Worksheet 3

1. Isopropyl alcohol can dissociate into acetone and hydrogen:

$(CH_3)CHOH\ (g) \leftrightharpoons (CH_3)CO\ (g) + H_2\ (g)$

At 179 °C, the equilibrium constant for this dehydrogenation reaction is 0.444.

(a) If 10.00 g of isopropyl alcohol is placed in a 10.00 L vessel and heated to 179°C, what is the partial pressure of acetone when equilibrium is attained?

T = 179°C = 452 K
K = 0.444
m = 10 g × 1mol / 60 g = 0.167 mol $(CH_3)CHOH$
V = 10.0 L

P = nRT / V = (0.167 mol)(0.08206 atm L mol^{-1} K^{-1})(452 K) / 10.0 L
$P_{(CH3)2CHOH}$ = 0.619 atm

	$(CH_3)CHOH$ (g) ⇋	$(CH_3)CO$ (g) +	H_2 (g)
initial P	**0.619 atm**	**0**	**0**
ΔP	**-x**	**+x**	**+x**
equilibrium P	**0.619 - x**	**x**	**x**

$(0.444) = x^2 / (0.619 - x)$
$0.275 - 0.444x = x^2$
$x^2 + 0.444x - 0.275 = 0$, solve using the Quadratic formula
$x = (-0.444 \pm \sqrt{(.444)^2 - 4(1)(0.275)}) / 2 = 0.347$ atm $= P_{acetone}$

(b) What fraction of isopropyl alcohol is dissociated at equilibrium?

The actual $P_{isopropyl\ alcohol}$ = 0.619 atm - 0.347 atm = 0.272 atm
The fraction of dissociated isopropyl alcohol = (0.619)(0.272) / 0.619 = 0.562

2. The equilibrium constant for the reaction:

$H_2\ (g) + I_2\ (s) \leftrightharpoons 2\ HI\ (g)$

at 25°C is K = 0.345.

(a) If the partial pressure of hydrogen is P_{H2} = 1.00 atm and solid iodine is present, what is the equilibrium partial pressure of hydrogen iodide, P_{HI}, at 25°C?

P_{H2} = 1.00 atm
K = 0.345
$K = (P_{HI})^2 / (P_{H2})$
$0.345 = (P_{HI})^2 / (1.00\ atm)$
P_{HI} = 0.587 atm

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(b) An excess of solid I_2 is added to a container filled with hydrogen at 25°C and a pressure of 4.00 atm. Calculate the pressures of H_2 (*g*) and HI (*g*) reached at equilibrium.

$H_2\ (g) + I_2\ (s) \leftrightharpoons 2\ HI\ (g)$

initial P	**4.00 atm**	**0**	**0**
ΔP	**-x**	**0**	**2x**
equilibrium P	**4.00 - x**	**0**	**2x**

$(0.345) = 2x^2 / (4.00 - x)$
$1.38 - 0.345x = 4x^2$
$4x^2 + 0.345x - 1.38 = 0$, solve using the Quadratic formula
$x = (-0.345 \pm \sqrt{}\ (.345)^2 - 4(4)(1.38)) / 8 = 0.546$ atm
$P_{H2} = 4.00$ atm - 0.546 atm = 3.45 atm
$P_{HI} = 2x = 1.09$ atm

3. At 300°C the equilibrium constant for the reaction

$PCl_5\ (g) \leftrightharpoons PCl_3\ (g) + Cl_2\ (g)$

is K = 11.5.

(a) Calculate the reaction quotient *Q* if initially $P_{PCL3} = 2.0$ atm, $P_{Cl2} = 6.0$ atm, and $P_{PCl5} = 0.10$ atm. State whether the reaction proceeds to the right or to the left as equilibrium is approached.

K = 11.5
T = 300°C = 573 K
$P_{PCL3} = 2.0$ atm, $P_{Cl2} = 6.0$ atm, and $P_{PCl5} = 0.10$ atm
$Q = (P_{PCl3})(P_{Cl3}) / P_{PCl5} = (2.0)(6.0) / 0.10 = 120$
$Q > K$, the reaction proceeds toward the left (reactants)

(b) Calculate P_{PCl3}, P_{Cl2}, and P_{PCl5}, at equilibrium.

$PCl_5\ (g) \leftrightharpoons PCl_3\ (g) + Cl_2\ (g)$

initial P	**0.10 atm**	**2.0 atm**	**6.0 atm**
ΔP	**+y**	**-y**	**-y**
equilibrium P	**0.10 + y**	**2.0 - y**	**6.0 - y**

$K = (P_{Cl3})(P_{Cl2}) / P_{PCl5} = (2.0 - y)(6.0 - y) / (0.10 + y) = 11.5$
$1.15 + 1.15y = 12.0 - 8.0y + y^2$
$y^2 - 19.5y + 10.85 = 0$, solve using the Quadratic formula
$y = (19.5 \pm \sqrt{}\ (19.5)^2 - 4(1)(10.85)) / 2 = 0.573$ atm
$P_{PCl5} = 0.10$ atm - 0.573 atm = 0.673 atm

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P_{PCl3} = 2.0 atm - 0.573 atm = 1.427 atm
P_{Cl2} = 6.0 atm - 0.573 atm = 5.427 atm

(c) If the volume of the system is then increased, will the amount of PCl_5 present increase or decrease?

The increase in volume causes the reaction to shift to the side having more moles of gas. Thus, the amounts of PCl5 will decrease.

4. At 1000 K, K_p = 19.9 for the reaction Fe_2O_3 (*s*) + 3 CO (*g*) ⇋ 2 Fe (*s*) + 3 CO_2 (*g*). What are the equilibrium partial pressures of CO and CO_2 if CO is the only gas present initially, at a partial pressure of 0.978 atm?

Fe_2O_3 (*s*) + 3 CO (*g*) ⇋ 2 Fe (*s*) + 3 CO_2 (*g*)

initial P	**0.978 atm**	**0 atm**
ΔP	**-3x**	**+3x**
equilibrium P	**0.978 - 3x**	**3x**

$K_p = (P_{CO2})^3 / (P_{CO})^3 = 19.9 = (3x)^3 / (0.978 - 3x)^3$, take the cube root of both sides to solve for x

$\sqrt[3]{19.9} = 2.71 = 3x / (0.978 - 3x)$
2.65 - 8.13x = 3x
2.65 = 11.13x
x = 2.65 / 11.13 = 0.238 atm
P_{CO} = 0.978 - 3x = 0.978 - 3(0.238) = 0.264 atm
P_{CO2} = 3x = 3(0.238) = 0.714 atm

5. In the gas phase at 400°C, isopropyl alcohol decomposes to acetone, an important industrial solvent:

$(CH_3)_2CHOH$ (*g*) ⇋ $(CH_3)_2CO$ (*g*) + H_2 (*g*) ΔH = +57.3 kJ

Does the amount of acetone increase, decrease, or remain the same when an equilibrium mixture of reactants and products is subjected to the following changes?

(a) The temperature is increased

An endothermic reaction shifts to the right as the temperature increases. The amount of acetone increases.

(b) The volume is increased

Because there is 1 mol of gas on the left side and 2 mol of gas on the right side of the balanced equation, the stress of an increase in volume (decrease in pressure) is

relieved by a shift in the reaction to the side with the larger number of moles of gas (in this case, to products). The amount of acetone increases.

(c) The addition of Argon

The addition of Ar (an inert gas) with no volume change does not affect the composition of the equilibrium mixture. The amount of acetone does not change.

(d) H_2 is added

H_2 (product) added; the amount of acetone decreases.

(e) A catalyst is added

A catalyst does not affect the composition of the equilibrium mixture. The amount of acetone does not change.