Chemistry of SULPHUR

A.SULPHUR (S)

Sulphur is an element in Group VI Group 16)of the Periodic table . It has atomic number 16 and electronic configuration 16 and valency 2 /divalent and thus forms the ion S^{2-}

A. Occurrence.

Sulphur mainly occurs :

(i) as **free** element in Texas and Louisiana in USA and Sicily in Italy.
(ii)**Hydrogen sulphide** gas in active volcanic areas e.g. Olkaria near Naivasha in Kenya
(iii)as **copper pyrites(**$CuFeS_2$**)** ,**Galena** (PbS,**Zinc blende**(ZnS))and **iron pyrites**(FeS_2) in other parts of the world.

B. Extraction of Sulphur from **Fraschs** process

Suphur occurs about 200 metres underground. The soil structure in these areas is usually **weak** and can easily **cave** in.

Digging of tunnels is thus discouraged in trying to extract the mineral. Sulphur is extracted by drilling three concentric /round pipes of diameter of ratios 2:8: 18 centimeters.

Superheated water at 170°C and 10atmosphere pressure is forced through the outermost pipe.

The high pressures ensure the water remains as liquid at high temperatures instead of vapour of vapour /gas.

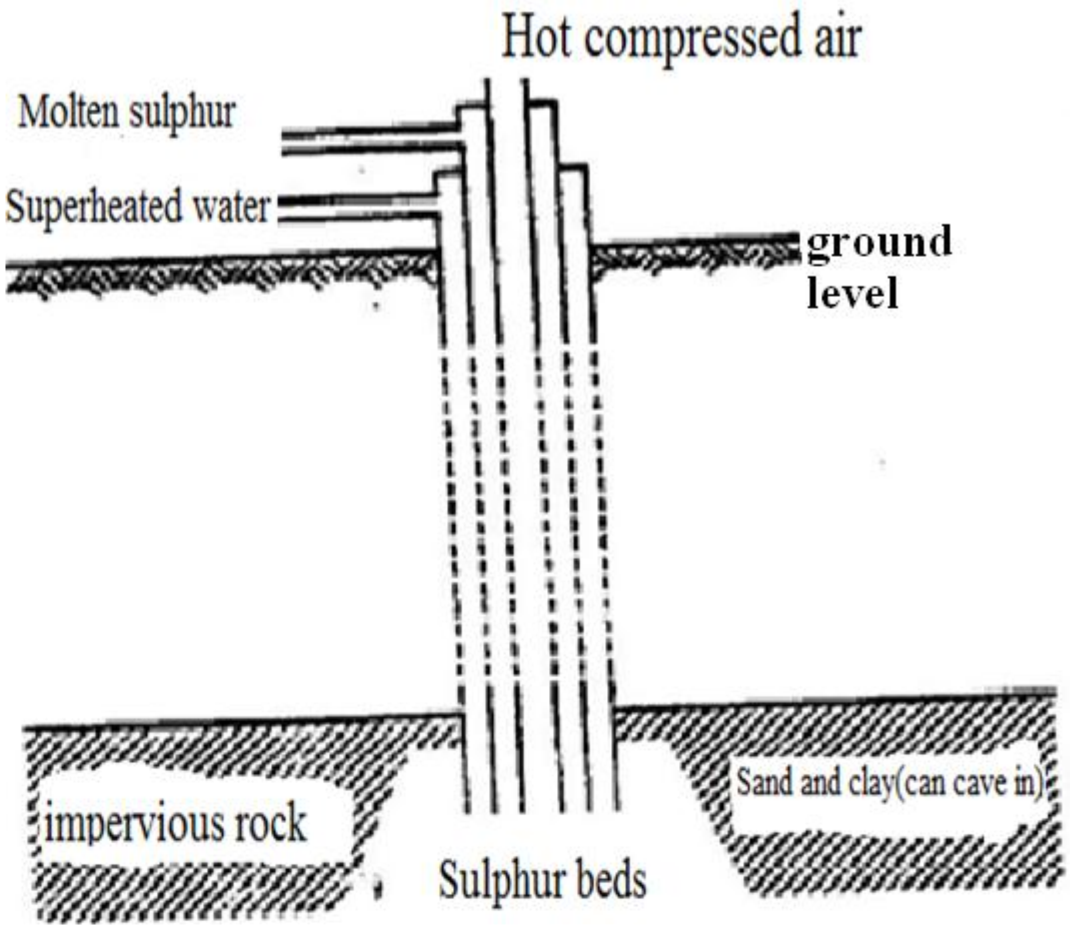
The superheated water melts the sulphur because the melting point of sulphur is lower at about at about 115°C.

A compressed air at 15 atmospheres is forced /pumped through the innermost pipe.

The hot air forces the molten sulphur up the middle pipe where it is collected and solidifies in a large tank.

It is about 99% pure.

<u>Diagram showing extraction of Sulphur from Fraschs Process</u>



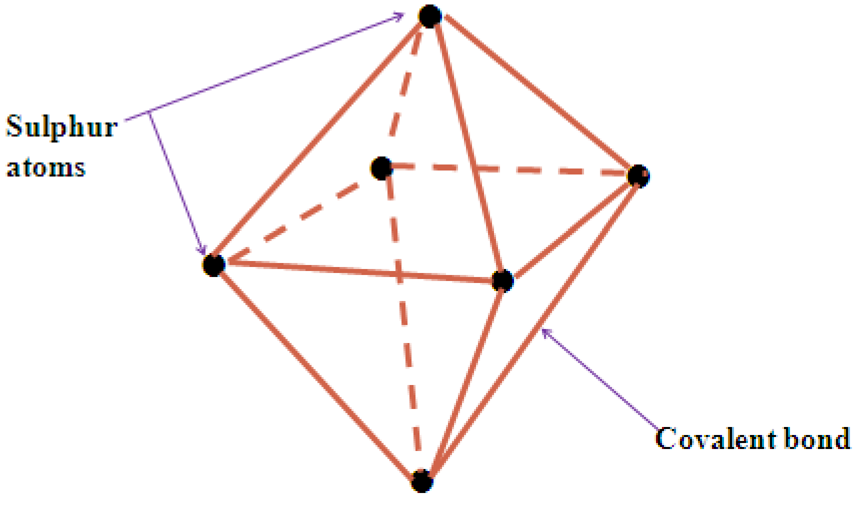
C. Allotropes of Sulphur.

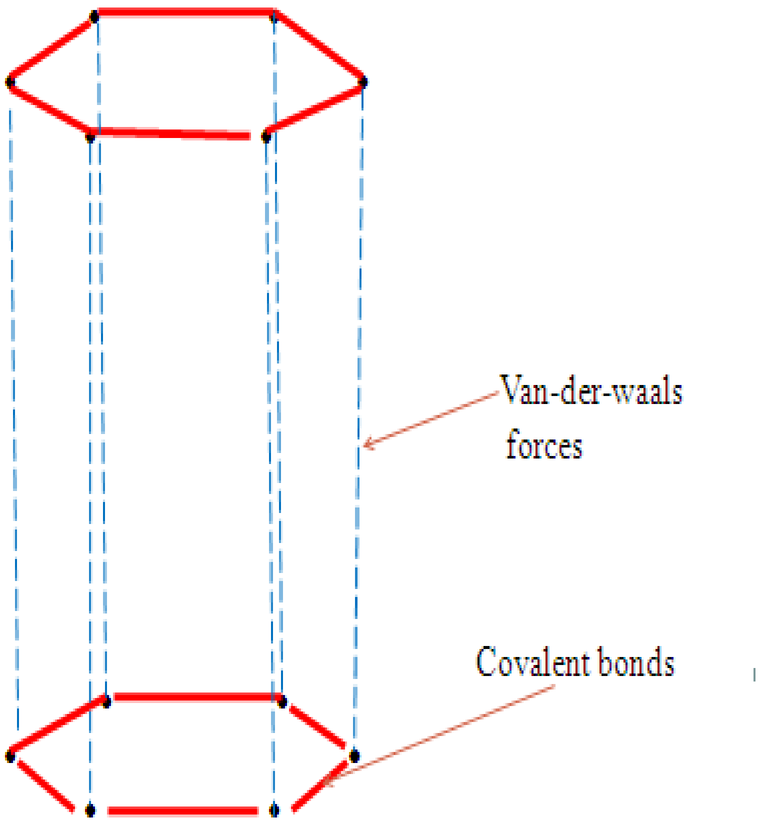
1. Sulphur exist as two crystalline allotropic forms:
(i)Rhombic sulphur
(ii)Monoclinic sulphur

Rhombic sulphur	Monoclinic sulphur
Bright yellow crystalline solid Has a melting point of 113°C Has a density of 2.06gcm^{-3} Stable below 96°C Has octahedral structure	Pale yellow crystalline solid Has a melting point of 119°C Has a density of 1.96gcm^{-3} Stable above 96°C Has a needle-like structure

Rhombic sulphur and Monoclinic sulphur have a **transition** temperature of 96°C.This is the temperature at which one allotrope changes to the other.

Sketch of Octahedral structure of Rhombic sulphur





Sketch of the needle-like structure of monoclinic sulphur

2. Sulphur exists in non-crystalline forms as:

(i)Plastic sulphur-

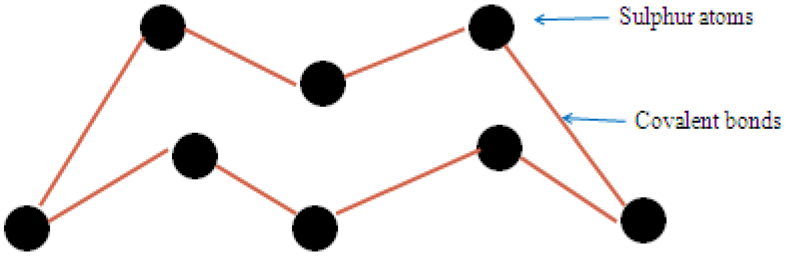
Plastic sulphur is prepared from heating powdered sulphur to boil then pouring a thin continuous stream in a beaker with cold water. A long thin elastic yellow thread of plastic sulphur is formed .If left for long it turn to bright yellow crystalline rhombic sulphur.

(ii)Colloidal sulphur-

Colloidal sulphur is formed when sodium thiosulphate ($Na_2S_2O_3$) is added hydrochloric acid to form a yellow precipitate.

D. Heating Sulphur.

A molecule of sulphur exists as puckered ring of eight atoms joined by covalent bonds as S_8.



On heating the yellow sulphur powder melts at 113°C to clear amber liquid with low viscosity and thus flows easily.

On further heating to 160°C the molten liquid darkens to a brown very viscous liquid that does not flow easily.

This is because the S_8 rings break into S_8 chain that join together to form very long chains made of over 100000 atoms of Sulphur.

The long chains **entangle** each other reducing their mobility /flow and hence increases their viscosity.

On continued further heating to above 160°C, the viscous liquid darkens but becomes more mobile/flows easily and thus less viscous.

This is because the long chains break to smaller/shorter chains.

At 444°C, the liquid boils and forms brown vapour of a mixture of S_8 ,S_6 ,S_2 molecules that solidifies to S_8 ring of “flowers of sulphur” on the cooler parts.

Summary of changes on heating sulphur

Observation on heating	Explanation/structure of Sulphur
Solid sulphur	Puckered S_8 ring
Heat to 113^{o}C Amber yellow liquid	Puckered S_8 ring in liquid form (low viscosity/flow easily)
Heat to 160^{o}C Liquid darkens	Puckered S_8 ring break/opens then join to form long chains that entangle (very high viscosity/very low rate of flow)
Heat to 444^{o}C Liquid boils to brown vapour	Mixture of S_8 ,S_6 ,S_2 vapour
Cool to room temperature Yellow sublimate (Flowers of Sulphur)	Puckered S_8 ring

E. Physical and Chemical properties of Sulphur.(Questions)

1. State three physical properties unique to Sulphur

Sulphur is a yellow solid, insoluble in water, soluble in carbon disulphide/tetrachloromethane/benzene, poor conductor of heat and electricity. It has a melting point of 115^{o}C and a boiling point of 444^{o}C.

2. Moist/damp/wet blue and red litmus papers were put in a gas jar containing air/oxygen. Burning sulphur was then lowered into the gas jar. State and explain the observation made.

Observations

-Sulphur melts then burns with a blue flame
Colourless gas produced that has a pungent smell
Red litmus paper remains red. Blue litmus paper turns red.

Explanation

Sulphur burns in air and faster in Oxygen to form Sulphur(IV)Oxide gas and traces/small amount of Sulphur(VI)Oxide gas. Both oxides react with water to form the corresponding acidic solution i.e

(i) Sulphur(IV)Oxide gas reacts with water to form sulphuric(IV)acid
(ii) Sulphur(VI)Oxide gas reacts with water to form sulphuric(VI)acid

Chemical equation

$S(s) + O_2(g) \rightarrow SO_2(g)$ (Sulphur(IV)Oxide gas)
$2S(s) + 3O_2(g) \rightarrow 2SO_3(g)$ (Sulphur(VI)Oxide gas traces)
$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$ (sulphuric(IV)acid)
$SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$ (sulphuric(VI)acid).

3. Iron filings were put in a test tube containing powdered sulphur then heated on a Bunsen flame. Stop heating when reaction starts. State and explain the observations made. Test the effects of a magnet on the mixture before and after heating. Explain.

Observations

Before heating, the magnet attracts iron filings leaving sulphur
After heating, the magnet does not attract the mixture.
After heating, a red glow is observed that continues even when heating is stopped..
Black solid is formed.

Explanation

Iron is attracted to a magnet because it is ferromagnetic.
When a mixture of iron and sulphur is heated, the reaction is exothermic giving out heat energy that makes the mixture to continue glowing even after stopping heating.
Black Iron(II)sulphide is formed which is a compound and thus not ferromagnetic.

Chemical equation

$Fe(s) + S(s) \rightarrow FeS(s)$ (Exothermic reaction/ $-\Delta H$)

Heated powdered heavy metals combine with sulphur to form **black** sulphides.

$Cu(s) + S(s) \rightarrow CuS(s)$
$Zn(s) + S(s) \rightarrow ZnS(s)$
$Pb(s) + S(s) \rightarrow PbS(s)$

4.The set up below show the reaction of sulphur on heated concentrated sulphuric(VI)acid.

(i)State and explain the observation made.

Observation

Yellow colour of sulphur fades
Orange colour of potassium dichromate(VI)paper turns to green.

Explanation

Hot concentrated sulphuric(VI)acid oxidizes sulphur to sulphur (IV)oxide gas. The oxide is also reduced to water. Traces of sulphur (VI)oxide is formed.

Chemical equation

$S(s) + 3H_2SO_4(l) \rightarrow 3SO_2(g) + 3H_2O(l) + SO_3(g)$

Sulphur (IV)oxide gas turns Orange potassium dichromate(VI)paper to green.

(ii)State and explain the observation made if concentrated sulphuric (VI) acid is replaced with concentrated Nitric (V) acid in the above set up.

Observation

Yellow colour of sulphur fades
Colurless solution formed
Brown fumes/gas produced.

Explanation

Hot concentrated Nitric(V)acid oxidizes sulphur to sulphuric (VI)acid. The Nitric (V) acid is reduced to brown nitrogen(IV)oxide gas.

Chemical equation

$S(s) + 6HNO_3(l) \rightarrow 6NO_2(g) + 2H_2O(l) + H_2SO_4(l)$

NB:
Hydrochloric acid is a weaker oxidizing agent and thus cannot oxidize sulphur like the other mineral acids.

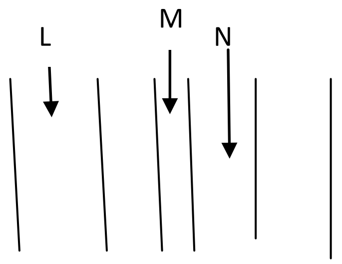
5.State three main uses of sulphur .

Sulphur is mainly used in:

(i)Contact process for the manufacture/industrial/large scale production of concentrated sulphuric(VI)acid.
(ii)Vulcanization of rubber to make it harder, tougher, stronger, and more durable.
(iii)Making gun powder and match stick heads
(iv) As ointments to treat fungal infections

6. Revision Practice

The diagram below represents the extraction of sulphur by Fraschs process. Use it to answer the questions that follow.



(a)Name the substances that passes through:

M Superheated water at 170oC and 10 atmosphere pressure
L Hot compressed air
N Molten sulphur

(b)What is the purpose of the substance that passes through L and M?

M- Superheated water at 170°C and 10 atmosphere pressure is used to melt the sulphur

L- Hot compressed air is used to force up the molten sulphur.

(c) The properties of the two main allotropes of sulphur represented by letters A and B are given in the table below. Use it to answer the questions that follow.

	A	**B**
Appearance	**Bright yellow**	**Pale yellow**
Density(gcm^{-3})	**1.93**	**2.08**
Melting point(°C)	**119**	**113**
Stability	**Above 96°C**	**Below 96°C**

I.What are allotropes?

Different forms of the same element existing at the same temperature and pressure without change of state.

II. Identify allotrope:

A. Monoclinic sulphur

B . Rhombic sulphur

III. State two main uses of sulphur.

-Manufacture of sulphuric(VI)acid
-as fungicide
-in vulcanization of rubber to make it harder/tougher/ stronger
-manufacture of dyes /fibres

(d)Calculate the volume of sulphur (IV)oxide produced when 0.4 g of sulphur is completely burnt in excess air.(S = 32.0 ,I mole of a gas occupies 24 dm3 at room temperature)

Chemical equation

$S(s) + O_2(g) \rightarrow SO_2(g)$

Mole ratio S: SO_2 = 1:1

Method 1

32.0 g of sulphur -> 24 dm3 of $SO_2(g)$

0.4 g of sulphur -> $\frac{0.4 \text{ g} \times 24 \text{ dm3}}{32.0 \text{ g}}$ = **0.3 dm3**

Method 2

Moles of sulphur used = $\frac{\text{Mass of sulphur}}{\text{Molar mass of sulphur}}$ => $\frac{0.4}{32}$ = 0.0125 moles

Moles of sulphur used = Moles of sulphur(IV)oxide used=>0.0125 moles

Volume of sulphur(IV)oxide used = Moles of sulphur(IV)oxide x volume of one mole of gas =>0.0125 moles x 24 dm3 = **0.3 dm3**

B.COMPOUNDS OF SULPHUR

The following are the main compounds of sulphur:

(i) Sulphur(IV)oxide
(ii) Sulphur(VI)oxide .
(iii) Sulphuric(VI)acid
(iv) Hydrogen Sulphide
(v) Sulphate(IV)/SO_3^{2-} and Sulphate(VI)/ SO_4^{2-} salts

(i) Sulphur(IV)oxide(SO_2)

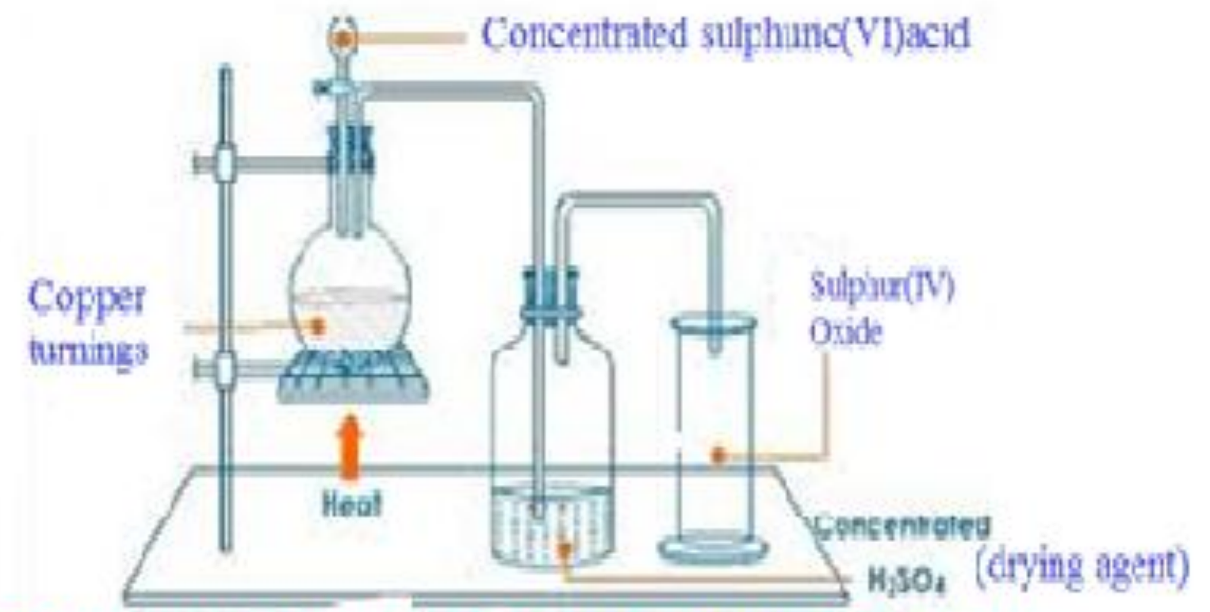
(a) Occurrence

Sulphur (IV)oxide is found in volcanic areas as a gas or dissolved in water from geysersand hot springs in active volcanic areas of the world e.g. Olkaria and Hells gate near Naivasha in Kenya.

(b) School laboratory preparation

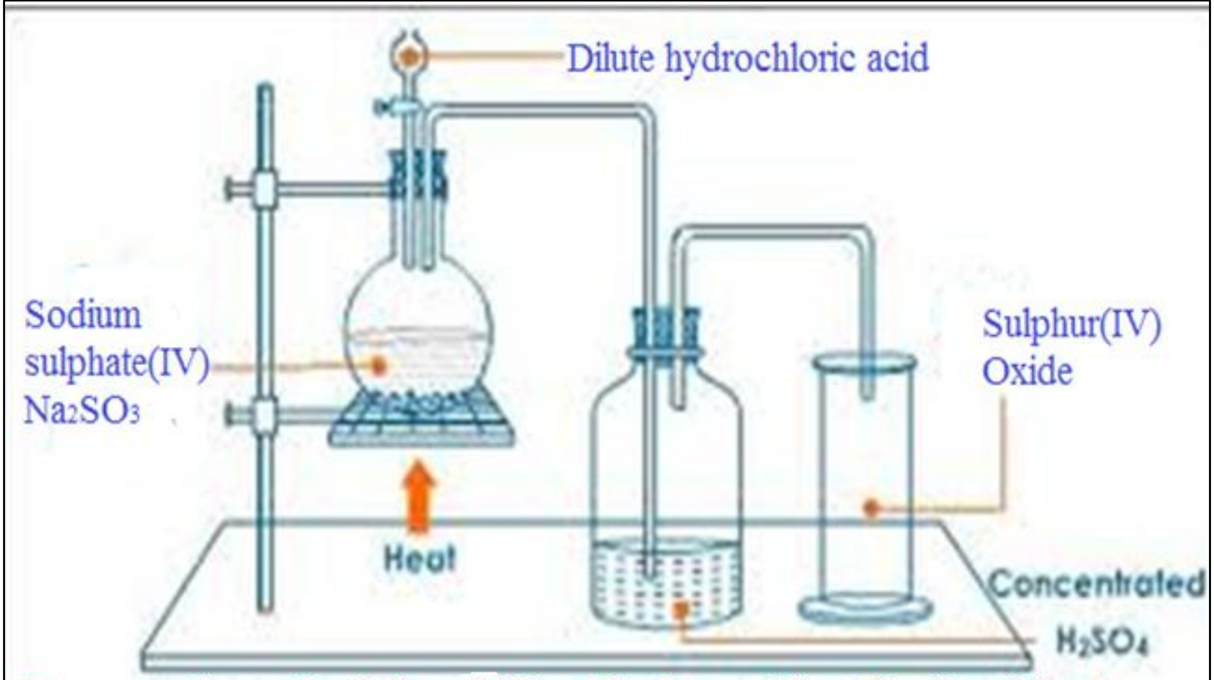
In a Chemistry school laboratory Sulphur (IV)oxide is prepared from the reaction of

Method 1:Using Copper and Sulphuric(VI)acid.



Preparation of sulphur(IV)oxide from Copper turnings and conc. Sulphuric(VI)acid

Method 2:Using Sodium Sulphate(IV) and hydrochloric acid.



Preparation of sulphur(IV)oxide from dilute hydrochloric acid and sodium sulphate(IV)

(c)Properties of Sulphur(IV)oxide(Questions)

1. Write the equations for the reaction for the formation of sulphur (IV)oxide using:

(i)Method 1

$Cu(s) + 2H_2SO_4(l) \rightarrow CuSO_4(aq) + SO_2(g) + 2H_2O(l)$
$Zn(s) + 2H_2SO_4(l) \rightarrow ZnSO_4(aq) + SO_2(g) + 2H_2O(l)$

$Mg(s) + 2H_2SO_4(l) \rightarrow MgSO_4(aq) + SO_2(g) + 2H_2O(l)$
$Fe(s) + 2H_2SO_4(l) \rightarrow FeSO_4(aq) + SO_2(g) + 2H_2O(l)$

Calcium ,Lead and Barium will form insoluble sulphate(VI)salts that will cover unreacted metals stopping further reaction thus producing very small amount/quantity of sulphur (IV)oxide gas.

(ii)Method 2

$Na_2SO_3(aq) + HCl(aq) \rightarrow NaCl(aq) + SO_2(g) + 2H_2O(l)$
$K_2SO_3(aq) + HCl(aq) \rightarrow KCl(aq) + SO_2(g) + 2H_2O(l)$

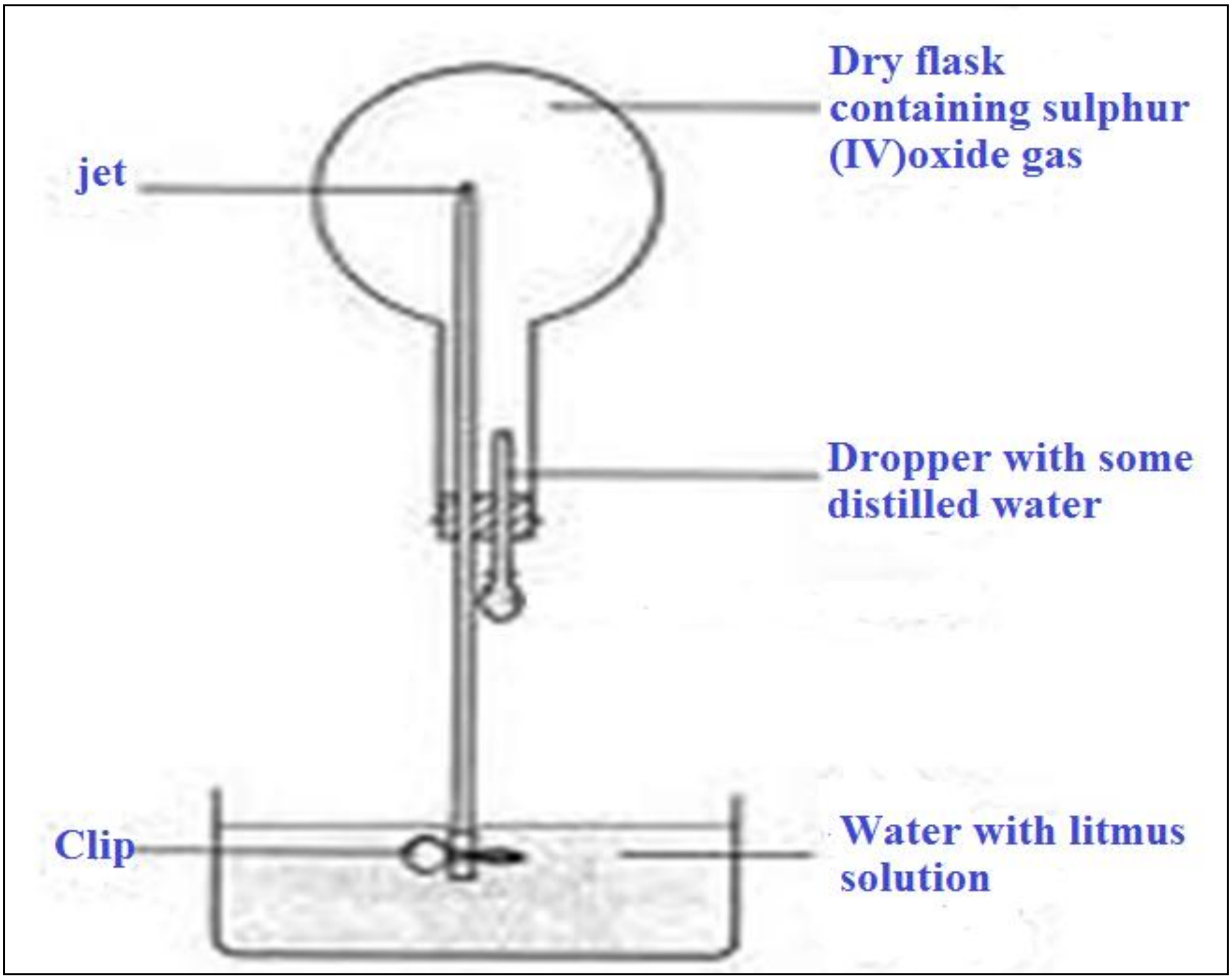
$BaSO_3(s) + 2HCl(aq) \rightarrow BaCl_2(aq) + SO_2(g) + H_2O(l)$
$CaSO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + SO_2(g) + H_2O(l)$
$PbSO_3(s) + 2HCl(aq) \rightarrow PbCl_2(s) + SO_2(g) + H_2O(l)$

Lead(II)chloride is soluble on heating thus reactants should be heated to prevent it coating/covering unreacted $PbSO_3(s)$

2.State the physical properties unique to sulphur (IV)oxide gas.

Sulphur (IV)oxide gas is a colourless gas with a pungent irritating and choking smell which **liquidifies** easily. It is about two times denser than air.

3. The diagram below show the solubility of sulphur (IV)oxide gas. Explain.



Sulphur(IV) oxide is very soluble in water.
One drop of water dissolves all the Sulphur (IV) oxide in the flask leaving a vacuum.
If the clip is removed, atmospheric pressure forces the water up through the narrow tube to form a fountain to occupy the vacuum.
An acidic solution of sulphuric (IV)acid is formed which turns litmus solution red.

<u>Chemical equation</u>
$SO_2(g)$ + $H_2O(l)$ -> H_2SO_3 (aq) (sulphuric(IV)acid turn litmus red)

4.Dry litmus papers and wet/damp/moist litmus papers were put in a gas jar containing sulphur(IV) oxide gas. State and explain the observations made.

<u>Observations</u>
(i)Dry Blue litmus paper remains blue.
Dry red litmus paper remains red.
(ii) Wet/damp/moist blue litmus paper turns red.
Moist/damp/wet red litmus paper remains red.

Both litmus papers are then bleached /decolorized.

Explanation

Dry sulphur(IV) oxide gas is a molecular compound that does not dissociate/ionize to release H+(aq)ions and thus has no effect on dry blue/red litmus papers.

Wet/damp/moist litmus papers contain water that dissolves /react with dry sulphur(IV) oxide gas to form a solution of weak sulphuric(IV)acid ($H_2 SO_3$ (aq)).

Weak sulphuric(IV)acid($H_2 SO_3$ (aq)) dissociates /ionizes into free H+(aq)ions:

$H_2 SO_3 (aq) \rightarrow 2H^+(aq) + SO_3^{2-} (aq)$

The free H^+(aq)ions are responsible for turning blue litmus paper turns red showing the gas is acidic.

The SO_3^{2-} (aq) ions in wet/damp/moist sulphur(IV) oxide gas is responsible for many reactions of the gas.

It is easily/readily oxidized to sulphate(VI) SO_4^{2-} (aq) ions making sulphur(IV) oxide gas act as a reducing agent as in the following examples:

(a)Bleaching agent

Wet/damp/moist coloured flowers/litmus papers are bleached/decolorized when put in sulphur(IV) oxide gas.

This is because sulphur(IV) oxide removes atomic oxygen from the coloured dye/ material to form sulphuric(VI)acid.

Chemical equations

(i)Formation of sulphuric(IV)acid

$SO_2(g) + H_2O(l) \rightarrow H_2 SO_3 (aq)$

(ii)Decolorization/bleaching of the dye/removal of atomic oxygen.

Method I. $H_2 SO_3 (aq) + \underset{\text{(coloured)}}{(dye + O)} \rightarrow H_2 SO_4 (aq) + \underset{\text{(colourless)}}{dye}$

Method II. $H_2 SO_3 (aq) + \underset{\text{(coloured)}}{(dye)} \rightarrow H_2 SO_4 (aq) + \underset{\text{(colourless)}}{(dye - O)}$

Sulphur(IV) oxide gas therefore bleaches by reduction /removing oxygen from a dye unlike chlorine that bleaches by oxidation /adding oxygen.

The bleaching by removing oxygen from Sulphur(IV) oxide gas is temporary.

This is because the bleached dye regains the atomic oxygen from the atmosphere/air in presence of sunlight as catalyst thus regaining/restoring its original colour. e.g.

Old newspapers turn brown on exposure to air on regaining the atomic oxygen. The bleaching through adding oxygen by chlorine gas is permanent.

(b)Turns Orange acidified potassium dichromate(VI) to green

Experiment:

(i)Pass a stream of Sulphur(IV) oxide gas in a test tube containing acidified potassium dichromate(VI) solution. or;

(ii)Dip a filter paper soaked in acidified potassium dichromate(VI) into a gas jar containing Sulphur(IV) oxide gas.

Observation:
Orange acidified potassium dichromate(VI) turns to green.

Explanation:
Sulphur(IV) oxide gas reduces acidified potassium dichromate(VI) from orange $Cr_2O_7^{2-}$ ions to green Cr^{3+} ions without leaving a residue itself oxidized from SO_3^{2-} ions in sulphuric(IV) acid to SO_4^{2-} ions in sulphuric(VI) acid.

Chemical/ionic equation:
(i)Reaction of Sulphur(IV) oxide gas with water

$$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$$

(ii)Dissociation /ionization of Sulphuric(IV)acid.

$$H_2SO_3(aq) \rightarrow 2H^+(aq) + SO_3^{2-}(aq)$$

(iii)Oxidation of SO_3^{2-} (aq)and reduction of $Cr_2O_7^{2-}$(aq)

$$3SO_3^{2-}(aq) + Cr_2O_7^{2-}(aq) + 8H^+(aq) \rightarrow 3SO_4^{2-}(aq) + 2Cr^{3+}(aq) + 4H_2O(l)$$

This is a **confirmatory** test for the presence of Sulphur(IV) oxide gas.

Hydrogen sulphide also reduces acidified potassium dichromate(VI) from orange $Cr_2O_7^{2-}$ ions to green Cr^{3+} ions leaving a **yellow** residue.

(c)Decolorizes acidified potassium manganate(VII)

Experiment:

(i)Pass a stream of Sulphur(IV) oxide gas in a test tube containing acidified potassium manganate(VII) solution. or;

(ii)Dip a filter paper soaked in acidified potassium manganate(VII) into a gas jar containing Sulphur(IV) oxide gas.

Observation:
Purple acidified potassium manganate(VII) turns to colourless/ acidified potassium manganate(VII) is decolorized.

Explanation:
Sulphur(IV) oxide gas reduces acidified potassium manganate(VII) from purple MnO_4^- ions to green Mn^{2+} ions without leaving a residue itself oxidized from SO_3^{2-} ions in sulphuric(IV) acid to SO_4^{2-} ions in sulphuric(VI) acid.

Chemical/ionic equation:
(i)Reaction of Sulphur(IV) oxide gas with water

$SO_2(g) + H_2O(l)$ -> $H_2SO_3(aq)$

(ii)Dissociation /ionization of Sulphuric(IV)acid.

$H_2SO_3(aq)$ -> $2H+(aq) + SO_3^{2-}(aq)$

(iii)Oxidation of $SO_3^{2-}(aq)$and reduction of $MnO_4^-(aq)$

$5SO_3^{2-}(aq) + 2MnO_4^-(aq) + 6H+(aq)$ -> $5SO_4^{2-}(aq) + 2Mn^{2+}(aq) + 3H_2O(l)$
(purple) (colourless)

This is another test for the presence of Sulphur(IV) oxide gas.

Hydrogen sulphide also decolorizes acidified potassium manganate(VII) from purple MnO_4^- ions to colourless Mn^{2+} ions leaving a **yellow** residue.

(d)Decolorizes bromine water

Experiment:

(i)Pass a stream of Sulphur(IV) oxide gas in a test tube containing bromine water . or;

(ii)Put three drops of bromine water into a gas jar containing Sulphur(IV) oxide gas. Swirl.

Observation:
Yellow bromine water turns to colourless/ bromine water is decolorized.

Explanation:
Sulphur(IV) oxide gas reduces yellow bromine water to colourless hydrobromic acid (HBr) without leaving a residue itself oxidized from SO_3^{2-} ions in sulphuric (IV) acid to SO_4^{2-} ions in sulphuric(VI) acid.

Chemical/ionic equation:
(i)Reaction of Sulphur(IV) oxide gas with water

$SO_2(g) + H_2O(l)$ -> $H_2SO_3(aq)$

(ii)Dissociation /ionization of Sulphuric(IV)acid.

$H_2 SO_3 (aq) \rightarrow 2H^+(aq) + SO_3^{2-} (aq)$

(iii)Oxidation of SO_3^{2-} (aq)and reduction of MnO_4^- (aq)
$SO_3^{2-}(aq) + Br_2 (aq) + H_2O(l) \rightarrow SO_4^{2-}(aq) + 2HBr(aq)$
(yellow) (colourless)

This can also be used as another test for the presence of Sulphur(IV) oxide gas.

Hydrogen sulphide also decolorizes yellow bromine water to colourless leaving a yellow residue.

(e)Reduces Iron(III) Fe^{3+} salts to Iron(II) salts Fe^{2+}

Experiment:

(i)Pass a stream of Sulphur(IV) oxide gas in a test tube containing about 3 cm3 of Iron (III)chloride solution. or;

(ii)Place about 3cm3 of Iron (III)chloride solution into a gas jar containing Sulphur(IV) oxide gas.Swirl.

Observation:
Yellow/brown Iron (III)chloride solution turns to green

Explanation:
Sulphur(IV) oxide gas reduces Iron (III)chloride solution from yellow/brown Fe^{3+} ions to green Fe^{2+} ions without leaving a residue itself oxidized from SO_3^{2-} ions in sulphuric(IV) acid to SO_4^{2-} ions in sulphuric(VI) acid.

Chemical/ionic equation:
(i)Reaction of Sulphur(IV) oxide gas with water
$SO_2(g) + H_2O(l) \rightarrow H_2 SO_3 (aq)$

(ii)Dissociation /ionization of Sulphuric(IV)acid.
$H_2 SO_3 (aq) \rightarrow 2H^+(aq) + SO_3^{2-} (aq)$

(iii)Oxidation of SO_3^{2-} (aq)and reduction of Fe^{3+} (aq)
$SO_3^{2-}(aq) + 2Fe^{3+} (aq) + 3H_2O(l) \rightarrow SO_4^{2-}(aq) + 2Fe^{2+}(aq) + 2H^+(aq)$
(yellow) (green)

(f)Reduces Nitric(V)acid to Nitrogen(IV)oxide gas

Experiment:

(i)Pass a stream of Sulphur(IV) oxide gas in a test tube containing about 3 cm3 of concentrated nitric(V)acid. or;

(ii)Place about 3cm3 of concentrated nitric(V)acid into a gas jar containing Sulphur(IV) oxide gas. Swirl.

Observation:
Brown fumes of a gas evolved/produced.

Explanation:
Sulphur(IV) oxide gas reduces concentrated nitric(V)acid to brown nitrogen(IV)oxide gas itself oxidized from SO_3^{2-} ions in sulphuric(IV) acid to SO_4^{2-} ions in sulphuric(VI) acid.

Chemical/ionic equation:

$$SO_2(g) + 2HNO_3(l) \rightarrow H_2SO_4(l) + NO_2(g)$$

(brown fumes/gas)

(g)Reduces Hydrogen peroxide to water

Experiment:

(i)Pass a stream of Sulphur(IV) oxide gas in a test tube containing about 3 cm3 of 20 volume hydrogen peroxide. Add four drops of Barium nitrate(V)or Barium chloride followed by five drops of 2M hydrochloric acid/ 2M nitric(V) acid.

Observation:
A white precipitate is formed that persist /remains on adding 2M hydrochloric acid/ 2M nitric(V) acid.

Explanation:
Sulphur(IV) oxide gas reduces 20 volume hydrogen peroxide and itself oxidized from SO_3^{2-} ions in sulphuric(IV) acid to SO_4^{2-} ions in sulphuric(VI) acid.
When Ba^{2+} ions in Barium Nitrate(V) or Barium chloride solution is added, a white precipitate of insoluble Barium salts is formed showing the presence of of either SO_3^{2-}, SO_4^{2-}, CO_3^{2-} ions. i.e.

Chemical/ionic equation:

$$SO_3^{2-}(aq) + Ba^{2+}(aq) \rightarrow BaSO_3(s)$$

white precipitate

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

white precipitate

$$CO_3^{2-}(aq) + Ba^{2+}(aq) \rightarrow BaCO_3(s)$$

white precipitate

If nitric(V)/hydrochloric acid is added to the three suspected insoluble white precipitates above, the white precipitate:

(i) persist/remains if SO_4^{2-}(aq)ions ($BaSO_4$(s)) is present.
(ii)dissolves if SO_3^{2-}(aq)ions ($BaSO_3$(s)) and CO_3^{2-}(aq)ions ($BaCO_3$(s))is present. This is because:

I. $BaSO_3$(s) reacts with Nitric(V)/hydrochloric acid to produce acidic SO_2 gas that turns Orange moist filter paper dipped in acidified Potassium dichromate to green.

Chemical equation

$BaSO_3(s) + 2H^+(aq) \rightarrow Ba^{2+}(aq) + SO_2(g) + H_2O(l)$

I. $BaCO_3$(s) reacts with Nitric(V)/hydrochloric acid to produce acidic CO_2 gas that forms a white precipitate when bubbled in lime water.

Chemical equation

$$BaCO_3(s) + 2H^+(aq) \rightarrow Ba^{2+}(aq) + CO_2(g) + H_2O(l)$$

5.Sulphur(IV)oxide also act as an oxidizing agent as in the following examples.

(a)Reduction by burning Magnesium

Experiment

Lower a burning Magnesium ribbon into agas jar containing Sulphur(IV)oxide gas

Observation

Magnesium ribbon continues to burn with difficulty.
White ash and yellow powder/speck

Explanation

Sulphur(IV)oxide does not support burning/combustion. Magnesium burns to produce enough heat energy to decompose Sulphur(IV)oxide to sulphur and oxygen.
The metal continues to burn on Oxygen forming white Magnesium oxide solid/ash.
Yellow specks of sulphur residue form on the sides of reaction flask/gas jar.
During the reaction, Sulphur(IV)oxide is reduced(oxidizing agent)while the metal is oxidized (reducing agent)

Chemical equation

$SO_2(g) + 2Mg(s) \rightarrow 2MgO(s) + S(s)$

(white ash/solid) (yellow speck/powder)

(b)Reduction by Hydrogen sulphide gas

Experiment

Put two drops of water into a gas jar containing dry Sulphur(IV)oxide gas
Bubble hydrogen sulphide gas into the gas jar containing Sulphur(IV)oxide gas.

Or
Put two drops of water into a gas jar containing dry Sulphur(IV)oxide gas
Invert a gas jar full of hydrogen sulphide gas over the gas jar containing Sulphur(IV)oxide gas. Swirl

Observation
Yellow powder/speck
Explanation
Sulphur(IV)oxide oxidizes hydrogen sulphide to yellow specks of sulphur residue and itself reduced to also sulphur that form on the sides of reaction flask/gas jar.
A little moisture/water act as catalyst /speeds up the reaction.
Chemical equation
$SO_2(g) + 2H_2S(g) \rightarrow 2H_2O(l) + 3S(s)$
(yellow speck/powder)

6.Sulphur(IV)oxide has many industrial uses. State three.

(i)In the contact process for the manufacture of Sulphuric(VI)acid
(ii)As a bleaching agent of pulp and paper.
(iii)As a fungicide to kill microbes'
(iv)As a preservative of jam, juices to prevent fermentation

(ii) Sulphur(VI)oxide(SO_3)

(a) Occurrence

Sulphur (VI)oxide is does not occur free in nature/atmosphere

(b) Preparation

In a Chemistry school laboratory Sulphur (VI)oxide may prepared from:

Method 1;**Catalytic oxidation of sulphur(IV)oxide gas**.

Sulphur(IV)oxide gas and oxygen mixture are first dried by being passed through Concentrated Sulphuric(VI)acid .
The dry mixture is then passed through platinised asbestos to catalyse/speed up the combination to form Sulphur (VI)oxide gas.
Sulphur (VI)oxide gas readily solidify as silky white needles if passed through a freezing mixture /ice cold water.
The solid fumes out on heating to a highly acidic poisonous gas.

Chemical equation
$2SO_2(g) + O_2(g) \xrightarrow{\text{platinised asbestos}} 2SO_3(g)$

Method 2; Heating Iron(II)sulphate(VI) heptahydrate

When green hydrated Iron(II)sulphate(VI) heptahydrate crystals are heated in a boiling tube ,it loses the water of crystallization and colour changes from green to white.

Chemical equation

$FeSO_4.7H_2O(s)$ -> $FeSO_4(s)$ + $7H_2O(l)$
(green solid) (white solid)

On further heating ,the white anhydrous Iron(II)sulphate(VI) solid decomposes to a mixture of Sulphur (VI)oxide and Sulphur (IV)oxide gas.
Sulphur (VI) oxide readily / easily solidify as white silky needles when the mixture is passed through a freezing mixture/ice cold water.
Iron(III)oxide is left as a brown residue/solid.

Chemical equation

$2FeSO_4$ (s) -> $Fe_2O_3(s)$ + SO_2 (g) + $SO_3(g)$
(green solid) (brown solid)

Caution

On exposure to air Sulphur (VI)oxide gas produces highly corrosive poisonous fumes of concentrated sulphuric(VI)acid and thus its preparation in a school laboratory is very risky.

(c) Uses of sulphur(VI)oxide

One of the main uses of sulphur(VI)oxide gas is as an intermediate product in the contact process for industrial/manufacture/large scale/production of sulphuric(VI)acid.

(iii) Sulphuric(VI)acid(H_2SO_4)

(a) Occurrence

Sulphuric (VI)acid(H_2SO_4) is one of the three mineral acids. There are three mineral acids;

Nitric(V)acid
Sulphuric(VI)acid
Hydrochloric acid.

Mineral acids do not occur naturally but are prepared in a school laboratory and manufactured at industrial level.

(b)The Contact process for industrial manufacture of H_2SO_4 .

I. Raw materials

The main raw materials for industrial preparation of Sulphuric(VI)acid include:

(i)**Sulphur** from Fraschs process or from heating metal sulphide ore like Galena(PbS),Zinc blende(ZnS)
(ii)**Oxygen** from fractional distillation of air
(iii)**Water** from rivers/lakes

II. Chemical processes

The contact process involves four main chemical processes:

(i)Production of Sulphur (IV)oxide

As one of the raw materials, Sulphur (IV)oxide gas is got from the following sources;

I. Burning/roasting sulphur in air.

Sulphur from Fraschs process is roasted/burnt in air to form Sulphur (IV)oxide gas in the **burners**

Chemical equation

$$S(s) + O_2(g) \rightarrow SO_2(g)$$

II. Burning/roasting sulphide ores in air.

Sulphur (IV)oxide gas is produced as a by product in extraction of some metals like:

- Lead from Lead(II)sulphide/Galena,(PbS)
- Zinc from zinc(II)sulphide/Zinc blende, (ZnS)
- Copper from Copper iron sulphide/Copper pyrites, ($CuFeS_2$)

On roasting/burning, large amount /quantity of sulphur(IV)oxide is generated/produced.

Chemical equation

(i)$2PbS(s) + 3O_2(g) \rightarrow 2PbO(s) + 2SO_2(g)$
(ii)$2ZnS(s) + 3O_2(g) \rightarrow 2ZnO(s) + 2SO_2(g)$
(ii)$2CuFeS_2(s) + 4O_2(g) \rightarrow 2FeO(s) + 3SO_2(g) + Cu_2O(s)$

Sulphur(IV)oxide easily/readily liquefies and thus can be transported to a far distance safely.

(ii)Purification of Sulphur(IV)oxide

Sulphur(IV)oxide gas contain dust particles and Arsenic(IV)oxide as impurities. These impurities "poison"/impair the catalyst by adhering on/covering its surface.

The impurities are removed by electrostatic precipitation method .
In the contact process Platinum or Vanadium(V)oxide may be used.
Vanadium(V)oxide is preferred because it is :

(i) cheaper/less expensive
(ii) less easily poisoned by impurities

(iii)Catalytic conversion of Sulphur(IV)oxide to Sulphur(VI)oxide

Pure and dry mixture of Sulphur (IV)oxide gas and Oxygen is heated to 450°C in a heat exchanger.
The heated mixture is passed through long pipes coated with pellets of Vanadium (V)oxide catalyst.
The close "contact" between the reacting gases and catalyst give the process its name.
Vanadium (V)oxide catalyse the conversion/oxidation of Sulphur(IV)oxide to Sulphur(VI)oxide gas.

Chemical equation

$$2SO_2\,(g) + O_2(g) \quad \text{-- } V_2O_5 \text{ -->} \quad 2SO_2\,(g)$$

This reaction is exothermic ($-\Delta H$) and the temperatures need to be maintained at around 450°C to ensure that:

(**i**)reaction rate/time taken for the formation of Sulphur(VI)oxide is not too **slow/long** at **lower** temperatures below 450°C

(**ii**) Sulphur(VI)oxide gas does not **decompose** back to Sulphur(IV)oxide gas and Oxygen gas at **higher** temperatures than 450°C.

(iv)Conversion of Sulphur(VI)oxide of Sulphuric(VI)acid

Sulphur(VI)oxide is the acid anhydride of concentrated Sulphuric(VI)acid.
Sulphur(VI)oxide reacts with water to form thick mist of fine droplets of very/highly corrosive concentrated Sulphuric(VI)acid because the reaction is highly exothermic.
To prevent this, Sulphur (VI)oxide is a passed up to meet downward flow of 98% Sulphuric(VI)acid in the absorption chamber/tower.
The reaction forms a very **viscous oily** liquid called **Oleum/fuming Sulphuric (VI) acid/ pyrosulphuric (VI) acid.**

Chemical equation

$$H_2SO_4\,(aq) + SO_3\,(g) \quad \text{->} \quad H_2S_2O_7\,(l)$$

Oleum/fuming Sulphuric (VI) acid/ pyrosulphuric (VI) acid is diluted carefully with distilled water to give concentrated sulphuric (VI) acid .

Chemical equation

$$H_2S_2O_7\,(l) + H_2O\,(l) \quad \text{->} \quad 2H_2SO_4\,(l)$$

The acid is stored ready for market/sale.

III. Environmental effects of contact process

Sulphur(VI)oxide and Sulphur(IV)oxide gases are atmospheric pollutants that form acid rain if they escape to the atmosphere.

In the Contact process, about 2% of these gases do not form sulphuric (VI) acid.

The following precautions prevent/minimize pollution from Contact process:

(i)recycling back any unreacted Sulphur(IV)oxide gas back to the heat exchangers.

(ii)dissolving Sulphur(VI)oxide gas in concentrated sulphuric (VI) acid instead of water.

This prevents the formation of fine droplets of the corrosive/ toxic/poisonous fumes of concentrated sulphuric (VI) acid.

(iii)**scrubbing-**This involves passing the exhaust gases through very tall chimneys lined with quicklime/calcium hydroxide solid.

This reacts with Sulphur (VI)oxide gas forming harmless calcium(II)sulphate (IV) /$CaSO_3$

Chemical equation

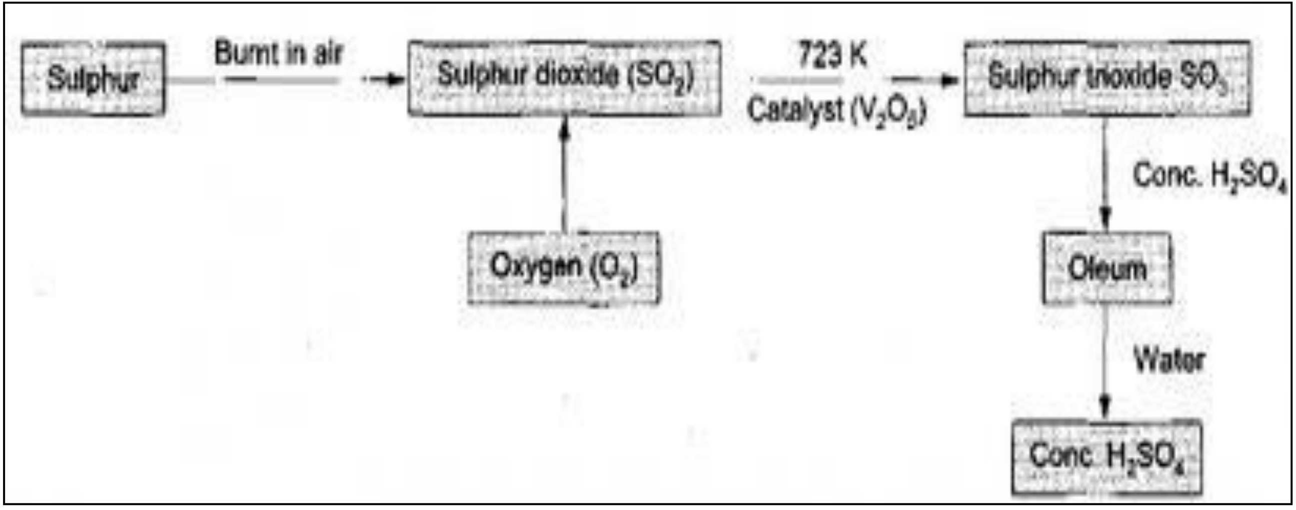
$$Ca(OH)_2\ (aq) + SO_2(g) \quad \text{-->} \quad CaSO_3\ (aq) + H_2O\ (g)$$

IV. Uses of Sulphuric(VI)acid

Sulphuric (VI) acid is used:

(i) in making dyes and paint
(ii)as acid in Lead-acid accumulator/battery
(iii) for making soapless detergents
(iv) for making sulphate agricultural fertilizers

VI. Sketch chart diagram showing the Contact process



(c) Properties of Concentrated sulphuric(VI)acid

(i)Concentrated sulphuric(VI)acid is a colourless oily liquid with a density of 1.84gcm^{-3}.It has a boiling point of 338^{o}C.

(ii) Concentrated sulphuric(VI)acid is very soluble in water.
The solubility /dissolution of the acid very highly exothermic.
The concentrated acid should thus be diluted slowly in excess water.
Water should never be added to the acid because the hot acid scatters highly corrosive fumes out of the container.

(iii) Concentrated sulphuric (VI)acid is a covalent compound. It has no free H^{+} ions.
Free H^{+} ions are responsible for turning the blue litmus paper red. Concentrated sulphuric (VI) acid thus do not change the blue litmus paper red.

(iv) Concentrated sulphuric (VI)acid is hygroscopic. It absorbs water from the atmosphere and do not form a solution.
This makes concentrated sulphuric (VI) acid very suitable as drying agent during preparation of gases.
(v)The following are some **<u>chemical properties</u>** of concentrated sulphuric (VI) acid:

I. As a dehydrating agent

<u>Experiment I;</u>
Put about four spatula end fulls of brown sugar and glucose in separate 10cm3 beaker.
Carefully add about 10cm3 of concentrated sulphuric (VI) acid .Allow to stand for about 10 minutes.
<u>Observation;</u>

Colour(in brown sugar)change from brown to **black**.
Colour (in glucose) change from white to **black**.
10cm3 beaker becomes very hot.

<u>Explanation</u>
Concentrated sulphuric (VI) acid is strong dehydrating agent.
It removes chemically and physically combined elements of water(Hydrogen and Oxygen in ratio 2:1)from compounds.
When added to sugar /glucose a vigorous reaction that is highly exothermic take place.
The sugar/glucose is **charred** to **black mass** of carbon because the acid dehydrates the sugar/glucose leaving carbon.
<u>Caution</u>
This reaction is highly exothermic that start slowly but produce fine particles of carbon that if inhaled cause quick suffocation by blocking the lung villi.

<u>Chemical equation</u>

Glucose: $C_6H_{12}O_6(s)$ --conc.H_2SO_4--> 6C (**s**) + $6H_2O(l)$
(white) (**black**)

Sugar: $C_{12}H_{22}O_{11}(s)$ --conc.H_2SO_4--> 12C (**s**) +$11H_2O(l)$
(brown) (**black**)

Experiment II;

Put about two spatula end full of hydrated copper(II)sulphate(VI)crystals in a boiling tube .Carefully add about 10cm3 of concentrated sulphuric (VI) acid .Warm .

Observation;

Colour change from blue to white.

Explanation

Concentrated sulphuric (VI) acid is strong dehydrating agent.It removes physically combined elements of water(Hydrogen and Oxygen in ratio 2:1)from hydrated compounds.

The acid dehydrates blue copper(II)sulphate to white anhydrous copper(II)sulphate .

Chemical equation

$CuSO_4.5H_2O(s)$ --conc.H_2SO_4--> $CuSO_4$ (s) + $5H_2O(l)$
(blue) (white)

Experiment III;

Put about 4cm3 of absolute ethanol in a boiling tube .Carefully add about 10cm3 of concentrated sulphuric (VI) acid.

Place moist/damp/wet filter paper dipped in acidified potassium dichromate(VI)solution on the mouth of the boiling tube. Heat strongly.

Caution:

Absolute ethanol is highly flammable.

Observation;

Colourless gas produced.

Orange acidified potassium dichromate (VI) paper turns to green.

Explanation

Concentrated sulphuric (VI) acid is strong dehydrating agent.

It removes chemically combined elements of water(Hydrogen and Oxygen in ratio 2:1)from compounds.

The acid dehydrates ethanol to ethene gas at about 170^{o}C.

Ethene with =C=C= double bond turns orange acidified potassium dichromate (VI) paper turns to green.

Chemical equation

$C_2H_5OH(l)$ --conc.H_2SO_4/170°C --> C_2H_4 (g) + $H_2O(l)$

NB: This reaction is used for the school laboratory preparation of ethene gas

Experiment IV;

Put about 4cm3 of methanoic acid in a boiling tube .Carefully add about 6 cm3 of concentrated sulphuric (VI) acid. Heat gently

Caution:

This should be done in a fume chamber/open

Observation;

Colourless gas produced.

Explanation

Concentrated sulphuric (VI) acid is strong dehydrating agent. It removes chemically combined elements of water (Hydrogen and Oxygen in ratio 2:1)from compounds.

The acid dehydrates methanoic acid to poisonous/toxic carbon(II)oxide gas.

Chemical equation

$HCOOH(l)$ --conc.H_2SO_4 --> $CO(g)$ + $H_2O(l)$

NB: This reaction is used for the school laboratory preparation of small amount carbon (II)oxide gas

Experiment V;

Put about 4cm3 of ethan-1,2-dioic/oxalic acid in a boiling tube .Carefully add about 6 cm3 of concentrated sulphuric (VI) acid. Pass any gaseous product through lime water.Heat gently

Caution:

This should be done in a fume chamber/open

Observation;

Colourless gas produced.

Gas produced forms a white precipitate with lime water.

Explanation

Concentrated sulphuric (VI) acid is strong dehydrating agent.

It removes chemically combined elements of water (Hydrogen and Oxygen in ratio 2:1)from compounds.

The acid dehydrates ethan-1,2-dioic/oxalic acid to a mixture of poisonous/toxic carbon(II)oxide and carbon(IV)oxide gases.

Chemical equation

$HOOCCOOH(l)$ --conc.H_2SO_4 --> $CO(g)$ + $CO_2(g)$ + $H_2O(l)$

NB: This reaction is also used for the school laboratory preparation of small amount carbon (II) oxide gas.

Carbon (IV) oxide gas is removed by passing the mixture through concentrated sodium/potassium hydroxide solution.

II. As an Oxidizing agent

Experiment I

Put about 2cm3 of Concentrated sulphuric (VI) acid into three separate boiling tubes. Place a thin moist/damp/wet filter paper dipped in acidified potassium dichromate (VI)solution on the mouth of the boiling tube. Put about 0.5g of Copper turnings, Zinc granule and Iron filings to each boiling tube separately.

Observation;

Effervescence/fizzing/bubbles
Blue solution formed with copper,
Green solution formed with Iron
Colourless solution formed with Zinc
Colourless gas produced that has a pungent irritating choking smell.
Gas produced turn orange moist/damp/wet filter paper dipped in acidified potassium dichromate (VI)solution to green.

Explanation

Concentrated sulphuric (VI) acid is strong oxidizing agent.
It oxidizes metals to metallic sulphate(VI) salts and itself reduced to sulphur(IV)oxide gas.
Sulphur (IV) oxide gas turn orange moist/damp/wet filter paper dipped in acidified potassium dichromate (VI)solution to green.
$CuSO_4$(aq) is a blue solution. $ZnSO_4$(aq) is a colourless solution. $FeSO_4$(aq) is a green solution.

Chemical equation

$$Cu(s) + 2H_2SO_4(aq) \rightarrow CuSO_4(aq) + SO_2(g) + 2H_2O(l)$$
$$Zn(s) + 2H_2SO_4(aq) \rightarrow ZnSO_4(aq) + SO_2(g) + 2H_2O(l)$$
$$Fe(s) + 2H_2SO_4(aq) \rightarrow FeSO_4(aq) + SO_2(g) + 2H_2O(l)$$

Experiment II

Put about 2cm3 of Concentrated sulphuric (VI) acid into two separate boiling tubes. Place a thin moist/damp/wet filter paper dipped in acidified potassium dichromate (VI)solution on the mouth of the boiling tube.
Put about 0.5g of powdered charcoal and sulphur powder to each boiling tube separately.
Warm.

Observation;

Black solid charcoal dissolves/decrease
Yellow solid sulphur dissolves/decrease

Colourless gas produced that has a pungent irritating choking smell.
Gas produced turn orange moist/damp/wet filter paper dipped in acidified potassium dichromate (VI)solution to green.

Explanation

Concentrated sulphuric (VI) acid is strong oxidizing agent. It oxidizes non-metals to non metallic oxides and itself reduced to sulphur(IV)oxide gas. Sulphur (IV) oxide gas turn orange moist/damp/wet filter paper dipped in acidified potassium dichromate (VI)solution to green.
Charcoal is oxidized to carbon(IV)oxide. Sulphur is oxidized to Sulphur(IV)oxide .

Chemical equation

$C(s) + 2H_2SO_4(aq) \rightarrow CO_2(aq) + 2SO_2(g) + 2H_2O(l)$

$S(s) + 2H_2SO_4(aq) \rightarrow 3SO_2(g) + 2H_2O(l)$

III. As the least volatile acid

Study the table below showing a comparison in boiling points of the three mineral acids

Mineral acid	Relative molecula mass	Boiling point(^oC)
Hydrochloric acid(HCl)	36.5	35.0
Nitric(V)acid(HNO_3)	63.0	83.0
Sulphuric(VI)acid(H_2SO_4)	98.0	333

1.Which is the least volatile acid? Explain

Sulphuric(VI)acid(H_2SO_4) because it has the largest molecule and joined by Hydrogen bonds making it to have the highest boiling point/least volatile.

2. Using chemical equations, explain how sulphuric(VI)acid displaces the less volatile mineral acids.

(i)Chemical equation

$KNO_3(s) + H_2SO_4(aq) \rightarrow KHSO_4(l) + HNO_3(g)$

$NaNO_3(s) + H_2SO_4(aq) \rightarrow NaHSO_4(l) + HNO_3(g)$

This reaction is used in the school laboratory preparation of Nitric(V) acid (HNO_3).

(ii)Chemical equation

$KCl(s) + H_2SO_4(aq) \rightarrow KHSO_4(s) + HCl(g)$

$NaCl(s) + H_2SO_4(aq) \rightarrow NaHSO_4(s) + HCl(g)$

This reaction is used in the school laboratory **preparation** of Hydrochloric acid (HCl).

(d) Properties of dilute sulphuric(VI)acid.

Dilute sulphuric(VI)acid is made when about 10cm3 of concentrated sulphuric (VI) acid is carefully added to about 90cm3 of distilled water.

Diluting concentrated sulphuric (VI) acid should be done carefully because the reaction is highly exothermic.

Diluting concentrated sulphuric (VI) acid decreases the number of moles present in a given volume of solution which makes the acid less corrosive.

On diluting concentrated sulphuric(VI) acid, water ionizes /dissociates the acid fully/wholly into two(**dibasic**)free H^+(aq) and SO_4^{2-}(aq)ions:

$$H_2SO_4\,(aq) \rightarrow 2H^+(aq) + SO_4^{2-}(aq)$$

The presence of free H^+(aq)ions is responsible for ;

(**i**)turn litmus red because of the presence of free H^+(aq)ions

(ii)have pH 1/2/3 because of the presence of many free H^+(aq)ions hence a strongly acidic solution.

(iii)Reaction with metals

Experiment:

Place 5cm3 of 0.2M dilute sulphuric(VI)acid into four separate clean test tubes. Add about 0.1g of Magnesium ribbon to one test tube. Cover the mixture with a finger as stopper. Introduce a burning splint on top of the finger and release the finger “stopper”. Repeat by adding Zinc, Copper and Iron instead of the Magnesium ribbon.

Observation:

No effervescence/ bubbles/ fizzing with copper

Effervescence/ bubbles/ fizzing with Iron ,Zinc and Magnesium

Colourless gas produced that extinguishes burning splint with a “pop” sound.

Colourless solution formed with Zinc and Magnesium.

Green solution formed with Iron

Explanation:

When a metal higher than hydrogen in the reactivity/electrochemical series is put in a test tube containing dilute sulphuric(VI)acid, effervescence/ bubbling/ fizzing takes place with evolution of Hydrogen gas.

Impure hydrogen gas extinguishes burning splint with a “pop” sound.

A sulphate (VI) salts is formed. Iron, Zinc and Magnesium are higher than hydrogen in the reactivity/electrochemical series.

They form Iron (II)sulphate(VI), Magnesium sulphate(VI) and Zinc sulphate(VI).

. When a metal lower than hydrogen in the reactivity/electrochemical series is put in a test tube containing dilute sulphuric(VI)acid, there is no effervescence/ bubbling/ fizzing that take place.

Copper thus do not react with dilute sulphuric(VI)acid.

Chemical/ionic equation

$$Mg(s) + H_2SO_4(aq) \text{ --> } MgSO_4(aq) + H_2(g)$$
$$Mg(s) + 2H^+(aq) \text{ --> } Mg^{2+}(aq) + H_2(g)$$

$$Zn(s) + H_2SO_4(aq) \text{ --> } ZnSO_4(aq) + H_2(g)$$
$$Zn(s) + 2H^+(aq) \text{ --> } Zn^{2+}(aq) + H_2(g)$$

$$Fe(s) + H_2SO_4(aq) \text{ --> } FeSO_4(aq) + H_2(g)$$
$$Fe(s) + H^+(aq) \text{ --> } Fe^{2+}(aq) + H_2(g)$$

NB:(i) Calcium,Lead and Barium forms insoluble sulphate(VI)salts that cover/coat the unreacted metals.

(ii)Sodium and Potassium react explosively with dilute sulphuric(VI)acid

(iv)Reaction with metal carbonates and hydrogen carbonates

Experiment:

Place 5cm3 of 0.2M dilute sulphuric(VI)acid into four separate clean boiling tubes. Add about 0.1g of sodium carbonate to one boiling tube. Introduce a burning splint on top of the boiling tube. Repeat by adding Zinc carbonate, Copper (II)carbonate and Iron(II)Carbonate in place of the sodium hydrogen carbonate.

Observation:

Effervescence/ bubbles/ fizzing.
Colourless gas produced that extinguishes burning splint.
Colourless solution formed with Zinc carbonate, sodium hydrogen carbonate and sodium carbonate.
Green solution formed with Iron(II)Carbonate
Blue solution formed with Copper(II)Carbonate

Explanation:

When a metal carbonate or a hydrogen carbonates is put in a test tube containing dilute sulphuric(VI)acid, effervescence/ bubbling/ fizzing takes place with evolution of carbon(IV)oxide gas. carbon(IV)oxide gas extinguishes a burning splint and forms a white precipitate when bubbled in lime water.

A sulphate (VI) salts is formed.

Chemical/ionic equation

$$ZnCO_3(s) + H_2SO_4(aq) \text{ --> } ZnSO_4(aq) + H_2O(l) + CO_2(g)$$
$$ZnCO_3(s) + 2H^+(aq) \text{ --> } Zn^{2+}(aq) + H_2O(l) + CO_2(g)$$

$$CuCO_3(s) + H_2SO_4(aq) \text{ --> } CuSO_4(aq) + H_2O(l) + CO_2(g)$$
$$CuCO_3(s) + 2H^+(aq) \text{ --> } Cu^{2+}(aq) + H_2O(l) + CO_2(g)$$

$$FeCO_3(s) + H_2SO_4(aq) \text{ --> } FeSO_4(aq) + H_2O(l) + CO_2(g)$$

$FeCO_3(s) + 2H^+(aq) \dashrightarrow Fe^{2+}(aq) + H_2O(l) + CO_2(g)$

$2NaHCO_3(s) + H_2SO_4(aq) \dashrightarrow Na_2SO_4(aq) + 2H_2O(l) + 2CO_2(g)$
$NaHCO_3(s) + H^+(aq) \dashrightarrow Na^+(aq) + H_2O(l) + CO_2(g)$

$Na_2CO_3(s) + H_2SO_4(aq) \dashrightarrow Na_2SO_4(aq) + H_2O(l) + CO_2(g)$
$NaHCO_3(s) + H^+(aq) \dashrightarrow Na^+(aq) + H_2O(l) + CO_2(g)$

$(NH_4)_2CO_3(s) + H_2SO_4(aq) \dashrightarrow (NH_4)_2SO_4(aq) + H_2O(l) + CO_2(g)$
$(NH_4)_2CO_3(s) + H^+(aq) \dashrightarrow NH_4^+(aq) + H_2O(l) + CO_2(g)$

$2NH_4HCO_3(aq) + H_2SO_4(aq) \dashrightarrow (NH_4)_2SO_4(aq) + H_2O(l) + CO_2(g)$
$NH_4HCO_3(aq) + H^+(aq) \dashrightarrow NH_4^+(aq) + H_2O(l) + CO_2(g)$

NB:
Calcium, Lead and Barium carbonates forms insoluble sulphate(VI)salts that cover/coat the unreacted metals.

(**v**)Neutralization-reaction of metal oxides and alkalis/bases

Experiment I:

Place 5cm3 of 0.2M dilute sulphuric(VI)acid into four separate clean boiling tubes. Add about 0.1g of copper(II)oxide to one boiling tube. Stir. Repeat by adding Zinc oxide, calcium carbonate and Sodium (II)Oxide in place of the Copper(II)Oxide.

Observation:

Blue solution formed with Copper(II)Oxide
Colourless solution formed with other oxides

Explanation:

When a metal oxide is put in a test tube containing dilute sulphuric(VI)acid, the oxide dissolves forming a sulphate (VI) salt.

Chemical/ionic equation

$ZnO(s) + H_2SO_4(aq) \dashrightarrow ZnSO_4(aq) + H_2O(l)$
$ZnO(s) + 2H^+(aq) \dashrightarrow Zn^{2+}(aq) + H_2O(l)$

$CuO(s) + H_2SO_4(aq) \dashrightarrow CuSO_4(aq) + H_2O(l)$
$CuO(s) + 2H^+(aq) \dashrightarrow Cu^{2+}(aq) + H_2O(l)$

$MgO(s) + H_2SO_4(aq) \dashrightarrow MgSO_4(aq) + H_2O(l)$
$MgO(s) + 2H^+(aq) \dashrightarrow Mg^{2+}(aq) + H_2O(l)$

$Na_2O(s) + H_2SO_4(aq) \dashrightarrow Na_2SO_4(aq) + H_2O(l)$
$Na_2O(s) + 2H^+(aq) \dashrightarrow 2Na^+(aq) + H_2O(l)$

$K_2CO_3(s) + H_2SO_4(aq) \dashrightarrow K_2SO_4(aq) + H_2O(l)$

$K_2O(s)$ + $H^+(aq)$ --> $2K^+$ (aq) + $H_2O(l)$

NB:
Calcium, Lead and Barium oxides forms insoluble sulphate(VI)salts that cover/coat the unreacted metals oxides.

Experiment II:
Fill a burette wuth 0.1M dilute sulphuric(VI)acid. Pipette 20.0cm3 of 0.1Msodium hydroxide solution into a 250cm3 conical flask. Add three drops of phenolphthalein indicator.Titrate the acid to get a permanent colour change.Repeat with0.1M potassium hydroxide solution inplace of 0.1Msodium hydroxide solution
Observation:

Colour of phenolphthalein changes from pink to colourless at the end point.

Explanation
Like other (mineral) acids dilute sulphuric(VI)acid neutralizes bases/alkalis to a sulphate salt and water only.
Colour of the indicator used changes when a slight excess of acid is added to the base at the end point
Chemical equation:

$2NaOH(aq)$ + $H_2SO_4(aq)$ --> $Na_2SO_4(aq)$ + $H_2O(l)$
$OH^-(s)$ + $H^+(aq)$ --> $H_2O(l)$

$2KOH(aq)$ + $H_2SO_4(aq)$ --> $K_2SO_4(aq)$ + $H_2O(l)$
$OH^-(s)$ + $H^+(aq)$ --> $H_2O(l)$

$2NH_4OH(aq)$ + $H_2SO_4(aq)$ --> $(NH_4)_2SO_4(aq)$ + $H_2O(l)$
$OH^-(s)$ + $H^+(aq)$ --> $H_2O(l)$

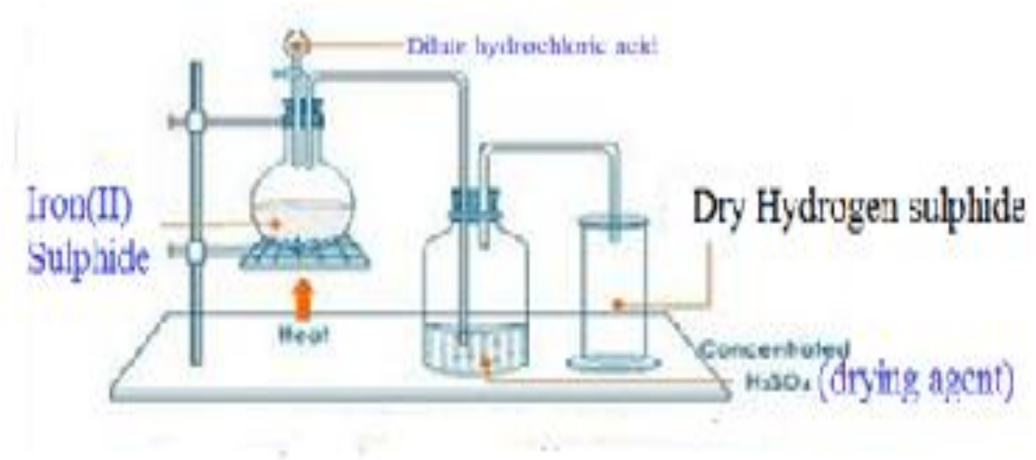
(iv) Hydrogen sulphide(H_2S)

(a) Occurrence

Hydrogen sulphide is found in volcanic areas as a gas or dissolved in water from geysers and hot springs in active volcanic areas of the world e.g. Olkaria and Hells gate near Naivasha in Kenya.
It is present in rotten eggs and human excreta.

(b) Preparation

Hydrogen sulphide is prepared in a school laboratory by heating Iron (II) sulphide with dilute hydrochloric acid.



(c) Properties of Hydrogen sulphide(Questions)

1. Write the equation for the reaction for the school laboratory preparation of Hydrogen sulphide.
Chemical equation: $FeS\ (s)\ +\ 2HCl\ (aq)\ \ ->\ H_2S\ (g)\ \ FeCl_2\ (aq)$

2. State three physical properties unique to Hydrogen sulphide.
Hydrogen sulphide is a colourless gas with characteristic pungent poisonous smell of rotten eggs. It is soluble in cold water but insoluble in warm water. It is denser than water and turns blue litmus paper red.

3. Hydrogen sulphide exist as a dibasic acid when dissolved in water. Using a chemical equation show how it ionizes in aqueous state.

$H_2S(aq) \rightarrow H^+(aq) + HS^-(aq)$

$H_2S(aq) \rightarrow 2H^+(aq) + S^{2-}(aq)$

Hydrogen sulphide therefore can form both normal and acid salts e.g
Sodium hydrogen sulphide and sodium sulphide both exist

4. State and explain one gaseous impurity likely to be present in the gas jar containing hydrogen sulphide above.

Hydrogen/ H_2
Iron(II)sulphide contains Iron as impurity .The iron will react with dilute hydrochloric acid to form iron(II)chloride and produce hydrogen gas that mixes with hydrogen sulphide gas.

5. State and explain the observations made when a filter paper dipped in Lead(II) ethanoate /Lead (II) nitrate(V) solution is put in a gas jar containing hydrogen sulphide gas.

Observations
Moist Lead(II) ethanoate /Lead (II) nitrate(V) paper turns black.

Explanation
When hydrogen sulphide is bubbled in a metallic salt solution, a metallic sulphide is formed.
All sulphides are insoluble black salts except sodium sulphide, potassium sulphide and ammonium sulphides.
Hydrogen sulphide gas blackens moist Lead (II) ethanoate /Lead (II) nitrate(V) paper .
The gas reacts with Pb^{2+} in the paper to form black Lead(II)sulphide.
This is the chemical test for the presence of H_2S other than the physical smell of rotten eggs.

Chemical equations

$Pb^{2+}(aq) + H_2S \rightarrow PbS\ (black) + 2H^+(aq)$

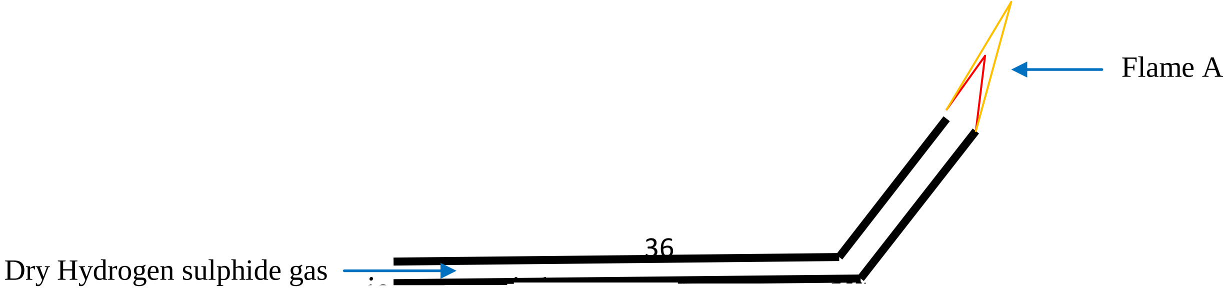
$Fe^{2+}(aq) + H_2S \rightarrow FeS\ (black) + 2H^+(aq)$

$Zn^{2+}(aq) + H_2S \rightarrow ZnS\ (black) + 2H^+(aq)$

$Cu^{2+}(aq) + H_2S \rightarrow CuS\ (black) + 2H^+(aq)$

$2Cu^{+}(aq) + H_2S \rightarrow Cu_2S\ (black) + 2H^+(aq)$

6. Dry hydrogen sulphide was ignited as below.



(i) State the observations made in flame A

Hydrogen sulphide burns in excess air with a blue flame to form sulphur(IV)oxide gas and water.
Chemical equation: $2H_2S(g) + 3O_2(g) \rightarrow 2H_2O(l) + 2SO_2(g)$

Hydrogen sulphide burns in limited air with a blue flame to form sulphur solid and water.
Chemical equation: $2H_2S(g) + O_2(g) \rightarrow 2H_2O(l) + 2S(s)$

7. Hydrogen sulphide is a strong reducing agent that is oxidized to yellow solid sulphur as precipitate. The following experiments illustrate the reducing properties of Hydrogen sulphide.

(a)Turns Orange acidified potassium dichromate(VI) to green

Experiment:

(i)Pass a stream of Hydrogen sulphide gas in a test tube containing acidified potassium dichromate (VI) solution. or;

(ii)Dip a filter paper soaked in acidified potassium dichromate (VI) into a gas jar containing Hydrogen sulphide gas.

Observation:
Orange acidified potassium dichromate (VI) turns to green.
Yellow solid residue.

Explanation:
Hydrogen sulphide gas reduces acidified potassium dichromate(VI) from orange $Cr_2O_7^{2-}$ ions to green Cr^{3+} ions leaving a yellow solid residue as itself is oxidized to sulphur.

Chemical/ionic equation:
$4H_2S(aq) + Cr_2O_7^{2-}(aq) + 6H+(aq) \rightarrow 4S(aq) + 2Cr^{3+}(aq) + 7H_2O(l)$

This test is used for differentiating Hydrogen sulphide and sulphur (IV)oxide gas.

Sulphur(IV)oxide also reduces acidified potassium dichromate(VI) from orange $Cr_2O_7^{2-}$ ions to green Cr^{3+} ions without leaving a yellow residue.

(b)Decolorizes acidified potassium manganate(VII)

Experiment:

(i)Pass a stream of Sulphur(IV) oxide gas in a test tube containing acidified potassium manganate(VII) solution. or;

(ii)Dip a filter paper soaked in acidified potassium manganate(VII) into a gas jar containing Hydrogen Sulphide gas.

Observation:
Purple acidified potassium manganate(VII) turns to colourless/ acidified potassium manganate(VII) is decolorized.
Yellow solid residue.

Explanation:
Hydrogen sulphide gas reduces acidified potassium manganate(VII) from purple MnO_4^- ions to green Mn^{2+} ions leaving a residue as the gas itself is oxidized to sulphur.
Chemical/ionic equation:

$$\underset{}{5H_2S(g)} + \underset{\text{(purple)}}{2MnO_4^-(aq)} + 6H+(aq) \rightarrow 5S(s) + \underset{\text{(colourless)}}{2Mn^{2+}(aq)} + 8H_2O(l)$$

This is another test for differentiating Hydrogen sulphide and Sulphur(IV) oxide gas.
Sulphur(IV) oxide also decolorizes acidified potassium manganate(VII) from purple MnO_4^- ions to colourless Mn^{2+} ions leaving no **yellow** residue.

(c)Decolorizes bromine water

Experiment:

(i)Pass a stream of Hydrogen sulphide gas in a test tube containing bromine water . or;

(ii)Put three drops of bromine water into a gas jar containing Hydrogen sulphide gas. Swirl.

Observation:
Yellow bromine water turns to colourless/ bromine water is decolorized.
Yellow solid residue

Explanation:
Hydrogen sulphide gas reduces yellow bromine water to colourless hydrobromic acid (HBr) leaving a yellow residue as the gas itself is oxidized to sulphur.

Chemical/ionic equation:

$$H_2S(g) + \underset{\text{(yellow solution)}}{Br_2(aq)} \rightarrow \underset{\text{(yellow solid)}}{S(s)} + \underset{\text{(colourless)}}{2HBr(aq)}$$

This is another test for differentiating Hydrogen sulphide and Sulphur(IV) oxide gas.

Sulphur(IV) oxide also decolorizes acidified potassium manganate(VII) from purple MnO_4^- ions to colourless Mn^{2+} ions leaving no yellow residue.

(d)Reduces Iron(III) Fe^{3+} salts to Iron(II) salts Fe^{2+}

Experiment:
(i)Pass a stream of Hydrogen sulphide gas in a test tube containing about 3 cm3 of Iron (III)chloride solution. or;

(ii)Place about 3cm3 of Iron (III)chloride solution into a gas jar containing Hydrogen sulphide gas. Swirl.

Observation:
Yellow/brown Iron (III)chloride solution turns to green.
Yellow solid solid

Explanation:
Hydrogen sulphide gas reduces Iron (III)chloride solution from yellow/brown Fe^{3+} ions to green Fe^{2+} ions leaving a yellow residue.The gas is itself oxidized to sulphur.

Chemical/ionic equation:

$$\underset{}{H_2S(aq)} + \underset{\text{(yellow solution)}}{2Fe^{3+}(aq)} \rightarrow \underset{\text{(yellow residue)}}{S(s)} + \underset{\text{(green)}}{Fe^{2+}(aq)} + 2H^+(aq)$$

(e)Reduces Nitric(V)acid to Nitrogen(IV)oxide gas

Experiment:

(i)Pass a stream of Hydrogen sulphide gas in a test tube containing about 3 cm3 of concentrated nitric(V)acid. or;

(ii)Place about 3cm3 of concentrated nitric(V)acid into a gas jar containing Hydrogen sulphide gas. Swirl.

Observation:
Brown fumes of a gas evolved/produced.
Yellow solid residue

Explanation:
Hydrogen sulphide gas reduces concentrated nitric(V)acid to brown nitrogen(IV)oxide gas itself oxidized to yellow sulphur.

Chemical/ionic equation:

$$H_2S(g) + 2HNO_3(l) \rightarrow 2H_2O(l) + \underset{\text{(yellow residue)}}{S(s)} + \underset{\text{(brown fumes)}}{2NO_2(g)}$$

(f)Reduces sulphuric(VI)acid to Sulphur

Experiment:

(i)Pass a stream of Hydrogen sulphide gas in a test tube containing about 3 cm3 of concentrated sulphuric(VI)acid. or;

(ii)Place about 3cm3 of concentrated sulphuric (VI) acid into a gas jar containing Hydrogen sulphide gas. Swirl.

Observation:
Yellow solid residue

Explanation:
Hydrogen sulphide gas reduces concentrated sulphuric(VI)acid to yellow sulphur.

Chemical/ionic equation:
$3H_2S(g) + H_2SO_4(l)$ -> $4H_2O(l)$ + $4S(s)$
(yellow residue)

(g)Reduces Hydrogen peroxide to water

Experiment:

(i)Pass a stream of Hydrogen sulphide gas in a test tube containing about 3 cm3 of 20 volume hydrogen peroxide.
Observation:
Yellow solid residue

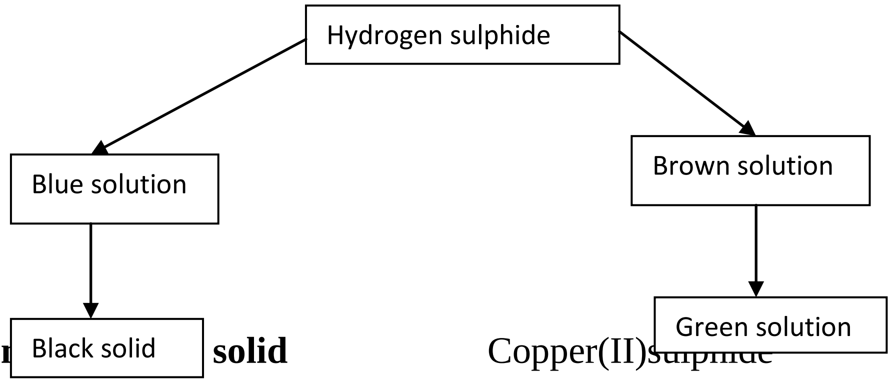
Explanation:
Hydrogen sulphide gas reduces 20 volume hydrogen peroxide to water and itself oxidized to yellow sulphur
Chemical/ionic equation:
$H_2S(g) + H_2O_2(l)$ -> $2H_2O(l)$ + $S(s)$
(yellow residue)

8.Name the salt formed when:
(i)equal volumes of equimolar hydrogen sulphide neutralizes sodium hydroxide solution:
Sodium hydrogen sulphide
Chemical/ionic equation:
$H_2S(g) + NaOH(l)$ -> $H_2O(l)$ + $NaHS(aq)$

(ii) hydrogen sulphide neutralizes excess concentrated sodium hydroxide solution:
Sodium sulphide
Chemical/ionic equation:
$H_2S(g) + 2NaOH(l)$ -> $2H_2O(l)$ + $Na_2S(aq)$

Practice

Hydrogen sulphide gas was bubbled into a solution of metallic nitrate(V)salts as in the flow chart below



(a)Na **solid** Copper(II)sulphide

(b)Identify the cation responsible for the formation of:

I. Blue solution	$Cu^{2+}(aq)$
II. Green solution	$Fe^{2+}(aq)$
III. Brown solution	$Fe^{3+}(aq)$

(c)Using acidified potassium dichromate(VI) describe how you would differentiate between sulphur(IV)Oxide and hydrogen sulphide

-Bubble the gases in separate test tubes containing acidified Potassium dichromate(VI) solution.

-Both changes the Orange colour of acidified Potassium dichromate(VI) solution to green.

-Yellow solid residue/deposit is formed with Hydrogen sulphide

Chemical/ionic equation:

$4H_2S(aq) + Cr_2O_7^{2-}(aq) + 6H+(aq) \rightarrow 4S(aq) + 2Cr^{3+}(aq) + 7H_2O(l)$

$3SO_3^{2-}(aq) + Cr_2O_7^{2-}(aq) + 8H+(aq) \rightarrow 3SO_4^{2-}(aq) + 2Cr^{3+}(aq) + 4H_2O(l)$

(d)State and explain the observations made if a burning splint is introduced at the mouth of a hydrogen sulphide generator.

ObservationGas continues burning with a blue flame

Explanation: Hydrogen sulphide burns in excess air with a blue flame to form sulphur(IV)oxide gas and water.

Chemical equation: $2H_2S(g) + 3O_2(g) \rightarrow 2H_2O(l) + 2SO_2(g)$

(v)Sulphate (VI) (SO_4^{2-})and Sulphate(IV) (SO_3^{2-}) salts

1. Sulphate (VI) (SO_4^{2-}) salts are normal and acid salts derived from Sulphuric (VI)acid H_2SO_4.
2. Sulphate(IV) (SO_3^{2-}) salts are normal and acid salts derived from Sulphuric (IV)acid H_2SO_3.
3. Sulphuric (VI)acid H_2SO_4 is formed when sulphur(VI)oxide gas is bubbled in water.

The acid exist as a dibasic acid with two ionisable hydrogen. It forms therefore the Sulphate (VI) (SO_4^{2-}) and hydrogen sulphate (VI) (HSO_4^-) salts.
i.e.

$$H_2SO_4 (aq) \rightarrow 2H^+(aq) + SO_4^{2-}(aq)$$
$$H_2SO_4 (aq) \rightarrow H^+(aq) + HSO_4^-(aq)$$

All Sulphate (VI) (SO_4^{2-}) salts **dissolve** in water/are soluble except Calcium (II) sulphate (VI) ($CaSO_4$), Barium (II) sulphate (VI) ($BaSO_4$) and Lead (II) sulphate (VI) ($PbSO_4$)
All Hydrogen sulphate (VI) (HSO_3^-) salts **exist** in solution/dissolved in water. Sodium (I) hydrogen sulphate (VI) ($NaHSO_4$), Potassium (I) hydrogen sulphate (VI) ($KHSO_4$) and Ammonium hydrogen sulphate (VI) (NH_4HSO_4) exist also as solids.
Other Hydrogen sulphate (VI) (HSO_4^-) salts do not **exist** except those of Calcium (II) hydrogen sulphate (VI) ($Ca (HSO_4)_2$) and Magnesium (II) hydrogen sulphate (VI) ($Mg (HSO_4)_2$).

4. Sulphuric (IV)acid H_2SO_3 is formed when sulphur(IV)oxide gas is bubbled in water.

The acid exist as a dibasic acid with two ionisable hydrogen. It forms therefore the Sulphate (IV) (SO_3^{2-}) and hydrogen sulphate (VI) (HSO_4^-) salts.
i.e.

$$H_2SO_3 (aq) \rightarrow 2H^+(aq) + SO_3^{2-}(aq)$$
$$H_2SO_3 (aq) \rightarrow H^+(aq) + HSO_3^-(aq)$$

All Sulphate (IV) (SO_3^{2-}) salts **dissolve** in water/are soluble except Calcium (II) sulphate (IV) ($CaSO_3$), Barium (II) sulphate (IV) ($BaSO_3$) and Lead (II) sulphate (IV) ($PbSO_3$)
All Hydrogen sulphate (IV) (HSO_3^-) salts **exist** in solution/dissolved in water.
Sodium (I) hydrogen sulphate (IV) ($NaHSO_3$), Potassium (I) hydrogen sulphate (IV) ($KHSO_3$) and Ammonium hydrogen sulphate (IV) (NH_4HSO_3) exist also as solids.
Other Hydrogen sulphate (IV) (HSO_3^-) salts do not **exist** except those of Calcium (II) hydrogen sulphate (IV) ($Ca(HSO_3)_2$) and Magnesium (II) hydrogen sulphate (IV) ($Mg(HSO_3)_2$).

5.The following experiments show the effect of heat on sulphate(VI) (SO_4^{2-})and sulphate(IV) (SO_3^{2-}) salts:

Experiment:
In a clean dry test tube place separately about 1.0g of :
Zinc(II)sulphate (VI), Iron(II)sulphate(VI), Copper(II)sulphate(VI),Sodium (I) sulphate (VI), Sodium (I) sulphate (IV).Heat gently then strongly. Test any gases produced using litmus papers.

Observations:
-Colourless droplets of liquid forms on the cooler parts of the test tube in all cases.
-White solid residue is left in case of Zinc (II)sulphate(VI),Sodium (I) sulphate (VI) and Sodium (I) sulphate (IV).
-Colour changes from green to brown /yellow in case of Iron (II)sulphate(VI)
-Colour changes from blue to white then black in case of Copper (II) sulphate (VI)
-Blue litmus paper remain and blue and red litmus paper remain red in case of Zinc(II)sulphate(VI), Sodium (I) sulphate (VI) and Sodium (I) sulphate (IV)
-Blue litmus paper turns red and red litmus paper remain red in case of Iron (II)sulphate(VI) and Copper (II) sulphate (VI).

Explanation
(i)All Sulphate (VI) (SO_4^{2-}) salts exist as **hydrated** salts with water of crystallization that condenses and collects on cooler parts of test tube as a colourless liquid on gentle heating. e.g.

$K_2SO_4.10H_2O(s)$ -> $K_2SO_4(s)$ + $10H_2O(l)$
$Na_2SO_4.10H_2O(s)$ -> $Na_2SO_4(s)$ + $10H_2O(l)$
$MgSO_4.7H_2O(s)$ -> $MgSO_4(s)$ + $7H_2O(l)$
$CaSO_4.7H_2O(s)$ -> $CaSO_4(s)$ + $7H_2O(l)$
$ZnSO_4.7H_2O(s)$ -> $ZnSO_4(s)$ + $7H_2O(l)$
$FeSO_4.7H_2O(s)$ -> $FeSO_4(s)$ + $7H_2O(l)$
$Al_2(SO_4)_3.6H_2O(s)$ -> $Al_2(SO_4)_3(s)$ + $6H_2O(l)$

$CuSO_4.5H_2O(s) \rightarrow CuSO_4(s) + 5H_2O(l)$

All Sulphate (VI) (SO_4^{2-}) salts do not decompose on heating **except** Iron (II) sulphate (VI) and Copper (II) sulphate (VI).

(i)Iron (II) sulphate (VI) decomposes on strong heating to produce acidic sulphur (IV)oxide and sulphur(VI)oxide gases. Iron(III)oxide is formed as a brown /yellow residue.

Chemical equation

$2FeSO_4(s) \rightarrow Fe_2O_3(s) + SO_2(g) + SO_3(g)$

This reaction is used for the school laboratory preparation of small amount of sulphur(VI)oxide gas.

Sulphur (VI) oxide readily /easily solidifies as white silky needles when the mixture is passed through freezing mixture/ice cold water.

Sulphur (IV) oxide does not.

(ii) Copper(II)sulphate(VI) decomposes on strong heating to black copper (II) oxide and Sulphur (VI) oxide gas.

Chemical equation

$2CuSO_4(s) \rightarrow CuO(s) + SO_3(g)$

This reaction is used for the school laboratory preparation of small amount of sulphur(VI)oxide gas.

6. The following experiments show the test for the presence of sulphate (VI) (SO_4^{2-})and sulphate(IV) (SO_3^{2-}) ions in a sample of a salt/compound:

Experiments/Observations:

(a)Using Lead(II)nitrate(V)

I. To about 5cm3 of a salt solution in a test tube add four drops of Lead(II)nitrate(V)solution. Preserve.

Observation	Inference
White precipitate/ppt	SO_4^{2-} , SO_3^{2-} , CO_3^{2-} , Cl^- ions

II. To the preserved sample in (I) above, add six drops of 2M nitric(V) acid . Preserve.

Observation 1

Observation	Inference
White precipitate/ppt persists	SO_4^{2-} , Cl^- ions

Observation 2

Observation	Inference
White precipitate/ppt dissolves	SO_3^{2-} , CO_3^{2-} , ions

III.(a)To the preserved sample observation 1 in (II) above, Heat to boil.

Observation 1

Observation	Inference
White precipitate/ppt persists on boiling	SO_4^{2-} ions

Observation 2

Observation	Inference
White precipitate/ppt dissolves on boiling	Cl^- ions

.(b)To the preserved sample observation 2 in (II) above, add 4 drops of acidified potassium manganate(VII) /dichromate(VI).

Observation 1

Observation	Inference
(i)acidified potassium manganate(VII)decolorized (ii)Orange colour of acidified potassium dichromate(VI) turns to green	SO_3^{2-} ions

Observation 2

Observation	Inference
(i)acidified potassium manganate(VII) not decolorized (ii)Orange colour of acidified potassium dichromate(VI) does not turns to green	CO_3^{2-} ions

Experiments/Observations:

(b)Using Barium(II)nitrate(V)/ Barium(II)chloride

I. To about 5cm3 of a salt solution in a test tube add four drops of Barium(II) nitrate (V) / Barium(II)chloride. Preserve.

Observation	Inference
White precipitate/ppt	SO_4^{2-} , SO_3^{2-} , CO_3^{2-} ions

II. To the preserved sample in (I) above, add six drops of 2M nitric(V) acid . Preserve.

Observation 1

Observation	Inference
White precipitate/ppt persists	SO_4^{2-} , ions

Observation 2

Observation	Inference
White precipitate/ppt dissolves	SO_3^{2-} , CO_3^{2-} , ions

III.To the preserved sample observation 2 in (II) above, add 4 drops of acidified potassium manganate(VII) /dichromate(VI).

Observation 1

Observation	Inference
(i)acidified potassium manganate(VII)decolorized (ii)Orange colour of acidified potassium dichromate(VI) turns to green	SO_3^{2-} ions

Observation 2

Observation	Inference
(i)acidified potassium manganate(VII) not decolorized (ii)Orange colour of acidified potassium dichromate(VI) does not turns to green	CO_3^{2-} ions

Explanations

Using Lead(II)nitrate(V)

(i)Lead(II)nitrate(V) solution reacts with chlorides(Cl^-), Sulphate (VI) salts (SO_4^{2-}), Sulphate (IV)salts (SO_3^{2-}) and carbonates(CO_3^{2-}) to form the insoluble white precipitate of Lead(II)chloride, Lead(II)sulphate(VI), Lead(II) sulphate (IV) and Lead(II)carbonate(IV).

Chemical/ionic equation:

$$Pb^{2+}(aq) \quad + \quad Cl^-(aq) \quad -> \quad PbCl_2(s)$$
$$Pb^{2+}(aq) \quad + \quad SO_4^{2+}(aq) \quad -> \quad PbSO_4(s)$$
$$Pb^{2+}(aq) \quad + \quad SO_3^{2+}(aq) \quad -> \quad PbSO_3(s)$$
$$Pb^{2+}(aq) \quad + \quad CO_3^{2+}(aq) \quad -> \quad PbCO_3(s)$$

(ii)When the insoluble precipitates are acidified with nitric(V) acid,

- Lead(II)chloride and Lead(II)sulphate(VI) do not react with the acid and thus their white precipitates remain/ persists.

- Lead(II) sulphate (IV) and Lead(II)carbonate(IV) reacts with the acid to form **soluble** Lead(II) nitrate (V) and produce/effervesces/fizzes/bubbles out **sulphur(IV)oxide** and **carbon(IV)oxide** gases respectively.

. Chemical/ionic equation:

$PbSO_3(s) + 2H^+(aq) \rightarrow H_2O(l) + Pb^{2+}(aq) + SO_2(g)$

$PbCO_3(s) + 2H^+(aq) \rightarrow H_2O(l) + Pb^{2+}(aq) + CO_2(g)$

(iii)When Lead(II)chloride and Lead(II)sulphate(VI) are heated/warmed;

- Lead(II)chloride dissolves in hot water/on boiling(recrystallizes on cooling)

- Lead(II)sulphate(VI) do not dissolve in hot water thus its white precipitate persists/remains on heating/boiling.

(iv)When sulphur(IV)oxide and carbon(IV)oxide gases are produced;

- **sulphur(IV)oxide** will decolorize acidified potassium manganate(VII) and / or Orange colour of acidified potassium dichromate(VI) will turns to green. **Carbon(IV)oxide will not.**

Chemical equation:

$5SO_3^{2-}(aq) + \underset{(purple)}{2MnO_4^-(aq)} + 6H^+(aq) \rightarrow 5SO_4^{2-}(aq) + \underset{(colourless)}{2Mn^{2+}(aq)} + 3H_2O(l)$

$3SO_3^{2-}(aq) + \underset{(Orange)}{Cr_2O_7^{2-}(aq)} + 8H^+(aq) \rightarrow 3SO_4^{2-}(aq) + \underset{(green)}{2Cr^{3+}(aq)} + 4H_2O(l)$

- **Carbon(IV)oxide** forms an insoluble white precipitate of calcium carbonate if three drops of lime water are added into the reaction test tube when effervescence is taking place. **Sulphur(IV)oxide will not.**

Chemical equation:

$Ca(OH)_2(aq) + CO_2(g) \rightarrow CaCO_3(s) + H_2O(l)$

These tests should be done immediately after acidifying to ensure the gases produced react with the oxidizing agents/lime water.

Using Barium(II)nitrate(V)/ Barium(II)Chloride

(i)Barium(II)nitrate(V) and/ or Barium(II)chlo**ride** solution reacts with Sulphate (VI) salts (SO_4^{2-}), Sulphate (IV)salts (SO_3^{2-}) and carbonates(CO_3^{2-}) to form the insoluble white precipitate of Barium(II)sulphate(VI), Barium(II) sulphate (IV) and Barium(II)carbonate(IV).

Chemical/ionic equation:

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

$Ba^{2+}(aq) + SO_3^{2+}(aq) \rightarrow BaSO_3(s)$

$Ba^{2+}(aq) + CO_3^{2+}(aq) \rightarrow BaCO_3(s)$

(ii)When the insoluble precipitates are acidified with nitric(V) acid,

- Barium (II)sulphate(VI) do not react with the acid and thus its white precipitates remain/ persists.

- Barium(II) sulphate (IV) and Barium(II)carbonate(IV) reacts with the acid to form **soluble** Barium(II) nitrate (V) and produce /effervesces /fizzes/ bubbles out **sulphur(IV)oxide** and **carbon(IV)oxide** gases respectively.

. Chemical/ionic equation:

$BaSO_3(s) + 2H^+(aq) \rightarrow H_2O(l) + Ba^{2+}(aq) + SO_2(g)$

$BaCO_3(s) + 2H^+(aq) \rightarrow H_2O(l) + Ba^{2+}(aq) + CO_2(g)$

(iii) When sulphur(IV)oxide and carbon(IV)oxide gases are produced;

- **sulphur(IV)oxide** will decolorize acidified potassium manganate(VII) and / or Orange colour of acidified potassium dichromate(VI) will turns to green. **Carbon(IV)oxide will not.**

Chemical equation:

$5SO_3^{2-}(aq) + 2MnO_4^-(aq) + 6H+(aq) \rightarrow 5SO_4^{2-}(aq) + 2Mn^{2+}(aq) + 3H_2O(l)$
(purple) (colourless)

$3SO_3^{2-}(aq) + Cr_2O_7^{2-}(aq) + 8H+(aq) \rightarrow 3SO_4^{2-}(aq) + 2Cr^{3+}(aq) + 4H_2O(l)$
(Orange) (green)

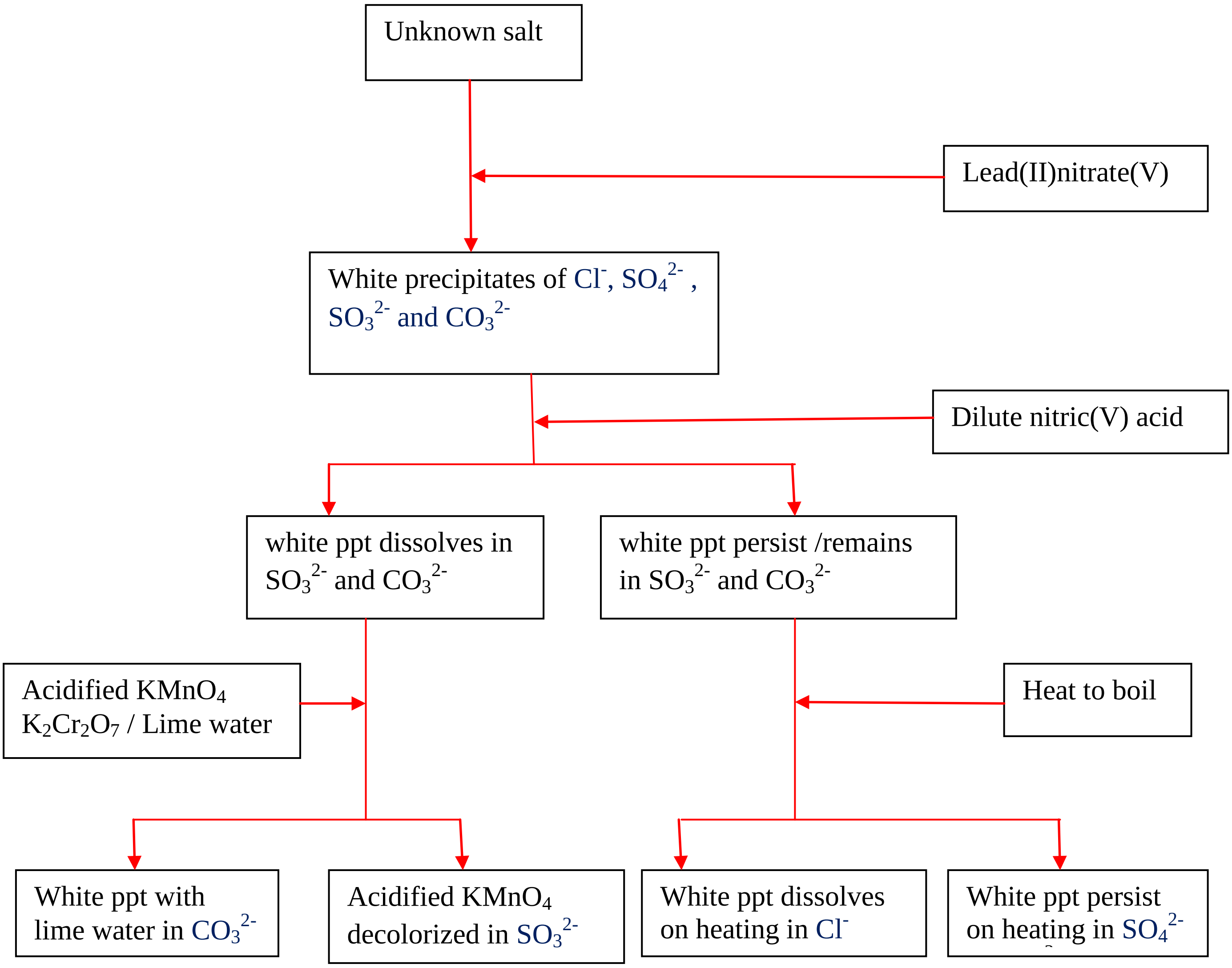
- **Carbon(IV)oxide** forms an insoluble white precipitate of calcium carbonate if three drops of lime water are added into the reaction test tube when effervescence is taking place. **Sulphur(IV)oxide will not.**

Chemical equation:

$Ca(OH)_2(aq) + CO_2(g) \rightarrow CaCO_3(s) + H_2O(l)$

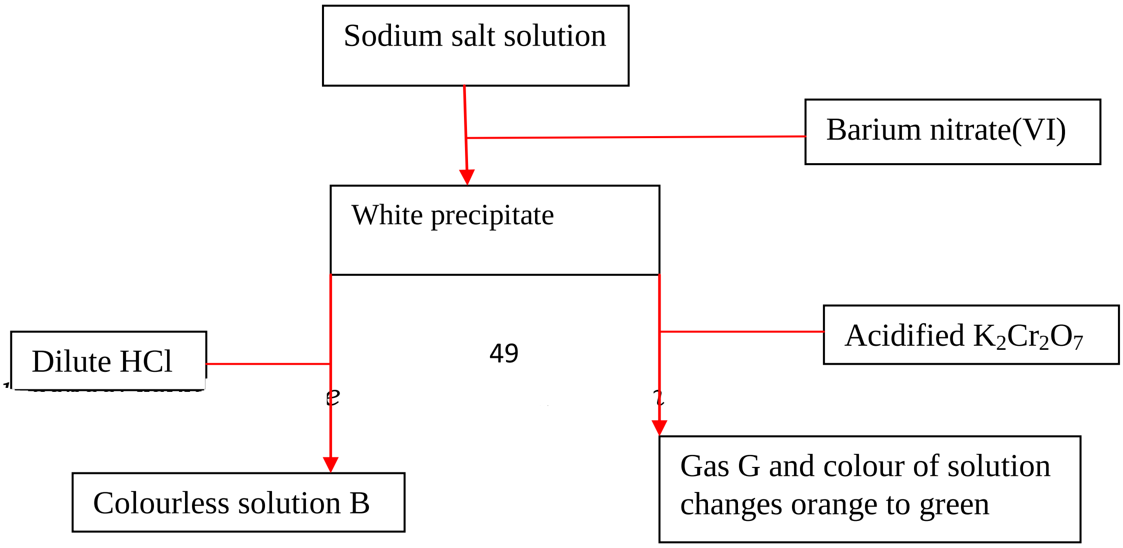
These tests should be done immediately after acidifying to ensure the gases produced react with the oxidizing agents/lime water.

Summary test for Sulphate (VI) (SO_4^{2-})and Sulphate(IV) (SO_3^{2-}) salts



Practice revision question

1. Study the flow chart below and use it to answer the questions that follow



(a)**Identify the:**

I: Sodium salt solution

Sodium sulphate(IV)/Na_2SO_3

II: White precipitate

Barium sulphate(IV)/$BaSO_3$

III: Gas G

Sulphur (IV)Oxide /SO_2

IV: Colourless solution H

Barium chloride /$BaCl_2$

(b)**Write an ionic equation for the formation of:**

I.White precipitate

Ionic equation $Ba^{2+}(aq) + SO_3^{2-}(aq) \rightarrow BaSO_3(s)$

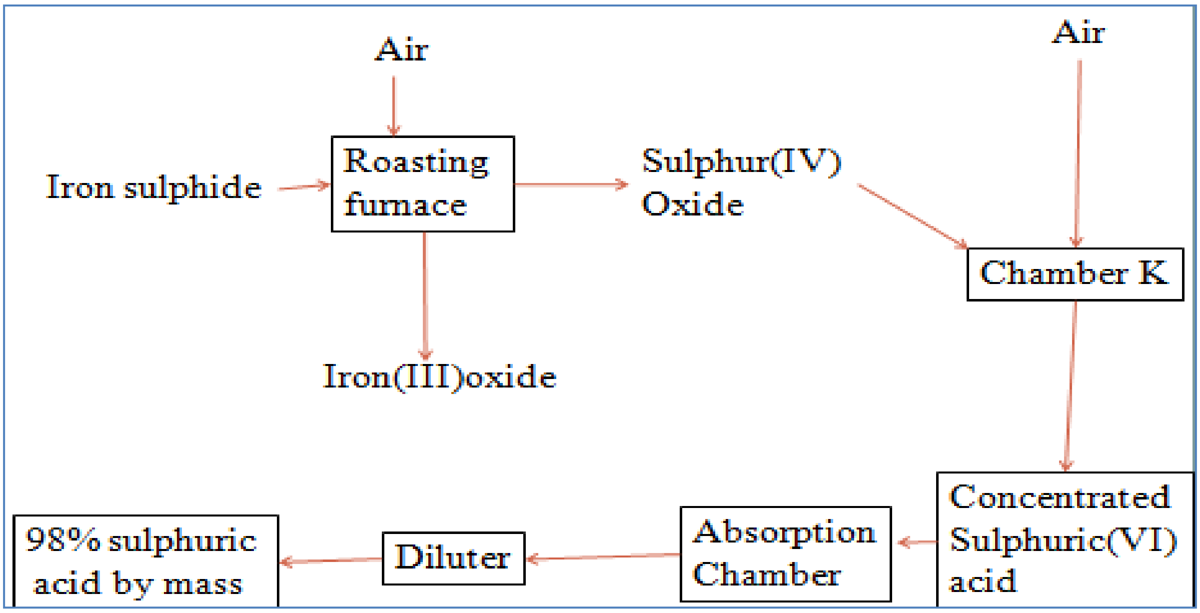
II.Gas G

Ionic equation $BaSO_3(s) + 2H^+(aq) \rightarrow SO_2(g) + H_2O(l) + Ba^{2+}(aq)$

III. Green solution from the orange solution

$$\underset{\text{(Orange)}}{3SO_3^{2-}(aq) + Cr_2O_7^{2-}(aq)} + 8H+(aq) \rightarrow 3SO_4^{2-}(aq) + \underset{\text{(green)}}{2Cr^{3+}(aq)} + 4H_2O(l)$$

2. Study the flow chart below and answer the questions that follow.



(i)Write equation for the reaction taking place at:

I.The roasting furnace (1mk)

$2FeS_2\,(s) + 5O_2\,(g) \rightarrow 2FeO(s) + 4SO_2\,(g)$

II.The absorption tower (1mk)

$H_2SO_4\,(l) + SO_3\,(g) \rightarrow H_2S_2O_7(l)$

III.The diluter (1mk)

$H_2S_2O_7(l) + H_2O(l) \rightarrow 2H_2SO_4\,(l)$

(ii)The reaction taking place in chamber K is

$$SO_{2\,(g)} + {}^{1}/_{2}O_{2\,(g)} \rightleftharpoons SO_{3\,(g)}$$

I. Explain why it is necessary to use excess air in chamber K

To ensure all the SO_2 reacts

II.Name another substance used in chamber K

Vanadium(V)oxide

3.(a)Describe a chemical test that can be used to differentiate between sodium sulphate (IV) and sodium sulphate (VI).

Add acidified Barium nitrate(V)/chloride.
White precipitate formed with sodium sulphate (VI)

No white precipitate formed with sodium sulphate (IV)

(b)Calculate the volume of sulphur (IV) oxide formed when 120 kg of copper is reacted with excess concentrated sulphuric(VI)acid.(Cu = 63.5 ,1 mole of a gas at s.t.p =22.4dm3)

Chemical equation

$Cu(s) + 2H_2SO_4(l) \rightarrow CuSO_4(aq) + H_2O(l) + SO_2(g)$

Mole ratio Cu(s: SO_2 (g) = 1:1

Method 1

1 Mole Cu =63.5 g -> 1 mole SO_2 = 22.4dm3

(120 x 1000) g -> $\frac{(120 \times 1000)\text{ g } \times 22.4\text{.dm3)}}{63.5\text{ g}}$

= **42330.7087**

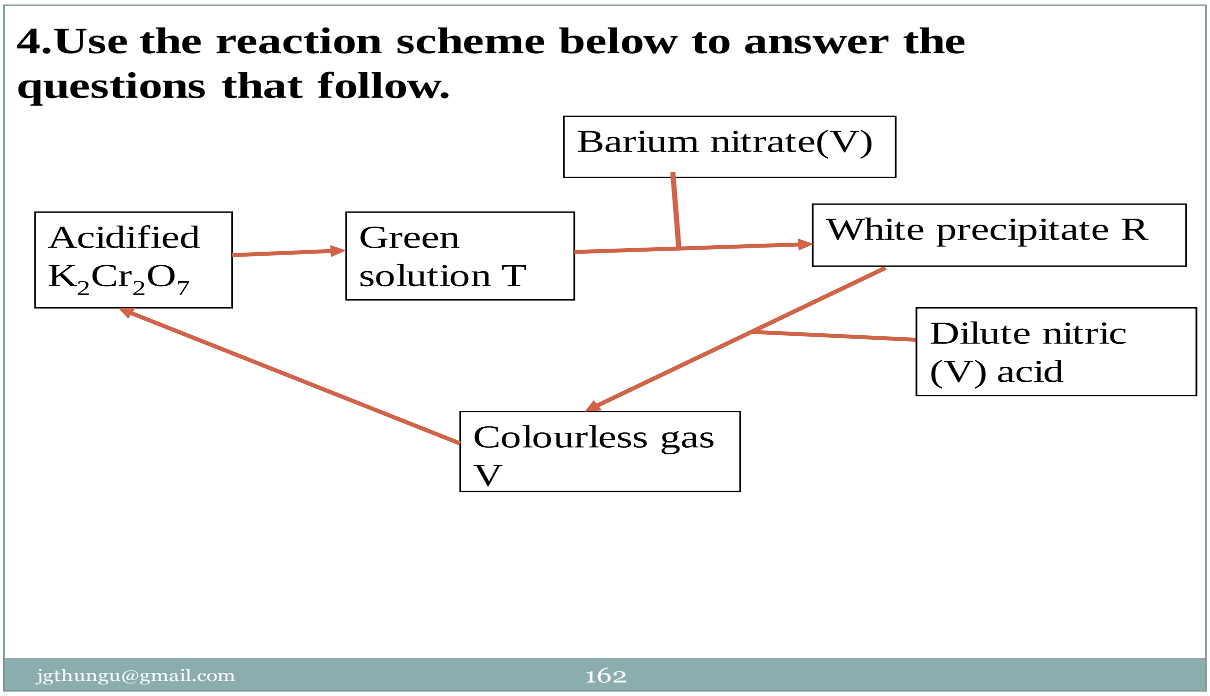
Method 2

Moles of Cu = $\frac{(120 \times 1000)\text{ g}}{63.5}$ =**1889.7639** moles

Moles SO_2 = Moles of Cu = **1889.7639** moles

Volume of SO_2 = Mole x molar gas volume = (1889.7639 moles x 22.4)

= **42330.7114**



4.Use the reaction scheme below to answer the questions that follow.

Barium nitrate(V)

Acidified $K_2Cr_2O_7$

Green solution T

White precipitate R

Dilute nitric (V) acid

Colourless gas V

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(a)Identify the:

(i)cation responsible for the green solution T

Cr^{3+}

(ii)possible anions present in white precipitate R

CO_3^{2-}, SO_3^{2-}, SO_4^{2-}

(b)Name gas V

Sulphur (IV)oxide

(c)Write a possible ionic equation for the formation of white precipitate R.

$Ba^{2+}(aq) + CO_3^{2-}(aq) \rightarrow BaCO_3(s)$

$Ba^{2+}(aq) + SO_3^{2-}(aq) \rightarrow BaSO_3(s)$

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

********************END*********************

- *Primary school schemes of work.*
- *Primary school revision papers to all classes.*
- *Marking schemes to primary school past papers.*
- *K.C.P.E past papers.*