CHLORINE AND ITS COMPOUNDS

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By the end of this Chapter, the learner should be able to:

(a) Describe and explain the laboratory preparation, properties and uses of chlorine gas.
(b) Describe and explain the laboratory preparation, properties and uses of hydrogen chloride gas.
(c) Explain the effect of a solvent on the properties of hydrogen chloride.
(d) Describe the industrial manufacture of hydrochloric acid.
(e) Explain the environmental pollution caused by chlorine and chlorine containing compounds.

CHLORINE AND ITS COMPOUNDS

Chlorine is a non-metallic element, a halogen in group VII of the periodic table.

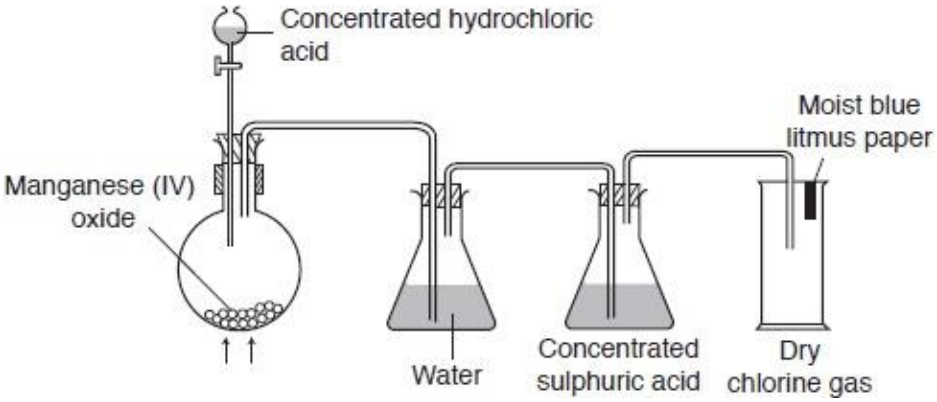
The electronic arrangement of the atom is 2.8.7. It forms a diatomic molecular gas, chlorine. Chlorine does not occur freely due to its reactivity. It is always found combined with other elements. The chief source of chlorine is sodium chloride. Sodium chloride is found in sea water and is known as rock salt.

1. Chlorine

(a) Laboratory preparation of Chlorine

Chlorine gas may be prepared in the laboratory by the oxidation of concentrated hydrochloric acid with a suitable oxidising agent such as manganese(IV) oxide.

$$MnO_2(s) + 4HCl(aq) \longrightarrow MnCl_2(aq) + 2H_2O + Cl_2(g)$$



Discussion Questions

1. State the role of the following in the set-up:

(a) Manganese(IV) oxide.

Manganese(IV) oxide acts as an oxidising agent. It oxidises HCl to water and chlorine.

$$MnO_2(s) + 4HCl(aq) \longrightarrow MnCl_2(aq) + 2H_2O + Cl_2(g)$$

(b) Water.

During the preparation of chlorine, the gas is passed through water to remove the more soluble hydrogen chloride gas vapourised from the hydrochloric acid by the heat.

(c) Concentrated sulphuric acid.

The gas is passed through concentrated sulphuric(VI) acid to be dried.

(d) Moist blue litmus paper.

The purpose of the blue litmus paper in the experiment is to show when the gas jar is full of chlorine. When the gas jar is full, the blue litmus turns red then white. Chlorine is not collected over water because it is soluble in water.

2. Name the method of collection used in the set-up. Explain.

Dry chlorine is collected by downward delivery (upward displacement of air) because the gas is denser than air. Chlorine is not collected over water because it is soluble in water.

3. Write a balanced chemical equation for the reaction between concentrated hydrochloric acid manganese(IV) oxide.

$$MnO_2(s) + 4HCl(aq) \longrightarrow MnCl_2(aq) + 2H_2O + Cl_2(g)$$

4. Suggest other reagents that could be used instead of manganese(IV) oxide.

Heating speeds up the reaction between manganese(IV) oxide and concentrated hydrochloric acid. Chlorine can also be prepared by other methods such as oxidation of concentrated hydrochloric acid by potassium manganate(VII) or lead(IV) oxide.

$$16HCl(aq) + 2KMnO_4(s) \longrightarrow 5Cl_2(g) + 2MnCl_2(aq) + 8H_2O(l) + 2KCl(aq)$$

or

$$PbO_2(s) + 4HCl(aq) \longrightarrow PbCl_2(s) + Cl_2(g) + 2H_2O(l)$$

In these reactions, concentrated hydrochloric acid acts as a reducing agent and is itself oxidised to water and chlorine.

(b) Physical Properties of Chlorine

Discussion Questions

1. State some physical properties of chlorine.

Chlorine is a green-yellow gas with an unpleasant chocking and irritating smell. It is denser than air and this makes it possible to collect the gas by downward delivery (upward displacement of air).

2. Explain why the level of water rises in a gas jar when a gas jar full of Chlorine is inverted in a trough of water.

Chlorine is fairly soluble in water. At 0 °C. 1 volume of water dissolves 3 volumes of the gas. This explains why the level of water rises inside the gas jar when inverted in a trough of water.

3. Chlorine is collected by upward displacement of air. Explain.

It is denser than air and this makes it possible to collect the gas by downward delivery (upward displacement of air). Chlorine is fairly soluble in water.

(c)Chemical Properties Of Chlorine

(i) Reaction with water

Discussion Qestions

1. What is the colour of the solution formed when chlorine is bubbled through water.

Chlorine reacts with water forming both chloric(I) acid, (hypochlorous acid) and hydrochloric acid. This green-yellow solution is commonly referred to as chlorine water and is acidic.

$$Cl_2(g) + H_2O(l) \longrightarrow HOCl(aq) + HCl(aq).$$

2. Write the equation for the reaction between chlorine and water.

$$Cl_2(g) + H_2O(l) \longrightarrow HOCl(aq) + HCl(aq).$$

3. What observations were made when:

(a) Dry blue and red litmus papers were placed in chlorine?

Dry chlorine has no effect on litmus paper and dyes if materials are dry because chloric(I) acid does not form.

(b) Moist litmus papers and fresh coloured flowers were placed in chlorine? Explain.

Moist blue litmus paper placed in a gas jar full of chlorine first turns red and is then decolourised (bleached). Coloured flowers are decolourised too. The chloric(I) acid formed when chlorine dissolves in water is not a stable compound. It readily gives up its oxygen atom (nascent oxygen, especially when exposed to sunlight). In the process the green yellow solution looses colour.

$$\underset{\text{(Green-yellow)}}{HOCl(aq)} \xrightarrow{Sunlight} \underset{\text{(colourless)}}{HCl(aq)} + \underset{\text{(nascent oxygen)}}{[O]}$$

4. Write an equation to show the effect of chlorine on dyes.

When mixed with dyes, the free oxygen atom released by chloric(I) acid readily combines with the dyes to form colourless matter.

$$Dye + HOCl(aq) \longrightarrow HCl(aq) + \text{colourless matter}$$

This explains the bleaching action of chlorine. Chlorine bleaches by oxidation. Bleaching by oxidation is long lasting as compared to bleaching by reduction.

(ii) Reaction with metals

Generally, chlorine reacts with metals such as magnesium and iron to form the respective metal chlorides.

Discussion Questions

1. What observations were made when:

(a) Burning magnesium was lowered into a gas jar chlorine?

Burning magnesium continues to burn in chlorine gas forming white fumes of magnesium chloride.

$$Mg(s) + Cl_2(g) \longrightarrow MgCl_2(s)$$

Magnesium continues to burn because the heat produced sustains the reaction.

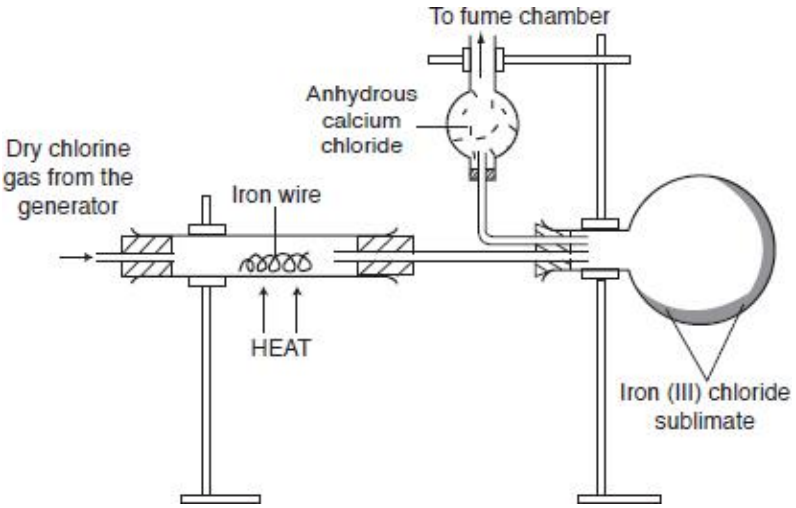
(b) Hot iron wire was lowered into a gas jar of chlorine?

When hot iron is lowered into a gas jar full of chlorine, the wire starts to glow. The wire continues glowing as black crystals of iron(III) chloride are formed.

$$2Fe(s) + 3Cl_2(g) \longrightarrow 2FeCl_3(s)$$

The glow continues for a long time because the reaction between iron and chlorine is exothermic.

3. What observations are made when a stream of dry chlorine was passed over a hot iron wire coil as shown below?



When dry chlorine is passed over a hot iron wire coil, the iron wire continues to glow and after some time, the iron(III) chloride formed collects in the flask as a sublimate.

4. Why does the glow continue for a long time?

The glow continues for a long time because the reaction between iron and chlorine is exothermic.

5. What is the role of anhydrous calcium chloride? What else can be used in place of anhydrous calcium chloride?

Anhydrous calcium chloride allows dry chlorine fumes to escape and also prevents the entry of moisture. Calcium oxide may be used to replace calcium chloride because being basic, it reacts with the acidic chlorine gas to form a salt, thus, preventing air pollution.

(iii) Reaction with non-metals

Chlorine and hydrogen do not react at room temperature. However, when a jet of burning hydrogen is lowered into a jar of chlorine gas, combustion continues and white fumes of hydrogen chloride are seen at the mouth of the jar. Chlorine also reacts vigorously with phosphorus.

Discussion Questions

1. **What is observed when warm red phosphorus is lowered into a gas of chlorine gas? Write the equation for the reaction between phosphorus and chlorine.**

When a piece of warm red phosphorous is lowered into a gas jar of chlorine a vigorous reaction takes place producing white fumes. The white fumes are a mixture of phosphorous(III) and phosphorous(V) chloride.

$$P_4(s) + 6Cl_2(g) \longrightarrow 4PCl_3(s)$$

$$P_4(s) + 10Cl_2(g) \longrightarrow 4PCl_5(s)$$

(iv) Oxidising Properties of Chlorine

Chlorine is a strong oxidising agent and oxidises many substances. When bubbled through a solution of sodium sulphite, chlorine oxidises the sulphite ions to sulphate ions. Chlorine also reacts with ammonia to form white fumes of ammonium chloride.

The following tests can be done to investigate the oxidisng properties of Chlorine.

1. Bubble chlorine gas through sodium sulphite solution in a beaker for a few minutes. Put 2 cm^3 of the resulting solution into two separate test-tubes, labeled A and B.

   (a) To test-tube (A), add a few drops of dilute nitric acid followed by a few drops of barium nitrate solution.

   (b) To test-tube (B), add a few drops of lead nitrate solution. Warm the mixture.

2. Bubble chlorine gas through aqueous ammonia.

Discussion Questions

1. **What observations were made when:**

   (a) Barium nitrate solution was added to acidified solution in test (a)?

When barium nitrate is added to an acidified solution of sodium sulphite through which chlorine has been bubbled, a white precipitate is formed. The white precipitate confirms the presence of sulphate ions. Chlorine is a strong oxidising agent and oxidises many substances. When bubbled through a solution of sodium sulphite, chlorine oxidises the sulphite ions to sulphate ions.

$$Cl_2(g) + Na_2SO_3(aq) + H_2O(l) \longrightarrow 2HCl(aq) + Na_2SO_4(aq)$$

or

$$Cl_2(g) + SO_3^{2-}(aq) + H_2O(l) \longrightarrow 2H^+(aq) + 2Cl^-(aq) + SO_4^{2-}(aq)$$

When barium nitrate is added to the mixture, the barium ions combine with the sulphate ions to form insoluble barium sulphate.

$$Ba^{2+}(aq) + SO_4^{2-}(aq) \longrightarrow BaSO_4(s)$$

(b) Lead nitrate solution was added to the solution in test (b)?

When lead(II) nitrate is added to the solution formed by bubbling chlorine gas through sodium sulphite solution, a white precipitate is formed. The white precipitate does not dissolve on warming. This confirms the presence of sulphate ions.

$$Pb^{2+}(aq) + SO_4^{2-}(aq) \longrightarrow PbSO_4(s)$$

Any precipitate of lead(II) chloride formed dissolves when the mixture is warmed.

2. Why is the solution first acidified before barium nitrate solution is added?

The solution is first acidified before barium nitrate solution is added to eliminate the possibility of sulphite ions.

3. What observations were made when chlorine was bubbled through aqueous ammonia? Write an equation for the reaction

Chlorine reacts with ammonia to form white fumes of ammonium chloride.

$$8NH_3(g) + 3Cl_2(g) \longrightarrow 6NH_4Cl(s) + N_2(g)$$

4. What observation is made when chlorine is mixed with moist hydrogen sulphide gas?

When chlorine is mixed with moist hydrogen sulphide gas, a yellow deposit of sulphur is seen in the gas jar. Chlorine oxidises sulphide ions in the moist hydrogen sulphide to pale–yellow solid sulphur.

$$H_2S(aq) + Cl_2(g) \longrightarrow S(s) + 2HCl(g)$$

(v) Reaction of Chlorine with Alkaline Solutions

The product formed when chlorine reacts with alkalis depends on the temperature and concentration of the alkali.

Discussion Questions

1. **What is observed when chlorine is bubbled through:**

(i) Cold dilute sodium hydroxide?

Chlorine reacts with cold dilute sodium hydroxide or potassium hydroxide forming a pale-yellow solution of chlorite(I) and the chlorides of the respective metals.

$$Cl_2(g) + 2NaOH(aq) \longrightarrow NaOCl(aq) + NaCl(aq) + H_2O(l)$$

$$Cl_2(g) + 2KOH(aq) \longrightarrow KOCl(aq) + KCl(aq) + H_2O(l)$$

(ii) Hot concentrated sodium hydroxide?

With hot concentrated sodium or potassium hydroxide, the respective metal chlorate(V) and chlorides are formed.

$$6NaOH(aq) + 3Cl_2(g) \longrightarrow NaClO_3(aq) + 5NaCl(aq) + 3H_2O(l)$$

$$6KOH(aq) + 3Cl_2(g) \longrightarrow KClO_3(aq) + 5KCl(aq) + 3H_2O(l)$$

A similar reaction takes place when chlorine is bubbled through solutions of calcium hydroxide.

$$2Ca(OH)_2(aq) + 2Cl_2(g) \longrightarrow CaCl_2(aq) + Ca(OCl_2)(aq) + 2H_2O(l)$$

Calcium hypochlorite, $Ca(OCl)_2$, is commonly referred to as bleaching powder.

(vi) Reaction with bromides and iodides

The reactions between chloride and other halides is an example of displacement reactions. Chlorine oxidises bromide ions to orange bromine liquid and also oxidises iodide ions to iodine which in the presence of iodide ions is a reddish-brown solution.

Discussion Questions

1. What is observed when chlorine is bubbled through a solution of:

(a) Potassium bromide?

When chlorine gas is bubbled through a solution containing bromide ions, the colourless solution turns orange. Chlorine has a higher tendency to gain electrons than bromine. It therefore readily oxidises bromide ions to bromine.

$$Cl_2(g) + 2KBr(aq) \longrightarrow 2KCl(aq) + Br_2(aq)$$

orange

Ionic equation:

$$Cl_2(g) + 2Br^-(aq) \longrightarrow 2Cl^-(aq) + Br_2(aq)$$

(b) Potassium iodide?

when chlorine is bubbled through a solution containing iodide ions, the colourless solution turns brown. Chlorine oxidises iodide ions to iodine which in the presence of iodide ions is a reddish-brown solution.

$$Cl_2(g) + 2KI(aq) \longrightarrow 2KCl(aq) + I_2(aq)$$

Ionic equation.

$$Cl_2(g) + 2I^-(aq) \longrightarrow 2Cl^-(aq) + I_2(aq)$$

These reactions are examples of displacement reactions.

(d)Test for Chloride Ions

The presence of chloride ions can be tested using lead nitrate solution in which a white precipitate which dissolves on warming is formed. To test for hydrogen chloride gas, the suspected gas is placed allowed to react with aqueous ammonia. Formation if dense white fumes confirms presence of hydrogen chloride gas.

Test:

1. Place a spatulaful of sodium chloride in a boiling tube. Place moist blue and red litmus papers at the mouth of the boiling tube. Add 1cm^3 of concentrated sulphuric(VI) acid. Bring a glass rod dipped in aqueous ammonia above the mouth of the boiling tube.
2. Prepare 5 cm^3 of sodium chloride solution.

(i) To a 2 cm^3 portion of the solution add a few drops of lead(II) nitrate solution.

(ii) Warm the resulting solution from 2 (i).

Discussion Questions

1. What observations are made when concentrated sulphuric(VI) acid is added to sodium chloride?

When concentrated sulphuric(VI) acid is added to sodium chloride crystals, white fumes are produced. The fumes turn moist blue litmus red. The white fumes are hydrogen chloride.

To confirm the presence of hydrogen chloride, a glass rod dipped in ammonia solution is held over the mouth of the gas jar as the gas is liberated.

Formation of dense white fumes of ammonia chloride confirms the presence of hydrogen chloride hence chloride ions in the solid substance.

$$NH_3(g) + HCl(g) \longrightarrow NH_4Cl(s)$$
(White fumes)

2. What observations are made when:

(i) Lead(II) nitrate is added to sodium chloride solution?

Presence of chloride ions in a solution can be tested with the lead(II) nitrate solution. In this case, a white precipitate of lead(II) chloride is formed.

$$Pb(NO_3)_2(aq) + 2HCl(aq) \longrightarrow PbCl_2(s) + 2HNO_3(aq)$$

(ii) The solution mixture of sodium chloride and lead(II) nitrate solutions is warmed

When warmed, the lead(II) chloride precipitate dissolves in the solution. It however recrystallises on cooling.

(e)Uses of Chlorine and its Compounds

Chlorine and its compounds are put into a wide range of use in industries, some of these are:

- Manufacture of hydrochloric acid.
- Manufacture of bleaching agents such as sodium chlorate(I) used in the cotton and paper industries.
- Chlorine is used in the treatment of drinking water and in sewage plants.
- Manufacture of chloroform, an anaesthetic.
- Manufacture of solvents such as trichloroethane and some chlorofluorocarbons (CFCs).
- CFC(s) commonly referred to as 'freons' are used as refrigerants in fridges and air conditioning units due to their low boiling points.
- Compounds of chlorine are used in the manufacture of plastics such as polyvinyl chloride (PVC).
- Manufacture of germicides, fungicides and pesticides such as DDT and some CFCs.
- CFCs are used to manufacture aerosol propellants.

Review Exercise 1

1. (a) Write a balanced equation for the reaction which takes place when a mixture of concentrated hydrochloric acid and solid manganese(IV) oxide is heated.

(b) A mixture of 1g of solid manganese(IV) oxide and concentrated hydrochloric acid containing 1g of pure acid is heated in the above reaction. Calculate the maximum number of moles of chlorine gas that could be formed.

(Mn = 55, Cl = 35.5, O = 16, H = 1.0).

2. (a) Chlorine is obtained commercially by the electrolysis of fused sodium chloride.

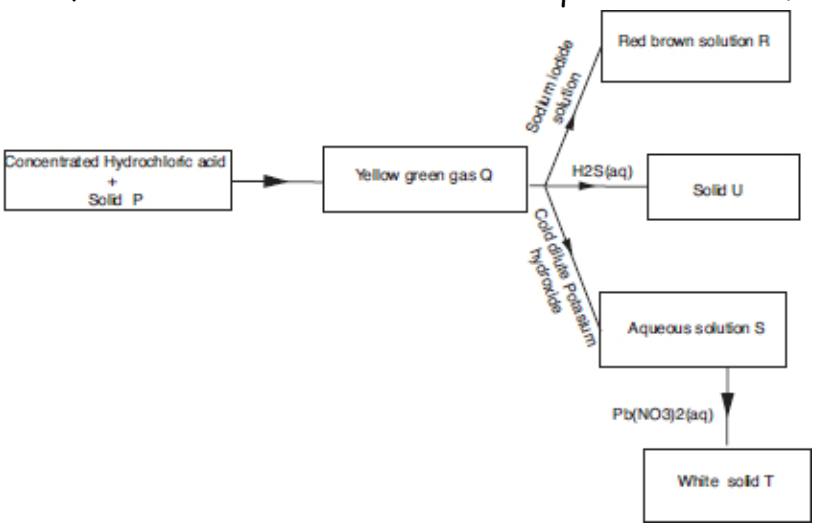
(i) Write down the equation for the production of chlorine at the appropriate electrode and name the type of chemical reaction taking place.

(ii) Give two industrial uses of chlorine.

(b) Explain how the bleaching action of moist chlorine is achieved.

(c) Bromine and iodine are members of the same group in the Periodic Table as chlorine. Describe tests by which these three members could be arranged in order of their reactivity.

3. Study the flowchart below and answer the questions below.



(a) Name:

(i) Solid P

(ii) Gas Q

(iii) Solid T

(iv) Solid U

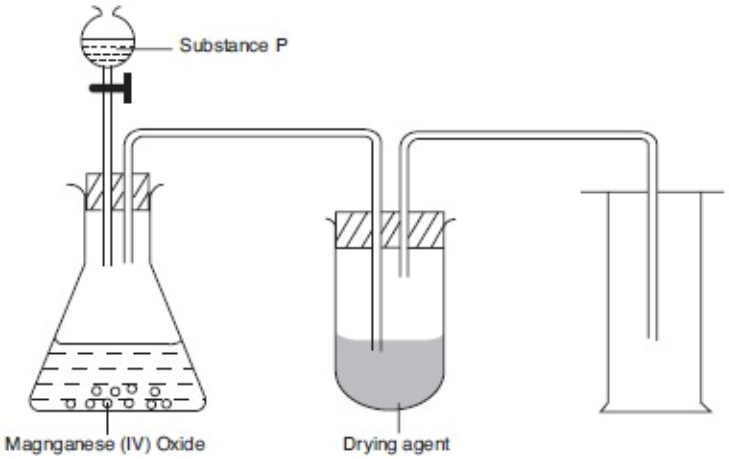
(b) Write an ionic equation for the formation of the redish brown liquid R.

(c) Give a commercial application of solution S.

(d) State and explain the observation made when a gas jar containing chlorine gas is inverted over a gas jar containing hydrogen sulphide gas.

4. Give a reason why chlorine is used in the manufacture of pesticides and germicides.

5. The diagram below shows a set-up for the laboratory preparation of dry chlorine gas.



(a) Name:

(i) substance P.

(ii) a suitable drying agent.

(b) What property of chlorine makes it possible for it to be collected as shown in the diagram?

6. When excess chlorine is bubbled through cold dilute potassium hydroxide, the resulting solution acts as a bleaching agent.

(a) Write an equation for the reaction between chlorine gas and dilute potassium hydroxide.

(b) Explain how the resulting solution acts as a bleaching agent

7. Chlorine gas is prepared in the laboratory by reacting a mixture of lead(IV) oxide and substance H. When dry chlorine is passed over heated iron wool, a dark brown solid S is formed.

(i) Identify substance H and S.

(ii) Name the drying agent used to dry chlorine gas.

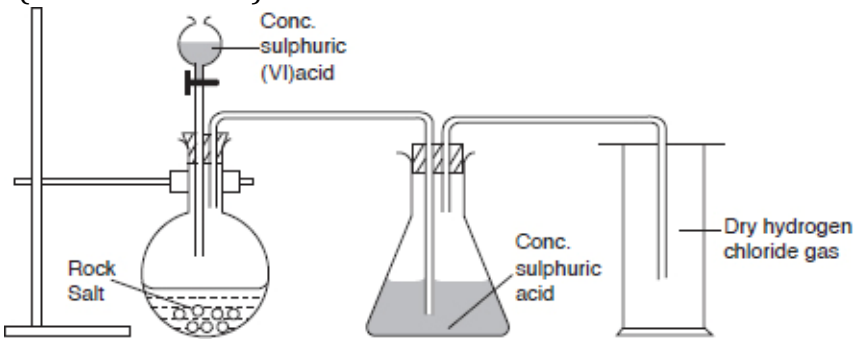
(iii) Explain the observation made when chlorine is bubbled through a solution of sodium iodide.

2. Hydrogen Chloride

Hydrogen chloride (hydrochloric acid gas) is a compound of hydrogen and chlorine. It is a molecular substance which exists as a gas at room temperature.

(a) Laboratory preparation and physical properties of hydrogen chloride

Hydrogen chloride gas is prepared by the addition of concentrated sulphuric(VI) acid drop-wise to rock salt (sodium chloride).



Discussion Questions

1. State some physical properties of hydrogen chloride gas.

Hydrogen chloride is a colourless gas with a pungent choking smell. It is denser than air and is collected by downward delivery (upward displacement of air). Hydrogen chloride is very soluble in water.

Hydrogen chloride gas turns moist blue litmus paper red showing that hydrogen chloride gas is acidic.

2. What observation is made when a gas jar of hydrogen chloride is inverted into a trough of water? Explain.

Hydrogen chloride is very soluble in water. When a gas jar full of hydrogen chloride is inverted into a trough of water, the water rises rapidly in the gas jar. At 0°C, 1 volume of water dissolves about 500 volumes of the gas. The 'fountain' experiment is a more dramatic demonstration of the solubility of the gas in water.

3. What observation is made when ammonia gas comes into contact with hydrogen chloride gas? Write an equation for the reaction.

When hydrogen chloride gas comes in contact with ammonia gas, dense white fumes of ammonium chloride are formed.

$$NH_3(g) + HCl(g) \longrightarrow \underset{\text{(white fumes)}}{NH_4Cl(s)}$$

This is used as the test for the gas.

4. What is the effect of hydrogen chloride gas on moist litmus paper?

Hydrogen chloride gas turns moist blue litmus paper red showing that hydrogen chloride gas is acidic.

4. Comment on the method of collection of the gas.

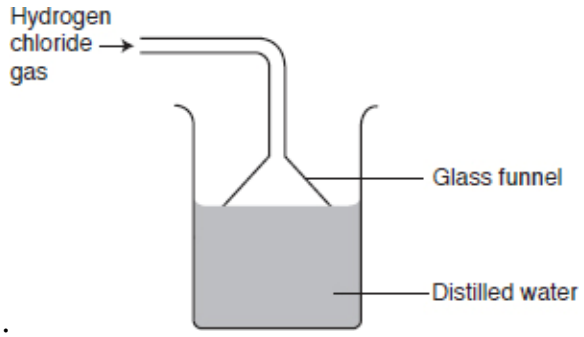
Hydrogen chloride is denser than air and is collected by downward delivery (upward displacement of air).

(b) Chemical Properties of Hydrogen Chloride

Hydrogen chloride gas turns moist litmus paper red, indicating that the gas is acidic. When the gas is dissolved in methyl benzene, it does not exhibit the acid properties.

Preparation of aqueous hydrogen chloride

To prepare aqueous hydrogen chloride, the hydrogen chloride gas is bubbled into a large beaker filled with distilled water to about three-quarter ($\frac{3}{4}$) its capacity through a filter funnel fitted at the end of the delivery tube.



In aqueous solution, hydrogen chloride dissociates into hydrogen and chloride ions.

$$HCl(g) \longrightarrow H^+(aq) + Cl^-(aq)$$

In methylbenzene, the gas does not dissociate hence does not display its acidic properties.

Discussion Questions

1. Why is the glass funnel dipped just below the water surface?

The filter funnel provides a large surface area for the gas to dissolve in the water. It is dipped just bellow the surface of the water to prevent sucking back.

2. What observations are made when aqueous hydrogen chloride reacts with:

(a) Metals?

All metals above hydrogen in the reactivity series react with hydrochloric acid liberating hydrogen gas.

$$Zn(s) + 2HCl(aq) \longrightarrow ZnCl_2(aq) + H_2(g)$$

$$Mg(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + H_2(g)$$

$$Fe(s) + 2HCl(aq) \longrightarrow FeCl_2(aq) + H_2(g)$$

Very reactive metals such as sodium and potassium react explosively with hydrochloric acid forming a salt and hydrogen gas.

$$2Na(s) + 2HCl(aq) \longrightarrow 2NaCl(aq) + H_2(g)$$

Copper metal which is below hydrogen in the reactivity series does not react with hydrochloric acid solution.

(b) Sodium hydroxide solution?

When hydrochloric acid reacts with hydroxides or basic oxides, neutralisation takes place. A salt and water are the only products of the reaction. The resulting solution is neutral to litmus.

(c) Carbonates and hydrogen carbonates?

Hydrogen chloride solution reacts with carbonates and hydrogen carbonates liberating carbon(IV) oxide (carbon dioxide) gas.

$$CaCO_3(s) + 2HCl(aq) \longrightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$$

$$ZnCO_3(s) + 2HCl(aq) \longrightarrow ZnCl_2(aq) + H_2O(l) + CO_2(g)$$

$$CuCO_3(s) + 2HCl(aq) \longrightarrow CuCl_2(aq) + H_2O(l) + CO_2(g)$$

$$NaHCO_3(s) + HCl(aq) \longrightarrow NaCl(aq) + H_2O(l) + CO_2(g$$

3. What is observed when the tests in 2(a) – (d) were done using a solution of hydrogen chloride in methylbenzene?

When the gas is dissolved in methyl benzene gas doesn't react with any of the above reagents.

4. What is observed when litmus paper is placed in a solution of hydrogen chloride in:

(i) Distilled water?

The litmus paper turns red.

When hydrogen chloride gas dissolves in water hydrochloric acid is formed. In aqueous solution, hydrogen chloride dissociates into hydrogen and chloride ions.

$$HCl(g) \longrightarrow H^+(aq) + Cl^-(aq)$$

It is the presence of hydrogen ions (H^+) that gives a solution its acidic nature.

(ii) Methyl benzene?

In methyl benzene, hydrogen chloride gas dissolves but does not ionise. It exists as molecules. This explains why the solution has no effect on moist blue litmus paper.

5. What is the test for hydrogen chloride gas?

When hydrogen chloride gas comes in contact with ammonia gas, dense white fumes of ammonium chloride are formed.

$$NH_3(g) + HCl(g) \longrightarrow NH_4Cl(s)$$

(white fumes)

This is used as the test for the gas.

(c) Large Scale Manufacture of Hydrochloric Acid

Hydrogen and chlorine are the **major raw materials.**

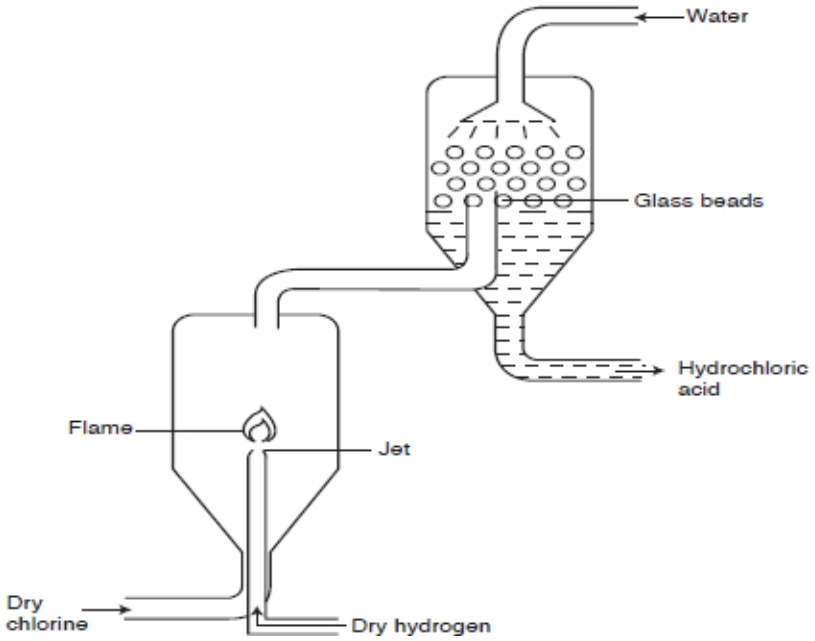
Hydrogen may be obtained by electrolysis of brine, cracking of long chain hydrocarbons or reacting methane gas (natural gas) with steam at high temperature.

Chlorine may be obtained by the electrolysis of either fused sodium chloride or brine.

In the industrial process, a mixture of chlorine and hydrogen is burned to form hydrogen chloride gas.

$$H_2(g) + Cl_2(g) \longrightarrow 2HCl(g)$$

A mixture of chlorine and hydrogen **reacts explosively when heated**. To control the reaction, a **small amount of hydrogen gas** is allowed to burn in excess chlorine **through a jet** as illustrated below.



The hydrogen chloride gas formed is dissolved in water **over glass beads.** The beads **increase the surface area** over which the gas dissolves in water.

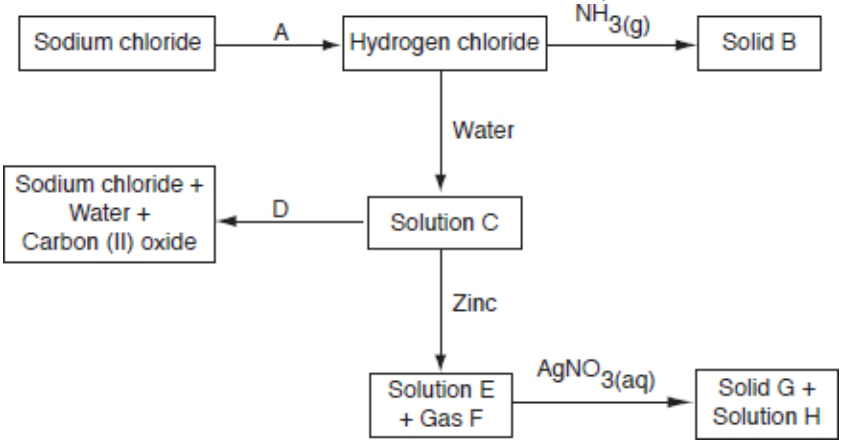
Commercial hydrochloric acid is about **35% pure.** Hydrochloric acid is transported in steel tanks lined inside with rubber. In Kenya, hydrochloric acid is manufactured on a large scale at Webuye.

(d) Uses of hydrochloric Acid

- Removing rust from metal. For example: de-scaling iron before it is galvanised, other metals before they are electroplated.
- Treatment of water (chlorination) at the water works.
- Sewage treatment.
- Making dyes, drugs and photographic materials such as silver chloride on photographic films.
- pH control and neutralisation in industries that require purity.

Review Exercises 2

1. When a mixture of hydrogen and chlorine gas is left in diffused light for sometime, the green-yellow colour gradually fades and a gas that fumes with ammonia is formed. If a similar mixture is passed over a hot platinum wire, the green-yellow colour fades quickly.
   (i) Identify the gas that fumes with ammonia gas.
   (ii) What effect does hot-platinum wire have on the mixture of gases?
   (iii) Write an equation for the reaction that occurs between hydrogen and chlorine.
2. Use the reaction scheme below to answer the questions that follow.



   (a) Name substances A to H.
   (b) Write down the equation for the reaction between solution E and aqueous silver nitrate.
   (c) Describe a test by which you could identify gas F.
3. (a) Hydrogen chloride gas is commercially obtained from the reaction between hydrogen and chlorine gas. State the sources of hydrogen and chlorine gas in this process.
   (b) (i) Explain why small amounts of hydrogen gas are burnt in excess chlorine gas during commercial preparation of hydrogen chloride gas.
   (ii) Write an equation for the reaction between chlorine and hydrogen gas.
   (c) Hydrogen chloride gas reacts with lead(II) ions in solution according to the equation.

$$2HCl(g) + Pb^{2+}(aq) \longrightarrow PbCl_2(s) + 2H^+(aq)$$

   2.4 litres of hydrogen chloride gas was carefully bubbled through 50 cm^3 of 1.0 M solution of lead(II) ions at room temperature.

   Calculate:
   (i) The number of moles of lead ions that reacted.

(ii) The number of moles of hydrogen chloride.

(iii) The mass in grams of lead chloride formed.

(one mole of gas occupies 24 dm^3 at r.t.p. Cl = 35.5, Pb = 207)

Environmental Pollution by Chlorine and its Compounds

Environmental pollution encompasses water pollution, air pollution and land pollution. Chlorine gas as an element, if allowed into the atmosphere can be dangerous particularly during the rains. It may dissolve in the rain and fall as acid rain. Acid rain may have adverse effects on both plant and animal life as well as on buildings and some nutrients in the soil.

Chlorofluorocarbons (CFC's or "Freons") are gaseous organic halogen compounds that have a wide range of applications in industry and in the laboratory. They are non-biodegradable and hence have a long life span. For instance, CCl_3F has a life span of 75 years and CCl_2F_2 has a life span of 110 years.

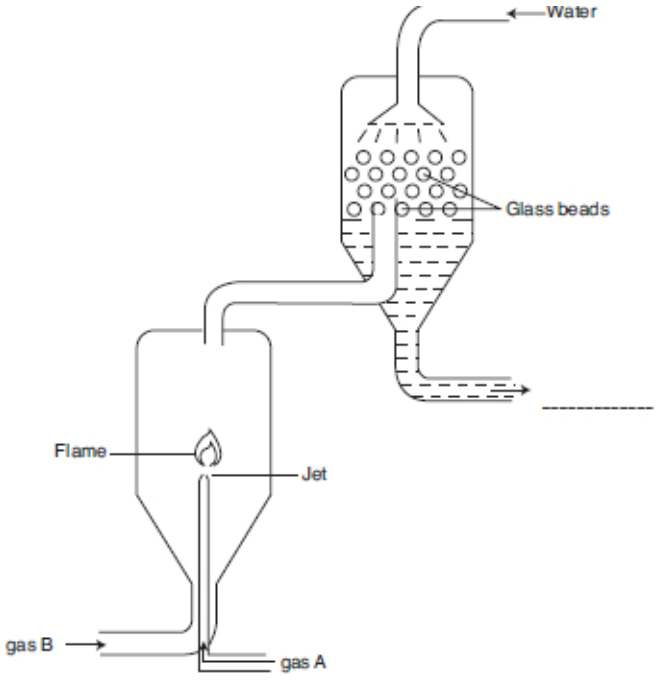
Over time, CFC's slowly diffuse into the atmosphere where they break down into free chlorine and fluorine atoms. The reactions of these free atoms with other substances under the influence of ultraviolet light accelerate the disintegration of the ozone layer, (O_3). Chlorine gas is therefore classified as one of the green house gases. The ozone layer prevents ultraviolet radiations from reaching the earth's surface where they would have adverse effects on plant and animal life.

Polyvinylchloride (PVC) plastics are non-biodegradable and are major land pollutants.

Dichlorodiphenyltrichloroethane (DDT), a pesticide, is a compound of chlorine. The compound has a long life span and so affects both plants and animal life. Use of DDT has been restricted to Public Health use in Malaria control through the International Stockholm Convention. Many other countries, Kenya included have completely banned the use of DDT. The National Environmental Management Authority which monitors the environmental impacts of various activities advises increased use of natural pyrethroids in mosquito control. Kenya is a leading producer of pyrethrum which is the source of the pyrethroids.

Revision Exercise

1. Coloured flowers placed in a gas jar containing gas X immediately turned colourless. A solution of gas X formed a white precipitate with silver nitrate solution. The precipitate was insoluble in nitric(V) acid but dissolves in excess aqueous ammonia.
   (a) What is the identity of gas X?
   (b) Write down the equation for the reactions that took place when:
   (i) A solution of gas X reacted with silver nitrate solution.
   (j) Aqueous ammonia was added through the resulting solution in (b) (i).
2. Commercial hydrochloric acid is about 35% by mass. Calculate its molarity given that at 25°C, the density of the acid is 1.08 g cm^{-3}.
3. Substance M, with a general formula, $C_x H_y$ burnt in chlorine with a red flame producing a cloud of black specks and a colourless gas G.
   (a) State the collective name for compounds to which M belongs.
   (b) State the identity of the black specks and the colourless gas G. Give reasons for the choice of your answer.
   (c) Suggest an experiment you would perform to test gas G.
   (d) Write a general equation for the reaction between compound M and chlorine.
4. The following diagram represents a section of the plant for the large scale manufacture of hydrochloric acid.



   (a) Name gases A and B.
   (b) State the role of the glass beads in the plant.
   (c) Why is gas A introduced into the reaction chamber through a jet?

(d) Write the chemical equation for the reaction between the gaseous substances represented by A and B.

5. Two solutions containing cations of metals P and Q were separately added to a solution containing chloride ions. In both cases, a white precipitate was formed. It was divided into two portions. To the first portion of each, a few drops of nitric (V) acid were added. The chloride compound of P was warmed. The chloride compound of Q dissolved while that of P did not.
   (a) Identify the ions of metals P and Q.
   (b) Write ionic equations for the reactions that occurred when cations of P and Q reacted with chloride ions.

6. Chlorine is used to treat water in drinking water supply plants, in a process called chlorination. Briefly explain how it eradicates the micro-organisms from water.

7. (a) What does the abbreviation CFCs stand for?
   (b) State three factors which make chlorofluorocarbons serious gaseous pollutants.
   (c) Name two other forms of environmental pollution.

8. The atomic number of carbon and chlorine are 6 and 17 respectively.
   (a) Draw a diagram to show the electron structure of:
      (i) Carbon.
      (ii) Chlorine.
   (b) Which bond would be formed when carbon and chlorine react?
   (c) Would you expect the compound in (b) to conduct electricity? Give a reason.