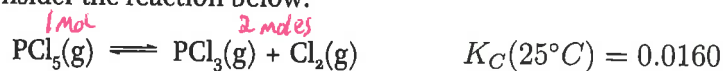


## Quiz 6.1 - Equilibrium

Name: Key

## The Equilibrium Constant

Consider the reaction below:



- Find the value of  $K_p$  for this reaction at  $25^\circ\text{C}$

*Note which version of R we use*

$$K_p = K_C \cdot (RT)^{\Delta n} \quad K_p = 0.0160 \cdot (0.08206 \frac{\text{L} \cdot \text{bar}}{\text{mol} \cdot \text{K}} \cdot 298 \text{ K}) = 0.396$$

- Find the value of  $\Delta G_{\text{rxn}}^\ominus$  for this reaction at  $25^\circ\text{C}$

(\*Note that the standard state for all chemical species in this reaction is a gas at 1 bar\*)

$$\Delta G^\ominus = -RT \ln K = -0.008314 \frac{\text{kJ}}{\text{mol} \cdot \text{K}} \cdot 298 \text{ K} \cdot \ln(0.396) = 2.30 \frac{\text{kJ}}{\text{mol}}$$

- Find the value of  $\Delta G_{\text{rxn}}$  when  $p_{\text{PCl}_5} = 0.53 \text{ bar}$ ,  $p_{\text{PCl}_3} = 0.22 \text{ bar}$ , and  $p_{\text{Cl}_2} = 0.47 \text{ bar}$

$$Q = \frac{0.22 \text{ bar} \cdot 0.47 \text{ bar}}{0.53 \text{ bar}} = 0.195$$

$$\Delta G = \Delta G^\ominus + RT \ln Q = 2.30 \frac{\text{kJ}}{\text{mol}} + 0.008314 \frac{\text{kJ}}{\text{mol} \cdot \text{K}} \cdot 298 \text{ K} \cdot \ln(0.195) = -1.75 \frac{\text{kJ}}{\text{mol}}$$

## Le Châtelier's Principle

Syngas, a mixture of carbon monoxide and hydrogen gas, can be produced by reacting methane with water in the reaction below:



You are a chemical engineer designing a new syngas production plant, and you want to maximize the amount of syngas produced (maximize  $\xi$ ) at equilibrium.\*

- Should you run the reaction at high or low temperature?

High T

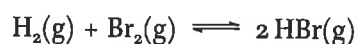
- Should you run the reaction with high partial pressures or low partial pressures?

Low pressures

\*Really, chemical engineers consider far more diverse and complex factors when designing plants

**The van't Hoff Equation**

Consider the reaction below:



For all these problems, use  $\ln\left(\frac{K_2}{K_1}\right) = -\frac{\Delta H^\circ}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$

This reaction is carried out at two temperatures while monitoring equilibrium composition. At  $25^\circ\text{C}$ , the reaction has  $K = 62.5$ , and at  $175^\circ\text{C}$  the reaction has  $K = 0.00343$ .

Use these data to find  $\Delta H_{\text{rxn}}^\circ$  for this reaction.

$$\ln\left(\frac{0.00343}{62.5}\right) = \frac{-\Delta H^\circ}{0.008314 \frac{\text{kJ}}{\text{mol}\cdot\text{K}}}\left(\frac{1}{448 \text{ K}} - \frac{1}{298 \text{ K}}\right) \rightarrow \Delta H^\circ = -72.6 \frac{\text{kJ}}{\text{mol}}$$

What is the value of  $K$  at  $-15^\circ\text{C}$ ?

$$\ln\left(\frac{K_2}{62.5}\right) = \frac{+72,600 \frac{\text{J}}{\text{mol}}}{8.314 \frac{\text{J}}{\text{mol}\cdot\text{K}}}\left(\frac{1}{258 \text{ K}} - \frac{1}{298 \text{ K}}\right) \rightarrow K_2 = 5870$$

At what temperature is  $K = 1.00$ ?

$$\ln\left(\frac{1.00}{62.5}\right) = \frac{72,600 \frac{\text{J}}{\text{mol}}}{8.314 \frac{\text{J}}{\text{mol}\cdot\text{K}}}\left(\frac{1}{T_2} - \frac{1}{298 \text{ K}}\right) \rightarrow T_2 = 347 \text{ K} \quad (74^\circ\text{C})$$

At right, draw a rough van't Hoff plot for this reaction, including:

- Equation for the best fit line  $y = 8731x - 25.2$
- Relationship for the slope  $\text{slope} = -\frac{\Delta H}{R}$
- $K$  in the high temperature limit  $1.14 \cdot 10^{-11}$
- $K$  in the low temperature limit  $\infty$

