

1. Write the equilibrium constants  $K$  and  $K_c$  for the following equilibria:

(a)



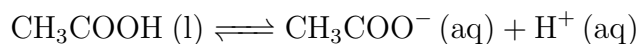
$$K = P_{\text{CO}_2} \quad K_c = [\text{CO}_2]$$

(b)



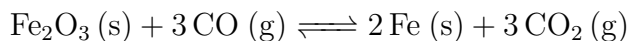
$$K = P_{\text{NH}_3} \cdot P_{\text{HCl}} \quad K_c = [\text{NH}_3][\text{HCl}]$$

(c)



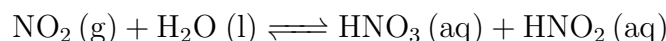
$$K = [\text{CH}_3\text{COO}^-][\text{H}^+] \quad K_c = [\text{CH}_3\text{COO}^-][\text{H}^+]$$

(d)



$$K = \frac{(P_{\text{CO}_2})^3}{(P_{\text{CO}})^3} \quad K_c = \frac{[\text{CO}_2]^3}{[\text{CO}]^3}$$

(e)



$$K = \frac{[\text{HNO}_3][\text{HNO}_2]}{P_{\text{NO}_2}} \quad K_c = \frac{[\text{HNO}_3][\text{HNO}_2]}{[\text{NO}_2]}$$

2. (a) Consider the equilibrium  $\text{X}(\text{g}) \rightleftharpoons \text{Y}(\text{g})$ . A series of experiments were performed by combining the listed amounts of X and Y and allowing the mixtures to reach equilibrium at the same temperature. Which experiment has the largest amount of Y at equilibrium?

Experiment A: 3 moles of X and 4 moles of Y

Experiment B: 1 mole of X and 6 moles of Y

Experiment C: 6 moles of X and 3 moles of Y

Cannot be determined

(b) For the same equilibrium reaction, if  $K > 1$ , which experiment has the largest amount of Y at equilibrium?

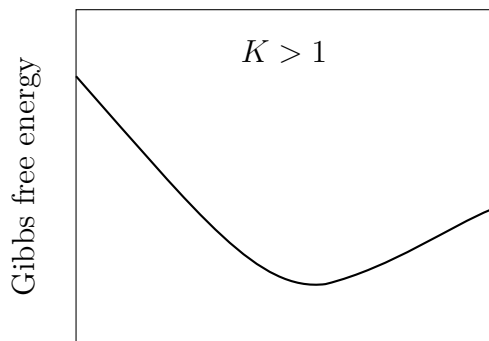
Experiment A: 3 moles of X and 4 moles of Y

Experiment B: 1 mole of X and 6 moles of Y

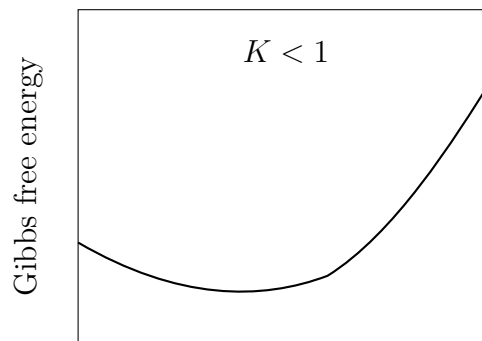
Experiment C: 6 moles of X and 3 moles of Y

Cannot be determined

3. Label each graph with either  $K > 1$  or  $K < 1$ .

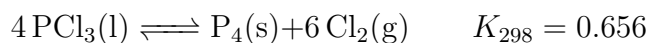


Reactants  $\longrightarrow$  Products



Reactants  $\longrightarrow$  Products

4. Consider the following equilibrium reaction:



$\Delta H_f^\circ$ (kJ/mol)	Value
$\text{PCl}_3(\text{l})$	-287.0
$\text{P}_4(\text{s})$	0

(a) Circle all the statements that are true:

$\text{PCl}_3(\text{l})$  is thermodynamically stable at low temperatures

The reaction is spontaneous at high temperatures

$K = K_C$

At equilibrium, there are 4 mol of  $\text{PCl}_3(\text{l})$ , 1 mol of  $\text{P}_4(\text{s})$  and 6 mol of  $\text{Cl}_2(\text{g})$

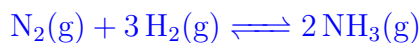
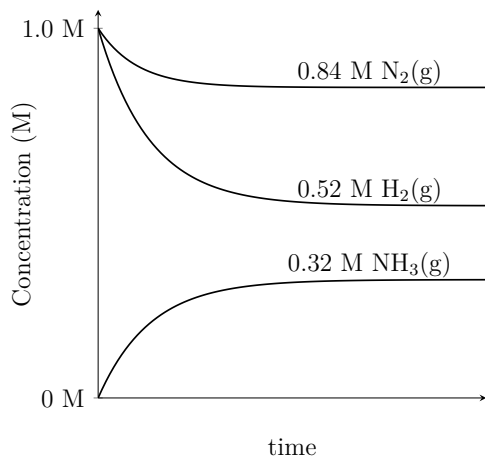
(b) Calculate  $\Delta G_{298\text{K}}^\circ$

$$\begin{aligned} \Delta G^\circ &= -RT \ln K \\ &= -(8.314 \frac{\text{J}}{\text{mol}\cdot\text{K}})(298 \text{ K}) \ln(0.656) \\ &= \boxed{1040 \frac{\text{J}}{\text{mol}}} \end{aligned}$$

(c) What is the partial pressure of  $\text{Cl}_2(\text{g})$  when  $\text{PCl}_3(\text{l})$  is sealed in a 1.0 L container at 298 K and equilibrium is reached?

$$\begin{aligned} K_p &= P_{\text{Cl}_2}^6 = 0.656 \\ P_{\text{Cl}_2} &= (0.656)^{1/6} \\ &= \boxed{0.936 \text{ bar}} \end{aligned}$$

5. Write the balanced equilibrium reaction based on the graph of concentration vs time, and determine  $K$  and  $K_C$  at standard conditions.



$$K_c = \frac{[\text{NH}_3]^2}{[\text{N}_2][\text{H}_2]^3} = \frac{(0.32 \frac{\text{mol}}{\text{L}})^2}{(0.84 \frac{\text{mol}}{\text{L}})(0.52 \frac{\text{mol}}{\text{L}})^3} = 0.867$$

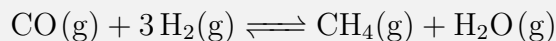
$$K = \left( \frac{c^\circ RT}{P^\circ} \right)^{\Delta n} K_c$$

$$= \left( \frac{(1 \frac{\text{mol}}{\text{L}})(0.08314 \frac{\text{L}\cdot\text{bar}}{\text{mol}\cdot\text{K}})(298 \text{ K})}{1 \text{ bar}} \right)^{-2} (0.867)$$

$$= 0.0014$$

### Homework Problem 23

1. At 298 K, a 2.0 L rigid flask is at equilibrium:



with these quantities: 0.12 mol CO, 0.36 mol H<sub>2</sub>, 0.48 mol CH<sub>4</sub>, and 0.48 mol H<sub>2</sub>O. Calculate the equilibrium constant  $K$ .