

## Worksheet 7: Gases and Equilibrium

**Useful Information**

$R = 0.08206 \text{ L}\cdot\text{atm}/\text{mol}\cdot\text{K}$

$R = 8.314 \text{ J}/\text{mol}\cdot\text{K}$

STP:  $0^\circ\text{C}$ , 1 atm (both exact)

1 atm = 760 torr

$PV = nRT$

$PM = dRT$

1. Which of the following actions would you take to establish a pressure of 2.00 atm in a 2.24 L cylinder containing 1.60 g oxygen gas at  $0^\circ\text{C}$ ?

(MW<sub>O</sub> = 16.00 g/mol; MW<sub>He</sub> = 4.003 g/mol)

- A. add 1.60 g oxygen gas  
 B. release 0.80 g oxygen gas  
 C. add 2.00 g helium gas  
 D. add 0.60 g helium gas

Assume an ideal gas:  $PV = nRT$ 

$$\text{Current mol } O_2: n_{O_2} = (1.60 \text{ g } O_2) \left( \frac{\text{mol } O_2}{32.00 \text{ g } O_2} \right) = 0.0500 \text{ mol } O_2$$

moles gas needed to get 2.00 atm:

$$n_{\text{need}} = \frac{PV}{RT} = \frac{(2.00 \text{ atm})(2.24 \text{ L})}{(0.08206 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(273 \text{ K})} = 0.200 \text{ mol of gas needed}$$

moles to add to current  $O_2$ :  $n_{\text{add}} = n_{\text{need}} - n_{O_2} = 0.200 \text{ mol} - 0.0500 \text{ mol} = 0.150 \text{ mol}$ Is it  $O_2$   
or He?

$$(0.150 \text{ mol } O_2) \left( \frac{32.00 \text{ g } O_2}{\text{mol } O_2} \right) = 4.80 \text{ g } O_2$$

$$(0.150 \text{ mol He}) \left( \frac{4.003 \text{ g He}}{\text{mol He}} \right) = 0.600 \text{ g He} \Rightarrow \text{D.}$$

2. For which of the following gaseous equilibria do  $K_P$  and  $K_C$  differ the most (assuming a constant temperature)?

- A.  $2 \text{ H}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2 \text{ H}_2\text{O}(\text{g})$   
 B.  $\text{NH}_3\text{BH}_3(\text{g}) \rightleftharpoons \text{NH}_2\text{BH}_2(\text{g}) + \text{H}_2(\text{g})$   
 C.  $\text{NO}(\text{g}) + \text{O}_3(\text{g}) \rightleftharpoons \text{NO}_2(\text{g}) + \text{O}_2(\text{g})$   
 D.  $\text{B}_3\text{N}_3\text{H}_6(\text{g}) + 3 \text{ H}_2(\text{g}) \rightleftharpoons \text{B}_3\text{N}_3\text{H}_{12}(\text{g})$   
 E.  $\text{BH}_3(\text{g}) + 3 \text{ HCl}(\text{g}) \rightleftharpoons \text{BCl}_3(\text{g}) + 3 \text{ H}_2(\text{g})$

How are  $K_P$  and  $K_C$  related?

$$K_P = K_C (RT)^{\Delta n}$$

where  $\Delta n$  is the difference between the sum of the product coefficients and the sum of the reactant coeffs.

A:  $\Delta n = (2) - (2+1) = -1$

B:  $\Delta n = (1+1) - (1) = 1$

C:  $\Delta n = (1+1) - (1+1) = 0$

D:  $\Delta n = (1) - (1+3) = -3 \in \text{largest } |\Delta n|, \text{ therefore } K_P \text{ and } K_C \text{ will}$

E:  $\Delta n = (1+3) - (1+3) = 0$

differ by the largest factor of  $(RT)$

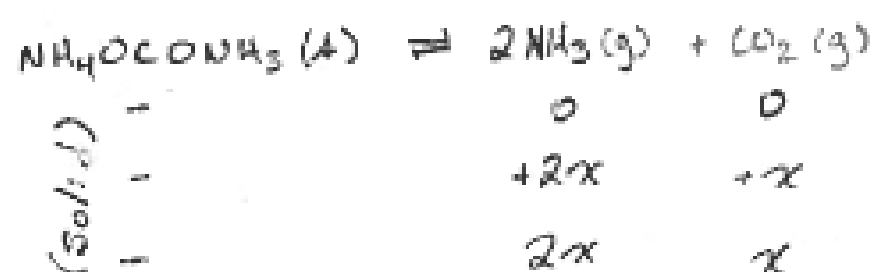
3. Ammonium carbamate decomposes into ammonia and carbon dioxide as follows:



A sample of ammonium carbamate is placed in an evacuated glass vessel at 25°C, which is then sealed. When the system reaches equilibrium, the total pressure of the gases is found to be 0.115 atm. What is  $K_p$  for this reaction at 25°C?

- A.  $2.25 \times 10^{-4} \text{ atm}^3$
- B.  $1.52 \times 10^{-3} \text{ atm}^3$
- C.  $6.08 \times 10^{-3} \text{ atm}^3$
- D. It is impossible to determine from the given data.
- E. None of the above.

I  
C  
E



Law of Partial Pressures

$$P_{\text{total}} = P_{\text{NH}_3} + P_{\text{CO}_2}$$

$$= 2x + x$$

$$0.115 \text{ atm} = 3x$$

$$\therefore x = 0.0383 \text{ atm}$$

$$K_p = P_{\text{NH}_3}^2 \cdot P_{\text{CO}_2} = (2x)^2 (x) = 4x^3$$

$$= 4(0.0383 \text{ atm})^3$$

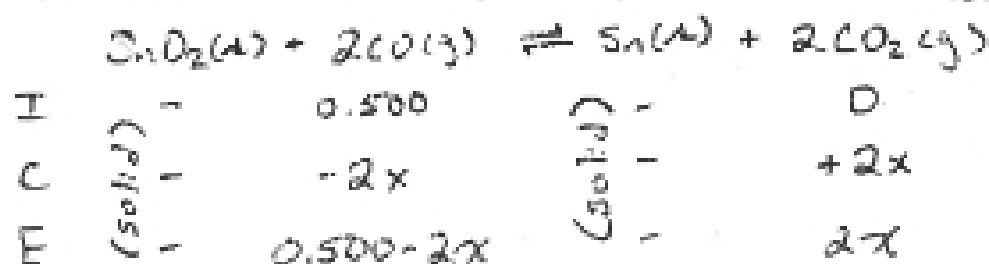
$$= 2.25 \times 10^{-4} \text{ atm}^3$$

4. Consider the following reaction, where  $K_p = 0.025$  at 500°C



The reaction is initiated by adding  $\text{CO}(\text{g})$  at a pressure of 0.500 atm to a rigid vessel containing excess  $\text{SnO}_2(\text{s})$ . At equilibrium, what is the partial pressure of  $\text{CO}_2(\text{g})$ ?

- A. 0.00625 atm
- B. 0.0125 atm
- C. 0.0683 atm
- D. 0.112 atm
- E. None of the above.



$$K_p = \frac{P_{\text{CO}_2}^2}{P_{\text{CO}}^2} = \frac{(2x)^2}{(0.500 - 2x)^2} = 0.025$$

Solve for  $x$ :

$$\sqrt{\frac{(2x)^2}{(0.500 - 2x)^2}} = \sqrt{0.025}$$

$$\frac{2x}{0.500 - 2x} = \sqrt{0.025}$$

$$2x = (0.500 - 2x) \sqrt{0.025}$$

$$2x = 0.500 \sqrt{0.025} - 2 \sqrt{0.025} x$$

$$(2 + 2\sqrt{0.025})x = 0.500 \sqrt{0.025}$$

$$x = \frac{0.500 \sqrt{0.025}}{2 + 2\sqrt{0.025}}$$

$$x \approx 0.0341$$

Solve for partial pressure of  $\text{CO}_2$

$$P_{\text{CO}_2} = 2x = 2(0.0341) = 0.0682 \text{ atm}$$

5. The following reaction is carried out in an enclosed container of 20.0 L at 200. °C  
 $\text{CO}(g) + 2 \text{H}_2(g) \rightleftharpoons \text{CH}_3\text{OH}(g)$

- a. If 2 moles of  $\text{CO}(g)$  and 3 moles of  $\text{H}_2(g)$  are mixed in the container, what is the pressure inside the container before the reaction starts?

Law of Partial Pressures

$$P_{\text{total}} = P_{\text{CO}} + P_{\text{H}_2} + P_{\text{CH}_3\text{OH}}$$

$$= (n_{\text{CO}} + n_{\text{H}_2} + n_{\text{CH}_3\text{OH}}) \left( \frac{RT}{V} \right)$$

$$= (2 \text{ mol} + 3 \text{ mol} + 0 \text{ mol}) \left( \frac{RT}{V} \right)$$

$$= (5 \text{ mol}) \left[ \frac{(0.08206 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(473 \text{ K})}{20.0 \text{ L}} \right] = 9.70 \text{ atm} = \boxed{10 \text{ atm}}$$

$n_{\text{CH}_3\text{OH}} = 0$  because the rxn hasn't begun yet

- b. As the reaction proceeds, do you expect the pressure inside the container to decrease or increase? Why?

reactants  $\rightarrow$  products

$$n_{\text{react}} = 3 \rightarrow n_{\text{prod}} = 1$$

Since the total number of moles is decreasing, the pressure inside will decrease because

$$P = n \frac{RT}{V}$$

- c. At equilibrium, the pressure inside the container is measure to be 4.75 atm. Calculate  $K_p$  and  $K_c$  for this reaction.

Need partial pressures:  $P_{\text{CO}} = \frac{n_{\text{CO}}RT}{V} = \frac{(2 \text{ mol})(0.08206 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(473 \text{ K})}{(20.0 \text{ L})} = 3.88 \text{ atm}$

$$P_{\text{H}_2} = \frac{n_{\text{H}_2}RT}{V} = 5.82 \text{ atm}$$

	$\text{CO}(g)$	$2\text{H}_2(g)$	$\rightleftharpoons$	$\text{CH}_3\text{OH}(g)$
I	3.88	5.82		0
C	-x	-2x		+x
E	3.88-x	5.82-2x		x

$$K_p = \frac{P_{\text{CH}_3\text{OH}}}{P_{\text{CO}} \cdot P_{\text{H}_2}^2} = \frac{x}{(3.88-x)(5.82-2x)^2} = \boxed{2.40 \text{ atm}^{-2}}$$

$$K_c = \frac{K_p}{(RT)^{\Delta n}} = \frac{2.40 \text{ atm}^{-2}}{\left[ (0.08206 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(473 \text{ K}) \right]^{-2}} = \boxed{3.62 \times 10^3 \text{ M}^{-2}}$$

To find x given final (equilibrium) pressure:

$$P_{\text{total}} = P_{\text{CH}_3\text{OH}} + P_{\text{CO}} + P_{\text{H}_2}$$

$$4.75 \text{ atm} = (x) + (3.88-x) + (5.82-2x)$$

$$4.75 \text{ atm} = 9.70 - 2x$$

$$\therefore x = 2.48 \text{ atm}$$