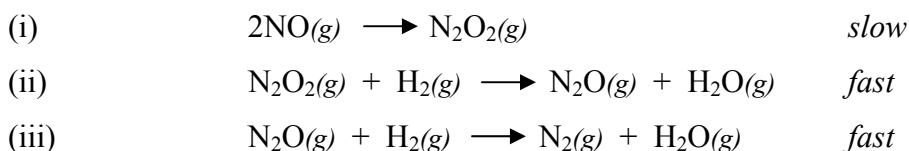


The reaction mechanism for the reaction of NO with H₂ reveals that the overall reaction occurs via 3 elementary steps. Use the information for the three elementary reactions listed below to answer questions 3 – 5.



3. What are the intermediates in the 3-step reaction mechanism shown above?

- a. N₂O₂(g), N₂O(g) b. N₂O₂(g), N₂O(g), H₂(g)
c. N₂O₂(g), H₂O(g) d. N₂O₂(g), H₂(g)

4. The overall balanced chemical equation for the shown above is:

- a. $2\text{NO}(g) + \text{H}_2(g) \longrightarrow \text{N}_2(g) + \text{H}_2\text{O}(g)$
b. $2\text{NO}(g) + 2\text{N}_2\text{O}_2(g) + 2\text{H}_2(g) \longrightarrow \text{N}_2\text{O}(g) + \text{N}_2(g) + 2\text{H}_2\text{O}(g)$
 c. $2\text{NO}(g) + 2\text{H}_2(g) \longrightarrow \text{N}_2(g) + 2\text{H}_2\text{O}(g)$
d. $\text{N}_2\text{O}(g) + \text{H}_2(g) \longrightarrow \text{N}_2(g) + \text{H}_2\text{O}(g)$

5. What is the rate law for the overall reaction?

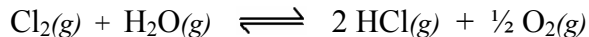
- a. rate = k [NO]²
b. rate = k [NO] [H₂]
c. rate = k [NO]² [H₂]²
d. the rate law can't be determined from the information given.

6. The equilibrium constant, K, for the reaction below is 5.7 at 1500 °C. The reaction mixture is tested and found to contain 0.2 M CO, 0.6 M H₂, 0.7 M CH₄, and 0.1 M H₂O. Will the reaction continue to form product?

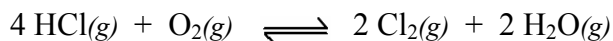


- a. Yes, because Q < K b. Yes, because Q > K
c. No, because Q < K d. No, because Q > K

7. The equilibrium constant, K , for the reaction below is 0.274 at 753 K.

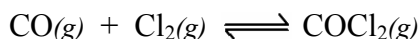


What is the equilibrium constant for the following reaction?



- a. 3.65 b. 0.0751 **c. 13.3** d. 177

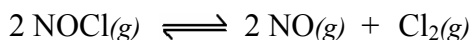
8. At 100 °C, the equilibrium constant for the following reaction is $K = 4.56 \times 10^9$.



If an equal molar mixture of CO and Cl_2 are introduced into a reaction vessel, what is the predominant species at equilibrium?

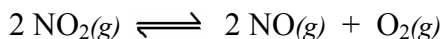
- a. CO and COCl_2 b. CO and Cl_2 c. Cl_2 and COCl_2 **d. COCl_2**

9. The equilibrium constant, K , for the reaction below is 0.0080. At equilibrium, the concentration of $\text{NOCl}(g)$ is 0.25 M and the concentration of $\text{NO}(g)$ is 0.10 M. What is the equilibrium concentration of $\text{Cl}_2(g)$?



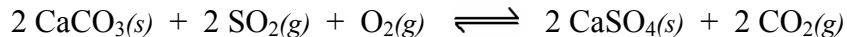
- a. 0.20 M **b. 0.050 M** c. 2.0 M d. 0.50 M

10. The following reaction was carried out at 25 °C with the initial concentration of NO_2 being 0.70 M. Assume that NO and O_2 are not present initially. At equilibrium, the NO_2 concentration was found to be 0.28 M. What is the equilibrium constant for this reaction?



- a. 3.8 b. 1.9 c. 0.14 **d. 0.47**

11. Which equilibrium expression applies to the reaction below?



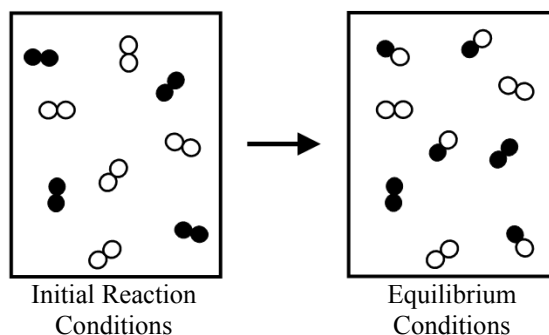
a. $K = \frac{[\text{CaCO}_3]^2[\text{SO}_2]^2[\text{O}_2]}{[\text{CaSO}_4]^2[\text{CO}_2]^2}$

b. $K = \frac{[\text{CO}_2]^2}{[\text{SO}_2]^2[\text{O}_2]}$

c. $K = \frac{[\text{CO}_2]^2}{[\text{O}_2]}$

d. $K = \frac{[\text{CaSO}_4]^2[\text{CO}_2]^2}{[\text{CaCO}_3]^2[\text{SO}_2]^2[\text{O}_2]}$

12. In the diagrams below, open circles (o) represent atoms of element A and closed circles (●) represent atoms of element B. The diagram on the left shows the initial starting conditions for the reaction of A₂ with B₂. The diagram on the right shows the reaction at equilibrium. What is the equilibrium expression for this reaction?



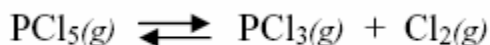
a. $\frac{[\text{AB}]^4[\text{A}_2]^3[\text{B}_2]^2}{[\text{A}_2]^5[\text{B}_2]^4}$

b. $\frac{[\text{AB}]^4}{[\text{A}_2]^5[\text{B}_2]^4}$

c. $\frac{[\text{AB}]^4}{[\text{A}_2]^3[\text{B}_2]^2}$

d. $\frac{[\text{AB}]^2}{[\text{A}_2][\text{B}_2]}$

13. Consider the following reaction at equilibrium



Adding PCl₃(g) to this reaction at equilibrium will cause the reaction to

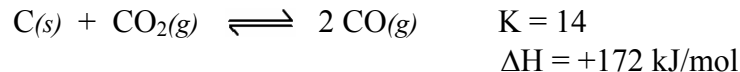
a. shift to the left. When equilibrium is reestablished, the value of the equilibrium constant will be less than it was before the addition of PCl₃(g).

b. shift to the right. When equilibrium is reestablished, the value of the equilibrium constant will be greater than it was before the addition of PCl₃(g).

c. shift to the left. When equilibrium is reestablished, the value of the equilibrium constant will be the same as it was before the addition of PCl₃(g).

d. shift to the right. When equilibrium is reestablished, the value of the equilibrium constant will be the same as it was before the addition of PCl₃(g).

14. Consider the following reaction at equilibrium.



Raising the temperature of this reaction will

- a. cause the equilibrium to shift to the left.
- b. decrease the value of K.
- c. increase the amount of $\text{CO}(g)$ present.
- d. not change the amount of $\text{C}(s)$ present.

15. Which of the following is the best description of a base according to the Brønsted-Lowry definition?

I. proton donor II. proton acceptor III. hydroxide ion donor

- a. II only
- b. II and III
- c. I and III
- d. none of the above

16. Which one of the following is the conjugate acid of NH_3 ?

- a. NH_4^+
- b. H_3O^+
- c. NH_2^-
- d. none of these

17. Which one of the following is the conjugate base of CO_3^{2-} ?

- a. CO_2^{2-}
- b. HCO_3^{1-}
- c. OH^-
- d. none of these

18. Calculate the pH of a 0.099 M solution of HCl.

- a. 0.051
- b. 0.12
- c. 1.004
- d. 2.42

19. Calculate the pH of a 2.5×10^{-2} M solution of $\text{Ca}(\text{OH})_2$.

- a. 12.70
- b. 12.40
- c. 1.60
- d. 1.30

Use the following table of K_a and K_b values to answer questions 20 - 22.

Acid Dissociation Constants	K_a	Base Dissociation Constants	K_b
Acetic acid ($\text{HC}_2\text{H}_3\text{O}_2$)	1.8×10^{-5}	Ammonia (NH_3)	1.8×10^{-5}
Chlorous (HClO_2)	1.1×10^{-2}	Carbonate (CO_3^{2-})	1.8×10^{-4}
Citric ($\text{H}_3\text{C}_6\text{H}_5\text{O}_7$)	7.4×10^{-4}	Hydroxylamine (HONH_2)	1.1×10^{-8}
Hydrofluoric (HF)	6.8×10^{-4}	Hypochlorite (ClO^-)	3.3×10^{-7}
Hydrocyanic (HCN)	4.9×10^{-10}		
Nitrous (HNO_2)	4.5×10^{-4}		
Hydrosulfuric (H_2S)	9.5×10^{-8}		

20. Place the following in order of weakest to strongest acid?



- a. $\text{HClO}_2 < \text{HCN} < \text{H}_2\text{S} < \text{HClO}_4$
- b. $\text{HCN} < \text{H}_2\text{S} < \text{HClO}_2 < \text{HClO}_4$**
- c. $\text{HClO}_4 < \text{HCN} < \text{H}_2\text{S} < \text{HClO}_2$
- d. $\text{HClO}_4 < \text{HClO}_2 < \text{H}_2\text{S} < \text{HCN}$

21. Calculate the hydroxide concentration in a 0.10 M solution of hydroxylamine.

- a. 3.0×10^{-10} M
- b. 0.10 M
- c. 1.1×10^{-9} M
- d. 3.3×10^{-5} M**

22. Calculate the number of moles of acetic acid that must be added to 1.0 L of solution in order to prepare a solution with a pH of 3.10.

- a. 7.9×10^{-4}
- b. 3.5×10^{-2}**
- c. 1.2×10^{-5}
- d. 1.8×10^{-5}

Important Formulas and Constants

$$PV = nRT \qquad \frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2} \qquad PV = \frac{mRT}{M} \qquad P_T = P_1 + P_2 + P_3 + \dots$$

$$X_a = \frac{n_a}{n_T} \qquad P_a = X_a P_T \qquad \frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}} \qquad q = \Delta H_{\text{vap}} m \qquad q = cm\Delta t$$

$$R = 0.0821 \text{ L}\cdot\text{atm}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}$$

$$K = ^\circ\text{C} + 273$$

$$1 \text{ atm} = 760 \text{ mmHg} = 760 \text{ torr} = 101.3 \text{ kPa}$$

$$\text{For sc: } 2r = a \quad \text{For fcc: } 4r = a\sqrt{2} \quad \text{For bcc: } 4r = a\sqrt{3}$$

$$M = \frac{\text{moles}_{\text{solute}}}{L_{\text{solution}}} \qquad m = \frac{\text{moles}_{\text{solute}}}{\text{kg}_{\text{solvent}}} \qquad \text{ppm} = \frac{\text{mg}_{\text{solute}}}{\text{kg}_{\text{solution}}} \qquad \text{ppb} = \frac{\mu\text{g}_{\text{solute}}}{\text{kg}_{\text{solution}}}$$

$$C_g = kP_g \qquad P_A = \chi_A P_A^0 \qquad \Delta T_b = iK_b m \qquad \Delta T_f = -iK_f m$$

$$\text{Rate} = \frac{-\Delta[A]}{\Delta t} \qquad \text{Rate} = k[A]^m[B]^n \qquad \ln[A] = -kt + \ln[A]_0 \qquad t_{1/2} = \frac{0.693}{k}$$

$$k = Ae^{\frac{-E_a}{RT}}$$

$$\text{For the reaction: } aA + bB \rightleftharpoons cC + dD \qquad K = \frac{[C]^c[D]^d}{[A]^a[B]^b}$$

$$\text{For the reaction: } \text{HA}(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{A}^-(aq) \qquad K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]}$$

$$\text{For the reaction: } \text{B}(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{BH}^+(aq) + \text{OH}^-(aq) \qquad K_b = \frac{[\text{BH}^+][\text{OH}^-]}{[\text{B}]}$$

$$\text{pH} = -\log[\text{H}_3\text{O}^+]$$

$$K_w = [\text{H}_3\text{O}^+][\text{OH}^-] = 1.0 \times 10^{-14}$$

$$\text{pH} + \text{pOH} = 14$$

$$K_a K_b = K_w$$