Category-wise Cut Off

YEAR	GEN	OBC-NCL/EWS	SC/ST/PWD
2021	25.9	23.3	17.2
2022	39.6	35.6	26.4
2023	27.7	24.9	18.4
2024	37.9	34.1	25.2
2025	26.1	23.4	17.4
2026	30	27	20

I N D E X

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GATE ENVIRONMENTAL SCIENCE:
NUMBER OF QUESTIONS ASKED IN PREVIOUS EXAMS (2021-2026)

ENVIRONMENTAL CHEMISTRY		2021	2022	2023	2024	2025	2026
3.1	Fundamentals of Environmental Chemistry	1	1	-	1	-	3
3.2	Principles of Water Chemistry	5	5	2	5	4	2
3.3	Soil Chemistry	-	-	-	-	-	1
3.4	Atmospheric Chemistry	1	1	-	1	1	2

3

ENVIRONMENTAL CHEMISTRY

-: Unit 3.1 Fundamentals of Environmental Chemistry:-

Covalent and ionic bonding; Chemical equations, concentration and activity; Structure and chemistry of organic molecules; Radioactivity of elements; Chemical equilibria; Thermodynamics and kinetics of chemical reactions.

Multiple Choice Questions (MCQ)

[2021: 1 Mark]

1. **The Oxidation states of $^{-}N^{*}$ in NHI_4^+, NO_2^-, and NO are respectively.**
   (A) $+2, -3$, and +3 (B) $-3, +3$, and +2
   (C) $-3, +3$, and -4 (D) $+4, -2$, and +2

[2024: 1 Mark]

2. **The maximum coordination number of Sn 4+ is _____.**
   (A) 4 (B) 8
   (C) 6 (D) 2

[2026: 1 Mark]

3. **In the reversible reaction shown below, k_f is the forward reaction rate constant and k_r is the reverse reaction rate constant.**
   The CORRECT expression representing the reaction equilibrium constant is ___ -
   $A + B \underset{k_r}{\overset{k_f}{\rightleftharpoons}} C + D$
   (A) $k_f + k_r$ (B) $k_f \times k_r$
   (C) $\frac{k_f}{k_r}$ (D) $\frac{k_r}{k_f}$

Multiple Select Questions (MSQ)

[2022: 1 Mark]

1. **If G represents Gibbs free energy, select the correct statement(s)**
   (A) If $\Delta G = 0$, reaction will proceed only in one direction
   (B) If $\Delta G = 0$, reaction will be in equilibrium
   (C) If $\Delta G < 0$, reaction will proceed forward
   (D) If $\Delta G > 0$, reaction will not proceed forward

Numerical Answer Type Questions (NAT)

[2026: 2 Mark]

1. **Reaction $A \rightarrow B$ follows first-order elementary kinetics and the reaction rate constant for A is 0.01 per min.**
   The time taken to reduce the concentration of A from 100 M to 10 M in a batch reactor is ___ min (rounded off to one decimal place)

[2026: 2 Mark]

2. **The following two reactions describe the chemistry of S(IV) in an aquatic system.**
   Under ideal conditions, the equilibrium constants for reactions (i) and (ii) are $1.3 \times 10^{-2} M(K_{s1})$ and $6.6 \times 10^{-8} M(K_{s2})$, respectively.
   If the pH of the system is 4.0 and the equilibrium concentration of $SO_{2(aq)}$ is 1.0 M , the equilibrium concentration of SO_3^{2-} is ___ mM (rounded off to one decimal place).

$$SO_{2(aq)} \rightleftharpoons H^+ + HSO_3^-$$
$$HSO_3^- \rightleftharpoons H^+ + SO_3^{2-}$$

ANSWER KEY		
Multiple Choice Questions (MCQ)		
1	**2**	**3**
B	C	**C**
Multiple Select Questions (MSQ)		
1		
B,C,D		
Numerical Answer Type Questions (NAT)		
1	**2**	
225 to 235	80 to 90	

EXPLANATION

Multiple Choice Questions (MCQ)

1. **Explanation: (B)** To determine the oxidation states of nitrogen in NHI_4^+ , NO_2^-, and **NO**, let's break it down:

1. **In NHI_4^+** (Ammonium ion): The charge on the ion is +1, and hydrogen has an oxidation state of +1. Since there are four hydrogens, their total oxidation state is +4. To balance this, nitrogen must have an oxidation state of **-3.**
2. **In NO_2^-** (Nitrite ion): The charge on the ion is -1, and oxygen has an oxidation state of -2 (since it's typically -2 in most compounds). With two oxygens, the total oxidation state for oxygen is -4. To balance the -4, nitrogen must have an oxidation state of **+3.**

3. **In NO** (Nitric oxide): The molecule is neutral, and oxygen has an oxidation state of -2. To balance this, nitrogen must have an oxidation state of **+2.**
   Thus, the oxidation states of nitrogen in $\mathbf{NHI_4^+}$, $\mathbf{NO_2^-}$, and **NO** are **-3, +3, and +2**, respectively.

2. Explanation: (C)

Coordination number refers to the number of ligand donor atoms directly bonded to the central metal ion in a complex.

For **Sn^{4+} (tin in +4 oxidation state)**, its relatively small ionic radius and high positive charge allow it to attract more ligands. It can **accommodate up to 6 ligands** around it due to its electronic structure and size, especially in complexes like **$[SnCl_6]^{2-}$**.

3. Explanation: (C)

At equilibrium, the forward rate equals the reverse rate.
Rate forward = kf [A][B]
Rate reverse = kr [C][D]
Set the two rates equal (since equilibrium means no net change).
kf [A][B] = kr [C][D]
Rearrange to group the rate constants together and concentrations together.
kf / kr = [C][D] / [A][B]
Compare this with the standard equilibrium constant expression.
K(eq) = [C][D] / [A][B]
Therefore, it follows that:
K(eq) = kf / kr

Multiple Select Questions (MSQ)

1. Explanation: (B), (C), (D)

ΔG = 0: The reaction is at equilibrium, meaning no net change occurs, and it can proceed in both directions equally.

- **ΔG < 0**: The reaction is **spontaneous** and will proceed forward in the direction that decreases Gibbs free energy.
- **ΔG > 0**: The reaction is **non-spontaneous** and will not proceed forward unless external energy is supplied.

Numerical Answer Type Questions (NAT)

1. Explanation: (225 to 235)

Time (t) = 1/K ln { yi/ye}
= 1/0.01 ln {100/10}
= ln (10) 2.303 log (10)/1
= ln (100) 2.303 x 1
= 230 min

2. Explanation: (80 to 90)

$(i) K_{s_1} = 1.3 \times 10^{-2}$m
$(ii) K_2 = 6.6 \times 10^{-8}$M
Concentrations:
Ks1 = [Product] / [Reactant]

$$1.3 \times 10^{-2} = \frac{[10^{-4}][HSO_3^-]}{1}$$

$$[HSO_3^-] = 1.3 \times 10^{-2}\ M$$

$$K_{a_2} = \frac{[HSO_3^-]}{[HSO_3^-]}$$

$$6.6 \times 10^{-8} = \frac{10^{-2}}{1.3} \text{ x } \frac{[HSO_3^-]}{[HSO_3^-]}$$

$\{SO_3^{2-}\} = 6.6 \times 10^{-8}$M x 1.3×10^{-2}m/10^{-4}

$$= 0.066 \times 1.3$$
$$= 0.0858\ M$$
$$= \mathbf{85.8}\ \boldsymbol{mM}$$

-: Unit 3.2 Principles of Water Chemistry:-

Water quality parameters and their measurement; Acid-base equilibria; Buffer solution; Carbonate system; Solubility of gases in water; Complexation, precipitation, and redox reactions; Inorganic and organic contaminants in water and their speciation.

Multiple Choice Questions (MCQ)

[2021: 1 Mark]

1. What is the pH is of a water sample having H' concentration of 10 mg L.?
The atomie weight of H is 1 s'mol.
(A) 2 (B) 4
(C) 6 (D) 8

[2024: 1 Mark]

2. Hardness in water is NOT caused by _____.
(A) Ca2+ (B) Si2+
(C) Mg2+ (D) $CO3\ 2-$

[2021: 2 Marks]

3. A 200mL sample of water has an initial $\text{pH} = 9$. In order to determine alkalinity, the sample was titrated using $0.02\ \text{NH}_2\text{SO}_4$ acid to an end point of $\text{pH} = 4.5$. In the titration, 25 mL of 0.02 N H_2SO_4 acid was required. What is the total alkalinity of the sample in ' mg/L as NaHCO_3 '?
[Atomic weight (g/mol): $\text{Ca} = 40, \text{Na} = 23, \text{H} = 1, \text{C} = 12, \text{S} = 32$, and $O = 16$]
(A) 20 (B) 125
(C) 210 (D) 305

[2022: 1 Mark]

4. A student reported following arsenic concentrations in water samples:

Arsenic concentration (mg/L)	0.10	0.12	0.20	0.05	0.40	0.30	0.35

Which one of the following is a correct statement about arsenic concentration distribution?
(A) Arsenic concentration distribution is symmetric
(B) Arsenic concentration distribution is positively skewed
(C) Arsenic concentration distribution is negatively skewed
(D) Arsenic concentration is following Weibull distribution

[2022: 1 Mark]

5. Specific conductance is used in water analysis to indirectly estimate dissolved solids. The measurements used in the method accounts for
(A) Cations only (B) All ions
(C) Anions only (D) Un-ionized species

[2022: 1 Mark]

6. Carbon dioxide is used in re carbonation process. A solution has 1 mole/L supersaturated calcium carbonate. Estimated amount of carbon dioxide (in grams) needed to completely convert calcium carbonate to calcium ions in 1 litre solution is
(A) 44.000 gram (B) 0.044 gram
(C) 40.000 gram (D) 0.040gram

[2023: 1 Mark]

7. For testing alkalinity for a water sample, first phenolphthalein indicator is added. The water remains colorless. However, when a few drops of methyl arrange is added to the sample, the color turns yellow. As per these observations, the correct choice is
(A) Absence of $\text{CO}^{2\ 2}$ andlor HCOr^-but the presence of OH^-ions in the sample
(B) Absence of CO_3^{2-}, $\text{HCO}_3^-$and OH^-ions in the sample
(C) Presence of $\text{CO}_3^{\ 3-}$ and/or $\text{HCO}_3^{\ -}$but the absence of OH^-ions in the sample
(D) Presence of $\text{CO}_3^{\ 2-}$, $\text{HCO}_3^{\ -}$and OH^-ions in the sample

[2024: 2 Mark]

8. A saturated CaCO3 stock solution is existing at 25°C. In one experiment (i) 25 g Na2CO3 is added to the stock solution. In another experiment (ii) 25 g Na2SO4 is added to the stock solution. Select the correct statement from the following.
(A) Addition of (i) increases the concentration of Ca2+ and addition of (ii) decreases the concentration of Ca2+
(B) Addition of (i) decreases the concentration of Ca2+ and addition of (ii) increases the concentration of Ca2+
(C) Addition of (i) and (ii) increase the concentration of Ca2+
(D) Addition of (i) and (ii) decrease the concentration of Ca2+

[2025: 1 Mark]

9. Choose the redox reaction from the following
(A) $\text{H}_2\text{CO}_3 \leftrightarrow \text{H}^+ + \text{HCO}_3^-$
(B) $\text{Hg}^{2+} + 2\text{OH}^- \leftrightarrow \text{Hg(OH)}_2$
(C) $\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \leftrightarrow 6\text{CO}_2 + 6\text{H}_2\text{O}$
(D) $\text{CaCO}_3(\text{s}) \leftrightarrow \text{Ca}^{2+} + \text{CO}_3^{2-}$

[2025: 2 Mark]

10. A researcher added certain amount of $HgCl_2$ to water at pH 10. He calculated the expected concentration of mercury in the water. He asked his student to measure the concentration. His student used an instrument that can measure only the free metal, Hg^{2+}. The student observed that the concentration measured by him was significantly less than the concentration calculated by the researcher. How can he explain the paradox to the researcher?

Explanation 1: Significant fraction of the mercury would have changed phase from aqueous to gaseous phase, thus leaving less mercury in the water

Explanation 2: Fraction of the mercury added to water would have formed aqueous complexes

Explanation 3: Fraction of the mercury added to water could have precipitated

Choose the correct option from the following

(A) only Explanation 1 is correct

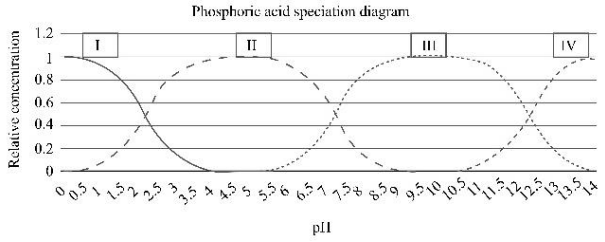
(B) Explanations 1 and 2 are correct

(C) Explanations 1 and 3 are correct

(D) Explanations 2 and 3 are correct

[2025: 2 Mark]

11. Correctly label the speciation diagram below:



(A) $I = PO_4^{3-}, II = HPO_4^{2-}, III = H_2PO_4^{-}, IV = H_3PO_4$

(B) $I = H_3PO_4, II = HPO_4^{2-}, III = H_2PO_4-, IV = PO_4^{3-}$

(C) $I = H_3PO_4, II = H_2PO_4-, III = HPO_4^{2-}, IV = PO_4^{3-}$

(D) $I = PO_4^{3-}, II = H_2PO_4-, III = H_3PO_4, IV = HPO_4^{2-}$.

[2026: 2 Mark]

12. The analysis of a water sample is shown in the table. The hardness of the water sample is ___ mg/L as $CaCO_3$.

Atomic weight $(g/mol): Ca = 40; Mg = 24; Na = 23; Cl = 35.5; S = 32; O = 16; N = 14$

Species	Concentration (mg/L)
Na^+	30
Ca^{2+}	10
Mg^{2+}	15
Cl^-	30
SO_4^{2-}	60
NO_3^-	5

(A) 87.5 (B) 62.5

(C) 25.5 (D) 47.5

Multiple Select Questions (MSQ)

[2025: 2 Mark]

1. Choose the correct option(s) from the following regarding the solubility in water

(A) Water is a polar molecule because of the asymmetric distribution of charge between the oxygen and hydrogen atoms of the water molecule.

(B) In a water molecule, the electrons shared between oxygen and hydrogen are attracted more towards the hydrogen atom.

(C) Non-polar compounds are highly soluble in water because of their strong interaction with water molecules.

(D) Aromaticity and charge of molecules influence their solubility in water.

Numerical Answer Type Questions (NAT)

[2021: 2 Marks]

1. The concentration of NO y_t in the air at NTP is reported as 0.30 ppmv (ppm by volume). The concentration of NO_2 in $\mu g/m^3$ is …… (rounded off to the nearest integer).

[At NTP, temperature $= 298$ K, pressure $= 1$ atm, and one mole of ideal gas occupies 24.45 L]

[Molecular weight of $NO_1 = 46$ g/mol]

[2021: 2 Marks]

2. The molar concentrations $(M$, i.e. $mol/L)$ of some ionic species in a water sample were estimated as follows $Na^+ = 0.25M; Ca^{2+} = 0.12M; Cl^- = 0.32M; HCO_3^- = 0.05M$

The ionic strength of this water sample is……M (Correct up to two decimal places).

[2021: 2 Marks]

3. Excess amount of solid calcium sulphate $(CaSO_4)$ was added to a pure water sample ($pH = 7$) so that some solids remain undissolved at the equilibrium. The solubility product of $CaSO_4$ is $\times 10^{-5}$ mol^2/L^2. The molar concentration of SO_4^{2-} in this water sample at

equilibrium will be ……. $\mathbf{mol/L}$ (rounded off to three decimal places).

[2022: 2 Mark]

4. **A solution has $0.\frac{001\ \text{mole}}{\text{L}}$ zinc ions having pH of 6. Solubility product of zinc hydroxide is given as $\times 10^{-18}(\ \text{mole/L})^3$. Ignoring activity corrections, the ratio (rounded off to two decimal places) of reaction coefficient to solubility product would be_____.**

[2022: 2 Mark]

5. **The Henry's law constant of CO_2 is 3.4×10^{-2}M per atm in neutral water at $25°$C. The dissolved CO_2 (i.e., $CO_2.H_2O$) at equilibrium undergoes the following reactions.**

$$CO_2 \cdot H_2O \rightleftharpoons H^+ + HCO_3^- (\text{Equilibrium constant } = 4.3 \times 10^{-7}\text{M}$$

$$HCO_3^- \rightleftharpoons H^+ + CO_3^{2-} (\text{ Equilibrium constant } = 4.7 \times 10^{-11}\text{M})$$

If ambient CO_2 concentration is 300 ppm, the total dissolved $CO_2(\text{in}\mu\text{M}$, rounded off to one decimal place) is _____.

[2023: 2 Mark]

6. **The solubility of gas A is 16 mg/L in water and its vapor pressure is 0.042 atm. At $25°C$. In closed system, the gas phase concentration of A is 10^{-3} mol/L. Assuming Ideal gas constant (R) value as 0.0821 L-atm/mol-K, the concentration of gas A in water at $25°C$ is _____(in mg/L, wounded off to two decimal places.)**

[2024: 2 Mark]

7. **The pH of a solution containing 0.1 M of acetic acid and 0.05 M of sodium acetate is…….**
(rounded off to 2 decimal places).
The pKa value of ionization of acetic acid is 4.76.

[2024: 2 Mark]

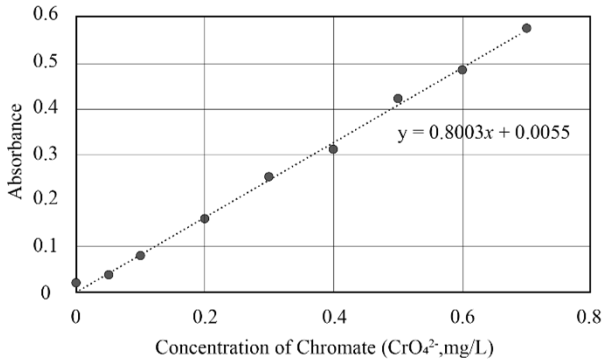
8. **The ionic strength of a solution containing 0.01 M of $CaCl_2$ and 0.001 M of Na_2SO_4 is**
M (rounded off to 3 decimal places).

[2024: 2 Mark]

9. **Initially a bottle contained 400 g of ethanol. Half of ethanol was used by a student for preparing the stock solution in an environmental chemistry laboratory just before summer vacation of 90 days. After completing the procedure, the student left the bottle uncorked. If the unsealed bottle losses ethanol at a rate of 0.5 g/ day, the ethanol that will be left in the bottle at the end of the summer vacation is …… g (an integer value).**

[2026: 2 Mark]

10. **The calibration graph between absorbance and the concentration of chromate (CrO_4^{2-}) in a water sample is shown in the figure.**
For an absorbance of 0.35 in a water sample, the estimated $Cr(VI)$ concentration is ___ mg/L (rounded off to two decimal places).
Use the atomic weight (g/mol) of Cr and O as 52 and 16, respectively.



ANSWER KEY									
Multiple Choice Questions (MCQ)									
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
A	D	C	B	B	A	B	B	C	D
11	**12**								
C	A								
Multiple Select Questions (MSQ)									
1									
A, D									
Numerical Answer Type Questions (NAT)									
1	**2**	**3**	**4**	**5**					
562 to 566	0.50 to 0.68	0.004 to 0.006	0.01 to 0.02	54.0 to 54.2					
6	**7**	**8**	**9**	**10**					
9.1 to 9.7	4.46 to 4.46	0.033	155	0.18 to 0.21					

EXPLANATION

Multiple Choice Questions (MCQ)

1. Explanation: (A)

- To calculate the pH of a water sample, we use the formula: $pH = -\log[H^+]$
- Given that the concentration of H^+ is 10 mg/L, we first need to convert this to mol/L (molarity).
- The atomic weight of hydrogen (H) is 1 g/mol, so: $10\frac{mg}{L} = 0.01\ g/L$
- Now, convert grams to moles: $Moolar\ Concentration = \frac{0.01\ g/L}{1\ g/mol} = 0.01\ mol/L$

- Now calculate the pH: pH = - log(0.01) = - log (10^{-2}) = **2**

Thus, the pH of the water sample is 2.

2. Explanation: (D) Hardness in water is caused by **Ca^{2+}** and **Mg^{2+}** ions. These metal ions react with soap and form scum. **CO_3^{2-} (carbonate ion)** does **not** cause hardness by itself — instead, it **removes hardness** by precipitating Ca^{2+}/Mg^{2+} as carbonates in **temporary hardness** treatment. Hence, **CO_3^{2-} does not *cause* hardness.**

3. Explanation (C) To determine the **total alkalinity** of the water sample in **mg/L as $NaHCO_3$**, follow these steps:

Step 1: Calculate the Equivalents of Acid Used

The equivalents of H_2SO_4 used in the titration are:

$$\text{Equivalents of acid} = \text{Normality} \times \text{Volume (L)}$$
$$= 0.02\ \text{N} \times 0.025\ \text{L} = 0.0005\ \text{eq}$$

Step 2: Relate Acid Equivalents to Alkalinity

Since alkalinity is expressed as $NaHCO_3$, we use its equivalent weight:

$$\text{Equivalent weight of } NaHCO_3 = \frac{\text{Molecular weight}}{1}$$
$$= \frac{23 + 1 + 12 + 48}{1} = 84\ \text{g/eq}$$

Step 3: Calculate Alkalinity in mg/L

$$\text{Alkalinity (mg/L as } NaHCO_3) = \frac{\text{Equivalents of acid} \times \text{Equivalent weight of } NaHCO_3}{\text{Volume of sample (L)}} \times 1000$$
$$= \frac{0.0005 \times 84}{0.2} \times 1000 = \frac{0.042}{0.2} \times 1000 = \mathbf{210\ mg/L}$$

4. Explanation: (B)

Data in Order: 0.05, 0.10, 0.12, 0.20, 0.30, 0.35, 0.40mg/L

Median (Middle Value)**:** 0.20

Mean (average): $\frac{0.05+0.10+0.12+0.20+0.30+0.35+0.40}{7}$ = 0.22mg/L

- Mean (0.22) > Median (0.20), indicating a **longer tail on the right**.

∴ The distribution is **positively skewed** (right-skewed) because higher values pull the mean above the median.

5. Explanation: (B) Specific conductance measures water's ability to conduct electricity, which depends on the presence of dissolved ions (cations and anions). Uncharged molecules don't affect conductivity. It's often used to estimate Total Dissolved Solids (TDS), which reflects water's ionic content.

6. Explanation: (A) To convert 1 mole of calcium carbonate ($CaCO_3$) to calcium ions (Ca^{2+}), 1 mole of carbon dioxide (CO_2) is required. The reaction is $CaCO_3 + CO_2 + H_2O \rightarrow Ca^{2+} + 2HCO_3^-$

1 mole/L $CaCO_3$ requires **1 mole CO_2** (44 g/mol).

Calculation = 1 mole × 44 g/mol = **44 grams CO_2**.

7. Explanation: (B) The water remains colorless with phenolphthalein, showing no strong alkalinity (no significant OH^- ions). The yellow color with methyl orange suggests the presence of **HCO_3^- ions** (bicarbonate), which are weakly basic. This indicates the absence of **CO_3^{2-}** (carbonate), **HCO_3^-**, and **OH^- ions** in the sample.

8. Explanation: (B)

When **Na_2CO_3** is added, it increases the **CO_3^{2-}** concentration, which leads to more **$CaCO_3$** precipitation, reducing the **Ca^{2+}** concentration. On the other hand, when **Na_2SO_4** is added, it increases the **SO_4^{2-}** concentration, which increases the solubility of **$CaSO_4$**, resulting in an increase in the **Ca^{2+}** concentration.

9. Explanation: (C) This is a redox reaction because it involves both **oxidation** and **reduction**. In this reaction, **glucose ($C_6H_{12}O_6$)** is **oxidized** (carbon atoms go from lower to higher oxidation state in CO_2), and **oxygen (O_2)** is **reduced** (from 0 to -2 in H_2O). A redox reaction always includes a transfer of electrons, which happens here through changes in oxidation states.

10. Explanation: (D)

- **Explanation 1** is incorrect because the **$HgCl_2$** would not significantly change to the **gas phase** under typical conditions in water at pH 10.
- **Explanation 2** is correct because at higher pH, mercury can form **aqueous complexes** like **$Hg(OH)_2$** or other complexes, reducing the concentration of free **Hg^{2+}** in the solution.
- **Explanation 3** is also correct because at **higher pH**, mercury can **precipitate** as **mercury hydroxide ($Hg(OH)_2$)** or other solid phases, further decreasing the concentration of mercury in the aqueous phase.

11. Explanation: (C)

- In the **speciation diagram** for phosphoric acid, the different species are formed depending on the **pH** of the solution.

I **(H_3PO_4)** is the **strong acid form** and is dominant at **low pH**.

II **($H_2PO_4^-$)** represents the **dihydrogen phosphate** form, which is more prevalent at **slightly acidic pH**.

III **(HPO_4^{2-})** occurs when the solution is **near neutral**.

IV **(PO_4^{3-})** is the **phosphate ion** form, which dominates at **high pH**.

Option **C** correctly labels these species based on the **pH speciation diagram** for phosphoric acid.

12. Explanation: (A)

Given = Atomic weight $(\mathbf{g/mol})$: $\mathbf{Ca = 40; Mg = 24; Na = 23; Cl = 35.5; S = 32; O = 16; N = 14}$

TH = (Ca^2) × 50/20 + (Mg^2) × 50/12

= 10 × 50/12 + 15 × 50/12

= 87.5 mg/L as CACO3

Multiple Select Questions (MSQ)

1. Explanation: (A), (D)

(A) TRUE: Water is a **polar molecule** because of the **asymmetric charge distribution** between the oxygen and hydrogen atoms. Oxygen is more electronegative, pulling the shared electrons closer, creating a dipole.

(B) FALSE: The **electrons in a water molecule** are **attracted more towards oxygen**, not hydrogen, because of oxygen's higher electronegativity.

(C) FALSE: Non-polar compounds are typically **not soluble in water** because they do not form strong interactions with the polar water molecules.

(D) TRUE: Aromaticity and charge of molecules **influence their solubility** in water. Polar, charged, or aromatic molecules tend to interact better with water molecules, enhancing their solubility.

Numerical Answer Type Questions (NAT)

1. Explanation:- (562 to 566)

The concentration of NO_x in the air at NTP is given as 0.30 ppmv (parts per million by volume). We need to find the concentration of NO_2 in $\mu g/m^3$, assuming that all NO_x is present as NO_2. The molecular weight of NO_2 is given as 46 g/mol.

At NTP (Normal Temperature and Pressure), the temperature is 298 K, the pressure is 1 atm, and one mole of an ideal gas occupies 24.45 L.

A concentration of 0.30 ppmv means that for every 10^6 volumes of air, there are 0.30 volumes of NO_2.

To convert ppmv to $\mu g/m^3$, we can use the following formula:

$$\text{Concentration } \left(\frac{\mu g}{m^3}\right) = \frac{\text{Concentration } (ppmv) \times \text{Molecular weight } \left(\frac{g}{mol}\right) \times 1000}{\text{Molar volume at NTP } (L/mol)}$$

$$\text{Concentration } (\mu g/m^3) = \frac{0.30 \times 46 \times 1000}{24.45}$$

$$\text{Concentration } (\mu g/m^3) = \frac{13.8 \times 1000}{24.45} = \frac{13800}{24.45}$$

$$\text{Concentration } (\mu g/m^3) \approx 564.417$$

Rounding off to the nearest integer, the concentration of NO_2 in $\mu g/m^3$ is **564.**

2. Explanation: (0.50 to 0.68)

To calculate the **ionic strength (I)** of the water sample, we use the formula:

$$I = \frac{1}{2}\sum c_i z_i^2$$

Step 1: Calculate Contribution of Each Ion

$$I = \frac{1}{2}\left(c_{Na^+} z_{Na^+}^2 + c_{Ca^{2+}} z_{Ca^{2+}}^2 + c_{Cl^-} z_{Cl^-}^2 + c_{HCO_3^-} z_{HCO_3^-}^2\right)$$

Substitute the values:

$$I = \frac{1}{2}((0.25 \times 1^2) + (0.12 \times 2^2) + (0.32 \times 1^2) + (0.05 \times 1^2))$$

$$I = \frac{1}{2}(0.25 + (0.12 \times 4) + 0.32 + 0.05)$$

$$I = \frac{1}{2}(0.25 + 0.48 + 0.32 + 0.05)$$

$$I = \frac{1}{2} \times 1.10 = 0.55 \text{ M}$$

The ionic strength of the water sample is **0.55 M** (correct to two decimal places).

3. Explanation: (0.004 to 0.006)

To solve for the molar concentration of SO_4^{2-} at equilibrium, we can use the **solubility product (Ksp)** equation for calcium sulfate $CaSO_4$.

The dissolution equation for $CaSO_4$ is:

$$CaSO_4(s) \rightleftharpoons Ca^{2+}(aq) + SO_4^{2-}(aq)$$

The **solubility product (Ksp)** for $CaSO_4$ is:

$$K_{sp} = [Ca^{2+}] \times [SO_4^{2-}]$$

Thus, the equation becomes:

$$K_{sp} = x \times x = x^2$$

Substitute the given K_{sp}:

$$2 \times 10^{-5} = x^2$$

Solve for x:

$$x = \sqrt{2 \times 10^{-5}} = 4.47 \times 10^{-3} \text{ mol/L}$$

Thus, the molar concentration of SO_4^{2-} at equilibrium is approximately **0.004 mol/L**.

4. Explanation: (0.01 to 0.02)

Write the solubility equilibrium for zinc hydroxide:

$$Zn(OH)_2(s) \rightleftharpoons Zn^{2+}(aq) + 2OH^-(aq)$$

The solubility product is: $K_{sp} = [Zn^{2+}][OH^-]^2$

Determine the hydroxide ion concentration:

- pH = 6, so the pOH is: $pOH = 14 - 6 = 8$
- The concentration of hydroxide ions $[OH^-]$ is:$[OH^-] = 10^{-pOH} = 10^{-8}$ mol/L

Substitute values into the Ksp expression:

$K_{sp} = (0.001) \times (10^{-8})^2 = 0.001 \times 10^{-16} = 10^{-19}$

The given **Ksp** is 10^{-18}, and the ratio of the reaction coefficient to Ksp is:

$$\frac{10^{-19}}{10^{-18}} = 0.1$$

∴ The ratio is approximately **0.01 to 0.02**.

5. Explanation: (54.0 to 54.2)

$P_{CO2} = 3 \times 10^{-4}$ atm.

$[CO_2 \cdot H_2O] = (3.4 \times 10^{-2})(3 \times 10^{-4}) = 10.2 \times 10^{-6}$ M.

$[H^+] = 10^{-7}$ M (neutral water).

$[HCO_3^-] = \frac{(4.3\times10^{-7})(10.2\times10^{-6})}{10^{-7}} = 43.86 \times 10^{-6}$ M.

$[CO_3^{2-}] = \frac{(4.7\times10^{-11})(43.86\times10^{-6})}{10^{-7}} = 0.0002 \times 10^{-6}$ M.

Total dissolved CO_2 $= (10.2 + 43.86 + 0.0002) \times 10^{-6}$ M $= 54.06 \times 10^{-6}$ M.

∴ In µM: $\mathbf{54.06\ \mu M}$.

6. Explanation: (9.1 to 9.7)

Solubility of gas A in water: 16 mg/L

Vapor pressure of gas A: 0.042 atm

Gas phase concentration of A: 10^{-3} mol/L

Ideal gas constant (R): 0.0821 L·atm/mol·K

Temperature: 25 °C (298 K)

The concentration of a gas in liquid to its partial pressure in the gas phase.

$$C_{water} = K_H \cdot P_{gas}$$

Where,

C_{water} = Concentration of gas in water (mg/L)

K_H= Henry's Law constant (mg/L·atm)

P_{gas}= Partial pressure of the gas (atm)

So,

$$K_H = \frac{C_{water}}{P_{gas}} = \frac{16\ mg/L}{0.042\ atm} = 380.95 \frac{mg}{L} \cdot atm$$

Using the gas phase concentration (10^{-3} mol/L) and the Ideal Gas Law:

$$P_{gas} = \left(\frac{n}{V}\right) \cdot RT = (10^{-3} mol/L) \times (0.0821 L \cdot atm/mol \cdot K) \times (298K)$$

$P_{gas} = 0.02446$ atm

Using Henry's Law,

$$C_{water} = K_H \cdot P_{gas} = 380.95 \frac{mg}{L} \cdot atm \times 0.02446 atm$$

$$C_{water} = 9.32\ mg/L$$

7. Explanation: (4.46 to 4.46)

To calculate the pH of the solution, we use the **Henderson-Hasselbalch equation**:

$pH = pKa + \log(\frac{[A-]}{[HA]})$

Where:

- **pKa** = 4.76 (given)
- **$[A^-]$** = concentration of acetate (from sodium acetate) = 0.05 M
- **[HA]** = concentration of acetic acid = 0.1 M

Substituting the values:

$pH = 4.76 + \log(\frac{0.05}{0.1})$

Ph = 4.76 + log (0.5)

pH = 4.76 + (-0.3010)

pH = 4.46

Thus, the pH of the solution is **4.46** (rounded to two decimal places).

8. Explanation: (0.033) To calculate the ionic strength (I) of a solution, we can use the formula:

$I = \frac{1}{2} \sum c_i z_i^2$

Where:

- $c_i$is the molar concentration of each ion
- z_i^2 is the charge of each ion

Let's solve for the ionic strength step by step.

Step 1: Break down the dissociation of salts

1. **For CaCl_2**

- The dissociation of $\boldsymbol{CaCl_2}$
- The concentration of $\boldsymbol{CaCl_2}$ is 0.01 M.
- For Ca^{2+}, the concentration is 0.01 M, and the charge is z=2
- For Cl^-, the concentration is 2×0.01=0.022 M, and the charge is z=−1

2. **For $\boldsymbol{Na_2SO_4}$**:

- The dissociation of $\boldsymbol{Na_2SO_4}$: gives 2 Na^+ ions and 1 SO_4^{2-} ion.
- The concentration of $\boldsymbol{Na_2SO_4}$ is 0.001 M.
- For Na^+, the concentration is 2×0.001=0.0022 M, and the charge is z=+1.
- For SO_4^{2-}, the concentration is 0.001 M, and the charge is z=−2.

Step 2: Apply the formula

Now, let's calculate the ionic strength III:

$$\mathbf{I} = \frac{1}{2}\left([\boldsymbol{c_{Ca^{2+}}}]\boldsymbol{X}\ \boldsymbol{z_{Ca^{2+}}^2} + [\boldsymbol{c_{Cl^-}}]\boldsymbol{X}\ \boldsymbol{z_{Cl^-}^2} + [\boldsymbol{c_{Na^+}}]\ \boldsymbol{X}\ \boldsymbol{z_{Na^+}^2} + \left[\boldsymbol{c_{So_4{}^{2-}}}\right]\ \boldsymbol{X}\ \boldsymbol{z_{So4^{2-}}^2}\right)$$

$\mathbf{I} = \frac{1}{2}((0.01\times22)+(0.02\times12)+(0.002\times12)+(0.001\times22))$

$\mathbf{I} = \frac{1}{2}(0.01\times4)+(0.02\times1)+(0.002\times1)+(0.001\times4))$

I $=\frac{1}{2}$(0.04+0.02+0.002+0.004)

I $=\frac{1}{2}$(0.066)

I = 0.033

9. Explanation: (155) Given:

- Initial ethanol in the bottle = 400 g
- Half of ethanol used = 400÷2=200 g used
- Ethanol remaining after usage = 200 g
- Ethanol loss rate = 0.5 g/day
- Duration = 90 days

Calculate the ethanol loss over 90 days

The total ethanol lost over 90 days is:

Ethanol lost=0.5 g/day×90 days=45 g

Calculate the ethanol remaining in the bottle

The ethanol remaining in the bottle at the end of the summer vacation is:

Ethanol remaining=200 g−45 g = 155 g

10. Explanation: (0.18 to 0.21)

From Graph Absorbance of $\boxed{0.35}$ gives

$$CrO_4^{-2} = 0.41\ mg/L$$

$$Conc: 0.41\frac{?}{52}$$

$$Mol_wt: 52 + (4 \times 16)$$

$$= 116$$

$$\therefore C_r = 0.41 \times \frac{52}{116}$$

$$0.1837 \text{ mg / L}$$

-: Unit 3.3 Soil Chemistry:-

Organic matter, nitrogen, phosphorous, potassium, cation exchange capacity, base saturation, and sodium absorption ratio

Multiple Choice Questions (MCQ)

1. The characteristics of a water sample are as follows: $\mathbf{Na^+ = 92mg/L}$, $\mathbf{K^+ = 19.5mg/L}$, $\mathbf{Ca^{2+} = 40mg/L}$, and $\mathbf{Mg^{2+} = 24mg/L}$. What is the sodium adsorption ratio (SAR) of the water sample which may be considered for irrigation purposes?
[Atomic weight (g/mol): $= 23$, $\mathbf{K = 39}$, $\mathbf{Ca = 40}$, and $\mathbf{Mg = 24}$]
(A) 2.83 (B) 1.94
(C) 2.00 (D) 4.00

Multiple Select Questions (MSQ)

[2026: 1 Mark]

1. Which of the following processes is/are primarily used to remove the organic matter in sludge?
(A) Digestion (B) Incineration
(C) Magnetic separation (D) Wet-oxidation

ANSWER KEY
Multiple Choice Questions (MCQ)
1
A
Multiple Select Questions (MSQ)
1
A, B, C

EXPLANATION

Multiple Choice Questions (MCQ)

1. Explanation: (A) The sodium adsorption ratio (SAR) is a measure of the relative proportion of sodium (Na+) to calcium (Ca2+) and magnesium (Mg2+) ions in water. It is used to assess the suitability of water for irrigation. The formula for SAR is:

$$SAR = \frac{[\mathrm{Na^+}]}{\sqrt{\frac{[\mathrm{Ca^{2+}}] + [\mathrm{Mg^{2+}}]}{2}}}$$

where the concentrations of the ions are expressed in milliequivalents per liter (meq/L).

First, we need to convert the concentrations from mg/L to meq/L. The formula for conversion is:

$$\text{meq/L} = \frac{\text{Concentration (mg/L)}}{\text{Equivalent weight (mg/meq)}}$$

The equivalent weight of an ion is given by:

$$\text{Equivalent weight} = \frac{\text{Atomic weight}}{\text{Valence}}$$

Given atomic weights: Na = 23, K = 39, Ca = 40, Mg = 24.

Valence: Na = 1, K = 1, Ca = 2, Mg = 2.

Concentration of $\mathrm{Na^+}$ = 92 mg/L

Equivalent weight of $\mathrm{Na^+} = \frac{23}{1} = 23$ mg/meq

$$[\mathrm{Na^+}] = \frac{92}{23} = 4 \text{ meq/L}$$

Concentration of $\mathrm{K^+}$ = 19.5 mg/L

Equivalent weight of $\mathrm{K^+} = \frac{39}{1} = 39$ mg/meq

$$[\mathrm{K^+}] = \frac{19.5}{39} = 0.5 \text{ meq/L}$$

Concentration of $\mathrm{Ca^{2+}}$ = 40 mg/L

Equivalent weight of $\mathrm{Ca^{2+}} = \frac{40}{2} = 20$ mg/meq

$$[\mathrm{Ca^{2+}}] = \frac{40}{20} = 2 \text{ meq/L}$$

Concentration of $\mathrm{Mg^{2+}}$ = 24 mg/L

Equivalent weight of $\mathrm{Mg^{2+}} = \frac{24}{2} = 12$ mg/meq

$$[\mathrm{Mg^{2+}}] = \frac{24}{12} = 2 \text{ meq/L}$$

Now, substitute the meq/L values into the SAR formula:

$$SAR = \frac{4}{\sqrt{\frac{2+2}{2}}} = \frac{4}{\sqrt{\frac{4}{2}}} = \frac{4}{\sqrt{2}}$$

$$SAR = \frac{4}{\sqrt{2}} \times \frac{\sqrt{2}}{\sqrt{2}} = \frac{4\sqrt{2}}{2} = 2\sqrt{2}$$

The value of $\sqrt{2}$ is approximately 1.414.

$$SAR = 2 \times 1.414 = 2.828$$

Rounding to two decimal places, SAR = **2.83.**

Multiple Select Questions (MSQ)

1. Explanation: (A, B, C)
Digestion breaks down organic matter biologically through microbial activity, incineration destroys organics by high-temperature combustion reducing sludge to ash, and wet-oxidation chemically oxidizes organics under high temperature and pressure in an aqueous medium. Other options are incorrect because magnetic separation as it only removes ferrous /metallic particles, not organic matter.

-: Unit 3.4 Atmospheric Chemistry:-

Composition of the atmosphere; Reactivity of trace substances in the atmosphere; Urban atmosphere —smog and particulate pollution; Chemistry of ozone formation; Chemistry of stratosphere.

Multiple Choice Questions (MCQ)

[2021: 2 Marks]

1. Match the entries io Column I with the correct entries in Column II.

Column I	Column II
P. Diffusion	(i) Pasquill
Q. Drag force	(ii) Fick
R. Atmospheric stability	(iii)Stokes

Code:

(A) P-(ii), Q-(ii), R-(i) (B) P -(ii) Q -(i) , R-(imi)

(C) P -(i) Q -(iii) R -(ii) (D) P-(ii) Q-(iii). R-(i)

[2026: 1 Mark]

2. The general atmospheric composition of gases in the decreasing order is _____.

(A) $N_2 > O_2 > CO > CO_2 > NH_3$

(B) $N_2 > O_2 > CO_2 > CO > NH_3$

(C) $N_2 > CO_2 > O_2 > NH_3 > CO$

(D) $N_2 > CO_2 > NH_3 > CO > O_2$

Multiple Select Questions (MSQ)

[2022: 2 Mark]

1. During night, in troposphere, which of the following is/are NOT correct

(A) $NO_2 + h\upsilon \rightarrow NO + O$

(B) Most of the NOx (i.e., $NO + NO_2$) converts to NO

(C) $NO + O_3 \rightarrow NO_2 + O_2$

(D) Most of the NOx (i.e., $NO + NO_2$) converts to NO_2

[2026: 1 Mark]

2. Which of the following chemical reactions is/are related to smog formation in the troposphere?

(A) $CFCl_3 + h\nu \rightarrow CFCl_2 + Cl\cdot$

(B) $CH_3O_2 + NO + O_2 \rightarrow HCHO + HO_2 + NO_2$

(C) $NO_2 + O_2 + h\nu \xrightarrow{M} O_3 + NO$

(D) $CH_4 + 8O_2 \rightarrow CO + H_2O + 2OH\cdot + 4O_3$

Numerical Answer Type Questions (NAT)

[2024: 2 Mark]

1. The concentration of Ozone corresponding to a mixing ratio of 120 ppbv at pressure of 1 atmosphere and temperature of $25^{\circ}C$ is…… $\mu g/m^3$ (rounded off to I decimal place).

[2025: 2 Mark]

2. A solid waste of composition $C_{60}H_{135}O_{50}N_5$ is to be composted aerobically in a closed vessel mechanical composting facility. Given: all ammonia generated escapes the facility; air contains 23% of Oxygen by weight; 100% excess air requirement for the closed vessel composting facility. The atomic weights: $C - 12$, $H - 1, O - 16, N - 14$. The actual air required for composting is_____ kg per kg waste. (rounded off to one decimal place)

ANSWER KEY	
Multiple Choice Questions (MCQ)	
1	**2**
D	B
Multiple Select Questions (MSQ)	
1	**2**
A, B	B, C, D
Numerical Answer Type Questions (NAT)	
1	**2**
234.0 to 236.0	10.4 to 10.6

EXPLANATION

Multiple Choice Questions (MCQ)

1. Explanation: (D)

P. Diffusion: The theory of diffusion is described by **Fick's Law** (Q matches with ii).

Q. Drag force: Drag force is commonly associated with **Stokes' Law** (R matches with iii).

R. Atmospheric stability: **Pasquill** is known for his work on atmospheric stability (P matches with i).

2. Explanation: (B)

Earth's atmosphere is composed mainly of **nitrogen (≈78%)** followed by **oxygen (≈21%)**. Among the remaining gases, **carbon dioxide (CO_2)** is present in a much higher concentration than **carbon monoxide (CO)** and **ammonia (NH_3)**.

Carbon monoxide and ammonia occur only in **trace amounts** in the atmosphere.

Hence, the correct decreasing order is **N2> O2> CO2> CO> NH3N_2 > O_2 > CO_2 > CO > NH_3N2> O2> CO2> CO> NH3**.

Multiple Select Questions (MSQ)

1. **Explanation: (A) (B)** During the night, there is no sunlight (hv) to drive the photolysis of **NO_2**, so the reaction **NO_2 + hv → NO + O** does not occur. Photodissociation requires light, which is absent at night. At night, **NOx** (NO + NO_2) does not predominantly convert to **NO**. In the absence of sunlight, NO reacts with **ozone (O_3)** to form **NO_2**, rather than converting to NO. Hence, the main reaction at night is **NO + O_3 → NO_2 + O_2**

2. **Explanation: (B, C, D)**
   Reaction (B) involves the oxidation of methyl peroxy radical with no producing formaldehyde (HCHO) and NO_2, which are key steps in photochemical smog formation, while reaction (C) shows the photolysis of NO_2 in the presence of oxygen producing ozone (O_3), it is indicator of photochemical smog in the troposphere. Reaction (D) involves methane oxidation, contributing to tropospheric smog chemistry. Option (A) is incorrect as it represents CFC photolysis occurring in the stratosphere, not tropospheric smog formation.

Numerical Answer Type Questions (NAT)

1. **Explanation: (234.0 to 236.0)** Atomic weight of oxygen $= 16; \mathrm{R} = 8.314\ \mathrm{J/K\text{-}g.mole}$.
   To convert 120 ppbv of ozone to µg/m³ at 25°C and 1 atm:
   Using the formula: Concentration (µg/m³) = $\frac{ppbv \times Molecular\ weight\ of\ O_3 \times P \times T}{\mathrm{R} \times 10^9}$
   Substituting the values: Concentration = $\frac{120 \times 48 \times 101.325 \times 298.15}{8.314 \times 10^9} \approx 234.0 \mu g/m3$
   So, the concentration is **234.0 µg/m³** (rounded to 1 decimal place).

2. **Explanation: (10.4 to 10.6)**
1. **Write the balanced reaction equation for aerobic composting:**
   C60H135O50N5 + 62.5O2 → 60CO2 + 65H2O + 2.5N2 + 2.5NH3 (Ammonia escapes)
2. **Calculate the molecular weight of the solid waste (C60H135O50N5):**
   (60 * 12) + (135 * 1) + (50 * 16) + (5 * 14) = 720 + 135 + 800 + 70 = 1725 g/mol
3. **Calculate the amount of oxygen required:**
   From the balanced equation, 1 mole of solid waste requires 62.5 moles of O2.
   Mass of O2 required = 62.5 mol * 32 g/mol = 2000 g
4. **Calculate the theoretical amount of air required:**
   Since air contains 23% oxygen by weight, the theoretical amount of air required is:
   (2000 g O2) / 0.23 = 8695.65 g air
5. **Consider the 100% excess air requirement:**
   Actual air required = 2 * theoretical air required = 2 * 8695.65 g = 17391.3 g
6. **Express the air requirement per kg of waste:**
   (17391.3 g air) / (1725 g waste) = 10.08 kg air/kg waste