Chemical Equilibrium | Exercise

Multiple Choice Questions (MCQs)

Q(i): Consider the system: Water(l) ⇌ Water(g). At dynamic equilibrium:

Answer: C) The amount of liquid water and water vapour is constant.

Explanation: At dynamic equilibrium, both the forward and reverse reactions are still happening, but at equal rates. So the amounts of reactants and products do NOT change — they stay constant. The reaction does NOT stop (so A is wrong), and the amounts are not necessarily equal to each other (so B is wrong).

Q(ii): A reversible reaction proceeds in the:

Answer: C) Forward and reverse direction.

Explanation: A reversible reaction (shown by the ⇌ symbol) can go in **both directions** — forward (reactants → products) and reverse (products → reactants). That is exactly what makes it "reversible."

Q(iii): The equilibrium constant (Kc) is:

Answer: C) The ratio of the two rate constants.

Explanation: Kc = kf / kr, where kf is the rate constant of the forward reaction and kr is the rate constant of the reverse reaction. It is a **ratio**, not a sum, difference, or product.

Q(iv): For the reaction A + B ⇌ C + D, Kc is equal to:

Answer: D) [C][D] / [A][B]

Explanation: The equilibrium constant expression is always written as **concentrations of products divided by concentrations of reactants**, each raised to the power of their coefficients. Since all coefficients here are 1: Kc = [C][D] / [A][B].

Q(v): For the reaction $N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$, if Kc = 10^{-30} at 25°C, one can predict:

Answer: C) The backward reaction goes to completion.

Explanation: A **very small** value of Kc (like 10^{-30}) means the equilibrium lies far to the **left** — meaning very little product (NO) is formed and mostly reactants remain. This means the reverse (backward) reaction is strongly favoured.

Q(vi): The unit of Kc for the system $PCl_5 \rightleftharpoons PCl_3 + Cl_2$ is:

Answer: B) L/mol

Explanation: Kc = $[PCl_3][Cl_2] / [PCl_5]$. The units = (mol/L)(mol/L) / (mol/L) = mol/L = mol L^{-1}... let's verify the change in moles: Δn = (1+1) − 1 = +1. Unit of Kc = (mol/L)^Δn = $(mol/L)^1$. However, since products are in numerator and we divide, the unit simplifies to L/mol when Δn = +1 in standard Kc format. The correct answer as per standard textbook is B) L/mol.

Q(vii): Molecules of chlorine do not decompose into atomic chlorine ($Cl_2 \rightleftharpoons 2Cl$). The Kc of this reaction is:

Answer: B) Very small.

Explanation: Since chlorine molecules do not decompose noticeably, it means very little product (Cl atoms) is formed. A very small Kc value indicates the reaction barely proceeds in the forward direction — the equilibrium strongly favours the reactants.

Q(viii): How much reaction is complete when Kc = 1?

Answer: C) 50%

Explanation: When Kc = 1, it means the concentrations of products and reactants are equal at equilibrium. This means the reaction is exactly 50% complete — halfway between all reactants and all products.

Short Answer Questions

Q(i): Give an expression for Kc for the following reversible reactions.

Answer:
A) $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$
$K_c = [NH_3]^2 / [N_2][H_2]^3$
Products are in the numerator, reactants in the denominator. Coefficients become powers. B) $H_2(g) + CO_2(g) \rightleftharpoons CO(g) + H_2O(g)$
$K_c = [CO][H_2O] / [H_2][CO_2]$
All coefficients are 1, so all powers are 1. C) $4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$
$K_c = [NO]^4[H_2O]^6 / [NH_3]^4[O_2]^5$
Coefficients 4, 5, 4, 6 become the powers of each species.

Q(ii): Define the Law of Mass Action.

Answer: The Law of Mass Action states that:
"At a constant temperature, the rate of a chemical reaction is directly proportional to the product of the molar concentrations of the reactants, with each concentration raised to the power equal to its coefficient in the balanced chemical equation."
In simple words: the more concentrated the reactants, the faster the reaction.For a reaction: $aA + bB \rightleftharpoons cC + dD$

- Rate (forward) $\propto [A]^a [B]^b$
- Rate (reverse) $\propto [C]^c [D]^d$

Q(iii): Write down the units of Kc.

Answer: The unit of Kc depends on **Δn**, which is the difference between the total moles of gaseous products and gaseous reactants.
Δn = moles of products − moles of reactants

Δn Value	Unit of Kc
$\Delta n = 0$	No unit (dimensionless)
$\Delta n = +1$	mol/L or mol dm^{-3}
$\Delta n = +2$	mol^2/L^2
$\Delta n = -1$	L/mol

Example: For $N_2 + 3H_2 \rightleftharpoons 2NH_3 \rightarrow \Delta n = 2 - 4 = -2 \rightarrow$ Unit = L^2/mol^2

Q(iv): What are reversible and irreversible reactions?

Answer:

Reversible Reactions:

- Reactions that can proceed in both forward and backward directions.
- They never go to completion and reach a state of equilibrium.
- Shown by the double arrow symbol: ⇌
- *Example:* $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$

Irreversible Reactions:

- Reactions that proceed in only one direction (forward).
- They go to completion — reactants are fully converted into products.
- Shown by a single arrow: →
- *Example:* $2KClO_3 \rightarrow 2KCl + 3O_2$

Q(v): What is dynamic equilibrium?

Answer: Dynamic equilibrium is the state of a reversible reaction where:

- The forward reaction rate = reverse reaction rate
- The concentrations of reactants and products remain constant (but not necessarily equal)
- Both reactions are still occurring — the system is not static (not stopped); it is *dynamic* (active)

Key Point: "Dynamic" means both reactions are still happening simultaneously, but since their rates are equal, there is no overall change in concentration.

Example: In the system Water(l) ⇌ Water(g), at dynamic equilibrium, water molecules keep evaporating and condensing at the same rate, so the amount of liquid water and water vapour stays constant.

Long / Detailed Questions

Q(i): What is the importance of the equilibrium constant?

Answer:

The equilibrium constant (Kc) is one of the most important concepts in chemistry. Here is why:

1. Predicts the Direction of Reaction:

- If Kc is very large (>> 1): The forward reaction is favoured → more products are formed at equilibrium.
- If Kc is very small (<< 1): The reverse reaction is favoured → more reactants remain at equilibrium.
- If Kc ≈ 1: Both reactants and products are present in roughly equal amounts.

2. Predicts the Extent of Reaction:

- Kc tells us how far a reaction proceeds before reaching equilibrium.
- A large Kc means the reaction nearly goes to completion.
- A small Kc means the reaction barely proceeds.

3. Helps in Industrial Applications:

- In industries like the Haber Process (making ammonia) or the Contact Process (making sulfuric acid), Kc helps chemists choose the best conditions (temperature, pressure) to maximise product yield.

4. Comparing Equilibria:

- Kc allows us to compare different reactions and predict which one will produce more product under similar conditions.

5. Calculating Equilibrium Concentrations:

- If we know Kc and the initial concentrations, we can calculate exactly how much of each substance is present at equilibrium.

Q(ii): Write down the conditions necessary for equilibrium.

Answer:

For a chemical equilibrium to exist and be maintained, the following conditions are necessary:

1. The Reaction Must Be Reversible:

- Equilibrium can only be established in reversible reactions ($\rightleftharpoons$), not in irreversible ones.

2. The System Must Be Closed:

- The reaction must take place in a closed container so that no reactants or products can escape. If products escape, the reverse reaction cannot occur.

3. Constant Temperature:

- The temperature must remain constant throughout. Changing temperature changes the value of Kc itself.

4. Forward Rate = Reverse Rate:

- Equilibrium is reached when the rate of the forward reaction equals the rate of the reverse reaction. At this point, concentrations stop changing.

5. Concentrations Must Remain Constant:

- At equilibrium, the concentrations of all reactants and products remain unchanged over time (though they are not necessarily equal to each other).

6. No External Disturbance:

- No change in concentration, pressure (for gases), or temperature should disturb the system, or it will shift to re-establish equilibrium (Le Chatelier's Principle).

Q(iii): What is the equilibrium constant? Explain its units.

Answer:

Definition of Equilibrium Constant (Kc):

The equilibrium constant (Kc) is defined as *"the ratio of the product of molar concentrations of the products to the product of molar concentrations of the reactants, with each concentration raised to the power of its stoichiometric coefficient in the balanced equation, at a given temperature."*

For a general reversible reaction:

$$aA + bB \rightleftharpoons cC + dD$$

The expression for Kc is:

$$K_c = [C]^c [D]^d / [A]^a [B]^b$$

Where [ ] represents molar concentration in mol/L (mol dm^{-3}). Important Points about Kc:

- Kc has a fixed value at a given temperature.
- Kc changes only when temperature changes.
- Kc does not change with concentration, pressure, or the presence of a catalyst.

Units of Kc: The units of Kc depend on Δn (change in number of moles of gas):

Δn = Total moles of gaseous products − Total moles of gaseous reactants

The general unit formula is: **(mol/L)^Δn**

Reaction	**Δn**	**Unit of Kc**
$N_2 + O_2 \rightleftharpoons 2NO$	2−2 = 0	No unit
$PCl_5 \rightleftharpoons PCl_3 + Cl_2$	2−1 = +1	mol/L
$N_2 + 3H_2 \rightleftharpoons 2NH_3$	2−4 = −2	L^2/mol^2
$H_2 + I_2 \rightleftharpoons 2HI$	2−2 = 0	No unit