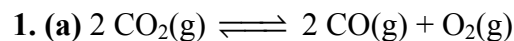


## Section 7.2: Equilibrium Law and the Equilibrium Constant

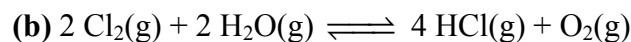
### Tutorial 1 Practice, page 431



Products:  $2 \text{CO}(\text{g})$ ;  $\text{O}_2(\text{g})$

Reactant:  $2 \text{CO}_2(\text{g})$

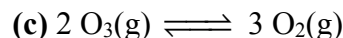
Equilibrium law equation: 
$$K = \frac{[\text{CO}(\text{g})]^2[\text{O}_2(\text{g})]}{[\text{CO}_2(\text{g})]^2}$$



Products:  $4 \text{HCl}(\text{g})$ ;  $\text{O}_2(\text{g})$

Reactants:  $2 \text{Cl}_2(\text{g})$ ;  $2 \text{H}_2\text{O}(\text{g})$

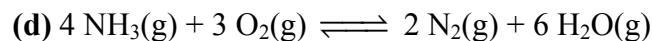
Equilibrium law equation: 
$$K = \frac{[\text{HCl}(\text{g})]^4[\text{O}_2(\text{g})]}{[\text{Cl}_2(\text{g})]^2[\text{H}_2\text{O}(\text{g})]^2}$$



Product:  $3 \text{O}_2(\text{g})$

Reactant:  $2 \text{O}_3(\text{g})$

Equilibrium law equation: 
$$K = \frac{[\text{O}_2(\text{g})]^3}{[\text{O}_3(\text{g})]^2}$$



Products:  $2 \text{N}_2(\text{g})$ ;  $6 \text{H}_2\text{O}(\text{g})$

Reactants:  $4 \text{NH}_3(\text{g})$ ;  $3 \text{O}_2(\text{g})$

Equilibrium law equation: 
$$K = \frac{[\text{N}_2(\text{g})]^2[\text{H}_2\text{O}(\text{g})]^6}{[\text{NH}_3(\text{g})]^4[\text{O}_2(\text{g})]^3}$$

2. **Given:**  $\text{CO}(\text{g}) + 2 \text{H}_2(\text{g}) \rightleftharpoons \text{CH}_3\text{OH}(\text{g})$ ;  $[\text{CO}(\text{g})]_{\text{equilibrium}} = 0.079 \text{ mol/L}$ ;

$[\text{H}_2(\text{g})]_{\text{equilibrium}} = 0.158 \text{ mol/L}$ ;  $[\text{CH}_3\text{OH}(\text{g})]_{\text{equilibrium}} = 0.021 \text{ mol/L}$

**Required:**  $K$

**Solution:** Write the equilibrium law equation using the balanced chemical equation. Then, substitute the equilibrium concentrations into the equilibrium law equation and solve for  $K$ .

$$\begin{aligned} K &= \frac{[\text{CH}_3\text{OH}(\text{g})]}{[\text{CO}(\text{g})][\text{H}_2(\text{g})]^2} \\ &= \frac{(0.021)}{(0.079)(0.158)^2} \end{aligned}$$

$$K = 11$$

**Statement:** The equilibrium constant,  $K$ , for the reaction is 11.

**3. Given:**  $K = \frac{[\text{NO}(\text{g})]^2[\text{Br}_2(\text{g})]}{[\text{NOBr}(\text{g})]^2}$

**Required:** the balanced chemical equation for the reaction

**Analysis:** Use the general equilibrium law equation to determine the balanced reaction equation.

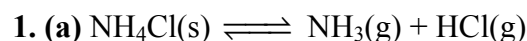
**Solution:** Products: 2 NO(g); Br<sub>2</sub>(g)

Reactant: 2 NOBr(g)

Balanced chemical equation:  $2 \text{NOBr}(\text{g}) \rightleftharpoons 2 \text{NO}(\text{g}) + \text{Br}_2(\text{g})$

**Statement:** The balanced chemical equation is  $2 \text{NOBr}(\text{g}) \rightleftharpoons 2 \text{NO}(\text{g}) + \text{Br}_2(\text{g})$ .

### Tutorial 2 Practice, page 434



Products: NH<sub>3</sub>(g); HCl(g)

Reactant: NH<sub>4</sub>Cl(s)

Equilibrium law equation:  $K = [\text{NH}_3(\text{g})][\text{HCl}(\text{g})]$

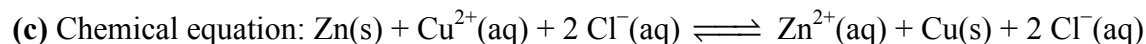


Balanced chemical equation:  $2 \text{NaHCO}_3(\text{s}) \rightleftharpoons \text{Na}_2\text{CO}_3(\text{s}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{g})$

Products: Na<sub>2</sub>CO<sub>3</sub>(s); CO<sub>2</sub>(g); H<sub>2</sub>O(g)

Reactant: 2 NaHCO<sub>3</sub>(s)

Equilibrium law equation:  $K = [\text{CO}_2(\text{g})][\text{H}_2\text{O}(\text{g})]$



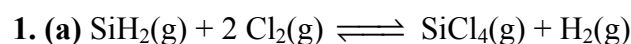
Net ionic equation:  $\text{Zn}(\text{s}) + \text{Cu}^{2+}(\text{aq}) \rightleftharpoons \text{Zn}^{2+}(\text{aq}) + \text{Cu}(\text{s})$

Products: Zn<sup>2+</sup>(aq); Cu(s)

Reactants: Zn(s); Cu<sup>2+</sup>(aq)

Equilibrium law equation:  $K = \frac{[\text{Zn}^{2+}(\text{aq})]}{[\text{Cu}^{2+}(\text{aq})]}$

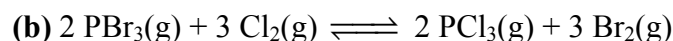
### Section 7.2 Questions, page 436



Products: SiCl<sub>4</sub>(g); H<sub>2</sub>(g)

Reactants: SiH<sub>2</sub>(g); 2 Cl<sub>2</sub>(g)

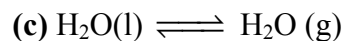
Equilibrium law equation:  $K = \frac{[\text{SiCl}_4(\text{g})][\text{H}_2(\text{g})]}{[\text{SiH}_2(\text{g})][\text{Cl}_2(\text{g})]^2}$



Products: 2 PCl<sub>3</sub>(g); 3 Br<sub>2</sub>(g)

Reactants: 2 PBr<sub>3</sub>(g); 3 Cl<sub>2</sub>(g)

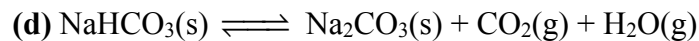
Equilibrium law equation:  $K = \frac{[\text{PCl}_3(\text{g})]^2[\text{Br}_2(\text{g})]^3}{[\text{PBr}_3(\text{g})]^2[\text{Cl}_2(\text{g})]^3}$



Product:  $\text{H}_2\text{O}(\text{g})$

Reactant:  $\text{H}_2\text{O}(\text{l})$

Equilibrium law equation:  $K = [\text{H}_2\text{O}(\text{g})]$



Products:  $\text{Na}_2\text{CO}_3(\text{s})$ ;  $\text{CO}_2(\text{g})$ ;  $\text{H}_2\text{O}(\text{g})$

Reactant:  $2 \text{NaHCO}_3(\text{s})$

Equilibrium law equation:  $K = [\text{CO}_2(\text{g})][\text{H}_2\text{O}(\text{g})]$

**2. Given:**  $2 \text{NOCl}(\text{g}) \rightleftharpoons 2 \text{NO}(\text{g}) + \text{Cl}_2(\text{g})$ ; volume = 3.0 L;

quantities at equilibrium:  $\text{Cl}_2(\text{g}) = 2.4 \text{ mol}$ ;  $\text{NOCl}(\text{g}) = 1.0 \text{ mol}$ ;  $\text{NO}(\text{g}) = 4.5 \times 10^{-3} \text{ mol}$

**Required:**  $K$

**Solution:**

**Step 1.** Write the equilibrium law equation using the balanced chemical equation.

$$K = \frac{[\text{NO}(\text{g})]^2[\text{Cl}_2(\text{g})]}{[\text{NOCl}(\text{g})]^2}$$

**Step 2.** Calculate the equilibrium concentrations of the reactant and products.

$$[\text{Cl}_2(\text{g})]_{\text{equilibrium}} = \frac{2.4 \text{ mol}}{3.0 \text{ L}}$$

$$[\text{Cl}_2(\text{g})]_{\text{equilibrium}} = 0.8 \text{ mol/L}$$

$$[\text{NOCl}(\text{g})]_{\text{equilibrium}} = \frac{1.0 \text{ mol}}{3.0 \text{ L}}$$

$$[\text{NOCl}(\text{g})]_{\text{equilibrium}} = 0.33 \text{ mol/L}$$

$$[\text{NO}(\text{g})]_{\text{equilibrium}} = \frac{4.5 \times 10^{-3} \text{ mol}}{3.0 \text{ L}}$$

$$[\text{NO}(\text{g})]_{\text{equilibrium}} = 1.5 \times 10^{-3} \text{ mol/L}$$

**Step 3.** Substitute the equilibrium concentrations into the equilibrium law equation and solve for  $K$ .

$$\begin{aligned} K &= \frac{[\text{NO}(\text{g})]^2[\text{Cl}_2(\text{g})]}{[\text{NOCl}(\text{g})]^2} \\ &= \frac{(1.5 \times 10^{-3})^2(0.80)}{(0.33)^2} \end{aligned}$$

$$K = 1.6 \times 10^{-5}$$

**Statement:** The equilibrium constant,  $K$ , for the reaction is  $1.6 \times 10^{-5}$ .

**3. Given:**  $4 \text{ Fe(s)} + 3 \text{ O}_2\text{(g)} \rightleftharpoons 2 \text{ Fe}_2\text{O}_3\text{(s)}$ ; volume = 2.0 L;

quantities at equilibrium:  $\text{Fe(s)} = 1.0 \text{ mol}$ ;  $\text{O}_2\text{(g)} = 1.0 \times 10^{-3} \text{ mol}$ ;  $\text{Fe}_2\text{O}_3\text{(s)} = 2.0 \text{ mol}$

**Required:**  $K$

**Solution:**

**Step 1.** Write the equilibrium law equation using the balanced chemical equation.

$$K = \frac{1}{[\text{O}_2\text{(g)}]^3}$$

**Step 2.** Calculate the equilibrium concentration of oxygen gas.

$$[\text{O}_2\text{(g)}]_{\text{equilibrium}} = \frac{1.0 \times 10^{-3} \text{ mol}}{2.0 \text{ L}}$$

$$[\text{O}_2\text{(g)}]_{\text{equilibrium}} = 5.0 \times 10^{-4} \text{ mol/L}$$

**Step 3.** Substitute the equilibrium concentration of oxygen gas into the equilibrium law equation and solve for  $K$ .

$$K = \frac{1}{[\text{O}_2\text{(g)}]^3}$$
$$= \frac{1}{(5.0 \times 10^{-4})^3}$$

$$K = 8.0 \times 10^9$$

**Statement:** The equilibrium constant,  $K$ , for the reaction is  $8.0 \times 10^9$ .

**4.**

#### Comparison of Homogeneous and Heterogeneous Equilibria

	Homogeneous equilibrium	Heterogeneous equilibrium
reactants and products	<ul style="list-style-type: none"><li>all same state of matter (either gases or solutions)</li></ul> <p><i>Sample chemical equation:</i></p> $\text{H}_2\text{(g)} + \text{I}_2\text{(g)} \rightleftharpoons 2 \text{ HI(g)}$	<ul style="list-style-type: none"><li>present in at least two different states (e.g., gases and solids)</li></ul> <p><i>Sample chemical equation:</i></p> $\text{PCl}_5\text{(s)} \rightleftharpoons \text{PCl}_3\text{(l)} + \text{Cl}_2\text{(g)}$
equilibrium law equation	<ul style="list-style-type: none"><li>all reactants and products appear</li></ul> <p><i>Sample equilibrium law equation:</i></p> $K = \frac{[\text{HI(g)}]^2}{[\text{H}_2\text{(g)}][\text{I}_2\text{(g)}]}$	<ul style="list-style-type: none"><li>pure solids and liquids are not included</li></ul> <p><i>Sample equilibrium law equation:</i></p> $K = [\text{Cl}_2\text{(g)}]$
explanation	<ul style="list-style-type: none"><li>Concentrations of substances in gas state or solution can vary.</li></ul>	<ul style="list-style-type: none"><li>Concentrations of pure substances and liquids cannot change; they are constants.</li></ul>

5. Formation of methanol gas from carbon monoxide gas and hydrogen gas:

(a) Unbalanced chemical equation:  $\text{CO(g)} + \text{H}_2\text{(g)} \rightleftharpoons \text{CH}_3\text{OH(g)}$

Balanced chemical equation:  $\text{CO(g)} + 2 \text{H}_2\text{(g)} \rightleftharpoons \text{CH}_3\text{OH(g)}$

(b) 
$$K = \frac{[\text{CH}_3\text{OH(g)}]}{[\text{CO(g)}][\text{H}_2\text{(g)}]^2}$$

If  $K = 6.3 \times 10^{-3}$ , the concentration of methanol would be expected to be much lower than the concentration of carbon monoxide and hydrogen.

(c) This equilibrium system would not be useful for generating large quantities of methanol because the equilibrium favours the reactants.

(d) The equilibrium constant for the reverse reaction,  $K'$ , is the reciprocal of  $K$ .

$$K' = \frac{1}{K}$$
$$= \frac{1}{6.3 \times 10^{-3}}$$

$$K' = 160$$

6. Formation of carbon monoxide from coal and carbon dioxide gas:

(a) Unbalanced chemical equation:  $\text{C(s)} + \text{CO}_2\text{(g)} \rightleftharpoons \text{CO(g)}$

Balanced chemical equation:  $\text{C(s)} + \text{CO}_2\text{(g)} \rightleftharpoons 2 \text{CO(g)}$

(b) Product:  $2 \text{CO(g)}$

Reactants:  $\text{C(s)}$ ;  $\text{CO}_2\text{(g)}$

$$K = \frac{[\text{CO(g)}]^2}{[\text{CO}_2\text{(g)}]}$$

(c) More carbon monoxide gas will be produced at  $1000^\circ\text{C}$  than at  $25^\circ\text{C}$  because the equilibrium constant is much higher at  $1000^\circ\text{C}$  ( $1.7 \times 10^2$  compared to  $1.6 \times 10^{-2}$ ), indicating that equilibrium favours the product more at the higher temperature than at the lower temperature.

(d) Answers may vary. Sample answer: Some advantages of a gaseous fuel over a solid fuel are that gaseous fuels can be delivered through pipelines, so it is easier to control their flow into a combustion chamber and they can disperse throughout the volume so they are likely to burn faster.

(e) Sample answer. Some safety issues involved in working with carbon monoxide gas at high temperatures are that leaks of high-temperature gas can cause severe burns and that carbon monoxide is toxic.