Chapter 6 Challenge Problem Solutions

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> **Problem:** Nitric oxide and bromine at initial pressures of 98.4 and 41.3 torr, respectively, were allowed to react at 300. K. At equilibrium the total pressure was 110.5 torr. The reaction is as follows.
>
> $$2\,\mathrm{NO} + \mathrm{Br_2} \rightleftharpoons 2\,\mathrm{NOBr}$$
>
> a) Calculate the value of K_p
>
> b) What would be the partial pressures of all species if NO and Br_2, both at an initial partial pressure of 0.30 atm, were allowed to come to equilibrium at this temperature?

Solution: We model the change in pressure of each substance through an ICE table and note the concentrations.

	[2 NO]	+	$[Br_2]$	$\rightleftharpoons$	[2 NOBr]
I	98.4		41.3		
C	$-2x$		$-x$		$+2x$
E	$(98.4-2x)$		$(41.3-x)$		$(+2x)$

We are told that $P_E = 110.5$ torr, meaning that we can solve for x

$$\begin{aligned}
P_E &= P_{\mathrm{NO}} + P_{\mathrm{Br_2}} + P_{\mathrm{NOBr}} \\
110.5 &= (98.4-2x) + (41.3-x) + (2x) \\
x &= 29.2 \text{ torr}
\end{aligned}$$

Solving for each equilibrium concentration gives us a K_p value of

$$K_p = \frac{58.4^2}{40.0^2 \times 12.1} = 0.176 \text{ torr}^{-1} = \boxed{134 \text{ atm}^{-1}}$$

Solving for the second part of the problem becomes a bit more convoluted. We are given that the initial concentrations of the reactants NO and Br_2 are 0.3 atm each.

Writing an ICE table for the following reaction is trivial and is omitted. We end with a K_p of

$$134 = \frac{(2x)^2}{(0.3 - 3x)^2(0.3 - x)}$$

Solving for x is complicated to do algebraically, but graphically, we see that $x = 0.125$ atm. Knowing that the equilibrium concentrations of NO and Br_2 are $(0.3 - 2x)$ and $(0.3 - x)$, and NOBr is $2x$, we see that the partial pressures of each of the substances are

$$\boxed{P_{\mathrm{NO}} = 0.052\,\mathrm{atm} \qquad P_{\mathrm{Br_2}} = 0.18\,\mathrm{atm} \qquad P_{\mathrm{NOBr}} = 0.25\,\mathrm{atm}}$$

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Problem: Consider the reaction

$$\mathrm{P_4(g)} \rightleftharpoons 2\,\mathrm{P_2(g)}$$

where $K_p = 1.00 \times 10^{-1}$ at 1325 K. In an experiment where P_4(g) was placed in a container at 1325 K, the equilibrium mixture of P_4(g) and P_2(g) has a total pressure of 1.00 atm. Calculate the equilibrium pressures of P_4(g) and P_2(g). Calculate the fraction (by mole) of P_4(g) that has dissociated to reach equilibrium.

Solution: In this problem, we have a few unknowns, including the original pressure of P_4(g) and of course the equilibrium pressures of P_4(g) and P_2(g). Our basic ICE table gives us two unknowns, the initial concentration of P_4(g) y, and the change variable x. I have omitted the ICE table again for this problem, but writing it out would give us the equilibrium concentrations of the two substances in terms of y and x.

$$\mathrm{P_4(g)} = y - x$$
$$\mathrm{P_2(g)} = 2x$$

The problem statement also gives us the total pressure as $P = 1.00$ atm, which we can rewrite to get our system of equations

$$K_p = \frac{(2x)^2}{(y - x)} \tag{1}$$
$$P = (y - x) + (2x) \tag{2}$$

Solving this system of equations is simply algebraic manipulation, which gives us $y = 0.865$ atm, and $x = 0.135$ atm. Finding our answers is simply arithmetic.

$$P_{P_4} = 0.73\,\text{atm} \qquad P_{P_2} = 0.270\,\text{atm} \qquad 16\% \text{ of } P_4 \text{ decomposed}$$

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Problem: Consider the reaction

$$3\,O_2(g) \rightleftharpoons 2\,O_3(g)$$

At 175 °C and a pressure of 128 torr an equilibrium mixture of O_2 and O_3 has a density of 0.168 g/L. Calculate the K_p for the above reaction at 175 °C.

Solution: We first must come up with a method of finding density in terms of pressure. Density's units are $\text{g}\,\text{L}^{-1}$, and the equation that relates pressure and volume is

$$PV = nRT$$

However, we must manipulate this equation to introduce mass. We do this by introducing molar mass (M) and obtain

$$PM = M\frac{n}{V}RT = \rho RT$$

$$\frac{PM}{RT} = \frac{P_{O_2}M_{O_2} + P_{O_3}M_{O_3}}{RT} = \rho = 0.168$$

We also know that $P = 128$ torr, or $0.168\,\text{atm}$. Our second equation is

$$P = P_{O_2} + P_{O_3} = 0.168$$

This is a simple system of equations with two unknowns (P_{O_2} and P_{O_3}). Once solved, we find that $P_{O_2} = 0.118\,\text{atm}$ and $P_{O_3} = 0.05\,\text{atm}$. Which gives us a final answer

$$K_p = \frac{{P_{O_3}}^2}{{P_{O_2}}^3} = 1.5\,\text{atm}^{-1}$$