# UNIT 12

## NON-METALS AND THEIR COMPOUNDS

## Answers

**Lesson 1 – What are non-metals and what are some of their properties?**

**Summary Activity 1.1: What can you remember about Non-Metals?**

- A non-metal is an element which does not contain metallic bonding (or which contains covalent bonding)
- Hydrogen, carbon, oxygen, nitrogen, fluorine, chlorine, bromine, iodine
- Diamond - giant covalent structure (lattice of carbon atoms held together by covalent bonds)
- Chlorine – two atoms held together by a covalent bond to form a molecule; weak Van der Waal's forces between the molecules

**Test your knowledge 1.2: Group 0 – the noble gases**

(a) Eg ionisation energies very high so cannot lose electrons, outer shell full so cannot share or accept electrons easily

(b) Increase on descending the group; more electrons per atom so stronger Van der Waal's forces between atoms

(c) Increase on descending the group; mass of nucleus increases much faster than volume of atoms

**(d)** Helium – hot air balloons/oxygen tanks for diving; neon – lighting; argon – inert atmosphere

**Test your knowledge 1.3: Group 7 – the halogens (physical properties)**

(a) Eg ionisation energies very high so cannot lose electrons, outer shell full so cannot share or accept electrons easily

(b) Increase on descending the group; more electrons per atom so stronger Van der Waal's forces between atoms

(c) Increase on descending the group; mass of nucleus increases much faster than volume of atoms

(d) Helium – hot air balloons/oxygen tanks for diving; neon – lighting; argon – inert atmosphere

# Unit 12 – Non-Metals and their Compounds

## Lesson 2 – What are the main chemical properties of halogens and halides (part 1)?

### Test your knowledge 2.1: Group 7 – redox properties of halogens and halides

(a) Decreases down the group from fluorine to iodine; more shells means more shielding, so electrons are less strongly attracted into the outer shell on descending the group and the halogen does not accept an electron as readily
(b) Increases down the group from fluoride to iodide; more shells means more shielding, so electrons in the outer shell as less strongly held and can be more easily lost
(c) The orange colour disappears and a yellow/brown colour appears; this is because $I_2$ is being produced; $Br_2 + 2I^- \rightarrow 2Br^- + I_2$; $Br_2$ is a stronger oxidising agent than $I_2$ so Br will displace I from its compounds
(d) No reaction; ; $Br_2$ is a weaker oxidising agent than $I_2$ so Br will not displace Cl from its compounds

### Practical 2.2: Halogen displacement reactions

Chemicals needed per group: access to bottles containing solutions of $Cl_2$, $Br_2$, $I_2$, KCl, KBr, KI and cyclohexane - each group will require around 5 $cm^3$ - each bottle must have its own dropping pipette
Apparatus needed per group: 6 test tubes and a test tube rack
In water, all solutions can appear yellow/orange/brown after the reaction; the addition of cyclohexane should give a distinct orange colour (for bromine) and a distinct purple colour (for iodine)

| | $Cl_2$ | | $Br_2$ | | $I_2$ | |
|---|---|---|---|---|---|---|
| | water | cyclohexane | water | cyclohexane | water | cyclohexane |
| $Cl^-$ | | | yellow/orange | orange | yellow/brown | purple |
| $Br^-$ | yellow/orange | orange | | | yellow/brown | purple |
| $I^-$ | yellow/brown | purple | yellow/brown | purple | | |

The halogen changes during the following reactions:
$Cl_2$ with KBr and KI, $Br_2$ with KI:
$Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$; $Cl_2 + 2I^- \rightarrow 2Cl^- + I_2$; $Br_2 + 2I^- \rightarrow 2Br^- + I_2$;

## Lesson 3 – What are the main chemical properties of halogens and halides (part 2)?

### Test your knowledge 3.1: Group 7 – reactions of halogens with metals, water and alkalis

(a) $Mg + Cl_2 \rightarrow MgCl_2$; $Mg + Br_2 \rightarrow MgBr_2$
(b) Chlorine is more reactive than bromine as it attracts electrons more strongly
(c) $Cl_2(g) + H_2O(l) == HCl(aq) + HClO(aq)$; HClO is an oxidising agent and can kill bacteria but is not harmful to humans in small concentrations
(d) $Cl_2(g) + 2NaOH(aq) \rightarrow NaCl(aq) + NaClO(aq) + H_2O(l)$; NaClO is a strong oxidising agent and is used in domestic bleach
(e) It changes from 0 to +1 and -1
(f) Use blue litmus paper; chlorine turns it red and then bleaches it

**Test your knowledge 3.2: Group 7 – reactions of halides with concentrated sulphuric acid**

(a) $H_2SO_4(l) + 2KCl(s) \rightarrow K_2SO_4(s) + 2HCl(g)$
(b) $2H_2SO_4(l) + 2KBr(s) \rightarrow SO_2(g) + Br_2(g) + 2H_2O(l) + K_2SO_4(s)$
(c) $5H_2SO_4(l) + 8KI(s) \rightarrow H_2S(g) + 4I_2(g) + 4H_2O(l) + 4K_2SO_4(s)$
(d) $Cl^-$ is the weakest reducing agent; it does not reduce $H_2SO_4$; $Br^-$ is a stronger reducing agent; it reduces S in $H_2SO_4$ from +6 to +4; $I^-$ is the strongest reducing agent; it reduces S in $H_2SO_4$ from +6 to -2;
(e) HCl is prepared by reacting KCl with concentrated $H_2SO_4$; it is soluble in water so cannot be collected over water; it is more dense than air so will move downwards through air

**Demonstration 3.3: Prepare HCl gas in the laboratory**

**Equipment and chemicals needed as described above; you must use gloves for this experiment, and use a fume cupboard if you have one**

- HCl collected by downward delivery as it is more dense than air
- HCl not collected over water as it is very soluble in water
- $H_2SO_4(l) + 2KCl(s) \rightarrow K_2SO_4(s) + 2HCl(g)$
- $HCl(g) \rightarrow H^+(aq) + Cl^-(aq)$ ($H^+$ turns the blue litmus red)
- $NH_3(g) + HCl(g) \rightarrow NH_4Cl(s)$ ($NH_4Cl$ is the white smoke)

**Demonstration 3.4: Compare the reactions of concentrated sulphuric acid with the different halide ions**

**Equipment and chemicals needed as described above; you must use gloves and a fume cupboard for this experiment**

The vapour with KCl is white; the vapour with KBr is orange; the vapour with KI is purple; $NH_3$ will give a white smoke with all gases as HBr and HI are also produced and also give a white smoke with ammonia

White – HCl; orange – $Br_2$; purple – $I_2$; KCl reaction not redox; in KBr reaction S in $H_2SO_4$ is reduced and $Br^-$ is oxidised; in KI reaction S in $H_2SO_4$ is reduced and $I^-$ is oxidised

**Lesson 4 – What are the main chemical properties of halogens and halides (part 3)?**

**Summary Activity 4.1: What can you remember about tests for halide ions and HCl gas?**

- Lower a piece of filter paper soaked in $NH_3$; if a white smoke appears, HCl is present (this test is also positive with HBr and HI); HCl also turns blue litmus red
- Add $HNO_3$ and then $AgNO_3$; $Cl^-$ will give a white precipitate, $Br^-$ will give a cream precipitate and $I^-$ will give a yellow precipitate
- Add concentrated $H_2SO_4$; $Cl^-$ ions will give off white fumes which give a positive test for HCl; $Br^-$ ions will give off an orange vapour; $I^-$ ions will give off a purple vapour

**Demonstration 4.2: Prepare $Cl_2$ gas in the laboratory**

**Equipment and chemicals needed as described above; you must use gloves for this experiment**

Bubbles can be clearly seen when the conc HCl is added, and bubbles should be seen passing through the water and the sulphuric acid; the gas may appear as a pale green colour in the gas jar

- $MnO_2 + 4HCl \rightarrow MnCl_2 + Cl_2 + 2H_2O$
- The Mn is reduced from +4 to +2; the $Cl^-$ is oxidised to $Cl_2$ (-1 to 0)
- Water removes the HCl and concentrated $H_2SO_4$ removes the water
- Chlorine gas is more dense than air
- $Cl_2(g) + H_2O(l)$ == HCl(aq) + HClO(aq); HCl contains $H^+$ and turns litmus red; HClO is a bleaching agent and turns it white

**Test your knowledge 4.3: Group 7 – other reactions of halogens and halides**

(a) Add concentrated HCl to $MnO_2$; Mn is reduced from +4 to +2 and $Cl^-$ is oxidised to $Cl_2$ (from -1 to 0); $Cl_2$ is more dense than air so is collected by downward delivery
(b) Add $HNO_3$ and then $AgNO_3$; $Cl^-$ will give a white precipitate, $Br^-$ will give a cream precipitate and $I^-$ will give a yellow precipitate
(c) Chlorine used to sterilise water; iodine used to sterilise wounds; sodium chlorate (I) used in bleach, silver bromide used in photography

**Lesson 5 – What do I need to know about hydrogen and hydrogen ions?**

**Summary Activity 5.1: What do you know about hydrogen?**

- It is simple molecular, forming diatomic molecules ($H_2$) with very weak Van der Waal's forces holding the molecules together
- Eg $Mg + 2HCl \rightarrow MgCl_2 + H_2$; Mg, Al, Zn, Fe, Sn and Pb react steadily with acids; hydrogen gas is produced in this reaction
- It will turn blue litmus red; also it will give bubbles if added to $CaCO_3$ or another carbonate

**Demonstration 5.2: Prepare $H_2$ gas in the laboratory**

**Equipment and chemicals needed as described above**

Bubbles can be clearly seen when the HCl is added, and bubbles should be seen entering the gas jar; the water level in the gas jar should drop

- $Zn + 2HCl \rightarrow ZnCl_2 + H_2$
- Zn is oxidised (from 0 to +2) and the $H^+$ in the acid is reduced from +1 to 0
- it is insoluble in water because it is non-polar
- hydrogen gas is less dense than air so it rises, if you remove the lid from underneath the jar, most of the gas will remain in the jar; if you remove the lid from the top of the jar, the gas will all escape
- It burns with a squeaky pop
- The hydrogen is reacting with oxygen: $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

**Test your knowledge 5.3: Preparation and reactions of hydrogen**

(a) Add hydrochloric acid to zinc granules; collect the hydrogen by upward delivery over water
(b) Insert a lit splint into the test tube – the hydrogen burns with a squeaky pop
(c) Add blue litmus paper – it turns red or add $CaCO_3$ – it fizzes

## Lesson 6 – Why is water special?

**Summary Activity 6.1: What can you remember about water?**

- It is simple molecular, forming molecules ($H_2O$) in which one O atom is joined to two H atoms with covalent bonds; the molecules are held together by hydrogen bonding
- Heat a sample of water in a flask connected to a distillation apparatus with a thermometer in the head; record the maximum temperature reached
- the intermolecular forces in water are stronger than between other molecules of a similar size, due to hydrogen bonding
- hydroxide ions turn red litmus paper blue; they also give a pungent-smelling gas when warmed with ammonium chloride

**Demonstration 6.2: Demonstrate the polarity of water**

Apparatus needed: an inflated balloon and some water
The water stream should bend towards the balloon
This is because water is polar and polar molecules are attracted to charged particles
Ethanol and ethanoic acid should give the same effect
Most oils and paraffin should give no effect

**Practical 6.3: Investigating the solubility of different substances in water**

Chemicals needed: salt, sugar, chalk, wax, sand (1 g per group); paraffin and ethanol (2 $cm^3$ per group) each bottle needs its own dropping pipette
Apparatus needed per group: seven test tubes and one test tube rack; one 10 $cm^3$ measuring cylinder
Salt, sugar and ethanol will dissolve; wax, sand, chalk and paraffin will not

- Salt and chalk are ionic; ionic compounds sometimes dissolve in water, but only if the attraction between the ions and water is stronger than the attraction between the ions; in NaCl it is but in $CaCO_3$ it is not
- wax, sugar, ethanol and paraffin are simple molecular; simple molecular substances will dissolve in water if they can form hydrogen bonds with water; sugar and ethanol (which have -OH groups) can, wax and paraffin (which are non polar) cannot
- sand is giant covalent and giant covalent structures are usually insoluble in water

# Unit 12 – Non-Metals and their Compounds

## Lesson 7 – What else do I need to know about water, and what is hydrogen peroxide?

**Demonstration 7.1: Prepare $O_2$ gas in the laboratory**

**Equipment and chemicals needed as described above (wear gloves for this experiment)**

Bubbles can be clearly seen when the $H_2O_2$ is added, and bubbles should be seen entering the gas jar; the water level in the gas jar should drop

- $2H_2O_2(l) \rightarrow 2H_2O + O_2(g)$
- In this reaction the O is both oxidised (from -1 to O, in $O_2$) and reduced (from -1 to -2, in $H_2O$)
- it is insoluble in water because it is non-polar
- It relights a glowing splint
- The wood in the splint is reacting with the oxygen in a combustion reaction

**Test your knowledge 7.2: Water and hydrogen peroxide**

(a) High boiling point, high surface tension and lower density in solid state than liquid state; these anomalous properties are due to strong hydrogen bonding in water
(b) Sodium chloride (and most ionic compounds), sucrose, ethanol (and most molecules with hydrogen bonding) all dissolve in water; chalk (and some other ionic compounds), sand (and most giant covalent substances), wax and paraffin (and most non-polar molecules) do not
(c) Add NaOH or $AgNO_3$ - a precipitate may form if dissolved substances are present; test pH - if not 7 then dissolved substances are present; test conductivity - if conducts then dissolved substances are present; evaporate off water – if residue left then dissolved substances are present
(d) Add a few drops to anhydrous copper sulphate; if the copper sulphate turns blue then water is present
(e) Add positively charged ions to water, which causes some particles and dissolved substances to coagulate; separate off larger particles which settle at bottom; filter remaining water; add disinfectant
(f) H-O-O-H
(g) $2H_2O_2 \rightarrow 2H_2O + O_2$; used in the laboratory preparation of oxygen

## Lesson 8 – What do I need to know about oxygen and oxides?

**Summary Activity 8.1: What can you remember about oxygen and oxides?**

- It is simple molecular, forming diatomic molecules ($O_2$) in which two O atoms are joined by double covalent bonds; the molecules are held together by weak Van der Waal's forces
- Decompose $H_2O_2$ using $MnO_2$ as a catalyst; oxygen is only slightly soluble in water so can be collected over water
- Oxygen gas relights a glowing splint
- CaO: $CaO + 2HCl \rightarrow CaCl_2 + H_2O$; $Na_2O$: $Na_2O + 2HCl \rightarrow 2NaCl + H_2O$
- $SO_2$ :$SO_2 + 2NaOH \rightarrow Na_2SO_3 + H_2O$; $Cl_2O$: $Cl_2O + 2NaOH \rightarrow 2NaClO + H_2O$
- ZnO: $ZnO + 2HCl \rightarrow ZnCl_2 + H_2O$; $ZnO + 2NaOH \rightarrow Na_2ZnO_2 + H_2O$

**Test your knowledge 8.2 – Oxygen and Oxides**

(a) The air is cooled to a very low temperature to ensure that $N_2$, $O_2$ and Ar all condense; liquid air run into base of fractionating column; temperature allowed to rise slowly; $N_2$ and Ar boil first, leaving oxygen at base of column
(b) $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$; this is how all living things generate energy to function
(c) Covalent oxides (ie oxides of non-metals) are acidic; ionic oxides (ie oxides of metals) are basic
(d) Acidic: $CO_2$, $SO_3$, ClOH, $HPO(OH)_2$, $SiO_2$; basic: MgO, NaOH, FeO; amphoteric: $Al_2O_3$
(e) $CaO + SO_2 \rightarrow CaSO_3$; $2NaOH + SiO_2 \rightarrow Na_2SiO_3 + H_2O$; $CO_2 + MgO \rightarrow MgCO_3$

**Lesson 9 – What do I need to know about nitrogen and ammonia?**

**Summary Activity 9.1: What can you remember about nitrogen and ammonia?**

- It is simple molecular, forming diatomic molecules ($N_2$) in which two N atoms are joined by triple covalent bonds; the molecules are held together by weak Van der Waal's forces
- It is simple molecular, consisting of ($NH_3$) molecules in which the N atom is attached to three H atoms by covalent bonds; the molecules are held together by hydrogen bonds
- $NH_3 + HCl \rightarrow NH_4Cl$
- It turns red litmus blue and forms a white smoke in the presence of concentrated HCl
- If warmed with NaOH, it gives off $NH_3$ which has a pungent smell

**Demonstration 9.2: Prepare $NH_3$ gas in the laboratory**

**Equipment and chemicals needed as described above**

Bubbles should be visible after gently heating the mixture for a short time

- $Ca(OH)_2(s) + 2NH_4Cl(s) \rightarrow CaCl_2(s) + 2NH_3(g) + 2H_2O(l)$
- A neutralisation or acid-base reaction is taking place
- Ammonia is very soluble in water so cannot be collected over water
- To remove any water from the gaseous mixture
- It is less dense than air
- It turns red litmus paper blue; $NH_3$ is a base and reacts with water on the paper to form $OH^-$ ions

**Demonstration 9.3: Prepare $N_2$ gas in the laboratory**

**Equipment and chemicals needed as described above**

Bubbles should be visible after gently heating the mixture for a short time

- $NaNO_2(s) + NH_4Cl(s) \rightarrow N_2(g) + NaCl(s) + 2H_2O(l)$
- N in $NH_4Cl$ is oxidised from -3 to 0 (in $N_2$); N in $NaNO_2$ is reduced from +3 to 0 (in $N_2$)
- nitrogen is insoluble in water so can be collected over water

**Test your knowledge 9.4 – Nitrogen and Ammonia**

(a) The air is cooled to a very low temperature to ensure that $N_2$, $O_2$ and Ar all condense; liquid air run into base of fractionating column; temperature allowed to rise slowly; Ar boils first, then $N_2$, so $N_2$ collected at top of column
(b) $NH_4Cl$ reacts with $NaNO_2$; redox reaction; $N_2$ not very soluble in water so can be collected over water
(c) $Ca(OH)_2$ reacts with $NH_4Cl$; acid-base reaction; $NH_3$ very soluble in water so not collected over water; less dense than air so collected by upward delivery
(d) Low temperature gives higher yield of ammonia but slows down reaction so compromise temperature of 450 °C used; high pressure gives higher yield of ammonia and fast reaction so 25 MPa used; Fe catalyst speeds up reaction
(e) To make fertilisers

**Lesson 10 – What do I need to know about nitric acid and nitrates?**

**Summary Activity 10.1: What can you remember about nitric acid and nitrates?**

- $HNO_3$, $NO_3^-$
- Nitric acid is a strong acid, so nitrate ions are neutral
- $HNO_3 + NH_3 \rightarrow NH_4NO_3$
- Add almuminium powder, NaOH and heat; a pungent gas ($NH_3$) is given off which turns damp red litmus paper blue

**Practical 10.2: Decompose different nitrate salts**

Chemicals needed per group: calcium nitrate and sodium nitrate (around 2 g per group)
Apparatus needed per group: 2 test tubes, 1 tongs, 1 Bunsen burner, 1 splint

$2NaNO_3(s) \rightarrow 2NaNO_2(s) + O_2(g)$
The N is reduced from + 5 to +3 and the O is oxidised from -2 to 0
$2Ca(NO_3)_2(s) \rightarrow 2CaO(s) + 4NO_2(g) + O_2(g)$
The N is reduced from +5 to +4 and the O is oxidised from -2 to 0
The glowing splint re-lights, confirming the presence of oxygen
The brown gas is $NO_2$

**Test your knowledge 10.3 – Nitric acid and nitrates**

(a) By adding concentrated sulphuric acid to potassium nitrate: $H_2SO_4(l) + KNO_3(s) \rightarrow HNO_3(g) + K_2SO_4(s)$; acid-base or acid-salt reaction
(b) To make fertilisers (mainly ammonium nitrate)
(c) $2NaNO_3(s) \rightarrow 2NaNO_2(s) + O_2(g)$; $2Cu(NO_3)_2(s) \rightarrow 2CuO(s) + 4NO_2(g) + O_2(g)$

## Unit 12 – Non-Metals and their Compounds

**Lesson 11 – What do I need to know about sulphur and sulphur dioxide?**

**Summary Activity 11.1: What can you remember about sulphur dioxide?**

- $SO_2$; it is acidic – $SO_2 + 2OH^- \rightarrow SO_3^{2-} + H_2O$
- It will turn blue litmus paper red and will turn acidified dichromate paper from orange to green

**Demonstration 11.2: Prepare $SO_2$ gas in the laboratory (Part 1)**

**Equipment and chemicals needed as described above; you must use gloves for this experiment**

Bubbles can be clearly seen when the dilute HCl is added; heating should increase the rate of production of bubbles and bubbles should be seen passing through the sulphuric acid

- $Na_2SO_3(s) + 2HCl(aq) \rightarrow 2NaCl(aq) + SO_2(g) + H_2O(l)$
- Acid-base reaction
- concentrated $H_2SO_4$ removes the water
- $SO_2$ is more dense than water
- SO cannot be collected over water as it is soluble in water
- $SO_2(g) + H_2O(l) == H_2SO_3(aq) == 2H^+(aq) + SO_3^{2-}(aq)$; $H^+$ and turns litmus red
- $SO_2$ is a reducing agent; it gets oxidised to $SO_4^{2-}$ ions and reduces dichromate ions to $Cr^{3+}$

**Test your knowledge 11.3 – sulphur dioxide and sulphate (IV) ions**

(a) By adding hydrochloric acid to sodium sulphate (IV): $Na_2SO_3(s) + HCl(aq) \rightarrow 2NaCl(aq) + SO_2(g) + H_2O(l)$; acid-base or neutralisation reaction

(b) The S can be oxidised from +4 to +6; $SO_2$ is added to wine and sulphate (IV) ions are added to food to prevent oxidation

(c) Low temperature gives higher yield of $SO_3$ but slows down reaction so compromise temperature of 450 $^oC$ used; high pressure gives higher yield of $SO_3$ and fast reaction but is expensive so 200 kPa used; $V_2O_5$ catalyst speeds up reaction

**Lesson 12 – What do I need to know about sulphuric acid and sulphides?**

**Summary Activity 12.1: What can you remember about sulphuric acid and sulphides?**

- $H_2SO_4$; (i) $H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$, acid-base or neutralisation; (ii) $H_2SO_4 + 2NH_3 \rightarrow (NH_4)_2SO_4$, acid-base or neutralisation; (iii) $H_2SO_4 + 2NaCl \rightarrow Na_2SO_4 + 2HCl$, acid-base or acid-salt; (iv) $2H_2SO_4 + 2NaBr \rightarrow Na_2SO_4 + Br_2 + SO_2 + 2H_2O$, redox; (v) $2H_2SO_4 + 2NaBr \rightarrow Na_2SO_4 + Br_2 + SO_2 + 2H_2O$, redox; $5H_2SO_4(l) + 8NaI(s) \rightarrow H_2S(g) + 4I_2(g) + 4H_2O(l) + 4K_2SO_4(s)$, redox
- $Na_2S$, $S^{2-}$
- Add dilute HCl and then $BaCl_2$ (aq), white precipitate seen

**Demonstration 12.2: Prepare $SO_2$ gas in the laboratory (Part 2)**

**Equipment and chemicals needed as described above; you must use gloves for this experiment**

Bubbles should be seen when the mixture is heated

- $Cu + 2H_2SO_4 \rightarrow CuSO_4 + SO_2 + 2H_2O$
- S reduced from +6 to +4; Cu oxidised from 0 to +2

**Test your knowledge 12.3 – sulphur trioxide, sulphuric acid and sulphate (VI) ions**

(a) State the acid-base properties of sulphur trioxide and explain how acid rain is produced
(b) Give a use for sulphuric acid (i) as an acid; (ii) as an oxidising agent; (iii) as a dehydrating agent

(a) It is an acid and reacts with water in the air to form acid rain: $SO_3 + H_2O \rightarrow H_2SO_4$
(b) (i) it reacts ammonia to make ammonium sulphate which is a fertiliser and it can be used in the laboratory preparation of HCl and $HNO_3$; (ii) it is used in the laboratory preparation of $SO_2$; (iii) it is used to dry the $SO_2$ produced in the laboratory preparation of $SO_2$

**Test your knowledge 12.4 – sulphide ions and hydrogen sulphide**

(a) Write an equation to show how zinc reacts with sulphur
(b) Write an equation to show how zinc sulphide reacts with dilute hydrochloric acid
(c) Write an equation to show how zinc sulphide reacts with oxygen and explain why this reaction is useful
(d) State how the oxidation number of S changes during the reactions above
(e) State how hydrogen sulphide gas can be identified

(a) $Zn + S \rightarrow ZnS$ (S reduced from O to -2)
(b) $ZnS + 2HCl \rightarrow ZnCl_2 + H_2S$ (not a redox reaction)
(c) $2ZnS + 3O_2 \rightarrow 2ZnO + 2SO_2$ (S oxidised from -2 to +4) this is the first stage in the extraction of Zn from its ore
(d) See above
(e) It smells of rotten eggs

**Lesson 13 – What do I need to know about carbon and its oxides?**

**Summary Activity 13.1: What can you remember about carbon, carbon dioxide and carbonate ions?**

- Diamond has a giant covalent structure; each C atom attached to four other C atoms in a tetrahedral shape; graphite has a giant covalent structure; each C atom attached to three other C atoms in a trigonal planar shape; this results in hexagonal layers; the layers are held together by Van der Waal's forces; each C has one extra electron in its outer shell which is delocalised; graphite conducts electricity due to its delocalised electrons but diamond does not; graphite is soft as the layers can slide over each other but diamond is hard because all atoms are fixed in place
- $CO_2 + H_2O$ $H_2CO_3$ $H^+ + HCO_3^-$; $CO_2 + 2NaOH \rightarrow Na_2CO_3 + H_2O$ ($CO_2$ is acidic)
- Turns limewater milky and then colourless again
- Bubbles on addition of HCl; $CO_2$ given off; precipitate formed on addition of $BaCl_2$ but precipitate dissolves in HCl

**Test your knowledge 13.2 – different forms of carbon**

(a) Peat is plant and animal matter partially decayed in acidic, anaerobic conditions (<60% C); lignite is a sedimentary rock formed when peat is compressed (60 – 70% C); continued pressure converts lignite into coal (70 – 87% C) and continued high temperature and pressure converts coal into a metamorphic rock called anthracite (>87% C)
(b) Coke is produced by the destructive distillation of coal; coal gas, coal tar and coal oil are also produced
(c) Mixture of CO and $H_2$, produced by heating coke at 700 °C in a limited supply of oxygen

**Demonstration 13.3: Prepare $CO_2$ gas in the laboratory**

**Equipment and chemicals needed as described above**

Bubbles can be clearly seen when the dilute HCl is added

- $CaCO_3(s) + 2HCl(aq) \rightarrow 2CaCl_2(aq) + CO_2(g) + H_2O(l)$
- Acid-base reaction
- $CO_2$ is more dense than water
- $CO_2$ turns limewater milky and then colourless again; the milky appearance is due to the insoluble calcium carbonate; $CO_2(g) + Ca(OH)_2(aq) \rightarrow CaCO_3(s) + H_2O(l)$; $CaCO(s) + CO_2(g) + H_2O(l) \rightarrow Ca(HCO_3)_2(aq)$
- Carbon dioxide extinguishes a lit splint as it is not flammable

**Test your knowledge 13.4 – carbon dioxide, carbonates and hydrogencarbonates**

(a) $CO_2 + 2OH^- \rightarrow CO_3^{2-} + H_2O$; $CO_3^{2-} + 2H^+ \rightarrow CO_2 + H_2O$; $2HCO_3^- \rightarrow CO_3^{2-} + CO_2 + H_2O$ or $HCO_3^- + H^+ \rightarrow CO_2 + H_2O$ and $HCO_3^- + OH^- \rightarrow CO_3^{2-}$
(b) Add dilute HCl to $CaCO_3$; collect $CO_2$ by downward delivery
(c) It is not flammable and more dense than air
(d) $Na_2CO_3$ – water softener and used to make glass; $CaCO_3$ – used in steel manufacture and to neutralise acidic soil; $NaHCO_3$ – baking powder

**Lesson 14 – What do I need to know about rocks?**

**Test your knowledge 14.1 – rocks**

(a) Mineral – substance of fixed composition found in the earth's crust; rock – mixture of minerals
(b) Igneous – formed by cooling lava or magma; sedimentary – formed by small rock deposits being compressed; metamorphic – formed by subjecting sedimentary rocks to high temperature and pressure
(c) Breaking down of rocks into smaller particles
(d) Hydrolysis - breaking down a rock by reacting it with water, acid or alkali; hydration - absorption of water by a rock; carbonation – dissolving a rock in carbonic acid; oxidation – reaction of a rock with oxygen

**Lesson 15 – What have I learned about non-metals and their compounds?**

## 15.1 END-OF-UNIT QUIZ
## UNIT 12 – NON-METALS AND THEIR COMPOUNDS

1. Ar = simple atomic, Van der Waal's forces between atoms; $Cl_2$, $H_2$, $O_2$, $N_2$ = simple molecular, diatomic molecules with single covalent bonds (Cl-Cl and H-H) or double covalent bonds (O=O) or triple covalent bonds (N≡N between atoms; $S_8$ crown shaped molecule with eight S atoms held together in a ring by single covalent bonds, Van der Waal's forces between all molecules
2. $O_2$: decomposition of $H_2O_2$ in presence of $MnO_2$; $Cl_2$: oxidation of concentrated HCl by $MnO_2$; $N_2$: oxidation of $NH_4Cl$ by $NaNO_2$; redox reactions; $Cl_2$ collected by downward delivery as denser than air and reacts with water; $N_2$ and $O_2$ collected over water as they are not very soluble in water
3. HCl: $H_2SO_4$ with KCl (acid-base or acid-salt); $NH_3$: $NH_4Cl$ with $Ca(OH)_2$ (acid-base); $CO_2$: $CaCO_3$ with HCl (acid-base); HCl and $NH_3$ highly soluble in water so not collected over water; HCl denser than air so collected by downward delivery; $NH_3$ less dense than air so collected by upward delivery; $CO_2$ denser than air so collected by downward delivery (or over water)
4. $H_2$: burns with a squeaky pop; $O_2$: relights a glowing splint; $Cl_2$: turns blue litmus paper red and then white; $N_2$: negative test for all other gases
5. (a) $Cl_2 + 2NaOH \rightarrow NaCl + NaClO + H_2O$
   (b) $Cl_2 + 2NaBr \rightarrow 2NaCl + Br_2$
6. Fractional distillation; air is cooled until it completely liquefies and inserted into the base of a fractionating column; $N_2$ has a lower boiling point and is collected at the top of the fractionating column
7. $N_2 + 3H_2 \quad\quad 2NH_3$; 450 °C (compromise temperature: high temperature gives faster reaction but lower yield); 25 MPa (high pressure gives fast reaction and good yield); Fe catalyst to increase rate of reaction
8. (a) $2Ca(NO_3)_2 \rightarrow 2CaO + 4NO_2 + O_2$
   (b) $2NaNO_3 + 2NaNO_2 + O_2$
   (c) $2CuS + 3O_2 \rightarrow 2CuO + 2SO_2$
9. Peat compressed into lignite and then into coal; over millions of years it is further compressed at high temperatures into anthracite
10. Igneous – formed from cooling lava or magma; sedimentary – formed by compression and sedimentation of small rock deposits; metamorphic – formed by further compression of sedimentary rock at high temperature
11. Breaking down of rocks into smaller pieces (hydration, hydrolysis, carbonation and oxidation)