

How to Solve Equilibrium Problems

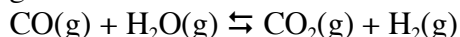
Many chemistry students consider equilibrium problems to be the bane of their existence. This is because they **memorize** how to do them instead of **understanding** the problem. Needless to say, its pretty easy to write questions to check understanding. Therefore we can understand what is happening by just considering and thinking through several examples. This is what we are going to do for the next three days.

You should already understand the following:

- 1) What makes an equilibrium reaction different from our standard “baby” reactions we have considered to this point (in fact is there a difference)
- 2) How you know when you have reached equilibrium?
 - i) Graphically
 - ii) Numerically
- 3) How the equilibrium state is measured quantitatively (K_p and K_c), how to interconvert between these two.
- 4) How to calculate a K_p or K_c for a reaction that is
 - i) multiplied by a constant
 - ii) Reversed
 - iii) two or more reactions added together

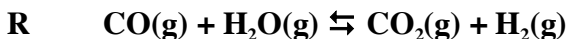
Now, the biggest problem is: You have a chemical reaction that you know is **not** at equilibrium. What will happen to the amounts of reactants and products when equilibrium is reached? To answer these questions, let us work the following problems:

- 1) Consider the following reaction:



At a certain temperature, equilibrium is reached when $[\text{CO}] = [\text{H}_2\text{O}] = [\text{H}_2] = 0.10 \text{ M}$, and the $[\text{CO}_2] = 0.40 \text{ M}$.

- a) Write down the equilibrium constant expression for the reaction
- b) What are the values of K_p and K_c ?
- c) 0.60 moles of H_2 is added to the 2.0 L container. What are the equilibrium concentrations of all substances when equilibrium is reestablished?

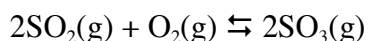


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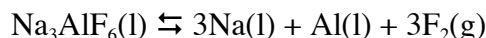
- 2) A quality control engineer examining the conversion of SO_2 to SO_3 in the manufacture of sulfuric acid determines that $K_c = 1.7 \times 10^8$ at 600 K for the reaction:



- a) At equilibrium, $P_{\text{SO}_3} = 300. \text{ atm}$, and $P_{\text{O}_2} = 100. \text{ atm}$, Calculate P_{SO_2} .
- b) The engineer places a mixture of 0.0040 mol of SO_2 and 0.0028 mol of O_2 in a 1.0 L container and raises the temp. to 1000 K. At equil., 0.0020 mol of SO_3 are present. Calculate K_p and K_c for this reaction at 1000. K

3) Phosgene (COCl_2) is a toxic substance that forms readily from carbon monoxide and chlorine at elevated temperatures. If 0.350 mol of each reactant are placed in a 0.500 L flask at 600 K, what are the concentrations of each substance at equilibrium?

4) Aluminum is one of the most versatile metals. It is produced by the Hall – Heroult process, in which molten cryolite, Na_3AlF_6 , is used as a solvent for aluminum ore. Cryolite undergoes very slight decomposition with heat to produce a time amount of F_2 , which escapes into the atmosphere above the solvent. K_c is 2×10^{-104} at 1300K for the reaction:



What is the concentration of F_2 over a bath of molten cryolite at this temperature?

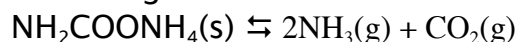
5) The gas arsine, AsH_3 , decomposes as follows.



In an experiment at a certain temperature, pure $\text{AsH}_3(\text{g})$ was placed in an empty, rigid, sealed flask at a pressure of 392.0 torr. After 48 hours the pressure in the flask was observed to be constant at 488.0 torr.

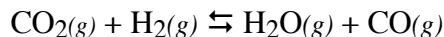
- a) Calculate the equilibrium pressure of H_2 .
- b) Calculate K_p for the reaction.

6) Ammonium carbanate ($\text{NH}_2\text{COONH}_4$) is a salt of carbamic acid that is found in the blood and urine of mammals. At 250 degrees C, $K_c = 1.58 \text{ E}-8$ for the following reaction:



If 7.80 g of $\text{NH}_2\text{COONH}_4$ is introduced into a 0.500 L evacuated container, what is the total pressure inside the container at equilibrium? What is the percent dissociation of the $\text{NH}_2\text{COONH}_4$?

7)



When $\text{H}_2(g)$ is mixed with $\text{CO}_2(g)$ at 2,000 K, equilibrium is achieved according to the equation above. In one experiment, the following equilibrium concentrations were measured.

$$[\text{H}_2] = 0.20 \text{ mol/L}$$

$$[\text{CO}_2] = 0.30 \text{ mol/L}$$

$$[\text{H}_2\text{O}] = [\text{CO}] = 0.55 \text{ mol/L}$$

- What is the mole fraction of $\text{CO}(g)$ in the equilibrium mixture?
- Using the equilibrium concentrations given above, calculate the value of K_c , the equilibrium constant for the reaction.
- Determine K_p in terms of K_c for this system.
- When the system is cooled from 2,000 K to a lower temperature, 30.0 percent of the $\text{CO}(g)$ is converted back to $\text{CO}_2(g)$. Calculate the value of K_c at this lower temperature.
- In a different experiment, 0.50 mole of $\text{H}_2(g)$ is mixed with 0.50 mole of $\text{CO}_2(g)$ in a 3.0-liter reaction vessel at 2,000 K. Calculate the equilibrium concentration, in moles per liter, of $\text{CO}(g)$ at this temperature.

8) Ammonium hydrogen sulfide is a crystalline solid that decomposes as follows:



- Some solid NH_4HS is placed in an evacuated vessel at 25°C. After equilibrium is attained, the total pressure inside the vessel is found to be 0.659 atmosphere. Some solid NH_4HS remains in the vessel at equilibrium. For this decomposition, write the expression for K_p and calculate its numerical value at 25°C.
- Some extra NH_3 gas is injected into the vessel containing the sample described in part (a). When equilibrium is reestablished at 25°C, the partial pressure of NH_3 in the vessel is twice the partial pressure of H_2S . Calculate the numerical value of the partial pressure of NH_3 and the partial pressure of H_2S in the vessel after the NH_3 has been added and the equilibrium has been reestablished.
- In a different experiment, NH_3 gas and H_2S gas are introduced into an empty 1.00 liter vessel at 25°C. The initial partial pressure of each gas is 0.500 atmospheres. Calculate the number of moles of solid NH_4HS that is present when equilibrium is established.