Chemistry

GCSE (9–1) | AQA | 8462

Stretch and Challenge Articles

For GCSE AQA Chemistry

Pack 1 (Topics 1-5)

zigzageducation.co.uk

POD 7710

Contents

Teacher's Introduction

These 'Stretch and Challenge' articles are designed to be complementary to the new (9-1) GCSE Chemistry specifications. They contain 15 articles that cover areas of topical interest to chemists, where there are significant links to the GCSE specification. These articles cover the first half of the specification (topics 1-5).

They are designed to give higher-ability students a challenge, providing information about chemistry in the wider world, and bolstering interest in the subject as a whole.

For each article, the following activities are included:

- Keyword identification to ensure important concepts are recognised.
- Comprehension questions to ensure understanding of and participation in the task.
- Discussion questions to encourage debate of topical issues and wider scientific and ethical questions.
- Extension tasks, encouraging students to conduct further research and teaching them to structure a written piece, such as a newspaper article, a letter to government or advice to doctors.
- Further reading, where content is aimed at an appropriate level, allows enthusiastic students to broaden their knowledge further.

Each article has a direct link to the specification, which is given on the contents page, but also goes beyond the specification too, including recent discoveries, case studies of diseases and application of theories to the wider natural world.

The articles are between 500 and 1,000 words each, and are expected to take a student approximately 15 minutes to read. The keywords and comprehension questions are expected to be short, and the discussion questions can be whole-class activities, guided by the teacher, or small-group activities to encourage less-confident students to take part.

Extension tasks can be given as homework together with the suggested further reading tasks that are included. All resources can be copied into black and white.

We hope you enjoy reading and using 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/7710***

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

September 2017

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Elements (and Compounds) of L

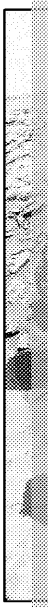
Could life ever have existed on Mars?

4.1 Atoms, elements and compounds

Keywords

Element – a substance made from only one type of atom
Compound – a substance made from multiple types of atom, chemically bonde
Mixture – a substance which is a combination of elements and compounds
Organic compound – a compound made mostly from carbon and hydrogen

Could life ever have existed on Mars? In order to find out, we need to know which elements and compounds are on Mars. NASA sent a rover called 'Curiosity' to Mars to analyse the elements, compounds and mixtures found on the planet. The rover was launched in November 2011, and landed on Mars in August 2012.



The wa atm

Martian atmosphere

An important part of the Curiosity rover mission is to analyse the Martian atmosphere.

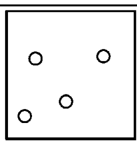
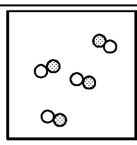
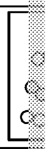
A planet's atmosphere is made up of a **mixture** of different gases. For example, on Earth, our atmosphere is a mixture of the **elements** nitrogen, N_2, oxygen, O_2, and argon, Ar. The **compounds** carbon dioxide and methane are also found in the atmosphere in smaller amounts. Humans rely on oxygen, O_2, in order to live.

Mars' atmosphere is made up of 95 % nitrogen and 3 % carbon dioxide, and has 100 times fewer particles as the atmosphere of Earth, because the atmosphere has been slowly lost over time. One way to track the speed of the loss is by tracking two **elements**, Xenon and Krypton. These are both in group 0 of the periodic table. They are gases found in Mars' atmosphere in very lo compounds suggest that Mars has lost its atmosphere slowly and steadily over tir had an atmosphere which could support living organisms.

Martian soils

The Curiosity rover is also able to drill holes in the planet's surface and detect compounds in the soil and rocks.
From the drilled samples, the Curiosity rover found **water, carbon dioxide, oxygen, sulfur dioxide and hydrogen sulfide.** Scientist think that these compounds are everything life would need to have developed on Mars, which means that the planet could once have been home to bacterial life.

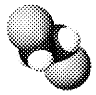
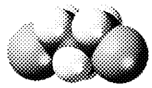
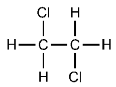
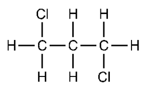
Key chemis

A pure element, Xe	A pure compound, NO	A mi elem
		
Xe is useful for predicting the history of Mars' atmosphere.	*The element nitrogen was discovered bonded to oxygen.*	*Earth's mix*

Organic compounds

NASA has particularly focused on looking for **organic compounds**, which are mostly mad can contain other elements such as oxygen, nitrogen, phosphorous and sulfur. Life on Ear of molecule. On Earth, organic compounds can be made by organisms such as bacteria a thought to be made by chemical reactions in water, or by arriving on an asteroid or come

One simple organic compound found on Mars is methane, CH_4. NASA has been specif if it exists in Mars' atmosphere it would increase the chance of life having once existed have been **chlorinated** organic molecules. These compounds contain chlorine, as well the chlorinated organic molecules found on Mars are shown below.

dichloroethane	dichloropropane	
		
		

Curiosity's achievements

Since landing on Mars, the Curiosity rover has driven over 15 km and has discovered e as well as enough of the elements and compounds required for life to exist. In 2015, N discovered nitrogen for the first time, as nitric oxide, NO, and more recently, Boron, B, find out if there is – or ever was – life on Mars, and the discovery of these elements an life could certainly have existed on Mars.

Comprehension questions

1. Organic compounds have been found on Mars. Explain how these could h
2. Recently, Curiosity has found nitrous oxide and boron. Are these element
3. Curiosity found water (H_2O), carbon dioxide (CO_2), oxygen (O_2), sulfur diox (H_2S) on Mars. Represent these as particle diagrams like the ones in the ar

Discussion questions

Could there be life on Mars? Could there ever have been life on Mars?

Extension

NASA wants to send humans to Mars in 2030. Design a resources list for a space elements, compounds and mixtures you'll need to take, and what you'll be able t atmosphere.

Further reading

The Curiosity rover has discovered three main types of rock on the surface of pyroxene and olivine.

See if you can find out which elements make up these types of rock. Do the t elements? Do any of the rocks have unique elements within them?

The University of Minnesota has a website covering many types of minerals a **esci.umn.edu/courses/1001/minerals**

Periodic Updates

A brief history (and future) of the periodic table

4.1.1.3 Development of the periodic table

Key words

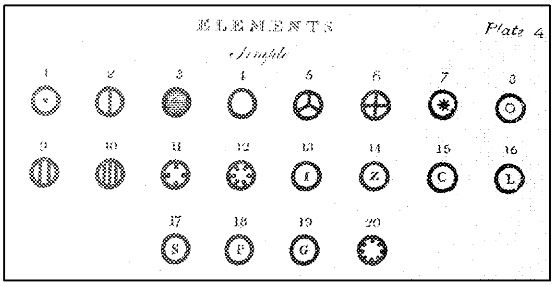
Element – a substance made from only one type of atom
Atomic number – the number of protons that an atom has in its nucleus
Relative atomic mass – the total mass of the protons and neutrons in an atom the mass of ^{12}C.
Alchemist – a person who searches for a way to create gold from other metals

Early discovery of elements

Copper was the first element known to humans. In 9000 BC humans were using coppe weapons, tools, ornaments and jewellery. Other elements, such as lead, zinc and tin, ha been known to humans for thousands of years. Yet we are still discovering elements to

Hennig Brand

Hennig Brand was a bankrupt German merchant who was an alchemist searching for a to make gold from other metals (and also cure all illnesses). He was convinced that if he boiled down human urine he could create a material which would make him incredibly rich. In the end, he created a strange, stinking substance, much to the upset of his wife. When he burnt it, however, it gave out an amazing glow and he named the substance 'phosphorous', which means 'light-bearing'. This is the first recorded discovery of an element.



Dalton assigned symbols to different elements.

Lavoisier

A Frenchman named Lavoisier is kn claimed that oxygen, nitrogen, hyd and sulfur were 'simple substances This is the basic idea of elements. L and 'caloric' (heat), which we now k

Unfortunately, before he could ta head chopped off during the Fren

Mendeleev

Mendeleev was the first person to organise the elements in a way similar to the moder Mendeleev had organised elements in order of their atomic mass, but Mendeleev was other pattern to the elements.

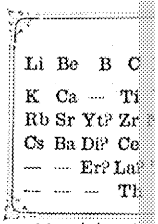
Mendeleev wrote the name of every element he knew on pieces of card, and organise find a way to arrange them.

He awoke the next day and wrote in his diary:

> 'In a dream I saw a table where all the elements fell into place as required. Awak down on a piece of paper.'

Mendeleev set to work, and finally managed to turn his list into a table, where columns Using his table, Mendeleev was able to predict the existence of some elements. Look at table. He noticed that there were elements missing between Zn (zinc) and As (arsenic). H perform the same reactions as Al (aluminium) and Si (silicon). Mendeleev called these ek

Mendeleev used **relative atomic mass** to order elements, but, since 1914, we have ordered them by **atomic number** (the number of protons in the nucleus).



Mendeleev's

Recent discoveries

The most recent discoveries of the periodic table are all in the bottom right corner of the periodic table. Because the periodic table is in order of atomic number, the bottom right elements have very high numbers of protons, which makes them very **unstable**, and they fall apart very easily. Some of these second! Francium, for example, is so unstable that there is only 30 g of it at any one time periodic table. It will say that some elements have been reported but not fully authentica have now been named:

Atomic number	113	115	117
Name	nihonium	Moscovium	Tenness
Symbol	Nh	Mc	Ts
Named after	日本 'nihon', the Japanese word for Japan, where it was discovered	Mosow, the city where it was discovered	Tennessee, the many of its disco

Which elements will we discover next?

The most recently discovered elements have been difficult to confirm because they only Scientists have predicted that slightly larger atoms are likely to be even more unstable. H stability' for atoms of much higher mass, around atomic number 164. Perhaps element 1

Comprehension questions

1. Mendeleev predicted the existence of eka-aluminium and eka-silicon. Find the periodic table.
2. Mendeleev ordered the elements by atomic mass. How are they ordered now?
3. Why did Mendeleev put the elements in columns rather than in one long line?
4. Find an example on your periodic table of two elements ordered by atomic m

Discussion question

Will the periodic table ever be completed?

Extension

In 1817, before Mendeleev's periodic table had been invented, Johann Wolfgang some elements into 'triads' (groups of three):

1. chlorine, bromine and iodine
2. calcium, strontium and barium
3. sulfur, selenium and tellur
4. lithium, sodium and potas

Write a paragraph which answers these questions:

- How do you think Döbereiner decided which elements to put in each triad?
- Are elements in a triad ordered in any way?
- How are these triads similar to the periodic table?

Further reading

A small mining town in Sweden called Ytterby has a 'claim to fame' relating to the out what it is. Why could this only happen in a mining town? If you get stuck, try help: **www.youtube.com/watch?v=I6lGe5jgZgI**

Aurora Borealis

What even is it?

4.1.1.7 Electronic structure

Keywords

Solar wind – a stream of charged particles (protons and electrons) which are e
Aurora borealis – also called the 'Northern Lights'. A natural light display only

Introduction

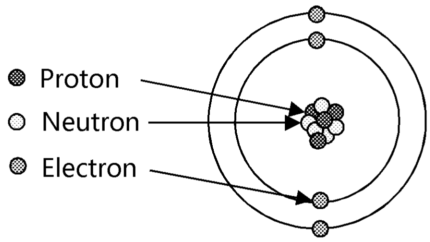
You may have heard of, or even seen, the Northern Lights. Also known as the 'aurora borealis', the Northern Lights are a natural light display which occasionally lights up the night sky in the Arctic and northern parts of Canada.

Aurora borealis was named by Galileo, who named it after Aurora, the Roman goddess of the wind, and Borealis, the Greek god of the northern wind.

Aurora borealis
sky in Northern

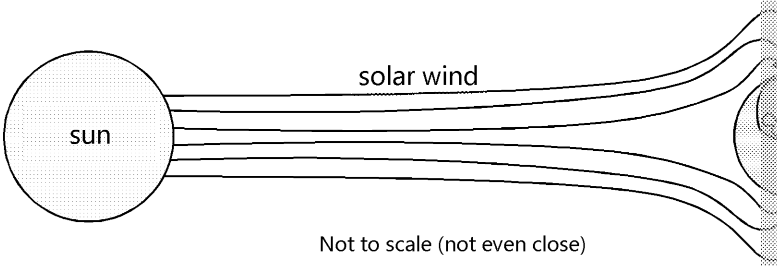
How does the aurora borealis occur?

Auroras are caused by solar winds bombarding Earth. The sun constantly emits ch electrons into space, which is known as 'solar wind'. These are the same as the **pro** see in diagrams of atoms. In atoms, protons are found in the nucleus of the atom,



Subatomic particle
Proton
Neutron
Electron

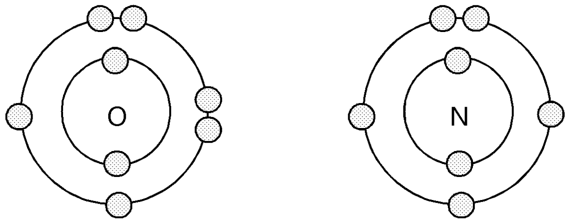
In solar wind, protons and electrons do not form atoms, but travel independently. Earth, the charged particles are deflected towards the north and south poles by Ea



When the **charged particles** come into contact with atoms and molecules in Earth aurora borealis.

Atoms in our atmosphere

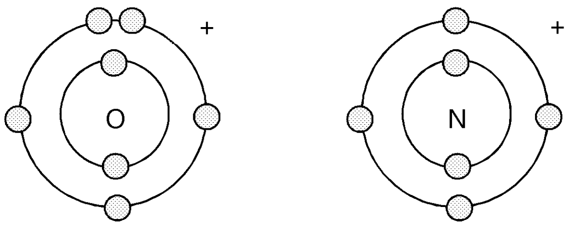
In Earth's upper atmosphere, some of the oxygen and nitrogen exists as atoms (O and N_2). These atoms have protons in their nuclei, and electrons in shells. The num the number of electrons (–), so the overall charge of the atoms is zero. In other wo Here are some electron shell diagrams of the atoms:



The chemistry of the aurora

When an electron from the solar wind collides with a nitrogen or oxygen atom, an ion. When an electron from solar wind hits an atom of oxygen or nitrogen, it can r atom, and an ion is formed.

Both of these atoms now have a positive charge. This is because they have lost a n protons (+) in the nucleus is now one more than the number of electrons (–), so, o



Eventually (over a few seconds) the ion gains an electron, and the original atom is which is why you see the aurora. Different gases emit different colours of light (in different colour flames in flame tests). Oxygen glows orange-red, and nitrogen gl colours, but nitrogen and oxygen are the main atoms in the upper atmosphere.

Comprehension questions

1. What kind of subatomic particles make up solar wind?
2. What charge is on each of these subatomic particles?
3. What does solar wind interact with in our atmosphere?
4. Explain how auroras happen.
5. Other atoms can light up when they interact with solar winds. These at form. Explain why these colours are not seen as regularly as the colours

Discussion question

Other planets have different atoms in their atmosphere. How do you think other planets?

Extension

Neon lights work by electrons flowing through a tube of neon atoms. Ne reason that solar winds cause auroras.

Draw the electronic structure of an atom of neon and a Ne^{+} ion.

Use your diagrams to explain how electrons can cause neon to light up in

Further reading

This article has mostly referred to the auroras seen at the North Pole – the *borealis*. The diagram shows that the charged particles in solar wind also e out what this is called.

If you're interested in seeing some auroras for yourself, AuroraWatch UK a aurora activity. You can set up email alerts to notify you when there may b

What Do You Call a Noble Gas

Whatever you want: it won't react

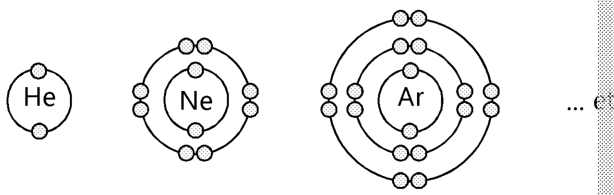
4.1.2.4 Group 0

Keywords

Boiling point – the temperature at which a substance changes from a liquid to
Relative atomic mass – the total mass of the protons and neutrons in an atom.
twelfth the mass of ^{12}C.
Inert – something which does not easily react

Noble gases

Noble gases are in group 0 of the periodic table. They all have eight electrons in th
helium, which has two.

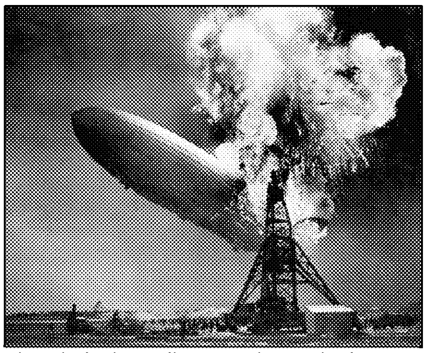


Noble gases are not very good at forming compounds. This is because they have a
They cannot form ions, so cannot form ionic bonds or metallic bonds, and they can
cannot form covalent bonds.

Noble gases might not be very reactive, but that doesn't mean they aren't useful. In
are so useful!

Noble gases are super-cool

MRI machines are used in hospitals as a safer alternative to X-rays. MRI machines h
which work better when they are very cold. Generally these magnets are cooled us
You will have learnt that noble gases lower in group 0 have a higher boiling point.
and so has the lowest boiling point of all the noble gases: -269 °C. Helium is useful
because it is still a gas at very low temperatures, and so it can be pumped around t
was a liquid.



The Hindenburg disaster, where a hydrogen airship ignited while it was docking

Airships

Another use for helium is in airships such as t
hydrogen, H_2, but hydrogen is very reactive.
popular until the famous Hindenburg disaste
almost 100 people ignited and crashed. This
people began to think that airships were not
Airships and weather balloons are now filled
so unreactive, there is no danger of a disaster
happening again when noble gases are used.

Lightbulbs

Noble gases are also found in lightbulbs. If a lightbulb's filament comes into conta with oxygen in the air, it will begin to burn. Instead, these bulbs are filled with argo gas, which means that there is no oxygen to react with the filament.

Just as in airships, noble gases are useful in light bulbs because they are inert, and the filament.

Dangers of noble gases

Just because noble gases are unreactive, doesn't mean they are safe. If a person b voice go very high because helium is lighter than air. This is also why helium ballo that helium will replace the oxygen needed by the body, causing dizziness and eve

Moving down group 0, the noble gases get heavier. Elements lower in group 0 hav because they have more protons and neutrons in their nuclei. If you filled a balloo heavier than a balloon filled with exhaled air. One danger of working with argon is sinks to the bottom of your lungs and it is very difficult to breathe the argon back argon can result in asphyxiation, because your body cannot get enough oxygen.

Comprehension questions

1. Draw the electron structure of argon.
2. Why are noble gases inert?
3. How does the boiling point of the noble gases change down group 0?

Discussion question

How would the world be different if there were no noble gases?

Extension

The world's supply of helium is running out, and it is impossible to make letter to the prime minister to:

- explain how the world would be different if there was not enough heli
- persuade them to make new laws which could prevent the shortage o

Further reading

You'll learn in school (and here) that noble gases are completely unreacti searching for noble gas compounds on the Internet. Over 100 exist! (You c

This *New Scientist* article might get you started:
newscientist.com/article/mg21328481-700-impossible-chemistry-fo

Mete-Ores

Mining in space

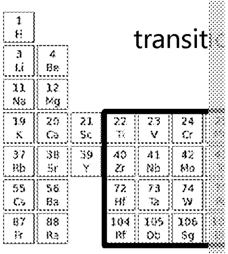
4.1.3.2 Properties of metals

Keywords

Transition metal – elements from the middle of the periodic table, including c cobalt, nickel and copper
Catalyst – something which can speed up a reaction, but is not used up

Introduction

Transition metals are very valuable materials. They are typically strong, less reactive than other metals, useful for catalysing reactions, and can form coloured compounds. But as we use transition metals in more applications, our supply of transition metals may begin to run out. Some people think that mining asteroids might be a good way to find more metals.

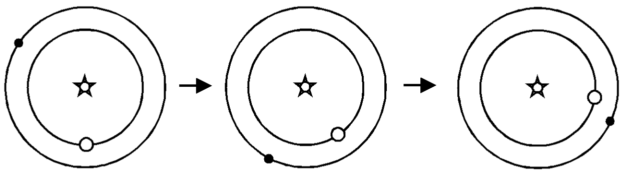


How to mine an asteroid

Asteroids are large objects in space which orbit the sun. Asteroids range from 6 m three types: carbon-rich (C-type), silicon-rich (S-type), and metal-rich (M-type).

Some companies think that if they can find a way to mine asteroids, especially M-t lot of money selling the transition metals.

1: Find an asteroid and wait for it to get close to Earth



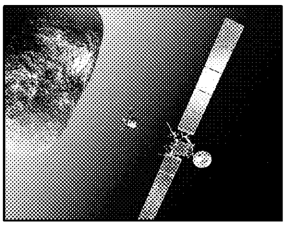
There are more than half a million known asteroids.

Only a small number of these are M-type asteroids. These are worth mining because they contain a large amount of transition metals.

2: B

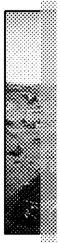
There ar compani rocket

3: Get to the asteroid and drill into the surface



The only current mission going to an asteroid is the European Space Agency's *Rosetta* mission, which reached a comet in 2014. However, this was not a mining mission, and was just used to analyse the comet.

4: Get th



Both NASA and t JAXA have launch hope to return sa scientific study

How much is an asteroid worth?

NASA has recently said it wants to visit an asteroid which, if it could bring the whole thing to Earth, would be worth ten thousand quadrillion dollars ($10,000,000,000,000,000). But NASA has no plans to mine this asteroid – they have said they just want to send a probe which can analyse it.

Asteroi
Ryugu, 1989 M Didymos, 1992 SG10, 2002
2011 UW
Anteros, 200

Which asteroids?

The Asterank database has put together a list of asteroids which could be mined a profit that could be made from them. These asteroids generally contain the transiti Some asteroids also contain platinum and aluminium.

Why are transition metals worth so much money?

Transition metals have some very important, large-scale applications:

- **Iron** is very important in engineering and construction because it is very **stro**
- **Nickel** is a valuable **catalyst** in processes such as making margarine.
- **Platinum** is a very expensive **catalyst** used in catalytic converters in cars and
- **Cobalt** is used in pigments (colours) for art such as stained glass and pottery **coloured compounds**.

But the most exciting applications of transition metals are a bit more niche:

- Gold, one of the most iconic metals, has been valued throughout civilisations a colour other than grey and it doesn't corrode, making it perfect for decorat incredibly good electrical conductor, and is used in high-performance electro 10 tonnes of old computers than there is in 10 tonnes of gold ore.
- Silver, also known for its use in jewellery, is used for developing photographs sliver bromide and silver chloride, change colour when exposed to light. This make an image from the light that hits them, and then turned into photograp
- An alloy of nickel and titanium, in a specific ratio of nickel to titanium, can be which will return to its shape after being bent. Smart alloys are used in dental into the desired position.

Comprehension questions

1. Space flight is very expensive. Explain why asteroid mining could still be v
2. Name a transition metal other than nickel that can be found on asteroids
3. Describe **two** uses for nickel.
4. Why are C-type and S-type asteroids not good targets for asteroid minin

Discussion question

What advantages and disadvantages are there to mining asteroids for more r

Extension

Design a robot which could be used to extract transition metals from an aste need? How is it going to return to Earth? Will it only extract certain metals?

Further reading

NASA is planning an *Asteroid Redirect Mission* which will be the first mission t sample to Earth. Read more about it on the NASA website.
nasa.gov/content/what-is-nasa-s-asteroid-redirect-mission

Silicon Lifeforms

It's life, Jim, just not as we know it

4.2.1.4 Covalent bonding

Keywords

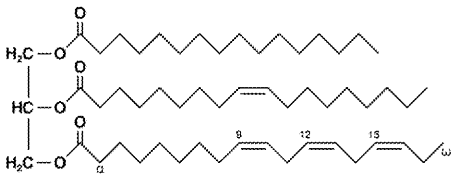
Carbon-based – something which is mostly made out of carbon. All life on Ear

Covalent bond – the bond formed between two atoms when they share a pair

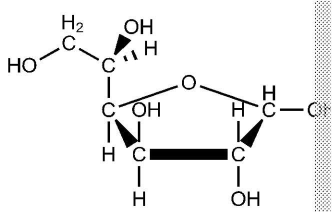
Introduction

Carbon and silicon are in the same group in the periodic table. This means that th properties. Both make four covalent bonds to other atoms when they form compo them have four electrons in their outer shell.

Fatty acids, sugars and amino acids are all based on carbon:



Fatty acids



Sugar

Despite their similarities, all life on Earth is **carbon-based**, and very little life on Ea elements, silicon is the most similar to carbon, because they are in the same group this, scientists think that if another element is used for life instead of carbon, it wil enough to carbon for this to happen?

Why is life carbon-based?

Life on Earth is based on carbon. Just about every molecule in your body is made and animals we eat are carbon-based too, because our food is our source of carbo in the form of sugars, proteins and fats.

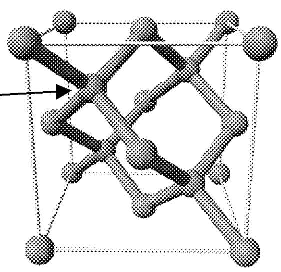
Scientists think that carbon is used for almost everything in life because it can for that are relatively stable, like carbohydrates, proteins and DNA.

Similarities between carbon and silicon

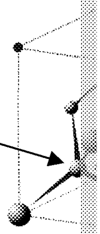
Carbon and silicon both form four covalent bonds with the atoms around them. A structures.

For example, both diamond and silicon form structures like the ones below. Not a diagrams, so you have to imagine that the structure keeps on going outwards in a

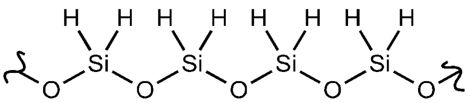
Silicon atom



Carbon atom



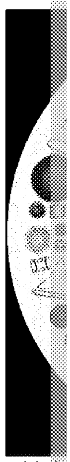
Pure silicon cannot form polymers because it burns in oxygen. However, silicon com
make long molecules, just like carbon is able to. An example of a silicon polymer sec



Because silicon is able to form molecules very similar to the molecules made from
silicon probably could replace carbon in some places in biological life.

Silicon used by life

Despite the similarities between carbon and silicon, there are very few examples of natural life using silicon. Some algae use silica (silicon dioxide) to make their cell walls. Even though these algae have silicon in them, they do not have any carbon–silicon bonds, and the rest of their biological function is carbon-based.



This
the s

Carbon–silicon bonds

Carbon–silicon bonds are very often made by scientists in laboratories, and have widespread uses. Carbon–silicon bonds are found in materials used for TV and computer screens, paints, glues and solar panels.

However, carbon–silicon bonds have never been found in nature. Scientists find this puzzling because silicon is readily available on Earth in rocks. Despite this, compounds containing silicon can have biological effects. For example, some silicon-containing carbon-based compounds are used as insecticides, to protect crops, and it is also known that some compounds with carb
affect bees.

Recent discovery by scientists

In 2016, scientists working at the California Institute of Technology in the USA were
can form carbon–silicon bonds. They found a protein in a bacterial cell which mak
of silicon. The scientists took the DNA responsible for making the protein and put
then selectively bred the bacteria until it could create carbon–silicon bonds.

This discovery is exciting because the bacteria they produced could make carbon–s
any other process humans have developed. This might be helpful for designing an
if bacteria can be made to do this on Earth, then because there are so many stars a
people think that silicon-based lifeforms are inevitable.

Comprehension questions

1. Name an example of biological life using silicon.
2. What was new about the discovery made by the scientists at the Cali
3. How could the discovery be used in the future?
4. What non-biological uses are there for carbon–silicon bonds?
5. Draw a dot-and-cross diagram for
   a. CH_4
   b. SiH_4

Discussion questions

Could life ever incorporate silicon? Could silicon-based life exist?

Extension

Design a planet for a silicon-based life form. Silicon compounds tend to b because of the oxygen, so think carefully about which gases could be in th What sort of things would be different on the planet? What kinds of food

Further reading

The astronomer Carl Sagan predicted that if alien life exists, it may not be other elements could be used. One of them was silicon. Can you predict w can find out. Does your prediction match Carl Sagan's prediction?

This Wikipedia article has a comprehensive rundown of alternative eleme **en.wikipedia.org/wiki/Hypothetical_types_of_biochemistry**

Trapped Gas

Methane bubbles trapped in Abraham Lake

4.2.2 How bonding and structure are related to the properties o

Keywords

Particle diagram – a diagram used to show how particles, represented by spheres
Space-filling model – a model which shows how atoms are arranged in a mol
State change – when a substance changes between state, e.g. solid, liquid, gas

Abraham Lake

This picture is of Abraham Lake in Canada. Canada gets cold enough in the winter that the lake freezes over, forming a layer of ice. But can you see anything unusual in this picture? In the bottom left corner there are a few white circles.

Abraham Lake in Can… bottom left of this pict… methane gas trapped …

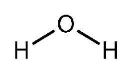
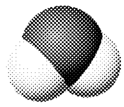
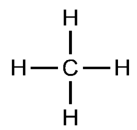
What are they?

If you haven't figured it out already from the title of this article, these are bubbles of trapped gas. But the gas isn't just any gas – it's methane, a highly flammable gas.
Methane is produced by plants decomposing (rotting) on the lakebed. In the summer, the gas escapes, but in the winter the gas gets trapped under the ice layer. As more ice forms, more methane gets trapped under the ice, forming these bubbles.

Properties of water and methane

The temperature of Abraham Lake gets down to about -15 °C. At this temperatur liquid (l) to solid (s). But methane, CH_4, does not change state, and remains as a g

So why is it that water and methane have such different properties? After all, both bonded only to hydrogen atoms. This is easy to see in diagrams, and in **space-fill**

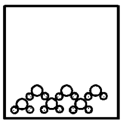
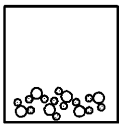
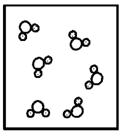
Water		Meth
		

The particles are clearly different sizes and shapes to each other, but this doesn't are in different states at the same temperature.

To figure out why this is the case, we need to think about what happens when som

State changes

Both methane and water are substances made up of small covalent molecules. Th At higher temperatures, these forces start to break down. And when the forces br molecules separate from each other and spread out. This is the reason that substa

Solid	Liquid	Gas
Regular forces between particles	Some of the forces between particles are broken	Very few forces between particles
		

The difference between water and methane is that water has **stronger forces bet** These forces are given their own name – 'hydrogen bonds'.

These forces take more thermal energy to break, so water melts at 0 °C, and is liqu comparison, methane has already melted at -182 °C, when there is much less ther

At -15 °C:

- water is below its melting point, so is a solid
- methane is well above its boiling point, so is a gas

Exploding lakes?

Abraham Lake releases methane very slowly, but there have been cases elsewhere from under the water.

One of these is Lake Nyos in Cameroon, where large amounts of carbon dioxide b a large landslide caused a huge cloud of over 100,000 tonnes of carbon dioxide to lake. A silent, invisible cloud of CO_2 swept over the surrounding village, which led livestock in their sleep. Lake Nyos is one of only three lakes in the world known to

Comprehension questions

1. Draw particle diagrams for methane, ice and liquid water.
2. Explain why methane is a gas at 25 °C, whereas water is a liquid.

Discussion question

In what situations will methane and water be in the same state? (Hint: the

Extension

Four students are having an argument on Twitter about why water has a hi

Angela: 'It's because water has stronger covalent bonds than methane.'
Barack: 'The strength of the covalent bonds doesn't matter.'
Theresa: 'Water has stronger forces between molecules.'
Donald: 'Water and methane are broken up into atoms when they boil.'

Who do you agree with? Write an explanation for each comment about why

Further reading

Molecules similar to water (H_2O), such as H_2S, H_2Se and H_2Te, do not hav you think their melting and boiling points compare to H_2O?

Find out more about hydrogen bonding here: **chemguide.co.uk/atoms**

Seventeenth-century Nanoscien

Are nanotubes the secret to an ancient metal's strength

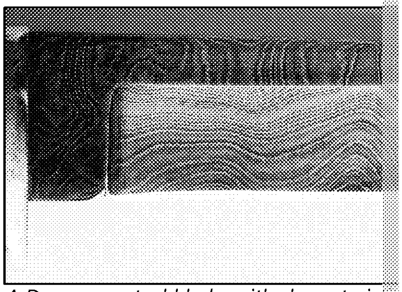
4.2.4 Bulk and surface properties of matter including nanoparti

Keywords

Nanoparticle – any particle which is 1–100 nm (10^{-9}–10^{-7} m)
Alloy – a mixture of metals

Nanotechnology

Back in the seventeenth century in the Near East, steelworkers had perfected a recipe for producing a very strong steel now known as Damascus steel. The legend went that the steel was so strong that Damascus swords could cut through other swords, and that they were so sharp that if a piece of silk fell on the blade, the weight of the silk was enough to cut the silk in two.



A Damascus steel blade, with characteristi exact method for recreating this pattern h

Since then, the process for making Damascus steel has been lost, and nobody has managed to replicate the process without usi researchers are still interested in finding out why these swords are so strong, and p method.

What is steel?

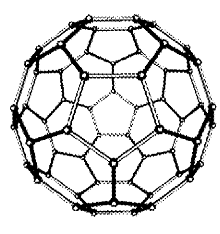
We know that Damascus steel was made mostly from iron, with small amounts of b of other impurities such as carbon. The carbon in the wood is incorporated into th a mixture called an 'alloy' is formed. Many alloys are stronger than pure metals be metal structure.

Why are Damascus swords so strong?

But Damascus steel isn't just any alloy. A recent discovery by German scientists found that the carbon in Damascus swords is arranged into carbon nanotubes.

A carbon nanotube is a type of fullerene. Fullerenes are hollow nanoparticles of carbon. Other fullerenes include buckyballs, which are nano-sized spheres of carbon atoms covalently bonded together. The pattern on a buckyball looks like the black and white sections on a football.

Buckyball



Nanoparticles like the ones abov contain around 100 carbon atom

Scientists think that the nanotubes in Damascus steel are partly responsible for th thought that the fibres of nanotubes hold the steel together more strongly withou

The future of nanomaterials

Nanotubes are well known for their high strength, and are being developed by sci
such as those used in the manufacture of **sports equipment** and in **building**, whe
strong and flexible.

Because of the regular arrangement of atoms in carbon nanotubes, scientists have
where carbon nanotubes are incorporated to improve their strength. Some **baseb**
manufactured so that carbon nanotubes are added as they are created.

Carbon nanotubes could also be used for delivering **drug molecules** to very spec
researchers are looking into creating nanotube 'needles' which can inject into indi
precision for delivering medicine. This may be useful for targeting individual cells,
example.

Comprehension questions

1. How large are nanoparticles? Give your answer in standard form, in m
2. Name and describe two nanoparticle structures.
3. Describe the composition of Damascus steel.
4. Explain what properties of Damascus steel make it better than normal

Discussion questions

Could you make nanoparticles from other elements? Why do you think th
from carbon nanoparticles?

Extension

What other uses can you think of for nanotube-reinforced materials? Writ
explain how nanotubes improve the performance of that material.

Further reading

Carbon fullerenes have turned up in some unexpected places. Do some re
any places where carbon nanostructures have developed naturally.

This article goes in-depth about one of the first discoveries of fullerenes i
universetoday.com/76732/buckyballs-could-be-plentiful-in-the-univ

Biopolymers

The polymers which keep you alive

4.2.2.5 Polymers

Keywords

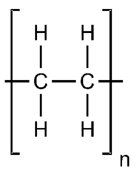
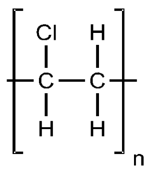
Synthetic – made by humans (not found naturally)
Polymer – a long molecule with a repeating structure
Monomer – one repeating unit of a polymer

Not just plastics

When you think of polymers, you probably think about plastics, and other *extreme*
But did you know that your body contains loads of different kinds of polymers wh
from your cell walls to your skin to the sugar you eat is made of polymers.

What's a polymer?

Your textbook and your teacher will tell you that polymers are made of repeating
monomers covalently bond together to form very large molecules. Some example
polyethene (polythene), polyvinyl chloride and polystyrene.

polyethene	polyvinyl chloride	
		

The small 'n' in the bottom right corner of the structures shows that everything wi
many times. These diagrams show one **monomer**, which repeats to form a **polym**

Synthetic polymers can be manufactured to have very different properties:

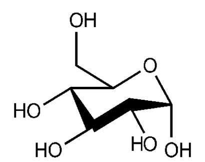
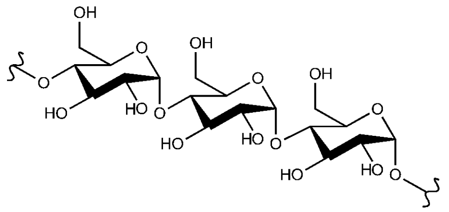
- Kevlar is very hard, and is used for bulletproof vests.
- Polyethene is cheap, and is used in supermarket bags and plastic bottles.
- Polyvinyl chloride is very unreactive, so is used for making sewer pipes.
- Glues are also polymers. PVA and superglue are both polymers with very stro chains.

Where does the human body use polymers?

Just like synthetic polymers, natural polymers also have very different properties,
more exciting. The different properties of natural polymers are even more varied t
they do very specific things in nature.

Polysaccharides

Polysaccharides are repeating chains of saccharide monomers, also known as 'sugars'.
as a way of storing sugars. When a plant performs photosynthesis, it produces glucos
source. The plant then converts the sugar monomers into polymers so that the energ

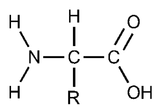
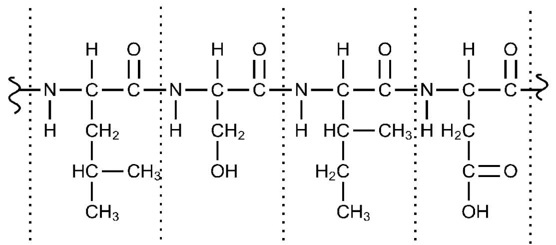
A saccharide monomer	A section of a polysaccharide	A
		

When an animal eats a plant, the animal digests the polysaccharides back into shorter sugars, such as glucose, as well as some molecules with two sugar monomers called 'disaccharides'. These shorter molecules are then used as an energy source.

Polypeptides

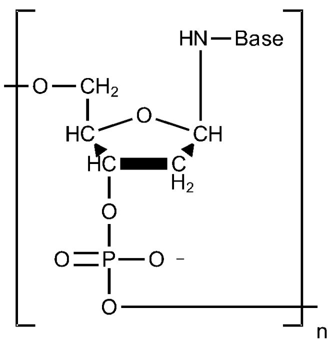
In your cells, enzymes are the molecules which do almost everything. They aid digestion and ensure that cells have the minerals they need. They are known as 'biological catalysts'.

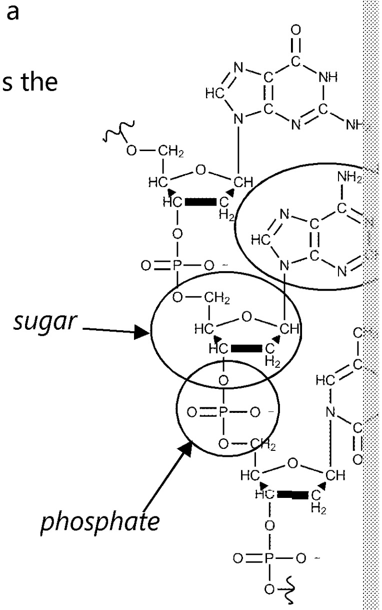
An enzyme is a type of polymer called a polypeptides. A single peptide monomer joi
Polypeptides are special because they 'fold up' to form large 3D structures. The shap
specific, and allows the polypeptide or enzyme to hold specific molecules and break

One amino acid	A polypeptide, with a repeating structure of amino acids
	

DNA

Every cell in your body has a complete copy of your DNA (deoxyribonucleic acid).
up of nucleotide monomers. Each nucleotide is made up of a phosphate, a sugar a
The phosphates and sugars join together to create a chain with a repeating structure. Two chains join together to form the famous 'double helix', which is the name for the type of spiral seen in DNA.
The repeating structure is shown below:





Comprehension questions

1. Give the monomers of each of these polymers:
   a. polysaccharide
   b. polypeptide
   c. DNA
2. When are polysaccharides broken down into their monomers, and why
3. What components make up a DNA monomer?
4. In DNA, there is an alternating chain of phosphates and sugars. What k the phosphate to the atoms in the sugar? Are these bonds weak or str
5. There is a specific way of drawing polymers showing only one repeati drawing polymers.

Discussion question

Why do you think there are so many kinds of polymer in biology?

Extension

It is difficult to separate these polymer molecules from the rest of a living enough to see them. But if you could, what do you think they would look

Write a short paragraph explaining what state you would expect these po to isolate them. Compare that to the state you would expect a monomer Consider intermolecular forces in your answer.

Further reading

Cellulose is another polymer found in biology. Look it up at **scienceclarified.com/Ca-Ch/Cellulose.html** or find out about it in a bo

Which of the polymers in this article is cellulose most like, and why? How why does it have those differences?

The Hip New Joint in Town

A new alloy has properties for artificial joints

4.2.2.7 Properties of metals and alloys

Keywords

Alloy – a mixture of metals
Hardness – how resistant a material is to being bent or shaped
Corrosion – when a material reacts with oxygen in the air. Corrosion can lead to

Alloys

An alloy is a mixture of metals. Alloys have been used for thousands of years; for example, bronze is an alloy of copper and tin, and the earliest bronze artefacts date from around 4500 BCE. To make bronze, both copper and tin must be melted and then added together in the correct amounts.

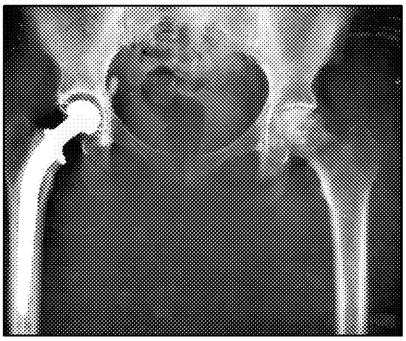
Why did people go to all this trouble thousands of years ago to create alloys? The answer is because of their properties. Pure metals such as copper and tin are very soft and are easily bent. Alloys such as bronze are much harder than the metals from which they are made. Bronze's improved properties made it useful in making armour and weaponry.

Forming an alloy can also change a metal's appearance. The different 'carats' of go because they have different amounts of other metals mixed in. For instance, 18 ca metals. The Ancient Greeks liked to use an alloy called 'white gold' – for ornament 'stainless steel' which is an alloy of iron that includes chromium, is also used for its

Modern alloys

Nowadays we use alloys for many purposes. The most commonly alloyed metal is iron reacts easily with water, causing rust to build up. This process is called corrosi corroding than pure iron.

Alloys are often used in jewellery. Pure gold is very soft, and so can be worn down gold with silver and copper are commonly made to increase the hardness of the g



This X-ray image shows a titanium hip joint.

Alloys for artificial joints

What kind of material would you use for an need to be a material which does not **corro** joint would break down inside the body. It w **durable**, because the two parts of the joint w together as the joint was used. As the metal material must also be **non-toxic**.

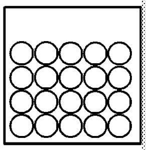
Normally, artificial joints are made from allo non-toxic and reasonably hard.

A new titanium alloy

In 2016, scientists at Rice University in Texas, USA, discovered a new alloy made from **titanium and gold**. When developing this compound, the scientists tested multiple different alloys of titanium, and found that the hardest titanium–gold alloy was when the material had a ratio of 3:1 titanium to gold and so the researchers imaginatively called it titanium-3-gold. This is almost 4 times harder than the pure metal – imagine kicking your toe on a piece of that! Even more importantly it is not toxic, so could be used for long lasting hip-replacements. It's basically the next step to creating Wolverine!

Alloys are hard
the layout of

Pure metal



The layers can slide over each other

The scientists think that the new material would be very useful in applications which need a hard substance, e.g. in artificial joints. It could also be used to create materials for drills or in sports equipment. Ti surprise in store, however. Even though gold and titanium are not **magnetic**, and a catch is that it needs to be cooled to -237°C for this to be seen.

Comprehension questions

1. Explain why titanium is used in medical implants such as artificial joints
2. Draw particle diagrams of tin, copper and bronze.
3. Draw a diagram of the alloy gold–titanium. Remember that it has a rati
4. Explain why this alloy is harder than pure titanium.

Discussion question

Why might or might not the NHS start using this new alloy?

Extension

Some private health companies may be interested in developing high-gra

Write an advert for medical implants made from this new alloy. This advert medical companies.

Further reading

Current artificial joints aren't made of pure titanium. See if you can find o alloyed with.

Supra Alloys have published information about the advantages of titanium biomedical implants here: **supraalloys.com/medical-titanium.php**

Applications of Graphene

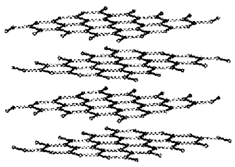
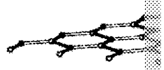
Using graphene to generate electricity

4.2.3.3 Graphene and fullerenes

Keywords
Graphene – a single layer of graphite

What is graphene?

Graphene is a single layer of carbon atoms. It was first discovered by scientists wh tape to remove a few layers at a time until there was only one layer left. Yes, it rea

Graphite	G
	
Multiple layers of carbon atoms	*A single la*

After graphene was first made in this way, more methods were developed for its p larger quantities. Since then, graphene has been used in a wide range of places, b with more uses being developed.

Properties of graphene

Pencils contain gr

Graphene has properties which scientists think will make it very useful. The most important properties of graphene are that it can **conduct electricity** and that it is **very strong** compared to its weight. It is much stronger than graphite because it does not have a layer structure, so it is not soft like graphite is. It also has a very large surface area because all of the carbon atoms are exposed, unlike in graphite where carbon atoms on the inside layers are

Why is graphene strong?

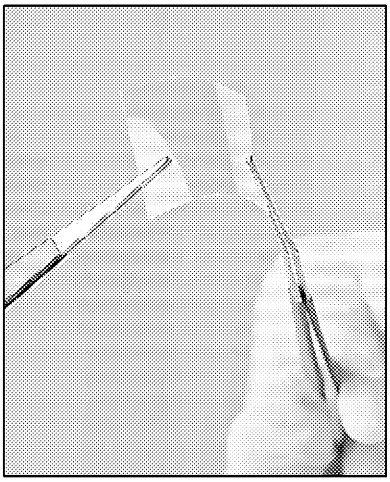
Comparing graphene to graphite, you might expect graphene to be very soft, just l graphite is soft is that the layers can slide over each other. This is what happens wh layers slide off and are left behind on the paper. When this happens, the bonds *wit* bonds are very strong. Graphene is strong because it is held together by these str atoms.

Why is graphene conductive?

Look closely at the diagram of graphene above. Each carbon atom has three covale around it. Carbon has four electrons in its outer shell, but only three of these are us electron is able to move along the graphene layer, and so graphene can conduct el

Printing circuits

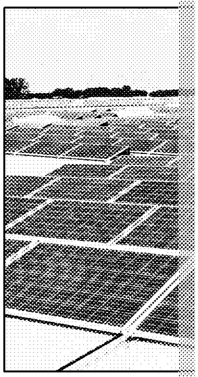
A company in China quickly found a use for graphene by utilising its electrical conductivity: printed electronic circuits.
The company makes see-through plastic films which have circuits printed onto them.



Solar panels

One potential
panels. Resear
have develop
which can abs
light, but not

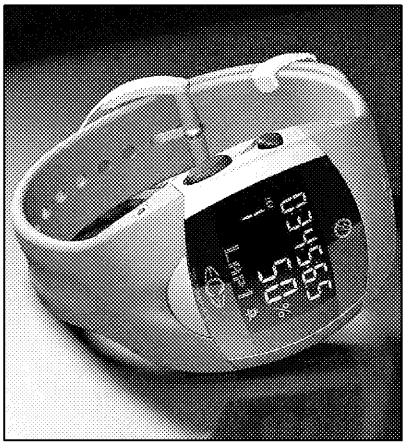
The researche
a textured lay
eyes. This text
more light tha
researchers th
might be used
panels.



Electricity from rain

Another use for graphene's high conductivity could be in generating electricity from rain. Scientists have developed a graphene-based material which can use the salts dissolved in raindrops to generate electrical energy. The graphene material could be used as a coating on solar panels.

Graphene is so thin that the material is transparent and can let the light through, and so the solar panel is not affected. Having a layer of graphene on a solar panel would mean that the solar panels can generate electricity even when it's raining.



Body sensors

One of the most exciting uses of graphene is
Graphene is very flexible, and has been deve
University of Surrey as a body monitor.

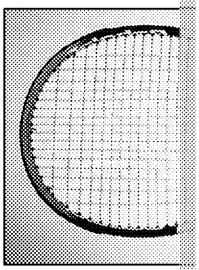
The researchers created a rubber chest strap
allowed the team to measure the breathing
sensor. As the person's chest expanded, the
graphene stretched, the electrical conductivi
measured how fast the graphene stretched,
person was breathing.

Similar future uses for graphene could be gr
measure pulse, breathing rate or movement

Sports equipment

Graphene's high strength has meant that many sports companies are interested in developing it so it can be used in high-performance sports equipment.

Graphene is currently being used in tennis racquets, and many cycling companies are developing graphene so that it can be used to reduce the weight of bicycles.



Comprehension questions

1. Describe why graphene would be a suitable material for:
   a. body sensors
   b. high-performance sport equipment
   c. a coating on solar panels
2. Describe the structure of graphene.
3. Use your answer from 2 to explain why graphene has the properties t

Discussion question

What things in your home could be improved using graphene?

Extension

A dress made from graphene was unveiled in early 2017 which changes c heart beats. Design another item of clothing which incorporates graphene of what it does, and why graphene is a suitable material for this purpose.

Further reading

Graphene has a huge number of applications across all of the sciences. M website which allows you to explore the discovery and applications of gra **graphene.manchester.ac.uk**

It's Not Rocket Science! Oh Wait,

Why NASA needs to know its moles

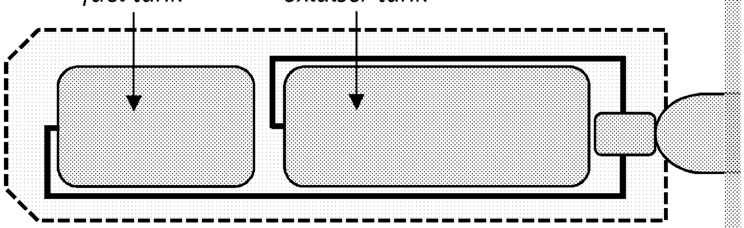
4.3 Quantitative chemistry

Keywords

In excess – a reactant which will not be used up when a reaction has complete
Limiting reactant – the reactant which is not in excess
Conservation of mass – the law that the total mass of products is the same as
Relative formula mass – the sum of the relative atomic masses of the atoms i

How does a rocket work?

Rockets work by burning a fuel, and propelling the exhaust gas (burnt fuel) out th exhaust gas being pushed out the back of the rocket pushes the rocket in the opp reach speeds of up to 3.1 km / s in order to get into orbit.



Rocket scientists need to be very careful about the amount of fuel that goes into a as light as possible while also having enough fuel to propel it fast enough.

Limiting reactants

Rocket engines are usually fuelled by hydrogen. Rockets also carry their own oxyg there's no oxygen in space! Both the fuel and the oxygen are cooled down and pr rather than a gas. This means that the fuel tanks can be smaller.

To figure out how much fuel to put in a rocket, rocket scientists have to calculate t to space. The amount of oxygen required to burn all of that fuel is then calculated ratio of fuel to oxygen is calculated, so that no fuel or oxygen is left over. In a perf the fuel is a **limiting reactant**, and neither reactant is **in excess**.

How many moles of fuel?

Rocket scientists use moles to find the amount of oxygen required to completely b fuel is hydrogen.

The equation for hydrogen burning in a rocket engine is:

$$2H_2 + O_2 \rightarrow 2H_2O$$

106,261 kg of liquid hydrogen is required to lift the space shuttle into space. To fi required, we need to do a mole calculation:

106,261 kg is 106,261,000 g of liquid hydrogen.
The relative formula mass of hydrogen is 2.
The number of moles of hydrogen is $\frac{106,261,000}{2}$ = 53 130 500 moles.

To find the number of moles of oxygen, we need to look at the ratio they react in. that every two moles of hydrogen react with one mole of oxygen. In other words, oxygen.

Half of 53,130,500 is $\frac{53,130,500}{2}$ = 26 565 250 moles of oxygen.
Oxygen has a relative formula mass of 16.
The mass of oxygen required is 26 565 250 × 32 = 850 088 000 g = 850 088

What mass of exhaust gas?

The whole reason rocket fuel is burnt is so that it is ejected from the rear of the rocket. Rocket scientists need to know what the mass of the exhaust gas is, so that they can tell how fast the rocket will accelerate. To find the mass of the exhaust gas we can do another mole calculation.

From the reaction, we know that every two moles of hydrogen is converted into two moles of water. In other words, there is a 1:1 ratio of hydrogen to water.

We know from earlier that the number of moles of hydrogen in the rocket is 53,130,500 moles.

This is the same as the number of moles of water produced.

The relative formula mass of water is 18.

The amount of exhaust gas produced is 53 130 500 × 18 = 956 349 000 g = 956 349 kg.

Conservation of mass

Compare the mass of the reactants with the mass of the products. At the start, there was 106,261 kg of hydrogen and 850,088 kg of oxygen. In total there was 106,261 + 850,088 = 956,349 kg of reactants.

This is the same mass as the mass of products (exhaust gas). This is because of a **mass**.

No atoms are made or destroyed when a rocket burns its fuel. As in all chemical rearranged to form new molecules. The same atoms are in the products and react not go up or down.

Comprehension questions

1. Hydrazine, N_2H_4, is another rocket fuel. Unlike hydrogen, it does not n also does not need to be cooled, because it is a liquid.
   Hydrazine reacts in the following equation:

   $$3N_2H_4 \rightarrow 4NH_3 + N_2$$

   a. Explain why there are no limiting reactants in this reaction.
   b. 118,300 kg of hydrazine fuel was used to launch Titan II.
      i. Calculate the relative formula mass of hydrazine (N_2H_4), amm
      ii. Calculate the number of moles of hydrazine used in launchin
      iii. Calculate the mass of nitrogen produced during the launch.
      iv. Calculate the mass of ammonia produced during the launch.
      v. Add up the masses of ammonia and nitrogen. Their total mas starting mass of hydrazine. Explain why.

Discussion question

In a rocket, it is important to calculate the exact amount of fuel and oxyge that neither is in excess. What would happen if one was in excess?

Extension

Research and write an informative blog post about the advantages and dis or hydrogen-oxygen as rocket propellant.

Further reading

You may have noticed that the space shuttle in the picture in the article ha the liquid fuel tank. These are solid rocket boosters, which give the rocket launch. Have a look at **blogs.nasa.gov/Rocketology/2016/04/21/weve**

See if you can find out which chemicals are used in the boosters, and whic chemicals are produced.

Acidophiles and Alkaliphiles

The bacteria which can survive at dangerous pH levels

4.4.2.4 Acids and alkalis

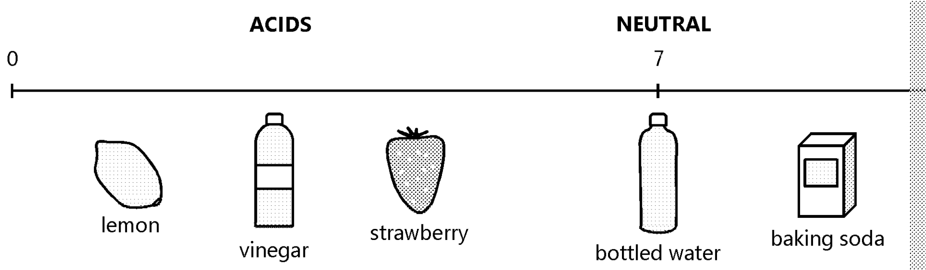
Keywords

Strong acid – an acid which completely ionises in water, releasing all of its H^+
Extremophile – a bacteria which can survive under extreme conditions, e.g. ve
temperature.
Acidophile – an 'acid lover'. Bacteria which can survive in very acidic (low pH)
Alkaliphile – an 'alkali lover'. Bacteria which can survive in very alkaline (high

Acids and alkalis

You may have come across some acids and alkalis in your school laboratory. You acid) and vinegar (ethanoic acid) are both acids, and that bleach and baking powd

The level of acidity and alkalinity of a solution is measured using the pH scale. Hig pH is acidic. You probably know that very acidic solutions can be dangerous, but y is true for very alkaline solutions. Some alkalis can corrode skin in the same way a



Acidophiles

Acidic solutions can be found all over the world. The most acidic natural environm or in rivers flowing from abandoned mines. In these environments, people wouldn some bacteria – called **acidophiles** – which thrive in these environments. In one ca bacteria were found in water at pH 0!

The bacteria are actually responsible for producing the acids. Acidophiles convert sulfuric acid.

$$2FeS_2 + 2H_2O + 7O_2 \rightarrow 2FeSO_4 + \ldots$$

pyrite + water + oxygen → iron sulfate +

The sulfuric acid is a **strong acid**, which means that it completely ionises in water, surrounding the acidophiles. As the acidophiles digest more pyrite rock, more sulf environment's pH gradually lowers. Acidic pHs kill many of the organisms which w but extremophiles continue living because they can easily control the pH inside th

How do acidophiles survive?

The most amazing thing is, these bacteria are basically neutral pH inside their cell The bacteria use a 'proton pump', which removes H^+ ions from the cell. This lower the cell, and keeps the pH around 7.

Alkaliphiles

Strongly alkaline environments, once thought to be impossible for life to grow in, have recently been found to be full of bacterial life. Mono Lake in California is home to **alkaliphilic** bacteria which can survive up to pH 11. These bacteria, like acidophiles, manage to keep the pH inside their cells down to around pH 7.

Alkaliphiles also have to move H^+ ions across their cell membranes, but in the other direction to acidophiles. Alkaliphiles have to pump H^+ ions into their cells. This causes a neutralisation reaction between the OH^- ions and the H^+ ions, which lowers the pH.

$$H^+ + OH^- \rightarrow H_2O$$

Comprehension questions

1. Give the neutralisation reaction used by alkaliphiles to keep their cellu
2. Explain why the digestion of pyrite leads to acidic conditions.
3. Sulfuric acid is a strong acid. Explain what this means.

Discussion question

Acidophiles often develop in abandoned mine shafts, digesting pyrite and
How might this affect the organisms living in the environment?

Extension

Mud volcanoes emit iron sulfide. Draw a picture of a mud volcano, and la
see high, low and neutral pH levels if you were to test the soil around the

Further reading

Alkaliphiles can be categorised into obligate alkaliphiles, facultative alkali
you can find out the difference between these categories using **en.wikipe**

When you find out, predict which of these is likely to be the one at Mono
concentration of salt.

Making Heavy Water

And other cool things you can do with electrolysis

4.4.3 Electrolysis

Keywords

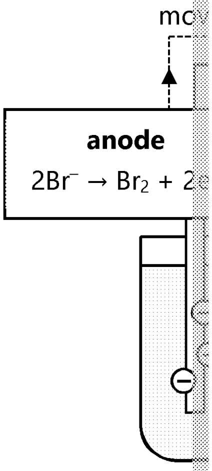
Electrolyte – the liquid which has electrodes inserted into it
Anode – the electrode which anions are attracted to
Cathode – the electrode which cations are attracted to

Electrolysis

Electrolysis is a process which uses electricity to separate the elements in a compound. Electrodes are placed into the electrolyte, and the ions in the electrolyte migrate to the electrodes depending on their charge.

Electrolysis can only happen when the ions in the compound are free to move, i.e. when the compound is in the liquid or aqueous state. When the compound is solid, the ions are fixed in place and so cannot move to the electrodes.

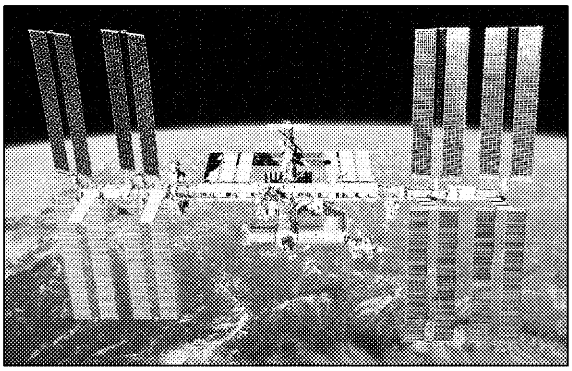
Ke



In the electrolysis o
are produced. Br
catio

Common uses of electrolysis

Electrolysis of some compounds is easy. Lead bromide, for example, melts very easily, and so lead and bromine can easily be extracted. Aluminium oxide is a bit trickier because its melting point is over 2,000 °C, so much more energy is required to separate the aluminium. Scientists use a compound called cryolite in order to dissolve the aluminium oxide. Cryolite is a solid at room temperature, but melts at about 1,000 °C. When it melts, it is possible to dissolve solid aluminium oxide in it. This allows aluminium oxide to be dissolved at much lower temperatures, so less energy is required.



The International Space Station (ISS) uses large solar panels to generate electricity used to perform electrolysis of water to produce oxygen. The electricity is also used to power the exercise equipment, lights and life-support systems.

Power sources

Fossil fuels aren't the only opti
electrolysis. In fact, because it u
electrolysis plants are develope
The most common source of p
Hydroelectric power stations u
electricity. The water runs past
converts the movement of the
electrolysis process.

On the International Space Sta
convert water into oxygen, whi
astronauts and cosmonauts on
hydrogen is jettisoned into spa
hoping to use it to produce me

Separating water

Electrolysis was first used in 1785 to separate metals from their salts, and, only 15 y separate the hydrogen and oxygen in water. Separating water is a very valuable pr produced can be used as a fuel in **fuel cell cars**. Generally, fossil fuels still need to electrolysis process which produces hydrogen and oxygen, but because this occurs each individual car, the process is much more energy efficient, and the carbon diox collected rather than released into the atmosphere.

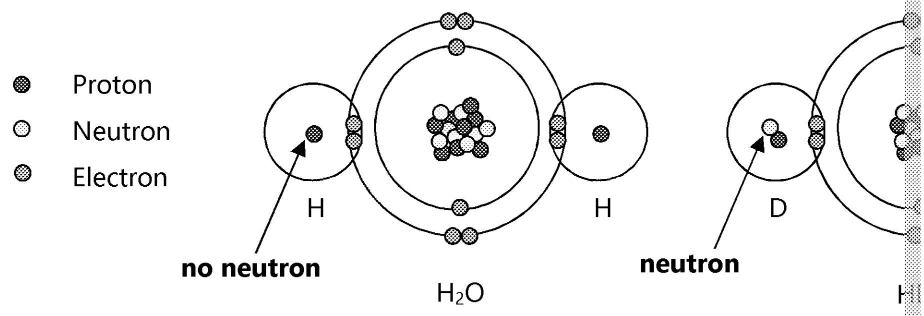
When water is electrolysed, the following half-equations occur:

Cathode	Anode
$2H^+ + 2e^- \rightarrow H_2$	$4OH^- \rightarrow O_2 + 2H_2O +$ 4

Producing deuterated water

An interesting outcome of electrolysis was developed at the Vemork hydroelectric Norway. The hydroelectric plant was used to create a substance known as **'heavy** electrolysis process ran for long enough, the water remaining in the electrolysis ta hydrogen with one neutron instead of two.

This isotope of hydrogen is known as **Deuterium**, which has the chemical symbol called **deuterated water**, and its chemical formula can be written as HDO. The dia between H_2O and HDO in terms of subatomic particles: the only difference is that neutron.



Deuterated water is separated much less easily than regular water, so HDO is left '

The scientists measured that 1 in 6,400 hydrogen atoms in water is deuterium. In th electrolysis, about 1 in 40 hydrogen atoms was deuterium. The power station was Allied forces in order to prevent Nazi forces from developing an atomic bomb usi

Deuterated water is now used to create deuterium (D_2), which can be used in nucl

You can also buy deuterated water, starting at £18 for 10 g. Pricey!

Comprehension questions

1. Explain why electrolysis must be performed on liquids or solutions and
2. Describe how aluminium is extracted from its oxide, and explain why th
3. Explain how electrolysis is used on the International Space Station.
4. How is deuterated water produced?
5. Write the half-equations for the electrolysis of water.

Discussion question

Electrolysis is often used to separate metals from ions in their salts. What c your GCSE course can you think of to separate copper metal from copper come in handy.

Extension

D_2, hydrogen gas with two deuterium isotopes of hydrogen, is produced u Suggest a two-step electrolysis process to produce D_2 from ordinary wate deuterium atom per 6,400 atoms of hydrogen).

Further reading

If you are interested in the production of heavy water in Norway, search fo *Sabotage* on Wikipedia.

The article 'Breathing Easy on the Space Station', at **science.nasa.gov/scie nasa/2000/ast13nov_1** has some more information about air manageme Space Station.

Is the future of electric cars in chemical or fuel cells?

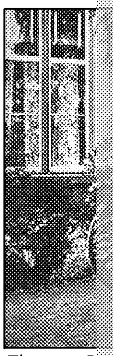
4.5.2 Chemical cells and fuel cells

Keywords

Chemical cell – contains chemicals which can react to produce electricity
Fuel cell – constantly supplied fuel which can react to produce electricity

A brief history of electric cars

You might think that electric cars are a thing of the future. Almost every car you'll see on the road is powered by petrol or diesel, and occasionally you'll see a hybrid, which is powered partially by electricity.

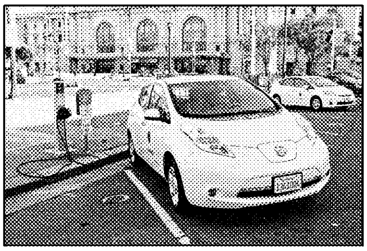


Thomas P
invented.

But in the late 1800s to early 1900s, the most popular cars ran on electricity. At that time, electric motors were more comfortable and easier to use than cars which used internal combustion engines (petrol engines).

But as the internal combustion engine became easier to use, electric cars became unpopular due to their limited top speed and range.

For about 100 years, internal combustion engines have ruled the road. But as peo
about the effects of global warming, electric cars are being developed again.



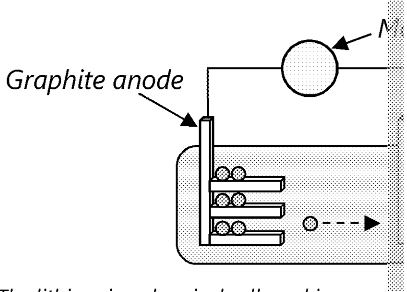
The Nissan Leaf *is the most-sold electric car in the world.*

Using chemical cells in electric cars

Many big car manufacturers are now developing
lead the electric car market, having sold over a q
Nissan uses a rechargeable battery made from li
chemical cells contain a graphite cathode and a l
electrolyte is a gel polymer. This is a **chemical c**
its reactants.

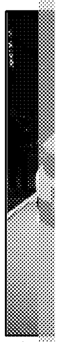
When the cell is being charged, positive lithium ions build up on the graphite electrode. When the car is in use, the positive lithium ions move from the anode to the cathode (as shown in the diagram), and electrons move through the motor.

Lithium ion cells are rechargeable because the movement of lithium ions is a reversible chemical reaction. The recharging process for a car using these cells takes between four and eight hours.



The lithium ion chemical cell used in many
direction that lithium ions move during us
way when the cell is being recharged.

Fuel cells in electric cars



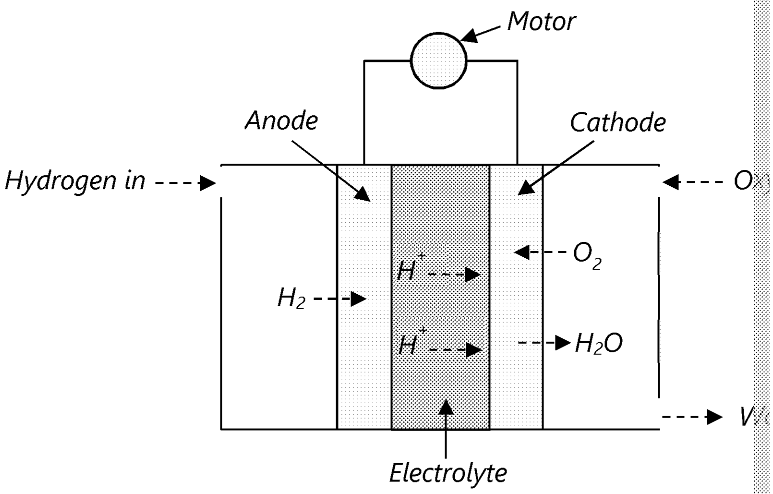
The t
the r

Some electric cars use fuel cells instead of chemical cells. Fuel cells also produce electricity, but they do not contain their reactant as chemical cells do. Instead, they may contain one reactant, such as hydrogen, and then use another one from the air, such as oxygen.

The development of fuel cell cars is at a much earlier stage than that of chemical cell cars. At the beginning of 2017, there were only three fuel cell cars in production, all of which use hydrogen fuel cells.

The advantage of a fuel cell is that the fuel can be topped up in a tank, and is immediately ready for use. In comparison, a chemical cell needs many hours to recharge.

In hydrogen fuel cells, hydrogen enters the side of the anode and oxygen enters th move across the electrolyte and water (H_2O) is formed at the cathode.



Putting hydrogen fuel cells in cars is difficult, because the hydrogen is very explosi small spark could lead to a rather large explosion! Owning a hydrogen car can be d pumps are not as common as petrol and diesel pumps, and so hydrogen cars are d

This table shows what happens at each electrode. The electrons in the half-equatio travel through the motor, and are used at the cathode to make water.

Electrode	Anode	Catho
Role	Converts hydrogen (H_2) into hydrogen ions (H^+)	Converts ox water (using h ions)
Half-equation	$2H_2 \rightarrow 4H^+ + 4e^-$	$O_2 + 4H^+ + 4e$
Full equation	$2H_2 + O_2 \rightarrow 2H_2O$	

Comprehension questions

1. Some of the first vehicles ran on alkaline batteries which undergo an i when they generate electricity. Describe why lithium ion cells are bette running cars.
2. Give the half-equations occurring at each electrode in a hydrogen fue
3. What kind of ion moves through the electrolyte in a hydrogen fuel ce
4. Why do people think it is important to develop electric cars?
5. Describe the difference between a chemical cell and a fuel cell.
6. What are the advantages and disadvantages of using a car running o rather than a hydrogen fuel cell?

Discussion question

Which of chemical cells or fuel cells is going to be the future of cars, and

Extension

Your local council wants to prepare your local area for the future. It has d fuel stations for fuel cell cars, or to build electric power lines to refill chem

Write a letter to your councillor to persuade them of which you think the

Further reading

The Union of Concerned Scientists explain how a plug-in hybrid car work **ucsusa.org/clean-vehicles/electric-vehicles/how-do-plug-in-hybrid-e**

See if you can find out how plug-in hybrid cars work. Some people think t stepping stone towards introducing more all-electric cars. Why do you th

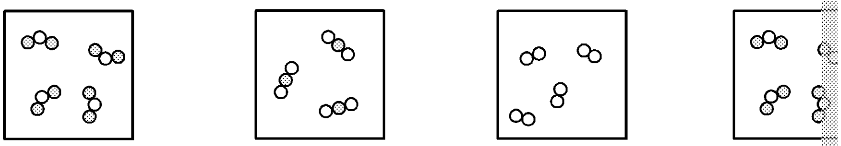
Answers

Elements (and Compounds) of Life

1. By chemical reactions in water
   Arrived on a comet or asteroid

2. Nitrous oxide is a compound
   Boron is an element

3.



Water (H_2O) Carbon dioxide (CO_2) Oxygen (O_2) Sulfur dioxid

Periodic Updates

1. Gallium and germanium

2. By atomic number (number of protons)

3. Elements in columns (groups) have similar chemical properties

4. Argon (Ar) and Potassium (K) / Iodine (I) and Tellurium (Te) / Cobalt (Co) and Nickel (

Aurora Borealis

1. Protons and electrons

2. Protons: +1
   Electrons: -1

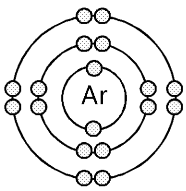
3. With atoms of nitrogen and oxygen

4. Charged particles like electrons from solar wind knock electrons off atoms, forming i
   get their electrons back, light is emitted.

5. Nitrogen and oxygen are the most common atoms in our upper atmosphere.

What Do You Call a Noble Gas?

1.



2. They have a full outer shell, and do not form ionic, metallic or covalent bonds.

3. It increases down group 0 (with increasing atomic mass).

Mete-ores

1. Because asteroids are made from transition metals, which are worth a lot of money

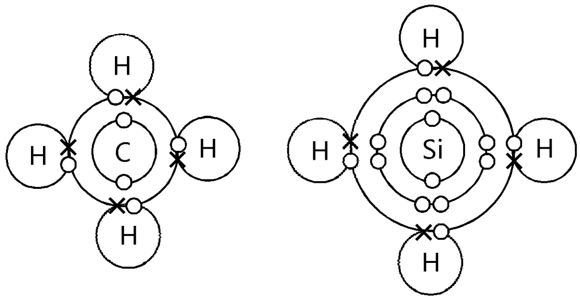
2. Platinum/iron/cobalt

3. • Catalyst for margarine production
   • Alloyed with nickel to make smart alloys.

4. They do not contain transition metals (they contain carbon/silicon)

Silicon Lifeforms

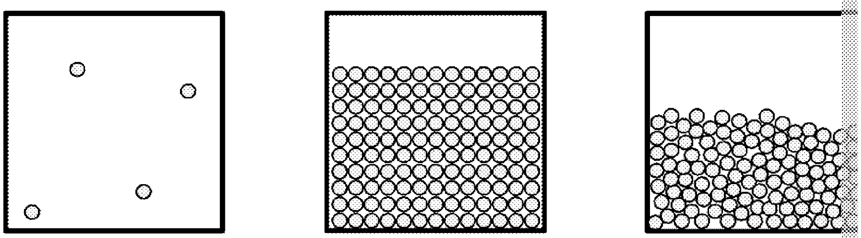
1. Diatoms (algae), which use silica for their cell walls.
2. It was the first example of biological life producing a carbon–silicon bond.
3. To create carbon–silicon bonds in the manufacture of drugs and materials.
4. TV and computer screens, paints, glues and solar panels.
5.



Trapped Gas

1.

Methane | **Ice** | **Liquid water**



$CH_4(g)$ | $H_2O(s)$ | $H_2O(l)$

2. Methane has weaker forces between particles, so less thermal energy (a lower tem forces between molecules than in water, where the forces between molecules are q

Seventeenth-century Nanoscience

1. 10^{-7}–10^{-9} m
2. Buckyballs: spheres of carbon organised in hexagonal (and pentagonal) rings.
   Carbon nanotubes: hollow tubes/cylinders of carbon organised in hexagonal rings.
3. Iron containing carbon organised into nanotubes.
4. The nanotubes run as fibres through the steel structure and increase the forces bet increases the strength of the metal without causing it to become brittle.

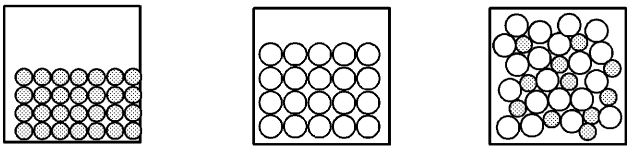
Biopolymers

1. a. saccharide or sugar
   b. amino acid
   c. nucleotide
2. During digestion, so that the sugar can be used for energy.
3. A base, a phosphate and a sugar
4. Covalent bonds, which are strong
5. • square brackets
   • n to show repeat
   • repeating monomer inside the brackets
   • bonds from the edge atoms to outside the brackets

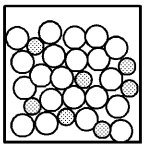
The Hip New Joint in Town

1. It is non-corrosive, hard and non-toxic.

2. Tin Copper Bronze



3. Titanium: ○ Gold: ◎



Ratio of titanium to gold must be 3:1. Here, there are 21 titanium ions and seven go

4. In pure titanium, ions are in layers which can slide over each other. In the alloy, diff layers, so the metal cannot easily be reshaped.

Applications of Graphene

1. a. It can conduct electricity and is flexible
   b. It is very strong
   c. It is transparent, absorbs light and conducts electricity

2. A single layer of graphite, with carbon atoms bonded in a hexagonal lattice. Every c electron from each carbon is delocalised.

3.
   - The regular, strong covalent bonds mean that graphene is very strong.
   - The delocalised electrons allow charge to flow, so graphene is conductive.
   - Graphene is flexible as it is in single layers.

It's not rocket science! Oh wait, it is.

1. a. Hydrazine does not react with anything.
   b. i. N_2H_4: 2×14 + 4×1 = 32
   NH_3: 14 + 3×1 = 17
   N_2: 14 × 2 = 28

   ii. 118 300 kg = 118 300 000 g
   Moles of hydrazine = $\frac{11,300\,000}{32}$ = 3 696 875 mol

   iii. 3:1 ratio of hydrazine : nitrogen.
   Moles of nitrogen = $\frac{3\,696\,875}{3}$ = 1 232 292 mol
   Mass of nitrogen = 1 232 292 × 28 = 34 504 176 g (34 504 kg)

   iv. 3:4 ratio of hydrazine to ammonia.
   Moles of ammonia = $\frac{3\,696\,875}{3}$ × 4 = 4 929 167 mol
   Mass of ammonia = 3 696 875 × 17 = 83 795 833 g (83 796 kg)

   v. 34 504 + 83 796 = 118 300 kg
   Conservation of mass – no atoms are created or destroyed.

Acidophiles and Alkaliphiles

1. $H^+ + OH^- \rightarrow H_2O$
2. FeS_2 is digested by bacteria to produce sulfuric acid.
3. It completely dissociates when dissolved in water. This leads to a high concentration of

Making Heavy Water

1. The ions must be able to move.
2. It is dissolved in molten cryolite. Cryolite melts at 1000 °C, and aluminium oxide melt dissolving in cryolite is more energy efficient.
3. It is used to split water into oxygen and hydrogen. The hydrogen is not used but the by the astronauts.
4. Electrolysis of water over a long time, and it builds up.
5. $2H^+ + 2e^- \rightarrow H_2$
   $4OH^- \rightarrow O_2 + 2H_2O + 4e^-$

Shocking New Development

1. Lithium ion cells are rechargeable, so can be used more than once.
2. $2H_2 \rightarrow 4H^+ + 4e^-$
   $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$
3. H^+
4. Electric cars do not use fossil fuels to run.
5. Chemical cells contain their reactants, whereas fuel cells contain a fuel and use a con oxygen from the air.
6. **Advantage**: Rechargeable cells are safer because they do not need to store hydroger
   Disadvantage: Fuel cells are quicker to refuel than rechargeable cells because they c
   Chemical cells need to charge, which can take a long time.