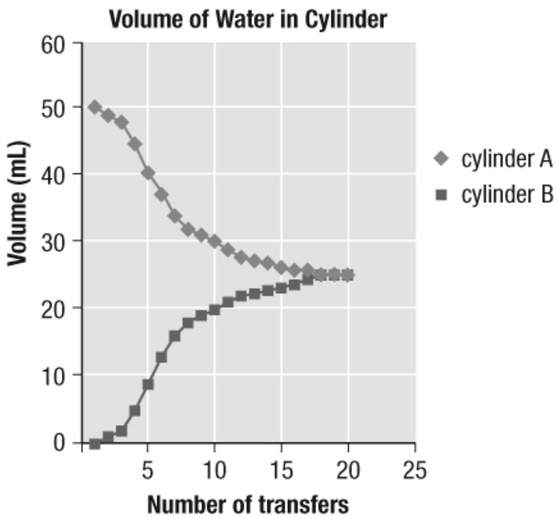
Section 7.1: Equilibrium Systems

Mini Investigation: The Water Exchange, page 422

A. Answers may vary. Sample answer:



B. The volume of water in cylinder A decreased to about 25 mL. The volume of water in cylinder B increased to about 25 mL. When the volumes approached 25 mL, the increases and decreases with each transfer became smaller.
C. Equilibrium was established when the graph became level, indicating no change between the two cylinders.
D. The system is closed because no matter is transferred to or from the surroundings.
E. The investigation modelled a dynamic equilibrium because the transfer of water was equal in both directions.

Tutorial 1 Practice, page 427

1. Given: $[N_2O_4(g)]_{initial}$ = 0.25 mol/L; $[NO_2(g)]_{initial}$ = 0.00 mol/L; $[NO_2(g)]_{equilibrium}$ = 0.25 mol/L
Required: $[N_2O_4(g)]_{equilibrium}$
Analysis: Use an ICE table to determine the relationship between the equilibrium concentrations of the reactant and the product.

	$N_2O_4(g)$	$\rightleftharpoons$	$2\ NO_2(g)$
I	0.25		0
C	$-x$		$+2x$
E	$0.25 - x$		$2x$

Solution: x represents the change in concentration of $N_2O_4(g)$.

$[NO_2(g)]_{equilibrium} = 0.25$ mol/L

$[NO_2(g)]_{equilibrium} = 2x$

$2x = 0.25$ mol/L

$x = 0.125$ mol/L (one extra digit carried)

$[N_2O_4(g)]_{equilibrium} = 0.25 \text{ mol/L} - x$

$= 0.25 \text{ mol/L} - 0.125 \text{ mol/L}$

$[N_2O_4(g)]_{equilibrium} = 0.12 \text{ mol/L}$

Statement: The equilibrium concentration of dinitrogen tetroxide gas is 0.12 mol/L.
2. Given: initial quantity of NOCl(g) = 3.00 mol; volume = 3.00 L;
$[NO(g)]_{initial}$ = 0.00 mol/L; $[Cl_2(g)]_{initial}$ = 0.00 mol/L; $[NO(g)]_{equilibrium}$ = 0.043 mol/L
Required: $[NOCl(g)]_{equilibrium}$; $[Cl_2(g)]_{equilibrium}$
Solution:
Step 1. Calculate the initial concentration of nitrosyl chloride gas.

$$[NOCl(g)]_{initial} = \frac{3.00 \text{ mol}}{3.00 \text{ L}}$$

$[NOCl(g)]_{initial} = 1.00 \text{ mol/L}$

Step 2. Use an ICE table to determine the relationship between the equilibrium concentrations of the reactant and the products.

	2 NOCl(g)	$\rightleftharpoons$	**2 NO(g)**	**+**	**$Cl_2(g)$**
I	1.00		0		0
C	$-x$		$+x$		$+0.5x$
E	$1.00 - x$		x		$0.5x$

Step 3. Determine the value of x.

x represents the change in concentration of NO(g).

$[NO(g)]_{equilibrium} = 0.043 \text{ mol/L}$

$x = 0.043 \text{ mol/L}$

Step 4. Use the value of x to calculate the equilibrium concentrations of nitrosyl chloride gas and chlorine gas.

$[NOCl(g)]_{equilibrium} = 1.00 \text{ mol/L} - x$

$= 1.00 \text{ mol/L} - 0.043 \text{ mol/L}$

$[NOCl(g)]_{equilibrium} = 0.96 \text{ mol/L}$

$[Cl_2(g)]_{equilibrium} = 0.5x$

$= 0.5(0.043 \text{ mol/L})$

$[Cl_2(g)]_{equilibrium} = 0.022 \text{ mol/L}$

Statement: The equilibrium concentration of nitrosyl chloride gas is 0.96 mol/L and the equilibrium concentration of chlorine gas is 0.022 mol/L.

3. Given: initial quantity of $C_2H_4(g)$ = 2.00 mol; initial quantity of $Br_2(g)$ = 1.25 mol; volume = 0.500 L; $[C_2H_4Br_2(g)]_{initial}$ = 0.0 mol/L; graph of $[C_2H_4(g)]$ v. time (Figure 8)
Required: $[C_2H_4(g)]_{equilibrium}$; $[Br_2(g)]_{equilibrium}$; $[C_2H_4Br_2(g)]_{equilibrium}$
Solution:
Step 1. Calculate the initial concentrations of ethene gas and bromine gas.

$$[C_2H_4(g)]_{initial} = \frac{2.00 \text{ mol}}{0.500 \text{ L}}$$

$$[C_2H_4(g)]_{initial} = 4.00 \text{ mol/L}$$

$$[Br_2(g)]_{initial} = \frac{1.25 \text{ mol}}{0.500 \text{ L}}$$

$$[Br_2(g)]_{initial} = 2.50 \text{ mol/L}$$

Step 2. Using Figure 8, determine the amount of ethene gas at equilibrium, once the amount remains stable. Since the amount is stable at the last time point, $[C_2H_4(g)]_{equilibrium}$ = 2.5 mol/L
Step 3. Use an ICE table to determine the relationship between the equilibrium concentrations of the reactant and the products.

	$C_2H_4(g)$	+	$Br_2(g)$	$\rightleftharpoons$	$C_2H_4Br_2(g)$
I	4.0		2.5		0
C	$-x$		$-x$		$+x$
E	$4.0 - x$		$2.5 - x$		x

Step 4. Calculate the value of x, using the initial, change, and equilibrium concentrations of ethene gas.

$$\begin{aligned} 4.00 \text{ mol/L} - x &= 2.5 \text{ mol/L} \\ -x &= -1.5 \text{ mol/L} \\ x &= 1.5 \text{ mol/L} \end{aligned}$$

Step 5. Use the value of x to calculate the equilibrium concentrations of bromine gas and 1,2-dibromoethane gas.

$$\begin{aligned} [Br_2(g)]_{equilibrium} &= 2.5 \text{ mol/L} - x \\ &= 2.5 \text{ mol/L} - 1.50 \text{ mol/L} \\ [Br_2(g)]_{equilibrium} &= 1.0 \text{ mol/L} \end{aligned}$$

$$[C_2H_4Br_2(g)]_{equilibrium} = x$$

$$[C_2H_4Br_2(g)]_{equilibrium} = 1.5 \text{ mol/L}$$

Statement: The equilibrium concentration of ethene gas is 2.5 mol/L; the equilibrium concentration of bromine gas is 1.0 mol/L; and the equilibrium concentration of 1,2-dibromoethane gas is 1.5 mol/L.

Section 7.1 Questions, page 428

1. (a) A sealed bottle of pop is a dynamic equilibrium because the rate of conversion between carbon dioxide and carbonic acid is equal in both directions in the closed system.
(b) When I open the pop bottle, carbon dioxide leaves the bottle, so the equilibrium conditions no longer exist and a new equilibrium must form between the pop and the atmosphere.
2. (a) No change will be observed at equilibrium.
(b) At the molecular level, the forward and reverse reactions are occurring at the same rate.
(c) The reaction is dynamic.
3. (a) A balanced equation for this chemical reaction system is

$$H_2(g) + I_2(g) \rightleftharpoons 2\ HI(g)$$

(b) If I carry out a reaction starting with a 2.0 L flask containing 0.45 mol of hydrogen iodide, the concentrations of $H_2(g)$ and $I_2(g)$ will increase as the concentration of HI(g) decreases until an equilibrium state is reached.
(c) A completed ICE table for a reaction in which the concentrations of each of the gases was monitored is as follows:

	$H_2(g)$	**+**	**$I_2(g)$**	**$\rightleftharpoons$**	**2 HI(g)**
I	6.0		4.0		0.0
C	$-x$		$-x$		$+2x$
E	$6.0 - x$		$4.0 - x$		$2x$

4. Given: initial quantity of $SO_2(g)$ = 2.5 mol; initial quantity of $O_2(g)$ = 2.0 mol; volume = 1.0 L; $[SO_3(g)]_{initial}$ = 0.0 mol/L; $[SO_2(g)]_{equilibrium}$ = 0.75 mol/L
Required: $[O_2(g)]_{equilibrium}$; $[SO_3(g)]_{equilibrium}$
Solution:
Step 1. Calculate the initial concentrations of sulfur dioxide gas and oxygen gas.

$$[SO_2(g)]_{initial} = \frac{2.5\text{ mol}}{1.0\text{ L}}$$

$$[SO_2(g)]_{initial} = 2.5\text{ mol/L}$$

$$[O_2(g)]_{initial} = \frac{2.0\text{ mol}}{1.0\text{ L}}$$

$$[O_2(g)]_{initial} = 2.0\text{ mol/L}$$

Step 2. Use an ICE table to determine the relationship between the equilibrium concentrations of the reactant and the products.

	2 $SO_2(g)$	**+**	**$O_2(g)$**	**$\rightleftharpoons$**	**2 $SO_3(g)$**
I	2.5		2.0		0
C	$-x$		$-0.5x$		$+x$
E	$2.5 - x$		$2.0 - 0.5x$		x

Step 3. Calculate the value of *x,* using the initial, change, and equilibrium concentrations of sulfur dioxide gas.

$$2.5 \text{ mol/L} - x = 0.75 \text{ mol/L}$$
$$-x = -1.75 \text{ mol/L}$$
$$x = 1.75 \text{ mol/L (one extra digit carried)}$$

Step 4. Use the value of *x* to calculate the equilibrium concentrations of oxygen gas and sulfur trioxide gas.

$$[O_2(g)]_{\text{equilibrium}} = 2.0 \text{ mol/L} - 0.5x$$
$$= 2.0 \text{ mol/L} - 0.5(1.75 \text{ mol/L})$$
$$= 2.0 \text{ mol/L} - 0.875 \text{ mol/L}$$
$$[O_2(g)]_{\text{equilibrium}} = 1.1 \text{ mol/L}$$

$[SO_3(g)]_{\text{equilibrium}} = x$
$[SO_3(g)]_{\text{equilibrium}} = 1.8$ mol/L

Statement: The equilibrium concentration of oxygen gas is 1.1 mol/L and the equilibrium concentration of sulfur trioxide gas is 1.8 mol/L.

5. Given: initial quantity of $PCl_5(g)$ = 3.00 mol; volume = 1.50 L;
$[PCl_3(g)]_{\text{initial}}$ = 0.00 mol/L; $[Cl_2(g)]_{\text{initial}}$ = 0.00 mol/L;
quantity of $PCl_3(g)$ at equilibrium = 0.300 mol

Required: $[PCl_5(g)]_{\text{equilibrium}}$; $[Cl_2(g)]_{\text{equilibrium}}$

Solution:

Step 1. Calculate the initial concentration of phosphorus pentachloride gas.

$$[PCl_5(g)]_{\text{initial}} = \frac{3.00 \text{ mol}}{1.50 \text{ L}}$$
$$[PCl_5(g)]_{\text{initial}} = 2.00 \text{ mol/L}$$

Also, calculate the concentration of phosphorus trichloride gas at equilibrium.

$$[PCl_3(g)]_{\text{equilibrium}} = \frac{0.300 \text{ mol}}{1.50 \text{ L}}$$
$$[PCl_3(g)]_{\text{equilibrium}} = 0.200 \text{ mol/L}$$

Step 2. Use an ICE table to determine the relationship between the equilibrium concentrations of the reactant and the products.

	$PCl_5(g)$ $\rightleftharpoons$	$PCl_3(g)$ +	$Cl_2(g)$
I	2.00	0.00	0.00
C	$-x$	$+x$	$+x$
E	$2.00 - x$	x	x

Step 3. Determine the value of *x*.

x represents the change in concentration of phosphorus trichloride gas.

$$[PCl_3(g)]_{\text{equilibrium}} = 0.200 \text{ mol/L}$$
$$x = 0.200 \text{ mol/L}$$

Step 4. Use the value of x to calculate the equilibrium concentrations of phosphorous pentachloride gas and chlorine gas.

$$[PCl_5(g)]_{equilibrium} = 2.00 \text{ mol/L} - x$$

$$= 2.00 \text{ mol/L} - 0.200 \text{ mol/L}$$

$$[PCl_5(g)]_{equilibrium} = 1.80 \text{ mol/L}$$

$$[Cl_2(g)]_{equilibrium} = x$$

$$[Cl_2(g)]_{equilibrium} = 0.200 \text{ mol/L}$$

Statement: The equilibrium concentration of phosphorous pentachloride gas is 1.80 mol/L and the equilibrium concentration of chlorine gas is 0.200 mol/L.

6. (a) No, if you eat a meal that is rich in fructose, diffusion will not result in the absorption of all fructose molecules from the digesting food travelling through the intestine because at equilibrium there is fructose on both sides of the cell membrane.

(b) Cells maximize the diffusion of nutrients by rapidly moving absorbed nutrients away from the cell membrane, keeping the concentration on the inside of the membrane low.