CheggSolutions - Thegdp

Chemical Equilibrium

Given:

- Reaction: \(2 \text{NO}(g) \rightleftharpoons 2 \text{NO}_2(g) + \text{O}_2(g)\)
- \(K_P = 1.11 \times 10^{-5} \) at \(200 \, ^\circ\text{C} \)
- Volume of the vessel, \(V = 2.50 \, \text{L} \)
- Initial pressure of NO, \(P_{\text{initial, NO}} = 4.00 \, \text{atm} \)

Introduction:

The goal is to find the pressure of NO(g) at equilibrium when the initial pressure is given, and the system is allowed to come to equilibrium.

Step 1: Write the stoichiometric expression and initial pressures

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Initial:

\( \text{NO}(g) \rightleftharpoons \text{NO}_2(g) + \text{O}_2(g) \)

Initially, the pressure of NO is 4.00 atm. There are no NO2 and O2 present initially.

Pressure of:
- NO = 4.00 atm
- NO2 = 0 atm
- O2 = 0 atm
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Explanation: The initial setup involves introducing NO into the vessel with no initial NO2 or O2.

Step 2: Setup the expression for changes and equilibrium pressures

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Change:

\( 2 \text{NO}(g) \rightleftharpoons 2 \text{NO}_2(g) + \text{O}_2(g) \)

Let us denote the change in pressure of NO that reacts to form NO2 and O2 be x atm.

Changes in pressure:
- Pressure of NO: \( 4.00 - 2x \, \text{atm} \)
- Pressure of NO2: \( 0 + 2x \, \text{atm} \)
- Pressure of O2: \( 0 + x \, \text{atm} \)
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Explanation: Based on the stoichiometry, for every decrease of 2x atm in NO, NO2 increases by 2x atm and O2 increases by x atm.

Step 3: Write the expression for \(K_P \) using the equilibrium pressures

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At equilibrium:
- Pressure of NO: \( 4.00 - 2x \, \text{atm} \)
- Pressure of NO2: \( 2x \, \text{atm} \)
- Pressure of O2: \( x \, \text{atm} \)

Now write the equilibrium expression for \( K_P \):
\( K_P = \frac{(P_{\text{NO2}})^2 (P_{\text{O2}})}{(P_{\text{NO}})^2} \)

Substitute the equilibrium pressures:
\( 1.11 \times 10^{-5} = \frac{(2x)^2 (x)}{(4.00 - 2x)^2} \)
\( 1.11 \times 10^{-5} = \frac{4x^3}{(4.00 - 2x)^2} \)

Rearranging for solving,
\( 1.11 \times 10^{-5} = \frac{4x^3}{(16 - 16x + 4x^2)} \)

Multiply both sides by \( (16 - 16x + 4x^2) \) to clear the denominator:
\( 1.11 \times 10^{-5} \times (16 - 16x + 4x^2) = 4x^3 \)

Simplify and solve for \( x \).
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Explanation: Substituting equilibrium pressures into \(K_P \) expression and rearranging allows solving for the change in pressure \(x \).

Step 4: Solve the equation for \(x \) and find the pressures

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Let's solve:
\( 1.11 \times 10^{-5} (16 - 16x + 4x^2) = 4x^3 \)
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    Approximating:
    \( 1.78 \times 10^{-4} - 1.78 \times 10^{-4}x + 4.44 \times 10^{-5} x^2 = x^3 \)

    This is a cubic equation in \( x \). Solving numerically or graphically, assuming \( x \) is
small due to small \( K_P \):
    Approximating,
    \( 1.78 \times 10^{-4} \approx 4x^3 \)

    \( x^3 \approx \frac{1.78 \times 10^{-4}}{4} \)
    \( x^3 \approx 4.45 \times 10^{-5} \)
    \( x \approx \sqrt[3]{4.45 \times 10^{-5}} \)
    \( x \approx 0.035 \, \text{atm} \)

    Finally, the equilibrium pressure of NO:
    \( P_{\text{equilibrium, NO}} = 4.00 - 2x \approx 4.00 - 2(0.035) \approx 3.93 \, \text{atm}
\)
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Explanation: Solving the cubic equation for \(x \) and substituting to find equilibrium pressure of NO.

Final Solution:

The pressure of NO(g) at equilibrium is approximately **3.93 atm**