Opening extract from

How to Build a Universe from 92 Ingredients

Written by

Adrian Dingle

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Desk Editor: Rebecca Lee

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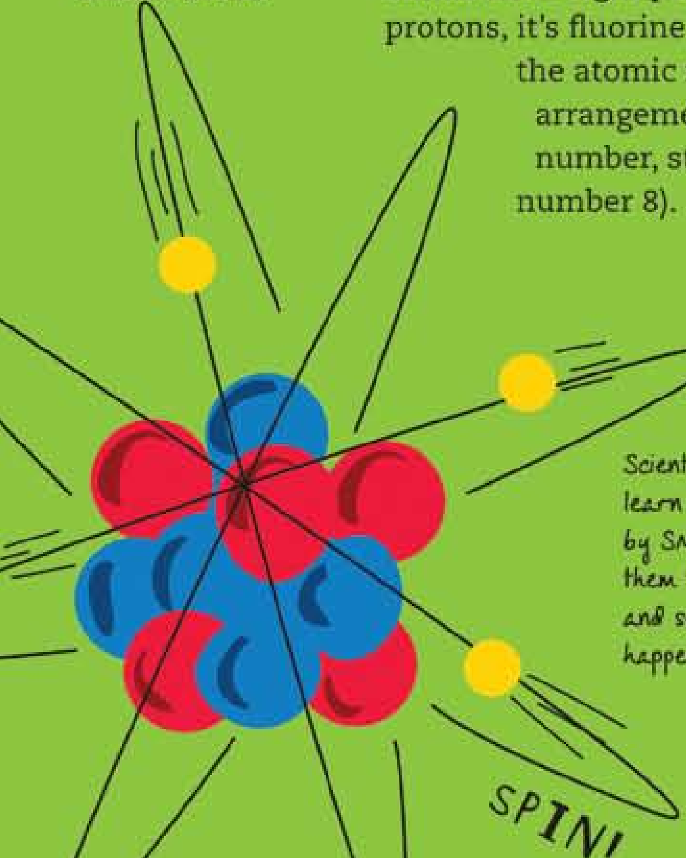
IT'S ELEMENTARY

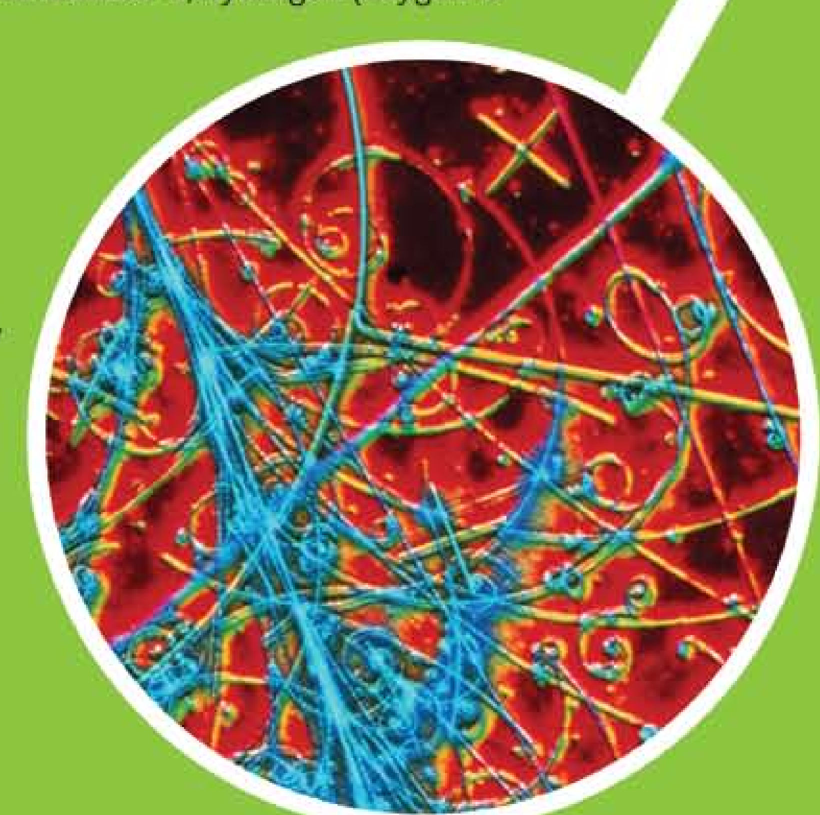
This book is about the elements. There aren't many of them, but they make up everything you see. They make up the world. In fact, they make up the whole universe. Oh ... and they make up YOU, too!

Chemists define an element as a substance that cannot be broken down into simpler substances by chemical means. If we take an element and try a chemical reaction with it, it cannot become any LESS complicated. It can only become MORE complicated (it can form a compound, say, by bonding together with a bunch of other elements). Each element is made up of very, very, very tiny particles called atoms. In turn, the atoms are made of subatomic particles: protons, neutrons and electrons. All the atoms of a particular element have the same number of protons and electrons. The number of protons DEFINES the element. If the atoms have eight protons, the element is oxygen; if there are nine protons, it's fluorine and so on. The number of protons is called the atomic number. All the elements are listed in an arrangement called the periodic table in order of atomic number, starting with number 1, hydrogen (oxygen is number 8).

The protons and neutrons form a dense nucleus and the electrons arrange themselves in bunches outside.

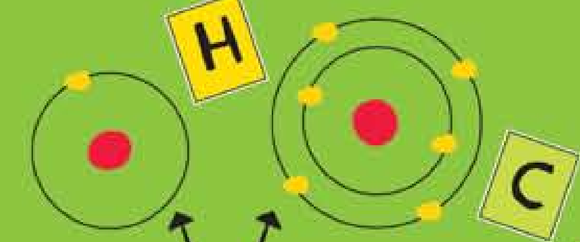


Scientists try to learn about atoms by SMASHING them together and seeing what happens.

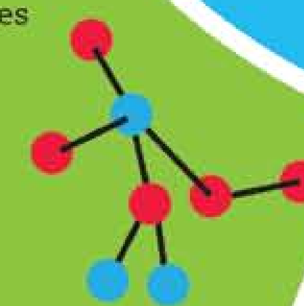


Neutron numbers

Although the atoms of an element have fixed numbers of protons and electrons, they can have different numbers of neutrons. Atoms of the same element with different numbers of neutrons are called isotopes. Most elements have several isotopes. Chlorine, for example, has two common types of atom; both have 17 protons and 17 electrons, but one has 18 neutrons and the other has 20 neutrons. The different numbers of neutrons mean that the different isotopes have different masses, or weights.



Hydrogen has one electron; carbon has six.



Are there really 92 naturally occurring elements?

Well, yes ... and no. All the elements with atomic numbers 1 to 92 do occur on Earth. But it's a bit more complicated than that! Of the 92 naturally occuring elements, some are very, VERY rare. Francium (87) and astatine (85) make up no more than a few grams each in the Earth's crust at any one time. Other radioactive elements from when Earth was formed (over 4.5 BILLION years ago) have virtually disappeared by decaying naturally, like technetium (43) and promethium (61). Elements 93 and 94 (plutonium and neptunium) also occur naturally, but again in ultra-tiny amounts. So, depending on which elements you count, you could argue that there are as few as 88 natural elements on Earth ... or as many as 94.

Every element has a symbol which is an abbreviation of its name. Some are pretty crazy, like Pb (lead). They're often based on elements' old names – but they've stuck!

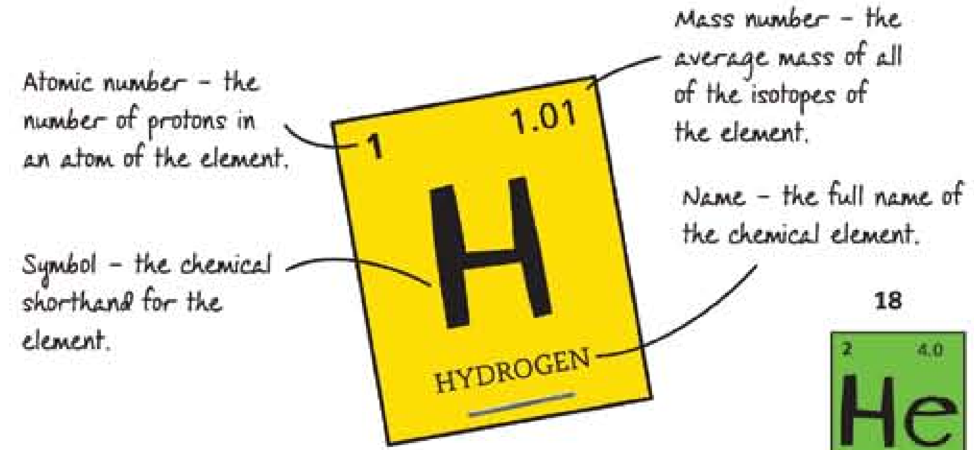
Tm Pa Eu Cf Th Pr

Above number 92

A periodic table (there's one on the next page) lists elements with atomic numbers higher than 92 ... up into the 100s. These elements don't occur naturally on Earth; they have to be made in laboratories. IUPAC (the International Union of Pure and Applied Chemistry) recognizes 112 elements (number 112 doesn't have an official name or symbol yet). These super-heavy elements are all radioactive; in many cases only a few atoms have ever been produced, maybe for fractions of a second. This usually means that they are not much use in the real world BUT at least one of these synthetic elements may be in your house RIGHT NOW! Element number 95, Americum, is used widely in smoke detectors!

The Periodic Table

The periodic table tells us loads about the elements and how they behave. It's like a guide to the whole universe ... all on a single piece of paper.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H 1.01 HYDROGEN																	2 He 4.0 HELIUM
2	3 Li 6.94 LITHIUM	4 Be 9.01 BERYLLIUM											5 B 10.81 BORON	6 C 12.01 CARBON	7 N 14.01 NITROGEN	8 O 16 OXYGEN	9 F 18.99 FLUORINE	10 Ne 20.12 NEON
3	11 Na 23.00 SODIUM	12 Mg 24.31 MAGNESIUM											13 Al 27.00 ALUMINIUM	14 Si 28.10 SILICON	15 P 31.00 PHOSPHORUS	16 S 32.10 SULPHUR	17 Cl 35.45 CHLORINE	18 Ar 39.95 ARGON
4	19 K 39.10 POTASSIUM	20 Ca 40.01 CALCIUM	21 Sc 44.96 SCANDIUM	22 Ti 47.88 TITANIUM	23 V 50.94 VANADIUM	24 Cr 52 CHROMIUM	25 Mn 54.94 MANGANESE	26 Fe 55.85 IRON	27 Co 58.93 COBALT	28 Ni 58.69 NICKEL	29 Cu 63.55 COPPER	30 Zn 65.39 ZINC	31 Ga 69.72 GALLIUM	32 Ge 72.61 GERMANIUM	33 As 74.92 ARSENIC	34 Se 78.96 SELENIUM	35 Br 79.9 BROMINE	36 Kr 83.8 KRYPTON
5	37 Rb 85.47 RUBIDIUM	38 Sr 87.62 STRONTIUM	39 Y 88.91 YTTRIUM	40 Zr 91.22 ZIRCONIUM	41 Nb 92.91 NIOBIUM	42 Mo 95.94 MOLYBDENUM	43 Tc (98) TECHNETIUM	44 Ru 101.07 RUTHENIUM	45 Rh 102.91 RHODIUM	46 Pd 106.42 PALLADIUM	47 Ag 107.87 SILVER	48 Cd 112.41 CADMIUM	49 In 114.82 INDIUM	50 Sn 118.71 TIN	51 Sb 121.75 ANTIMONY	52 Te 127.6 TELLURIUM	53 I 126.9 IODINE	54 Xe 131.29 XENON
6	55 Cs 132.91 CAESIUM	56 Ba 137.33 BARIUM	57 La* 138.91 LANTHANUM	72 Hf 178.49 HAFNIUM	73 Ta 180.95 TANTALUM	74 W 183.85 TUNGSTEN	75 Re 186.21 RHENIUM	76 Os 190.2 OSMIUM	77 Ir 192.22 IRIDIUM	78 Pt 195.08 PLATINUM	79 Au 196.97 GOLD	80 Hg 200.59 MERCURY	81 Tl 204.38 THALLIUM	82 Pb 207.2 LEAD	83 Bi 208.98 BISMUTH	84 Po (209) POLONIUM	85 At (210) ASTATINE	86 Rn (222) RADON
7	87 Fr (223) FRANCIUM	88 Ra (226) RADIUM	89 Ac** (227) ACTINIUM	104 Rf (257) RUTHERFORDIUM	105 Db (260) DUBNIUM	106 Sg (263) SEABORGIUM	107 Bh (262) BOHRIUM	108 Hs (265) HASSIUM	109 Mt (266) MEITNERIUM	110 Ds (271) DARMSTADTIUM	111 Rg (272) ROENTGENIUM							

*Lanthanoid series	58 Ce 140.12 CERIUM	59 Pr 140.91 PRASEODYMIUM	60 Nd 144.24 NEODYMIUM	61 Pm (145) PROMETHIUM	62 Sm 150.36 SAMARIUM	63 Eu 151.96 EUROPIUM	64 Gd 157.25 GADOLINIUM	65 Tb 158.93 TERBIUM	66 Dy 162.5 DYSPROSIUM	67 Ho 164.93 HOLMIUM	68 Er 167.26 ERBIUM	69 Tm 168.93 THULIUM	70 Yb 173.04 YTTERBIUM	71 Lu 174.97 LUTETIUM
**Actinoid series	90 Th 232.04 THORIUM	91 Pa 231.04 PROTACTINIUM	92 U 238.03 URANIUM	93 Np 237.05 NEPTUNIUM	94 Pu (244) PLUTONIUM	95 Am (243) AMERICIUM	96 Cm (247) CURIUM	97 Bk (247) BERKELIUM	98 Cf (251) CALIFORNIUM	99 Es (252) EINSTEINIUM	100 Fm (257) FERMIUM	101 Md (258) MENDELEVIUM	102 No (259) NOBELIUM	103 Lr (260) LAWRENCIUM

Let's form a group!

The periodic table arranges the elements into seven horizontal rows, or periods, numbered at the side, and 18 columns, or groups, numbered at the top. The chemicals in each group have the same number of electrons in their outer shell, so they tend to react in similar ways and have similar properties. Several groups have family names. The most common include:

Group 1 - The Alkali Metals
Group 2 – The Alkaline Earth Metals
Group 11 – The Coinage Metals
Group 15 – The Pnictogens
Group 16 – The Chalogens
Group 17 – The Halogens
Group 18 – The Noble Gases

KEY

Metals:
- 1 ALKALI METALS
- 2 ALKALINE EARTH METALS
- TRANSITION METALS
- LANTHANOIDS
- ACTINOIDS
- OTHER METALS

- SEMI-METALS

Non-metals:
- 16 CHALCOGENS
- 17 HALOGENS
- 18 NOBLE GASES

I'm Gonna Make You A STAR

Stars are cool. Of course, er, they're also VERY hot. Without our nearest star, the Sun, there would be no life on Earth (and you wouldn't be reading this).

Stars are massive collections of hot plasma. They form in space when hydrogen and helium nuclei (and a few heavier elements like oxygen and carbon) collapse in on themselves to create a huge ball of really hot gas. Inside the star nuclear reactions take place where new elements are formed. In the process, HUGE amounts of energy are released. In time the pressure and temperatures at the star's centre grow and lots of other nuclear reactions can take place, forming many other elements such as silicon, magnesium, sulphur and even iron.

Plasma is the term used in physics and chemistry for a gas that contains lots of charged particles or ions.

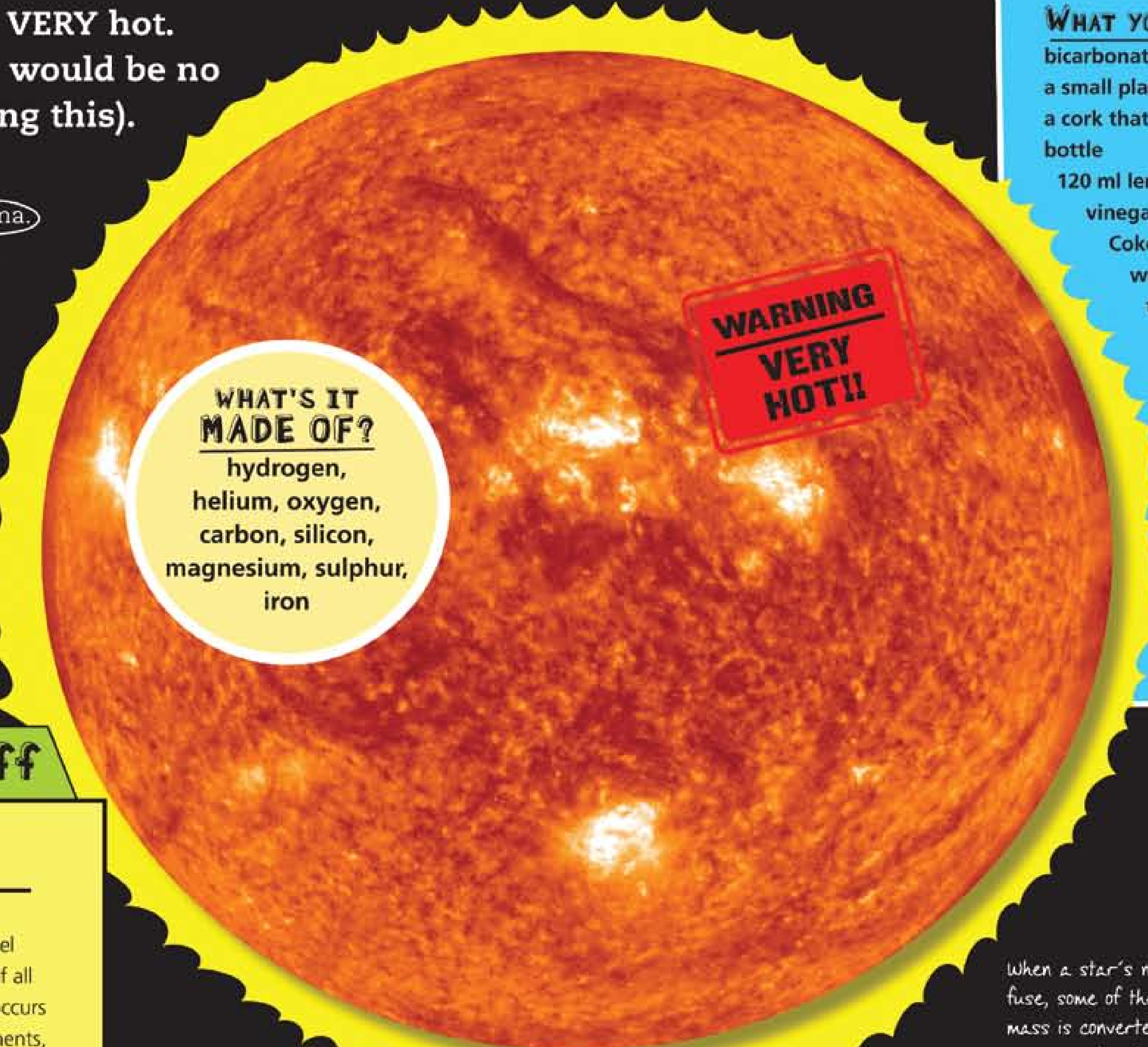
Elementary stuff

1 H HYDROGEN 1.01

Hydrogen

- **Atomic Number: 1**
- Atomic Mass: 1.01
- **Isotopes: 3 naturally occurring isotopes**
- Boiling Point: -253 ˚C
- **Melting Point: -259 ˚C**

Around 90 per cent of all atoms in the universe are hydrogen atoms. It is the fuel that makes stars glow. It is the lightest of all gases, and the most reactive. It usually occurs on Earth in combination with other elements, especially with oxygen – as water. It is also a basic element of life, with carbon and oxygen.



WHAT'S IT MADE OF?
hydrogen, helium, oxygen, carbon, silicon, magnesium, sulphur, iron

Learning about stars

No-one has ever been to a star, of course. We know about them from the light they give off. The light reveals which elements are inside, the star's temperature and even its age.

TRY THIS: Baking Soda ROCKET

You could fly among the stars with a rocket … But don't get TOO close!
SAFETY TIP: Flying corks can be dangerous so wear some eye protection!

WHAT YOU'LL NEED
- bicarbonate of soda
- a small plastic bottle
- a cork that fits the bottle
- 120 ml lemon juice
- vinegar
- Coke
- water
- toilet paper
- cotton

1 Take a large piece of toilet paper and put a tablespoon of bicarbonate of soda in the middle. Wrap the toilet paper around the baking soda and tie it up with a piece of cotton to make a small packet.
2 Put the lemon juice into the bottom of the bottle.
3 Add water carefully to the bottle by pouring it gently down the inside walls until the bottle is about half full.
4 Drop in the bicarbonate of soda packet and quickly pop in the cork.
5 Shake the bottle, place it on the ground and stand back!
6 Repeat the experiment using the vinegar or the Coke in place of the lemon juice.

How does that work?: Bicarbonate of soda is a chemical called sodium hydrogen carbonate. Lemon juice, vinegar and Coke all contain acids. When carbonates react with acids they produce carbon dioxide gas. The gas increases the pressure inside the bottle … until it eventually blows out the cork!

De-confusing fusion

About 98–99 per cent of the sun is made up of only two elements, hydrogen and helium. Hydrogen nuclei crash into one another and 'fuse' or join together. In the process they create helium and release a massive amount of energy. Also present in stars are oxygen, carbon, nitrogen, silicon, magnesium, neon, iron and sulphur.

When a star's nuclei fuse, some of their mass is converted to energy … heat! LOTs and LOTs of heat!

ILLUMINATION!

A lightbulb needs just three parts. The tricky bit is to get something hot enough to glow … without bursting into flames!

1 A FILAMENT: The glowing part of the bulb is made of 2 metres of very thin tungsten wire wound into a double coil.

2 INERT GAS: When it is hot enough to glow, the tungsten filament could react with oxygen in the air and combust. So to prevent the tungsten from bursting into flames the oxygen around the filament is replaced with an inert gas – one possibility is argon.

The inert gases got their name because they don't react with many other elements.

3 A GLASS BULB: This stops the gas from escaping. The filament and the inert gas are put inside a thin glass bulb made from silicon, oxygen and some other elements like mercury, bromine and iodine. Most bulbs are made of transparent glass, but opaque or coloured glass works, too.

WHAT'S IT MADE OF?
tungsten, argon, silicon, oxygen, mercury, bromine, iodine

INCANDESCENCE

Incandescence describes the tendency for materials to GLOW when heated and give off red, orange, yellow and white light. The problem is that, as well as the visible light, up to 90 percent of the energy is wasted as heat – which won't help you see in the dark but does explain why a lightbulb gets so hot.

WARNING VERY HOT!!

Elementary stuff

74 183.85
W
TUNGSTEN

- **Atomic Number: 74**
- Atomic Mass: 183.85
- **Isotopes: Five natural isotopes**
- Boiling Point: 5,700˚C
- **Melting Point: 3,407˚C**

Tungsten

Don't be misled by tungsten's chemical symbol into thinking that this tough element is really called 'wungsten'. In fact, tungsten was once known as wolfram (German for 'wolf dirt'), because it was extracted from the mineral wolframite. Tungsten has the highest melting point of any metal, so it's ideal for filaments. But it's also tough enough to be used for bulletproof armour plating. One of its compounds, tungsten carbide, is hard enough to make high-speed cutting tools and drill bits.

Edison was America's greatest inventor: he held well over 1,000 patents for his inventions – a record!

EDISON

How many filaments does it take to make a lightbulb?

Well, the answer for Thomas Alva Edison was LOTS! Edison experimented with hundreds, even thousands, of possible materials in the first lightbulbs. The key to success was finding a material for the filament that was long lasting but also cheap. In the early 20th century, General Electric Company engineer William Coolidge found that tungsten was an excellent material for filaments because it has such a high melting point (around 3,400 ˚C).

Filament Test Log
by T.A.Edison

~~Horsehair~~ RUBBISH!
~~platinum~~ Promising – but dear!
~~Gold~~ ~~Silver~~ TOO EXPENSIVE!
~~paper~~ Make sure it's carbonized first!
~~cotton~~ CARBONIZE!
~~bamboo~~ ?? Maybe if carbonized
tungsten ✓✓

Illuminating variations

HALOGEN BULBS use a group 17 element to react with the tungsten and redeposit atoms back on to the filament, which extends the life of the bulb.

All explained on page 9!

FLUORESCENT LIGHTS have a sealed tube containing noble gases and some mercury. Electricity excites electrons in the gas, which give off ultra-violet light. The UV light is converted to visible light when it hits the inside of the tube, which is coated with a phosphar.

Phosphars are metal compounds that glow after they have been exposed to a source of light.

NEON LIGHTS contain neon and other gases and give off coloured light when their electrons are 'excited'.

LET'S BE CLEAR ABOUT GLASS

Glass can be pretty SHATTERING! For one thing, its closest cousin is something that you can't see through, won't cut you and gets inside your swimming costume.

The best place to make glass is at the beach or in the desert. WHY? Because its main component is silicon dioxide (also known as silica), which most commonly occurs as sand! The silica is mixed with sodium carbonate to reduce its melting point and with lime (calcium oxide) to harden it into glass.

Don't try melting sand from the beach to get glass. You'd have to heat it to about 2,000 °C!

Adding oxides

Many types of glass can be made by adding metal oxides to the silica. Oxides are compounds that contain the oxide ion (an oxygen species with a negative charge). The most common type of glass is soda-lime glass. It has a silica base with sodium and calcium oxides added. It's cheap, tough and easy to recycle.

Need a reminder? Check out ions on pages 12–13.

Really COOL Science Bit

Is glass a LIQUID or SOLID?

This is something that chemists love to argue about. It's complicated – VERY complicated! You might hear people claim that glass is a liquid. It's true that glass is a bit MAD, but it's NOT a liquid. Instead, glass is an amphorous solid: its atoms are not arranged in as regular a pattern as most solids. That gives it some properties similar to liquids (but it's still NOT a liquid!). Try 'pouring' some glass – it's not happening! If you had a glass that was full of, umm … glass and you wanted to 'pour' the glass out of the, er … glass, it might happen … but you'd have to wait billions of years! That's no liquid!

Fancy glass

Posh glassware (sometimes called 'cut' glass or 'crystal') used in making chandeliers and fine glassware is basically soda-lime glass with the calcium oxide replaced with lead oxide. This glass is highly polished and reflects and refracts light to 'sparkle'.

Glass for the oven, glass for test-tubes

Adding boron oxides to the basic soda-lime glass mixture produces 'borosilicate' glass. This glass is very resistant to heat and temperature changes, so it can be used for ovenware and laboratory glassware. This type of glass is often better known by its trademarked name 'Pyrex'.

TRY THIS: Make SUGAR GLASS

Have you ever seen someone thrown through a pane of glass in the movies? Spectacular, isn't it? But it's also pretty dangerous with real glass – that's why they use this sugar glass instead.

WHAT YOU'LL NEED

- baking sheet
- non-stick spray
- 475 ml water
- 830 ml sugar
- 240 ml corn syrup
- 60 ml cream of tartar
- an old saucepan
- a kitchen thermometer

1. Use the non-stick spray to coat the baking sheet.
2. Place the water, sugar, corn syrup and cream of tartar in the saucepan and heat the mixture until it starts to boil.
3. Let the mixture boil, stirring constantly, until it reaches about 300 °C.
4. Pour the mixture onto the greased baking tray.
5. Allow the mixture to cool and harden and then use a knife to loosen the sheet of sugar glass and pop it out carefully from the edge.

Make sure you read THIS: Sugar glass is hygroscopic, which means that it attracts water, so it will soften soon after being made. You have to use it really quickly, or it's more like rubber than glass!

CHILL OUT!

BRRR!

Food and drinks are the only interesting things in your fridge, right? Wrong! What about the hidden gases that make a fridge really cool?

Why is it important?

The fridge is one of the most important modern appliances. All food contains bacteria that can cause it to go off: chilling food slows that process. Before modern refrigeration was invented, food was usually preserved by either salting or pickling. Refrigeration is far more convenient …

Don't ADD cold – TAKE heat

A liquid refrigerant is pumped through a compression valve into a refrigerator, where it rapidly expands and becomes REALLY COLD. The super-cold gas passes through coils inside the fridge. The heat from the contents of the fridge is absorbed by the gas, leaving the food compartment cold. The refrigerant gas starts to warm up, so it is pumped out of the fridge via a compressor (which makes it even hotter) to coils outside the cooling compartment at the back or bottom of the fridge. The hot coils give out heat to the room, and the gas cools and turns back into a liquid. The liquid is then pumped back into the fridge and the cycle repeats.

WHAT'S IT MADE OF?
carbon, fluorine, hydrogen (but no longer chlorine)

What about freezers?

A freezer has more coils inside than a fridge and the food compartment inside is often smaller. This means it can cool down a little more and the temperature drops below freezing.

TRY THIS

Make ICE CREAM

A quick and easy way to make a frozen treat, but it has some great chemistry in it.

WHAT YOU'LL NEED
- 220 ml single cream
- 220 ml milk
- vanilla flavouring
- 70 g sugar
- Ziploc bags
- 1 egg
- crushed ice
- rock salt

1. Make a batch of ice-cream mixture by mixing the single cream, milk and sugar in a Ziploc bag with the egg and 1 teaspoon of vanilla flavouring. Place about a quarter of the mixture into another Ziploc bag. Carefully push the air out from the bag and seal it tightly.
2. Fill a third Ziploc bag with crushed ice.
3. Add several handfuls of rock salt to the ice.
4. Place the sealed ice-cream mixture bag inside the ice bag and seal the outer bag.
5. Gently squeeze the mixture for about 20 minutes or until the ice-cream forms!

HOW DOES THAT WORK?: Adding salt to the ice causes the freezing point of the H_2O to fall below its normal freezing point, 0 °C. This is known as 'Freezing Point Depression'. It's called a colligative property and it depends on the amount of substance present – more salt means a lower freezing point. Eventually the bag will get cold enough to freeze the ice-cream mixture and make it solid. This is why we put salt on the roads in winter, so that the weather will have to reach really low temperatures before the salty water will freeze.

WARNING CHILLY!

Elementary stuff

9 | 18.99
F
FLUORINE

- **Atomic Number: 9**
- Atomic Mass: 18.99
- **Isotopes: One naturally occurring isotope**
- Boiling Point: –188 °C
- **Melting Point: –220 °C**

Fluorine

Fluorine is the most reactive element: it forms bonds with just about anything. This halogen is a yellowish gas which is often added to water or toothpaste to help strengthen teeth. Fluorine is also present in well-known organic compounds like CFC's (chlorofluorocarbons). CFC's were once used in fridges, but they damaged the ozone layer by converting ozone (O_3) to oxygen (O_2) and were mostly banned. Another place you'll find fluorine is in the non-stick polymer known by the trade name 'Teflon'.