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Chemistry - Chemical Equilibrium

Topic: Equilibrium Concentrations

Given:

Initial concentration of **[A] = 0.24 mol/L**

Initial concentration of **[B] = 0.36 mol/L**

Equilibrium constant, **K = 1.4×10^{-9}**

Reaction:

$3A(g) + B(g) \rightleftarrows C(g) + 2D(g)$

Objective:

To find the equilibrium concentrations of all chemicals ($[A]_{eq}$, $[B]_{eq}$, $[C]_{eq}$, $[D]_{eq}$).

Step 1: Introduction and Initial Setup

Start by writing the equilibrium expression for the given reaction:

K =

K =
$[C]_{eq} \cdot [D]_{eq}^2 / [A]_{eq}^3 \cdot [B]_{eq}$

Introduce the change in concentration using the variable **x**:

	3A(g)	**+ B(g)**	**⇄ C(g)**	**+ 2D(g)**
Initial	0.24	0.36	0	0
Change	-3x	-x	+x	+2x
Equilibrium	0.24 - 3x	0.36 - x	x	2x

Explanation: Set up the initial changes and equilibrium concentrations in terms of **x**.

Supporting Statement: This step defines how each concentration changes as the system reaches equilibrium.

Step 2: Write the Equilibrium Expression and Substitute Values

Substitute the equilibrium concentrations into the equilibrium expression:

K =

K =
$x \cdot (2x)^2 / (0.24 - 3x)^3 \cdot (0.36 - x)$

Given $K = 1.4 \times 10^{-9}$, the expression becomes:

$1.4 \times 10^{-9} =$

$x \cdot (2x)^2 / (0.24 - 3x)^3 \cdot (0.36 - x)$

Explanation: The equilibrium concentrations are substituted into the expression for the equilibrium constant.

Supporting Statement: The equilibrium expression connects the balanced chemical equation to the equilibrium constant.

Step 3: Simplifying and Solving for x

First, simplify the expression:

$1.4 \times 10^{-9} =$

$4x^3 / (0.24 - 3x)^3 \cdot (0.36 - x)$

Due to the small value of K, it suggests that x will be very small because the reaction does not proceed much to the right. Hence, assuming:

$(0.24 - 3x) \approx 0.24$ and $(0.36 - x) \approx 0.36$:

$1.4 \times 10^{-9} =$

$4x^3 / (0.24)^3 \cdot 0.36$

Solving for x:

$1.4 \times 10^{-9} =$

$4x^3 / 0.013824 \cdot 0.36$

$1.4 \times 10^{-9} =$

$4x^3 / 0.00497664$

$1.4 \times 10^{-9} \times 0.00497664 = 4x^3$

$6.967296 \times 10^{-12} = 4x^3$

$x^3 =$

$6.967296 \times 10^{-12}/4$

$x^3 = 1.741824 \times 10^{-12}$

$x =$

$\sqrt[3]{(1.741824 \times 10^{-12})}$

$x \approx 1.2 \times 10^{-4}$

Explanation: The approximation due to the small equilibrium constant simplifies the calculations and makes the math manageable.

Supporting Statement: Approximating simplifies the calculation steps, making it easier to find the value of x.

Step 4: Calculate Equilibrium Concentrations

Using the value of $x \approx 1.2 \times 10^{-4}$:

$[A]_{eq} = 0.24 - 3x = 0.24 - 3(1.2 \times 10^{-4}) = 0.24 - 0.00036 = 0.23964$ mol/L

$[B]_{eq} = 0.36 - x = 0.36 - 1.2 \times 10^{-4} = 0.36 - 0.00012 = 0.35988$ mol/L

$[C]_{eq} = x = 1.2 \times 10^{-4}$ mol/L

$[D]_{eq} = 2x = 2(1.2 \times 10^{-4}) = 2.4 \times 10^{-4}$ mol/L

Explanation: Substituting the value of x allows calculating the equilibrium concentrations of all species involved.

Supporting Statement: Calculating equilibrium concentrations ensures the solution is complete for the given conditions.

Final Solution:

At equilibrium, the concentrations are:

- $[A]_{eq} = 0.23964$ mol/L
- $[B]_{eq} = 0.35988$ mol/L
- $[C]_{eq} = 1.2 \times 10^{-4}$ mol/L
- $[D]_{eq} = 2.4 \times 10^{-4}$ mol/L

Explanation: The above calculations align with the equilibrium expression, confirming the values obtained solve the given equilibrium conditions.

Supporting Statement: The solution includes accurate equilibrium concentrations, adhering to the given equilibrium constant and initial conditions.