S1 Periodic table

OBJECTIVES

already from GCSE, you know that

- elements can be displayed in a periodic table
- elements with similar properties are found near to each other in the periodic table

and after this spread you should be able to

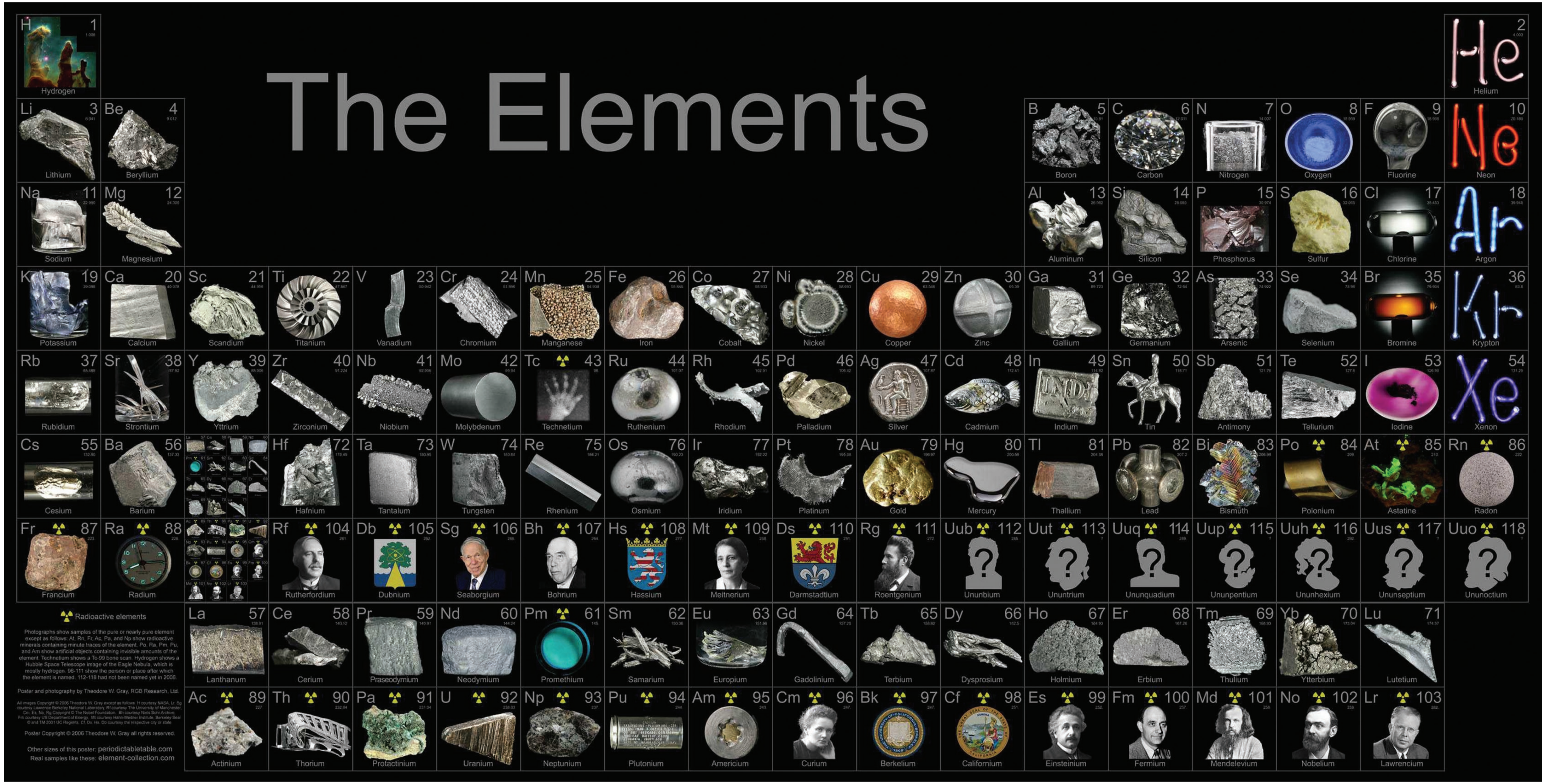
- understand how elements are arranged in the periodic table
- recall the properties of some of the groups in the periodic table

Groups and periods

Elements consist of just one type of atom. There are about a hundred different elements and they are often displayed in a periodic table.

In the modern periodic table the elements are arranged in rows in order of increasing atomic number, so that elements with similar properties occur periodically. This leads to the name the periodic table.

The vertical columns are called *groups* and the horizontal rows are called *periods*. Elements in the same group have similar chemical properties.



Metals

Metallic elements are found on the left hand side of the periodic table. The elements in group 1, including sodium and potassium, are known as the alkali metals. All the alkali metals are very reactive. They react vigorously with water to form a metal hydroxide solution and hydrogen. Reactivity increases down group 1.

Transition metals such as iron and copper are found in the central block of the periodic table. Transition metals are good thermal and electrical conductors and most can be hammered into shape. Mercury is the only metallic element which is liquid at room temperature.

Non-metals

Non-metallic elements are found on the right hand side of the periodic table. The elements in group 7 are known as the halogens. The halogens, which include chlorine and bromine, are typical non-metallic elements. They react with metals to form halides, e.g. sodium reacts with chlorine to form sodium chloride. Bromine is the only non-metallic element which is a liquid at room temperature.

The elements of group 0 are known as the noble gases. They are very unreactive.

Check your understanding

1. How are elements arranged in the periodic table?
2. What are the vertical columns in the periodic table called?
3. Name the two elements which are liquid at room temperature.

S2 Equations

OBJECTIVES

already from GCSE, you know that

- elements are represented by symbols
- that word and symbol equations can be used to represent what happens during chemical reactions

and after this spread you should be able to

- balance symbol equations
- recall some different types of reaction

Word equations

You can use word equations to represent what happens during a chemical reaction. The reaction between sodium and chlorine to form sodium chloride can be represented by the word equation:

sodium + chlorine → sodium chloride

Balanced symbol equations can also be used to represent reactions but they also tell us the proportions in which the substances react together.

The balanced symbol equation for the reaction between sodium and chlorine is:

$$2Na + Cl_2 \rightarrow 2NaCl$$

This equation shows us that two sodium atoms are required to react with each chlorine molecule.

Balancing equations

During chemical reactions atoms are not created or destroyed, they are just rearranged. This means that there must be the same number of each type of atom on both sides of the equation.

Magnesium reacts with oxygen to form magnesium oxide.

magnesium + oxygen → magnesium oxide

You can use the word equation to write the symbols for the reactants and products:

$$Mg + O_2 \rightarrow MgO$$

But the equation doesn't balance; you need to have the same number of each type of atom on both sides of the equation.

There are two oxygen atoms on the reactants side of the equation but only one oxygen atom on the products side so a 2 is placed in front of the MgO:

$$Mg + O_2 \rightarrow 2MgO$$

The oxygen atoms balance but the magnesium atoms don't, so a 2 is placed in front of the magnesium giving:

$$2Mg + O_2 \rightarrow 2MgO$$

so the equation now balances.

State symbols

You can add state symbols to equations to give extra information about the reactants and products. The symbols used are

- (s) for solid
- (l) for liquid
- (g) for gas
- (aq) for aqueous or dissolved in water

Neutralization reactions

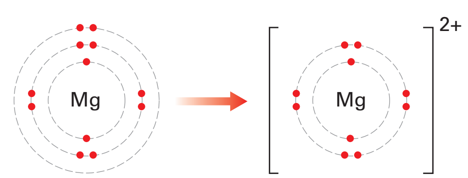
The reaction between an acid and a base is called neutralization. Hydrogen ions, H^+, make solutions acidic and hydroxide ions, OH^-, make solutions alkaline.

During neutralization reactions H^+ ions react with OH^- ions to form water molecules:

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$$

Oxidation reactions

During an oxidation reaction a species loses electrons. When magnesium reacts with oxygen to form magnesium oxide, the neutral magnesium atoms lose electrons to form magnesium ions, which have a 2+ charge.

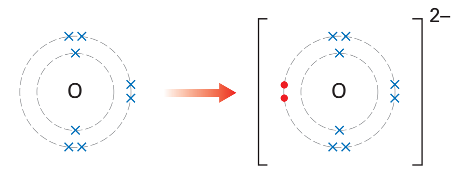


This magnesium atom loses electrons so it is oxidized.

Reduction reaction

During a reduction reaction a species gains electrons.

When magnesium reacts with oxygen to form magnesium oxide, the oxygen atoms gain electrons to form oxide ions, which have a 2– charge.



This oxygen atom gains electrons so it is reduced.

The attraction between the positively charged magnesium ions and the negatively charged oxide ions is an example of ionic bonding.

Oxidation and reduction always occur together, so these reactions are sometimes called redox reactions.

Double decomposition reactions

Insoluble salts can be made by reacting together solutions of soluble salts that contain the appropriate ions. The insoluble salt barium sulfate can be made by reacting a solution of barium chloride with a solution of copper(II) sulfate.

Barium chloride + copper(II) sulfate → barium sulfate + copper(II) chloride

$$BaCl_2(aq) + CuSO_4(aq) \rightarrow BaSO_4(s) + CuCl_2(aq)$$

You would see a white precipitate as the barium sulfate is formed. Effectively the two sets of ions have swapped partners and this is called a double decomposition reaction.

Check your understanding

1. Balance these equations
   - **a** $H_2 + Cl_2 \rightarrow HCl$
   - **b** $Ca + O_2 \rightarrow CaO$
   - **c** $K + I_2 \rightarrow KI$
2. Add state symbols to the equation:

   $$2Mg + O_2 \rightarrow 2MgO$$
3. Give the name or symbols of the ion that makes solutions acidic?

S3 Formulae

OBJECTIVES

already from GCSE, you know that

- an element is made of one type of atom
- formulae can be used to represent the atoms in a compound
- ionic compounds are formed when metals react with non-metals

after this spread you should know be able to

- understand how to interpret formulae
- be able to work out the formulae of some compounds from their names

Understanding formulae

Chemical formulae are used to show us the atoms in the smallest particle of a substance. You use formulae to represent the atoms in molecules, e.g. carbon dioxide which has the formula CO_2, or giant ionic compounds such as sodium chloride, which has the formula NaCl.

- CO_2 means one atom of carbon to two atoms of oxygen.
- NaCl means one atom of sodium to one atom of chlorine.

Brackets

Some formulae contain brackets. When this happens the small number placed after the bracket indicates what everything inside the brackets must be multiplied by to find the atoms in the smallest particle of the compound. Copper nitrate has the formula $Cu(NO_3)_2$. This means that everything inside the brackets must be multiplied by 2 so in the smallest particle of copper nitrate there is one atom of copper, two atoms of nitrogen, and six atoms of oxygen.

Strontium hydroxide has the formula $Sr(OH)_2$. This means in the smallest particle of strontium hydroxide there is one atom of strontium, two atoms of oxygen, and two atoms of hydrogen.

Naming compounds

Compounds are formed when atoms of two or more elements are chemically combined. When atoms of two elements join together to form a compound the name of the compound is found by combining the names of the two elements. If the compound is formed from a metal and a non-metal, the name of the metal is placed first and the name of the non-metal is changed to end in 'ide'.

Sodium reacts with chlorine to form the compound sodium chloride.

Iron reacts with sulfur to form iron sulfide.

The names of some compounds end in 'ate'. This means that the compound also contains oxygen.

Copper(II) sulfate contains copper, sulfur, and oxygen.

Learn to recognize groups of atoms in ionic formulae and the names used for them. Here are some groups of atoms and how they are named in formulae:

- CO_3 is carbonate
- SO_4 is sulfate
- NO_3 is nitrate
- OH is hydroxide
- NH_4 is ammonium

Writing formulae for ionic compounds

Metals react with non-metals to form ionic compounds. Metal atoms lose electrons to form positive ions, non-metal atoms gain electrons to form negative ions.

positive ions		negative ions	
name	formula	name	formula
hydrogen	H^+	chloride	Cl^-
sodium	Na^+	bromide	Br^-
silver	Ag^+	fluoride	F^-
potassium	K^+	iodide	I^-
lithium	Li^+	hydroxide	OH^-
ammonium	NH_4^+	nitrate	NO_3^-
barium	Ba^{2+}	oxide	O^{2-}
calcium	Ca^{2+}	sulfide	S^{2-}
copper(II)	Cu^{2+}	sulphate	SO_4^{2-}
magnesium	Mg^{2+}	carbonate	CO_3^{2-}
zinc	Zn^{2+}		
lead	Pb^{2+}		
iron(II)	Fe^{2+}		
iron(III)	Fe^{3+}		
aluminium	Al^{3+}		

The formulae of some common ions.

Compounds are neutral so we can use the table of ions to predict the formulae of compounds.

Calcium carbonate consists of calcium ions which have a 2+ charge and carbonate ions which have a 2– charge. The compound must be neutral overall so each Ca^{2+} ion is balanced by one CO_3^{2-} ion giving calcium carbonate the formula $CaCO_3$.

Magnesium chloride consists of Mg^{2+} and Cl^- ions. Each magnesium ion, Mg^{2+} must be balanced by two Cl^- ions giving magnesium chloride the formula $MgCl_2$.

Transition metal ions

Many transition metal atoms can form different ions. Iron commonly forms both Fe^{2+} and Fe^{3+} ions.

When naming transition metal compounds you show the charge on the transition metal ion by writing it in roman numerals in brackets after the name of the metal.

Fe_2O_3 consists of two Fe^{3+} ions and three O^{2-} ions so this compound is named iron(III) oxide.

Check your understanding

1. Identify all the elements, and how many of their atoms are present in the smallest particle of each of these compounds.
   - **a** CO
   - **b** Na_2O
   - **c** $NaNO_3$
2. Name these compounds
   - **a** $MgCO_3$
   - **b** NaOH
   - **c** $CaSO_4$

S4 Structure and bonding

OBJECTIVES

already from GCSE, you know that

- atoms can join together by sharing electrons or giving and taking electrons
- metals react with non-metals to form ionic compounds
- non-metal atoms can join together to form covalent structures
- metals have special properties

and after this spread you should be able to

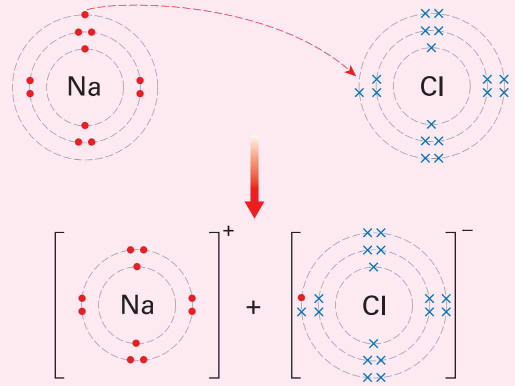
- describe what ionic bonds are and how they form
- recall some properties of ionic compounds
- describe how covalent structures form
- recall some properties of simple molecules and giant covalent structures
- describe metallic bonding and how it leads to the special properties of metals

Shells and levels

At GCSE you may have answered questions using *shells of electrons*. At AS/A2 you must refer instead to energy levels. So, the outer shell becomes the *highest occupied energy level* and a full shell becomes a *complete energy level*.

Ionic bonding

Ionic bonding involves the transfer of electrons from metal atoms to non-metal atoms. As electrons have a negative charge, the metal atoms become positively charged ions and the non-metal atoms become negatively charged ions. Both sets of ions have a full outer shell of electrons, like a noble gas atom.



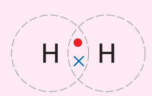
The metal sodium reacts with the non-metal chlorine to form the ionic compound sodium chloride.

Properties of ionic compounds

Ionic compounds have a giant ionic structure. Ionic bonding is the electrostatic attraction between the positively charged metal ions and the negatively charged non-metal ions. Ionic compounds have high melting points and boiling points because a lot of energy must be supplied to overcome the strong forces of attraction between the ions. Ionic compounds do not conduct electricity when solid, but they do conduct electricity when molten or dissolved in water because the ions are able to move.

Covalent bonding

Covalent bonding occurs between non-metal atoms. These atoms join together by sharing pairs of electrons so that all the atoms have a full outer shell, like a noble gas atom.



Hydrogen atoms can join together to form a hydrogen molecule.

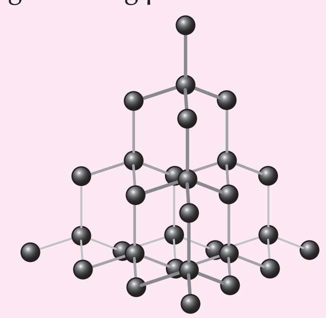
Properties of simple molecules

Simple molecules are formed when small numbers of non-metal atoms are joined together by covalent bonds. Most simple molecules are gases or liquids at room temperature and those that are solid tend to have quite low melting points. Although there are strong covalent bonds within the molecules, there are only very weak forces of attraction between molecules (intermolecular forces). Only the weak, intermolecular forces must be overcome for the substance to melt or boil, so simple molecules tend to have quite low melting and boiling points.

Simple molecules do not conduct electricity because they do not have an overall electrical charge.

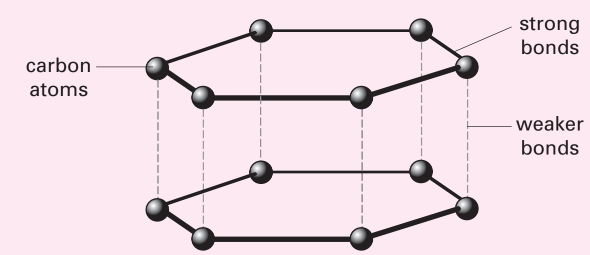
Properties of giant covalent structures

Diamond and graphite are both allotropes of the element carbon. They both have giant covalent structures. In diamond each carbon atom is joined to four other carbon atoms by strong covalent bonds so diamond has a very high melting point and is very hard.



The structure of diamond.

In graphite each carbon atom is bonded to three other carbon atoms in the same layer by strong covalent bonds but the bonding between layers is much weaker. Graphite has a high melting point but the layers can slip over each other quite easily so it is soft and slippery. It can conduct heat and electricity because it contains free electrons within its layers.



The structure of graphite.

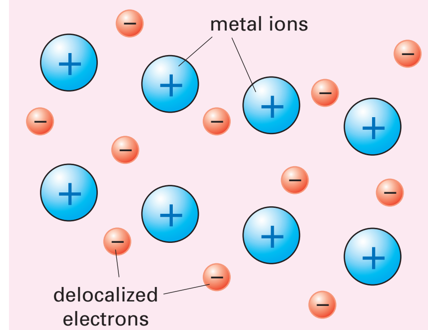
Check your understanding

1. What is an ionic bond?
2. What is a covalent bond?
3. Oxygen is a simple molecule. Why does it have quite a low boiling point?

Metallic bonding

Metals have a giant structure. In metal atoms the outermost electrons are delocalized. This leads to positive metal ions surrounded by negative delocalized electrons.

Metallic bonding is the attraction between these positive metal ions and the negative electrons. Metals are good thermal and electrical conductors because the delocalized electrons are free to move through the whole structure. Metals can be hammered into shape because the layers of atoms can slide over each other.



Metallic bonding is the attraction between the positive metal ions and negative delocalized electrons.

S5 Organic chemistry

OBJECTIVES

already from GCSE, you know

- what a hydrocarbon is
- the names of some hydrocarbon molecules
- that some hydrocarbon molecules make useful fuels

and after this spread you should be able to

- recognize some alkane and alkene molecules from their full structural displayed formula
- recall the general formula of alkanes and alkenes
- recall some uses of alkanes and alkenes

The importance of carbon

Organic chemistry is the study of the compounds formed by carbon.

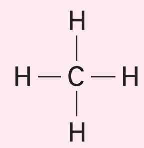
A carbon atom has four electrons in its outer shell. This means that it can form four covalent bonds with other atoms.

Alkanes

The alkanes are a family of organic compounds. All alkane molecules have a similar structure. Alkanes are saturated hydrocarbons because they only contain carbon and hydrogen atoms, and they do not have any carbon–carbon double bonds. The carbon–carbon bonds and the carbon–hydrogen bonds are both very strong, so alkanes are quite unreactive.

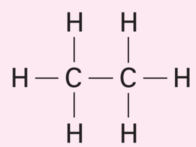
Alkanes are represented by the general formula C_nH_{2n+2}. Owing to their similar structures when different alkane molecules do react, they react in a similar way.

The simplest alkane molecule is called methane. It has the formula CH_4.

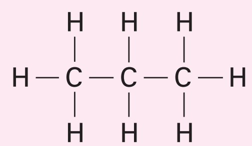


Each line represents a covalent bond.

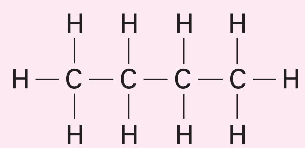
Ethane, propane, and butane are also alkanes.



Ethane has the formula C_2H_6.



Propane has the formula C_3H_8.



Butane has the formula C_4H_{10}.

Uses of alkanes

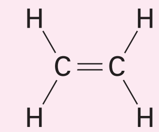
Many alkane molecules are good fuels. When they are burnt in a good supply of oxygen they produce carbon dioxide and water vapour and release a lot of energy. Methane is used as a fuel in Bunsen burners.

methane + oxygen → carbon dioxide + water

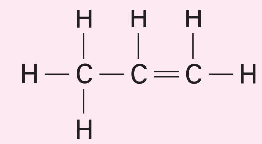
$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Alkenes

The alkenes are another hydrocarbon family. They all contain carbon–carbon double bonds so they are known as unsaturated hydrocarbons. Alkene molecules are represented by the general formula C_nH_{2n}. Owing to the similarities in their structures all alkene molecules react in a similar way.



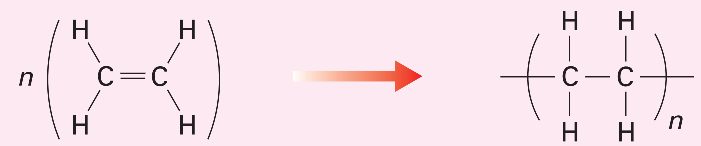
Ethene has the formula C_2H_4.



Propene has the formula C_3H_6.

Uses of alkenes

Alkene molecules are much more reactive than alkane molecules and they have a wide range of uses.



The ethene molecules are called monomers.

Some alkene molecules can be used to make very large molecules called polymers. In this way many ethene molecules can be joined together to make a polymer called poly(ethene) or polythene.

The alkene ethene can also be reacted with steam to form ethanol. The reaction requires a high temperature and a catalyst.

ethene + steam → ethanol

$$C_2H_4 + H_2O \rightarrow C_2H_5OH$$

Check your understanding

1. What is the general formula for
   - **a** alkanes
   - **b** alkenes?
2. How are many alkane molecules used?
3. Name the polymer made from a large number of ethene molecules
4. What is the symbol equation for the reaction between ethene and steam?

S6 Calculations

OBJECTIVES

already from GCSE, you know

- that different atoms have different masses
- because atoms are very small we use their relative atomic masses
- that we can look up the relative atomic mass of an element on a periodic table

and after this spread you should be able to find

- the relative formula mass of a substance
- the number of moles of a substance
- the percentage mass of an element in a compound

Relative atomic mass

The *Relative atomic mass* is used to compare the masses of different atoms. As most naturally occurring elements consist of a mixture of different isotopes, the relative atomic mass of an element is the average mass of an element compared with 1/12 of the mass of a carbon-12 atom. Relative atomic masses do not have units.

Relative formula mass

The formula of a compound shows us the type and number of atoms present in the smallest particle of a substance. The relative formula mass of a substance is worked out by adding together the relative atomic masses of all the atoms present in the formula of the substance.

The relative formula mass of carbon dioxide, CO_2, is worked out by adding together the relative atomic mass of one carbon atom and two oxygen atoms

$= (1 \times 12.0) + (2 \times 16.0) = 44.0$

The relative formula mass of calcium carbonate, $CaCO_3$

$= (1 \times 40.1) + (1 \times 12.0) + (3 \times 16.0) = 100.1$

The relative formula mass of copper nitrate, $Cu(NO_3)_2$

$= (1 \times 63.5) + (2 \times 14.0) + (6 \times 16.0) = 187.5$

You can use a periodic table to find the relative atomic mass of an element. (This Periodic table is photocopiable in the purchaser's institute.)

Times of discovery

- before 1800
- 1800–1849
- 1849-1899
- 1900-1949
- 1949-1999

Period	Group 1	2											3	4	5	6	7	0
1	1.0 H Hydrogen 1																	4.0 He Helium 2
2	6.9 Li Lithium 3	9.0 Be Beryllium 4											10.8 B Boron 5	12.0 C Carbon 6	14.0 N Nitrogen 7	16.0 O Oxygen 8	19.0 F Fluorine 9	20.2 Ne Neon 10
3	23.0 Na Sodium 11	24.3 Mg Magnesium 12											27.0 Al Aluminium 13	28.1 Si Silicon 14	31.0 P Phosphorus 15	32.1 S Sulfur 16	35.5 Cl Chlorine 17	39.9 Ar Argon 18
4	39.1 K Potassium 19	40.1 Ca Calcium 20	45.0 Sc Scandium 21	47.9 Ti Titanium 22	50.9 V Vanadium 23	52.0 Cr Chromium 24	54.9 Mn Manganese 25	55.8 Fe Iron 26	58.9 Co Cobalt 27	58.7 Ni Nickel 28	63.5 Cu Copper 29	65.4 Zn Zinc 30	69.7 Ga Gallium 31	72.6 Ge Germanium 32	74.9 As Arsenic 33	79.0 Se Selenium 34	79.9 Br Bromine 35	83.8 Kr Krypton 36
5	85.5 Rb Rubidium 37	87.6 Sr Strontium 38	88.9 Y Yttrium 39	91.2 Zr Zirconium 40	92.9 Nb Niobium 41	95.9 Mo Molybdenum 42	98.9 Tc Technetium 43	101.1 Ru Ruthenium 44	102.9 Rh Rhodium 45	106.4 Pd Palladium 46	107.9 Ag Silver 47	112.4 Cd Cadmium 48	114.8 In Indium 49	118.7 Sn Tin 50	121.8 Sb Antimony 51	127.6 Te Tellurium 52	126.9 I Iodine 53	131.3 Xe Xenon 54
6	132.9 Cs Caesium 55	137.3 Ba Barium 56	138.9 La Lanthanum 57	178.5 Hf Hafnium 72	180.9 Ta Tantalum 73	183.9 W Tungsten 74	186.2 Re Rhenium 75	190.2 Os Osmium 76	192.2 Ir Iridium 77	195.1 Pt Platinum 78	197.0 Au Gold 79	200.6 Hg Mercury 80	204.4 Tl Thallium 81	207.2 Pb Lead 82	209.0 Bi Bismuth 83	210.0 Po Polonium 84	210.0 At Astatine 85	222.0 Rn Radon 86
7	(223) Fr Francium 87	(226) Ra Radium 88	(227) Ac Actinium 89															

140.1 Ce Cerium 58	140.9 Pr Praseodymium 59	144.2 Nd Neodymium 60	144.9 Pm Promethium 61	150.4 Sm Samarium 62	152.0 Eu Europium 63	157.3 Gd Gadolinium 64	158.9 Tb Terbium 65	162.5 Dy Dysprosium 66	164.9 Ho Holmium 67	167.3 Er Erbium 68	168.9 Tm Thulium 69	173.0 Yb Ytterbium 70	175.0 Lu Lutetium 71
232.0 Th Thorium 90	231.0 Pa Protactinium 91	238.0 U Uranium 92	237.0 Np Neptunium 93	239.1 Pu Plutonium 94	243.1 Am Americium 95	247.1 Cm Curium 96	247.1 Bk Berkelium 97	252.1 Cf Californium 98	(252) Es Einsteinium 99	(257) Fm Fermium 100	(258) Md Mendelevium 101	(259) No Nobelium 102	(260) Lr Lawrencium 103

Moles

One mole of any substance contains the same number of particles. The relative formula mass of a substance, in grams, is known as the mass of one mole of that substance. This means;

- one mole of carbon dioxide, CO_2, has a mass of 44.0 g
- one mole of calcium carbonate, $CaCO_3$, has a mass of 100.1 g
- one mole of copper nitrate, $Cu(NO_3)_2$, has a mass of 187.5 g.

We cannot measure the number of moles in a substance directly but we can calculate the number of moles present by dividing the mass of the substance by its relative formula mass.

$$\text{number of moles} = \frac{\text{mass of substance}}{\text{relative formula mass of substance}}$$

The number of moles in 11.0 g of carbon dioxide, CO_2

$= 11.0/44.0 = 0.25$ moles

The number of moles in 125 g of calcium carbonate, $CaCO_3$

$= 125.0/100.1 = 1.25$ moles

The number of moles in 375 g of copper nitrate, $Cu(NO_3)_2$

$= 375/187.5 = 2.0$ moles

GCSE vs AS/A2

GCSE = moles
AS/A2 = mol

A_r numbers

GCSE =
whole numbers
(except copper, chlorine)

AS/A2 =
one decimal place

Percentage composition

We also use the relative formula mass of a substance when want to find out the percentage by mass of an element in a compound.

$$\text{percentage of an element in a compound} = \frac{\text{relative atomic mass of the element} \times \text{number of atoms of the element in the formula}}{\text{relative formula mass of the compound}} \times 100$$

The percentage of nitrogen by mass in the compound ammonium nitrate, NH_4NO_3

$$= \frac{14.0 \times 2}{80.0} \times 100 = 35\%$$

Check your understanding

1. What is the relative atomic mass of
   a carbon b chlorine c argon?
2. Calculate the relative formula mass of
   a carbon monoxide, CO b ethene, C_2H_4 c butane, C_4H_{10}
3. Calculate the number of moles present in
   a 2.8 g of ethene, C_2H_4 b 9.0 g of water, H_2O c 2.3 g of ethanol, C_2H_5OH
4. Calculate the percentage by mass of carbon in
   a carbon monoxide, CO b carbon dioxide, CO_2