Chapter 12

NITROGEN AND SULPHUR

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Student Learning Outcomes

After studying this chapter, students will be able to:

- Explain the lack of reactivity of nitrogen due to its triple bond strength and lack of polarity. **(Understanding)**
- Describe the basicity of ammonia using the Bronsted-Lowery theory. **(Understanding)**
- Identify the structure of the ammonium ion and explain how it is formed by an acid-base reaction. **(Understanding)**
- Describe how ammonia can be displaced from ammonium salts through an acid-base reaction. **(Understanding)**
- Describe natural and man-made occurrences of oxides of nitrogen and their catalytic removal from exhaust gases of internal combustion gases. **(Understanding)**
- Explain the role of NO and NO_2 in the formation of photochemical smog, specifically in the reaction with unburned hydrocarbons to form peroxyacetyl nitrate (PAN). **(Understanding)**
- Differentiate between nitrification and de-nitrification. **(Knowledge)**
- Explain the lack of reactivity of sulfur, with reference to its bonding and stability of its compounds. **(Understanding)**
- Describe the different oxidation states of sulfur and their relative stability. (Understanding)
- Describe the properties and uses of sulfuric acid, including its production and industrial applications. **(Understanding)**
- Describe the chemical reactions and processes involving sulfur, such as combustion and oxidation. **(Understanding)**
- Explain the uses of sulfur compounds in industry and everyday life, such as in fertilizers, gunpowder, and rubber, and in synthetic organic chemistry, including the synthesis of dyes, drugs, and fragrances. **(Understanding)**

NITROGEN

➢ **Occurrence:**

Nitrogen belongs to group 15 of the periodic table.

➢ **Preparation:**

(i) In industrial processes, nitrogen is typically obtained by cooling air until it becomes a liquid. Liquid nitrogen is commonly used for rapid cooling purposes.

(ii) In laboratory settings, nitrogen can be generated by slowly heating a solution of ammonium nitrite.

$$NH_4NO_{2(aq)} \xrightarrow{\Delta} N_{2(g)} + 2H_2O_{(l)}$$

Table: Physical Properties of Nitrogen ($_7N^{14}$)

Atomic number	7
Relative atomic mass	14.007 Da
Physical appearance	Colourless Gas
Electronic configuration	$[He]2s^2\ 2p^3$
Melting point	−210°C
Boiling point	−195.8°C
Covalent radius	74 pm

Ionic radius (3-)	171 pm
1st Ionization energy	1402 kJ/mol
Electronegativity	3.0
Electron affinity	−8.0 kJ/mol
Density	0.001145 g / cm^3
Principal oxidation states	3+ and 5+

REACTIVITY OF NITROGEN (N_2)

Reasons for Inertness of Nitrogen

Nitrogen is a significant component of the air, known for its low reactivity due to its small size, symmetrical electronic cloud, and nonpolar triple bond.

Rack Your Mind!

1. Summarize the reasons for inertness of nitrogen.

(i) High bond Energy

- Nitrogen has electronic configuration of $1s^2 2s^2 2p^3$.
- Nitrogen requires three electrons to complete its octet, forming a triple bond by sharing three electrons with another nitrogen atom (as shown in Figure). The bond has a bond enthalpy of +944 kJ mol^{-1}. High energy is required to break this bond to form new bonds, making N_2 very unreactive.

(ii) Non-Polar Nature of N_2

- N≡N is nonpolar.
- Both the atoms are the same having zero electronegativity difference. This causes equal sharing of the three bonded electrons between the two atoms making the bond nonpolar.

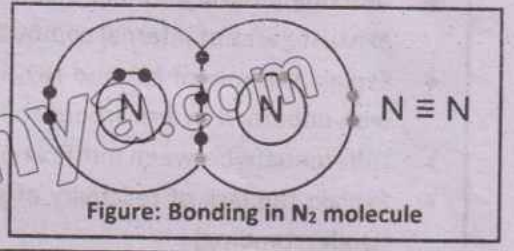


Figure: Bonding in N_2 molecule

Interesting Information!

Uses of Nitrogen:

(i) The high concentration of nitrogen in the air serves to dilute oxygen, preventing every spark in our atmosphere from igniting a massive fire.

(ii) In the case of large shipments of hydrocarbons or edible oils, it is crucial to utilize blankets of Nitrogen or any other inert gas on ships to safeguard them from oxygen and moisture.

(iii) It is also used in laboratory to carry out the reactions which require inert atmosphere.

AMMONIA (NH_3)

(Exercise L.Q.3)

Q. Explain the preparation and basicity of ammonia.

Preparation of Ammonia:

- Ammonia (NH_3) is an important industrial compound of nitrogen, which is mainly used as a fertilizer.
- Ammonia is prepared industrially by Haber-Bosch process.

$$N_{2(g)} + 3H_{2(g)} \overset{\Delta}{\rightleftharpoons} 2NH_{3(g)}$$

Q. Ammonia behaves as a Lowry-Bronsted base. Explain.

Basicity of Ammonia

Ammonia behaves as a Lowry-Bronsted base by accepting a proton (H^+) from an acid to form ammonium ion.

$$NH_{3(aq)} + H^{+1}{}_{(aq)} \rightleftharpoons NH_4^{1+}{}_{(aq)}$$

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Ammonia dissolves in water to form ammonium hydroxide (NH_4OH) and equilibrium is established between ammonia molecules and ammonium ions in the solution.

$$NH_{3(aq)} + H_2O_{(\ell)} \rightleftharpoons NH^{1+}_{4(aq)} + OH^{1-}_{(aq)} \qquad K_b = 1.8 \times 10^{-5}$$

Ammonia solution is a weak base due to the low basicity constant (K_b) and the equilibrium position being towards the far left side.

➲ Structure of Ammonium (NH_4^{1+})

Ammonia molecule has **pyramidal shape** due to lone pair of nitrogen. But when nitrogen atom in ammonia utilizes this lone pair of electrons to form ammonium ion, this ion adopts a **tetrahedral shape** in which all the bonds are of equal length and strength, (as depicted in Figure).

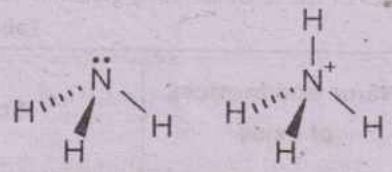


Figure: Pyramidal and tetrahedral shapes of ammonia and ammonium

➲ Synthesis of Ammonia from Ammonium Salts

Preparation of Ammonia

- **In Laboratory:**
  In the laboratory, ammonia gas can be synthesized by heating an ammonium salt such as ammonium chloride ($NH_4C\ell$) with a base like calcium hydroxide ($Ca(OH)_2$) as shown in Figure.

$$2NH_4C\ell_{(s)} + Ca(OH)_{2(aq)} \longrightarrow CaC\ell_{2(aq)} + 2H_2O_{(\ell)} + 2NH_{3(g)}$$

  In this acid-base reaction, NH_4^+ acts as an acid by donating H^+ ions, while OH^- acts as a base by accepting H^+ ions. This reaction displaces ammonia gas from the ammonium salt and produces salt and water.

- **Use in Salt Analysis:**
  It is commonly used to identify ammonium in salt analysis. If a gas with a pungent smell is released and turns moistened red litmus paper blue, it indicates the presence of ammonium in the compound.

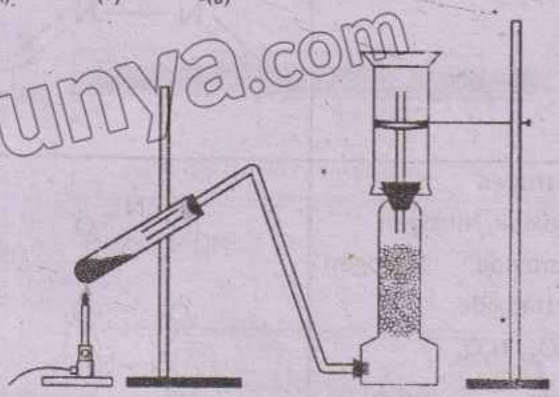


Figure: Synthesis of ammonia gas

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☑ QUICK CHECK 12.1

a) Why N_2 gas is used in food packaging?

Ans. N_2 gas is used in food packaging because it is inert and prevents oxidation and bacterial growth. By replacing oxygen (O_2) inside the package, N_2 slows down spoilage and keeps food fresh for longer. It is especially useful for snacks, chips, and ready-to-eat meals to maintain crispness and flavor.

b) Both CO and N_2 have triple bonds in their molecules. Why do you think CO is more reactive than N_2?

Ans. Although both CO and N_2 have triple bonds, CO is more reactive because:

- The bond is **slightly weaker** (bond energy 1072 kJ/mol as compared to bond energy of N_2 which is 946 kJ/mol).
- CO has a polar structure (C slightly positive, O slightly negative), making it more likely to react with other molecules compared to nonpolar N_2.

c) Ammonium salts such as $(NH_4)_2SO_4$ or $(NH_4)_2NO_3$ are commonly used as fertilizers. Why a farmer wouldn't treat a field with an ammonium fertilizer at the same time as using lime? What would be the chemical reactions?

Ans. Ammonium fertilizers like $(NH_4)_2SO_4$ react with lime ($Ca(OH)_2$ or CaO) to release ammonia gas (NH_3), reducing nitrogen content in the soil:

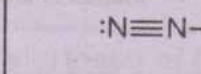
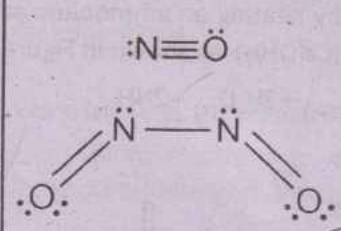
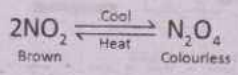
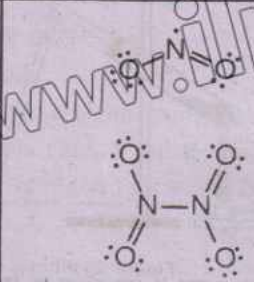
$$2NH_4^+ + Ca(OH)_2 \longrightarrow 2NH_3\uparrow + Ca^{2+} + 2H_2O$$

This reaction makes the fertilizer less effective and causes nitrogen loss, harming crop growth.

OXIDES OF NITROGEN

Oxides of nitrogen are NO, N_2O, NO_2, N_2O_4 and N_2O_5 in which oxidation states range from I+ to V+. N_2O_4 and N_2O_5 decay quickly to other oxides. NO and NO_2 are collectively called as NO_x. The structures, properties and uses of these oxides are given in Table.

Table: Properties of some common oxides of nitrogen

Name and formula of oxide	Structure	Formal oxidation state	Properties	Uses
Nitrous oxide/ Nitrogen oxide (Laughing gas) N_2O		1+	Colourless gas, water-soluble, neutral, sweet smelling, helps in combustion.	Dental anaesthetic, propellant for whipped ice cream, synthesis of NaN_3.
Nitic oxide, Nitrogen dioxide NO, N_2O_2		2+	Colourless gas, slightly water-soluble, neutral, NO is paramagnetic while N_2O_2 is diamagnetic, oxidizing as well as reducing in nature.	Biochemical messenger (Lowers blood pressure and role in other body functions), synthesis of nitrosyl carbonyls.
Nitrogen dioxide/Nitrogen peroxide, Nitrogen tetraoxide NO_2, N_2O_4 		4+	NO_2 is a reddish brown gas, paramagnetic, and reacts with water to form HNO_3 and HNO_2, N_2O_4 is colourless liquid or solid.	Rocket propellant, HNO_3 formation by Ostwald process, explosives.

Did You Know?

Name of Ammonia by IUPAC:
Another recommended name for ammonia by the International Union of Pure and Applied Chemistry (IUPAC) is **Azane** and for ammonium is **Azanium**. These names have been derived from Azote, a Greek name for nitrogen, meaning "no life". These names are used in naming derivatives of ammonia and ammonium e.g. sodium azide (NaN_3).

Rack Your Mind!

2. **Peroxy acetyl nitrate (PAN) is an irritant to human being and it effects:**
   A) Ears B) Stomach
   C) Eyes D) Nose

SOURCES OF OXIDES OF NITROGEN

The main categories of NO_x sources are:

➲ Natural Sources of NO_x

Natural sources include lightning, volcanoes, biological decay, forest fires, soil microorganisms, oceans, etc. NO is produced when N_2 and O_2 in the air react during lightning. It is produced by microorganism using air N_2.

➲ Anthropogenic (Man-made) Sources of NO_x

The main anthropogenic sources of NO_x are the combustion of fossil fuels in vehicles and power plants. Other sources include chemical plants, biomass burning, welding, etc.

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ROLE OF NO & NO_2 IN SMOG & PAN FORMATION

(Exercise L.Q.4)

Q. How oxides of nitrogen (NO_x) cause the formation of photochemical smog and PAN? Give its mechanism.

NO_x is responsible for numerous harmful effects on living organisms.

➲ Photochemical Smog

Photochemical smog (Los Angeles smog) forms in the atmosphere from NO_x and volatile organic compounds (VOCs) in the sunlight. It is oxidizing in nature. Photochemical oxidants, such as NO_2, ozone, and peroxyacyl nitrates (PANs) can react and oxidise specific compounds in the atmosphere. Photochemical smog is becoming more common than classical smog (London smog) due to increasing NO_x emissions.

Chemical Reactions:

The formation of photochemical smog involves the following chemical reactions.

$$N_{2(g)} + O_{2(g)} \longrightarrow 2NO_{(g)}$$

$$2NO_{(g)} + O_{2(g)} \longrightarrow 2NO_{2(g)}$$

$$NO_{2(g)} \xrightarrow{h\upsilon} NO_{(g)} + O_{(g)}$$

$$O_{(g)} + O_{2(g)} \longrightarrow O_{3(g)}$$

$$RCH=CHR_{(g)} + O_{3(g)} \longrightarrow RCO^{\bullet}_{3(g)} + RCH^{-}_{2(g)} \longrightarrow RC(O)OONO_2$$

Did You Know?

Lahore smog consists of volatile organic compounds (VOCs), NO_x, ground level ozone (O_3), particulate matter PM 2.5, CO and SO_2.

Rack Your Mind!

3. The yellow colour in photochemical smog is due to:
   A) NO B) NO_2
   C) N_2O D) N_2O_5

Alternate Reactions

$RCH=CHR + O_3 \longrightarrow 2RCHO + O_2$

$RCHO + OH^{\bullet} \longrightarrow RC(O)O^{\bullet} + H_2O$

$RC(O)O^{\bullet} + NO_2 \longrightarrow RC(O)OONO_2$

➲ Formation of Peroxyacyl Nitrates (PANs)

NO_x take part in a series of reactions leading to the formation of ozone (O_3), aldehydes, peroxyacyl nitrates (PANs) and peroxybenzoyl nitrate (PBN). PAN is one of the members of peroxyacyl nitrates as shown in Figure.

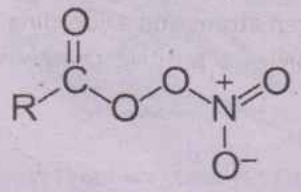


Figure: General structure of PANs

The R group in peroxyacetyl nitrate is $-CH_3$, but other hydrocarbon chains may also be present.

Rack Your Mind!

4. Mention the conditions which are required for the formation of smog?

Rack Your Mind!

5. Differentiate between oxidizing and reducing smog.

➢ Formation of PAN:

The main component of oxidizing smog is ozone, which oxidizes hydrocarbon to produce aldehyde. The aldehyde then reacts with hydroxyl radical to produce acyl radical. The acyl radical reacts with oxygen to produce peroxyacyl radical, which finally reacts with nitrogen peroxide to form peroxyacyl nitrate.

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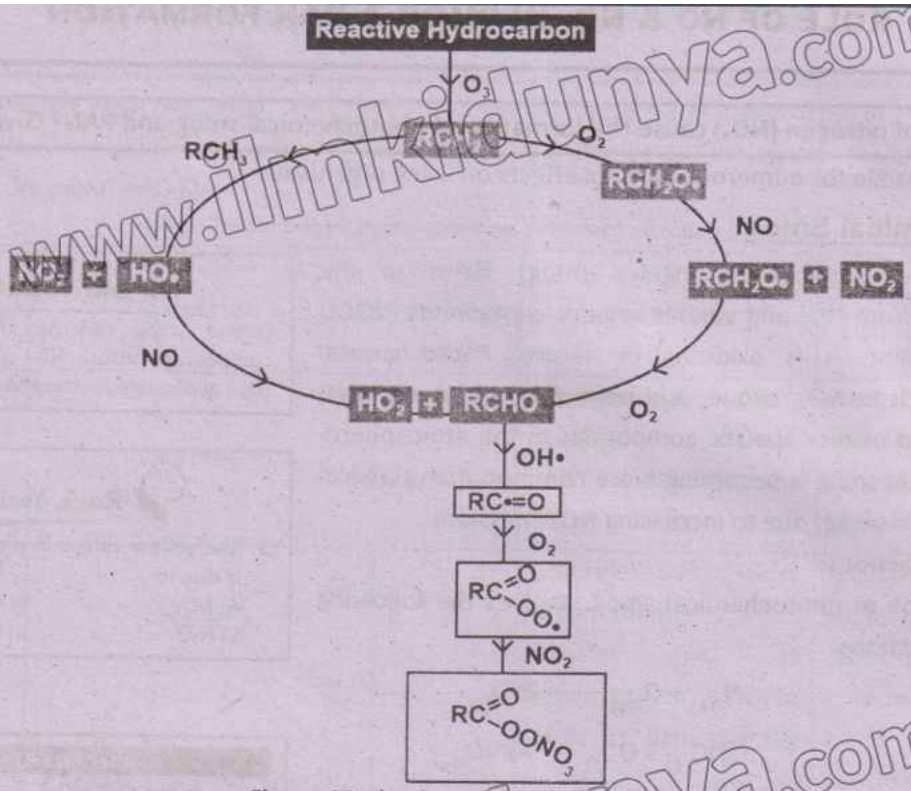


Figure: Mechanism of PAN formation

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☑ QUICK CHECK 12.2

a) Draw the structures of the following oxides of nitrogen. Also, briefly explain their bonding.
i) N_2O ii) NO iii) NO_2

Ans.

(i) N_2O (Nitrous oxide / Laughing gas)

Structure:

$$[N = N = O \longleftrightarrow N \equiv N - O]$$

Dinitrogen Oxide, N_2O (nitrous oxide)

Or $:N \equiv N^+ - O^-$ (linear molecule)

Bonding explanation:

- N_2O is linear, with a triple bond between the two nitrogen atoms and a coordinate bond to oxygen.
- It has resonance forms, and the terminal nitrogen carries a positive charge, while oxygen has a negative charge.

(ii) NO (Nitric oxide)

Structure:

$$:\ddot{N} = \ddot{O}:$$

Nitrogen Oxide, NO (nitric oxide)

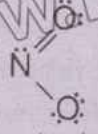
Or N = O• (linear with one unpaired electron)

Bonding explanation:

- NO is a diatomic, linear molecule with a double bond and one unpaired electron, making it a free radical.
- It is paramagnetic due to this lone unpaired electron.

(iii) NO_2 (Nitrogen dioxide)

Structure:



Nitrogen dioxide, NO_2 (nitrogen peroxide)

Or O = N – O• (bent molecule, 134°)

Bonding Explanation:

- NO_2 is angular (bent) and also a free radical with one unpaired electron. It has resonance structures and is paramagnetic due to the unpaired electron.

b) What does PAN stand for? Give its general formula.

Ans.

- PAN stands for Peroxyacetyl Nitrate. It is a toxic compound found in photochemical smog.
- Its general formula is $CH_3C(O)OONO_2$. It irritates eyes and affects plants and human health.

c) Write down the formulas of the compounds responsible for the formation of PAN.

Ans. PAN is formed from the reaction of the following compounds:

- Hydrocarbons (RH) $\rightarrow$ R – CHO (aldehydes)
- Nitrogen oxides (NO and NO_2)
- Oxygen (O_2) and sunlight

These react to form peroxyacyl radicals and then PAN.

d) If magnesium ribbon is ignited and placed in a jar containing N_2O, it continues to burn brightly, how does the product form in this reaction confirm the structure of N_2O?

Ans. When magnesium burns in N_2O, it produces magnesium oxide (MgO) and nitrogen gas (N_2). This reaction proves N_2O contains oxygen, as the flame is sustained by O release, confirming its structure $N \equiv N^+ - O^-$.

CATALYTIC CONVERTER

- A catalytic converter is a ceramic or metallic monolith with a honeycomb-like structure (as shown in Figure).
- Its inner channels have a layer of alumina to provide a high surface area.
- Noble precious (expensive) metals such as Pt (Platinum), Pd (Palladium), and Rh (Rhodium) are dispersed on the alumina.
- These metals catalyze three redox reactions to remove the half harmful exhaust gases.
- The three-way converter converts harmful CO, NO, and hydrocarbons into CO_2, N_2, and water.
- These precious metals can also be recycled.

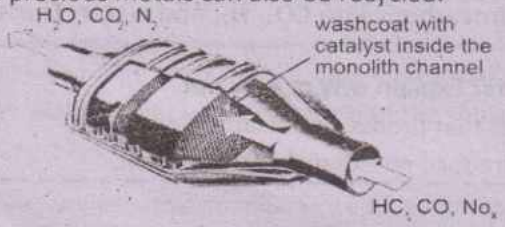


Figure: Three-way Catalytic Converter

Reduction: $2NO_{(g)} + 2CO_{(g)} \xrightarrow{Pt/Rd} N_{2(g)} + 2CO_{2(g)}$

Oxidation: $2CO_{(g)} + O_{2(g)} \xrightarrow{Pt/Rh} 2CO_{2(g)}$

$2C_2H_4 + 6O_{2(g)} \xrightarrow{Pt/Rd} 4CO_{2(g)} + 4H_2O_{(g)}$

Rack Your Mind!

6. What is the primary function of a catalytic converter in an automobile?

A) Increase engine
B) Improve fuel efficiency
C) Reduce harmful emissions
D) Enhance vehicle speed

Rack Your Mind!

7. What is catalytic convertor?

Rack Your Mind!

8. Which of the following gases are primarily reduced or oxidized by a catalytic converter?

A) Carbon dioxide, oxygen, and nitrogen
B) Methane, ammonia, and hydrogen
C) CO, nitrogen oxides, and hydrocarbons
D) Sulphur dioxide, ozone, and water vapour

NITRIFICATION AND DENITRIFICATION

- Nitrification and denitrification are the two phases of the nitrogen cycle.
- Nitrification involves the conversion of ammonium (NH_4^{1+}) to nitrite (NO_2^{1-}) and nitrate (NO_3^{1-}), while denitrification involves the conversion of nitrate (NO_3^{1-}) to Nitrogen (N_2).
- These two processes are also involved in the wastewater treatment to remove nitrogen. Some differences between nitrification and denitrification are given in Table.

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Table: Differences between Nitrification and Denitrification

Nitrification	Denitrification
In nitrification Ammonia ion (NH_4^{1+}) is converted into nitrite (NO_2^{1-}) and nitrate (NO_3^{1-}).	Nitrite (NO_2^{1-}) and nitrate (NO_3^{1-}) are converted back to N_2 that is released into the atmosphere.
Nitrifying bacteria aerobic conditions, pH 6.5 – 8.0, optimum temperature 20°C – 30°C.	Denitrifying bacteria anaerobic conditions, pH 7.0 – 9.0, optimum temperature 26°C – 38°C.
Plants absorb these nitrites and nitrates for their nutrition as they cannot assimilate nitrogen directly from the atmosphere.	It is important in wastewater treatment and useful for aquatic life, to oxidize NH_4^+ with NO_2^- to form N_2 gas.
Oxidation of nitrogen $NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$ $2NH_{4(aq)}^{1+} + 3O_{2(aq)} \rightarrow 2NO_{2(aq)}^{1-} + 4H_{(aq)}^+ + 2H_2O_{(\ell)}$ $2NO_{2(aq)}^{1-} + O_{2(aq)} \rightarrow 2NO_{3(aq)}^{1-}$	Reduction of nitrogen $NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$ $2NO_{3(aq)}^{1-} + 10e^- + 12H_{(aq)}^+ \rightarrow N_{2(g)} + 6H_2O_{(\ell)}$

☑ QUICK CHECK 12.3

a) Write down the reduction and oxidation reactions that occur in the catalytic converter in the vehicle exhausts.

Ans. These metals catalyze three redox reactions to remove the half harmful exhaust gases. The three-way converter converts harmful CO, NO, and hydrocarbons into CO_2, N_2, and water. These precious metals can also be recycled.

Reduction: $2NO_{(g)} + 2CO_{(g)} \longrightarrow N_{2(g)} + 2CO_{2(g)}$

Oxidation: $2CO_{(g)} + O_{2(g)} \xrightarrow{Pt/Rh} 2CO_{2(g)}$

$2CH_{4(g)} + 6O_{2(g)} \xrightarrow{Pt/Rd} 4CO_{2(g)} + 4H_2O_{(g)}$

b) What is the basic principle of catalytic converter? Describe the role of catalyst in the catalytic converter.

Ans. These metals catalyze three redox reactions to remove the half harmful exhaust gases. The three-way converter converts harmful CO, NO, and hydrocarbons into CO_2, N_2, and water. These precious metals can also be recycled.

c) Do hybrid and electric cars have catalytic converters? Explain why or why not.

Ans. Hybrids: Yes, because they still use gasoline engines that produce emissions.

Electric cars: No, since they run on batteries and produce no exhaust gases to treat.

SULPHUR

Sulphur is a member of group 16 which is also called the Chalcogen family. Some physical properties of sulphur are listed in Table.

Table: Physical properties of Sulphur

Atomic number	16	**Ionic radius**	184 pm
Relative atomic mass	32.06 a.m.u.	**1st Ionization energy**	1000 kJ/mol
Physical appearance	Solid Yellow	**Electronegativity**	2.5
Electronic configuration	[Ne]3 $s^2 3p^4$	**Electron affinity**	–200 kJ/mol
Melting point	113°C (honey yellow)	**Density**	2.07 g / cm^3
Boiling point	445°C (dark brown)	**Common oxidation states**	4+ and 6+
Covalent radius	104 pm	**Common Bonding**	Covalent bond

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➲ Reactivity of Sulphur

Sulphur usually forms single bonds with other sulphur atoms instead of double bonds due to poor overlapping of the orbitals. As a result, it forms larger molecules and structures through a process called catenation. S_8 is a crown-like molecule, as shown in Figure 12.7.

➲ Oxidation States of Sulphur

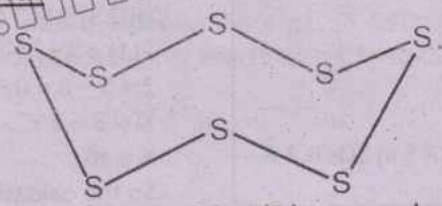


Figure: Cyclo-octasulphur, (S_8) crown molecule

Sulphur exhibits oxidation states of –2, 0, +2, +4, and +6. The electronic configuration of sulphur is depicted in Figure, where the oxidation state is determined by the number of unpaired electrons. Under standard conditions, sulphur and oxygen react to produce Sulphur dioxide (SO_2) in which sulphur has an oxidation state of +4. However, to form sulphur trioxide (SO_3) with an oxidation state of +6, high energy is required.

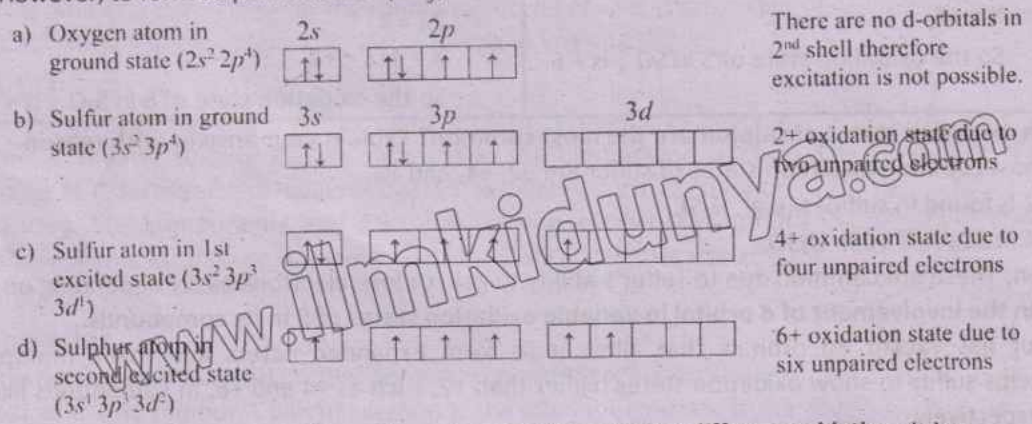


Figure: Electronic configurations of sulphur for attaining different oxidation states

STABILITY OF OXIDATION STATES OF SULPHUR

Sulphur displays a range of oxidation states, principally from -2 to +6. The stability of these states is influenced by the factors like pH, temperature, nature of the compound and the chemical environment.

➲ pH

In general, under acidic conditions, reduced forms (like H2S, -2 oxidation state) are more stable, while under basic or neutral conditions, oxidized forms (like SO_4^{2-}, +6 oxidation state) become more stable in water.

➲ Thermodynamics and Kinetics

Although Sulphur (+6), as in SO_3, is thermodynamically the most stable, kinetic limitations can prevent it from forming readily at standard temperatures, making Sulphur (+4), as in SO_2, the more frequent form.

➲ Nature of the Compound

The stability of Sulphur's oxidation state can be affected by the elements it is bonded to, and the overall chemical environment. In acidic environment SO_4^{2-} is kinetically stable due to strong O-S bonds.

➲ Catalyst

A catalyst can also enhance the rate of formation of a specific oxidation state, for example vanadium in the contact process increases the rate of formation of SO_3.

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QUICK CHECK 12.4

a) Determine the oxidation state of S in the following species.

i. SO_3 ii. H_2SO_4 iii. SO_4^{2-} iv. $S_2O_3^{2-}$

Ans.

(i) Oxidation state of SO_3

S(O.S) + O(O.S) = 0

X + 3(−2) = 0

X − 6 = 0

X = +6

So, the oxidation state of S in SO_3 is + 6.

(ii) Oxidation state of H_2SO_4

H(O.S) + S(O.S) + O(O.S) = 0

2(1) + X + 4(−2) = 0

2 + X − 8 = 0

X = 8 − 2

X = +6

So the oxidation state of S in H_2SO_4 is + 6.

(iii) Oxidation state of SO_4^{-2}

S(O.S) + O(O.S) = 0

X + 4(−2) = −2

X − 8 = −2

X = 8 − 2

X = +6

So the oxidation state of S in SO_4^{-2} is + 6.

(iv) Oxidation state of $S_2O_3^{-2}$

S(O.S) + O(O.S) = 0

2X + 3(−2) = −2

2X − 6 = −2

2X = 6 − 2

2x = 4

X = 4/2 = **+2**

So the oxidation state of S in $S_2O_3^{-2}$ is + 2.

b) Which oxidation states of sulphur are the most common? Explain your answer with reason.

Ans. The most common oxidation states of sulfur are −2, +4, and +6.

- −2 is found in sulfides (e.g., H_2S).
- +4 in SO_2 and +6 in H_2SO_4.

Reason: These are common due to sulfur's ability to gain or lose electrons easily depending on bonding.

c) Explain the involvement of d orbital in variable oxidation states of S in its compounds.

Ans. Sulphur has vacant 3d orbitals that allow it to form expanded octets and make multiple bonds. This helps sulfur to show oxidation states higher than +2, such as +4 and +6, in compounds like SO_2 and SO_3 respectively.

REACTIONS OF SULPHUR

Sulphur can combine with many elements to form a wide variety of inorganic and organic compounds. It is unreactive to water under normal conditions, dilute non-oxidizing acids, and noble gases. Its ability to catenate allows it to form ring structures and linear chains. Here are some important reactions of sulphur:

(i) Reaction with Air: Sulphur burns in the air to form SO_2 with a blue colour flame. The other main sulphur oxide is SO_3 which requires higher temperature and a catalyst for its formation.

$$S_{(s)} + O_{2(g)} \longrightarrow SO_{2(g)}$$

$$2SO_{2(g)} + O_{2(g)} \xrightarrow[Pt]{\Delta} 2SO_{3(g)}$$

(ii) Reaction with Nitric Acid: Sulphur can be oxidised by nitric acid to produce NO_2 and H_2SO_4.

$$S_{(s)} + 6HNO_{3(\ell)} \longrightarrow H_2SO_{4(\ell)} + 6NO_{2(g)} + 2H_2O_{(\ell)}$$

(iii) Reaction with Ion Electronegative Element: When sulphur reacts with elements that have lower electronegativity, it acts as an oxidizing agent and forms their sulfides. It tarnishes Ag, Cu, and Zn by forming a coating of metal sulfide. Sulphur does not react with Au and Pt.

$$2Ag_{(s)} + S_{(s)} \longrightarrow Ag_2S_{(s)}$$

$$Hg_{(\ell)} + S_{(s)} \longrightarrow HgS_{(s)}$$

$$2Cu_{(s)} + S_{(s)} \longrightarrow Cu_2S_{(s)}$$

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(iv) **Reaction with Cyanide:** Sulphur converts cyanide into thiocyanate which is also known as **pseudohalide**. It is used to analyse Fe^{3+}.

$$KCN_{(s)} + S_{(s)} \xrightarrow{\Delta} KSCN_{(s)}$$

(v) **Reaction with Halogens:** Sulphur reacts directly with F_2 to form SF_4 and SF_6. Sulphur hexafluoride (SF_6) is a gas and is very unreactive. It is used as an insulator gas in electric devices. Sulphur readily reacts with $C\ell_2$ to form $S_2C\ell_2$ (yellow liquid) which further reacts with $C\ell_2$ to form $SC\ell_2$ (red liquid).

$$S_{(s)} + 3F_{2(g)} \longrightarrow SF_{6(g)}$$

$$2S_{(s)} + C\ell_{2(g)} \longrightarrow S_2C\ell_{2(\ell)}$$

$$S_{(\ell)} + SC\ell_{2(g)} \longrightarrow S_2C\ell_{2(\ell)}$$

USES OF SULPHUR AND ITS COMPOUNDS

➲ Vulcanization

Sulphur is used as a cross linker for the rubber molecular chains. This is called vulcanization and it improves the strength of rubber as shown in Figure.

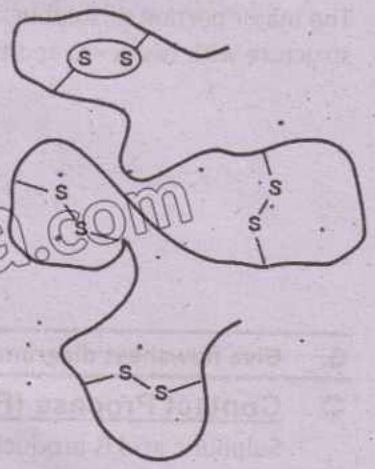


Figure: S-S cross-linkages between polymer chains

➲ Fertilizer

Sulphur is an essential nutrient for plant growth. When soils become depleted in sulfate, sulphur can be restored in soil by applying sulphur containing N/P fertilizers, or sulphur-coated fertilizers such as sulphur-coated urea. Soil components and microbes convert elemental sulphur into soluble forms for the use of plants. Gypsum ($CaSO_4 \cdot 2H_2O$) is also used as a fertilizer.

➲ Gun powder

Gun powder is a coarse blend of 75% potassium nitrate (KNO_3), 15% wood charcoal, and 10% sulphur. Charcoal carbon is the main fuel, nitrate is the oxidiser and sulphur is the additional fuel that burns the powder faster. The following reaction in burning takes place:

$$10KNO_{3(s)} + 3\,S_{(s)} + 8C_{(s)} \longrightarrow 2K_2CO_{3(s)} + 3\,K_2SO_{4(s)} + 6CO_{2(g)} + 5N_{2(g)}$$

☑ QUICK CHECK 12.5

a) What is the function of SO_2 and sulfite (SO_3^{2-}) salt in preserving the food?

Ans. SO_2 and sulfites act as **antimicrobial agents** and **antioxidants**, preventing bacterial/fungal growth and slowing food discoloration. They inhibit enzyme activity that causes spoilage in dried fruits, wines, and processed foods. Sulfites also maintain freshness by preventing oxidation reactions.

b) Give the reaction of S with HCℓ and NaOH.

Ans. With HCℓ: Sulfur **does not react** with HCℓ because it's non-reactive to non-oxidizing acids at normal conditions.

With NaOH: Sulfur reacts in hot NaOH solution, forming sulfides (Na_2S) and sulfites (Na_2SO_3).

$$3S + 6NaOH \longrightarrow 2Na_2S + Na_2SO_3 + 3H_2O$$

ROLE OF SULPHUR IN ORGANIC SYNTHESIS

Carbon-Sulphur bonds are present in a wide range of compounds with biological, pharmaceutical, and material properties. These bonds form a large number of organic compounds containing a variety of functional groups such as thiols or mercaptans, thioethers, sulfoxides, sulfones, etc.

➲ Drugs

Sulfa drugs are the antibacterial sulfonamides such as penicillins and cephalosporins contain sulphur. The common drug omeprazole, used in GERD (Gastroesophageal reflux disease) contains sulfoxide group.

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➲ Dyes

Sulphur dyes are synthesised by the process of thionation or sulphurization of organic compounds that contain nitro or amino groups. These compounds contain sulphur linkages. They generally give black, brown, khaki, blue, and green colours.

Examples are sulphur black 1, sulphur blue and sulphur brilliant green.

➲ Odorants/Fragrances

Mercaptans are used to give odour to natural gas. Some thiols have pleasant odours on high dilution, for example, thioterpineol is the key ingredient in the aroma of grapefruit. cisglabanum oxathiane is a fragrant compound. It is used in fine fragrances, soaps, shampoos and shower gels. Many naturally occurring odorants are produced synthetically and also applied as flavouring agents.

SULPHURIC ACID (H_2SO_4)

Sulphuric acid is called 'King of Chemicals'.

The major portion of sulphur, around 85% is used for the production of sulphuric acid (H_2SO_4). It has tetrahedral structure with two S – O and two S = O bonds as shown in Figure.

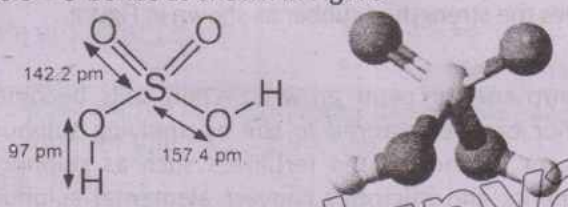


Figure: Structure of H_2SO_4

(Exercise L.Q.5)

Q. Give flowsheet diagram and equations involved in the contact process.

➲ Contact Process (For the Manufacture of Sulphuric Acid)

Sulphuric acid is produced by the contact process.

➢ Flow Sheet Diagram:

A flow sheet diagram of the contact process is shown in Figure.

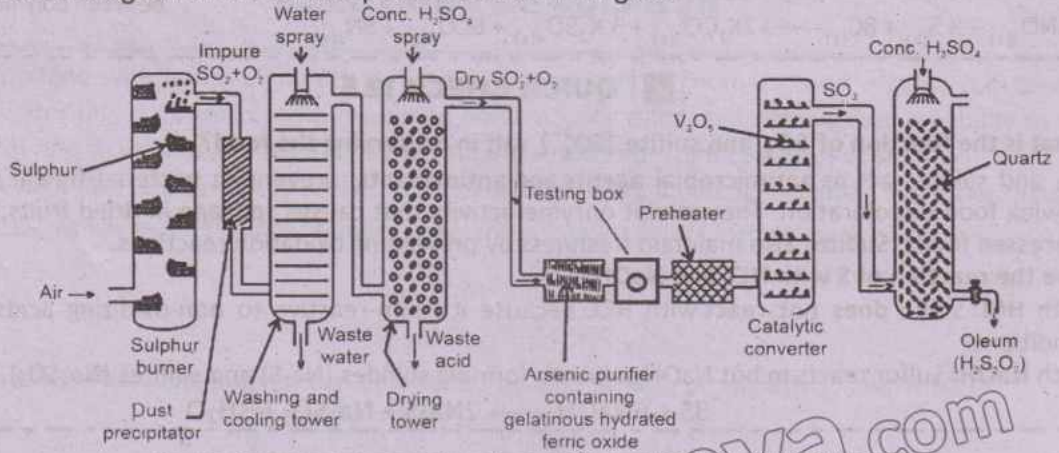


Figure: Contact process for the industrial production of sulphuric acid

➢ Stages:

The Contact process can be divided into the following stages.

➲ Sulphur/pyrite Burners

The process starts with the combustion of molten sulphur or by heating pyrites such as iron pyrite (FeS) in excess of air to produce sulphur dioxide SO_2.

$$S_{(s)} + O_{2(g)} \longrightarrow SO_{2(g)} \qquad \Delta H = -297.03\ kJ/mol$$

$$4FeS_{(s)} + 6O_{2(g)} \longrightarrow 2Fe_2O_{3(s)} + 4SO_{2(g)}$$

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Purification Unit

If pyrite ore is used as a sulphur source, the SO_2 gas formed may contain contaminants like dust particles, vapours, and arsenic oxide. These contaminants affect the efficiency of the catalyst. Hence, the gas needs to pass through the purification unit. In an arsenic purifier, gelatinous ferric hydroxide $Fe(OH)_3$ present in horizontal shelves, absorbs arsenic oxide As_2O_3.

$$As_2O_{3(g)} + 2Fe(OH)_{3(\ell)} \longrightarrow 2FeAsO_{3(\ell)} + 3H_2O_{(\ell)}$$

Ferric arsenite

Rack Your Mind!

9. **Arsenic oxides are removed during manufacture of H_2SO_4 by passing through:**
   A) Ferric hydroxide B) Sodium hydroxide
   C) Calcium hydroxide D) Potassium hydroxide

Contact Tower and Heat Exchangers

Purified SO_2 and air, preheated at $420°C - 450°C$, are fed to the first converter stage of the contact tower at 1 – 2 atm pressure. Here, these gases come in contact with vanadium pentoxide (V_2O_5) catalyst.

$$SO_{2(g)} + \frac{1}{2}O_{2(g)} \rightleftharpoons SO_{3(g)} \qquad \Delta H = -98.98\,kJ\,mol^{-1}$$

The catalyst works in two steps:

Oxidation of SO_2 into SO_3 by V^{5+}:

$$SO_{2(g)} + V_2O_{5(s)} \longrightarrow SO_{3(g)} + 4\,V_2O_{4(s)}$$

Oxidation of V^{4+} back into V^{5+} by oxygen (catalyst regeneration):

$$V_2O_{4(s)} + \frac{1}{2}O_{2(g)} \longrightarrow V_2O_{5(s)}$$

QUICK CHECK 12.6

a) Why is high temperature and catalyst needed to form SO_3 ?

Ans. The reaction in which SO_3 formed is an exothermic but slow at low temperatures. A high temperature (450°C) provides activation energy, on the other hand, the V_2O_5 (vanadium pentoxide) catalyst speeds up the reaction without being consumed, making the process industrially viable. The reaction is given below,

$$2SO_{2(g)} + \frac{1}{2}O_{2(g)} \rightleftharpoons SO_{3(g)} \qquad \Delta H = -98.98\ kJ/mol$$

b) Write down dehydration reactions of conc. H_2SO_4 with starch and oxalic acid.

Ans. The dehydration reactions of conc. H_2SO_4 with starch and oxalic acid are given below,

- **With starch $(C_6H_{10}O_5)_n$:** $(C_6H_{10}O_5)_n \xrightarrow{H_2SO_4} 6Cn + 5nH_2O$
- **With oxalic acid $(H_2C_2O_4)$:** $H_2C_2O_4 \xrightarrow{H_2SO_4} CO + CO_2 + H_2O$

c) How does the catalyst V_2O_5 function in the conversion of SO_2 to SO_3.

Ans. Vanadium(V) pentoxide **V_2O_5 provides a surface** for the reaction and helps in transferring oxygen: V_2O_5 temporarily forms V_2O_4, which is reoxidized by O_2, so it remains unchanged overall.

The catalyst works in two steps:

Oxidation of SO_2 into SO_3 by V^{5+}: $SO_{2(g)} + V_2O_{5(s)} \longrightarrow SO_{3(g)} + 4V_2O_{4(s)}$

Oxidation of V^{4+} back into V^{5+} by oxygen (catalyst regeneration): $\frac{1}{2}O_{2(g)} + V_2O_{4(s)} \longrightarrow V_2O_{4(s)}$

Absorption Tower

Sulphur trioxide (SO_3) is cooled and can be converted to sulphuric acid by reacting with water.

$$H_2O_{(\ell)} + SO_{3(g)} \longrightarrow H_2SO_{4(\ell)} \qquad \Delta H = -176.6\ kJ/mol$$

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Mixing SO_3 with water is not feasible because the reaction is extremely exothermic and acidic vapour or mist is produced rather than a liquid solution. Mainly, sulphur trioxide is dissolved in recirculating hot 98.5% sulphuric acid. The term fuming sulphuric acid or oleum is used for the mixtures of sulphur trioxide with 100 percent sulphuric acid.

Oleum undergoes a reaction with water to make a highly concentrated solution of H_2SO_4 whose concentration can be adjusted.

$$H_2SO_{4(\ell)} + SO_{3(g)} \longrightarrow H_2S_2O_{7(\ell)} \quad \text{(Oleum)}$$

$$H_2S_2O_{7(\ell)} + H_2O_{(\ell)} \longrightarrow 2H_2SO_{4(\ell)}$$

➲ Physical Properties

Sulphuric acid is soluble in water and hygroscopic in nature. It readily absorbs water vapour from the air. Anhydrous H_2SO_4 is a very polar liquid. It is highly corrosive to various materials. On contacting the skin, it causes chemical burns. Some physical properties of sulphuric acid are given in Table.

Table: Physical Properties of Sulphuric Acid

Molar mass	98.08 g/mol
Physical appearance	colourless viscous liquid
Odour	odourless
Melting point	10°C
Boiling point	290°C
Specific gravity (15°C)	1.83 g/cm^3
Viscosity	25.24 centipoise
Vapour pressure (25°C)	0.001 torr
Sulphuric acid is a highly corrosive substance. It can badly burn cloths, plastic, rubber and injured the human skin, eyes, etc,. Handle it very carefully.	

➲ Chemical Properties

i. Autoprotolysis

It self-ionizes or undergoes autoprotolysis as follows.

$$H_2SO_{4(\ell)} + H_2SO_{4(\ell)} \rightleftharpoons H_3SO^{1+}_{4(aq)} + HSO^{1-}_{4(aq)} \qquad K = 2.7\times10^{-4}$$

The equilibrium constant value is greater than that of water which makes it to be used as a non-aqueous protic solvent.

Rack Your Mind!

10. Discuss Sulphuric acid as dibasic acid.

Sulphuric acid is a strong acid as shown by its pK_{a1} value:

$$H_2SO_{4(aq)} \rightleftharpoons H_3O^{+}_{(aq)} + HSO^{1-}_{4(aq)} \quad (pK_{a1} = -2)$$

But hydrogensulphate (HSO_4^{1-}) is a far weaker acid due to a positive pK_{a2} value:

$$HSO^{1-}_{4(aq)} + H_2O_{(\ell)} \rightleftharpoons H_3O^{+}_{(aq)} + SO^{2-}_{4(aq)} \quad (pK_{a2} = 1.92)$$

(Exercise L.Q.6)

Q. Discuss sulphuric acid as an oxidizing agent and a dehydrating agent with three reactions for each.

ii. Sulphuric Acid as Dehydrating Agent

Concentrated sulphuric acid is a powerful dehydrating agent that removes water from many substances such as sucrose, starch, wood, and paper to produce carbon, steam, and heat.

It also dehydrates ethyl alcohol to ethene or ethoxyethane depending upon the reaction conditions.

$$C_2H_5OH_{(\ell)} + H_2SO_{4(\ell)} \longrightarrow C_2H_{4(s)} + H_2O_{(\ell)} + H_2SO_{4(aq)}$$

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Interesting Information!

Dehydration of Table Sugar:

A common laboratory demonstration is the dehydration of table sugar, where a black porous carbon mass called carbon snake protrudes out of the apparatus.

$$C_{12}H_{22}O_{11(s)} + H_2SO_{4(\ell)} \longrightarrow 12C_{(s)} + 11H_2O_{(\ell)} + H_2SO_{4(aq)}$$

Rack Your Mind!

11. When Conc. H_2SO_4 comes in contact with sugar later becomes black due to:

A) Hydrolysis B) Hydration
C) Decolourization D) Dehydration

iii. Reaction with NaCℓ

Hydrochloric acid (HCℓ) gas, is formed when sulphuric acid reacts with sodium chloride.

$$NaC\ell_{(s)} + H_2SO_{4(\ell)} \longrightarrow NaHSO_{4(s)} + HC\ell_{(g)}$$

iv. Reaction with Metals

Reactions of sulphuric acid with metals depend upon the metal, concentration of the acid, and temperature. Metals that are above hydrogen in electrochemical series such as Fe, Aℓ, Zn, Mn, Ni, and Mg react directly with dilute sulphuric acid to produce hydrogen gas and metal sulfates. But with cold conc. H_2SO_4, they liberate SO_2 and form sulphates.

$$Zn_{(s)} + H_2SO_{4(aq)} \longrightarrow H_{2(g)} + Zn^{2+}_{(aq)} + SO^{2-}_{4(aq)}$$

$$Zn_{(s)} + H_2SO_{4(\ell)} \longrightarrow SO_{2(g)} + Fe^{2+}_{(aq)} + SO^{2-}_{4(aq)} + 2H_2O_{(\ell)}$$

v. Sulphuric Acid as Oxidizing Agent

Metals like Cu, Ag, and Hg react with hot conc. H_2SO_4 to form metal sulfates. Sulphuric acid is not regarded as a typical oxidizing agent due to the stability of SO_4^{2-} anion. This anion is weakly oxidizing. However hot concentrated sulphuric acid is a moderately strong oxidizing agent due to high temperature, high concentration of protons (H^+), and formation of nascent oxygen. Hot concentrated sulphuric acid oxidises Cu, as given below:

$$Cu_{(s)} + 2H_2SO_{4(\ell)} \longrightarrow SO_{2(g)} + 2H_2O_{(\ell)} + SO^{2-}_{4(aq)} + Cu^{2+}_{(aq)}$$

QUICK CHECK 12.7

a) Write down dehydration reactions of conc. H_2SO_4 with starch and oxalic acid.

Ans. Starch

$$(C_6H_{10}O_5)n_{(s)} \xrightarrow{\text{conc. } H_2SO_4} 6nC_{(s)} + 5nH_2O_{(g)}$$

Oxalic acid:

$$\begin{matrix}COOH\\|\\COOH\end{matrix} \xrightarrow{\text{conc. } H_2SO_4} CO_{2(g)} + CO_{(g)} + H_2O_{(\ell)}$$

Paper and Sugar on reaction with conc.H_2SO_4 becomes black due to dehydration.

b) How does conc. H_2SO_4 react with NaCℓ? What is the importance of this reaction?

Ans. Hydrochloric acid (HCℓ) gas, is formed when sulphuric acid reacts with sodium chloride

$$NaC\ell_{(s)} + H_2SO_{4(\ell)} \longrightarrow NaHSO_{4(s)} + HC\ell_{(g)}$$

Sulfuric acid displaces the weaker acid (HCℓ) from its salt. This is important because it is used to **prepare pure HCℓ gas** in laboratories

c) What is the difference between the oxidizing power of cold and hot sulphuric acid?

Ans.

- Cold concentrated H_2SO_4 mainly acts as a dehydrating acid and shows weak oxidizing ability.
- Hot concentrated H_2SO_4 acts as a strong oxidizing agent, reacting with metals and nonmetals.

For example:

$$Cu + 2H_2SO_4 \xrightarrow{\text{Hot}} CuSO_4 + SO_2 + 2H_2O$$

The heat increases its reactivity and helps release SO_2 gas.

Uses and Industrial Applications of Sulphuric Acid

King of Chemicals:

Sulphuric acid is considered a king of chemicals and its consumption is an indicator of the industrial progress of a country.

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1. **Fertilizer Formation:** A major portion of the acid is used in making fertilizers, normally 77.67% is used to digest the phosphate rock containing calcium phosphate ($Ca_3(PO_4)_2$).
2. **Extraction of Metals:** It is used in the extraction of metals from ores such as Cu, Ni, steel etc.
3. **As a Catalyst:** It is utilized as a catalyst in oil and coal refining, polymers, synthetic rubber, and plastic industries.
4. It is used in the pulp and paper industry and involved in the production of pesticides, insecticides, herbicides, varnishes, dyes, pharmaceuticals, soaps and detergents.
5. **Formation of Explosive:** It is used for nitration in making explosives such as trinitrotoluene (TNT), nitroglycerine, picric acid, nitrocellulose, etc.
6. **Food Industry:** It is involved in the food industry for making sugar, starch, and corn syrup.
7. **Paint Industry:** It is used in the paint industry for making titanium dioxide (TiO_2) pigment.
8. **Dry Gases:** It is used to dry gases in industrial processes.
9. **Lead Storage Batteries:** 35.67% acid is used in lead storage batteries.
10. **Laboratory Reagent:** It is used as a laboratory reagent.

Even though it is used in various industries, it is rarely contained in the final product.

Did You Know?

Fluorapatite ($Ca_5(PO_4)_3F$) to make single superphosphate $Ca(H_2PO_4)_2$ and phosphoric acid (H_3PO_4). H_3PO_4 is further used to make double and triple superphosphates and ammonium phosphate. Sulphuric acid also reacts with ammonia to make ammonium sulfate fertilizer.

Solution File — Rack Your Brain!

Sr. #	Option	Explanation
1.	S.Q	(i) High bond Energy (941 kJ/mol) (ii) Non-Polar Nature of N_2 (iii) Electronic configuration stability (iv) Triple bond strength (v) No permanent dipole
2.	C	PAN causes eye irritation, leading to redness, itching, and tearing due to its oxidizing properties.
3.	B	NO_2 absorbs light and appears yellow-brown due to its molecular structure and absorption spectrum.
4.	S.Q	**Conditions for the Formation of Smog:** Following conditions are required for the formation of Smog. i. There must be sufficient NO, hydrocarbons and volatile organic compounds (VOC) emitted by the vehicular traffic. ii. There must be sunlight, so that some of the chemical reactions may occur at a rapid rate. iii. The movement of air mass must be little so that reactions are not disturbed.
5.	S.Q	There are two types of smog: (i) Reducing smog (ii) Oxidizing smog

Reducing Smog (Classical Smog)	Oxidizing Smog (Photochemical Smog)
It is formed due to the build up of sulphur dioxide from combustion of Coal.	It is formed due to photochemical reaction of sunlight on the nitrogen oxides and hydrocarbons produced by automobile and factories.
It involves smoke and fog.	It does not involve smoke and fog.
It mostly occurs in cool humid climate.	It occurs in warm, dry and sunny climate.
It has high concentration of SO_2 and is therefore reducing in character.	It has high concentration of oxidants like O_3 and therefore is oxidizing in nature.
It causes bronchitis and irritation i.e. problem in lungs.	It causes irritation in eyes and toxic to plants.

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6.	C	It converts pollutants like CO, NOx, and Hydrocarbons into harmless gases like CO_2, N_2, and H_2O, reducing emission and minimizing environmental impact.
7.	S.Q	A catalytic convertor is an emission control device to reduce harmful pollutants in exhaust gases from internal combustion engine.
8.	C	It converts pollutants gases into harmless gases: NOx → N_2, CO →, and HC → $CO_2 + H_2O$
9.	A	$As_2O_{3(s)} + 2Fe(OH)_{3(\ell)} \longrightarrow 2FeAsO_{3(\ell)} + 3H_2O_{(\ell)}$ Ferric arsenite
10.	S.Q	Sulphuric acid is a strong acid. In an aqueous solution, it completely ionizes to give hydronium ions and sulphate ions. The dissociation takes place in two steps. $H_2SO_{4(aq)} + H_2O_{(\ell)} \longrightarrow H_3O^+_{(aq)} + HSO^-_{4(aq)}$ $HSO^-_{4(aq)} + H_2O_{(\ell)} \longrightarrow SO^{2-}_{4(aq)} + H_3O^+_{(aq)}$
11.	D	The acid removes water from the sugar molecules, leading to the formatin of carbon, which appears black.

Exercise

MULTIPLE CHOICE QUESTIONS (MCQs)

Q.1 Four choices are given for each question. Select the correct choice.

I. Despite being the most abundant gas in the Earth's atmosphere, nitrogen does not readily participate in combustion reactions because:

a) It is denser than oxygen.
b) It has a high specific heat capacity.
c) Breaking the N≡N bond requires a large amount of energy.
d) It is a noble gas.

II. A student heats a solid ammonium salt with a solution of a strong alkali. The gas produced turns damp red litmus paper blue and has a characteristic pungent smell. The gas is:

a) Hydrogen (H_2) b) Carbon dioxide (CO_2) c) Ammonia (NH_3) d) Sulphur dioxide (SO_2)

III. The shape of ammonium (ion) is:

a) pyramidal b) triangular planar c) tetrahedral d) linear

IV. In a catalytic converter, the conversion of nitrogen oxides (NO_x) into nitrogen gas (N_2) and oxygen gas (O_2) is a process of:

a) Oxidation b) Reduction c) Combustion d) Neutralization

V. PAN formation starts when reacts with the hydrocarbon.

a) NO b) NO_2 c) O_3 d) HO^-

VI. Nitrification is the process by which:

a) Atmospheric nitrogen is converted into ammonia.
b) Nitrate is converted into nitrogen gas.
c) Ammonia is converted into nitrite and then nitrate.
d) Organic nitrogen is converted into ammonia.

VII. The most stable species in an acidic environment is:

a) SO_4^{2-} b) SO_2 c) H_2S d) S

VIII. Which gas is used in separating hard water from normal water?

a) SO_2 b) H_2S c) NH_3 d) NO

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IX. **The oxidation state of sulphur in H_2SO_4 is:**
a) +1 b) +2 c) +4 d) +6

X. **The drug omeprazole contains _____ group.**
a) Thiol b) Sulfoxide c) Bisulfide d) Sulfone

XI. **Sulphur dioxide (SO_2) produced from the combustion of sulphur can be further oxidized to sulphur trioxide (SO_3) under specific conditions, such as in the presence of a:**
a) Catalyst (e.g., vanadium (V) oxide) and high temperature.
b) Catalyst (e.g., iron) and low temperature.
c) Strong reducing agent and high pressure.
d) Dilute acid and room temperature.

XII. **Sulphur trioxide (SO_3) is not directly dissolved in water to produce sulphuric acid in the Contact Process because this reaction is:**
a) Too slow.
b) Reversible and would result in a low yield.
c) Highly exothermic and produces a mist of sulphuric acid.
d) Requires very high pressures.

Answer Key with Explanations

Sr.No.	Option	Answer	Explanation
I.	c	Breaking the N≡N bond requires a large amount of energy	• The N≡N triple bond has very high bond energy (946 kJ/mol), making nitrogen inert in combustion.
II.	c	Ammonia (NH_3)	• Heating ammonium salts with alkali produces NH_3, which turns damp red litmus blue (basic) and has a pungent smell.
III.	c	Tetrahedral	• NH_4^+ has sp^3 hybridization with 4 bond pairs, resulting in a tetrahedral shape.
IV.	b	Reduction	• In catalytic converters, $NO_x \rightarrow N_2 + O_2$ involves reduction of nitrogen (e.g., $NO \rightarrow N_2$).
V.	b	NO_2	• Peroxyacetyl nitrate (PAN) forms when NO_2 reacts with hydrocarbons in photochemical smog.
VI.	c	Ammonia is converted into nitrite and then nitrate	• Nitrification: $NH_3 \rightarrow NO_2^-$ (by Nitrosomonas) $\rightarrow NO_3^-$ (by Nitrobacter).
VII.	a	SO_4^{2-}	• Sulphate (SO_4^{2-}) is stable in acidic conditions, while H_2S/SO_2 may oxidize further.
VIII.	c	NH_3	• Ammonia precipitates Mg^{2+}/Ca^{2+} as hydroxides, softening hard water.
IX.	d	+6	• In H_2SO_4, sulphur has +6 oxidation state (**O.N. calculation:** $2(+1) + x + 4(-2) = 0 \rightarrow x = +6$)
X.	B	Sulfoxide	• Omeprazole is a PPI that reduces stomach acid by irreversibly inhibiting the H^+/K^+-ATPase enzyme. Its activity relies on a sulfoxide group (–S=O), making it a sulfoxide derivative of benzimidazole.
XI.	a	vanadium(V) oxide) and high temperature	• **Contact Process:** $SO_2 \rightarrow SO_3$ uses V_2O_5 catalyst at 450°C for optimal yield.
XII.	c	Highly exothermic and produces a mist of sulfuric acid	• Directly dissolving SO_3 in water creates an uncontrollable mist; instead, SO_3 is absorbed in conc. H_2SO_4 (oleum).

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SHORT ANSWER QUESTIONS

Q.2 Attempt the following short-answer questions:

a. List two reasons for the inertness of N_2.

Ans.

(i) **High Bond Energy:** The nitrogen molecule (N_2) is inert primarily due to its strong triple covalent bond ($N \equiv N$), which has a very high bond dissociation energy of 946 kJ/mol. This makes the bond extremely difficult to break under normal conditions.

(ii) **Non-Polar Nature:** N_2 is nonpolar because both nitrogen atoms have equal electronegativity, reducing its tendency to react with polar or ionic substances. The absence of lone pair availability for donation further contributes to its chemical inertness.

b. How is nitrogen isolated from air?

Ans. Nitrogen is isolated from air through a process called fractional distillation of liquefied air. First, air is filtered to remove dust and then compressed and cooled to very low temperatures (–200°C), turning it into a liquid. Since nitrogen has a lower boiling point (–196°C) than oxygen (–183°C), it evaporates first when the liquid air is gradually warmed. The nitrogen gas is then collected, while the remaining liquid contains oxygen, argon, and other trace gases. Further purification steps may be applied to obtain high-purity nitrogen.

c. Why ammonia (NH_3) is a weak base?

Ans. Reasons:

- **Partial Dissociation in Water:** NH_3 reacts with water to form NH_4^+ and OH^-, but only a small fraction dissociates, making it a weak base.
- **Lone Pair Availability:** The nitrogen lone pair can accept a proton (H^+), but it does so weakly compared to strong bases like NaOH.
- **Equilibrium Lies to the Left:** The reaction $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$ favors the reactants, resulting in a low concentration of OH^- ions.

d. Write down the reactions of photochemical smog formation?

Ans. Chemical Reactions:

The formation of photochemical smog involves the following chemical reactions.

$$N_{2(g)} + O_{2(g)} \longrightarrow 2NO_{(g)}$$

$$2NO_{(g)} + O_{2(g)} \longrightarrow 2NO_{2(g)}$$

$$NO_{2(g)} \xrightarrow{h\upsilon} NO_{(g)} + O_{(g)}$$

$$O_{(g)} + O_{2(g)} \longrightarrow O_{3(g)}$$

$$RCH=CHR_{(g)} + O_{3(g)} \longrightarrow RCO^{\bullet}_{3(g)} + RCH^{-}_{2(g)} \longrightarrow RC(O)OONO_2$$

Alternate For the Last Reaction:

$$RCH = CHR + O_3 \longrightarrow 2RCHO + O_2$$

$$RCHO + OH^{\bullet} \longrightarrow RC(O)O^{\bullet} + H_2O$$

$$RC(O)O^{\bullet} + NO_2 \longrightarrow RC(O)OONO_2$$

e. Write down the reactions of photochemical smog formation.

Ans. Photochemical smog (Los Angeles smog) forms in the atmosphere from NO_x and volatile organic compounds (VOCs) in the sunlight. It is oxidizing in nature. Photochemical oxidants, such as NO_2, ozone, and peroxyacyl nitrates (PANs) can react and oxidise specific compounds in the atmosphere.

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Photochemical smog is becoming more common than classical smog (London smog) due to increasing NO_x emissions. The formation of photochemical smog involves the following chemical reactions.

$$N_{2(g)} + O_{2(g)} \longrightarrow 2NO_{(g)}$$
$$2NO_{(g)} + O_{2(g)} \longrightarrow 2NO_{2(g)}$$
$$NO_{2(g)} \xrightarrow{h\nu} NO_{(g)} + O_{(g)}$$
$$O_{(g)} + O_{2(g)} \longrightarrow O_{3(g)}$$

f. What is the construction and function of a catalytic converter?

Ans. Construction:

A catalytic converter is a ceramic or metallic monolith with a honeycomb-like structure, Its inner channels have a layer of alumina to provide a high surface area. Noble expensive metals such as Pt (Platinum), Pd (Palladium), and Rh (Rhodium) are dispersed on the alumina.

Functions:

It functions in two stages:

(i) **Reduction Catalyst (Rh):** Converts harmful nitrogen oxides (NO_x) into nitrogen (N_2) and oxygen (O_2).

(ii) **Oxidation Catalyst (Pt/Pd):** Oxidizes carbon monoxide (CO) and unburned hydrocarbons into carbon dioxide (CO_2) and water (H_2O).

This process significantly reduces the toxicity of exhaust gases.

g. Why sulphur is quite unreactive at room temperature?

Ans. Sulfur is unreactive at room temperature because it exists as cyclic S_8 molecules (crown-shaped rings) held together by strong covalent S–S bonds. Breaking these bonds requires significant energy, making sulfur inert under mild conditions. Additionally, the nonpolar nature of S_8 reduces its interaction with polar solvents or reactants.

h. Which are the most stable oxidation states of sulphur in water at pH = 0 and pH=14?

Ans.

- At pH = 0 (strongly acidic conditions), sulfur's most stable oxidation states are:
  - +6 (sulfate, SO_4^{2-}) – Dominant due to high thermodynamic stability.
  - +4 (sulfur dioxide, SO_2 or sulfite, SO_3^{2-}) – Stable but can be oxidized further.
- At pH = 14 (strongly alkaline conditions), the stable forms shift to:
  - +6 (sulfate, SO_4^{2-}) – Remains stable.
  - −2 (sulfide, S^{2-}) – Favored in reducing environments.

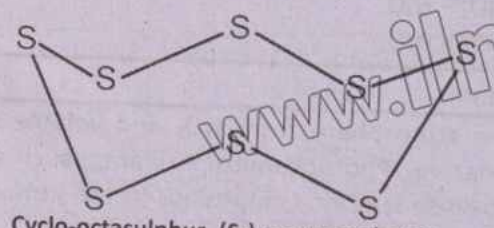
i. How does sulphur react with halogens?

Ans. Sulfur reacts directly with F_2 to form SF_4 and SF_6. Sulfur hexafluoride (SF_6) is a gas and is very unreactive. It is used as an insulator gas in electric devices. Sulfur readily reacts with Cl_2 to form S_2Cl_2 (yellow liquid) which further reacts with Cl_2 to form SCl_2 (red liquid).

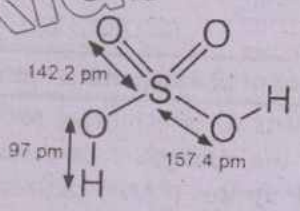
$$S_{(s)} + 3F_{2(g)} \longrightarrow SF_{6(g)}$$
$$2S_{(s)} + Cl_{2(g)} \longrightarrow S_2Cl_{2(l)}$$

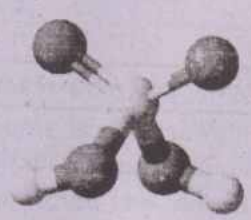
j. Draw the structures of cyclo-octasulphur (S_8) and sulphuric acid.

Ans.



Cyclo-octasulphur, (S_8) crown molecule





Structure of H_2SO_4

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k. What is the role of sulphur in the vulcanization of rubber?

Ans. Sulphur is used as a cross linker for the rubber molecular chains. This is called vulcanization and it improves the strength of rubber.

l. What is the composition and the chemical reaction of gunpowder combustion?

Ans. Gun powder is a coarse blend of 75% potassium nitrate (KNO_3), 15% wood charcoal, and 10% sulfur. Charcoal carbon is the main fuel, nitrate is the oxidiser and sulfur is the additional fuel that burns the powder faster. The following reaction in burning takes place:

$$10KNO_{3(s)} + 3S_{(s)} + 8C_{(s)} \longrightarrow 2K_2CO_{3(s)} + 3K_2SO_{4(s)} + 6CO_{2(g)} + 5N_{2(g)}$$

m. What is the importance of disulfide bridges?

Ans. Disulfide bridges (–S–S–) are covalent bonds between sulfur atoms in cysteine residues of proteins. They stabilize protein structures (e.g., keratin in hair, insulin) by linking distant parts of the polypeptide chain, ensuring proper folding and mechanical strength. Disruption of these bonds (e.g., by reducing agents) can denature proteins.

n. Write down self-ionization equation of sulphuric acid and its ionization in water.

Ans. It self-ionizes or undergoes autoprotolysis as follows.

$$H_2SO_{4(\ell)} + H_2SO_{4(\ell)} \rightleftharpoons H_3SO^{1+}_{4(aq)} + HSO^{1-}_{4(aq)} \qquad K = 2.7 \times 10^{-4}$$

The equilibrium constant value is greater than that of water which makes it to be used as a non-aqueous protic solvent.

Sulphuric acid is a strong acid as shown by its pK_{a1} value:

$$H_2SO_{4(aq)} \rightleftharpoons H_3O^{+}_{(aq)} + HSO^{1-}_{4(aq)} \qquad (pK_{a1} = -2)$$

But hydrogen sulphate (HSO_4^{1-}) is a far weaker acid due to a positive pK_{a2} value:

$$HSO^{1-}_{4(aq)} + H_2O_{(\ell)} \rightleftharpoons H_3O^{+}_{(aq)} + SO^{2-}_{4(aq)} \qquad (pK_{a2} = 1.92)$$

o. Give two examples where sulphuric acid acts as a dehydrating agent.

Ans. Dehydration of Alcohol:

H_2SO_4 dehydrates ethyl alcohol to ethene or ethoxyethane (Diethyl ether) depending upon the reaction conditions.

$$C_2H_5OH_{(\ell)} + H_2SO_{4(\ell)} \longrightarrow C_2H_{4(s)} + H_2O_{(\ell)} + H_2SO_{4(aq)}$$

Dehydration of sugar (sucrose):

$$C_{12}H_{22}O_{11} + H_2SO_4 \longrightarrow 12C + 11H_2O$$

p. How does V_2O_5 catalyze the formation of SO_3?

Ans. Vanadium pentoxide (V_2O_5) catalyzes the oxidation of SO_2 to SO_3 in the Contact Process:

(i) SO_2 reduces V_2O_5 to V_2O_4:

$$SO_2 + V_2O_5 \longrightarrow SO_3 + V_2O_4$$

(ii) O_2 reoxidizes V_2O_4 back to V_2O_5:

$$2V_2O_4 + O \longrightarrow 2V_2O_5$$

q. What is purpose of formation of oleum?

Ans. Oleum ($H_2S_2O_7$) is produced to safely transport and store sulfuric acid. Since concentrated H_2SO_4 tends to crystallize, oleum (a solution of SO_3 in H_2SO_4) prevents this problem. When diluted with water, oleum releases SO_3, which reacts to form additional H_2SO_4:

$$H_2S_2O_7 + H_2O \longrightarrow 2H_2SO_4$$

This ensures high-purity sulfuric acid delivery.

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DESCRIPTIVE QUESTIONS

Q.3 Explain the preparation and basicity of ammonia.

Ans. See Page No. (420)

Q.4 How oxides of nitrogen (NO_x) cause the formation of photochemical smog and PAN? Give its mechanism.

Ans. See Page No. (423)

Q.5 Give flowsheet diagram and equations involved in the contact process.

Ans. See Page No. (430)

Q.6 Discuss sulphuric acid as an oxidizing agent and a dehydrating agent with three reactions for each.

Ans. See Page No. (432)

ADDITIONAL SLOs BASED MCQs

1. **Which equations represent stages in the Contact process for manufacturing sulphuric acid?**
   A. $S + O_2 \rightarrow SO_2$ B. $H_2O + SO_2 \rightarrow H_2SO_3$ C. $H_2SO_3 + O_2 \rightarrow H_2SO_4$ D. $SO_3 + H_2O \rightarrow H_2SO_4$
2. **Nitrogen is absorbed by the plants in the form of:**
   A. Ammonium B. Nitrites C. Nitrates D. All
3. **Nitrogen fixation is the conversion of:**
   A. N_2 to N B. N_2 to NH_3 C. N_2 to NO_3 D. N_2 to urea
4. **Sulphur dioxide is an important food preservative. Which property makes sulphur dioxide useful in this role?**
   A. It is a gas. B. It is a reducing agent.
   C. It reacts with oxygen to form sulphur trioxide. D. It reacts with water to form an acidic solution.
5. **Most modern cars are fitted with three-way catalytic converters in the exhaust system. Which three gases are removed by such a catalytic converter?**
   A. carbon monoxide, hydrocarbons, nitrogen oxides B. carbon monoxide, carbon dioxide, nitrogen oxides
   C. carbon monoxide, nitrogen oxides, sulphur dioxide D. hydrocarbons, nitrogen oxides, sulphur dioxide
6. **Conversion of nitrates to nitrogen gas is called:**
   A. Ammonification B. Nitrification C. Nitrogen fixation D. Denitrification
7. **In the Contact process, what is the nature of the gaseous product and what is the identity of the catalyst?**

	Nature of gaseous product	Catalyst
A.	acidic	Fe^2
B.	acidic	V_2O_5
C.	basic	Fe_3
D.	basic	V_2O_5

8. **Conversion of nitrites to nitrates is called:**
   A. Nitrosococcus B. Clostridium C. Nitrobacter D. Nitrosomonas
9. **Which oxide of nitrogen is released from car engines?**
   A. Nitrogen dioxide B. Nitric oxide C. Nitrous oxide D. Nitrogen tetroxide
10. **Which compound of sulphur is used to bleach wood pulp?**
    A. Sulphuric Acid B. Sodium sulphate C. Sulphur dioxide D. Sodium sulphite

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Sr. #	Ans.	Explanations
1.	A	The Contact process involves the oxidation of sulphur to sulphur dioxide (SO_2), the further oxidation of SO_2 to sulphur trioxide (SO_3).
2.	D	Plants can absorb nitrogen in the form of ammonium (NH_4^+), nitrites (NO_2^-), and nitrates (NO_3^-), although nitrates are the most common form absorbed.
3.	B	Nitrogen fixation is the process of converting nitrogen gas (N_2) from the atmosphere into ammonia (NH_3), which can be used by plants.
4.	B	Sulphur dioxide acts as a reducing agent and inhibits the growth of bacteria and other microorganisms, making it useful as a food preservative.
5.	A	Three-way catalytic converters reduce emissions of carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx) from car exhaust.
6.	D	Denitrification is the process by which nitrates (NO_3^-) are converted to nitrogen gas (N_2), typically by bacteria, releasing nitrogen back into the atmosphere.
7.	B	The gaseous product (SO_3) formed in the Contact process is acidic, and the catalyst used is vanadium (V) oxide (V_2O_5).
8.	C	Nitrobacter bacteria are responsible for converting nitrites (NO_2^-) to nitrates (NO_3^-) in the nitrification process.
9.	B	Car engines typically release nitric oxide (NO) as part of the exhaust gases, which can further react to form nitrogen dioxide (NO_2).
10.	C	Sulphur dioxide (SO_2) is used in the bleaching of wood pulp because of its reducing properties, which help in removing lignin from the pulp.

SHORT ANSWER QUESTIONS

Q.1 What are the main categories of sources of NO_x?

Ans. The main categories of NO_X sources are:

- **Natural Sources of NO_x**
  Natural sources include lightning, volcanoes, biological decay, forest fires, soil microorganisms, oceans, etc. NO is produced when N_2 and O_2 in the air react during lightning. It is produced by microorganism using air N_2.
- **Man-made Sources of NO_x**
  The main anthropogenic sources of NO_x are the combustion of fossil fuels in vehicles and power plants. Other sources include chemical plants, biomass burning, welding, etc.

Q.2 Differentiate between nitrification and denitrification.

Ans.

Nitrification	Denitrification
Ammonia NH_3 / NH_4^{1+} is converted into nitrite (NO_2^{1-}) and nitrate (NO_3^{1-}).	Nitrite (NO_2^{1-}) and nitrate (NO_3^{1-}) are converted back to N_2 that is released into the atmosphere.
Nitrifying bacteria aerobic conditions, pH 6.5 – 8.0, optimum temperature 20 °C – 30 °C.	Denitrifying bacteria anaerobic conditions, pH 7.0 – 9.0, optimum temperature 26 °C – 38 °C.

Q.3 What is catalytic converter?

Ans. Catalytic Converter

A catalytic converter is a ceramic or metallic monolith with a honeycomb-like structure. Its inner channels have a layer of alumina to provide a high surface area.

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Q.4 Write down the natural sources of oxides of nitrogen.

Ans. Natural sources include lightning, volcanoes, biological decay, forest fires, soil microorganisms, oceans, etc. NO is produced when N_2 and O_2 in the air react during lightning. It is produced by microorganism using air N_2.

Q.5 Ammonia is basic in nature. How?

Ans. Ammonia behaves as a Lowry-Brønsted base by accepting a proton (H^+) from an acid to form ammonium:

$$NH_{3(aq)} + H^{+1}_{(aq)} \rightleftharpoons NH^{+1}_{4(aq)}$$

It dissolves in water to form ammonium hydroxide (NH_4OH) and equilibrium is established between ammonia molecules and ammonium ions in the solution.

$$NH_{3(aq)} + H_2O_{(\ell)} \rightleftharpoons NH^{1+}_{4(aq)} + OH^{1-}_{(aq)} \qquad K_b = 1.8\times10^{-5}$$

Ammonia solution is a weak base due to the low basicity constant (K_b) and the equilibrium position being towards the far left side.

Q.6 Write down the equation for the reaction between conc. H_2SO_4 and copper and explain what type of reaction is it.

Ans. Reaction between Conc.H_2SO_4 and Copper:

Hot conc. Sulphuric acid reacts with Cu to form Copper Sulphate and SO_2.

$$Cu^{0} + 2H_2\overset{+6}{S}O_4 \longrightarrow Cu^{+2}SO_4 + 2H_2O + \overset{+4}{S}O_2$$

(Oxidation: Cu → Cu^{+2}; Reduction: $\overset{+6}{S}$ → $\overset{+4}{S}$)

In this reaction, the oxidation state of Cu is changed from "zero" to "2" in $CuSO_4$ and thus Cu is oxidized. The oxidation state of S in H_2SO_4 is +6 whereas in SO_2 it is +4. This show that sulphur is reduced. Therefore the reaction is an oxidation reduction.

Q.7 Give the advantages of contact process for the manufacturing of sulphuric acid (H_2SO_4).

Ans. The advantages of contact process for the manufacture of H_2SO_4 are given below:-

(i) By using this process, we can get H_2SO_4 of any required concentration.
(ii) As no by product is obtained during this process. So, it is a environment friendly process.
(iii) It is used in commercial preparations.
(iv) The catalyst used i.e. V_2O_5 is solid. So, it can be handled easily.

Q.8 Why is SO_3 dissolved in H_2SO_4 and not in water?

Ans. When SO_3 is dissolved in 98% H_2SO_4, pyrosulphuric acid (oleum) is obtained.

$$H_2SO_{4(aq)} + SO_{3(g)} \longrightarrow H_2S_2O_{7(\ell)}$$

Oleum can be converted to sulphuric acid of any required concentration. By mixing adequate amount of water.

$$H_2S_2O_{7(\ell)} + H_2O_{(\ell)} \longrightarrow 2H_2SO_{4(aq)}$$

SO_3 is not dissolved in water directly because

(i) The reaction is highly exothermic.
(ii) SO_3 is less soluble in H_2O at high temperature.
(iii) A dense fog is produced which does not easily condense.
(iv) Sulphuric acid of required concentration cannot be prepared.

Q.9 H_2SO_4 is dehydrating agent. Write down some chemical equations to prove it.

Ans. Reactions as a Dehydrating Agent:

H_2SO_4 has a great affinity for water, so it acts as dehydrating agent and eliminates water from different compounds.

- $C_6H_{12}O_6 \xrightarrow{\text{Conc.}H_2SO_4} 6C + 6H_2O$
- $C_2H_5OH \xrightarrow[100^\circ C]{\text{Conc.}H_2SO_4} C_2H_4 + H_2O$

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- With oxalic acid it forms CO_2 and CO.

$$\begin{matrix}COOH\\|\\COOH_{(aq)}\end{matrix} \xrightarrow{\text{Conc. } H_2SO_4} CO_{2(g)} + CO_{(g)} + H_2O_{(l)}$$

- With formic acid, CO is formed:

$$HCOOH_{(aq)} \xrightarrow{\text{conc.}H_2SO_4} CO_{(g)} + H_2O_{(\ell)}$$

Q.10 Prove that H_2SO_4 acts as an oxidizing agent.

Ans. H_2SO_4 acts as a strong oxidizing agent.

(i) It oxidizes C and S giving CO_2 and SO_2 respectively.

$$C_{(s)} + 2H_2SO_{4(aq)} \longrightarrow CO_{2(g)} + 2SO_{2(g)} + 2H_2O_{(g)}$$

$$S_{(s)} + 2H_2SO_{4(aq)} \longrightarrow 3SO_{2(g)} + 2H_2O_{(\ell)}$$

(ii) H_2S is oxidized to S.

$$H_2S_{(g)} + H_2SO_{4(aq)} \longrightarrow S_{(s)} + SO_{2(g)} + 2H_2O_{(g)}$$

(iii) Reactions of H_2SO_4 with HBr and HI produce bromine and iodine respectively.

$$2HBr_{(aq)} + H_2SO_{4(aq)} \longrightarrow Br_{2(g)} + SO_{2(g)} + 2H_2O_{(g)}$$

$$2HI_{(aq)} + H_2SO_{4(aq)} \longrightarrow I_{2(g)} + SO_{2(g)} + 2H_2O_{(g)}$$

Q.11 Write reactions of H_2SO_4 with $NaCl_{(s)}$ and $NaBr_{(s)}$.

Ans. $2NaCl_{(s)} + H_2SO_{4(aq)} \longrightarrow Na_2SO_{4(aq)}$

$2NaBr_{(s)} + H_2SO_{4(aq)} \longrightarrow Na_2SO_{4(aq)} + 2HBr_{(g)}$

Q.12 Write four physical properties of sulphuric acid.

Ans. Physical Properties:

1. Pure sulphuric acid is a colourless oily liquid without an odour.
2. Its specific gravity is 1.834 at 18°C.
3. It freezes at 10.5°C.
4. Its boiling point is 338°C.
5. It dissolves in water liberating a lot of heat which raises the temperature of the mixture up to 120°C. H_2SO_4 should always be poured in water in a thin stream to avoid any accident.
6. Pure acid is a nonconductor of electricity but the addition of a little water makes it a good conductor.
7. It is extremely corrosive to skin and causes very serious burns to all the tissues.

Q.13 How does H_2SO_4 react with: (i) Zn (ii) Cu

Ans. (i) $H_2SO_{4(aq)} + Zn_{(s)} \longrightarrow ZnSO_{4(aq)} + H_2$

(ii) $Cu_{(s)} + 2H_2SO_{4(aq)} \longrightarrow CuSO_{4(aq)} + 2H_2O_{(l)} + SO_{2(l)}$

(It is an oxidation-reduction reaction).

Q.14 How Arsenic is removed in contact process?

Ans. Arsenic Purifier:

Arsenic oxide is then removed in the form of Ferric arsenite by passing the dry gases through a chamber provided with shelves packed with freshly prepared ferric hydroxide.

$$As_2O_3 + 2Fe(OH)_3 \longrightarrow 2FeAsO_3 + 3H_2O$$

(Ferric arsenite)

Q.15 Write four uses of sulphuric acid.

Ans. Uses of Sulphuric Acid (King of Chemicals):

It is used

(i) In the manufacture of fertilizers like ammonium sulphate and calcium superphosphate.

(ii) In refining of petroleum to remove nitrogen and sulphur compounds.

(iii) In electrical batteries and storage cells.

(iv) As a dehydrating agent for drying gases.

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SELF-ASSESSMENT Chapter # 12

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Total Mark: 30

Q.1 Encircle the correct option. (1 × 6 = 6)

(i) The oxidation State of S in $S_2O_3^{-2}$ is:

A. +1 B. +2 C. +3 D. +4

(ii) Despite being the most abundant gas in the Earth's atmosphere, nitrogen does not readily participate in combustion reactions because:

A. It is denser than oxygen.
B. It has a high specific heat capacity.
C. Breaking the N≡N bond requires a large amount of energy.
D. It is a noble gas.

(iii) The shape of ammonium (ion) is:

A. pyramidal B. triangular planar C. tetrahedral D. linear

(iv) Nitrification is the process by which:

A. Atmospheric nitrogen is converted into ammonia.
B. Nitrate is converted into nitrogen gas.
C. Ammonia is converted into nitrite and then nitrate.
D. Organic nitrogen is converted into ammonia.

(v) The most stable species in an acidic environment is:

A. SO_4^{2-} B. SO_2 C. H_2S D. S

(vi) Sulphur trioxide (SO_3) is not directly dissolved in water to produce sulphuric acid in the Contact Process because this reaction is:

A. Too slow.
B. Reversible and would result in a low yield.
C. Highly exothermic and produces a mist of sulphuric acid.
D. Requires very high pressures.

Q.2 Write short answers of the following questions. (2 × 8 = 16)

(i) If magnesium ribbon is ignited and placed in a jar containing N_2O, it continues to burn brightly. Explain this observation with reason.
(ii) Why N_2 gas is used in food packaging?
(iii) Write down the reduction and oxidation reactions that occur in the catalytic converter in the vehicle exhausts.
(iv) What is the basic principle of catalytic converter? Describe the role of catalyst in the catalytic converter.
(v) Give the reaction of S with NaOH.
(vi) Write down self-ionization equation of sulphuric acid and its ionization in water.

Q.3 Extensive Questions. (2 × 4 = 8)

(a) Discuss sulphuric acid as an oxidizing agent and a dehydrating agent with three reactions for each.
(b) How oxides of nitrogen (NO_x) cause the formation of photochemical smog and PAN? Give its mechanism.