (1) and can be fatal

Extension

1. **Any four from:**
   Complete combustion – produces carbon dioxide and water as products (1)
   - Products are not directly harmful to one's health (1)
   - Releases lots of energy (1)

   Incomplete combustion – produces carbon monoxide, water and sometimes soot (
   - Soot is a respiratory irritant, carbon monoxide is toxic (1)
   - Less energy released (1)

   Both – both release energy and produce water (1)

2. Complete combustion $C_{(s)} + O_{2(s)} \rightarrow CO_{2(g)}$ (1)
   Incomplete combustion $2C_{(s)} + O_{2(s)} \rightarrow 2CO_{(g)}$ (1) balancing (1)

Sweet crude oil

Comprehension questions

1. Alkanes and alkenes (1)
2. **Any two from:**
   Crude oil is very thick/viscous and does not burn easily (1). It also contains some im before combustion (1). It contains many different hydrocarbons, which have differe separated for various uses (1).
3. Fractional distillation, cracking and desulfurisation (2 marks for all three, 1 mark for
4. Mass carbon = 1.6 million × 160 × 2.353 = 602.4 million kg / 602 400 000 kg (2)

Discussion questions

1. **Any four from:**
   Sour crude oil contains more than 0.5 % sulfur (1) as impurity. Desulfurisation (1) is This is done by mixing crude oil with hydrogen in the presence of a catalyst (1), and sulfur, forming hydrogen sulfide (1). The removal of sulfur minimises/prevents the f contributes to formation of acid rain (1).
2. **Any four from:**
   Fossil fuels are more energy-dense than biofuels such as ethanol (1); they release m is burnt.
   Fossil fuels are non-renewable (1), and we are using them up at a very rapid rate and
   Fuels such as ethanol are considered renewable as they are obtained from crops wh
   Biofuels such as ethanol are considered more environmentally friendly as they do no rain (1) and they produce less greenhouse gases (1), although this is arguable.
   Fossil fuels when burnt release nitrogen and sulfur oxides which form acid rain (1). of landscape to plant crops and this reduces availability of farmland (1) and crops.

Extension

1. Cracking is important to produce smaller hydrocarbons which can be used as petrol
   $C_{11}H_{24} \rightarrow C_8H_{18} + C_3H_6$ (1 – all correct formulas)
2. **Any three from:**
   Fractional distillation separates substances based on their differences in boiling poin When the different fractions of crude oil are heated in the fractionating column they and it gets cooler some fractions start condensing (1) due to the fact they are now e their boiling points. Different fractions condense at different levels and they are col fractionating tower.

The issue with acid rain is...

Comprehension questions

1. Sulfur dioxide / sulfur trioxide and nitrogen oxides / nitrogen dioxide (1 – both gase
2. Corrosion/destruction/damage of metal and carbonate/marble structures (1)
   Washing/leaching of minerals out of soil, stunted plant growth (1)
   Dead lakes, ecosystems and food chains disrupted (1)
3. $SO_{3(g)} + H_2O_{(l)} \rightarrow H_2SO_{4(aq)}$ (1 – correct formulas) (1 – all state symbols correct)

Discussion questions

1. Although pollutant gases might be produced locally, natural wind and ocean curren
   distances, from country to country (1) and even across continents
2. **Any three from:**
   Acid rain has a huge impact on various ecosystems /food chains. It reduces plant gr
   farming and food security (1).
   It also affects lakes and other aquatic ecosystems (1), killing organisms, which could
   For example, it reduces the availability of some fishes such as trout or salmon (1).
   It damages infrastructure, metals and marble, which are costly to replace and repai
   Acid rain is able to travel long distances across continents so the activities of one co
   countries. It acidifies lakes, eventually leads to decreases in fish population, reduce
   chain and ecosystems on which we depend (1).

Extension

1. **Any two from:**
   Nitrogen molecules have a strong nitrogen to nitrogen triple bond (1) and this make
   energy is needed (1) to break the bond. During the combustion of fossil fuels the hi
   able to break these bonds and that allows the nitrogen and oxygen in air to react w
2. $S + O_2 \rightarrow SO_2$ (1)
   $2SO_2 + O_2 \rightarrow 2\ SO_3$ (1) (1 – balancing)
   $SO_3 + H_2O \rightarrow H_2SO_4$ (1)
3. Sulfur dioxide when released from the burning of fossil fuels reacts with oxygen in t
   which dissolves in water to produce sulfuric acid (1), which is the main acid respons
   Nitrogen oxides also react and dissolve in water to form nitric acid that further acid
   precipitations. Nitrogen oxides, however, play a bigger role as catalysts (1) for the c
   sulfur trioxide.

Water treatment around the world

Comprehension questions

1. Rainfall (1), aquifers (1), oceans (1) (any two)
2. Filtration removes large objects (1) and small suspended solid particles (1) from raw
3. Water needs to be treated to remove pathogens (1) which could pass on diseases, t chemicals (1) such as metals ions, acids and alkalis

Discussion questions

1. **Any two from:**
   Chlorination is a form of chemical treatment which kills pathogens (1) and other mi but it has long-term effects on human health (1). Chlorine is no longer used as an e used instead (1).
2. **Any four from:**
   Chemical treatment of water occurs in two main stages: sedimentation and chlorin compounds such as alum (1) are added to the water being treated. The alum cause together (coagulate) (1) and settle in holding tanks as sediments (1). Following this chlorinated (1) to kill pathogens and microorganisms (1).

Extension

1. Drinking water in the UK is mainly sourced from surface and underground reservoir screening, filtration, sedimentation and chlorination (1). Drinking water in Saudi Ar seawater / ocean water (1). The treatment involves desalination (1) which includes more expensive as distillation requires lots of energy to generate heat (1).
2. There are not many fresh water sources (1) such as lakes, aquifers or rivers (1)

Are we are running out of copper?

Comprehension questions

1. The copper from which the statue is made reacts with oxygen in the air to form cop forms a layer which coats the statue and acts as a barrier (1) preventing any further
2. **Any two from:**
   - Recycling of copper materials (1)
   - Extracting low-grade copper deposits using bioleaching (1)
   - Reducing use of copper – finding alternative materials (1)
3. A copper ore/deposit with <u>high quantities of copper which makes it more profitabl</u>

Discussion questions

1. It has lower operating costs / reduces mining (1)
   It is more environmentally friendly (1)
   Low-value/low-grade ores can be extracted profitably (1)
2. During the extraction of copper, copper ores are roasted to convert copper sulfide
   This releases sulfur dioxide, which contributes to formation of acid rain (1)

Extension

1. Impure copper sulfide is first roasted to produce copper oxide, (1)
   $2\ Cu_2S + 3\ O_2 \rightarrow 2\ Cu_2O + 2\ SO_2$ (1)
   In the next step the copper oxide is further heated to produce impure copper, (1)
   $2\ Cu_2O \rightarrow 4\ Cu + O_2$ (1)
2. **Any three from:**
   Copper is purified by electrolysis (1)
   Impure copper is made the anode and pure copper the cathode (1)
   Electricity is passed through the cell and copper dissolves from the impure anode (1
   on the cathode (1)
   The impurities produce a sludge (1)
3. Estimated years left = $\frac{870}{22.4}$ (1)
   = 38.8 years approx. 40 years (1)
   Year we will run out = 2020 + 40 = 2060

The life of a drink can

Comprehension questions

1. **Any two from:**
   - Aluminium has a low density and the cans are light (1)
   - Aluminium is corrosion-resistant and will not react with the contents of the can
   - Aluminium has a very low toxicity (1)
2. **Any two from:**
   Both iron and tin are reactive metals which corrode easily (1), reacting with air and
   food and juices (1), releasing metal ions into the food and also decreasing the shelf

Discussion questions

1. **Any three from:**
   - Mining – the machines and vehicles used for digging and transportation are us
     release greenhouse gases such as carbon dioxide (1)
   - Smelting – most smelting plants use coal as fuel, the combustion of coal releas
   - Electrolysis – the electricity needed is generated from the combustion of fossi
   - Transportation – releases more carbon dioxide (1)
2. Mining – clearing land and digging up aluminium ores such as bauxite (1)
   Reaction with sodium hydroxide to produce aluminium oxide (1)
   Smelting/electrolysis – mixing aluminium oxide with cryolite (1), melting the mixtur
   electricity through the mixture (1). In this stage pure aluminium is produced and fo
   The ingots are transported to factories where they are cut and fitted with other me

Extension

1. **Any six from:**
   - Recycling helps to preserve natural habitats and ecosystems (1) that mining w
   - Recycling saves up to 95 % of the energy used to extract aluminium from the e
   - Recycling reduces the waste produced as only 1 tonne of each 4 tonnes of ore
     waste is generated for every 4 tonnes (1)
   - Recycling aluminium does not change its properties (1), the metal is infinitely r
   - Recycling significantly reduces the release of carbon dioxide (1), a major green
   - Recycling reduces release of sulfur and nitrogen oxides (1) which contribute to
2. Other metals such as manganese are added (1)
   To help strengthen different parts of the can, such as the lid (1)

Alchemy and alloys

Comprehension questions

1. Copper, tin and other metals were extracted (1), melted and then mixed (1) to form

2. Ti (s) + O_2 (g) → TiO_2(s) (1 – all formulas correct) (1 – state symbols)

3. **Any two from:**
   - Resistant to high temperatures, not permanently deformed at high temperatu
   - High machinability, easily cut and shaped to make different parts (1)
   - Low density, relatively light compared to other metals (1)

Discussion questions

1. The useful properties of alloys are affected by the microscopic defects in their struc
   Nanotechnology alloys scientists to fix the defects by inserting, rearranging or remo

2. **Any two from:**
   Titanium is used to make medical screws, braces, implants and more (1). It has a hi
   biocompatible (1) and non-toxic.

3. **Any four from:**
   Most metals: malleable and ductile (1), hard and strong (1), high melting points (1),
   electrical and thermal conductors (1)
   Some metals: soft, very reactive (1)
   Alloys – nitinol – strong but very elastic, very unreactive (1)
   Titanium alloys – very unreactive, high machinability (1)

Extension

1. Pure titanium reacts with oxygen to form a protective layer of titanium oxide (1). T
   any further reaction and this makes the metal corrosion-resistant and durable (1).

2. 3D printing – used to mix/fuse metals and make alloys to exact specifications (1). Th
   print/make very small components from alloys (1). Nanotechnology has allowed sci
   properties of alloys by removing or improving defects by removing or adding individ

3. **Any two from:**
   Machinability allows alloys to be cut easily at a low cost (1) and malleability alloys th
   shapes without breaking (1). This allows alloys to be used to make many different c

When life gives you nitrogen and hydrogen, make ammonia...

Comprehension questions

1. Haber was the first scientist to successfully react nitrogen and hydrogen gas to prod up with conditions needed to produce ammonia on a large scale (1)
2. A dynamic equilibrium is reached in a closed container when the rate at which nitro ammonia (1) becomes equal to the rate at which the ammonia is breaking back dov In other words, the rates of the forward and backward reactions are equal (1).
3. Nitrogen + hydrogen → ammonia (1)
   $N_2 + 3H_2 \rightarrow 2NH_3$ (1)
4. Ammonia → nitrogen + hydrogen (1)
   $\mathbf{2}NH_3 \rightarrow N_2 + 3H_2$ (1)

Discussion questions

1. **Any two from:**
   Ammonia is produced at temperatures of 400–500 °C and pressures of around 200
   These conditions are chosen to get a process which is cheap/profitable (1), and pro ammonia and good rate of reaction. These conditions are a compromise (1) betwe
2. **Any four from (must include at least one point for each):**
   Advantages:
   Responsible for the production of ammonia sulfate fertiliser (1) and greater food av
   Ammonia is used to produce other substances such as salts and household cleaners

   Disadvantages:
   It uses a lot of fuel/energy which is mostly obtained from natural gas (1), which is a
   The hydrogen used is also obtained from the non-renewable natural gas (1)
   Hydrogen is obtained from fractional distillation of air, which is expensive (1)
   The global use of fertilisers has resulted in pollution/eutrophication (1) as fertilisers waterways and water resources. This can lead to eutrophication (1).

Extension

1. Le Chatelier's principle allows chemical engineers to understand how using differen pressure can affect the yield of a chemical reaction (1). It allows them to choose th make a chemical reaction as cheap and efficient as possible (1).
2. Ammonia + sulfuric acid → ammonium sulfate (1)
   $2\ NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$ (1)
   Sulfur trioxide + water → sulfuric acid (1)
   $SO_3 + H_2O \rightarrow H_2SO_4$ (1)