Chapter 19

NITROGEN AND SULPHUR

Ammonia | Sulphuric Acid | Oxides | Metals
Reactivity Series of Metals | Role of Oxides of Nitrogen in Air Pollution

DESCRIPTIVE QUESTIONS – Ammonia

Q.1 Why is ammonia regarded as an important chemical?

Ammonia gas is one of the most important chemicals produced globally for industrial use because:

- **Use in fertilizers:** urea and other ammonium salts are extensively used as fertilizers. About 80% of the ammonia produced industrially worldwide is used to produce these fertilizers.
- **Use in plastics and pharmaceuticals:** ammonia is also used in the production of plastics and pharmaceuticals.
- **As a refrigerant:** it is also used as a refrigerant.

Q.2 Explain the production of ammonia on industrial scale.

Haber process: Ammonia is produced industrially by the Haber process, discovered by German chemist F.J. Haber in 1913.

Process: A mixture of nitrogen and hydrogen, in the ratio of 1:3 by volume, is heated at 400–500°C under 200 atmospheric pressure and in the presence of catalyst Fe/Al_2O_3 to give ammonia.

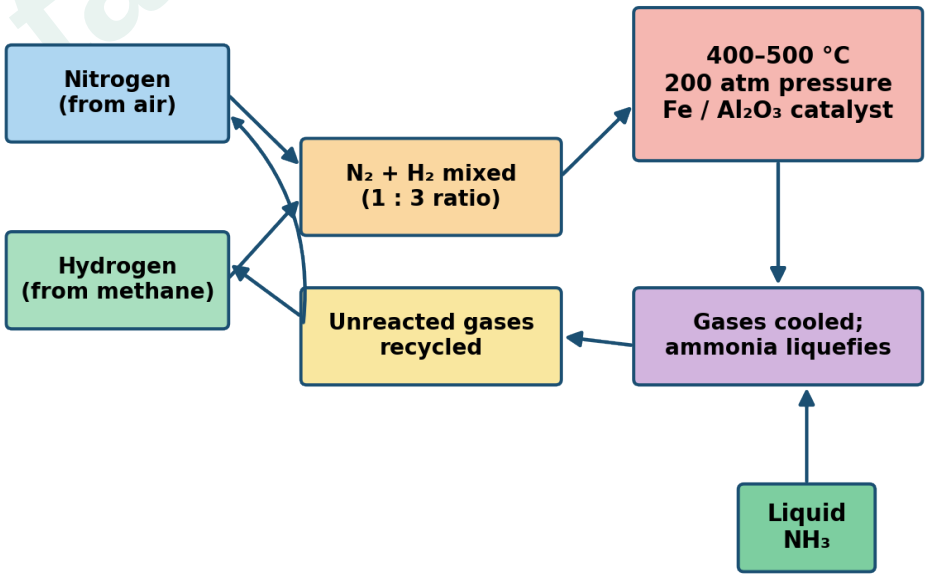
$$N_2(g) + 3H_2(g) \rightarrow (400–500°C, catalyst) \rightarrow 2NH_3(g)$$

The equilibrium mixture obtained contains **35% ammonia** by volume.

Liquefaction of ammonia: this mixture is cooled by refrigeration coils where ammonia gas changes to liquid ammonia at -33.4°C and is removed from the mixture.

Recycling of hydrogen and nitrogen: the other components of the mixture, hydrogen and nitrogen gases, are then recycled back into the reaction chamber.

The Haber Process



$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad [400–500°C, 200\ atm, Fe/Al_2O_3]$$

Fig. 19.1 – Haber process for the industrial production of ammonia

Q.3 How is nitrogen obtained from air?

One of the raw materials for the production of ammonia is nitrogen gas, obtained by the **fractional distillation of air**.

(a) Liquid air formation: carbon dioxide present in air is first removed.

- The air is subjected to about 200 atmospheric pressure. This compressed air is then cooled and allowed to pass through a spiral jet.
- While escaping through this jet, the air suffers sudden expansion and its temperature decreases. This process of compression and expansion is repeated again and again till the air is liquified.

(b) Distillation of liquid air: the liquid air is then fractionally distilled. Since the boiling point of nitrogen is less than oxygen, nitrogen evaporates first at -196°C leaving behind the oxygen. The separated nitrogen is reliquified and stored in specially designed cylinders.

Q.4 How is hydrogen obtained from methane?

By heating methane in limited oxygen: the second raw material of ammonia manufacturing, hydrogen, is produced by heating methane in a limited amount of oxygen that is not enough to completely oxidize methane to carbon dioxide and water. With less oxygen available, the reaction products contain primarily hydrogen and carbon monoxide, and a relatively small amount of carbon dioxide.

Conversion of CO to CO_2: the carbon monoxide obtained is then reacted with water to form carbon dioxide and more hydrogen gas.

$$CH_4(g) + H_2O(g) \rightarrow CO(g) + 3H_2(g)$$

$$CO(g) + H_2O(g) \rightarrow CO_2(g) + H_2(g)$$

Interesting Information
How much atmospheric nitrogen is used in the Haber process? 13% of total nitrogen fixation in the environment is contributed by the Haber process.

19.1 Quick Check
1. Why is ammonia gas turned into a liquid after its production?
Ans. Ammonia is produced as a gas in the Haber process, but gases take up a lot of space. When liquefied:
- Its volume decreases about 850 times.
- It becomes much easier to store in tanks and its transportation becomes easier.
- Liquefaction reduces storage and transport cost.
- Ammonia is toxic; liquid ammonia in a closed system is easier to contain.
- Many industrial processes use ammonia in liquid form.

That's why nearly all commercially produced ammonia is stored and transported as a liquid after production.

2. Why is high pressure maintained in the production of ammonia?
Ans. Reaction involved: $N_2(g) + H_2(g) \blacksquare 2NH_3(g)$. Reactants: 4 moles of gas ($1N_2 + 3H_2$). Products: 2 moles of gas ($2NH_3$). So it is clear that it is a reversible reaction in which the number of gas molecules decreases.
Effect of pressure: when pressure is increased up to 200 atm, it shifts the equilibrium towards the right side – the reaction speeds up, more ammonia is produced, yield and efficiency increase. Without high pressure, ammonia production would not be efficient enough on a large scale.

SULPHURIC ACID

Q.5 Why is sulphuric acid called the king of chemicals? Describe the contact process for the production of sulphuric acid.

Sulphuric acid as king of chemicals: sulphuric acid is one of the most important chemical compounds known. It is very commonly used in the laboratory and almost every manufacturing process makes use of this acid directly or indirectly at some stage. Therefore, it is called the **king of chemicals**.

Contact process: sulphuric acid is prepared industrially by the contact process, discovered by English chemist P. Philips in 1831.

Principle: this process is based on the catalytic oxidation of SO_2 to SO_3 in the presence of atmospheric oxygen. SO_3 is absorbed in concentrated H_2SO_4, and the oleum ($H_2S_2O_7$) formed can be converted into sulphuric acid by mixing an adequate quantity of water.

(i) Preparation of sulphur dioxide gas: produced either by burning elemental sulphur in air, or roasting a sulphur ore, iron pyrite, in excess of air.

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

$$4FeS_2(s) + 11O_2(g) \rightarrow 2Fe_2O_3(s) + 8SO_2(g)$$

Purification of sulphur dioxide: the SO_2 produced is passed through purifying chambers and sprayed with steam. This removes dust impurities as well as arsenic compounds present in the gas.

Removal of arsenic compound: this step is important because arsenic compounds poison the catalyst used later on.

Drying of gases: the moist gases (SO_2 and O_2) are then dried by passing through a drying tower in which concentrated sulphuric acid is sprayed – it acts as a dehydrating agent.

Source of oxygen: oxygen used in this reaction is obtained by the fractional distillation of air.

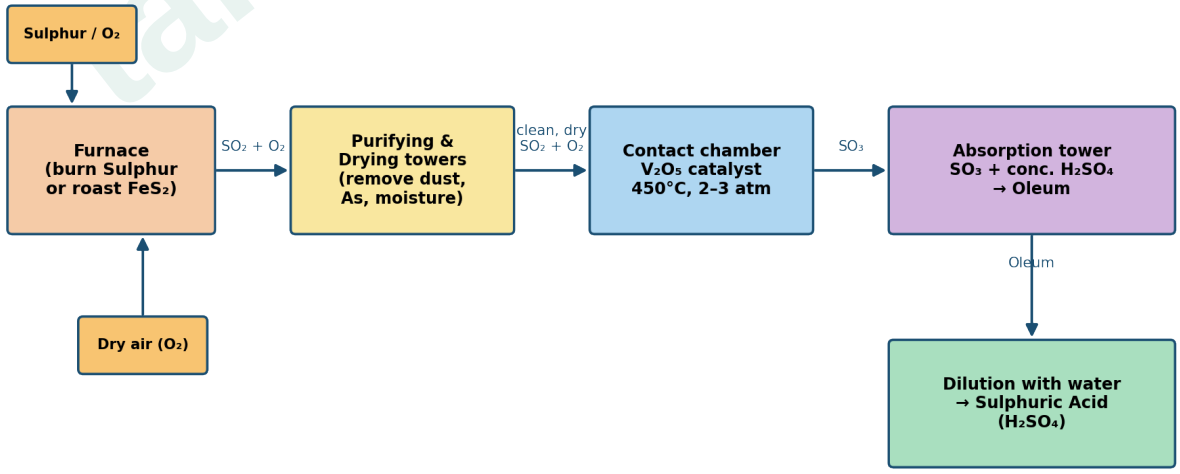
(ii) Oxidation of sulphur dioxide: the clean and dry gases (SO_2 and O_2) are passed over vanadium (V) oxide (vanadium pentaoxide) catalyst at 450°C and 2–3 atmospheric pressure through a contact chamber. Although the reaction is reversible, under these conditions 98% SO_2 gas is converted to SO_3.

$$2SO_2(g) + O_2(g) \rightarrow (V_2O_5,\ 450°C,\ 2–3\ atm) \rightarrow 2SO_3(g)$$

(iii) Formation of oleum (pyrosulphuric acid): sulphur trioxide gas formed in the contact chamber is absorbed into 98% sulphuric acid to give oleum.

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

Contact Process – Flow Sheet Diagram



$S(s) + O_2(g) \rightarrow SO_2(g)$ $\quad$ $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ [V_2O_5, 450°C]
$SO_3(g) + H_2SO_4(\ell) \rightarrow H_2S_2O_7(\ell)$ (oleum) $\quad$ $H_2S_2O_7(\ell) + H_2O(\ell) \rightarrow 2H_2SO_4(\ell)$

Fig. 19.2 – Contact process flow-sheet diagram

(iv) Production of sulphuric acid: the oleum is then mixed with an appropriate amount of water to produce sulphuric acid with the desired concentration.

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

Benefits of the contact process:

- The acid produced from this method is extremely pure.
- Any concentration of H_2SO_4 can be obtained by this method.

Interesting Information
Why is sulphuric acid king of chemicals? Sulphuric acid is called the “king of chemicals” because it is used in almost every industry.

19.2 Quick Check
1. How is SO_2 prepared from FeS_2?
Ans. SO_2 is prepared from iron pyrite (FeS_2) by a process called **roasting**. When iron pyrite is heated strongly in the presence of excess air, it reacts with oxygen to form iron (III) oxide and SO_2 gas:
$4FeS_2 + 11O_2 \rightarrow 2Fe_2O_3 + 8SO_2$

2. Why are SO_2 and oxygen purified before they react to produce SO_3?
Ans. Sulphur dioxide and oxygen are carefully purified before reacting ($2SO_2 + O_2$ ■ $2SO_3$ using V_2O_5 catalyst). If the gases contain impurities like dust particles, arsenic compounds and moisture, they can:
• Poison the catalyst • Reduce its efficiency • Damage the plant equipment (moisture) • Produce unwanted by-products
All these factors decrease the yield of SO_3 gas; without purification, the contact process would not be efficient or economical.

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OXIDES

Q.6 Define oxides. Give its types and explain the preparation and properties of basic and acidic oxides.

Oxides: binary compounds of elements with oxygen are called oxides. Oxygen shows an oxidation state of -2 in these oxides.

Metallic and non-metallic oxides:

- Metal oxides are commonly basic and amphoteric while non-metallic oxides are acidic in nature.
- Both basic and acidic oxides are formed when metals and non-metals are heated respectively in the presence of air or oxygen.
- Metal oxides are typically ionic compounds in which electrons are transferred from metals to oxygen.
- Non-metal oxides are covalent compounds where electrons are shared between non-metals and oxygen atoms.

Types of oxides: (i) Basic oxides (ii) Acidic oxides (iii) Neutral oxides (iv) Amphoteric oxides

(i) Basic oxides: oxygen reacts with metals to give oxides which are called basic oxides.

Chemical properties:

- When basic oxides dissolve in water, they produce hydroxides.
- They change red litmus blue.
- When treated with acids, they give salts.
- Mostly metallic oxides are ionic in nature.

Oxide of sodium:

$$4Na(s) + O_2(g) \rightarrow 2Na_2O(s) \quad Na_2O(s) + H_2O(l) \rightarrow 2NaOH(aq)$$

Oxide of calcium:

$$2Ca(s) + O_2(g) \rightarrow 2CaO(s) \quad CaO(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l)$$

Oxide of copper:

$$2Cu(s) + O_2(g) \rightarrow 2CuO(s) \quad CuO(s) + 2HCl(aq) \rightarrow CuCl_2(aq) + H_2O(l)$$

(ii) Acidic oxides: oxygen combines with non-metals (S, C, N) to give acidic oxides.

Chemical properties:

(i) These oxides react with water to give acids which turn blue litmus red.

$$S(s) + O_2(g) \rightarrow SO_2(g) \text{ (sulphur dioxide)}$$

$$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(l) \text{ (sulphurous acid)}$$

$$C(s) + O_2(g) \rightarrow CO_2(g)$$

$$CO_2(g) + H_2O(l) \rightarrow H_2CO_3(aq) \text{ (carbonic acid)}$$

(ii) Acidic oxides react with bases to give salts.

$$SO_2(g) + 2NaOH(aq) \rightarrow Na_2SO_3 + H_2O \text{ (sodium sulphite)}$$

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

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Q.7 Explain neutral and amphoteric oxides with example.

(i) Neutral oxides: neutral oxides are those oxides which on contact with water produce neither an acid nor a base.

Properties: their aqueous solutions have no action on blue or red litmus paper.

Examples: carbon monoxide (CO), nitric oxide (NO) and nitrous oxide (N_2O).

(ii) Amphoteric oxides: amphoteric oxides are usually formed when oxygen reacts with less electropositive metals. These oxides behave both as an acid and a base.

$$2Zn(s) + O_2(g) \rightarrow 2ZnO(s) \qquad 4Al(s) + 3O_2(g) \rightarrow 2Al_2O_3(s)$$

Examples: zinc oxide (ZnO), aluminium oxide (Al_2O_3) and H_2O.

(i) Properties as bases: zinc and aluminium oxides behave as bases in the presence of an acid.

$$ZnO(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2O(l)$$

$$Al_2O_3(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2O(l)$$

(ii) Properties as acids: zinc and aluminium oxides behave as acids in the presence of an alkali.

$$ZnO(s) + 2NaOH(aq) + H_2O(l) \rightarrow Na_2Zn(OH)_4(aq) \quad (sodium\ zincate)$$

$$Al_2O_3(s) + 2NaOH(aq) + 3H_2O(l) \rightarrow 2NaAl(OH)_4(aq) \quad (sodium\ aluminate)$$

(iii) No action on litmus paper: these oxides are insoluble in water and have no action on litmus paper.

Interesting Information
Why is water an amphoteric oxide? Water is an amphoteric substance. It can act as both an acid and a base, depending on the other substance it reacts with.

19.3 Quick Checks
1. Why is lead oxide called an amphoteric oxide?
Ans. Lead (II) oxide (PbO) is called an amphoteric oxide because it can behave both as an acid and a base.
a. Reaction with acids (basic nature): $PbO + 2HCl \rightarrow PbCl_2 + H_2O$
b. Reaction with bases (acidic nature): $PbO + 2NaOH + H_2O \rightarrow Na_2[Pb(OH)_4]$ (plumbite salt)
Reason: lead is a metal with intermediate character (not strongly metallic); such metals form amphoteric oxides.

2. Why do non-metals form covalent oxides?
Ans. Non-metals form covalent oxides mainly because of their electronic configuration and electronegativity. Non-metals have 4–7 valence electrons and need a few more electrons to complete their octet, so they strongly attract electrons. When two non-metals react, both attract electrons strongly; instead of transferring electrons, they share them, resulting in covalent bond formation. *Example:* CO_2, SO_2 and NO_2.

METALS

Q.8 Define metals. What are properties of metals? Discuss reactions of metals with cold water and steam.

Metals: nearly three-fourths of the elements shown in the periodic table are called metals. Metals show remarkable properties.

General properties of metals:

- Mostly metals occur in earth crust in the form of their oxides, hydroxides, carbonates and sulphides, etc.
- Metals have a tendency to lose electrons and form cations.
- Usually they form ionic bonds with other elements.
- They are good conductors of heat and electricity.

1. Reactions of metals with cold water: most of the elements present in the first and second group of the periodic table react vigorously with cold water, producing their respective hydroxides and hydrogen gas.

$$2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$$

$$2K(s) + 2H_2O(l) \rightarrow 2KOH(aq) + H_2(g)$$

Magnesium, however, reacts with cold water slowly, giving magnesium hydroxide and hydrogen gas.

$$Mg(s) + 2H_2O(l) \rightarrow Mg(OH)_2(s) + H_2(g)$$

2. Reactions of metals with steam: the more reactive the metal, the more readily it reacts with steam. Reactive metals like lithium, sodium, potassium and calcium react violently with steam and the reaction can be dangerous.

Beryllium and aluminium react with steam at high temperatures (around 700°C) to give their respective oxides and hydrogen.

$$Be(s) + H_2O(g) \rightarrow BeO(s) + H_2(g)$$

Magnesium, iron and zinc have a moderate reaction with steam, producing their respective oxides and hydrogen gas.

$$Mg(s) + H_2O(g) \rightarrow MgO(s) + H_2(g)$$

Interesting Information
What happens when two pieces of uncoated metal come in contact with each other in space and on earth? If two pieces of uncoated metal touch in space, they become permanently stuck together. It does not happen on Earth because the atmosphere puts a thin layer of oxide between the surfaces, which acts as a barrier preventing adhesion.

Q.9 Differentiate between first and second group metals based on their reactivities with oxygen and water.

First group metals	Second group metals
1. Reaction with oxygen: first group metals react rapidly with oxygen to form oxides, sometimes peroxides/superoxides. $4Na + O_2 \rightarrow 2Na_2O$ $2Na + O_2 \rightarrow Na_2O_2$	**1. Reaction with oxygen:** second group metals react less vigorously with oxygen to form simple oxides. $Ca + O_2 \rightarrow 2CaO$
2. Reaction with water: they react violently with cold water, producing hydroxide and hydrogen gas. $2Na + 2H_2O \rightarrow 2NaOH + H_2$ $2K + 2H_2O \rightarrow 2KOH + H_2$	**2. Reaction with water:** they react less vigorously; some react slowly with cold water, others with hot water or steam. $Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2$ $Be + H_2O \rightarrow BeO + H_2$

Q.10 Explain the reactions of metals with oxygen and dilute acid.

Reactions of metals with oxygen: metals react with oxygen to give metal oxides. The ease of reaction and the type of oxide formed depends upon the reactivity of the metal and the conditions used.

(i) Sodium burns in air with a yellow flame, producing both sodium oxide and sodium peroxide.

$$4Na(s) + O_2(g) \rightarrow 2Na_2O(s) \qquad 2Na(s) + O_2(g) \rightarrow Na_2O_2(s)$$

(ii) Magnesium, calcium, strontium and barium burn in oxygen with a colour of flame characteristic to each metal, giving their respective oxides.

$$Ca(s) + O_2(g) \rightarrow 2CaO(s)$$

Table 19.2 – Characteristic colours of flame

Metal	Colour of flame
Mg	Intense white flame
Ca	White flame with a tinge of red
Sr	Crimson flame
Ba	A pale green flame

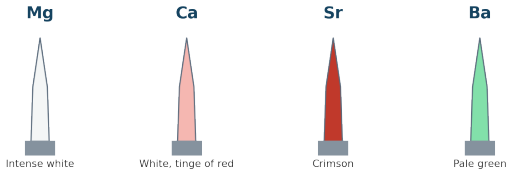

Fig. 19.3 / 19.4 – Characteristic flame colours of Group 1 & 2 metals

Reactions of metals with dilute acids:

(i) **Group 1 metals:** the more reactive the metal, the more vigorous its reaction with dilute acids. Sodium and potassium are very dangerous and react violently with dilute acids, giving their respective salts and hydrogen gas.

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

(ii) **Group 2 metals:** all group 2 elements react with dilute acids, giving their salts and hydrogen gas. The reaction generally becomes more vigorous as we move down the group.

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

19.4 Quick Check

1. Write the equation for the reaction between Ba and H_2O.
Ans. Barium reacts with cold water to form barium hydroxide and hydrogen gas:
$Ba(s) + 2H_2O(l) \rightarrow Ba(OH)_2(aq) + H_2(g)\uparrow$

2. How do aluminium and zinc react with water?
Ans. Aluminium does not react with cold water because it is protected by a thin oxide layer (Al_2O_3) on its surface. When it reacts with steam, aluminium oxide is formed and hydrogen gas is released:
$4Al(s) + 3H_2O(g) \rightarrow 2Al_2O_3(s) + 3H_2(g)$ (steam, high temp)
Zinc does not react with cold water either. It reacts with steam to form zinc oxide and hydrogen gas:
$Zn(s) + H_2O(steam) \rightarrow ZnO(s) + H_2(g)\uparrow$
Both of these oxides are amphoteric oxides.

REACTIVITY SERIES OF METALS

Q.11 Explain the reactivity series of metals.

Reactivity series of metals: based on their reactions with water and acids, metals can be arranged in decreasing order of their reactivities. Such an arrangement is called the reactivity series of metals.

Calcium and above metals in the activity series: according to this reactivity series, calcium and metals above it react with cold water to give metal hydroxides and hydrogen gas.

$2K + 2H_2O \rightarrow 2KOH + H_2$

$2Na + 2H_2O \rightarrow 2NaOH + H_2$

Metals below calcium in reactivity series: the metals below calcium do not react with cold water; instead, they react with steam to give metal oxides and hydrogen gas.

Reaction with dilute acids: only metals above hydrogen will be able to liberate H_2 upon reacting with dilute acids. Unreactive metals below hydrogen do not react with dilute acids. The more reactive the metal, the more vigorous its reaction will be with dilute acids. Reactive metals like potassium and sodium react with oxygen easily, whereas the less reactive metals like silver, copper and iron react with oxygen much more slowly.

Reducing agents: the metals at the top of the series are powerful reducing agents since they are easily oxidized. However, the reducing ability of metals decreases going down the series.

$Zn(s) + CuSO_4(aq) \rightarrow ZnSO_4(aq) + Cu(s)$

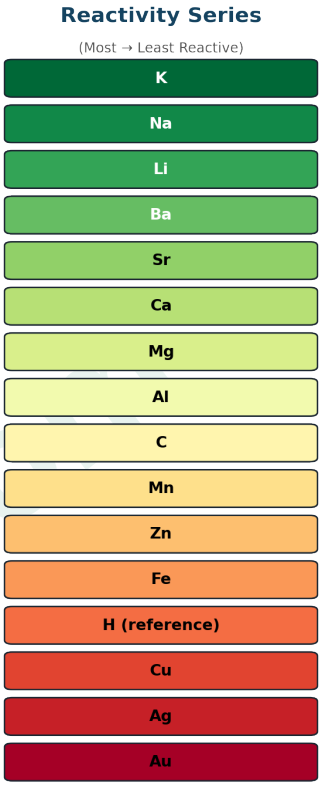

Table 19.1 – Reactivity series of metals

19.5 Quick Check

1. Which will react faster with HCl, Zn or Fe?

Ans. Zn is above Fe in the reactivity series, so it will react faster with dilute HCl to liberate hydrogen gas:

$Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)\uparrow$ (moderately fast)

2. Name one metal which will displace Zn from its salt.

Ans. A metal can displace zinc from its salt if it is more reactive than zinc in the reactivity series. Magnesium can easily displace zinc from zinc sulphate because it is more reactive:

$Mg(s) + ZnSO_4(aq) \rightarrow MgSO_4(aq) + Zn(s)$

ROLE OF OXIDES OF NITROGEN IN SPREADING AIR POLLUTION

Q.12 Describe the role of oxides of nitrogen in spreading air pollution.

Primary pollutants: the primary pollutants in the atmosphere include oxides of nitrogen, sulphur, carbon, and various hydrocarbons, etc.

Secondary pollutants: the primary pollutants are converted into secondary pollutants through various reactions going on in the atmosphere. The main secondary pollutants are ozone, peroxyacetyl nitrate (PAN), sulphuric acid, etc. All these compounds are toxic and their concentration in the atmosphere must be controlled.

Oxides of nitrogen: oxides of nitrogen which are harmful when present in the atmosphere include NO and NO_2, collectively represented by NO_x.

Sources of oxides of nitrogen: they are generated in the atmosphere through both natural and man-made sources.

(a) Natural sources: natural sources for the production of NO_x include electrical discharges during lightning, which can cause atmospheric nitrogen and oxygen to react, forming nitric oxide. This nitric oxide is rapidly converted into nitrogen dioxide by oxygen present in air.

$$N_2(g) + O_2(g) \rightarrow (electric\ arc) \rightarrow 2NO(g)$$

$$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$$

(b) Man-made sources:

- **Combustion of fuels:** combustion of fossil fuels in vehicles, various industrial processes and electricity power plants are the main man-made sources which generate NO_x in the atmosphere.
- **Agricultural activities:** agricultural activities and fertilizers also contribute to NO_x emission.
- **Heavy traffic:** heavy traffic during morning and evening hours, together with industrial processes, emits a huge amount of oxides of nitrogen (NO_x) and most volatile organic compounds (VOCs) into the atmosphere.
- **Formation of PAN:** ultraviolet radiation present in sunlight interacts with the oxides of nitrogen and VOCs through a complex series of chemical reactions to produce secondary pollutants like ozone, aldehydes and peroxyacetyl nitrate (PAN), which is also part of smog.

(v) Acid rain:

- **Oxides of nitrogen forming acid rain:** oxides of nitrogen are also responsible for the formation of another type of pollutant called acid rain. Especially NO_2 reacts with water and other chemicals present in air to produce vapours of nitric acid and nitrous acid.

$$2NO_2(g) + H_2O(l) \rightarrow HNO_3(g) + HNO_2(g)$$

These acidic vapours then mix with water vapours present in air and fall to earth as acid rain.

- **Oxides of nitrogen as catalyst in acid rain:** oxides of nitrogen (NO_x) can also act as catalyst to convert another primary pollutant, sulphur dioxide present in air, to sulphuric acid, which is another major component of acid rain.

$$2SO_2(g) + O_2(g) \rightarrow (oxides\ of\ nitrogen) \rightarrow 2SO_3(g)$$

$$SO_3(g) + H_2O(g) \rightarrow H_2SO_4(g)$$

Effects of acid rain: acid rain has a pH less than 5.6. Acid rain is damaging for the ecosystem – it can corrode materials and can lead to respiratory problems.

19.6 Quick Check

1. What are the harmful effects of oxides of nitrogen on human health?

Ans. Nitrogen oxides (NO and NO_2), collectively called NO_x, are harmful air pollutants with serious effects on human health:

- They irritate the respiratory tract, causing coughing and shortness of breath.
- Long-term inhalation can reduce lung function in children and adults.
- They can affect the functioning of the heart, causing high blood pressure and heart disease.
- NO_2 gas can irritate eyes, nose and throat, causing burning sensation and discomfort.
- NO_2 reacts with oxygen and sunlight to form photochemical smog, which disturbs the human respiratory system.
- NO_x reacts with water, causing acid rain, which can affect human health indirectly.

2. How do oxides of nitrogen pollute the environment?

Ans. NO_x are major environmental pollutants that affect the environment in several ways:

Acid rain formation: NO_x reacts with water in the atmosphere to produce nitric acid (HNO_3), causing acid rain, which damages plants, crops, lakes, rivers and aquatic life badly.

$2NO_2 + H_2O \rightarrow HNO_3 + HNO_2$

Smog formation: NO_x reacts with oxygen, volatile organic compounds (VOCs) and sunlight, forming photochemical smog (brownish haze), which reduces air quality and visibility, harms plants and animals, and promotes respiratory problems in humans.

Promotes other primary pollutants: NO_x can also act as a catalyst to convert another primary pollutant, SO_2, present in air to sulphuric acid, another major component of acid rain.

$2SO_2 + O_2 \rightarrow$(oxides of nitrogen) $\rightarrow 2SO_3$

$SO_3 + H_2O \rightarrow H_2SO_4$

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MULTIPLE CHOICE QUESTIONS (EXERCISE)

1. The reason for maintaining higher temperature for the production of ammonia is:
(a) activation energy of the reaction is very high (b) activation energy of the reaction is very low (c) nitrogen and hydrogen are both gases (d) at low temperature nitrogen and hydrogen change into liquids

2. The contact process used for the industrial production of H_2SO_4 is sensitive to the impurities present in SO_2 and O_2 because the impurities:
(a) affect the capability of the catalyst (b) affect the purity of H_2SO_4 (c) do not let SO_2 to react with oxygen (d) decrease the rate of reaction appreciably

3. Which of the following oxides is neutral in character?
(a) Al_2O_3 (b) SO_2 (c) CO_2 (d) NO

4. Sodium is considered more reactive than magnesium because:
(a) it is more electropositive than magnesium (b) it reacts with water slowly (c) it is present in second group (d) it is the less metallic

5. Secondary pollutants present in the atmosphere are:
(a) Oxides of nitrogen (b) Oxides of Sulphur (c) Ozone and PAN (d) Oxides of Carbon

6. SO_3 is absorbed in H_2SO_4 rather than H_2O during the production of sulphuric acid because:
(a) SO_3 does not react with H_2O (b) reaction of SO_3 with H_2O is highly exothermic producing mist of H_2SO_4 which is difficult to condense (c) it gives better yield of H_2SO_4 (d) reaction of SO_3 with H_2O can cause explosion

7. Oxides formed when oxygen reacts with metals:
(a) Acidic (b) Basic (c) Both basic and amphoteric (d) Neutral

8. Major components of acid rain are:
(a) H_2SO_4 and HNO_3 (b) H_2SO_3 and HNO_2 (c) H_2SO_4 and HCl (d) Acetic acid and HNO_3

9. Ammonia is one of the most important chemicals produced globally for the large scale production of:
(a) Urea (b) Ammonium salts (c) Fertilizers (d) All of these

10. By which percent ammonia is used to produce fertilizers:
(a) About 60% (b) About 70% (c) About 80% (d) About 90%

11. Ammonia produces:
(a) Fertilizers (b) Plastics (c) Pharmaceuticals (d) All of these

12. Ammonia was produced by a German Chemist _____ for the first time.
(a) Joseph Proust (b) F.J Haber (c) Berzelius (d) Edvin Kelvin

36. Binary compounds of elements with oxygen are called:
(a) Hydrides (b) Oxides (c) Nitrides (d) Sulphides

37. Oxidation state of oxygen in normal oxide:
(a) -1 (b) -2 (c) -3 (d) -1/2

38. Metal oxides are commonly:
(a) Basic (b) Acidic (c) Neutral (d) Amphoteric

39. Acidic nature of oxides is exhibited generally:
(a) Metallic oxide (b) Non-metallic oxide (c) Neutral oxide (d) Normal oxide

40. In metallic oxide formation electrons are transferred from metals to oxygen so they are:
(a) Ionic (b) Covalent (c) Metallic (d) Neutral

41. Covalent nature is the one of oxide:
(a) Metallic (b) Non metallic (c) Amphoteric (d) All of these

42. Basic oxide change:
(a) Blue litmus to red (b) Red litmus to blue (c) Both (a) and (b) (d) No effect on litmus

43. Which of the following is an acidic oxide?
(a) CaO (b) ZnO (c) CO_2 (d) Na_2O

44. Which oxide form sulphuric acid with water?
(a) SO_2 (b) SO_3 (c) CO_2 (d) NO_2

45. Which oxide reacts with water to form carbonic acid?
(a) CO (b) CO_2 (c) NO (d) SO_2

46. Which compound is produced when CO_2 reacts with $Ca(OH)_2$?
(a) $CaCl_2$ (b) $CaCO_3$ (c) $CaSO_4$ (d) $Ca(HCO_3)_2$

47. Na_2O is classified as:
(a) Acidic oxide (b) Basic oxide (c) Neutral oxide (d) Amphoteric oxide

13. In Haber process mixture of nitrogen and hydrogen gas is used in the ratio of:
(a) 1:2 (b) 2:3 (c) 3:4 (d) 1:3

14. Temperature needed for Haber process for ammonia synthesis is:
(a) 200–400°C (b) 400–500°C (c) 300–600°C (d) 200–500°C

15. The pressure required to maintain during Ammonia synthesis is:
(a) 100 atm (b) 200 atm (c) 300 atm (d) 400 atm

16. Catalyst used for ammonia synthesis:
(a) Ni (b) V_2O_5 (c) Pt (d) Fe/Al_2O_3

17. Which reaction involves the ammonia synthesis during Haber process:
(a) $N_2 + H_2 \blacksquare 2NH_3$ (b) $N_2 + 2H_2 \blacksquare 2NH_3$ (c) $N_2 + 3H_2 \blacksquare 2NH_3$ (d) $2N_2 + 3H_2 \blacksquare 2NH_3$

18. Haber process produces equilibrium mixture which contains about _____ % of ammonia:
(a) 25% (b) 35% (c) 45% (d) 50%

19. Liquid ammonia is collected by cooling gas at a temperature:
(a) -11.4°C (b) -22.3°C (c) -33.4°C (d) -44.4°C

20. Sources of nitrogen and hydrogen in the Haber process are:
(a) Water and air (b) Methane and air (c) Methane and water (d) Acid and methane

21. Nitrogen from air is collected by a process which is called:
(a) Distillation (b) Condensation (c) Evaporation (d) Fractional Distillation

22. During liquefaction air is compressed at about _____ atm pressure:
(a) 100 atm (b) 200 atm (c) 300 atm (d) 400 atm

23. During fractional distillation of air the compressed air is allowed to cool using an apparatus called:
(a) Spiral jet (b) Refrigeration coil (c) Cooling tower (d) Refrigeration chamber

24. Boiling point of nitrogen is:
(a) -120°C (b) -140°C (c) -196°C (d) -146°C

25. The second raw material for Ammonia synthesis other than nitrogen is:
(a) Methane (b) Water (c) Hydrogen (d) Acid

26. Sulphuric acid, because of its effective role in every industrial product is called:
(a) King of industry (b) Catalyst (c) King of chemicals (d) All of these

27. Industrially, sulphuric acid is produced by a process called:
(a) Haber process (b) Contact process (c) Ostwald process (d) Beroult process

48. Examples of neutral oxides are:
(a) CO (b) NO (c) N_2O (d) All of these

49. ZnO and aluminium oxide Al_2O_3, water are all examples of:
(a) Acidic oxide (b) Basic oxide (c) Neutral oxide (d) Amphoteric oxide

50. ZnO reacts with NaOH to form:
(a) Zinc oxide (b) Zinc hydroxide (c) Zinc chloride (d) Zincate

51. Sodium Zincate and Aluminates are generally:
(a) Soluble in water (b) Insoluble in water (c) Partially soluble (d) Sparingly soluble

52. Total coverage of metals in the periodic table is:
(a) One third (b) One fourth (c) Two third (d) Three fourth

53. Which metals reacts vigorously with cold water?
(a) Sodium (b) Potassium (c) Both a and b (d) Beryllium

54. Which metal react with HCl to produce hydrogen gas?
(a) Copper (b) Gold (c) Magnesium (d) Silver

55. Which metals react explosively with dilute acids?
(a) Copper, silver (b) Lead, Gold (c) Zinc, Iron (d) Sodium, Potassium

56. The temperature at which Be and Al react with steam:
(a) 500°C (b) 600°C (c) 700°C (d) 800°C

57. Which metal does not react with dil. HCl?
(a) Zinc (b) Iron (c) Magnesium (d) Copper

58. Sodium burns in air with color of flame:
(a) White (b) Blue (c) Red (d) Yellow

59. Color of flame of Magnesium is:
(a) Intense white (b) Milky (c) Crimson flame (d) Apple green

60. Calcium burns in air with flame of color:
(a) White (b) White with a tinge of red (c) Crimson (d) Apple green

61. A pale green colour is the characteristics flame of which metal?
(a) Mg (b) Ca (c) Sr (d) Ba

62. Crimson red colour of flame is shown by:
(a) Ba (b) Na (c) Sr (d) Ra

28. The ore from which sulphur dioxide is obtained for contact process:
(a) Haematite (b) Iron pyrite (c) Magnetite (d) Dolomite

29. Purification of Sulphur dioxide is needed in contact process because it may contain:
(a) Dust impurities (b) Arsenic compounds (c) Ammonia compounds (d) Both a and b

30. For drying the moist gases which chemical is sprayed in drying tower of contact process:
(a) Calcium Hydroxide (b) Hot air (c) Conc. H_2SO_4 (d) Conc. HCl

31. The catalyst used in contact process is:
(a) Nickel (b) Platinum (c) Fe_2O_3 (d) Vanadium(V)oxide

32. Temperature maintained in contact chamber for synthesis of Sulphur trioxide:
(a) 400°C (b) 440°C (c) 450°C (d) 470°C

33. 2–3 atmosphere pressure is required for which step in contact process:
(a) Production of Sulphur dioxide (b) Production of Sulphur trioxide (c) Production of Oleum (d) Purification of Sulphur dioxide

34. Which percentage of sulphuric acid is required for the conversion of SO_3 to oleum:
(a) 80% (b) 90% (c) 98% (d) 96%

35. Formula of Pyrosulphuric acid or oleum is:
(a) H_2SO_4 (b) H_2SO_3 (c) $H_2S_2O_7$ (d) HSO_4

63. Which gas is evolved when metals react with acids?
(a) Oxygen (b) Hydrogen (c) Nitrogen (d) Chlorine

64. What do highly reactive metals form with cold water?
(a) Hydroxides (b) Oxides (c) Salts (d) Peroxides

65. Which metal reacts very slowly with cold water?
(a) Rubidium (b) Sodium (c) Potassium (d) Magnesium

66. Primary pollutant which are present in atmosphere:
(a) Oxides of Nitrogen (b) Oxides of Sulphur (c) Oxides of Carbon (d) All of these

67. Which one is not secondary pollutant?
(a) Ozone (b) Proxy acetyl nitrate (PAN) (c) CO_2 (d) H_2SO_4

68. During lightning which gas is produced:
(a) NH_3 (b) NO (c) NO_2 (d) CO_2

69. Man-made activities which are source of NO_x production:
(a) Combustion of fossil fuels (b) Industrial process (c) Use of fertilizers (d) All of these

70. Secondary pollutants are produced from primary pollutant after a series of their chemical reaction with:
(a) Ozone (b) PAN (c) UV-radiations (d) None of these

ANSWER KEY

1	2	3	4	5	6	7	8	9	10
a	a	d	a	c	b	b	a	d	c
11	12	13	14	15	16	17	18	19	20
d	b	d	b	b	d	c	b	c	b
21	22	23	24	25	26	27	28	29	30
d	b	a	c	c	c	b	b	d	c
31	32	33	34	35	36	37	38	39	40
d	c	d	c	c	b	b	a	b	b
41	42	43	44	45	46	47	48	49	50
b	c	c	b	b	b	b	d	d	d
51	52	53	54	55	56	57	58	59	60
d	c	d	c	c	d	c	c	d	b
61	62	63	64	65	66	67	68	69	70
d	a	d	d	a	d	d	c	d	c

SHORT ANSWER QUESTIONS (EXERCISE)

1. How is nitrogen obtained from air?

Nitrogen is obtained by the fractional distillation of air.
(a) Fractional distillation: first, carbon dioxide present in air is removed. The air is subjected to about 200 atmospheric pressure; this compressed air is cooled and allowed to pass through a spiral jet, where it suffers sudden expansion; this compression-expansion cycle repeats until the air is liquified. **(b) Distillation of liquid air:** the liquid air is then fractionally distilled. Since the boiling point of nitrogen is less than oxygen, nitrogen evaporates first, leaving behind the oxygen. The separated nitrogen is reliquified and stored.

2. How is hydrogen produced from methane?

By heating methane in limited oxygen: hydrogen is produced by heating methane in a limited amount of oxygen that is not enough to completely oxidize methane to carbon dioxide and water. With less oxygen available, the products contain primarily hydrogen and carbon monoxide, and a relatively small amount of carbon dioxide. The carbon monoxide is then reacted with water to form carbon dioxide and more hydrogen gas.

$CH_4(g) + H_2O(g) \rightarrow CO(g) + 3H_2(g)$
$CO(g) + H_2O(g) \rightarrow CO_2(g) + H_2(g)$

3. Which conditions are used to oxidize SO_2 to SO_3?

The clean and dry gases (SO_2 and O_2) are passed over vanadium (V) oxide catalyst at 450°C and 2–3 atmospheric pressure through a contact chamber. Although the reaction is reversible, under these conditions 98% SO_2 gas is converted to SO_3.
$2SO_2(g) + O_2(g) \rightarrow (V_2O_5, 450°C, 2–3\ atm) \rightarrow 2SO_3(g)$

4. Why is CO_2 called an acidic oxide while CO is called a neutral oxide?

Carbon monoxide – neutral oxide: CO has a C≡O structure with a triple bond between carbon and oxygen, giving it less tendency to react because of the strong triple bond.
CO_2 – acidic oxide: its structure is linear, O=C=O. It reacts with water due to its structure to form carbonic acid: $CO_2 + H_2O \rightarrow H_2CO_3$

5. How do magnesium and calcium differ with each other towards their reactions with water?

They differ due to their position in the reactivity series. Calcium is above magnesium, so it is more reactive with water. **Magnesium** reacts very slowly (oxide layer on its surface) in the cold state, but reacts with steam to form magnesium oxide and hydrogen gas:
$Mg(s) + H_2O(g, steam) \rightarrow MgO(s) + H_2(g)\uparrow$
Calcium reacts readily with cold water to form calcium hydroxide:
$Ca(s) + 2H_2O(l) \rightarrow Ca(OH)_2(aq) + H_2(g)\uparrow$

6. How are the reactivities of metals determined?

Based on their reactions with water and acids, metals can be arranged in decreasing order of their reactivity – called the reactivity series of metals. Metals above hydrogen in the series are more reactive, while metals below hydrogen in the series are less reactive.
Reactivity series: K > Na > Ca > Mg > Al > Zn > Fe > Pb > Cu

7. Which secondary pollutants are produced by oxides of nitrogen?

Nitrogen oxides (NO and NO_2) are primary pollutants, but in the atmosphere they react to form secondary pollutants:
(i) Nitric acid: $2NO_2 + H_2O \rightarrow HNO_3 + HNO_2$
(ii) Sulphuric acid: oxides of nitrogen catalyse the production of sulphuric acid, also a major secondary pollutant: $2SO_2 + O_2 \rightarrow (\text{oxides of N}) \rightarrow 2SO_3$; $SO_3 + H_2O \rightarrow H_2SO_4$
(iii) Photochemical smog components: NO_2 reacts with VOCs and sunlight to form ozone (O_3) and peroxyacetyl nitrates (PANs) – both components of photochemical smog.

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SLO BASED SHORT ANSWER QUESTIONS

Ammonia

8. What is Haber process and what does it produce?

Ammonia is produced industrially by the German chemist F.J. Haber; therefore the process is called the Haber process, named after its discoverer.
Reaction: in this process a mixture of nitrogen and hydrogen in the ratio of 1:3 by volume is heated at 400–500°C under 200 atmospheric pressure and in the presence of catalyst Fe/Al_2O_3 to give ammonia.
$N_2(g) + 3H_2(g) \rightarrow (400–500°C, 200atm, Fe/Al_2O_3) \rightarrow 2NH_3(g)$

9. How is ammonia separated from the unreacted gases?

The mixture from the reaction contains 35% ammonia by volume. **Liquefaction of ammonia:** this mixture is cooled by the refrigeration coil where ammonia gas changes to liquid ammonia at -33.4°C and is removed from the mixture. The other components, hydrogen and nitrogen gases, are then recycled back into the reaction chamber.

10. Draw flow sheet diagram of Haber process for ammonia synthesis.

See Fig. 19.1 above for the complete Haber process flow diagram.

11. What are the sources of nitrogen in the Haber process?

One of the raw materials for the production of ammonia is nitrogen gas. This gas is abundantly found (78% by volume) in air, so it is obtained by the fractional distillation of air. After removing CO_2, the compressed air (200 atm) is allowed to pass through a spiral jet; sudden expansion decreases its temperature. This process is repeated until air is liquified. Nitrogen is then collected at -196°C by fractional distillation.

24. What are basic oxides? Which compounds are produced on dissolving them in water?

Basic oxides: when metals react with oxygen at high temperature, basic oxides are produced. *Examples:* Na_2O, CaO, etc.
$4Na + O_2 \rightarrow 2Na_2O$
$2Ca + O_2 \rightarrow 2CaO$
Basic oxides when combined with water produce alkalis (bases):
$Na_2O + H_2O \rightarrow 2NaOH$

25. What are amphoteric oxides? Give examples.

Amphoteric oxides: the oxides which can react with acids as well as with bases, displaying both acidic and basic properties, are called amphoteric oxides.
Examples: Al_2O_3, ZnO.

26. Discuss water as an amphoteric compound.

Water is an amphoteric substance. It can act as both an acid and a base, depending on the other substance it reacts with.
$H_2O + HCl \rightarrow H_3O^+ + Cl^-$ (water acting as base)
$H_2O + NH_3 \rightarrow NH_4^+ + OH^-$ (water acting as an acid)

Metals

27. Give general properties of metals.

Some general properties of metals are:
(i) Mostly metals occur in earth's crust in the form of their oxides, hydroxides, carbonates and sulphides.
(ii) Metals have a tendency to lose electrons and form cations.
(iii) Usually they form ionic bonds with other elements.
(iv) They are good conductors of heat and electricity.

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12. How 13% of nitrogen fixation occurs in the environment?

About 13% of total nitrogen fixation in the environment is contributed by the Haber process, which utilizes nitrogen to produce ammonia gas.

$N_2 + 3H_2 \rightarrow (Fe/Al_2O_3, 200atm, 400–500°C) \rightarrow 2NH_3$

13. What is the role of the catalyst in the Haber process?

The catalyst used in the Haber process is Fe/Al_2O_3. It increases the production of more ammonia without affecting the position of equilibrium. The catalyst allows the process to occur more efficiently, although it is a reversible reaction and ammonia is produced with a lower number of moles than the reactants.

14. How is ammonia separated from the unreacted gases?

The mixture obtained from the catalytic chamber contains 35% ammonia. This mixture is cooled by refrigeration coils where ammonia gas changes to liquid at -33.4°C and is removed from the mixture.

Sulphuric Acid

15. Why is sulphuric acid called “The king of chemicals”?

Sulphuric acid is called the king of chemicals because it is used in almost all industries including fertilizers, plastics, explosives, paints, textiles, leather tanning and metallurgy. Its demand is often considered an indicator of a country's industrial strength. It is involved directly or indirectly in the manufacturing of many essential products.

16. What is the main chemical reaction involved in the contact process?

The key chemical reaction in the contact process is the catalytic oxidation of SO_2 to SO_3 in the presence of oxygen:

$2SO_2 + O_2 \rightarrow (V_2O_5, 450°C, 2–3\ atm) \rightarrow 2SO_3$

This reaction is exothermic and reversible and requires optimum conditions for maximum yield.

28. Which metals react with cold water to liberate hydrogen gas?

Most of the elements present in the first and second groups of the periodic table react vigorously with cold water, producing their respective hydroxides and hydrogen gas.

$2Na + 2H_2O \rightarrow 2NaOH + H_2$

$2K + 2H_2O \rightarrow 2KOH + H_2$

29. How some reactive metals react with steam?

Reactive metals like Li, Na, K and Ca react violently with steam, and the reaction can be dangerous because these reactions are highly exothermic.

30. How Be, Al, Mg, Fe react with steam?

Be and Al react with steam at high temperatures (around 700°C) to give their respective oxides and hydrogen: $Be + H_2O \rightarrow BeO + H_2$. Mg, iron and zinc have a moderate reaction with steam, producing their respective oxides and hydrogen gas: $Mg + H_2O \rightarrow MgO + H_2$

31. How different metals can be identified by the colours of flames, when burnt with oxygen?

Flame test: metals react with oxygen to give metal oxides. They can be identified by the characteristic flame colour of their oxide.

$4Na + O_2 \rightarrow 2Na_2O$; $2Na + O_2 \rightarrow Na_2O_2$ – sodium burns in air to produce a yellow flame.

Mg → intense white flame; Ca → white flame with a tinge of red; Sr → crimson red flame; Ba → a pale green flame. This is called the flame test.

Reactivity Series

32. What is the reactivity series of the metals?

Reactivity Series: based on their reactions with water and acids, the metals can be arranged in decreasing order of their reactivities. Such an arrangement is called the reactivity series. Highly reactive > moderately reactive > less reactive > unreactive.

17. How is sulphur dioxide produced in the contact process?

Sulphur dioxide gas is produced either by burning elemental sulphur in air or roasting sulphur ore, iron pyrite, in excess of air.

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

$4FeS_2(s) + 11O_2(g) \rightarrow 2Fe_2O_3(s) + 8SO_2(g)$

18. How is SO_2 produced in the contact process purified?

Sulphur dioxide produced by burning sulphur or iron pyrite in excess of oxygen is passed through purifying chambers. A coke filter is used to remove traces of suspended particulate matter from the SO_2 gas. This purification step is essential to prevent catalyst poisoning.

19. How moist gases produced in contact process are dried?

The moist gases (SO_2 and O_2) in the contact process are dried by passing through a drying tower in which concentrated H_2SO_4 is sprayed, which acts as a dehydrating agent.

20. How is oleum produced in contact process?

Sulphur trioxide is absorbed in concentrated sulphuric acid (98%) in the absorption tower to form oleum ($H_2S_2O_7$).

$H_2SO_4 + SO_3 \rightarrow H_2S_2O_7$ (Oleum)

Oleum is a fuming liquid and a safer way to store and transport SO_3.

21. How different concentration of sulphuric acid are obtained from Oleum?

Concentrated sulphuric acid is produced by carefully adding water to oleum. In this way the desired concentration of sulphuric acid is produced.

$H_2S_2O_7 + H_2O \rightarrow 2H_2SO_4$

33. What is the position of powerful reducing agent in the reactivity series?

The metals at the top of the series are powerful reducing agents since they are easily oxidized. They have low standard reduction potential, increasing from top to bottom, making these top metals more reactive. Metals at the bottom of the reactivity series like Cu, Ag and Au etc. are least reactive or inert due to high standard reduction potential. They have the least tendency to lose electrons and form cations, so that is why they are less reactive metals.

Role of oxides of nitrogen in spreading air pollution

34. What are primary and secondary pollutants? Give examples.

Primary pollutants in the atmosphere are those harmful substances which are directly emitted into the atmosphere from natural or human-made sources. *Examples:* oxides of nitrogen and sulphur, etc. It also includes various hydrocarbons.

Secondary pollutants are pollutants which are not emitted directly but are produced when primary pollutants react with each other. *Examples:* O_3, PAN, H_2SO_4 (sulphuric acid) and nitric acid.

35. How are oxides of nitrogen produced in the atmosphere?

Oxides of nitrogen (NO_x) are produced:

- By electrical discharges during lightning
- By combustion of fossil fuels
- By agricultural activities and use of fertilizers
- By use of automobiles

36. What are the sources of secondary pollutants in atmosphere?

Ultraviolet radiation present in sunlight interacts with oxides of nitrogen and VOCs through a complex series of chemical reactions to produce secondary pollutants like ozone, aldehydes and peroxyacetyl nitrates (PAN).

Oxides

22. Define oxides. Write its classification.

Oxides: binary compounds of elements with oxygen are called oxides. Oxygen shows an oxidation state of -2 in these oxides. *Examples:* CaO, CO_2, SO_3, Na_2O, CuO and Al_2O_3. They can be classified into: Acidic oxide, Basic oxide, Neutral oxide, Amphoteric oxide.

23. Classify the following oxides with respect to their nature: Na_2O, CaO, CuO, SO_2, ZnO, CO_2, Al_2O_3, NO, CO, N_2O.

Acidic: SO_2, CO_2 **Basic:** Na_2O, CaO, CuO
Amphoteric: ZnO, Al_2O_3 **Neutral:** NO, CO, N_2O

37. How is nitric acid (HNO_3) formed in the atmosphere, contributing to acid rain?

Oxides of nitrogen are responsible for the formation of the pollutant called acid rain. Especially NO_x reacts with water and other chemicals present in air to produce vapours of nitric acid and nitrous acid.

$2NO_2 + H_2O \rightarrow HNO_3 + NHO_2$

These acidic vapours then mix with water vapours present in air and fall to earth as acid rain.

38. How does NO_2 catalyse the formation of sulphuric acid (H_2SO_4)?

Oxides of nitrogen (NO_x) can act as catalyst to convert the primary pollutant SO_2 present in air to sulphuric acid, which is a major component of acid rain.

$2SO_2 + O_2 \rightarrow$(oxides of nitrogen) $\rightarrow 2SO_3$

$SO_3 + H_2O \rightarrow H_2SO_4$

39. What is acid rain? How does it affect the environment?

Acid rain: rain having a pH lower than 5.6, caused by dissolving acidic oxides of nitrogen and sulphur in water, is called acid rain.

Effects of acid rain: it is damaging to our ecosystem, can corrode materials and buildings, and leads to respiratory problems.

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CONSTRUCTED RESPONSE QUESTIONS

1. Why is ammonia regarded as an important chemical?

See Q.1 from theory.

2. How is SO_2 present in the atmosphere converted to SO_3?

Oxides of nitrogen (NO_x) act as catalyst to convert a primary pollutant, sulphur dioxide present in air, to sulphuric acid, which is a major component of acid rain.

$2SO_2(g) + O_2(g) \rightarrow$(oxides of nitrogen) $\rightarrow 2SO_3(g)$

$SO_3(g) + H_2O(g) \rightarrow H_2SO_4(g)$

3. The burning of fossil fuels in a car engine is responsible for the production of oxides of nitrogen. Explain.

Burning of fossil fuels in car engines: the formation of nitrogen oxides (NO and NO_2), collectively called NO_x, in car engines is produced due to the combustion reaction of air-fuel mixture at high temperature. **Source of nitrogen oxides:** air contains 78% nitrogen (N_2) and 21% oxygen. During combustion in car engines, both these gases combine to give nitric oxide at the high temperature inside cylinders.

$N_2 + O_2 \rightarrow$(high temp) $\rightarrow 2NO$

This nitric oxide can then be oxidized in air to nitrogen dioxide.

$2NO + O_2 \rightarrow 2NO_2$

These are the primary pollutants contributing to acid rain, smog and respiratory problems.

4. The metals present at the top of the reactivity series are regarded as more reactive than those present at the bottom. Comment on this statement.

Metals present at the top of the reactivity series, like Li, Na, K, etc., have more tendency to lose electrons and form cations. They have low standard reduction potential, increasing from top to bottom, making these top metals more reactive. Metals at the bottom of the reactivity series like Cu, Ag and Au etc. are least reactive or inert due to high standard reduction potential; they have the least tendency to lose electrons and form cations, which is why they are less reactive metals.

5. How fossil fuels produce SO_2?

Sulphur in fossil fuels: SO_2 (sulphur dioxide) is produced when fossil fuels containing sulphur are burnt. Coal, petrol, diesel and natural gas often contain sulphur impurities. When sulphur in the fuel burns in oxygen (air) it forms sulphur dioxide.

$S + O_2 \rightarrow SO_2$

The reaction is highly exothermic. In this way SO_2, which is a primary pollutant, is produced from fossil fuels.

DESCRIPTIVE QUESTIONS (EXERCISE)

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1. Explain the production of ammonia on industrial scale.

See Q.2 from theory.

2. Describe the contact process for the production of sulphuric acid.

See Q.5 from theory.

3. Explain the formation and properties of acidic and basic oxides.

See Q.6 from theory.

4. Differentiate between first and second group metals based on their reactivities with oxygen and water.

See Q.9 from theory.

5. Describe the role of oxides of nitrogen in the formation of PAN and the acid rain.

See Q.12 from theory.

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