

Name \_\_\_\_\_

CALVIN

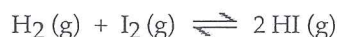
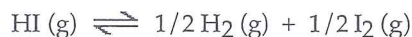
MULTIPLE CHOICE. Choose the one alternative that best completes the statement or answers the question.

- 1) At equilibrium, \_\_\_\_\_.
- A) the rates of the forward and reverse reactions are equal
- B) the rate constants of the forward and reverse reactions are equal
- C) all chemical reactions have ceased
- D) the value of the equilibrium constant is 1
- E) the limiting reagent has been consumed
- 2) Which one of the following will change the value of an equilibrium constant?
- A) adding other substances that do not react with any of the species involved in the equilibrium
- B) varying the initial concentrations of reactants
- C) changing temperature
- D) varying the initial concentrations of products
- E) changing the volume of the reaction vessel

- 3) The value of  $K_{eq}$  for the following reaction is 0.25:

Doubled so  $K^2$ The value of  $K_{eq}$  at the same temperature for the reaction below is \_\_\_\_\_.

- A) 0.062                      B) 16                      C) 0.25                      D) 0.50                      E) 0.12
- 4) The value of  $K_{eq}$  for the equilibrium

Reversed and cut in half so  $\left(\frac{1}{K}\right)^{1/2}$ is 794 at 25°C. At this temperature, what is the value of  $K_{eq}$  for the equilibrium below?

- A) 0.035                      B) 0.0013                      C) 28                      D) 397                      E) 1588

5) The  $K_{eq}$  for the equilibrium below is  $7.52 \times 10^{-2}$  at  $480^\circ\text{C}$ .



cut in  $\frac{1}{2}$

What is the value of  $K_{eq}$  at this temperature for the following reaction?

$$K' = K^{\frac{1}{2}}$$



- A) 0.150      **B) 0.274**      C) 0.0376      D)  $5.66 \times 10^{-3}$       E) 0.0752

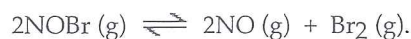
6) At 1000 K, the equilibrium constant for the reaction



Reversed

is  $K_p = 0.013$ . Calculate  $K_p$  for the reverse reaction,

$$K' = \frac{1}{K}$$



- A) 0.99      B) 1.1      C) 0.013      D)  $1.6 \times 10^{-4}$       **E) 77**

7) The expression for  $K_{eq}$  for the reaction below is \_\_\_\_\_.



**A)  $\frac{P_{\text{CO}_2} P_{\text{H}_2\text{O}}^2}{P_{\text{CH}_4}}$**

B)  $\frac{P_{\text{CH}_4}}{P_{\text{H}_2\text{O}}^2 P_{\text{CO}_2}}$

C)  $\frac{[\text{Cu}] P_{\text{CO}_2} P_{\text{H}_2\text{O}}^2}{[\text{CuO}]^4 P_{\text{CH}_4}}$

D)  $\frac{P_{\text{CH}_4}}{P_{\text{CO}_2} P_{\text{H}_2}^2}$

E)  $\frac{P_{\text{CO}_2} P_{\text{H}_2\text{O}}^2}{P_{\text{CuO}}}$

8) Acetic acid is a weak acid that dissociates into the acetate ion and a proton in aqueous solution:



At equilibrium at  $25^\circ\text{C}$  a 0.100 M solution of acetic acid has the following concentrations:

$[\text{HC}_2\text{H}_3\text{O}_2] = 0.0990 \text{ M}$ ,  $[\text{C}_2\text{H}_3\text{O}_2\text{G}] = 1.33 \times 10^{-3} \text{ M}$ , and  $[\text{H}^+] = 1.33 \times 10^{-3} \text{ M}$ . The equilibrium constant,  $K_{eq}$ , for the ionization of acetic acid at  $25^\circ\text{C}$  is \_\_\_\_\_.

- A)  $5.71 \times 10^4$       **B)  $1.79 \times 10^{-5}$**       C)  $1.75 \times 10^{-7}$       D)  $5.71 \times 10^6$       E) 0.100

$$K = \frac{[\text{H}^+][\text{C}_2\text{H}_3\text{O}_2]}{[\text{HC}_2\text{H}_3\text{O}_2]} = \frac{(1.33 \times 10^{-3})(1.33 \times 10^{-3})}{(0.0990)} = 1.79 \times 10^{-5}$$

9) At 200°C, the equilibrium constant for the reaction below is  $2.40 \times 10^3$ .

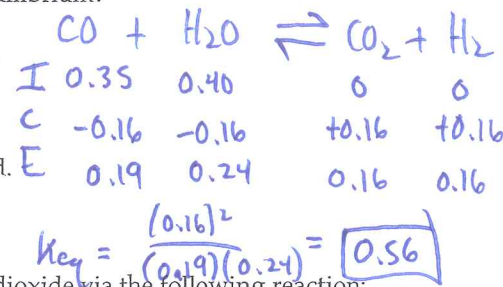


A closed vessel is charged with 36.1 atm of NO. At equilibrium, the partial pressure of O<sub>2</sub> is \_\_\_\_\_ atm.

- A) 35.7      **B) 18.1**      C)  $1.50 \times 10^{-2}$       D) 6.00      E) 294

10) How is the reaction quotient used to determine whether a system is at equilibrium?

- A) The reaction is at equilibrium when  $Q < K_{\text{eq}}$ .  
 B) The reaction is at equilibrium when  $Q > K_{\text{eq}}$ .  
 C) At equilibrium, the reaction quotient is undefined.  
 D) The reaction quotient must be satisfied for equilibrium to be achieved.  
**E) The reaction is at equilibrium when  $Q = K_{\text{eq}}$ .**



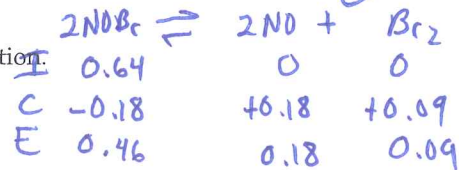
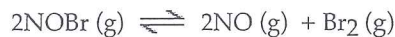
11) In the coal-gasification process, carbon monoxide is converted to carbon dioxide via the following reaction:



In an experiment, 0.35 mol of CO and 0.40 mol of H<sub>2</sub>O were placed in a 1.00-L reaction vessel. At equilibrium, there were 0.19 mol of CO remaining.  $K_{\text{eq}}$  at the temperature of the experiment is \_\_\_\_\_.

- A) 0.75      B) 1.0      C) 5.47      D) 1.78      **E) 0.56**

12) Nitrosyl bromide decomposes according to the following equation:



A sample of NOBr (0.64 mol) was placed in a 1.00-L flask containing no NO or Br<sub>2</sub>. At equilibrium the flask contained 0.46 mol of NOBr. How many moles of NO and Br<sub>2</sub>, respectively, are in the flask at equilibrium?

- A) 0.46, 0.23      **B) 0.18, 0.090**      C) 0.46, 0.46      D) 0.18, 0.360      E) 0.18, 0.18

13) In which of the following reactions would increasing pressure at constant temperature not change the concentrations of reactants and products, based on Le Châtelier's principle?

- A)  $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g})$   
 B)  $2\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{N}_2\text{O}(\text{g})$   
 C)  $\text{N}_2(\text{g}) + 2\text{O}_2(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$   
 D)  $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$   
**E)  $\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{NO}(\text{g})$**

$$K = 2400 = \frac{x^2}{(36.1 - 2x)^2}$$

$$2400 = \left( \frac{x}{36.1 - 2x} \right)^2$$

$$\sqrt{2400} = \frac{x}{36.1 - 2x}$$

$$49.0 = \frac{x}{36.1 - 2x}$$

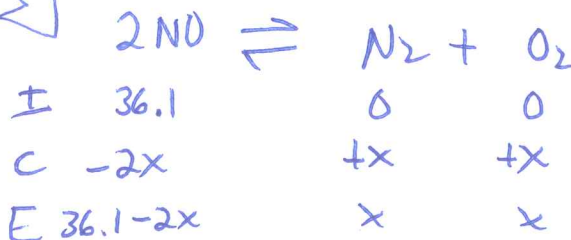
$$x = (49.0)(36.1 - 2x)$$

$$x = 1768.53 - 97.98x$$

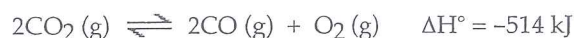
$$98.98x = 1768.53$$

$$x = 17.9$$

$$x = P_{\text{O}_2} = \boxed{17.9}$$



- 14) Consider the following reaction at equilibrium:

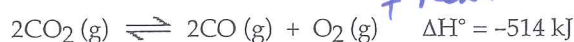


Le Chatelier's principle predicts that adding  $\text{O}_2(\text{g})$  to the reaction container will \_\_\_\_\_.

- A) decrease the partial pressure of  $\text{CO}_2(\text{g})$  at equilibrium
- B) decrease the value of the equilibrium constant
- C) increase the partial pressure of  $\text{CO}_2(\text{g})$  at equilibrium
- D) increase the value of the equilibrium constant
- E) increase the partial pressure of  $\text{CO}(\text{g})$  at equilibrium

Shifts LEFT

- 15) Consider the following reaction at equilibrium:

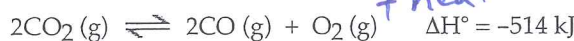


Le Chatelier's principle predicts that an increase in temperature will \_\_\_\_\_.

- A) increase the partial pressure of  $\text{O}_2(\text{g})$
- B) decrease the value of the equilibrium constant
- C) increase the partial pressure of  $\text{CO}$
- D) decrease the partial pressure of  $\text{CO}_2(\text{g})$
- E) increase the value of the equilibrium constant

Shifts LEFT

- 16) Consider the following reaction at equilibrium.



Le Chatelier's principle predicts that the equilibrium partial pressure of  $\text{CO}(\text{g})$  can be maximized by carrying out the reaction \_\_\_\_\_.

- A) at high temperature and high pressure
- B) at high temperature and low pressure
- C) at low temperature and low pressure
- D) at low temperature and high pressure
- E) in the presence of solid carbon

low temp  $\rightarrow$  shifts right  
low P  $\rightarrow$  shifts right

- 17) The effect of a catalyst on an equilibrium is to \_\_\_\_\_.

- A) increase the rate at which equilibrium is achieved without changing the composition of the equilibrium mixture
- B) increase the rate of the forward reaction only
- C) shift the equilibrium to the right
- D) increase the equilibrium constant so that products are favored
- E) slow the reverse reaction only

18) The following equilibrium is readily established:

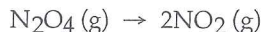


$$K = \frac{[\text{SO}_2][\text{Cl}_2]}{[\text{SO}_2\text{Cl}_2]} = \frac{(0.0287)(0.0287)}{(0.0106)} = 0.0777$$

At equilibrium at 373 K, a 1.00-L reaction vessel contains 0.0106 mol of  $\text{SO}_2\text{Cl}_2$  and 0.0287 mol each of  $\text{SO}_2$  and  $\text{Cl}_2$ . What is  $K_{\text{eq}}$  for the reaction at 373 K?

- A) 12.8                      B) 2.72                      C) 0.0781                      D) 2.39                      E) 0.418

19) Dinitrogen tetroxide partially decomposes according to the following equilibrium:



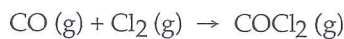
A 1.000-L flask is charged with  $3.00 \times 10^{-2}$  mol of  $\text{N}_2\text{O}_4$ . At equilibrium,  $2.36 \times 10^{-2}$  mol of  $\text{N}_2\text{O}_4$  remains.  $K_{\text{eq}}$  for this reaction is \_\_\_\_\_.

- A) 0.723  
B)  $1.92 \times 10^{-4}$   
C)  $6.93 \times 10^{-3}$   
D) 0.391  
E) 0.212

	$\text{N}_2\text{O}_4$	$\rightleftharpoons$	$2\text{NO}_2$	
I	0.0300		0	
C	-0.0064		+0.0128	
E	0.0236		0.0128	

$$K = \frac{(0.0128)^2}{(0.0236)} = 6.94 \times 10^{-3}$$

20) The  $K_{\text{eq}}$  for the reaction below is  $1.49 \times 10^8$  at  $100^\circ\text{C}$ :

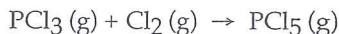


$$1.49 \times 10^8 = \frac{(x)}{(8.60 \times 10^{-4})^2} \quad x = 1.10 \times 10^2 \text{ atm}$$

In an equilibrium mixture of the three gases,  $P_{\text{CO}} = P_{\text{Cl}_2} = 8.60 \times 10^{-4}$  atm. The partial pressure of the product, phosgene ( $\text{COCl}_2$ ), is \_\_\_\_\_ atm.

- A)  $2.01 \times 10^{14}$                       B)  $1.72 \times 10^{11}$                       C)  $1.28 \times 10^5$                       D)  $4.96 \times 10^{-15}$                       E)  $1.10 \times 10^2$

21) Phosphorous trichloride and phosphorous pentachloride equilibrate in the presence of molecular chlorine according to the reaction:



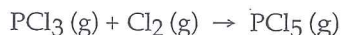
$$PV = nRT$$

$$P = \frac{(0.990 \text{ mol})(0.0821 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(500\text{K})}{1.000\text{L}} = 40.6 \text{ atm} \quad \text{See next page}$$

$K_{\text{eq}} = 2.01$  at 500 K. A 1.000-L reaction vessel is charged with 0.990 mol of  $\text{PCl}_5$  and allowed to equilibrate at this temperature. The equilibrium partial pressure of  $\text{PCl}_3$  is \_\_\_\_\_ atm.

- A) 0.702                      B) 4.25                      C) 4.50                      D) 36.4                      E) 0.496

22) Phosphorous trichloride and phosphorous pentachloride equilibrate in the presence of molecular chlorine according to the reaction:

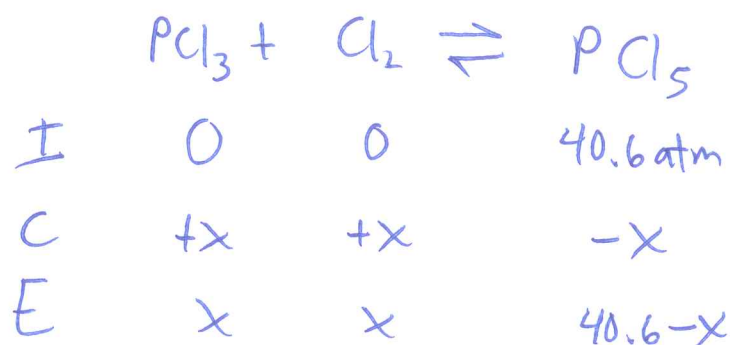


$K_{\text{eq}} = 2.01$  at 500 K. A 1.000-L reaction vessel is charged with 0.300 mol of  $\text{PCl}_5$  and allowed to equilibrate at this temperature. The equilibrium partial pressure of  $\text{PCl}_5$  is \_\_\_\_\_ atm.

- A) 0.1                      B) 0.386                      C) 2.24                      D) 2.48                      E) 0.211

$$21) PV = nRT$$

$$P = \frac{(0.990 \text{ mol})(0.0821 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(500 \text{ K})}{(1.000 \text{ L})} = 40.6 \text{ atm}$$



$$K_p = 2.01 = \frac{(40.6 - x)}{x^2}$$

$$2.01x^2 = 40.6 - x$$

$$2.01x^2 + x = 40.6$$

$$2.01x^2 + x - 40.6 = 0$$

$$a = 2.01$$

$$b = 1$$

$$c = -40.6$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$= \frac{-1 \pm \sqrt{1^2 - (4)(2.01)(-40.6)}}{(2)(2.01)}$$

$$= \frac{-1 \pm \sqrt{1 + 326.4}}{4.02} = \frac{-1 + 18.09}{4.02} = \boxed{4.25} \text{ atm } P_{\text{Cl}_2}$$

22)



I	0	0	12.3
C	+x	+x	-x
E	x	x	12.3-x

$$P = \frac{nRT}{V} = \frac{(0.300)(0.0821)(500)}{(1.00)}$$

$$= 12.3 \text{ atm}$$

$$K_p = 2.01 = \frac{12.3-x}{x^2}$$

$$2.01x^2 + x - 12.3 = 0$$

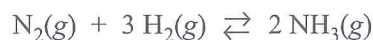
$$x = \frac{-1 \pm \sqrt{1 - (4)(2.01)(-12.3)}}{(2)(2.01)}$$

$$x = \frac{-1 + 10}{4.02} = \frac{9}{4.02} = 2.24$$

$$P_{Cl_5} = 12.3 - 2.24 = \boxed{10.1 \text{ atm}}$$

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**2004 SCORING GUIDELINES (Form B)**

**Question 1**



1. For the reaction represented above, the value of the equilibrium constant,  $K_p$ , is  $3.1 \times 10^{-4}$  at 700. K.

(a) Write the expression for the equilibrium constant,  $K_p$ , for the reaction.

$K_p = \frac{P_{\text{NH}_3}^2}{P_{\text{N}_2} \times P_{\text{H}_2}^3}$	1 point for pressure expression 1 point for correct substitution
--	---

(b) Assume that the initial partial pressures of the gases are as follows:

$$P_{\text{N}_2} = 0.411 \text{ atm}, P_{\text{H}_2} = 0.903 \text{ atm}, \text{ and } P_{\text{NH}_3} = 0.224 \text{ atm.}$$

(i) Calculate the value of the reaction quotient,  $Q$ , at these initial conditions.

$Q = \frac{P_{\text{NH}_3}^2}{P_{\text{N}_2} \times P_{\text{H}_2}^3} = \frac{(0.224)^2}{(0.411)(0.903)^3}$ $Q = 0.166$	1 point for calculation of $Q$ with correct mass action expression  Note: must be consistent with part (a)
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(ii) Predict the direction in which the reaction will proceed at 700. K if the initial partial pressures are those given above. Justify your answer.

Since $Q > K_p$ , the numerator must decrease and the denominator must increase, so the reaction must proceed from right to left to establish equilibrium.	1 point for direction or for stating that $Q > K_p$ 1 point for explanation
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(c) Calculate the value of the equilibrium constant,  $K_c$ , given that the value of  $K_p$  for the reaction at 700. K is  $3.1 \times 10^{-4}$ .

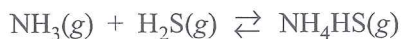
$K_p = K_c(RT)^{\Delta n}$ $\Delta n = 2 - 4 = -2$ $K_p = K_c(RT)^{-2}$ $3.1 \times 10^{-4} = K_c(0.0821 \frac{\text{L atm}}{\text{mol K}} \times 700 \text{ K})^{-2}$ $3.1 \times 10^{-4} = K_c(57.5)^{-2}$ $3.1 \times 10^{-4} = K_c(3.0 \times 10^{-4})$ $1.0 = K_c$	1 point for calculating $\Delta n$     1 point for correct substitution and value of $K_c$
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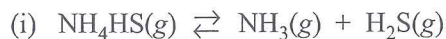
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**Question 1 (cont'd.)**

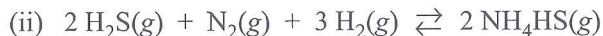
(d) The value of  $K_p$  for the reaction represented below is  $8.3 \times 10^{-3}$  at 700. K.



Calculate the value of  $K_p$  at 700. K for each of the reactions represented below.



$K_p = \frac{1}{8.3 \times 10^{-3}} = 1.2 \times 10^2$	1 point for the calculation of $K_p$
--	--------------------------------------



$2 \times [\text{NH}_3(g) + \text{H}_2\text{S}(g) \rightleftharpoons \text{NH}_4\text{HS}(g)] \quad K_p = (8.3 \times 10^{-3})^2$ $\text{N}_2(g) + 3 \text{H}_2(g) \rightleftharpoons 2 \text{NH}_3(g) \quad K_p = 3.1 \times 10^{-4}$	1 point for squaring $K_p$ for $\text{NH}_4\text{HS}$ or for multiplying $K_p$ 's
$2 \text{H}_2\text{S}(g) + \text{N}_2(g) + 3 \text{H}_2(g) \rightleftharpoons 2 \text{NH}_4\text{HS}(g)$ $K_p = (8.3 \times 10^{-3})^2 (3.1 \times 10^{-4}) = 2.1 \times 10^{-8}$	1 point for correct $K_p$