Applied Chemistry | 2025 Question Paper Sol

Group A

1.

i. Number of sub-shells present in M-shell is

Answer: **3**

Explanation: M-shell (n = 3) → subshells = 3s, 3p, 3d → total 3.

ii. pH of 0.01 M H_2SO_4 solution is

Answer: **1.7**

Explanation: H_2SO_4 gives ≈0.02 M H^+ → pH ≈ 1.70.

iii. 1 ppm is equal to

Answer: **1 mg/L**

Explanation: In water, 1 ppm ≈ 1 mg per litre.

iv. In the ground state, an element having 13 electrons in the M-shell is

Answer: *(None of the given options; correct element = Vanadium)*

Explanation: M-shell electrons = Z − 10 = 13 → Z = 23 → Vanadium.

v. Distilled water contains

Answer: **only H^+ & OH^- ions**

Explanation: No dissolved ions or gases except auto-ionization.

vi. Which element is not suitable to form H-bond?

Answer: **C**

vii. Froth flotation process is performed for

Answer: **Sulphide ore**

Explanation: Flotation selectively separates hydrophobic sulphide minerals.

viii. Proximate analysis of coal estimates % of

Answer: **moisture, volatile matter, ash, fixed carbon**

Explanation: These four components define proximate analysis.

ix. Which is NOT a characteristic of a good lubricant?

Answer: **high volatility**

Explanation: A good lubricant should be low-volatility and thermally stable.

x. Setting and hardening of cement involves

Answer: **hydration and hydrolysis**

xi. The synthesis of which of the following polymers requires the loss of water molecules on a regular basis?

Answer: **Nylon-6,6**

xii. The chemical added to detect leakage from LPG cylinder is

Answer: **ethyl mercaptan**

xiii. The amount of electricity required to produce 12 g of O_2 at respective electrode from acidulated water is

Answer: **1.5 F**

Explanation:

12 g O_2 = 0.375 mol.

O_2 formation requires 4 e^- per molecule → 4 × 0.375 = 1.5 mol e^- → **1.5 Faraday**.

xiv. Oxidation number of O in H_2O_2 is

Answer: **−1**

Explanation: Let oxidation number of O = x:

$2(+1) + 2x = 0 \rightarrow x = -1$.

xv. Octane number of petrol is calculated considering the percentage of

Answer: **iso-octane**

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Group B

2(a) How hydrogen atomic spectra can be explained from Bohr model?

Bohr's model successfully explains the line spectrum of the hydrogen atom using the following ideas:

1. **Quantized Orbits:**
   Bohr proposed that the electron revolves around the nucleus only in certain *fixed circular orbits* where angular momentum is quantized:
   $$mvr = n\hbar$$
2. **Energy Levels:**
   Each orbit has a definite energy:
   $$E_n = -\frac{13.6}{n^2}\ \mathrm{eV}$$
   Energy becomes less negative as n increases.
3. **Emission or Absorption of Radiation:**
   The electron **does not radiate energy** while in a fixed orbit.
   Radiation is emitted or absorbed **only when the electron jumps** between two energy levels.
   Energy of emitted photon:
   $$h\nu = E_i - E_f$$
4. **Explanation of Line Spectrum:**
   For hydrogen, different transitions give rise to different spectral series:
   - Lyman (UV): transitions to $n = 1$
   - Balmer (Visible): transitions to $n = 2$
   - Paschen (IR): transitions to $n = 3$, etc.

Thus, the Bohr model perfectly matches the experimentally observed wavelengths of hydrogen spectral lines.

2(b) State Hund's rule of maximum multiplicity and explain with example.

Hund's Rule of Maximum Multiplicity:

Electrons first fill all the degenerate orbitals singly with parallel spins before pairing occurs.

Explanation:

- Degenerate orbitals = orbitals of the same energy (e.g., p, d, f suborbitals).
- This arrangement minimizes electron–electron repulsion and maximizes total spin → leading to maximum stability.

Example: Nitrogen (Z = 7)

Electron configuration:

$$1s^2\,2s^2\,2p^3$$

In the **2p** subshell (three orbitals: p_x, p_y, p_z):

According to Hund's rule:

- One electron enters each of the three p-orbitals
- All with **parallel spins**

Diagram:

$$\text{2p: } \uparrow \uparrow \uparrow$$

This avoids pairing until necessary and gives nitrogen its stable half-filled $2p^3$ configuration.

2(c) Find all the quantum numbers of the last two electrons of O^{2-} ion.

Step 1: Determine electron configuration

Oxygen (Z = 8)
O^{2-} has gained 2 electrons → total electrons = **10**

So configuration becomes like neon:

$$1s^2\,2s^2\,2p^6$$

Last two electrons go into the **2p orbital**.

Step 2: Write quantum numbers

For **2p**, the quantum numbers possible:

- Principal quantum number: $n = 2$
- Azimuthal (subshell): $l = 1$

Magnetic quantum number (m_l) possible values:

$$-1,\ 0,\ +1$$

Spin quantum number (m_s):

$$+\frac{1}{2} \text{ or } -\frac{1}{2}$$

Because O^{2-} has a **fully filled** $2p^6$ subshell, we assign the last two electrons to the third p-orbital (pairing).

Quantum numbers of last two electrons:

Electron 1:

- $n = 2$
- $l = 1$
- $m_l = +1$
- $m_s = +\frac{1}{2}$

Electron 2:

- $n = 2$
- $l = 1$
- $m_l = +1$
- $m_s = -\frac{1}{2}$

(These two are paired in the same p-orbital.)

3(a) Explain why ethyl alcohol has a higher boiling point than dimethyl ether though they have the same molecular formula.

Ethyl alcohol (C_2H_5OH) and dimethyl ether (CH_3–O–CH_3) both have the formula $\mathbf{C_2H_6O}$, but their boiling points differ greatly.

Reason: Hydrogen Bonding

- **Ethyl alcohol contains –OH group**, which can form **strong intermolecular hydrogen bonds**.
- Hydrogen bonding requires a hydrogen atom directly bonded to a highly electronegative atom (O, N, F).
- These hydrogen bonds hold the alcohol molecules strongly together, so **more heat energy is required to break them**, resulting in a **higher boiling point**.

Dimethyl ether cannot form hydrogen bonds between its molecules

- Dimethyl ether has an oxygen atom, but **no O–H bond**.
- Therefore, it cannot form intermolecular hydrogen bonding.
- Only weak dipole–dipole forces exist, so it has a **much lower boiling point**.

3(b) Mention two structural differences between graphite and diamond.

Difference 1: Structure

- **Diamond:**
  - Each carbon atom is **sp^3 hybridized.**
  - Forms a **three-dimensional tetrahedral network.**
  - Very strong C–C bonds → very hard.
- **Graphite:**
  - Each carbon atom is **sp^2 hybridized.**
  - Forms **flat hexagonal layers** (two-dimensional sheets).
  - Layers are held by weak van der Waals forces → soft and slippery.

Difference 2: Electrical Conductivity

- **Diamond:** Does **not** conduct electricity (no free electrons).
- **Graphite: Good conductor** of electricity because each carbon has one delocalized electron in the layers.

3(c) Hybridisation of N is same in both NH_4^+ ion and NH_3 molecule although geometry of NH_4^+ ion is regular tetrahedral but NH_3 molecule is distorted tetrahedral. Explain why?

Hybridisation:

Both **NH_4^+** and **NH_3** involve **sp^3 hybridisation** of nitrogen.

Why their shapes differ:

NH_4^+ (Ammonium ion):

- Nitrogen forms **four N–H sigma bonds.**
- **No lone pair** remains on nitrogen.
- All four hybrid orbitals are occupied by bonding pairs.
- Repulsions are equal → **regular tetrahedral geometry** (bond angle = 109.5°).

NH_3 (Ammonia molecule):

- Nitrogen forms **three N–H sigma bonds.**
- One **lone pair** remains in the fourth hybrid orbital.
- Lone pair–bond pair repulsion > bond pair–bond pair repulsion.
- This pushes the N–H bonds closer together → **distorted tetrahedral** or **trigonal pyramidal** geometry (bond angle = 107° approx).

4(a) Why hard water does not produce lather easily on mixing with soap?

Hard water contains dissolved **calcium (Ca^{2+})** and **magnesium (Mg^{2+})** ions.

When soap (sodium salt of fatty acid, e.g., sodium stearate) is added to hard water:

$$2C_{17}H_{35}COO^- \, Na^+ + Ca^{2+} \rightarrow (C_{17}H_{35}COO)_2Ca \downarrow + 2Na^+$$

- The Ca^{2+}/Mg^{2+} react with soap and form **insoluble precipitates** called **scum.**
- Because of this precipitation, soap is **wasted**, and **very little soap remains free** to form lather.

Hence, hard water does not form lather easily.

4(b) Write down the principle and chemical reaction involved in resin process of softening of hard water.

Principle:

The resin process is based on **ion-exchange**, where:

- **Cation exchange resins (R–H type)** replace Ca^{2+} and Mg^{2+} ions by **H^+ ions.**
- **Anion exchange resins (R–OH type)** replace anions (Cl^-, SO_4^{2-}) by **OH^- ions.**

H^+ and OH^- combine to form **pure water.**

Chemical Reactions:

1. **Cation exchange resin:**

$$2R\text{–}H + Ca^{2+} \rightarrow R_2Ca + 2H^+$$

2. **Anion exchange resin:**

$$R\text{–}OH + Cl^- \rightarrow R\text{–}Cl + OH^-$$

3. **Final water formation:**

$$H^+ + OH^- \rightarrow H_2O$$

Thus, all hardness-causing ions are removed.

4(c) Calculation: Total volume of water softened by the zeolite softener

Given:

- Volume of NaCl used = **117 L**
- Strength = **50 g/L**
- Hardness of water = **500 ppm**
- Molar mass: NaCl = **58.5 g/mol**, $CaCO_3$ = **100 g/mol**

Step 1: Total mass of NaCl used

$$117 \text{ L} \times 50 \text{ g/L} = 5850 \text{ g NaCl}$$

Step 2: Convert NaCl mass to moles

$$\text{Moles of NaCl} = \frac{5850}{58.5} = 100 \text{ mol}$$

In zeolite regeneration:

$$Na_2Ze + Ca^{2+} \rightarrow CaZe + 2Na^{+}$$

1 mole of Ca^{2+} requires **2 moles of Na^{+}**, i.e., **2 moles of NaCl.**

Step 3: Moles of $CaCO_3$ hardness removed

$$\text{Moles of hardness} = \frac{100}{2} = 50 \text{ mol CaCO}_3$$

Step 4: Convert moles of $CaCO_3$ to mass

$$\text{Mass} = 50 \times 100 = 5000 \text{ g CaCO}_3$$

Step 5: Use ppm to calculate volume softened

Hardness = **500 ppm** = **500 mg/L** = **0.5 g/L**

So every litre contains **0.5 g $CaCO_3$** hardness.

$$\text{Volume softened} = \frac{5000 \text{ g}}{0.5 \text{ g/L}} = 10000 \text{ L}$$

5(a) Explain with chemical reaction the setting and hardening of Portland cement.

Setting and hardening of cement occur due to **hydration reactions** between the cement compounds and water.

Main compounds in Portland cement

- Tricalcium silicate (C_3S)
- Dicalcium silicate (C_2S)
- Tricalcium aluminate (C_3A)
- Tetracalcium aluminoferrite (C_4AF)

1. Setting (Initial hardening)

Setting is caused mainly by **hydration of C_3A and C_4AF.**

Reaction:

$$C_3A + 6H_2O \rightarrow C_3A \cdot 6H_2O \quad \text{(gel, causes initial set)}$$

Gypsum controls the fast reaction of C_3A.

2. Hardening (Final strength development)

Hardening occurs due to slow hydration of **C_3S and C_2S.**

Reactions:

1. **Tricalcium silicate (major strength giver):**

$$2C_3S + 6H_2O \rightarrow C_3S_2H_3 + 3Ca(OH)_2$$

This forms a strong **calcium silicate hydrate (C–S–H) gel.**

2. **Dicalcium silicate:**

$$2C_2S + 4H_2O \rightarrow C_3S_2H_3 + Ca(OH)_2$$

Hardens slowly and contributes to long-term strength.

5(b) Classify lubricants with proper example.

Lubricants are classified into **three main types:**

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1. Liquid lubricants (Oils)

Used in engines and machines.

Examples:

- Mineral oil
- Synthetic oils (e.g., ester oils)

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2. Semi-solid lubricants

Used where leakage must be avoided.

Examples:

- Grease (lime grease, sodium grease, calcium grease)
- Vaseline

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3. Solid lubricants

Used under high temperature or high pressure.

Examples:

- Graphite
- Molybdenum disulphide (MoS_2)
- PTFE (Teflon)

5(c) Explain the statement: "Octane number of a sample gasoline is 60".

The statement means:

The fuel behaves like a mixture containing 60% iso-octane and 40% n-heptane in knocking characteristics.

Meaning of the value:

- **Iso-octane** has octane number = 100 (excellent anti-knocking).
- **n-Heptane** has octane number = 0 (poor anti-knocking).

So, if the gasoline has an **octane number of 60**, it means:

> The knocking tendency of the fuel is equivalent to a mixture of **60% iso-octane** and **40% n-heptane**.

Thus, it is a moderately good fuel for internal combustion engines.

6. (a) Define calcinations and roasting.

Calcination is the process of heating an ore in the absence or limited supply of air to remove moisture or volatile impurities.

Roasting is the process of heating sulphide ores in the presence of excess air to convert them into oxides and remove sulphur as SO_2.

6. (b) Why cryolite is added during extraction of Al from Al_2O_3?

Cryolite is added to lower the melting point of Al_2O_3 and to increase its electrical conductivity, making electrolysis easier and economical.

6. (c) State the composition of producer gas and bio gas.

Producer gas mainly contains CO (≈30%) and N_2 (≈60%).

Bio gas mainly contains CH_4 (≈60%) and CO_2 (≈40%).

6. (d) What is vulcanisation of rubber?

Vulcanisation is the process of heating raw rubber with sulphur to improve its elasticity, strength, and durability.

7. (a) Mention the reaction occurring in blast furnace during iron extraction.

In the blast furnace, the following reactions occur:

1. **Formation of CO (reducing agent):**
   $C + O_2 \rightarrow CO_2$
   $CO_2 + C \rightarrow 2CO$
2. **Reduction of iron ore:**
   $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$
3. **Formation of slag:**
   $CaCO_3 \rightarrow CaO + CO_2$
   $CaO + SiO_2 \rightarrow CaSiO_3$ (slag)

(b) Explain electrolytic refining of copper metal.

Electrolytic refining is used to obtain **99.9% pure copper**.

- **Impure copper** → anode
- **Pure copper strip** → cathode
- **Electrolyte** → acidified $CuSO_4$ solution

At anode: $Cu \rightarrow Cu^{2+} + 2e^-$

At cathode: $Cu^{2+} + 2e^- \rightarrow Cu$ (pure copper deposited)

Impurities settle at the bottom as **anode mud.**

(c) Describe the principle of cathodic protection.

Cathodic protection prevents corrosion by making the metal act as a **cathode.**

Two methods:

1. **Sacrificial anode method:** A more reactive metal (Zn, Mg) is connected; it corrodes instead of the protected metal.
2. **Impressed current method:** External DC source supplies electrons to the metal, preventing oxidation.

This method is used for pipelines, ship hulls, underground tanks, etc.

8(a) A current of 2.5 A is passed through two electrolytic cells containing $ZnSO_4$ and $NiSO_4$ solution for an hour. Find the ratio of the masses of zinc to nickel deposited at the respective electrodes.

Answer :

Using **Faraday's First Law of Electrolysis,**

$$m = \frac{EIt}{F}$$

Since current and time are the same for both metals,

$$\frac{m_{Zn}}{m_{Ni}} = \frac{E_{Zn}}{E_{Ni}}$$

Equivalent weight,

$$E = \frac{\text{Atomic wt.}}{\text{valency}}$$

Zinc valency = 2

Nickel valency = 2

$$E_{Zn} = \frac{65}{2} = 32.5$$

$$E_{Ni} = \frac{59}{2} = 29.5$$

Thus,

$$\frac{m_{Zn}}{m_{Ni}} = \frac{32.5}{29.5} \approx 1.10 : 1$$

Ratio of masses deposited = 1.10 : 1 (Zn : Ni)

8(b) Establish the relation between equivalent weight and electrochemical equivalent weight.

Answer :

Let:

- E = equivalent weight
- Z = electrochemical equivalent
- F = Faraday's constant (96500 C)

From Faraday's law,

$$m = ZIt$$

But also,

$$m = \frac{EIt}{F}$$

Equating both expressions:

$$ZIt = \frac{EIt}{F}$$

$$Z = \frac{E}{F}$$

Relation:

$$\boxed{Z = \frac{E}{F}}$$

Electrochemical equivalent is equal to the equivalent weight divided by the Faraday constant.

8(c) Mention the electrodes used in a dry cell and write down the chemical changes taking place at different electrodes in a dry cell.

Answer :

Electrodes of a dry cell (Leclanché cell):

- **Anode (negative electrode):** Zinc container
- **Cathode (positive electrode):** Carbon rod surrounded by MnO_2

Chemical Reactions:

At Anode (Oxidation):

$$Zn(s) \rightarrow Zn^{2+} + 2e^-$$

At Cathode (Reduction):

$$2MnO_2 + 2NH_4^+ + 2e^- \rightarrow Mn_2O_3 + 2NH_3 + H_2O$$

Ammonia forms complexes with Zn^{2+} and moisture forms a paste.

9. (a) Calculate the pH of 10^{-8} M HCl solution.

In very dilute strong acids, water's auto-ionization must be considered.

Let total $[H^+]$ = $10^{-8} + x$, where $x = 10^{-7}$ from water.

Since $10^{-7} \gg 10^{-8}$,
$[H^+] \approx 1.1 \times 10^{-7}\ M$

pH = $-\log(1.1 \times 10^{-7})$
pH ≈ **6.96**

(b) What is buffer solution? Give one example of acidic buffer.

A buffer solution is a solution that **resists change in pH** when small amounts of acid or base are added.

Example of acidic buffer:

CH_3COOH + CH_3COONa (acetic acid + sodium acetate)

(c) A high-strength brass alloy contains 70% Cu, 25% Zn, 5% Fe. Find the mole fraction of each metal.

Given molar masses:

Cu = 63.5 g/mol, Zn = 65 g/mol, Fe = 56 g/mol

Take 100 g of alloy.

Moles of Cu:

70 / 63.5 = 1.102 mol

Moles of Zn:

25 / 65 = 0.3846 mol

Moles of Fe:

5 / 56 = 0.0893 mol

Total moles = 1.102 + 0.3846 + 0.0893 = 1.5759 mol

Mole fractions:

Cu = 1.102 / 1.5759 = **0.700**

Zn = 0.3846 / 1.5759 = **0.244**

Fe = 0.0893 / 1.5759 = **0.056**