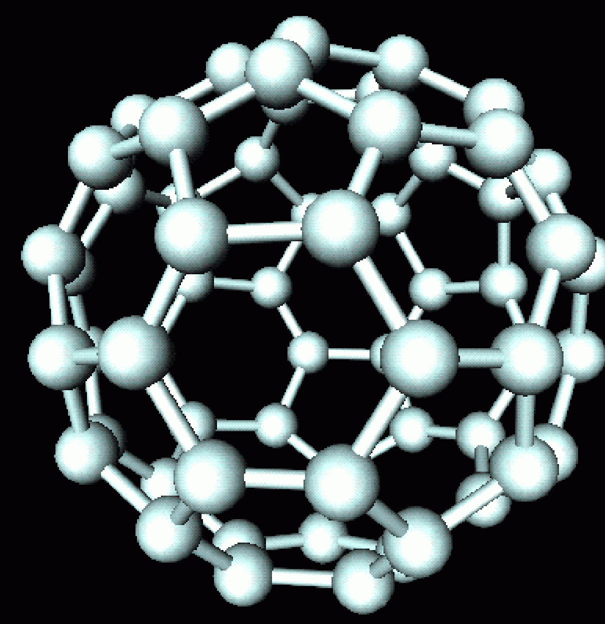
Key Concepts in Chemistry

EdExcel 2016 Chemistry topic 1



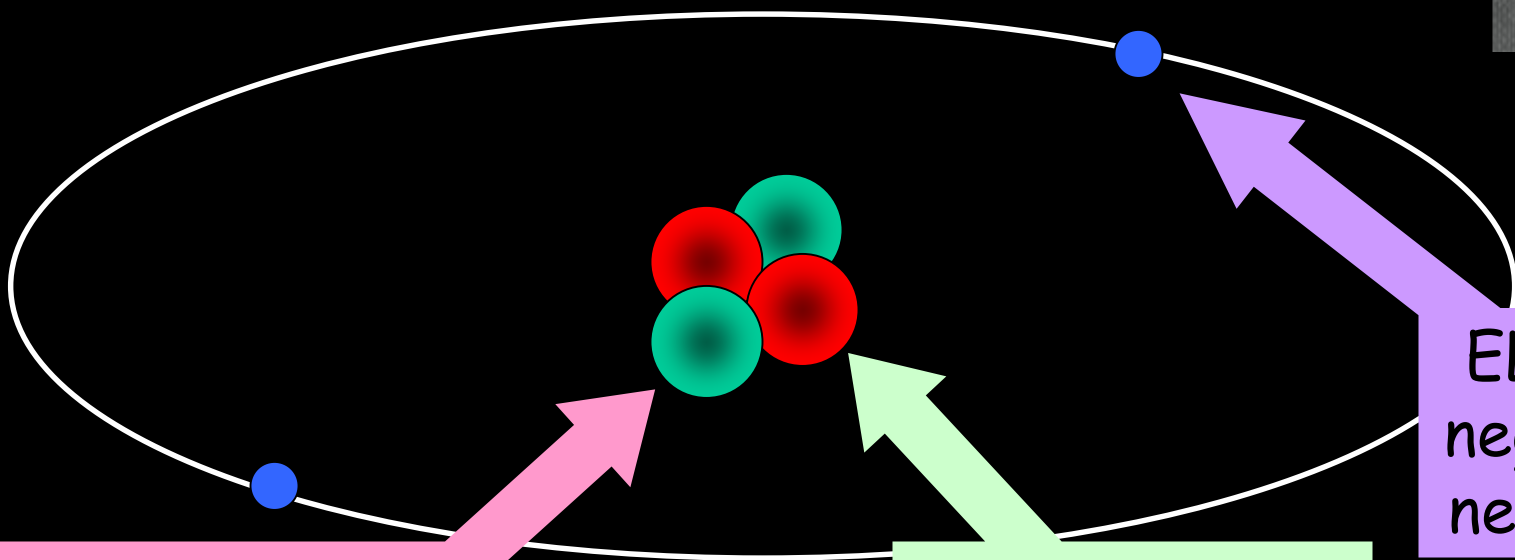
Atomic Structure

27/09/2017

The structure of the atom

I first came up with the idea of the atom (after the Ancient Greeks). Our understanding of what it looks like has changed over time due to discoveries of subatomic particles:

Dalton



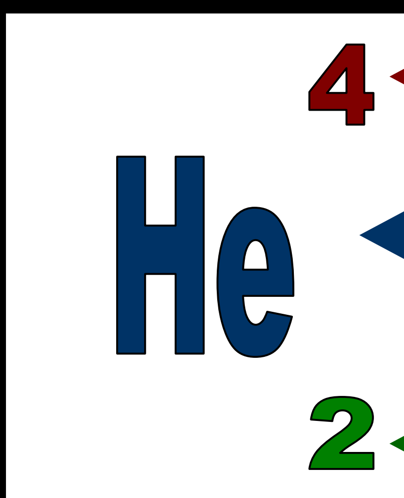
NEUTRON - neutral, same mass as proton ("1")

PROTON – positive, same mass as neutron ("1")

ELECTRON – negative, mass nearly nothing

The structure of the atom

Particle	Relative Mass	Relative Charge
Proton	1	+1
Neutron	1	0
Electron	1/2000 (i.e. 0)	-1



MASS NUMBER = number of protons + number of neutrons

SYMBOL

ATOMIC NUMBER = number of protons. All atoms of a particular element must have the same number of protons.

Mass and atomic number

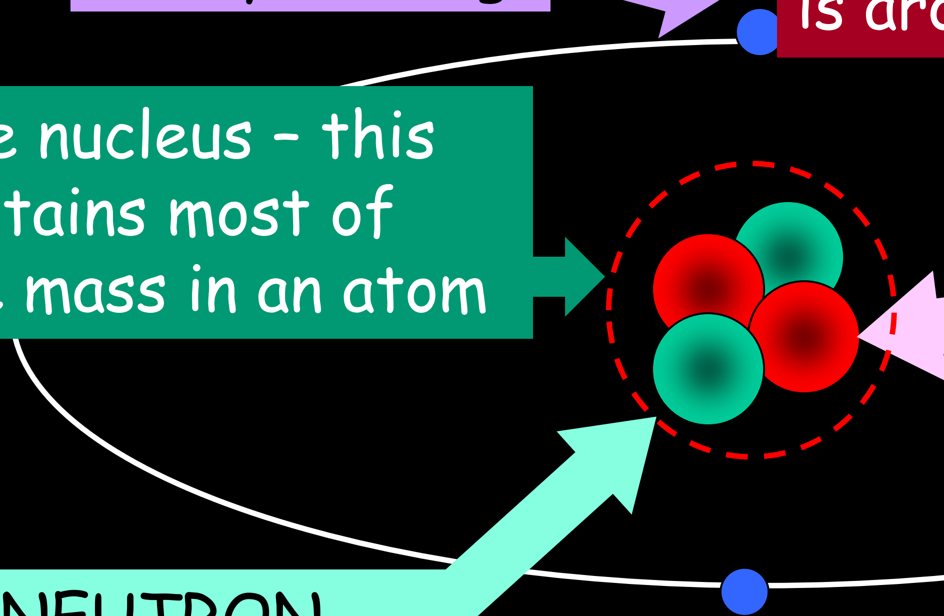
How many protons, neutrons and electrons?

1 **H** 1	11 **B** 5	16 **O** 8
23 **Na** 11	35 **Cl** 17	238 **U** 92

The structure of the atom in more detail

ELECTRON – negative, mass nearly nothing

The nucleus is around 10,000 times smaller then the atom! The diameter of the nucleus is around 10^{-14}m.



The nucleus – this contains most of the mass in an atom

PROTON – positive, same mass as neutron ("1")

NEUTRON – neutral, same mass as proton ("1")

Atoms always have the same number of protons and electrons so they are neutral overall. The atom is around 0.1nm big (i.e. 10-10m).

Isotopes

An isotope is an atom with a different number of neutrons:

Notice that the mass number is different. How many neutrons does each isotope have?

$^{16}_{8}O$ $^{17}_{8}O$ $^{18}_{8}O$

Each isotope has 8 protons – *if it didn't then it just wouldn't be oxygen any more.*

Strange atomic masses

27/09/2017

When you look at a periodic table sometimes the atomic mass is not a whole number. Consider chlorine, for example:

35.5
Cl
17

How can an atom have a decimal for its mass?

This is because out of every four naturally occurring chlorine atoms, 3 have a mass of 35 and 1 has a mass of 37 so the average atomic mass is:

$(3 \times 35 + 1 \times 37) / 4 = 35.5$

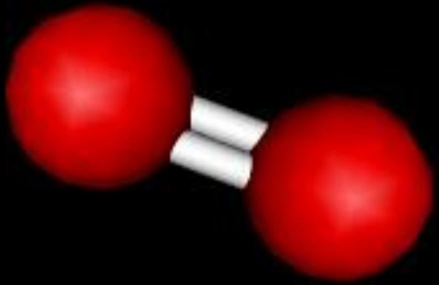
Q. Magnesium is often found as ^{24}Mg or ^{26}Mg. If 79% of magnesium is ^{24}Mg what is the average atomic mass?

$(79 \times 24 + 21 \times 26) / 100 = 24.4$

27/09/2017

Periodic Table Introduction

How would you arrange these elements into groups?

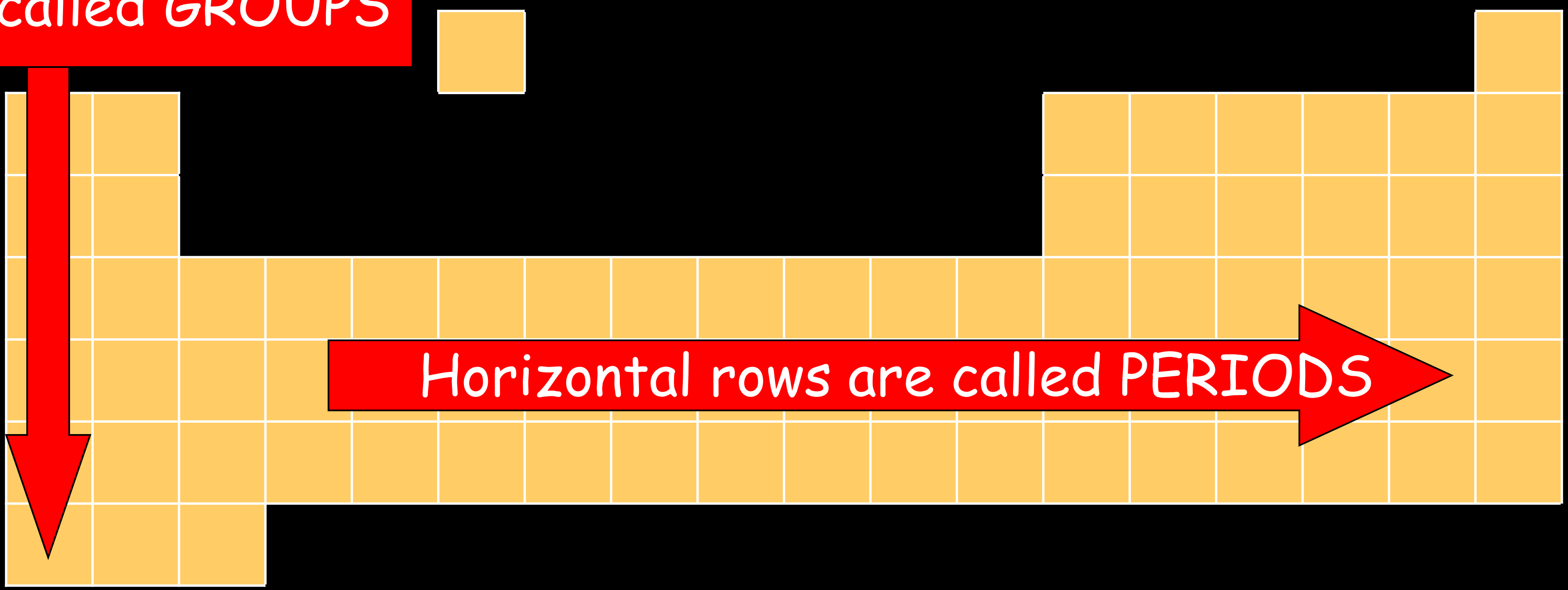


Periodic table

The periodic table arranges all the elements in groups according to their properties.

Mendeleev

Vertical columns are called GROUPS



Development of the Periodic Table

1864: John Newlands arranged the known elements in order of atomic mass and found out that every 8th element had similar properties:

Li	Be	B	C	N	O	F	Na	Mg	Al

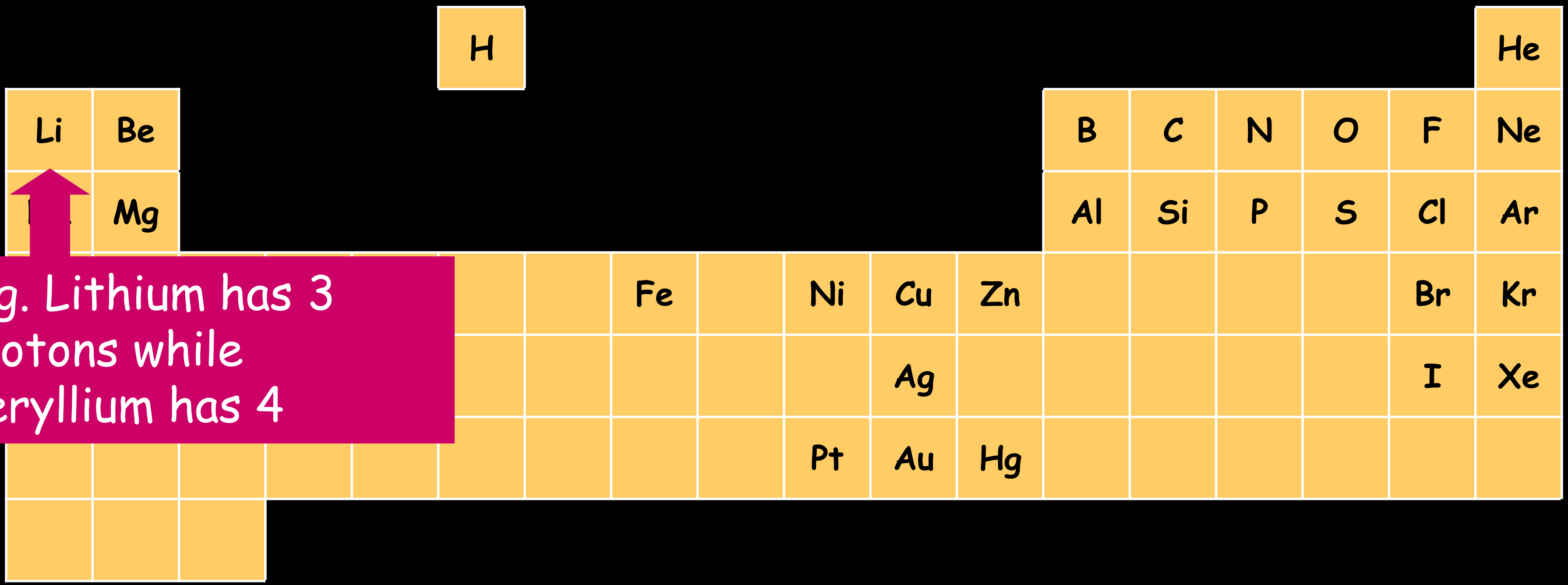
1869: Dimitri Mendeleev arranged the known elements in order of mass but he also left in gaps and was able to predict the properties of unknown elements:

Li	Be	B	C	N	O	F		Na	Mg

When I came up with my Periodic Table I thought that I had arranged elements in order of atomic mass. However, I was wrong because I did not take into account the masses of different isotopes.

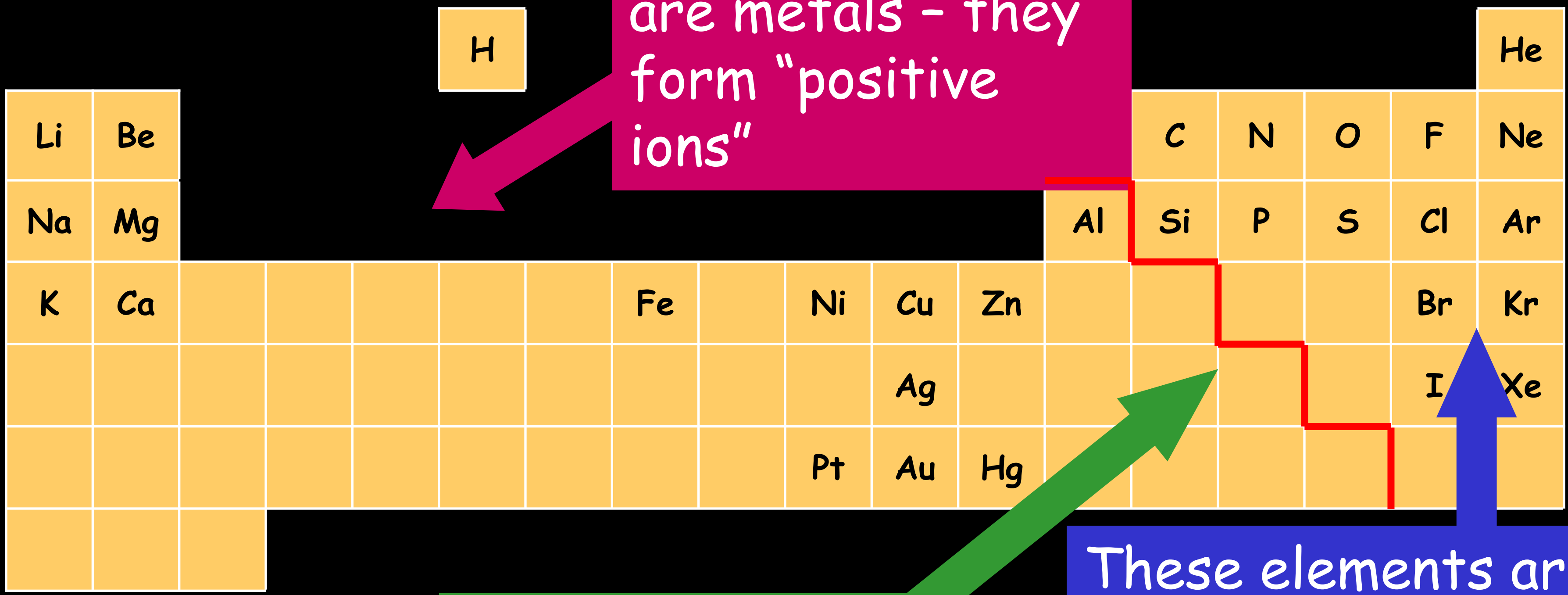
The Periodic Table

Fact 1: Elements in the periodic table are arranged in order of proton number:



The Periodic Table

Fact 2: Most of the elements are metals:



These elements are metals – they form "positive ions"

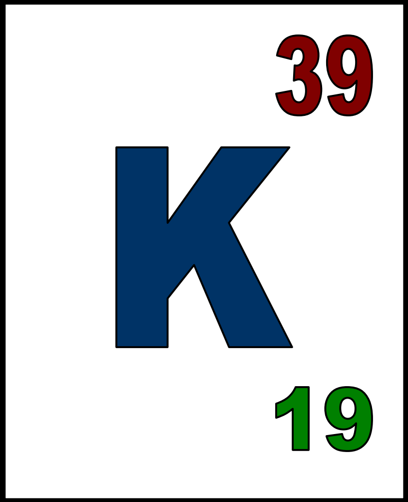
This line divides metals from non-metals

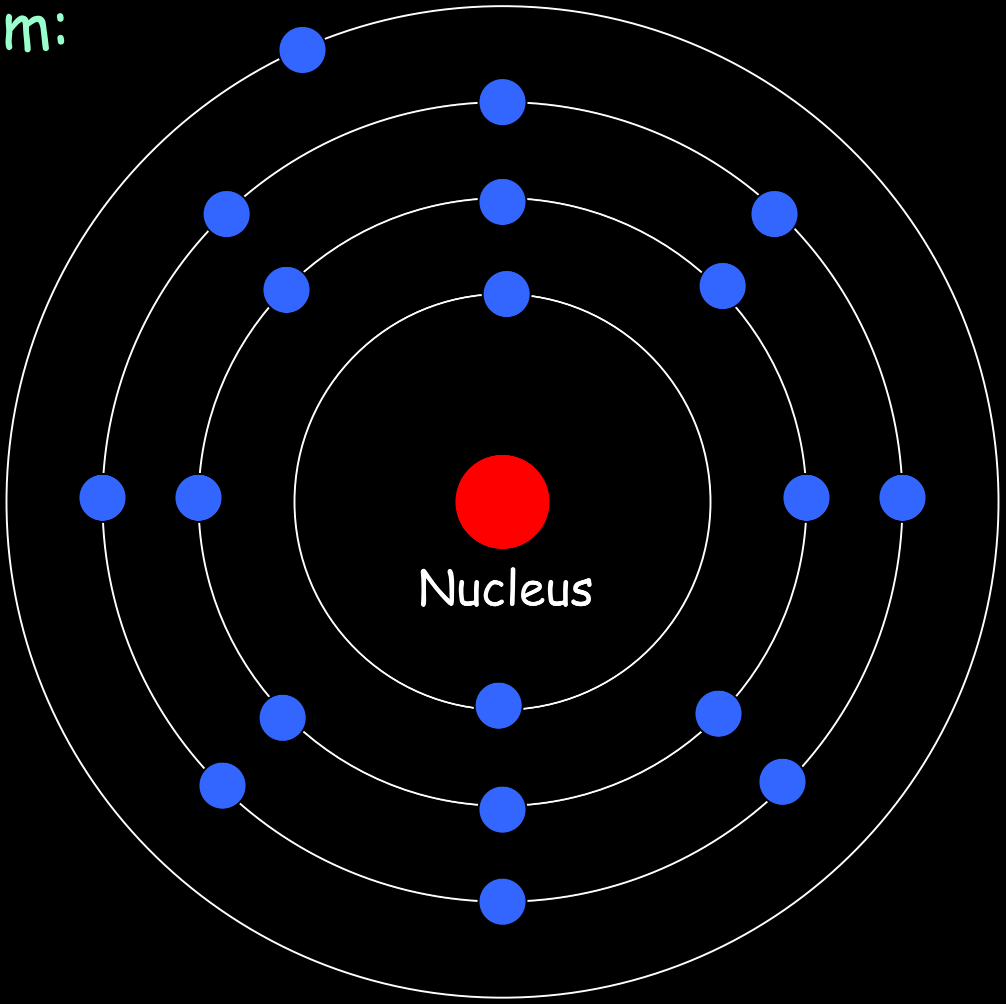
These elements are non-metals – they form "negative ions"

Electron structure

27/09/2017

Consider an atom of Potassium:





Potassium has 19 electrons. These electrons occupy specific energy levels "shells"…

The inner shell has __ electrons

The next shell has __ electrons

The next shell has __ electrons

The next shell has the remaining __ electron

Electron structure

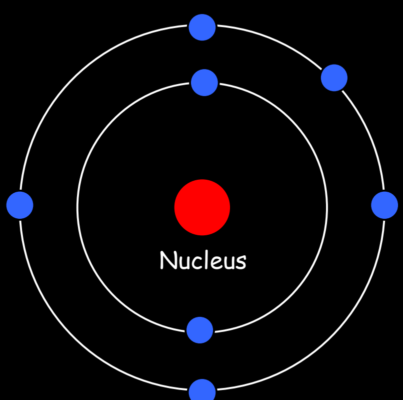
= 2,8,8,1

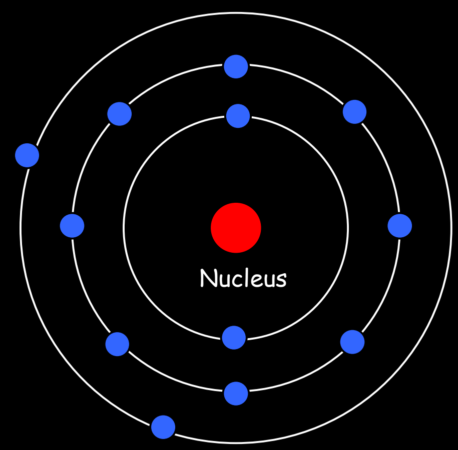
Electron structure

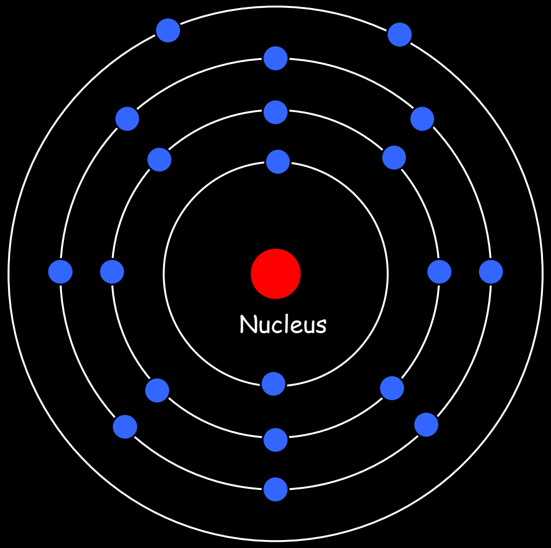
27/09/2017

Draw the electronic structure of the following atoms:

N	Mg	Ca
14	24	40
7	12	20







Electron structure = 2,5

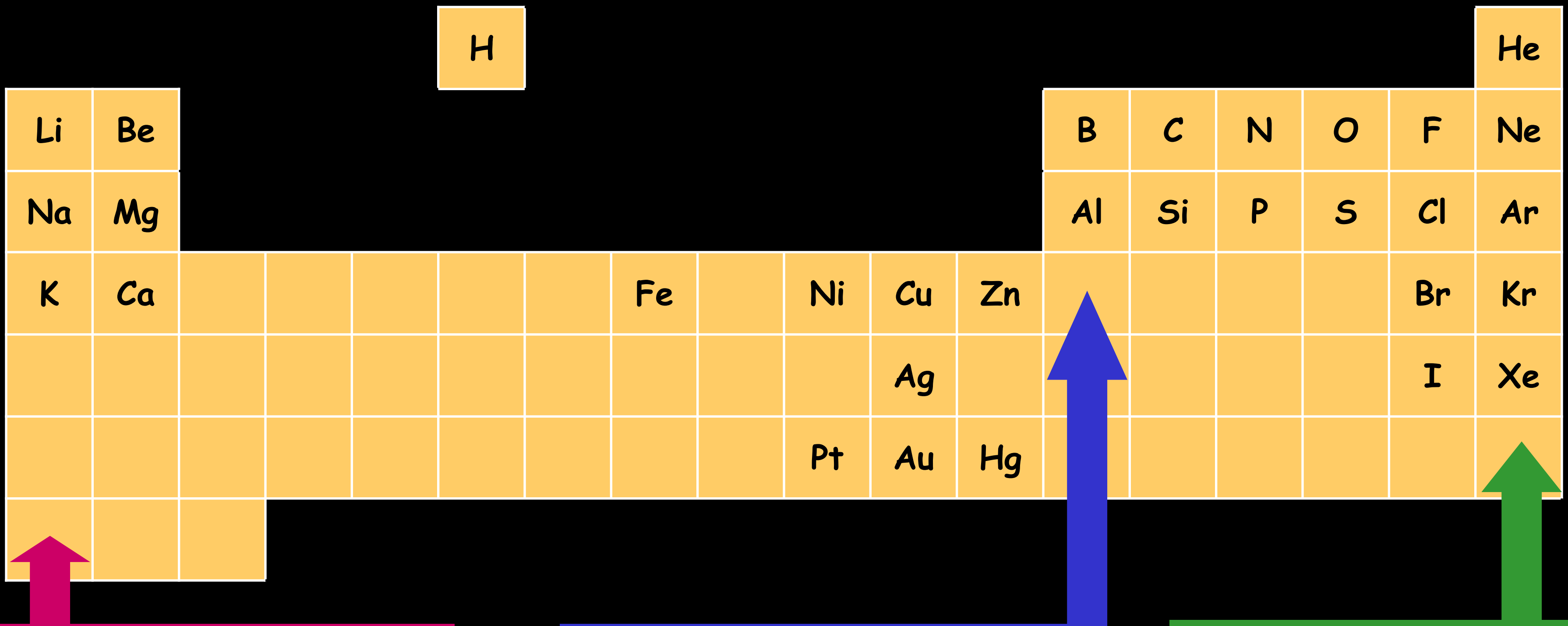
Electron structure = 2,8,2

Electron structure = 2,8,8,2

The Periodic Table

27/09/2017

Fact 3: Elements in the same group have the same number of electrons in the outer shell (this corresponds to their group number)



E.g. all group 1 metals have __ electron in their outer shell

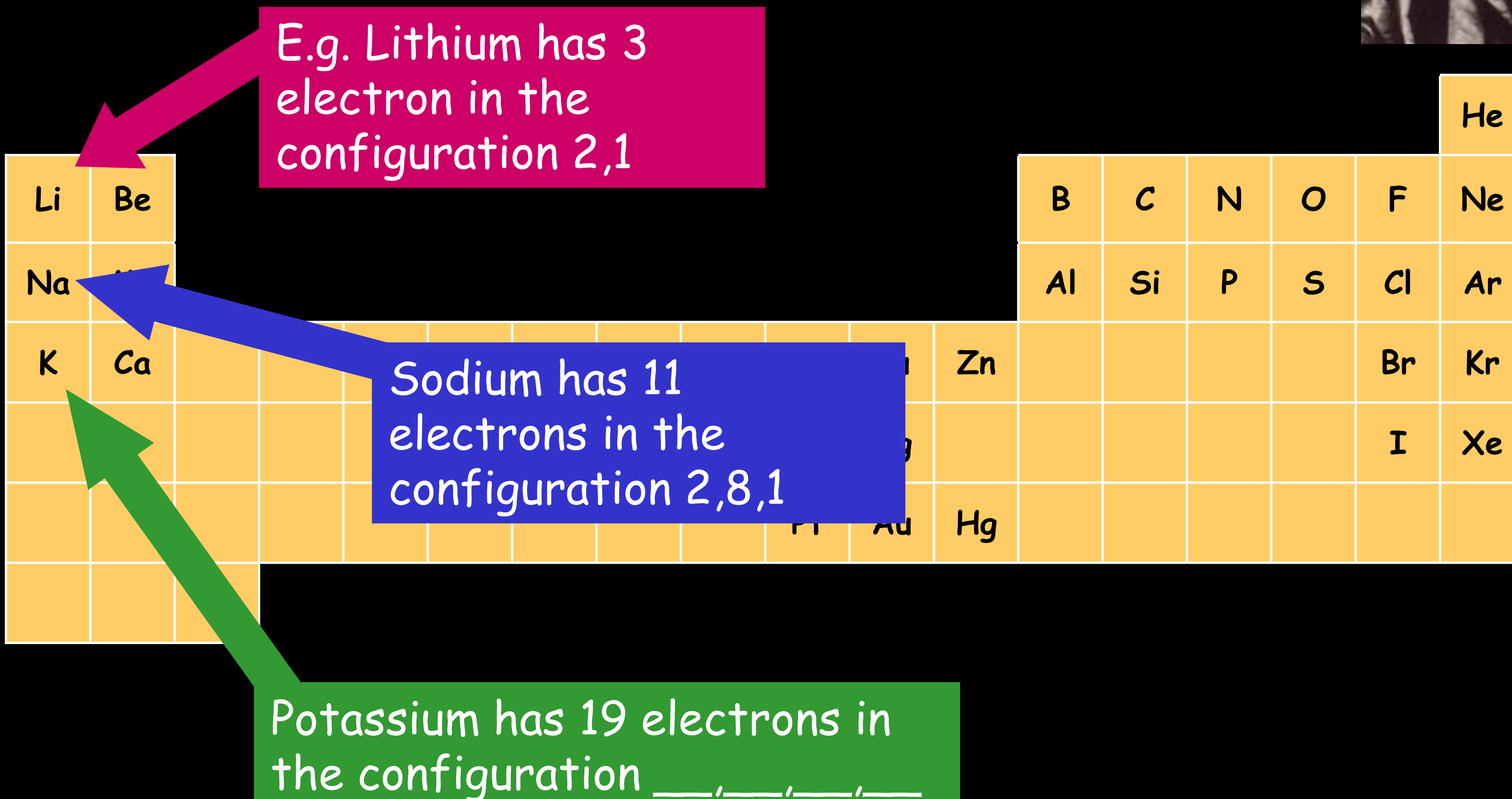
These elements have __ electrons in their outer shells

These elements have __ electrons in their outer shell

The Periodic Table

27/09/2017

Fact 4: As you move down through the periods an extra electron shell is added:

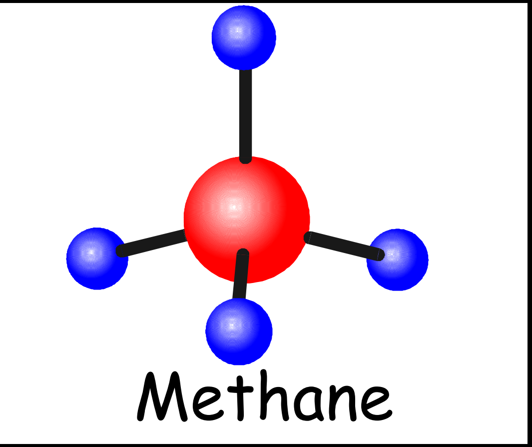


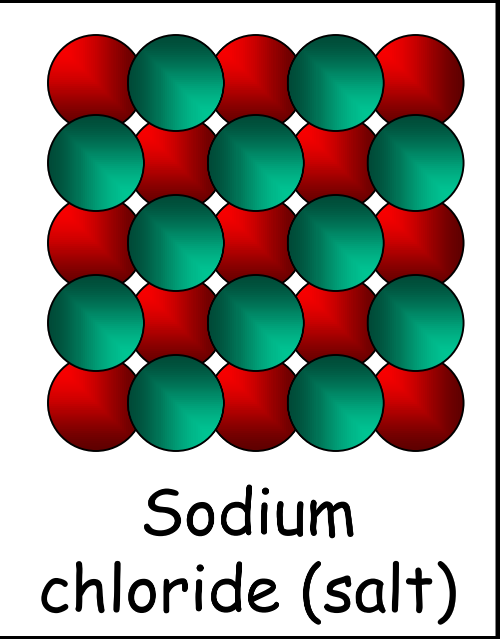
Ionic Bonding

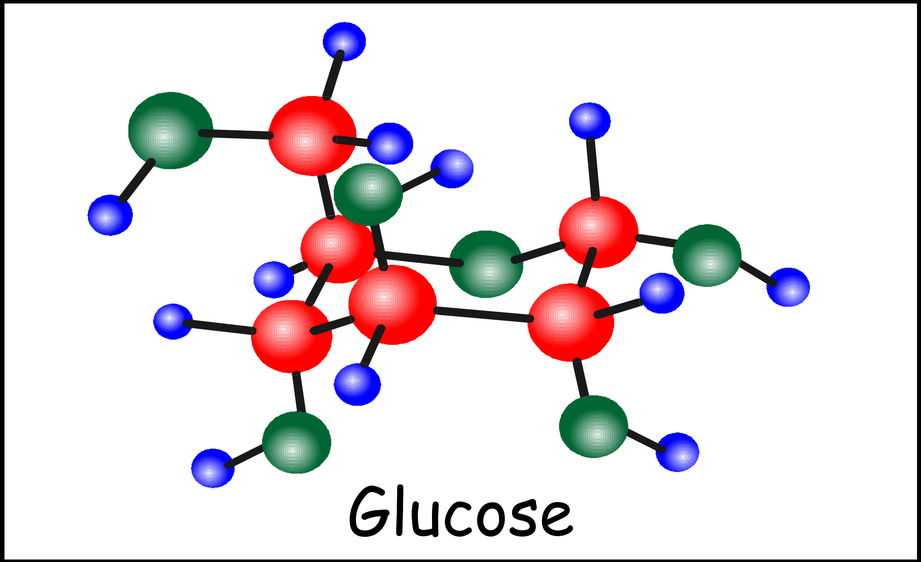
27/09/2017

Compounds

Compounds are formed when two or more elements are chemically combined. Some examples:

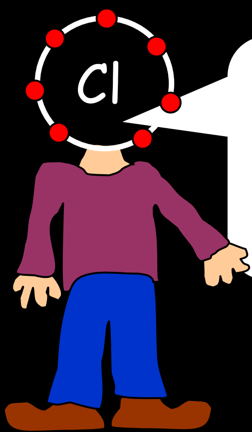




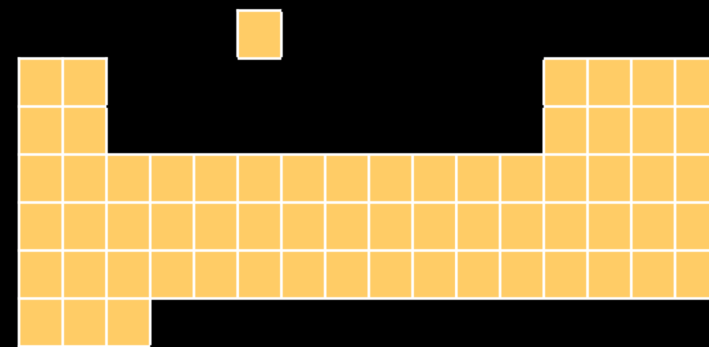


How are these compounds formed? Let's consider two ways – "ionic" and "covalent" bonding.

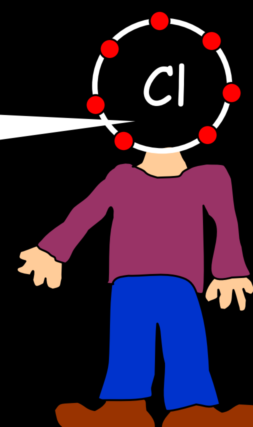
Introduction to Bonding



Hi. My name's Johnny Chlorine. I'm in Group 7, so I have 7 electrons in my outer shell

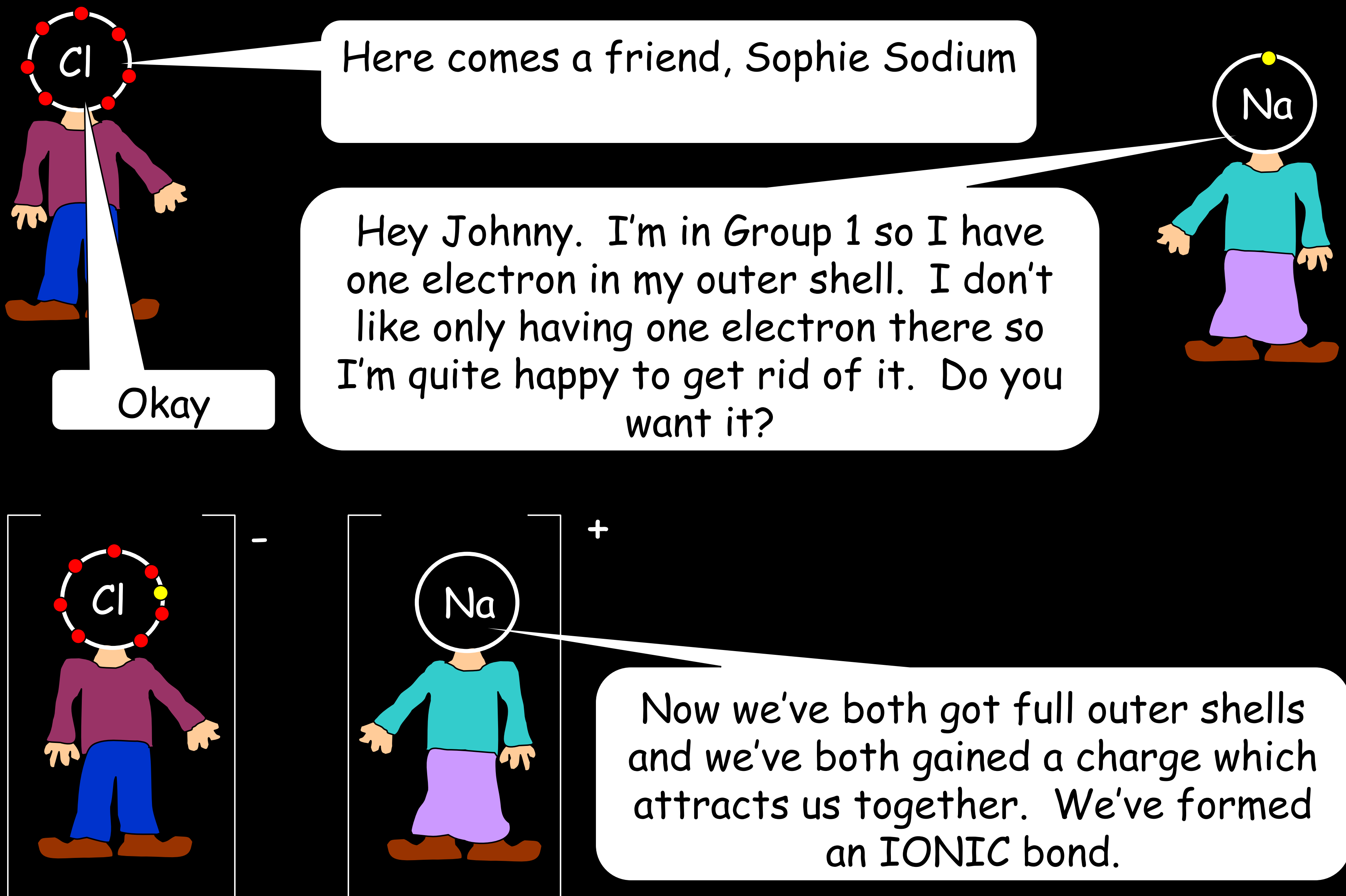


I'd quite like to have a full outer shell. To do this I need to GAIN an electron. Who can help me?



Ionic Bonding

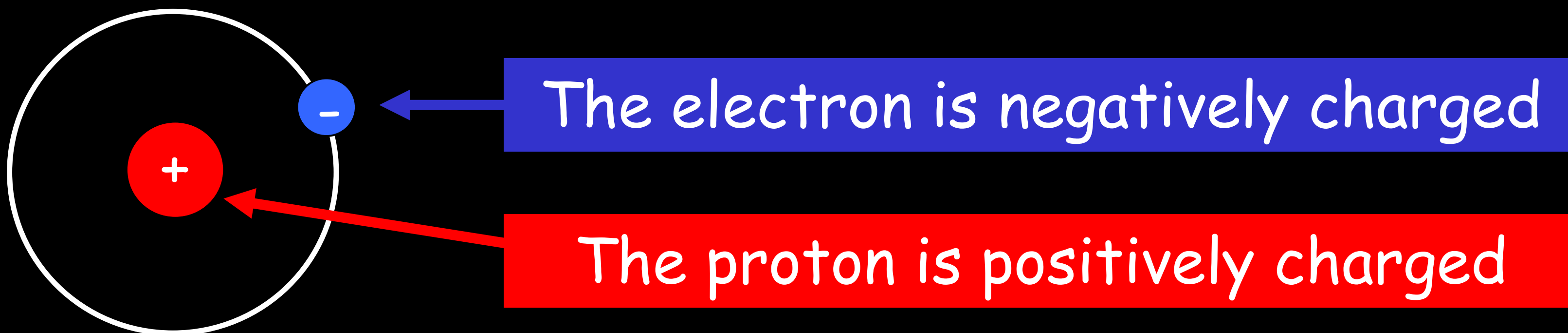
27/09/2017



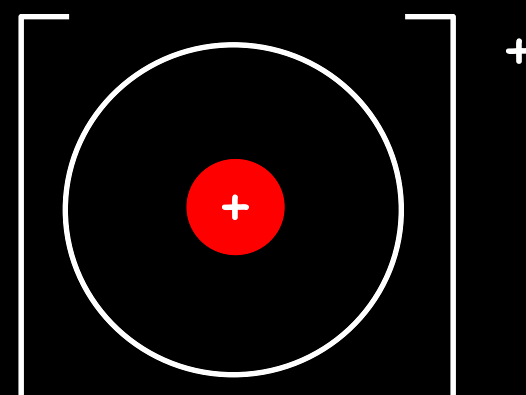
27/09/2017

Ions

An ion is formed when an atom gains or loses electrons and becomes charged:



If we "take away" the electron we're left with just a positive charge:

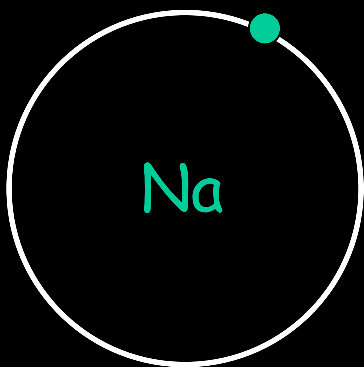


This is called an ion (in this case, a positive hydrogen ion, also called a cation).

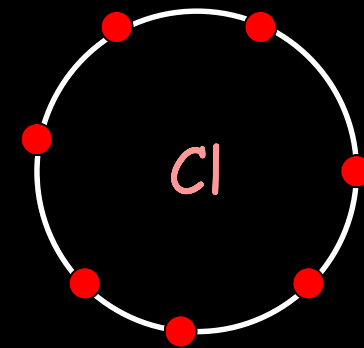
Ionic bonding

27/09/2017

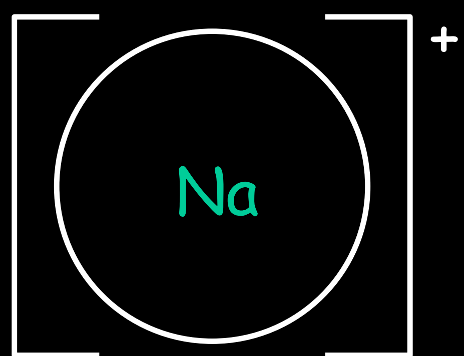
This is where a metal bonds with a non-metal (usually). Instead of sharing the electrons one of the atoms "______" one or more electrons to the other. For example, consider sodium and chlorine:

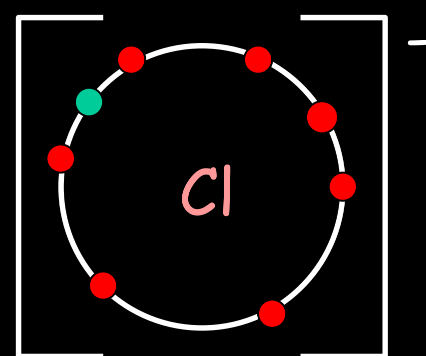


Sodium has 1 electron on its outer shell and chlorine has 7, so if sodium gives its electron to chlorine they both have a ____ outer shell and are ________.



A _________ charged sodium ion (cation)





A ___________ charged chloride ion (________)

Group 1 _________ will always form ions with a charge of +1 when they react with group 7 elements. The group 7 element will always form a negative ion with charge -1.

Words – full, transfers, positively, negatively, metals, anion, stable

Mass and atomic number

How many protons, neutrons and electrons would you find in these ions?

Element	Mass number	Atomic number	Ion
H	1	1	Hydrogen ion, H^+
Na	23	11	Sodium ion, Na^+
Cl	35	17	Chloride ion, Cl^-

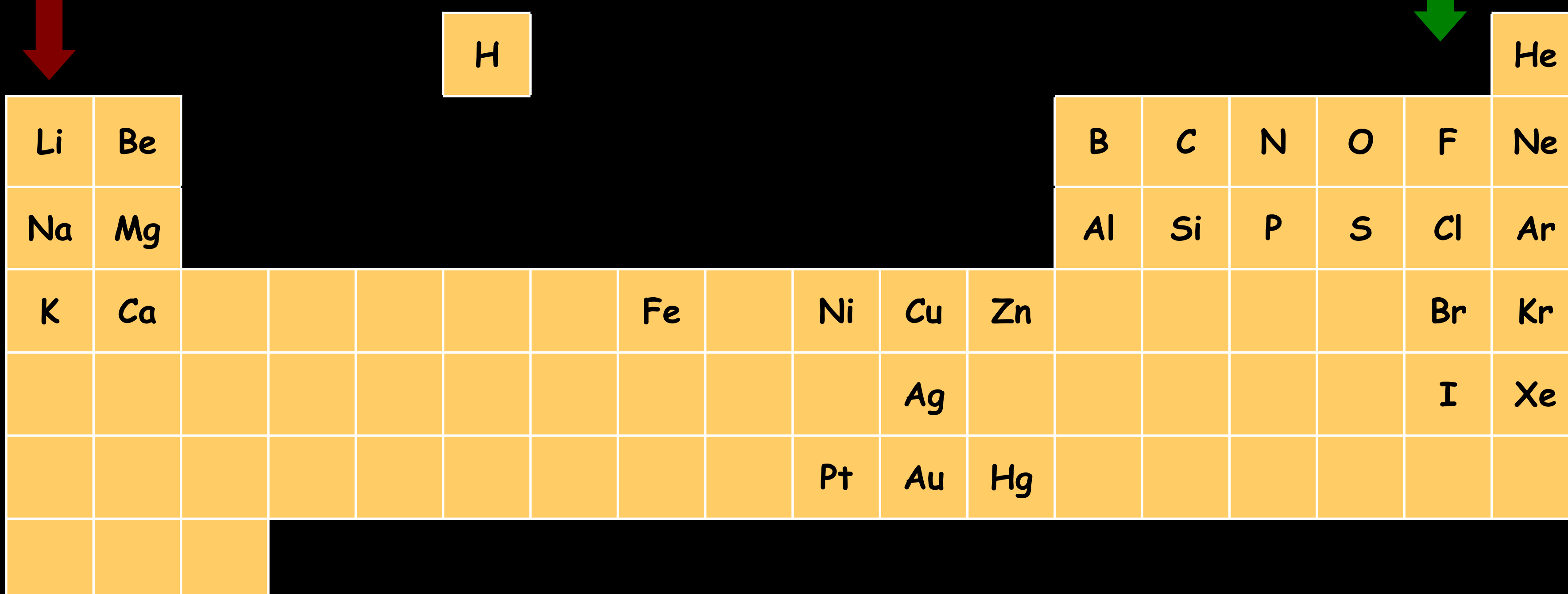
The Periodic Table

27/09/2017

Looking at their position in the Periodic Table and understanding their electron structure, we can predict the charge of different ions.

For example, group 1 elements all want to lose one electron so they will all form cations with a charge of +1

What type of ion (and its charge) will elements from groups 2, 6 and 7 form?



Naming compounds

Rule 1 – When two elements join and one is a halogen, oxygen or sulphur the name ends with ____ide

e.g. Magnesium + oxygen → magnesium oxide

1) Sodium + chlorine
2) Magnesium + fluorine
3) Lithium + iodine
4) Chlorine + copper
5) Oxygen + iron
6) KBr
7) LiCl
8) CaO
9) MgS
10) KF

Naming compounds

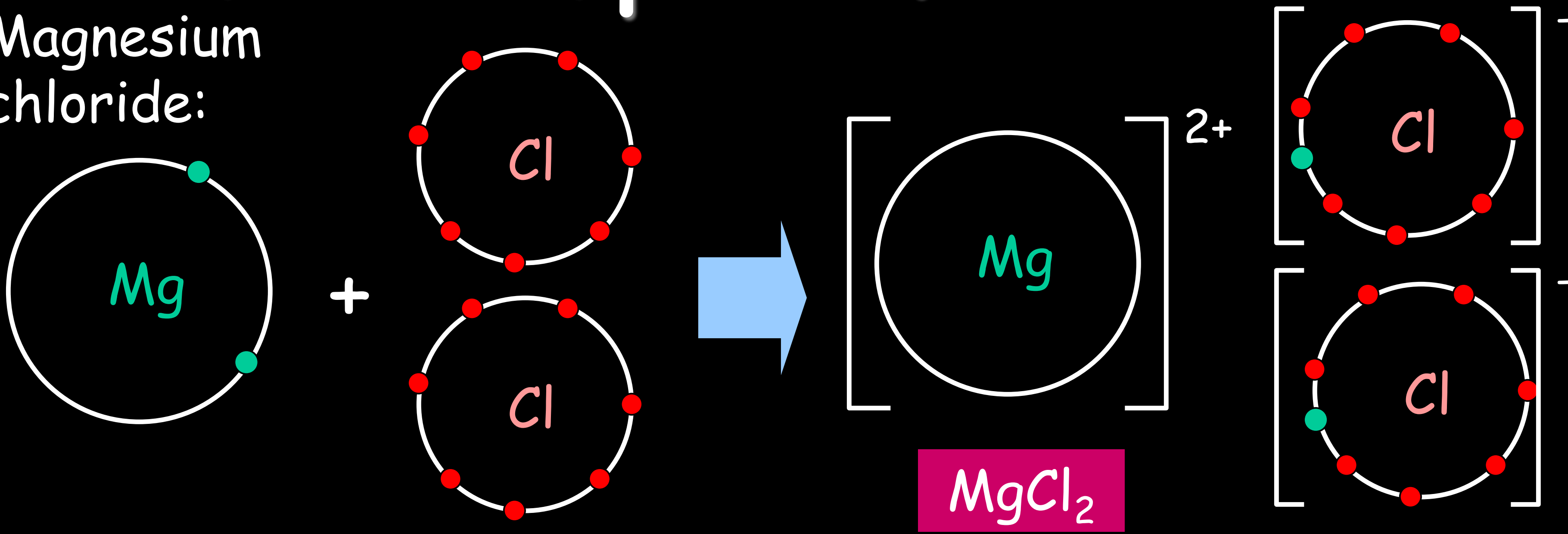
Rule 2 – When three or more elements combine and one of them is oxygen the ending is ______ate

e.g. Copper + sulphur + oxygen → Copper sulphate

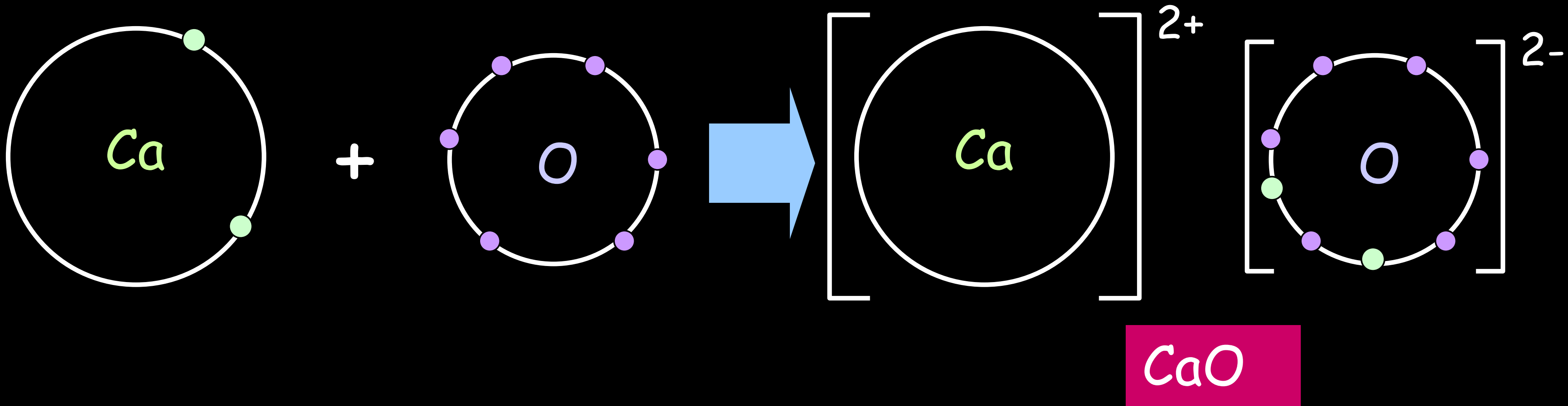
1) Calcium + carbon + oxygen
2) Potassium + carbon + oxygen
3) Calcium + sulphur + oxygen
4) Magnesium + chlorine + oxygen
5) Calcium + oxygen + nitrogen
6) $AgNO_3$
7) H_2SO_4
8) K_2CO_3

Some examples of ionic bonds

Magnesium chloride:



Calcium oxide:



Balancing ions

Some common ions:

Sodium – Na^+

Potassium – K^+

Magnesium – Mg^{2+}

Ammonium – NH_4^+

Chloride – Cl^-

Bromide – Br^-

Oxide – O^{2-}

Sulphate – SO_4^{2-}

Determine the formula of these compounds:

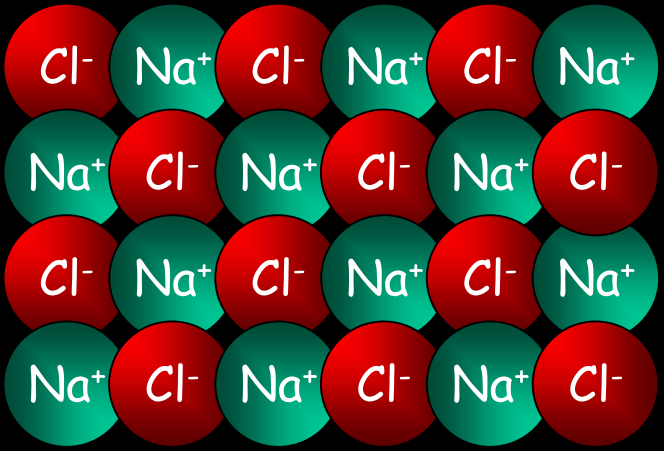
1) Sodium chloride
2) Magnesium oxide
3) Magnesium chloride
4) Ammonium chloride
5) Sodium sulphate
6) Sodium oxide

Answers:

1) NaCl
2) MgO
3) $MgCl_2$
4) NH_4Cl
5) Na_2SO_4
6) NaO

Giant Ionic Structures

When many positive and negative ions are joined they form a "giant ionic lattice" where each ion is held to the other by strong electrostatic forces of attraction (ionic bonds).

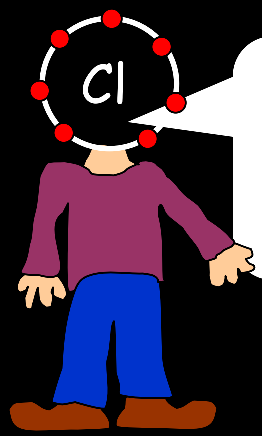


Notice that there is one chlorine ion for every sodium ion. Therefore the formula for this compound is NaCl.

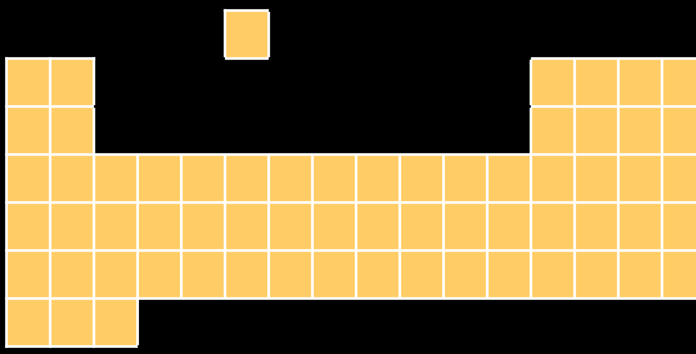
Covalent Bonding

27/09/2017

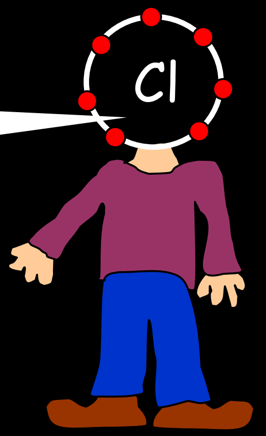
Introduction to Bonding Revision



Hi. My name's Johnny Chlorine. I'm in Group 7, so I have 7 electrons in my outer shell

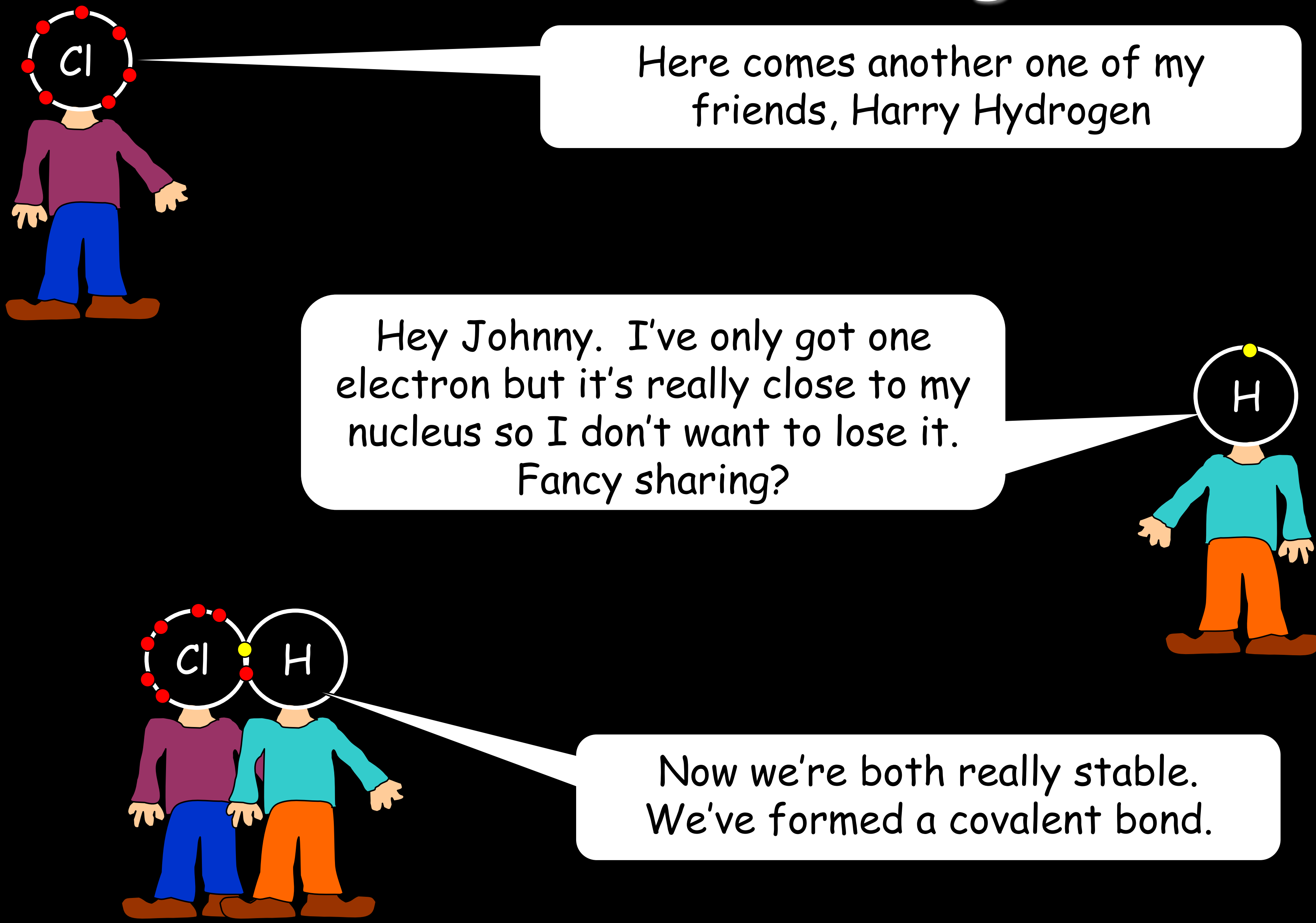


I'd quite like to have a full outer shell. To do this I need to GAIN an electron. Who can help me?



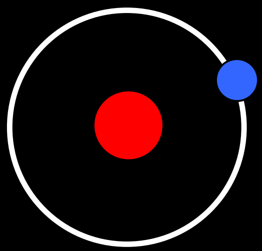
Covalent Bonding

27/09/2017

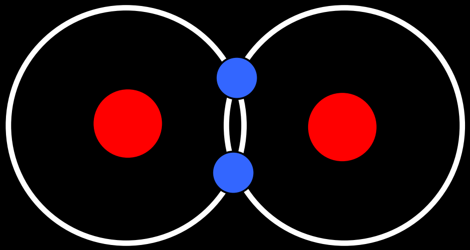


Covalent bonding

Consider an atom of hydrogen:

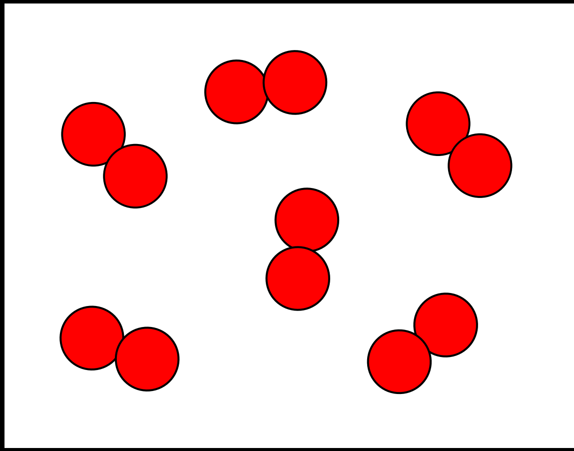


Notice that hydrogen has just __ electron in its outer shell. A full (inner) shell would have __ electrons, so two hydrogen atoms get together and "______" their electrons:



Now they both have a _____ outer shell and are more ______. The formula for this molecule is H_2.

When two or more atoms bond and form a molecule by sharing electrons we call it _______________ BONDING.



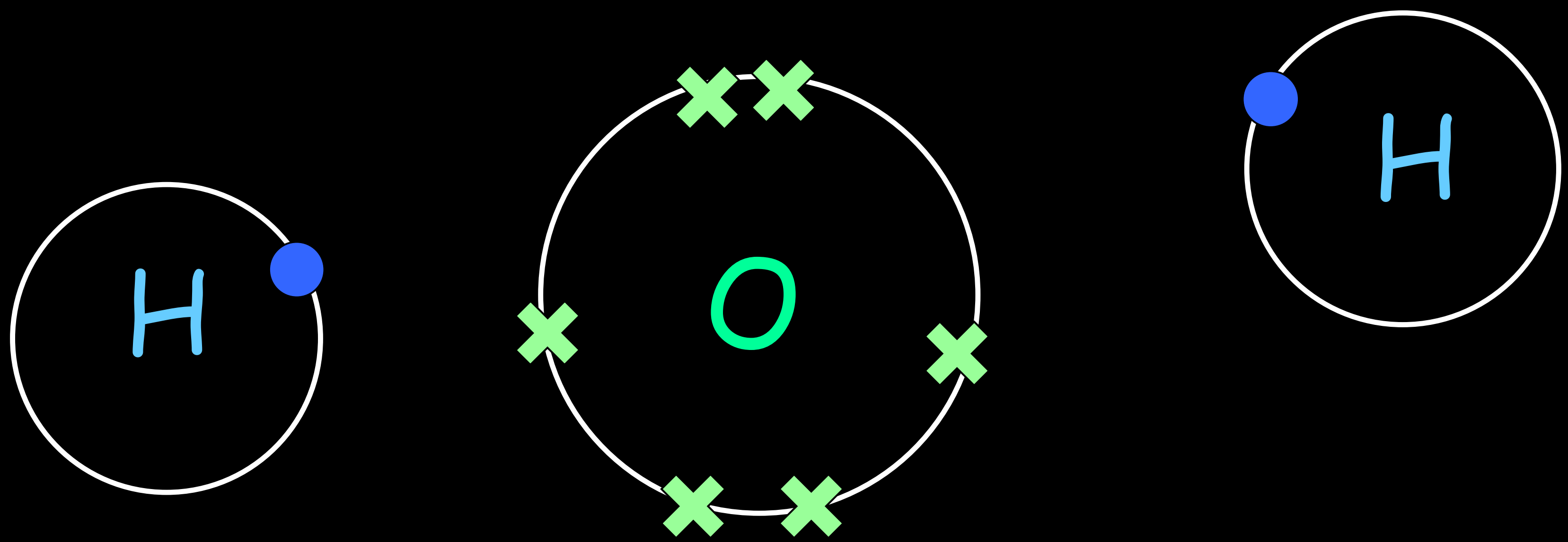
Words – covalent, 1, 2, share, full, stable

Types of Substance

27/09/2017

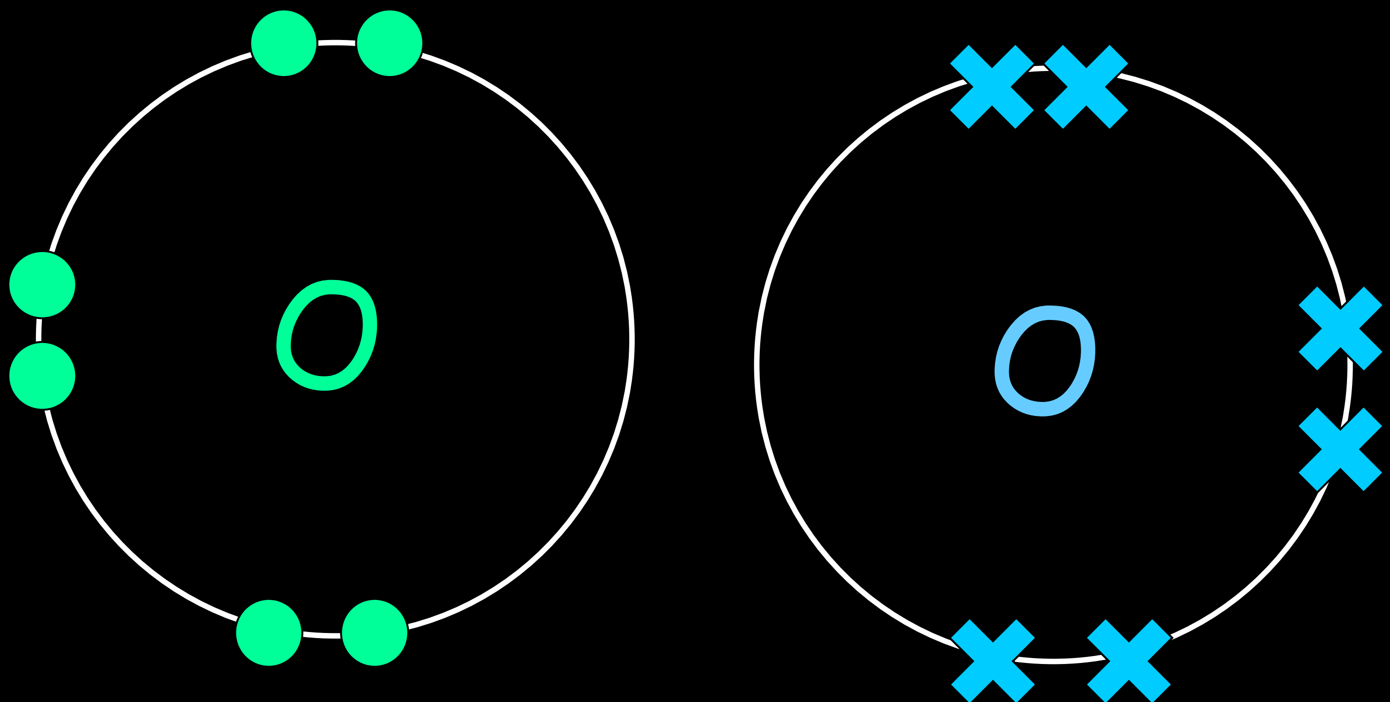
Dot and Cross Diagrams for Covalent Molecules

Water, H_2O:



Dot and Cross Diagrams for Covalent Molecules

Oxygen, O_2:

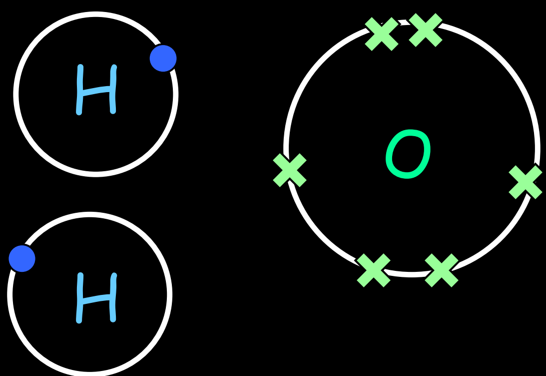


27/09/2017

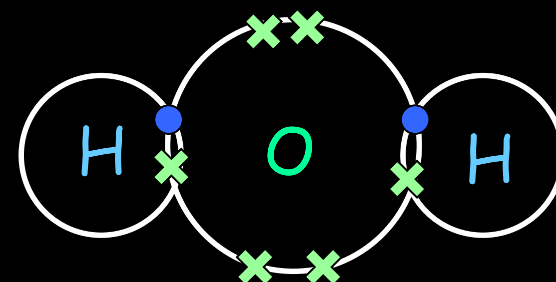
Dot and cross diagrams

Water, H_2O:

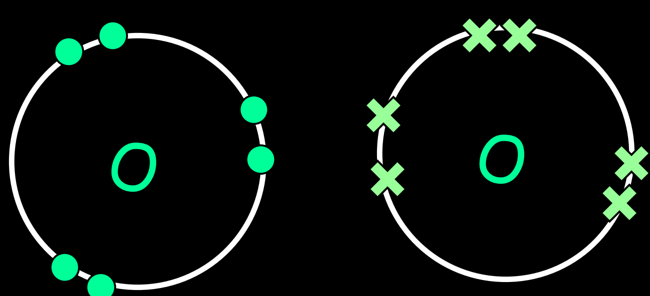
Step 1: Draw the atoms with their outer shell:

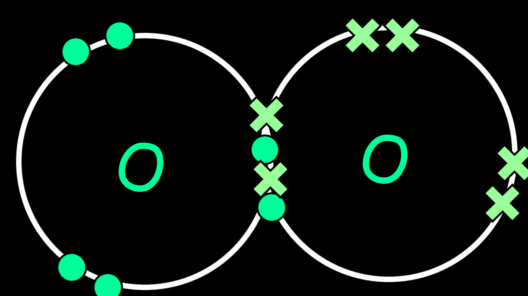


Step 2: Put the atoms together and check they all have a full outer shell:



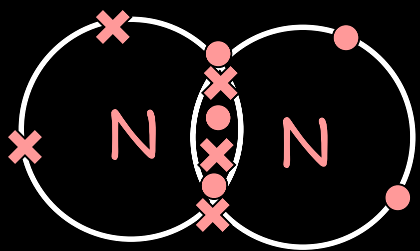
Oxygen, O_2:



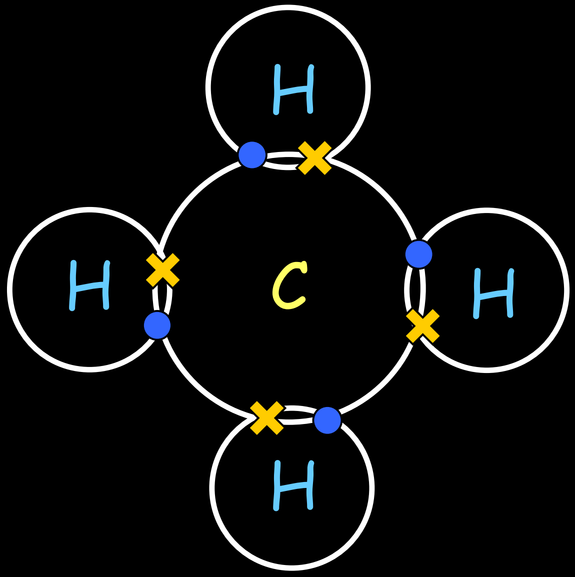


Dot and cross diagrams

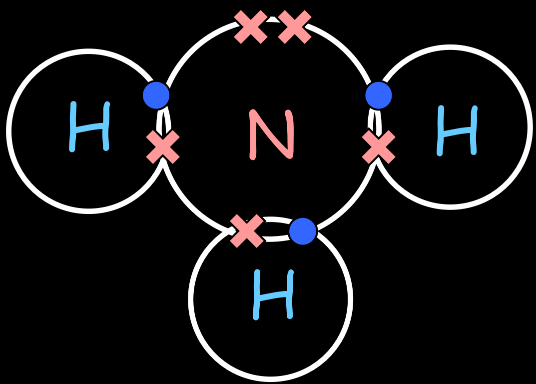
Nitrogen, N_2:



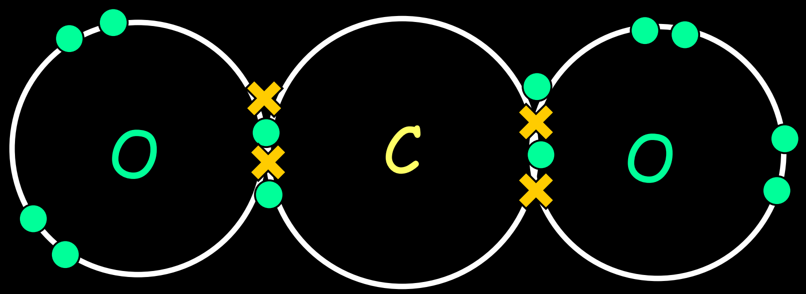
Methane CH_4:



Ammonia NH_3:

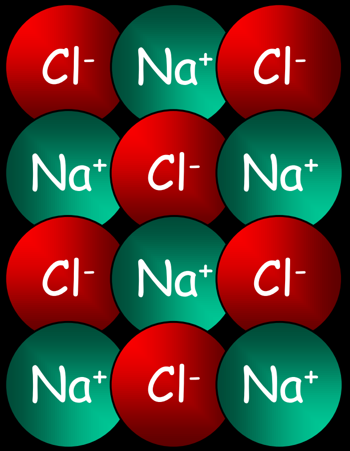


Carbon dioxide, CO_2:

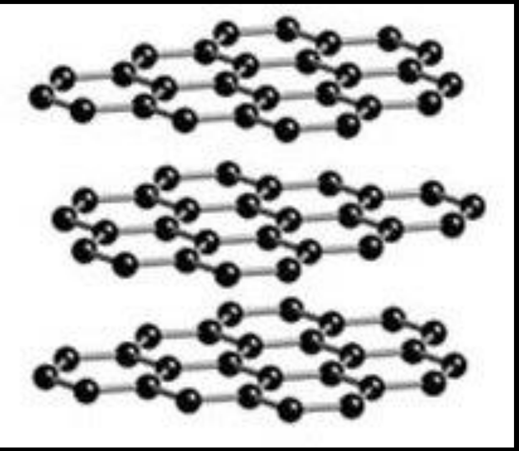


Different forms of elements and compounds

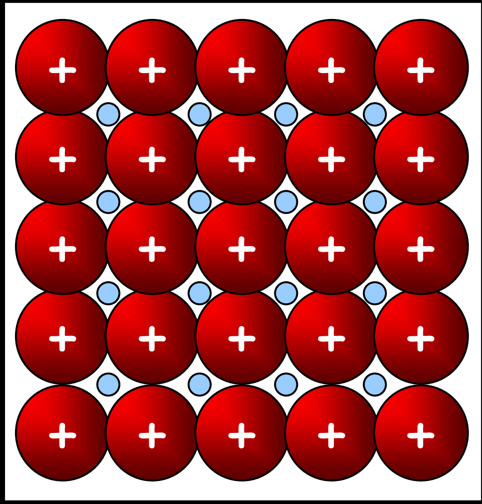
Elements and compounds can form many different structures, including:



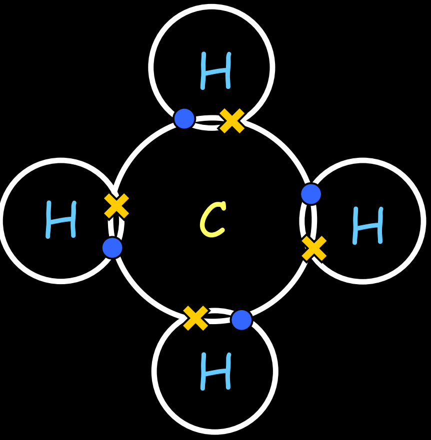
1) Ionic, like sodium chloride:



2) Giant covalent structures, like graphite:



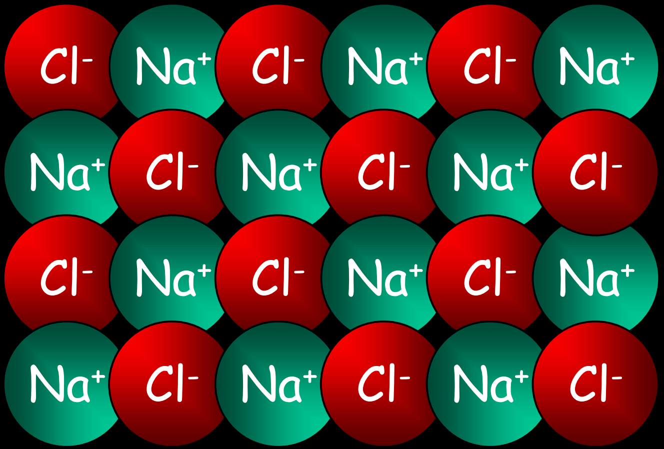
3) Metallic, like iron:



4) Simple covalent molecules, like methane:

Giant Ionic Structures recap

When many positive and negative ions are joined they form a "giant ionic lattice" where each ion is held to the other by strong electrostatic forces of attraction (ionic bonds).

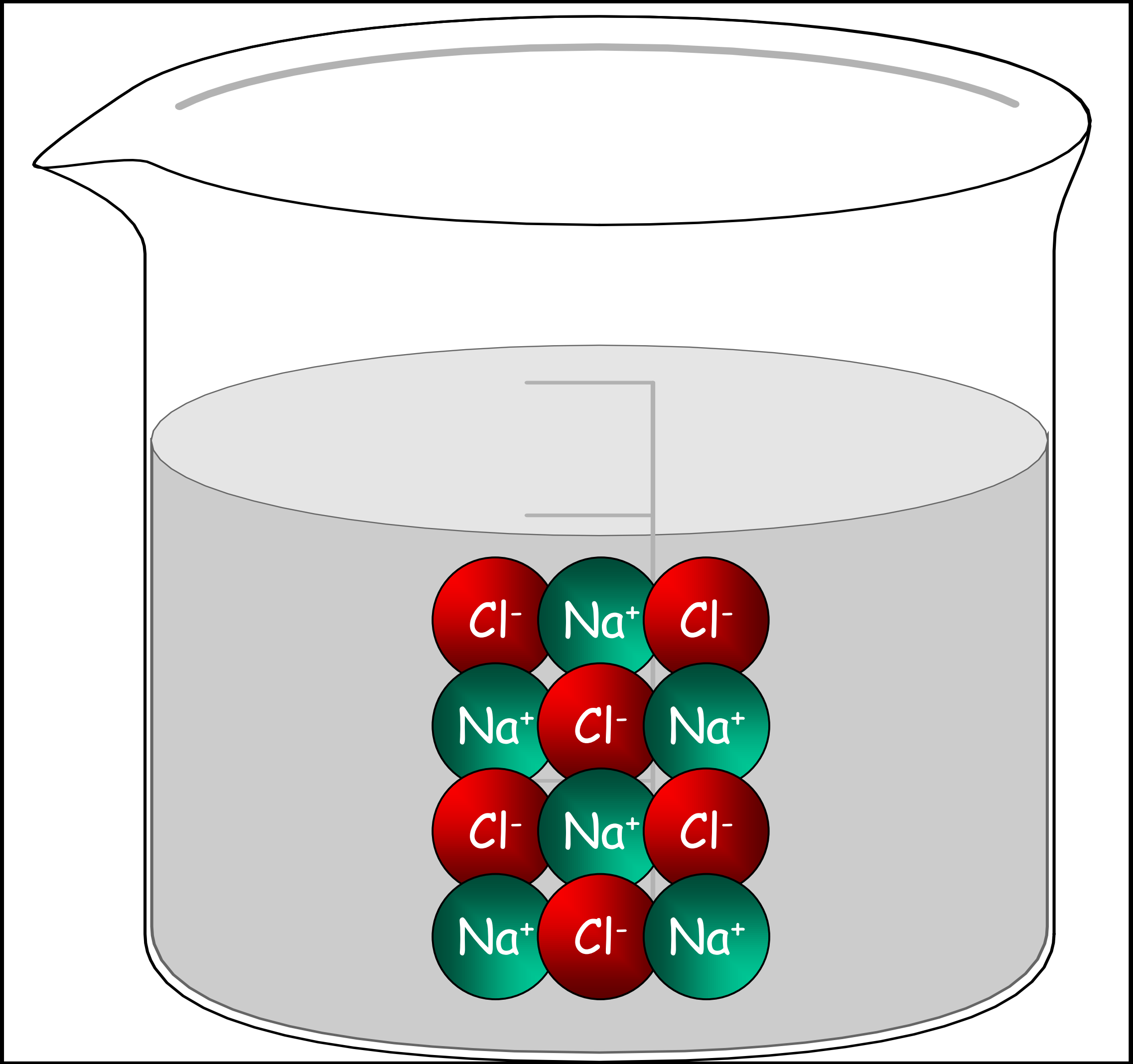


If these ions are strongly held together what affect would this have on the substance's:

1) Melting point?
2) Boiling point?
3) State (solid, liquid or gas) at room temperature?

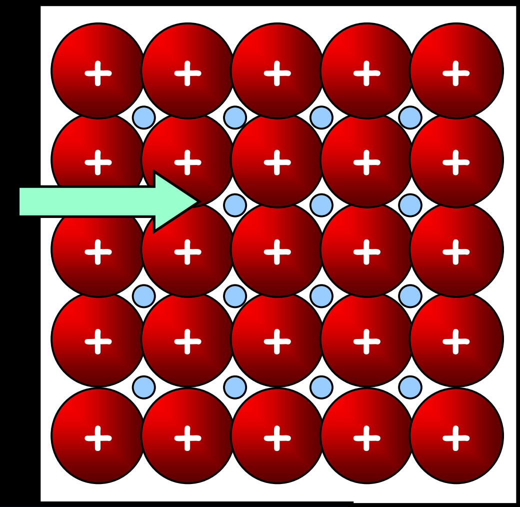
Dissolving Ionic Structures

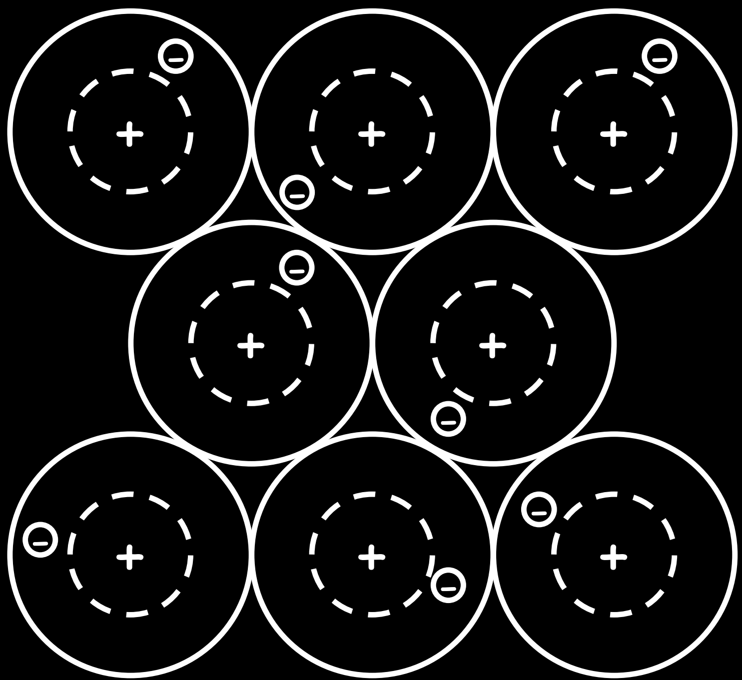
When an ionic structure like sodium chloride is dissolved it enables the water to conduct electricity as charge is carried by the ions:

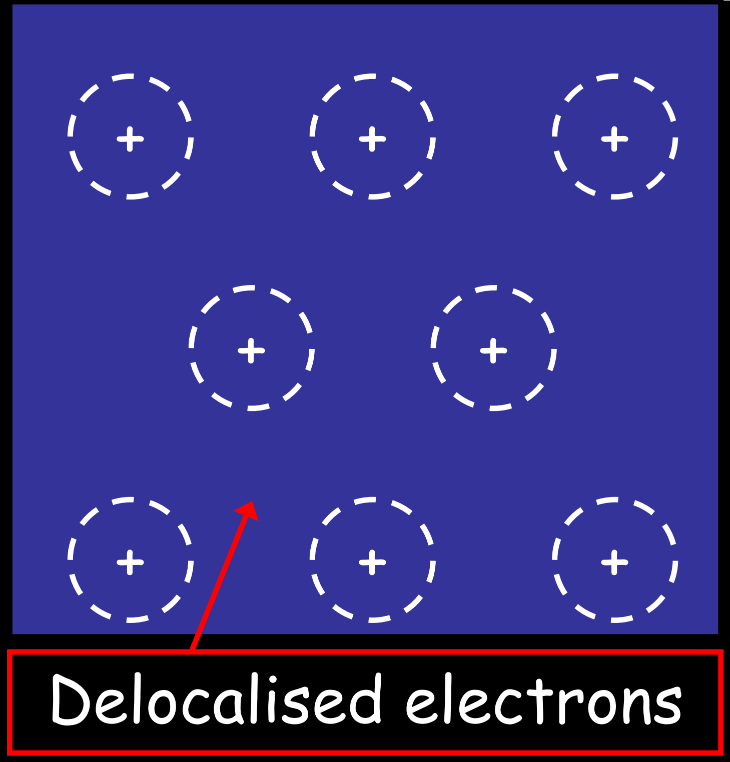


A closer look at metals

Metals are defined as elements that readily lose electrons to form positive ions. The electrons in the highest shells are delocalised and surround positive ions. These delocalised electrons can be used to conduct electricity. There are a number of ways of drawing this:

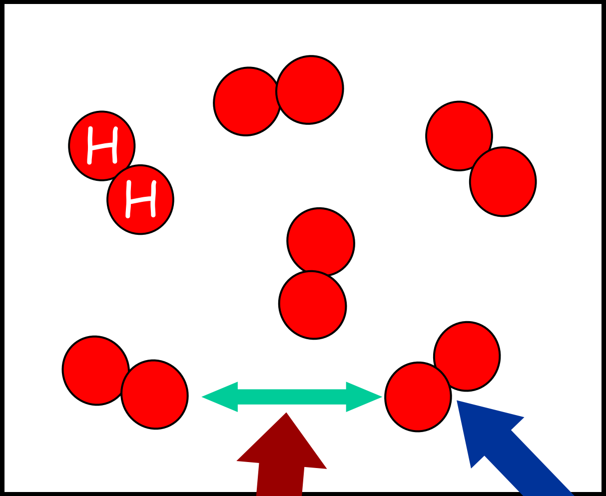






Simple Covalent Molecules

Recall our model of a simple covalent compound like hydrogen, H_2:



Hydrogen has a very low melting point and a very low boiling point. Why?

1) The intermolecular forces are very weak so each one of these H_2 molecules doesn't really care about the others – it's very easy to pull them apart.

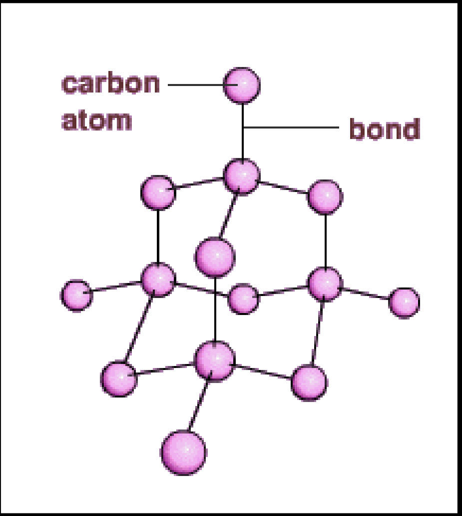
2) When a substance is heated it is the intermolecular forces that are overcome, NOT the covalent bond in each molecule, which is much stronger!

Also, the molecules do not carry a charge so covalent compounds usually do not conduct electricity.

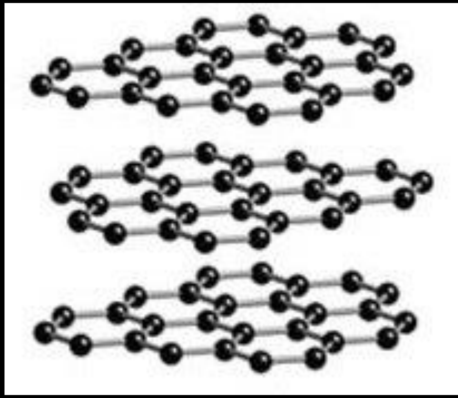
Giant Covalent structures ("lattices")

27/09/2017

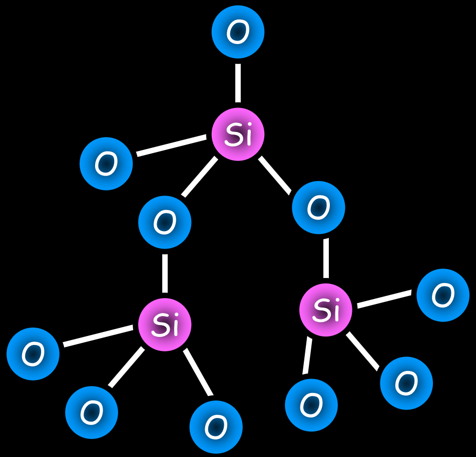
Notice that giant covalent structures have very different properties to individual covalent molecules:



1. Diamond – a giant covalent structure with a very _____ melting point due to _______ bonds between carbon atoms



2. Graphite – carbon atoms arranged in a layered structure, with free ________ in between each layer enabling carbon to conduct __________ (like metals)



3. Silicon dioxide (sand) – a giant covalent structure of silicon and oxygen atoms with strong ______ causing a high _______ point and it's a good insulator as it has no free electrons

Words – melting, high, electrons, bonds, strong, electricity

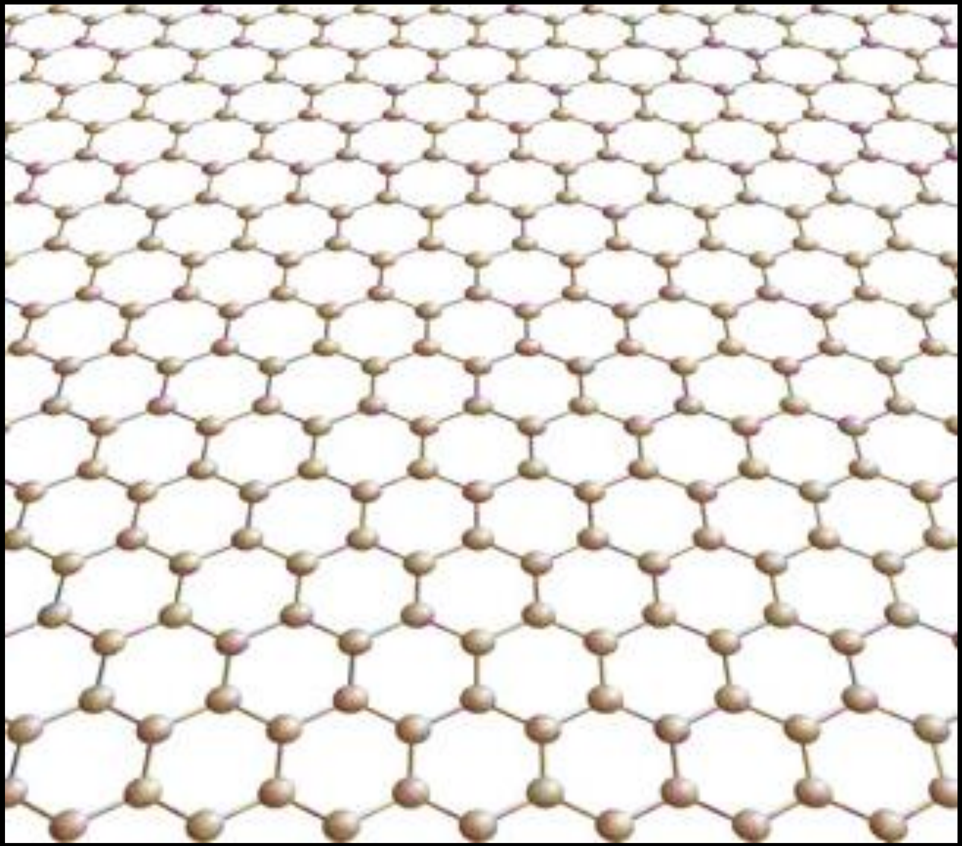
Using Covalent Structures

27/09/2017

Element/ compound	Property	Uses	Why?
Carbon – diamond	Very hard	Drill tips	Extremely strong covalent structure
Carbon - graphite	Soft	Lubricants	Layers "slip" off each other
Carbon - graphite	Conducts electricity	Making electrodes	Free electrons to carry charge

Graphene

27/09/2017

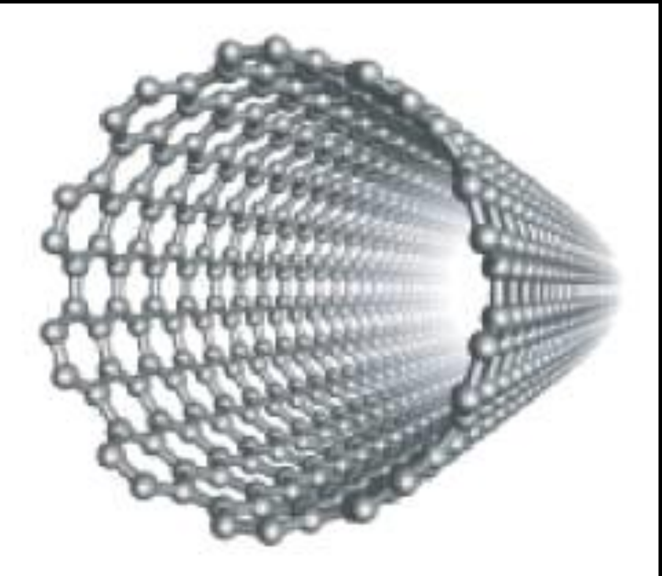


Graphene is a single layer of carbon atoms and is only one atom thick.

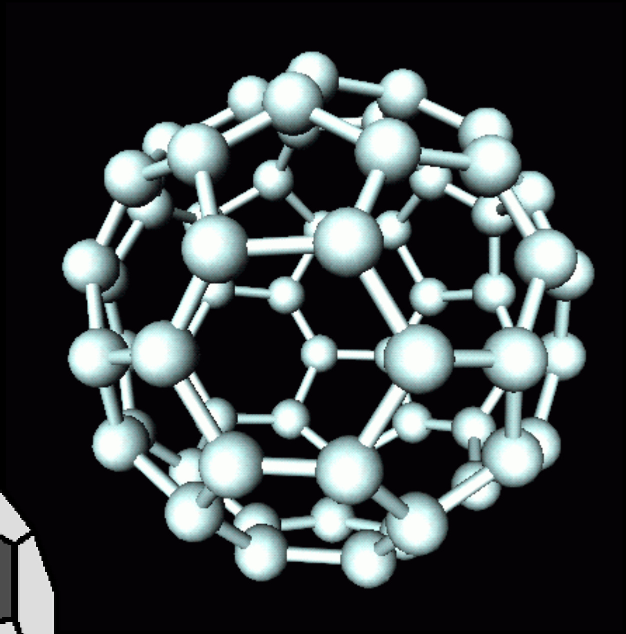
Q. What are the possible uses for graphene?

Fullerenes

Carbon can also be used to make structures called "fullerenes" (carbon atoms forming an empty shape). Fullerenes are compounds used for applications such as drug delivery, lubricants, catalysts and nanotubes and they have structures based on carbon atoms forming hexagonal rings:

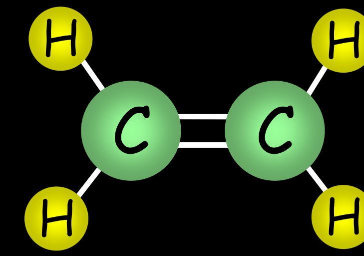


A "carbon nanotube" – high tensile strength, high electrical conductivity and high thermal conductivity



"Buckminster fullerene" – the first fullerene to be discovered in 1960.

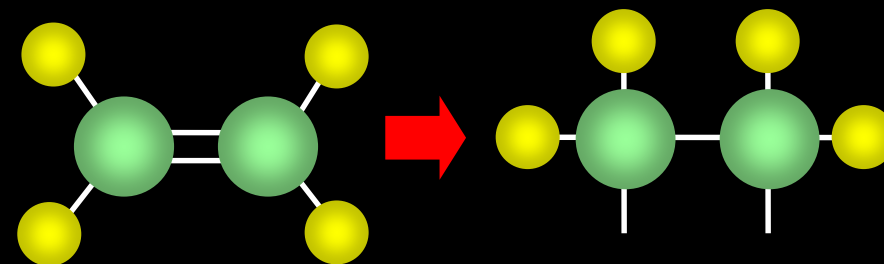
Polymers



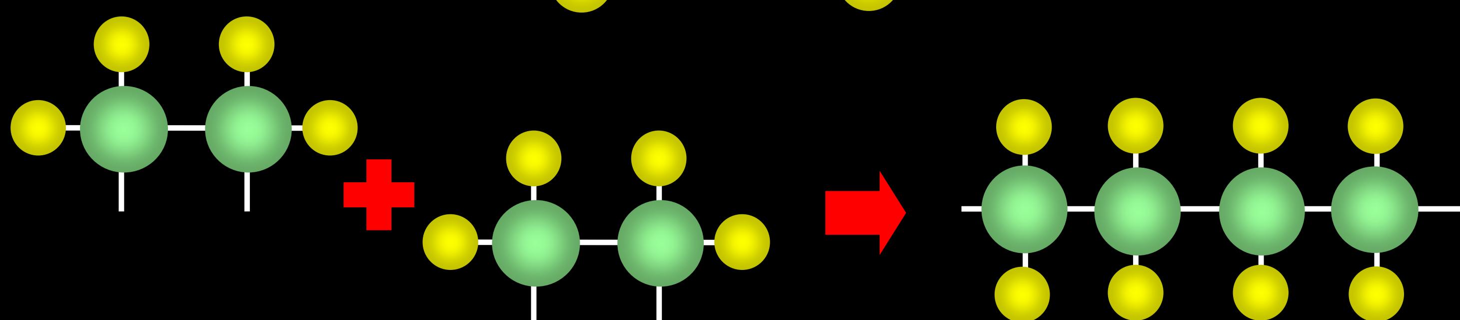
Ethene

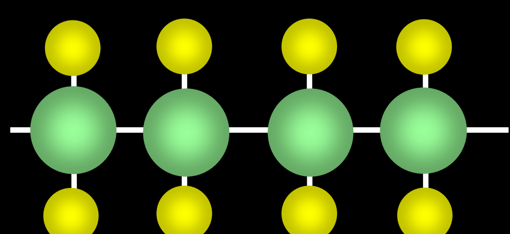
Polymers are compounds consisting of large molecules containing chains of carbon atoms. For example, take ethene:

Step 1: Break the double bond



Step 2: Add the molecules together:





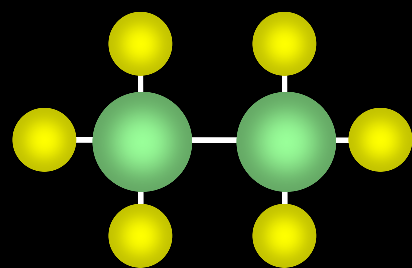
This molecule is called POLYETHENE – a common plastic.

27/09/2017

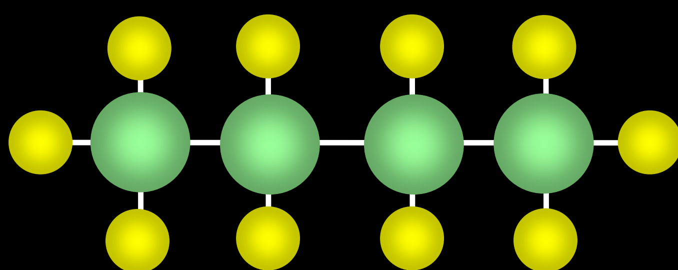
Polymers

Polymers are compounds consisting of large molecules containing chains of carbon atoms. For example:

ALKANES

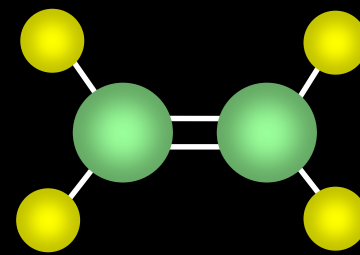


Ethane

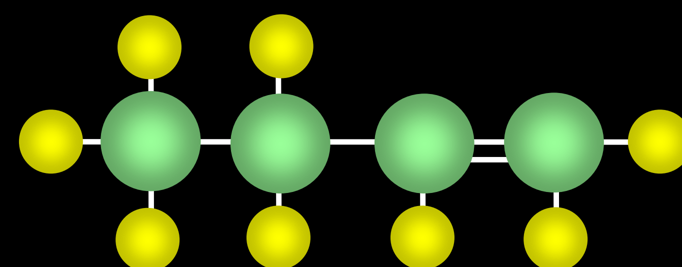


Butane

ALKENES



Ethene



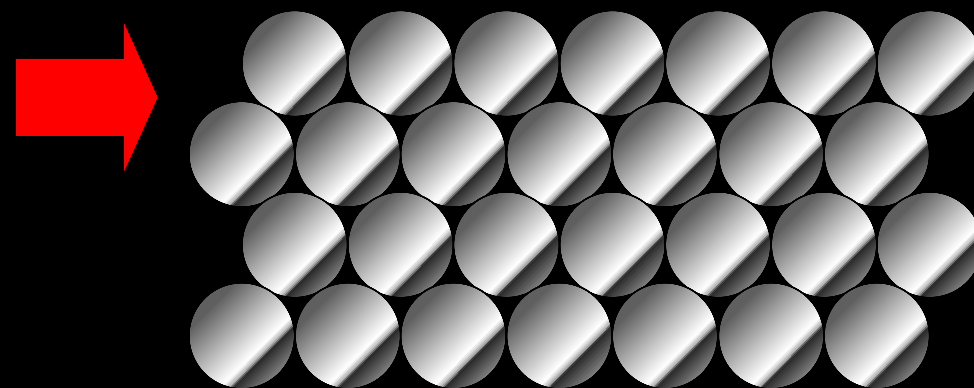
Butene

This double bond means that alkenes have the potential to join with other molecules – this make them REACTIVE. Alkenes turn bromine water colourless.

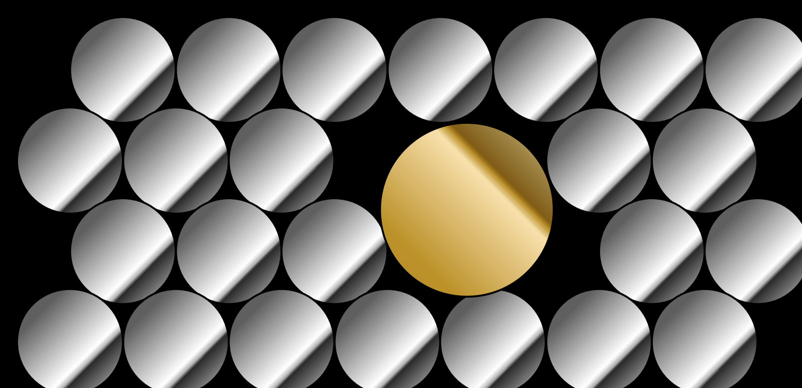
Metals and Alloys

Metals are also easy to bend and malleable. This is because the layers slide over each other:

A pure metal:



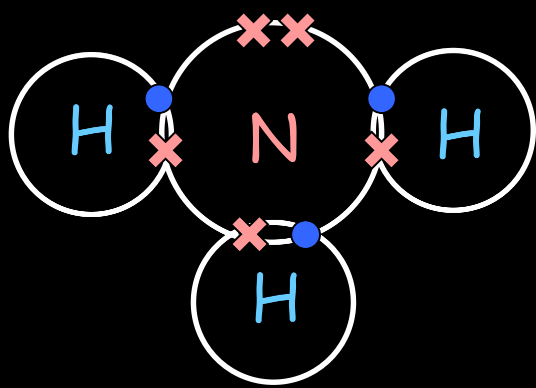
An alloy is a mixture of metals that causes the metal to behave differently:

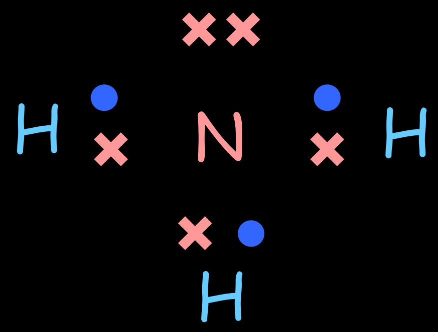


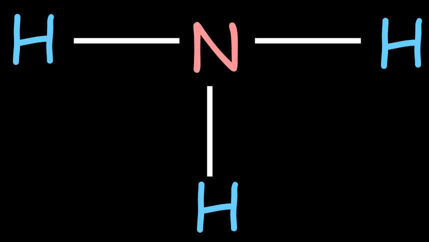
Calculations involving Masses

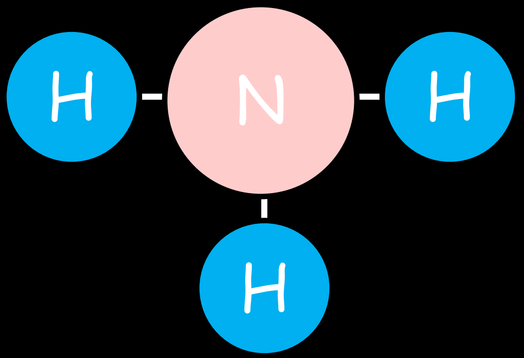
Other ways of drawing covalent bonds

Consider ammonia (NH_3):









What are the limitations of each way of drawing these molecules?

Metals vs Non-metals

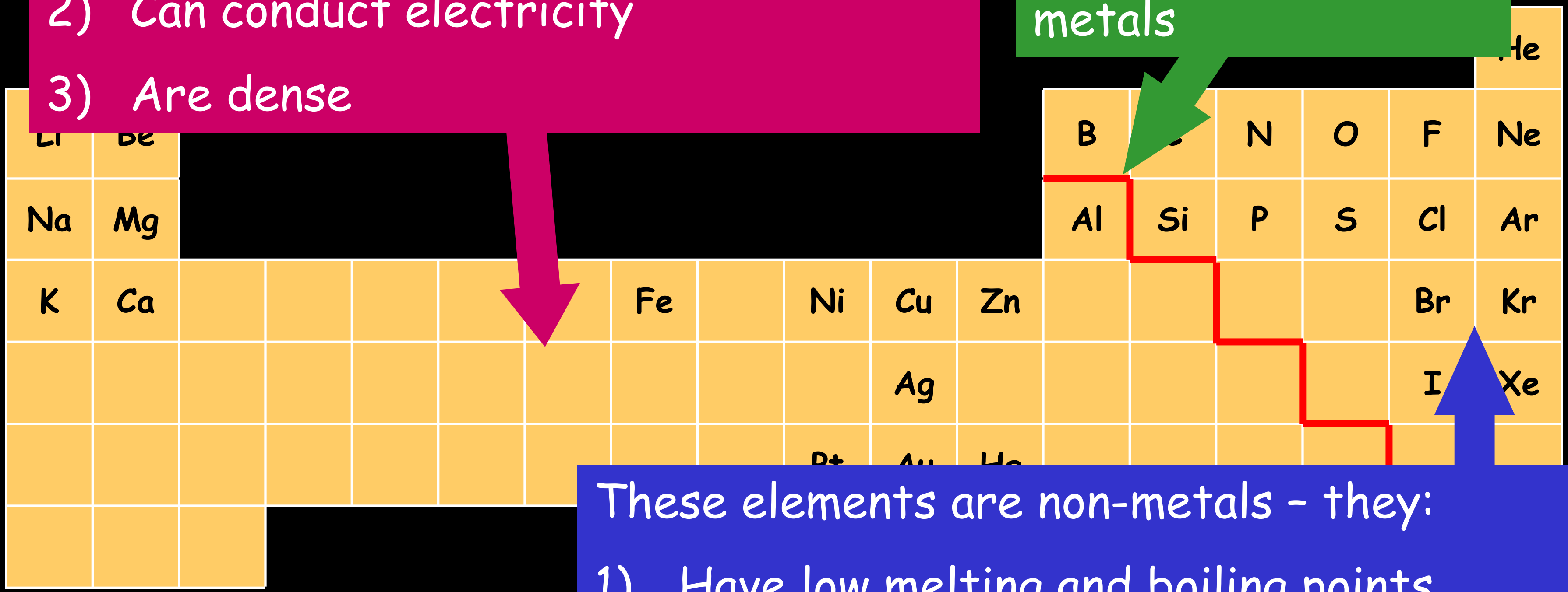
27/09/2017

Recall that most of the elements are metals:

These elements are metals – they:

1) Have high melting points
2) Can conduct electricity
3) Are dense

This line divides metals from non-metals



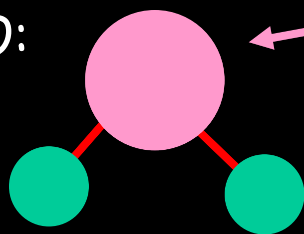
These elements are non-metals – they:

1) Have low melting and boiling points
2) Don't conduct electricity
3) Are not very dense

Relative formula mass, M_r

The *relative formula mass* of a compound is the relative atomic masses of all the elements in the compound added together.

E.g. water H_2O:



Relative atomic mass of O = 16

Relative atomic mass of H = 1

Therefore M_r for water = 16 + (2x1) = 18

Work out M_r for the following compounds:

1) HCl — H=1, Cl=35 so M_r = 36
2) NaOH — Na=23, O=16, H=1 so M_r = 40
3) $MgCl_2$ — Mg=24, Cl=35 so M_r = 24+(2x35) = 94
4) H_2SO_4 — H=1, S=32, O=16 so M_r = (2x1)+32+(4x16) = 98
5) K_2CO_3 — K=39, C=12, O=16 so M_r = (2x39)+12+(3x16) = 138

Empirical formulae

Empirical formulae is simply a way of showing how many atoms are in a molecule (like a chemical formula). For example, CaO, $CaCO_3$, H_20 and $KMnO_4$ are all empirical formulae. Here's how to work them out:

A classic exam question:

Find the simplest formula of 2.24g of iron reacting with 0.96g of oxygen.

Step 1: Divide both masses by the relative atomic mass:

For iron 2.24/56 = 0.04

For oxygen 0.96/16 = 0.06

Step 2: Write this as a ratio and simplify:

0.04:0.06 is equivalent to 2:3

Step 3: Write the formula:

2 iron atoms for 3 oxygen atoms means the formula is $\underline{Fe_2O_3}$

Example questions

1) Find the empirical formula of magnesium oxide which contains 48g of magnesium and 32g of oxygen.

MgO

2) Find the empirical formula of a compound that contains 42g of nitrogen and 9g of hydrogen.

NH_3

3) Find the empirical formula of a compound containing 20g of calcium, 6g of carbon and 24g of oxygen.

$CaCO_3$

Determining Empirical Formulae

Q. How could you use this experiment to deduce the empirical formula of magnesium oxide?

An example of Conservation of Mass

Here's a classic experiment where magnesium is burned in a crucible:

$2Mg + O_2 \rightarrow 2MgO$

Mass of magnesium and crucible after burning = 78.56g

Mass of magnesium and crucible before burning = 78.25g

Mass is always conserved in any reaction, so where did this extra mass come from?

Example Questions

For each of the following reactions, state whether or not the mass of the total system should go up or down and explain your answer:

1) Iron + oxygen $\longrightarrow$ iron oxide

2) Copper carbonate $\longrightarrow$ copper oxide + carbon dioxide

For higher tier, write a balanced equation for each reaction, given that iron oxide is Fe_2O_3 and copper carbonate is $CaCO_3$.

Calculating the mass of a product

E.g. what mass of magnesium oxide is produced when 60g of magnesium is burned in air?

IGNORE the oxygen in step 2 – the question doesn't ask for it

Step 1: READ the equation:

$$2Mg + O_2 \longrightarrow 2MgO$$

Step 2: WORK OUT the relative formula masses (M_r):

2Mg = 2 x 24 = 48   2MgO = 2 x (24+16) = 80

Step 3: LEARN and APPLY the following 3 points:

1) 48g of Mg makes 80g of MgO
2) 1g of Mg makes 80/48 = 1.66g of MgO
3) 60g of Mg makes 1.66 x 60 = 100g of MgO

1) When water is electrolysed it breaks down into hydrogen and oxygen:

$$2H_2O \longrightarrow 2H_2 + O_2$$

What mass of hydrogen is produced by the electrolysis of 6g of water?

Work out M_r: $2H_2O = 2 \times ((2\times1)+16) = 36$ $2H_2 = 2\times2 = 4$

1. 36g of water produces 4g of hydrogen
2. So 1g of water produces 4/36 = 0.11g of hydrogen
3. 6g of water will produce (4/36) x 6 = **0.66g of hydrogen**

2) What mass of calcium oxide is produced when 10g of calcium burns?

$$2Ca + O_2 \longrightarrow 2CaO$$

M_r: $2Ca = 2\times40 = 80$ $2CaO = 2 \times (40+16) = 112$

80g produces 112g so 10g produces (112/80) x 10 = **14g of CaO**

3) What mass of aluminium is produced from 100g of aluminium oxide?

$$2Al_2O_3 \longrightarrow 4Al + 3O_2$$

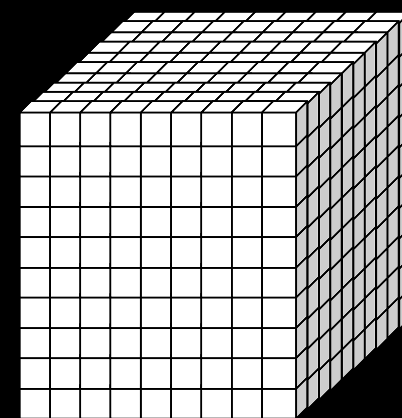
M_r: $2Al_2O_3 = 2\times((2\times27)+(3\times16)) = 204$ $4Al = 4\times27 = 108$

204g produces 108g so 100g produces (108/204) x 100 = **52.9g of Al_2O_3**

A note about volume…

The two most commonly used units of volume in chemistry are the cm^3 and the dm^3:

$1cm^3$



$1dm^3$ (= $1000cm^3$)

1) Convert $1250cm^3$ into dm^3
2) Convert $1cm^3$ into dm^3
3) Convert $0.056dm^3$ into cm^3
4) Convert $1.28dm^3$ into cm^3

A "Mole" in numbers (higher only)

Definition:

A mole of a substance is the relative formula mass of that substance in grams,

For example, 12g of carbon would be 1 mole of carbon...

...and 44g of carbon dioxide (CO_2) would be 1 mole etc...

Q. How many moles are the following?

1. 23g of sodium — 1 mol
2. 48g of magnesium — 2 mol
3. 36g of carbon — 3 mol
4. 28g of iron — 0.5 mol

A "Mole" (higher only)

Definition:

A mole of a substance ALWAYS contains the same number of molecules/ions/particles/atoms:

Avogadro's Constant: 1 mole = 6.02×10^{23} molecules

Q. How many moles are the following?

1. How many molecules are in 2 moles of carbon? 1.2×10^{24}
2. What about 2 moles of magnesium? 1.2×10^{24}
3. How many molecules are in 46g of sodium? 1.2×10^{24}
4. How many molecules are in 23g of iron? 3.0×10^{23}

Molar Calculations (higher only)

$$\text{No. of moles} = \frac{\text{Mass (g)}}{\text{Molar mass (g/mol)}} \qquad N = \frac{m}{M}$$

Some example questions:

1) Calculate the mass of 4 mol of lithium — 28g
2) Calculate the mass of 2 mol of sodium — 46g
3) Calculate the number of moles in 36g of carbon — 3 mol
4) Calculate the number of moles in 88g of carbon dioxide — 2 mol
5) Calculate the number of moles in 27g of water — 1.5 mol

Harder Molar Calculations (HT only)

$$\text{No. of moles} = \frac{\text{Mass (g)}}{\text{Molar mass (g/mol)}}$$

$$N = \frac{m}{M}$$

1 mole = 6.02×10^{23} molecules

Some example questions:

1) How many moles and how many molecules would be in 46g of sodium?

2 moles, 1.2×10^{24} molecules

2) How many grams would 1.806×10^{24} molecules of carbon weigh?

36g

3) How many grams would 1 millions molecules of hydrogen weigh?

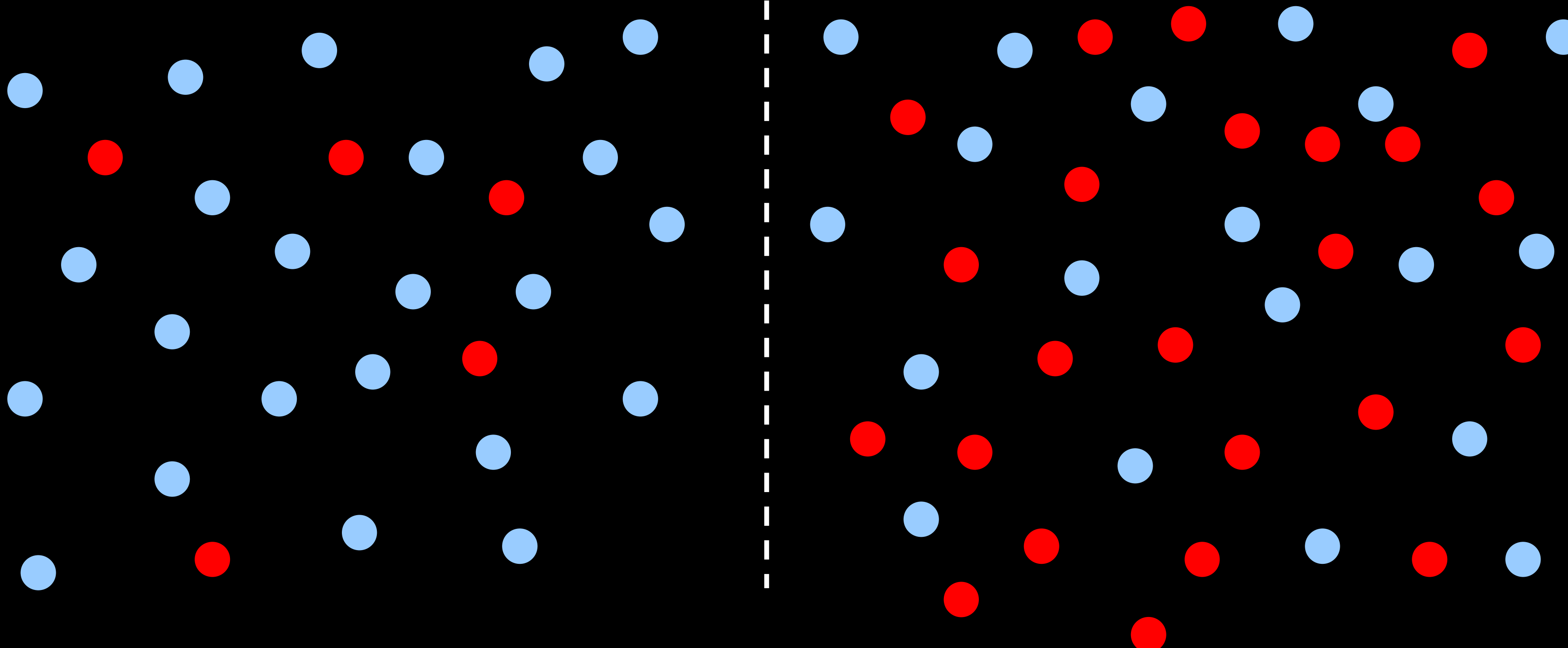
1.66×10^{-18}g

Concentration

Concentration means "how much of a chemical there is in a fixed volume" and can be measured in g/dm^3 or mol/dm^3.

A solution of low concentration ("dilute")

A solution of high concentration ("strong")



Questions on Concentration

To calculate the concentration of a substance you could use this formula:

$$\text{Conc.} = \frac{\text{Mass of substance (g)}}{\text{Volume of solvent (dm}^3\text{)}}$$

Calculate, with units, the concentration of the following:

1) A solution of 10g salt in $1dm^3$ of water
2) 2g of hydrochloric acid in $500cm^3$ of water
3) 10kg of salt in $200dm^3$ of water
4) 0.5g of sodium hydroxide in $100cm^3$ of water

Calculating the mass of a product using moles (higher only)

Let's try this question again but using moles:

Step 1: READ the equation:

$$2Mg + O_2 \longrightarrow 2MgO$$

"2 moles of magnesium + 1 mole of oxygen forms 2 moles of magnesium oxide"

Step 2: WORK OUT the relative formula masses (M_r) of MgO:

$$2MgO = 2 \times (24+16) = 80$$

Step 3: Apply these steps:

1) 60g of Mg is equal to 1.25 moles (60/48)
2) Therefore we will make 1.25 moles of magnesium oxide
3) Therefore we make 100g of MgO (1.25 moles)

Limiting Reactants (higher only)

What happens if you use too much of one compound? Example question:

Consider the reaction you have when you burn methane:

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

A student burns 32g of methane in 72g of oxygen. Which reactant is used up completely?

32g of methane is 2 moles. 72g of oxygen is 2.25 moles of O_2. Therefore this reaction is limited by the 2 moles of methane – the "limiting reactant" (i.e. the reactant that is not in excess).

Q. How much CO_2 would we expect to produce?

2 moles (88g)

Using Moles to balance equations higher only)

Example question:

130g of zinc reacts with 146g of hydrochloric acid (HCl) to form 272g of zinc chloride ($ZnCl_2$) and some hydrogen (H_2). Answer the following:

1) How much hydrogen was produced?

4g

2) How many moles of each substance were reacted/produced?

1 of Zn, 2 of HCl, 1 of $ZnCl_2$, 1 of H_2

3) Write a balanced chemical equation for this reaction.

$$Zn + 2HCl \longrightarrow ZnCl_2 + H_2$$