CHEMISTRY

Unit 12

NITROGEN, SULFUR & THEIR COMPOUNDS

MCQs • Short Questions • Long Questions

Complete Study Booklet with Answer Keys

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Section 1 | Multiple Choice Questions

Tick the correct option. Correct answers are highlighted in green with a check mark.

1. 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

2. 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 (H2)
(b) Carbon dioxide (CO2)
✓ **(c) Ammonia (NH3)**
(d) Sulfur dioxide (SO2)

3. The shape of ammonium ion (NH4+) is:

(a) Pyramidal
(b) Triangular planar
✓ **(c) Tetrahedral**
(d) Linear

4. In a catalytic converter, the conversion of nitrogen oxides (NOx) into nitrogen gas (N2) and oxygen gas (O2) is a process of:

(a) Oxidation
✓ **(b) Reduction**
(c) Combustion
(d) Neutralization

5. PAN formation starts when _____ reacts with the hydrocarbon.

(a) NO
(b) NO2
✓ **(c) O3**
(d) HO.

6. 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

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

✓ **(a) SO42-**
(b) SO2
(c) H2S
(d) S

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

(a) SO2
(b) H2S
✓ **(c) NH3**

(d) NO_2

9. The oxidation state of sulfur in H_2SO_4 is:

(a) +1
(b) +2
(c) +4
✓ **(d) +6**

10. The drug omeprazole contains _____ group:

(a) Thiol
✓ **(b) Sulfoxide**
(c) Bisulfide
(d) Sulfone

11. Sulfur dioxide (SO_2) produced from the combustion of sulfur can be further oxidized to sulfur 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

12. Sulfur trioxide (SO_3) is not directly dissolved in water to produce sulfuric 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 sulfuric acid**
(d) Requires very high pressures

13. Nitrogen belongs to which group of periodic table?

(a) 12
(b) 13
✓ **(c) 15**
(d) 18

14. Electronegativity of nitrogen is:

(a) 2.5
(b) 4.0
✓ **(c) 3.0**
(d) None of these

15. Ionic Radius of nitrogen N^{3-} is:

(a) 170 pm
(b) 121 pm
✓ **(c) 156 pm**
(d) 171 nm

16. Bond energy of nitrogen is:

✓ **(a) +944 kJ mol-1**
(b) +844 kJ mol-1
(c) +888 kJ mol-1
(d) +1000 kJ mol-1

17. IUPAC name of ammonia is:

✓ **(a) Azane**
(b) Azanium

(c) Azole
(d) None of these

18. Oxidation state of nitrogen in laughing gas (N2O) is:

✓ **(a) +1**
(b) +2
(c) +3
(d) +9

19. Classical smog is:

(a) Oxidizing
✓ **(b) Reducing**
(c) Both oxidizing and reducing
(d) None of these

20. Relative atomic mass of sulfur is:

(a) 30.06 a.m.u.
(b) 31.06 a.m.u.
✓ **(c) 32.06 a.m.u.**
(d) 39.06 a.m.u.

21. Electronegativity of sulfur is:

(a) 2.3
(b) 4.0
✓ **(c) 2.5**
(d) None of these

22. Common bonding exhibited by sulfur is:

(a) Ionic bond
✓ **(b) Covalent bond**
(c) Coordinate covalent bond
(d) Metallic bond

23. Most common oxidation states of sulfur are:

(a) +5 and +6
✓ **(b) +4 and +6**
(c) +4 and +8
(d) 0 and +1

24. The ability to form large rings and long chains is called:

(a) Sulfonation
✓ **(b) Catenation**
(c) Alkylation
(d) All above options are same

25. Gypsum is used as a fertilizer which nutrient is delivered by gypsum:

✓ **(a) S**
(b) P
(c) N
(d) Water

26. Omeprazole is used for the treatment of:

(a) Asthma
✓ **(b) Gastroesophageal reflux disease**
(c) Both a and b

(d) None of these

27. Vapour pressure of sulfuric acid at room temperature:

(a) 0.1 torr
✓ **(b) 0.001 torr**
(c) 0.01 torr
(d) 1 torr

28. Viscosity of sulfuric acid is:

(a) 30.33 centipoise
✓ **(b) 25.24 centipoise**
(c) 44 centipoise
(d) None of these

29. Molar mass of sulfuric acid is:

(a) 100.00 g/mol
✓ **(b) 98.08 g/mol**
(c) 15.9 g/mol
(d) None of the above

30. In laboratory sulfuric acid appears as:

(a) Yellow coloured gas
✓ **(b) Colourless viscous liquid**
(c) Solid crystals
(d) Pink coloured liquid

31. When sulfuric acid reacts with table sugar black porous mass is obtained which is:

✓ **(a) Carbon**
(b) Sulfur
(c) Nitrogen
(d) Alcohol

32. In contact process arsenic purifier uses for absorption of arsenic oxide:

(a) Vanadium pentaoxide
✓ **(b) Gelatinous ferric hydroxide**
(c) Iron pyrite
(d) None of above

33. Which of the following is used as raw material in contact process:

(a) Sulfur
(b) Iron pyrite
✓ **(c) Both a and b**
(d) None of these

34. In sulfuric acid how many oxygen atoms are attached to sulfur:

(a) 1
(b) 2
(c) 3
✓ **(d) 4**

35. In sulfuric acid number of oxygen-sulfur bonds are:

(a) 2
(b) 4
✓ **(c) 6**
(d) 8

36. Main fuel in gun powder is:

✓ **(a) Charcoal carbon**

(b) Nitrate

(c) Sulfur

(d) None of these

Section 2 | Short Questions

Q1. List two reasons for the inertness of N2.

1. High Bond Energy: the N#N bond has a bond enthalpy of +944 kJ/mol - high energy is required to break it, making N2 very unreactive.

2. Non-polarity of the Bond: both atoms are identical with zero electronegativity difference, so the three bonded electron pairs are shared equally, making the bond nonpolar.

Q2. How is nitrogen isolated from air?

Industrial: nitrogen is obtained by fractional distillation of liquid air (cooling air until it liquefies).

Laboratory: nitrogen can be generated by slowly heating a solution of ammonium nitrite: NH4NO2(aq) -> N2(g) + 2H2O(l) (upon heating).

Q3. Why is ammonia (NH3) a weak base?

Ammonia is a weak base due to its low basicity constant (Kb = 1.8x10^-5) and an equilibrium position lying far to the left: NH3(aq)+H2O(l) <=> NH4+(aq)+OH-(aq)

Q4. Write down the reactions of photochemical smog formation.

N2(g)+O2(g) -> 2NO(g); 2NO(g)+O2(g) -> 2NO2(g); NO2(g) -> NO(g)+O(g) (in presence of light)

O(g)+O2(g) -> O3(g); RCH=RCH(g)+O3(g) -> RCO3(g)+RCH2(g); RCO3(g)+RCH2(g) -> RCO(O)OONO2 (PAN formation)

Q5. What is the construction and function of a catalytic converter?

Construction: a ceramic/metallic honeycomb monolith with an alumina (Al2O3) layer for high surface area, on which noble metals (Pt, Pd, Rh) are dispersed.

Working: these metals catalyze redox reactions converting harmful CO, NO, and hydrocarbons into CO2, N2, and water. Reduction: 2NO(g)+2CO(g) -> N2(g)+2CO2(g) (Pt/Rh). Oxidation: 2CO(g)+O2(g) -> 2CO2(g) (Pt/Pd).

Q6. Why is sulfur quite unreactive at room temperature?

At room temperature sulfur occurs as cyclo-octasulfur (S8), a crown-shaped molecule that is quite unreactive and has high bond strength.

Q7. Which are the most stable oxidation states of sulfur in water at pH=0 and pH=14?

At pH=0 (strongly acidic): +6 is most stable, giving species like H2SO4 and SO4(2-).

At pH=14 (strongly basic): -2 is most stable, giving species like S2- and HS-.

Q8. How does sulfur react with halogens?

With Fluorine: S(s)+3F2(g) -> SF6(g) (sulfur hexafluoride - inert gas, used as insulator).

With Chlorine: 2S(s)+Cl2(g) -> S2Cl2(l) (yellow liquid); S2Cl2(l)+Cl2(g) -> 2SCl2(l) (red liquid).

Q9. Draw the structures of cyclo-octasulfur (S8) and sulfuric acid.

Cyclo-octasulfur (S8): a crown-shaped ring structure.

Sulfuric acid (H2SO4): tetrahedral structure with S at the center, two S=O bonds, and two S-OH bonds.

Q10. What is the role of sulfur in the vulcanization of rubber?

Sulfur acts as a cross-linker for rubber molecular chains (vulcanization), improving rubber's strength through S-S cross-linkages between polymer chains.

Q11. What is the composition and chemical reaction of gunpowder combustion?

Composition: 75% potassium nitrate (KNO3, oxidizer), 15% wood charcoal (C, main fuel), 10% sulfur (S, additional fuel).

Reaction: 10KNO3(s)+3S(s)+8C(s) -> 2K2CO3(s)+3K2SO4(s)+6CO2(g)+5N2(g)

Q12. What is the importance of disulfide bridges?

Disulfide bridges (S-S linkages) are crucial for the stability of large biomolecules like proteins, providing structural integrity.

Sulfur dyes, made by thionation/sulfurization of nitro or amino compounds, also rely on sulfur linkages and give black, brown, khaki, blue, and green colours.

Q13. Write the self-ionization equation of sulfuric acid and its ionization in water.

Self-ionization: H2SO4(l)+H2SO4(l) <=> H3SO4+(l)+HSO4-(l), K = 2.7x10^-4.

First ionization (strong acid): H2SO4(aq)+H2O -> H3O++HSO4-, pKa1=-2. Second ionization (weak acid): HSO4-(aq)+H2O(l) <=> H3O++SO4(2-)(aq), pKa2=1.92.

Q14. Give two examples where sulfuric acid acts as a dehydrating agent.

1. Dehydration of sucrose: C12H22O11(s)+H2SO4(l) -> 12C(s)+11H2O(g)+H2SO4(aq), forming a black porous carbon 'carbon snake'.

2. Dehydration of ethanol: C2H5OH(l)+H2SO4(l) -> C2H4(g)+H2O(l)+H2SO4(aq).

Q15. How does V2O5 catalyze the formation of SO3?

Purified SO2 and air (preheated 420-450 deg C, 1-2 atm) pass over V2O5 catalyst: 2SO2(g)+O2(g) <=> 2SO3(g), Delta H = -197.96 kJ/mol.

Step 1 (oxidation by V5+): SO2(g)+V2O5(s) -> SO3(g)+V2O4(s). Step 2 (catalyst regeneration): V2O4(s)+1/2 O2(g) -> V2O5(s).

Q16. What is the purpose of forming oleum?

Mixing SO3 directly with water is unfeasible (extremely exothermic, produces acid mist rather than a solution), so SO3 is dissolved in hot 98.5% sulfuric acid to form oleum (fuming sulfuric acid), which is later diluted safely.

Q17. Inertness of nitrogen is a blessing - justify.

High N2 concentration dilutes oxygen, preventing sparks from causing massive fires; nitrogen blankets protect hydrocarbon/oil shipments from oxygen and moisture; it is also used in labs for inert-atmosphere reactions.

Q18. Write a note on the structure of ammonia.

NH3 has a pyramidal shape due to the lone pair on nitrogen (sp3 hybridization with one lone pair).

When the lone pair forms a bond to make NH4+, the ion becomes tetrahedral, with all bonds of equal length and strength.

Q19. Write the main sources of oxides of nitrogen.

Natural sources: lightning, volcanoes, biological decay, forest fires, soil microorganisms, oceans.

Anthropogenic sources: combustion of fossil fuels in vehicles/power plants, chemical plants, biomass burning, welding.

Q20. Write the components of Lahore smog.

Volatile Organic Compounds (VOCs); NOx; ground-level ozone (O3); particulate matter (PM2.5); CO; SO2.

Q21. Write some characteristics of nitrogen.

A major component of air (78%); low reactivity due to small size, symmetrical electronic cloud, and nonpolar triple bond.

Electronic configuration: 1s2 2s2 2p3; forms a triple bond (N#N) by sharing three electrons to complete its octet.

Q22. Give the reduction reaction in a catalytic converter.

2NO(g) + 2CO(g) -> N2(g) + 2CO2(g) (catalyzed by Pt/Rh).

Q23. Write a short note on nitrification.

Nitrification converts ammonia (NH3/NH4+) into nitrite (NO2-) and then nitrate (NO3-).

Conditions: nitrifying bacteria, aerobic conditions, pH 6.5-8.0, optimum temperature 20-30 deg C.

Q24. What is meant by 'Fool's gold'?

Iron pyrite (FeS2) is called 'Fool's gold' because of its gold-like appearance, often mistaken for real gold when mined.

Q25. Give two factors affecting the stability of oxides of sulfur.

1. pH: under acidic conditions, reduced forms (like H2S, -2 state) are more stable; under basic/neutral conditions, oxidized forms (like SO4 2-, +6 state) are more stable.

2. Thermodynamics vs kinetics: sulfur +6 (SO3) is thermodynamically most stable, but kinetic limitations often make +4 (SO2) the more commonly observed form.

Q26. Why is sulfuric acid liquid at room temperature?

Its melting point is 10 deg C and boiling point is 290 deg C, so at room temperature it falls within this liquid range; being a strongly polar molecule also gives it a high boiling point and low vapour pressure.

Q27. How does NO2 catalyze the formation of SO3?

NO2 oxidizes SO2 to SO3 and is itself reduced to NO: 2SO2+2NO2 -> 2SO3+2NO. NO then reacts with O2 to regenerate NO2: 2NO+O2 -> 2NO2. Industrially, V2O5 is used instead.

Q28. Conversion of SO2 to SO3 is exothermic - why is high temperature used in the contact process?

High temperature increases the rate but lowers yield (Le Chatelier); low temperature gives higher yield but is too slow. A compromise temperature and catalyst are used, and excess O2 is added to shift equilibrium toward products.

Q29. How is the catalyst regenerated in the contact tower?

V2O4(s) + 1/2 O2(g) -> V2O5(s), oxidizing V4+ back to V5+.

Q30. Sulfuric acid is a stronger acid than hydrogen sulfate - discuss.

H2SO4's first ionization has pKa1=-2 (strong acid, ionizes completely); HSO4-'s second ionization has pKa2=1.92 (weak acid, only partially ionizes) - the negative pKa1 shows H2SO4 is the stronger acid.

Q31. In sulfuric acid, four oxygen atoms are attached to sulfur but different bond lengths are observed. Why?

Two oxygens form double bonds (S=O, shorter, stronger); two form single bonds (S-OH, longer, weaker). Double bonds are shorter and have greater bond energy than single bonds, giving the two different S-O bond lengths.

Q32. Give the reaction of sulfur with halogens.

With Fluorine: S(s)+3F2(g) -> SF6(g) (inert insulator gas). With Chlorine: 2S(s)+Cl2(g) -> S2Cl2(l) (yellow liquid); S2Cl2(l)+Cl2(g) -> 2SCl2(l) (red liquid).

Q33. If a magnesium ribbon burns in a jar of N2O, it continues to burn brightly. Explain.

2Mg(s)+N2O(g) -> 2MgO(s)+N2(g). This is highly exothermic; N2O acts as an oxidizing agent, providing oxygen for combustion, so the magnesium keeps burning brightly.

Section 3 | Descriptive Questions

Q3 (Descriptive). Explain the preparation and basicity of ammonia.

Ammonia is prepared in the lab by heating an ammonium salt (e.g. NH4Cl) with a base like Ca(OH)2: 2NH4Cl(s)+Ca(OH)2(aq) -> CaCl2(aq)+2H2O(l)+2NH3(g). Industrially, it is made via the Haber-Bosch process: N2(g)+3H2(g) <=> 2NH3(g).

Basicity: ammonia acts as a Lowry-Bronsted base, accepting H+ to form NH4+; in water it forms NH4OH: NH3(aq)+H2O(l) <=> NH4+(aq)+OH-(aq), Kb=1.8x10^-5 - a weak base since the equilibrium lies far to the left.

Q4 (Descriptive). How do oxides of nitrogen (NOx) cause photochemical smog and PAN formation? Give the mechanism.

N2(g)+O2(g) -> 2NO(g); 2NO(g)+O2(g) -> 2NO2(g); NO2(g) -> NO(g)+O(g) (light); O(g)+O2(g) -> O3(g).

The ozone formed then reacts with hydrocarbons: RCH=RCH(g)+O3(g) -> RCO3(g)+RCH2(g); RCO3(g)+RCH2(g) -> RCO(O)OONO2 (Peroxyacyl Nitrate, PAN) - an oxidizing component of photochemical smog.

Q5 (Descriptive). Give a flowsheet-style outline and equations for the contact process.

Stage 1 (Burners): 2S(s)+O2(g) -> 2SO2(g), or 4FeS2(s)+11O2(g) -> 2Fe2O3(s)+8SO2(g).

Stage 2 (Purification): removes contaminants like As2O3 using Fe(OH)3.

Stage 3 (Contact Tower): 2SO2(g)+O2(g) <=> 2SO3(g) over V2O5 catalyst at 420-450 deg C, 1-2 atm.

Stage 4 (Absorption): SO3 dissolved in hot 98.5% H2SO4 to form oleum (H2S2O7), later diluted to H2SO4.

Q6 (Descriptive). Discuss sulfuric acid as an oxidizing agent and a dehydrating agent, with three reactions for each.

Dehydrating agent examples: (1) sucrose -> carbon + water (carbon snake); (2) ethanol -> ethene + water; (3) dehydration of starch/oxalic acid similarly removes water, leaving carbon residues or CO/CO2.

Oxidizing agent examples (hot concentrated H2SO4): (1) Cu+2H2SO4(l) -> SO2(g)+2H2O(l)+SO4(2-)(aq)+Cu2+(aq); (2) reaction with Ag or Hg similarly releases SO2; (3) S+6HNO3(l) -> H2SO4(l)+6NO2(g)+2H2O(l) shows nitric acid oxidizing sulfur to sulfuric acid, illustrating related oxidizing chemistry.

Section 4 | Long Questions

Q1. What is nitrogen and ammonia gas? Explain their preparation and uses.

Nitrogen

Introduction: nitrogen belongs to Group 15, atomic number 7, atomic mass 14 amu - a non-metal p-block element.

Laboratory preparation: heating a solution of ammonium nitrite - NH4NO2(aq) -> N2(g)+2H2O(g) (upon heating).

Industrial preparation: fractional distillation of liquid air (cooling air until it liquefies).

Reactivity of Nitrogen (N2)

Nitrogen makes up 78% of air and is unreactive due to its small size, symmetrical electronic cloud, and nonpolar triple bond.

Electronic configuration: 1s2 2s2 2p3 - nitrogen needs three electrons to complete its octet, forming a triple bond (N#N) by sharing three electrons with another nitrogen atom.

Bond energy: +944 kJ/mol - high energy is required to break this bond; non-polarity arises because both atoms are identical (zero electronegativity difference).

Ammonia (NH3)

Industrial production - Haber-Bosch Process: N2(g)+3H2(g) <=> 2NH3(g).

Basicity: ammonia is a Lowry-Bronsted base, accepting a proton to form NH4+: NH3(aq)+H+(aq) <=> NH4+(aq). In water: NH3(aq)+H2O(l) <=> NH4+(aq)+OH-(aq), Kb=1.8x10^-5 - a weak base since the equilibrium lies far left.

Structure: NH3 is pyramidal (sp3 hybridization, one lone pair); NH4+ is tetrahedral.

Laboratory Preparation of Ammonia

Heating an ammonium salt (e.g. NH4Cl) with a base like Ca(OH)2: 2NH4Cl(s)+Ca(OH)2(aq) -> CaCl2(aq)+2H2O(l)+2NH3(g).

Acid-base roles: NH4+ acts as an acid (donates H+); OH- acts as a base (accepts H+).

Test for ammonium ion: a pungent gas that turns moistened red litmus paper blue confirms its presence.

Uses

Nitrogen: food packaging (inert atmosphere), rapid cooling (liquid nitrogen), laboratory inert atmosphere.

Ammonia: fertilizers, industrial synthesis.

Quick check: CO is more reactive than N2 despite both having triple bonds, because CO is slightly polar while N2 is non-polar. Ammonium fertilizers should not be applied with lime, since lime's alkaline pH converts ammonium into ammonia gas, causing nitrogen loss: (NH4)2SO4+Ca(OH)2 -> CaSO4.2H2O+2NH3.

Q2. What are oxides of nitrogen? Give their formulas, oxidation states, properties and uses.

Oxides of Nitrogen

Include NO, N2O, NO2, N2O4, and N2O5, with nitrogen oxidation states ranging from I to V. N2O4 and N2O3 decay quickly to other oxides. NO and NO2 are collectively called NOx.

IUPAC name of ammonia is Azane, and of ammonium is Azanium, derived from 'Azote' (Greek for nitrogen, meaning 'no life') - used in naming derivatives like sodium azide (NaN3).

Q3. What are the sources of oxides of nitrogen, and their role in smog and PAN formation?

Sources of Oxides of Nitrogen

(i) Natural sources: lightning, volcanic eruptions, forest fires, denitrifying bacteria in soil - NO forms when N2 and O2 react during lightning; N2O is produced by microorganisms.

(ii) Anthropogenic sources: combustion of fossil fuels in vehicles/power plants, chemical plants, biomass burning, welding.

Photochemical Smog and PAN Formation

Photochemical smog forms from NOx and volatile organic compounds (VOCs) in sunlight, and is oxidizing in nature - oxidants include NO2, ozone, and peroxyacyl nitrates (PANs).

Reactions: N2(g)+O2(g) -> 2NO(g); 2NO(g)+O2(g) -> 2NO2(g); NO2(g) -> NO(g)+O(g) (light); O(g)+O2(g) -> O3(g); RCH=RCH(g)+O3(g) -> RCO3(g)+RCH2(g); RCO3(g)+RCH2(g) -> RCO(O)OONO2 (PAN formation).

PAN (peroxyacyl nitrate) general formula: RCO(O)OONO2, derived from NOx and O3.

Quick Check

Magnesium burning brightly in N2O: 2Mg+N2O -> 2MgO+N2. This confirms that in N2O, oxygen is attached to a nitrogen bound to another nitrogen by a strong N-N triple bond, structure :N#N-O:

Q4. What are catalytic converters? Also explain nitrification and denitrification.

Catalytic Converter

Construction: a ceramic or metallic honeycomb monolith with an alumina (Al2O3) layer for high surface area; noble metals (Pt, Pd, Rh) are dispersed on the alumina.

Working: these metals catalyze redox reactions to remove harmful exhaust gases - the three-way converter turns CO, NO, and hydrocarbons into CO2, N2, and water.

Reduction: 2NO(g)+2CO(g) -> N2(g)+2CO2(g) (Pt/Rh). Oxidation: 2CO(g)+O2(g) -> 2CO2(g) (Pt/Pd); 2C2H4+6O2(g) -> 4CO2(g)+4H2O(g) (Pt/Pd).

Nitrification

Definition: the process by which ammonia (NH3/NH4+) is converted into nitrite (NO2-) and then nitrate (NO3-).

Conditions: nitrifying bacteria, aerobic conditions, pH 6.5-8.0, optimum temperature 20-30 deg C.

Denitrification

Definition: the process by which nitrate (NO3-) is converted back to nitrogen gas (N2), completing the nitrogen cycle: NO3- -> NO2- -> NO -> N2O -> N2.

Conditions: denitrifying bacteria, anaerobic conditions.

Quick Check

Hybrid cars have catalytic converters (they still emit some harmful gases); fully electric cars do not need them since they emit no exhaust gases.

Q5. Write a note on reactivity and oxidation state of sulfur, and the stability of these states.

Sulfur

Sulfur is a member of Group 16 (the Chalcogen family).

Reactivity of Sulfur

Sulfur usually forms single bonds with other sulfur atoms (not double bonds) due to poor orbital overlap, and forms larger structures via catenation - S8 is a crown-shaped molecule (cyclo-octasulfur).

Oxidation States of Sulfur

Sulfur shows oxidation states of -2, 0, +2, +4, and +6; the most common are +4 and +6, determined by the number of unpaired electrons.

+4 state: from an excited configuration (3s2 3p3 3d1) with four unpaired electrons.

+6 state: from a further excited configuration (3s1 3p3 3d2) with six unpaired electrons.

Quick Check

+4 and +6 are the most common and stable oxidation states in basic/neutral conditions - SO2 shows +4 and SO3 shows +6. The variable oxidation states arise from the involvement of d-orbitals allowing more unpaired electrons to form additional bonds.

Q6. Explain the reactions of sulfur.

Reactivity Overview

Sulfur is unreactive to water, dilute non-oxidizing acids, and noble gases under normal conditions, but its ability to catenate lets it form rings and chains.

(i) Burning of Sulfur

S(s)+O2(g) -> SO2(g) (blue flame); 2SO2(g)+O2(g) -> 2SO3(g) (needs higher temperature and catalyst).

Sulfur can also be oxidized by nitric acid: S(s)+6HNO3(l) -> H2SO4(l)+6NO2(g)+2H2O(l).

(ii) Sulfur as an Oxidizing Agent

With less electronegative elements, sulfur acts as an oxidizing agent, forming sulfides: 2Ag(s)+S(s) -> Ag2S(s); Hg(l)+S(s) -> HgS(s); 2Cu(s)+S(s) -> Cu2S(s). Sulfur does not react with Au or Pt.

(iii) Reaction with Cyanate

Sulfur converts cyanate into thiocyanate (a pseudohalide), used to analyze Fe3+: KCN(s)+S(s) -> KSCN(s) (upon heating).

(iv) Reaction with Halogens

With fluorine: S(s)+3F2(g) -> SF6(g) (inert insulator gas). With chlorine: 2S(s)+Cl2(g) -> S2Cl2(l) (yellow liquid); S2Cl2(l)+Cl2(g) -> 2SCl2(l) (red liquid).

Quick Check

With NaOH: 3S+6NaOH -> 2Na2S+Na2S2O3+3H2O. With HCl: no reaction at room temperature; at higher temperature, 2HCl+S -> SCl2+H2.

Q7. Explain the uses of sulfur and its compounds, and its role in organic synthesis.

Uses of Sulfur and its Compounds

1. Vulcanization: sulfur cross-links rubber chains, improving rubber's strength through S-S linkages.

2. Fertilizer: sulfur is an essential plant nutrient; gypsum (CaSO4.2H2O) and sulfur-coated urea are used as fertilizers.

3. Gunpowder: 75% KNO3 (oxidizer), 15% wood charcoal (main fuel), 10% sulfur (additional fuel); reaction: 10KNO3(s)+3S(s)+8C(s) -> 2K2CO3(s)+3K2SO4(s)+6CO2(g)+5N2(g).

Role of Sulfur in Organic Synthesis

Sulfur-containing functional groups: thiols/mercaptans (R-SH), thioethers (R-S-R'), sulfoxides (R-S(=O)-R'), sulfones (R-S(=O)2-R').

Drugs: sulfa drugs (antibacterial sulfonamides); penicillins and cephalosporins contain sulfur; omeprazole (for GERD) contains a sulfoxide group.

Dyes: sulfur dyes, made by thionation/sulfurization of nitro or amino compounds, give black, brown, blue, and green colours.

Odorants: mercaptans give natural gas its smell; thioterpineol contributes to grapefruit aroma; cis-galbanum oxathiane is used in fine fragrances and personal care products.

Food preservation: SO2 and sulfite salts provide antimicrobial/antioxidative action, preventing browning and spoilage.

Q8. What is the structure of sulfuric acid? Explain the contact process for manufacturing H2SO4.

Structure of Sulfuric Acid

Tetrahedral structure with sulfur at the center: two S=O (double) bonds and two S-OH (single) bonds.

Contact Process - Stage 1: Sulfur/Pyrite Burners

Combustion of molten sulfur or heating pyrite (FeS2) in excess air produces SO2:

2S(s)+O2(g) -> 2SO2(g), Delta H = -297.03 kJ/mol; 4FeS2(s)+11O2(g) -> 2Fe2O3(s)+8SO2(g)

Stage 2: Purification Unit

If pyrite ore is used, contaminants like arsenic oxide (As2O3) must be removed to protect the catalyst: As2O3(g)+2Fe(OH)3(l) -> 2FeAsO3(l)+3H2O(l), using gelatinous ferric hydroxide as an arsenic purifier.

Stage 3: Contact Tower and Heat Exchangers

Purified SO2 and preheated air (420-450 deg C, 1-2 atm) meet V2O5 catalyst: 2SO2(g)+O2(g) <=> 2SO3(g), Delta H = -197.96 kJ/mol.

Catalyst mechanism: Step 1 (oxidation by V5+): SO2(g)+V2O5(s) -> SO3(g)+V2O4(s). Step 2 (regeneration): V2O4(s)+1/2 O2(g) -> V2O5(s).

Stage 4: Absorption Tower

Mixing SO3 directly with water is unfeasible (highly exothermic, produces acid mist); SO3 is dissolved in hot 98.5% sulfuric acid to form oleum: H2SO4(l)+SO3(g) -> H2S2O7(l) (oleum); H2S2O7(l)+H2O(l) -> 2H2SO4(l).

Quick Check

High temperature and catalyst are both needed: the catalyst increases rate; higher temperature also increases rate but lowers yield, so a compromise temperature is used, and excess O2 is added to boost yield.

Dehydration with conc. H2SO4: starch -> carbon + water; oxalic acid -> CO+CO2+H2O.

Q9. Discuss the chemical and physical properties of sulfuric acid.

Physical Properties

Soluble in water and hygroscopic (absorbs water vapour from air); anhydrous H2SO4 is a very polar liquid; highly corrosive, causing chemical burns on contact with skin - handle with great care.

Chemical Properties - Self-Ionization

H2SO4(l)+H2SO4(l) <=> H3SO4+(l)+HSO4-(l), K=2.7x10^-4 - a value greater than water's, making H2SO4 useful as a non-aqueous protic solvent.

First ionization (strong acid): H2SO4(aq)+H2O -> H3O++HSO4-, pKa1=-2. Second ionization (weak acid): HSO4-(aq)+H2O(l) <=> H3O++SO4(2-)(aq), pKa2=1.92.

Dehydrating Agent

Concentrated H2SO4 is a powerful dehydrating agent: sucrose -> carbon 'snake' + water; ethanol -> ethene + water.

Other Reactions

With NaCl: NaCl(s)+H2SO4(l) -> NaHSO4(s)+HCl(g).

With metals: dilute H2SO4 + metals above hydrogen gives H2 gas (e.g. Zn); cold conc. H2SO4 + Zn gives SO2; hot conc. H2SO4 + Cu/Ag/Hg gives SO2 as well.

Oxidizing power: H2SO4 is not a typical strong oxidizing agent (due to SO4 2- stability), but hot concentrated H2SO4 is a moderately strong oxidizer due to high temperature, high H+ concentration, and nascent oxygen formation.

Uses of Sulfuric Acid

Drying agent for gases in industrial processes; used in lead storage batteries (about 35.67% acid); widely used as a laboratory and industrial reagent, though rarely present in final products.

Section 5 | Answer Key & Formula Summary

MCQ Answer Key (Q1-Q36)

Q.No	Ans	Q.No	Ans	Q.No	Ans	Q.No	Ans
1	C	10	B	19	B	28	B
2	C	11	A	20	C	29	B
3	C	12	C	21	C	30	B
4	B	13	C	22	B	31	A
5	C	14	C	23	B	32	B
6	C	15	C	24	B	33	C
7	A	16	A	25	A	34	D
8	C	17	A	26	B	35	C
9	D	18	A	27	B	36	A

Important Formulas

Formula	Description
NH4NO2(aq) -> N2(g) + 2H2O(l)	Laboratory preparation of Nitrogen
N2(g) + 3H2(g) <=> 2NH3(g)	Haber-Bosch process for Ammonia
NH3(aq) + H2O(l) <=> NH4+(aq) + OH-(aq)	Basicity of Ammonia (Kb = 1.8 x 10^-5)
2NO(g) + 2CO(g) -> N2(g) + 2CO2(g)	Catalytic converter reduction reaction
2SO2(g) + O2(g) <=> 2SO3(g)	Contact Process (V2O5 catalyst)
H2SO4(l) + SO3(g) -> H2S2O7(l)	Formation of Oleum (fuming sulfuric acid)
H2SO4(aq) + H2O -> H3O+ + HSO4-	First ionization of Sulfuric Acid (pKa1 = -2)
HSO4-(aq) + H2O(l) <=> H3O+ + SO4(2-)(aq)	Second ionization of Sulfuric Acid (pKa2 = 1.92)

Key Constants & Notes

Constant/Note	Value
Bond Energy of N#N (triple bond)	+944 kJ/mol
Kb of NH3	1.8 x 10^-5
pKa1 of H2SO4	-2 (strong acid)
pKa2 of H2SO4 (as HSO4-)	1.92 (weak acid)
Self-ionization constant of H2SO4	K = 2.7 x 10^-4
Melting point of H2SO4	10 deg C
Boiling point of H2SO4	290 deg C
Molar Mass of H2SO4	98.08 g/mol

Electronegativity of Nitrogen	3.0
Electronegativity of Sulfur	2.5
Relative Atomic Mass of Sulfur	32.06 amu

Most Stable Oxidation State of Sulfur by pH

pH Condition	Stable State	Common Species
pH = 0 (Strongly Acidic)	+6	H2SO4, SO4(2-)
pH = 14 (Strongly Basic)	-2	S2-, HS-

Key Structures

Compound	Structure
N2	Triple bond (N#N)
NH3	Pyramidal (sp3 with one lone pair)
NH4+	Tetrahedral
S8 (Cyclo-octasulfur)	Crown-shaped ring
H2SO4	Tetrahedral with two S=O and two S-OH bonds

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