Equations to explain the formation of complex ions

$Ag_2O(s) + 4NH_3(aq) + H_2O(\ell) \ \$ \ 2[Ag(NH_3)_2]^+(aq) + 2OH^-(aq)$

$AgCl(s) + 2NH_3(aq) \ \$ \ [Ag(NH_3)_2]^+(aq) + Cl^-(aq)$

$Zn(OH)_2(s) + 4NH_3(aq) \ \$ \ [Zn(NH_3)_4]^{2+}(aq) + 2OH^-(aq)$

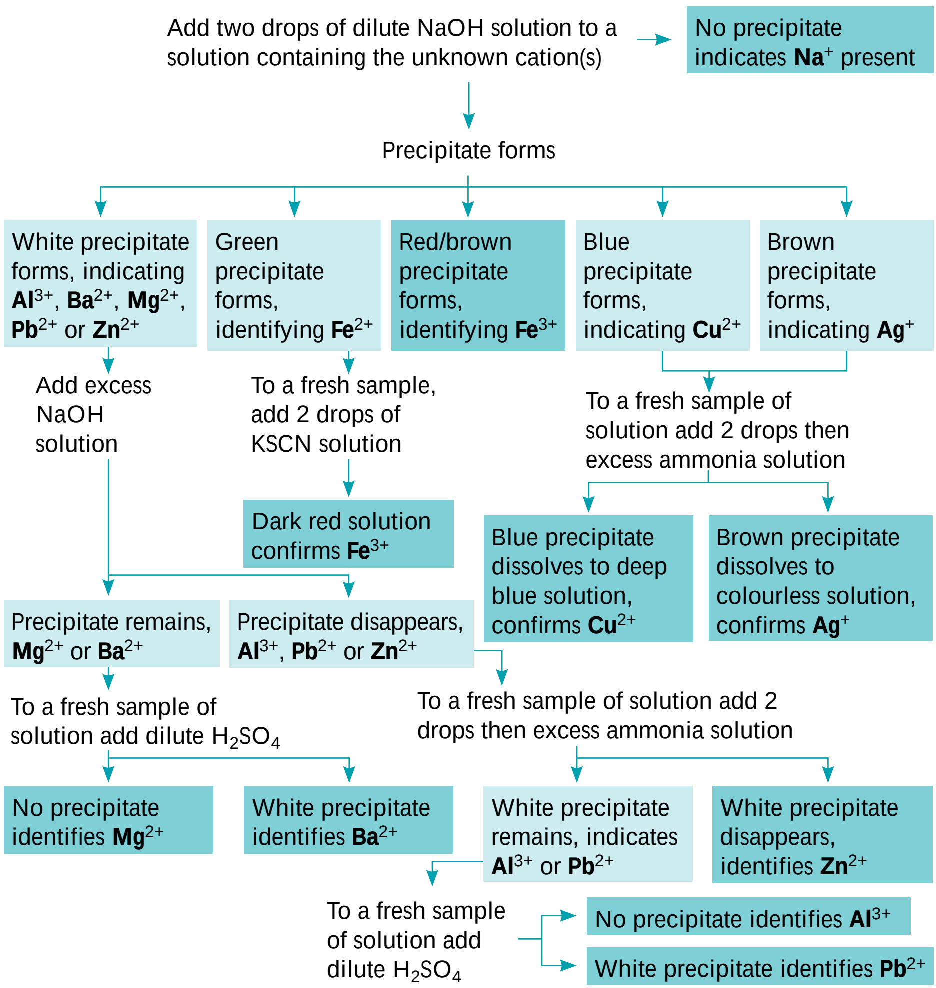
$Zn(OH)_2(s) + 2OH^-(aq) \ \$ \ [Zn(OH)_4]^{2-}(aq)$

$Cu(OH)_2(s) + 4NH_3(aq) \ \$ \ [Cu(NH_3)_4]^{2+}(aq) + 2OH^-(aq)$

$Al(OH)_3(s) + OH^-(aq) \ \$ \ [Al(OH)_4]^-(aq)$

Identifying cations

The presence of Ag^+, Na^+, Ba^{2+}, Cu^{2+}, Fe^{2+}, Mg^{2+}, Pb^{2+}, Zn^{2+}, Al^{3+} or Fe^{3+} ions can be detected using the following procedures.



Ions

When atoms gain or lose electrons they produce i*ons*.

Ions are either cations or anions.

A cation (cat iron)

- **Cations** or *positively* charged ions form when atoms or groups of (*covalently bonded*) atoms lose electrons. Cations have *fewer* electrons than protons (e.g. magnesium ions, Mg^{2+}, have 10 electrons and 12 protons whereas the atoms of the element, Mg, have 12 electrons and 12 protons; aluminium ions, Al^{3+}, have 10 electrons and 13 protons, whereas atoms of the element, Al, have 13 electrons and 13 protons).
- **Anions** or *negatively* charged ions form when atoms or groups of (*covalently bonded*) atoms gain electrons. Anions have *more* electrons than protons (e.g. chloride ions, Cl^-, have 18 electrons, whereas atoms of the element, Cl, have 17 electrons and 17 protons; oxide ions, O^{2-}, have 10 electrons, whereas atoms of the element, O, have 8 electrons).

Ions are written with the charge shown on the *right* and *above* the symbol for the atom or group of atoms.

Examples

The sodium ion is written Na^+, which indicates that a sodium atom loses one electron when it forms a sodium *cation.*

The oxygen ion is written O^{2-}, which indicates that an oxygen atom gains two electrons when it forms an oxide *anion*.

Atoms gain or lose electrons to produce stable valence shells.

Cations

Metals are on the left of the periodic table in Groups 1, 2 and 13, and tend to *lose* electrons to form **monatomic** ('one atom') *cations.*

Example

Sodium atoms and sodium ions

Sodium is element number 11 and has 11 protons and 11 electrons. Sodium ions form when sodium atoms lose an electron from the third energy level.

Chapter 8

Physical properties of the alkanes

Alkanes:

- are colourless compounds
- are *non-polar* and hence are *insoluble* in water
- have densities less than water (i.e. < 1 g cm^{-3}), so they float on water
- dissolve in each other and are often used as solvents for other organic molecules, and act as grease removers
- do not conduct heat or electricity because they do not contain ions or electrons which are free to move
- show increased melting and boiling points as the length of the carbon chain increases.

Name	Molecular formula	Melting point (°C)	Boiling point (°C)
methane	CH_4	–183	–162
ethane	C_2H_6	–183	–89
propane	C_3H_8	–188	–42
butane	C_4H_{10}	–138	–1
pentane	C_5H_{12}	–130	36
hexane	C_6H_{14}	–95	69
heptane	C_7H_{16}	–91	98
octane	C_8H_{18}	–57	126

At room temperature:

- alkanes with molecules with up to four carbon atoms are gases
- alkanes with molecules with between five and 15 carbon atoms are liquids
- alkanes with molecules with more than 15 carbon atoms are soft, waxy solids.

The smaller liquid alkanes are **volatile** – i.e. they become gaseous with minimal application of heat.

Propane gas tank

Petrol contains liquid octane

Volatile hydrocarbons burn fiercely and rapidly because plenty of vapour is available to burn.

Substitution

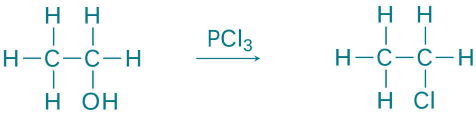
The –OH group of an alcohol molecule can be replaced by a halogen atom to form a haloalkane molecule. This type of reaction is known as a **substitution reaction**.

Common reagents for this reaction are phosphorus trichloride, PCl_3, phosphorus pentachloride, PCl_5, and thionyl chloride, $SOCl_2$.

Bromo compounds PBr_3 and PBr_5 are also used, to substitute –OH with bromine.

Example

Substitution of ethanol to form chloroethane



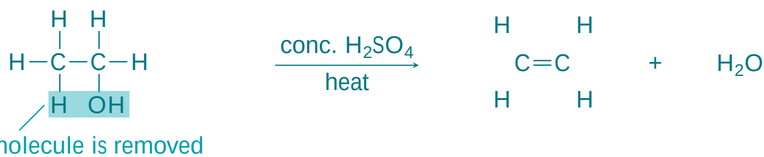
Elimination

Removing a water molecule from an alcohol molecule produces an alkene molecule. The reaction occurs when an alcohol is heated with concentrated sulfuric acid.

The removal of two atoms or groups of atoms is known as an **elimination reaction**; the –OH group and a hydrogen atom from a carbon atom adjacent to the carbon atom bonded to –OH are removed.

Example

Dehydration (elimination) of ethanol



Activity 14C: Reactions of alcohols Ans p. 319

1. Write an equation for the combustion of the following with excess oxygen:

a. methanol **b.** ethanol

2. Give an observation for the reaction occurring when propan-1-ol is warmed with dilute acidified:

a. potassium permanganate **b.** potassium dichromate

3. Draw structural formulae for the organic products of the following reactions:

a. $CH_3CH_2CH_2CH_2OH \xrightarrow{Cr_2O_7^{2-}/H^+}$

b. $CH_3CH_2CH_2OH \xrightarrow[\text{heat}]{\text{conc. } H_2SO_4}$

c. $CH_3CH_2\underset{\displaystyle OH}{\underset{|}{C}}HCH_2CH_3 \xrightarrow[\text{heat}]{\text{conc. } H_2SO_4}$

Reactions when one of the products is a gas

The rate of reaction can be determined by measuring how much gas is produced after a certain time interval.

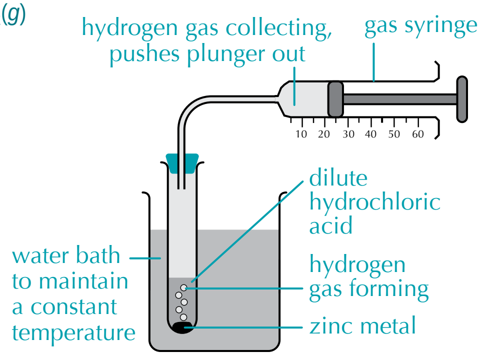
Example

The equation for the reaction of zinc metal with dilute hydrochloric acid is:

$$Zn(s) + 2H^{+}(aq) \rightarrow Zn^{2+}(aq) + H_2(g)$$

The hydrogen gas produced can be collected and its volume measured after certain time intervals.

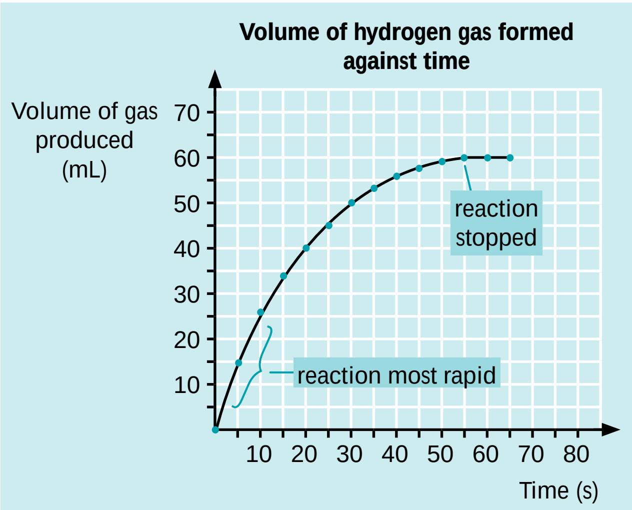
Experimental set-up for hydrogen gas collection



Results from one experiment using the apparatus were:

Time from start (s)	0	5	10	15	20	25	30	35	40	45	50	55	60	65
Volume of gas collected (mL)	0	15	26	34	40	45	50	53	56	57	59	60	60	60

Results are best presented on a graph:



Volume of hydrogen gas formed against time

Achievement Standard 91167 (Chemistry 2.7)

Achievement Standard 91167 (Chemistry 2.6) is internally assessed and worth 3 credits.

Achievement criteria

Achievement	Achievement with Merit	Achievement with Excellence
Demonstrate understanding of oxidation-reduction.	Demonstrate *in-depth* understanding of oxidation-reduction.	Demonstrate *comprehensive* understanding of oxidation-reduction.

Achievement

'Demonstrate understanding' involves describing, identifying, naming, giving an account of oxidation-reduction and describing oxidation-reduction reactions. This requires the use of chemistry vocabulary, symbols and conventions.

Oxidation-reduction is limited to:

- oxidation numbers
- electron transfer in reactions
- oxidants and/or reductants
- observations for reactions
- balanced oxidation-reduction half equations
- overall balanced oxidation-reduction equations.

Knowledge of the appearance of redox reactants and their products includes a selection from, but is not limited to:

- oxidants – these include a selection from, but are not limited to, O_2, I_2, Br_2, Cl_2, OCl^- H^+, Fe^{3+}, Cu^{2+}, H_2O_2, MnO_4^-/H^+, $Cr_2O_7^{2-}/H^+$, concentrated HNO_3, IO_3^-
- reductants – these include a selection from, but are not limited to, metals, C, H_2, Fe^{2+}, Br^-, I^-, H_2S, SO_2, SO_3^{2-}, HSO_3^-, H_2O_2

Achievement with Merit

'Demonstrate *in-depth* understanding' involves making and explaining links between oxidation-reduction reactions, observations and equations. This requires explanations that use chemistry vocabulary, symbols and conventions.

Achievement with Excellence

'Demonstrate *comprehensive* understanding' involves justifying, evaluating, comparing and contrasting, or analysing links between oxidation-reduction reactions, observations and equations. This requires the consistent use of chemistry vocabulary, symbols and conventions.

7. 44.0 g mol^{-1}
8. 32.0 g mol^{-1}
9. 40.3 g mol^{-1}
10. 111.0 g mol^{-1}
11. 136.1 g mol^{-1}
12. 249.7 g mol^{-1}
13. 286.0 g mol^{-1}
14. 59.0 g mol^{-1}
15. 95.0 g mol^{-1}

Activity 2B: Mole calculations (page 14)

1. **a.** $M(CH_4) = M(C) + 4M(H)$

$= 12.0 + 4 \times 1.0 = 16.0 \text{ g mol}^{-1}$

b. $m = n \times M = 2 \times 16.0 = 32.0 \text{ g}$

c. $n = \frac{m}{M} = \frac{64.0 \text{ g}}{16.0 \text{ g mol}^{-1}} = 4.00 \text{ mol}$

d. $m = n \times M = 3 \text{ mol} \times 16.0 \text{ g mol}^{-1}$

$= 48.0 \text{ g}$

2. **a.** $M(CaCO_3) = M(Ca) + M(C) + 3M(O)$

$= 40.1 + 12.0 + 3 \times 16.0$

$= 100.1 \text{ g mol}^{-1}$

b. $m = n \times M = 0.0500 \text{ mol} \times 100.1 \text{ g mol}^{-1}$

$= 5.00 \text{ g}$

c. $n = \frac{m}{M} = \frac{10.0 \text{ g}}{100.1 \text{ g mol}^{-1}} = 0.10 \text{ mol}$

d. $n = \frac{m}{M} = \frac{50.0 \text{ g}}{100.1 \text{ g mol}^{-1}} = 0.500 \text{ mol}$

1 mol = 6.02×10^{23} Ca^{2+} ions

0.5 mol = 3.01×10^{23} Ca^{2+} ions

3. $M(CO_2) = M(C) + 2M(O)$

$= 12.0 + 2 \times 16.0 = 44.0 \text{ g mol}^{-1}$

4. $n = \frac{m}{M} = \frac{6\,400 \text{ g}}{64.1 \text{ g mol}^{-1}} = 99.8 \text{ mol}$

5. $n = \frac{m}{M} = \frac{8\,000 \text{ g}}{80.1 \text{ g mol}^{-1}} = 99.9 \text{ mol}$

6. $M(C_3H_8) = 44.0 \text{ g mol}^{-1}$

$n(C_3H_8) = \frac{88.0 \text{ g}}{44.0 \text{ g mol}^{-1}} = 2.00 \text{ mol}$

$n(C) = 3 \times 2.00 = 6.00 \text{ mol}$

7. $m = n \times M$

a. $m = 5.50 \text{ mol} \times 46.0 \text{ g mol}^{-1} = 253 \text{ g}$

b. $m = 0.150 \text{ mol} \times 84.0 \text{ g mol}^{-1} = 12.6 \text{ g}$

c. $m = 10.7 \text{ mol} \times 58.0 \text{ g mol}^{-1} = 620.6 \text{ g}$

d. $m = 1.25 \text{ mol} \times 143.5 \text{ g mol}^{-1} = 179.4 \text{ g}$

e. $m = 0.600 \text{ mol} \times 180 \text{ g mol}^{-1} = 108 \text{ g}$

f. $m = 25.0 \text{ mol} \times 254 \text{ g mol}^{-1} = 6\,350 \text{ g}$

g. $M(CCl_4) = 154 \text{ g mol}^{-1}$

$m = 0.50 \text{ mol} \times 154 \text{ g mol}^{-1} = 77 \text{ g}$

h. $M(CuO) = 79.6 \text{ g mol}^{-1}$

$m = 0.250 \text{ mol} \times 79.6 \text{ g mol}^{-1} = 19.9 \text{ g}$

5. a. SiO_2 consists of Si and O atoms held together by covalent bonds in a 3-D network. As all the bonds in the network are strong, they are difficult to break, so large amounts of energy are required to separate the atoms, and the structure has a high m.p. CO_2 is a molecular solid made up of molecules with weak forces between the molecules. As these attractions are weak, little energy is needed to separate the molecules and the melting point is low.

   b. Sodium atoms are held together in a 3-D lattice by metallic bonding, in which valence electrons are 'pooled' and attracted to a large number of neighbouring atoms. These electrons are able to move freely through the solid, allowing it to conduct electricity. Solid I_2 is made up of molecules and there are no free-moving charged particles, so I_2 cannot conduct electricity.

   c. KCl is an ionic compound. In the solid there is a regular 3-D array of K^+ and Cl^- ions. These are held in fixed positions and cannot move around, so the solid does not conduct electricity. In the liquid, the ions separate and are free to move around and so conduct electricity.

   d. Ag is a metallic solid with the Ag atoms in a 3-D array and the valence electrons 'pooled' among the neighbouring atoms. The atoms are held together by the attraction of valence electrons to a large number of metallic atoms (or cations). This is a non-directional force, so layers of atoms can slide over each other without disrupting the lattice and breaking the bond. Sodium chloride consists of a 3-D array of positive and negative ions. If the lattice is distorted, like charges line up next to each other. Since these repel, the layers separate and the structure breaks up.

   e. Graphite has a 2-D arrangement of C atoms with covalent bonds between them. The layers are held together by weak intermolecular forces. These are easily broken, allowing the layers to slide over each other and a layer can be rubbed onto paper. In diamond, all the bonds are covalent and the atoms are arranged in a 3-D tetrahedral arrangement. This makes the substance very hard, and hence it can cut paper.

   f. Ice is a molecular solid consisting of water molecules held together by weak intermolecular forces. These are easily broken with little energy input, so the melting point is low. Magnesium oxide is an ionic solid made up of Mg^{2+} and O^{2-} ions held together by a strong ionic bond. These ionic attractions are strong, so more energy is needed to separate the ions than the water molecules, so the melting point of MgO is high.

6. Zn is a metal in which Zn atoms are arranged in ordered layers and held together by strong attractive forces (metallic bonding). Valence electrons are attracted to a number of neighbouring atoms or cations.
   - *Malleability* – the attraction between the atoms and valence electrons is non-directional, so layers can slide over one another without breaking and, as a consequence, zinc metal can be hammered into shape.
   - *Solubility* – zinc cannot dissolve in water because the forces between the zinc atoms are stronger than the attraction between water molecules and the atoms in the zinc metal.

   $ZnCl_2$ is an ionic solid held together in a lattice by strong electrostatic forces (ionic bonds).

Answers

iii. $$\begin{array}{ccccccccccccccc} & & H & & H & & H & & H & & H & & H & & \\ & & | & & | & & | & & | & & | & & | & & \\ H & - & C & - & C & - & C & - & C & - & C & - & C & - & H \\ & & | & & | & & | & & | & & | & & | & & \\ & & H & & H & & H & & H & & H & & H & & \end{array}$$

b. $CH_3-CH_2-CH_2-CH_2-CH_2-CH_3$ or $CH_3(CH_2)_4CH_3$

3. **a.** C_2H_6 **b.** C_4H_{10} **c.** $C_{10}H_{22}$ **d.** $C_{32}H_{66}$

4. **a.** pentane **b.** butane **c.** heptane **d.** methane **e.** octane

5. **a.** **i.** Family of compounds with the same functional group and where each new member contains an additional $-CH_2-$ group.

ii. A compound of hydrogen and carbon with only single bonds between atoms.

b. The alkanes form a homologous series. The alkanes are saturated hydrocarbons.

Activity 12B: Naming alkanes (page 161)

1. **a.** 3-methylpentane **b.** 3-methylhexane
c. 3,4-dimethylhexane **d.** 2,3-dimethylpentane

2. **a.** $$\begin{array}{ccc} & CH_3 & \\ & | & \\ CH_3- & CH & -CH_3 \end{array}$$

b. $$\begin{array}{ccc} & CH_3 & \\ & | & \\ CH_3- & CH & -CH_2-CH_3 \end{array}$$

c. $$\begin{array}{ccc} & CH_3 & \\ & | & \\ CH_3CH_2 & CHCH_2CH_2CH_3 & \end{array}$$

d. $$\begin{array}{ccc} & CH_3 & \\ & | & \\ CH_3- & C & -CH_3 \\ & | & \\ & CH_3 & \end{array}$$

e. $CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$

f. $$\begin{array}{ccccc} & CH_3 & & CH_3 & \\ & | & & | & \\ CH_3- & C & - & CH & -CH_3 \\ & | & & & \\ & CH_3 & & & \end{array}$$

3. $$\begin{array}{ccccc} CH_3- & CH & - & CH & -CH_2-CH_3 \\ & | & & | & \\ & CH_3 & & CH_2 & \\ & & & | & \\ & & & CH_3 & \end{array}$$

4. **a.** pentane $CH_3CH_2CH_2CH_2CH_3$

methylbutane $$\begin{array}{ccc} & CH_3 & \\ & | & \\ CH_3 & CHCH_2CH_3 & \end{array}$$

$$\begin{array}{ccc} & CH_3 & \\ & | & \\ CH_3- & C & -CH_3 \\ & | & \\ & CH_3 & \end{array}$$ dimethylpropane

b. hexane $CH_3CH_2CH_2CH_2CH_2CH_3$

2-methylpentane $$\begin{array}{ccc} & CH_3 & \\ & | & \\ CH_3 & CHCH_2CH_2CH_3 & \end{array}$$

3-methylpentane $$\begin{array}{ccc} & CH_3 & \\ & | & \\ CH_3 & CHCH_2CH_2CH_3 & \end{array}$$

2,2-dimethylbutane $$\begin{array}{ccc} & CH_3 & \\ & | & \\ CH_3- & C & -CH_2CH_3 \\ & | & \\ & CH_3 & \end{array}$$

2,3-dimethylbutane $$\begin{array}{ccccc} & CH_3 & & CH_3 & \\ & | & & | & \\ CH_3- & CH & - & CH & -CH_3 \end{array}$$

Answers

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