7.3 on next Page.

$$[NH_{3(g)}]^2 = 8.00 \times 10^{-7} \times [N_{2(g)}][H_{2(g)}]^3$$
$$= 8.00 \times 10^{-7} [1.50][0.50]^3$$
$$[NH_{3(g)}]^2 = 1.5 \times 10^{-7}$$
$$[NH_{3(g)}] = 3.9 \times 10^{-4} \text{ mol/L}$$

The equilibrium concentration of ammonia is 3.9×10^{-4} mol/L.

5. (a) $C_4H_{10(l)} \rightleftharpoons C_4H_{10(g)}$

$$K = [C_4H_{10(g)}]$$

(b) The amount of butane in the gas phase varies directly with the temperature. As the temperature increases, for example, more butane will be found in the gas phase. However, the butane concentration at a particular temperature is a constant. Since the value of the equilibrium constant depends only on $[C_4H_{10(g)}]$, it also is constant.

(c) The concentration of butane gas depends only on the temperature and not on the amount of liquid butane. If the volume of liquid butane decreases, there's more space above the liquid for gaseous butane to occupy. The number of moles of butane may have increased but the mol/L remains the same.

6. (a) $2\,HBr_{(g)} \rightleftharpoons H_{2(g)} + Br_{2(g)}$

(b) $K = \dfrac{[H_{2(g)}][Br_{2(g)}]}{[HBr_{(g)}]^2}$

(c) $n_{HBr_{(g)}} = C_{HBr_{(g)}} \times 2.00 \text{ L}$

$$= 0.100 \text{ mol/L} \times 2.00 \text{ L}$$

$$n_{HBr_{(g)}} = 0.200 \text{ mol}$$

0.200 mol of $HBr_{(g)}$ is present at equilibrium.

(d) $n_{HBr} = 0.100 \text{ mol/L} \times 2.00 \text{ L}$

$$n_{HBr} = 0.200 \text{ mol}$$

0.200 mol of hydrogen bromide is present at equilibrium.

$$n_{HBr_{reacted}} = n_{HBr_{initial}} - n_{HBr_{equilibrium}}$$
$$= 1.00 \text{ mol} - 0.200 \text{ mol}$$
$$n_{HBr_{reacted}} = 0.800 \text{ mol}$$

0.800 mol of hydrogen bromide reacted.

(e) Given the 2:1 ratio, 0.400 mol of both hydrogen and bromine are produced.

(f) $[H_2] = \dfrac{0.400 \text{ mol}}{2.00 \text{ L}}$

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

$$[H_2] = [Br_2]$$

The concentrations of hydrogen and bromine are both 0.200 mol/L, while the hydrogen bromide concentration is 0.100 mol/L.

(g) $K = \dfrac{[H_{2(g)}][Br_{2(g)}]}{[HBr_{(g)}]^2}$

$$= \frac{[0.20][0.20]}{[0.100]^2}$$

$$K = 4.0$$

The value of the equilibrium constant is 4.00.

7. (a) One could specify either the value of the equilibrium constant or the extent of reaction (as percent reaction).
   (b) Both methods measure the extent to which reactants become products in a closed system. However, percent reaction describes the extent of the reaction as the yield of product at equilibrium compared to the maximum possible yield. The value of the equilibrium constant gives the ratio of products to reactants at equilibrium. Furthermore, the percent reaction is variable, for a given reaction, depending on the concentration of reactants; the equilibrium constant is independent of concentration.
   (c) Both methods are effective in describing the extent of the reaction. However, they also have their limitations. The value of the equilibrium constant is valid only for a given temperature. Percent reaction values depend not only on temperature but on concentration as well.

Applying Inquiry Skills

8. **Analysis**

   (a) $K = \frac{[SO_{3(g)}]^2}{[SO_{2(g)}]^2[O_{2(g)}]}$

   For trial 1...

   $$K = \frac{[3.50 \times 10^{-2}]^2}{[1.50 \times 10^{-1}]^2[1.26 \times 10^{-2}]}$$

   $K = 4.32$

   For trial 2...

   $$K = \frac{[2.60 \times 10^{-3}]^2}{[5.90 \times 10^{-2}]^2[4.50 \times 10^{-4}]}$$

   $K = 4.32$

   For trial 3...

   $$K = \frac{[3.6 \times 10^{-3}]^2}{[1.00 \times 10^{-2}]^2[3.0 \times 10^{-2}]}$$

   $K = 4.32$

Making Connections

9. The small value of the equilibrium constant suggests that the equilibrium strongly favours oxygen. Only a negligible amount of ozone is produced by this reaction.

7.3 QUALITATIVE CHANGES IN EQUILIBRIUM SYSTEMS

PRACTICE

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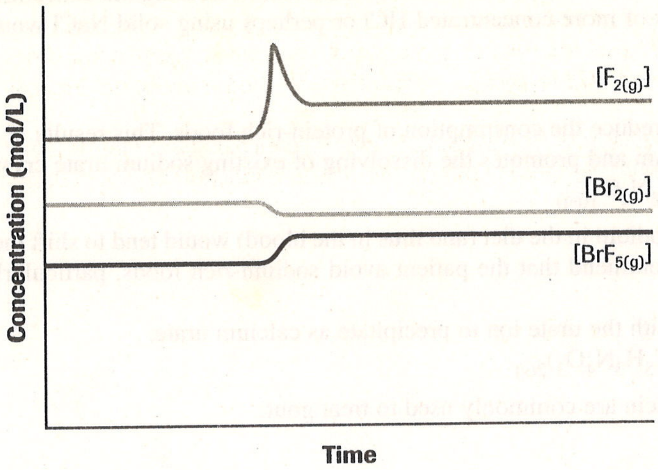
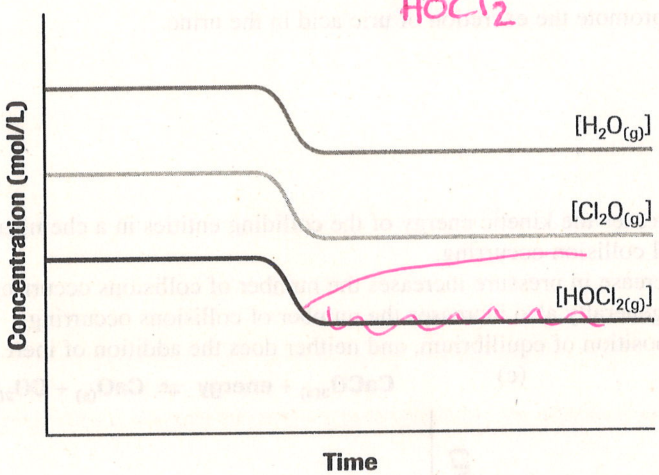
Understanding Concepts

1. The equilibrium will shift to the
   (a) left
   (b) right
   (c) left
   (d) ~~right~~ left
   (e) right

2. (a) **Graph Showing Adjustment of $BrF_{5(g)}$ Equilibrium**



(b) **Graph Showing Adjustment of ~~FeSCN~~ $HOCl_2$ Equilibrium**



3. (a) The catalyst reduces the time required for the system to reach equilibrium.
   (b) The equilibrium concentration of hydrogen would not be affected by the use of a catalyst.
4. The warmer temperatures of summer shift the equilibrium to the left, increasing the concentration of the brown gas, NO_2.
5. Based on Le Châtelier's principle, the conditions that favour the production of methane include:
   - decreasing the pressure on the system
   - increasing the concentration of the reactants
   - removing the products as they are produced
   - cooling the reaction chamber

   (In practice, raising the reaction temperature increases the rate of both reactions, thereby increasing the yield of methane.)
6. (a) An increase in acidity would favour the forward reaction, thereby promoting the decomposition of the stalagmites and stalactites.
   (b) Water hardness, which results from increased levels of ions such as Ca^{2+} and Mg^{2+}, favours the reverse reaction, promoting the growth of the stalagmites and stalactites.

Applying Inquiry Skills

7. **Prediction**
   (a) The addition of chloride ions will shift the equilibrium to the right.

   Analysis
   (b) The addition of chloride ions shifts the equilibrium to the right, changing the colour of the solution to green.

Evaluation

(c) The addition of hydrochloric acid also increased the total volume of the solution, decreasing the concentration of entities in the equilibrium. Smaller volumes of more concentrated HCl or perhaps using solid NaCl would have improved the results.

Making Connections

8. (a) One possible dietary recommendation is to reduce the consumption of protein-rich foods. This results in a lower concentration of urate ions in the bloodstream and promotes the dissolving of existing sodium urate crystals.

$$NaC_5H_3N_4O_{3(s)} \rightleftharpoons Na^+_{(aq)} + C_5H_3N_4O^-_{3(aq)}$$

Alternatively, a reduction in the amount of sodium in the diet (and thus in the blood) would tend to shift the dissociation to the right. The dietitian might recommend that the patient avoid sodium-rich foods, particularly table salt.

(b) Excess calcium in the blood can combine with the urate ion to precipitate as calcium urate.

$$Ca^{2+}_{(aq)} + 2\ C_5H_3N_4O^-_{3(aq)} \rightleftharpoons Ca(C_5H_3N_4O_3)_{2(s)}$$

(c) Anti-inflammatory drugs such as indomethacin are commonly used to treat gout.
Non-dietary treatments of gout include:

- Tylenol for pain relief.
- anti-inflammatory drugs such as Indomethacin to help reduce the swelling.
- specific medications, e.g., benemid, that promote the excretion of uric acid in the urine.

SECTION 7.3 QUESTIONS

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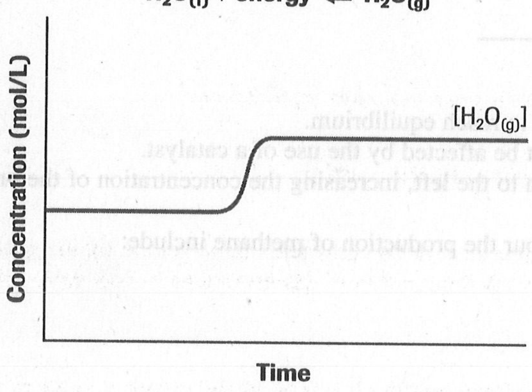
Understanding Concepts

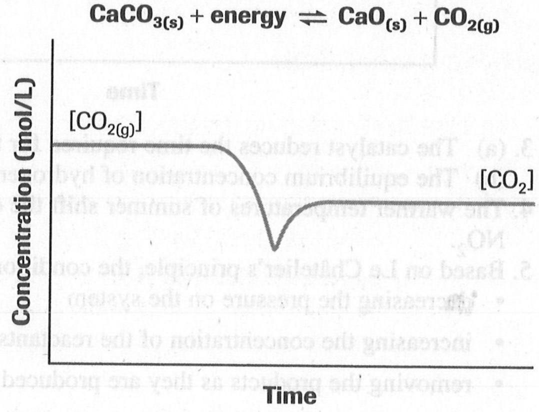
1. (a) temperature: An increase in temperature increases the kinetic energy of the colliding entities in a chemical reaction, increasing the likelihood of a successful collision occurring.
pressure: For systems involving gases, an increase in pressure increases the number of collisions occurring.
concentration: An increase in concentration generally also increases the number of collisions occurring.

(b) Catalysts and surface area do not affect the position of equilibrium, and neither does the addition of inert gases.

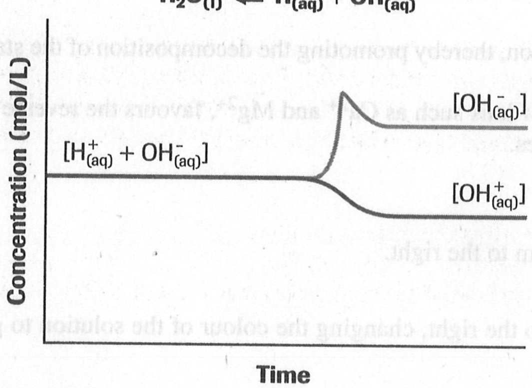
2. (a) $H_2O_{(l)} + \text{energy} \rightleftharpoons H_2O_{(g)}$



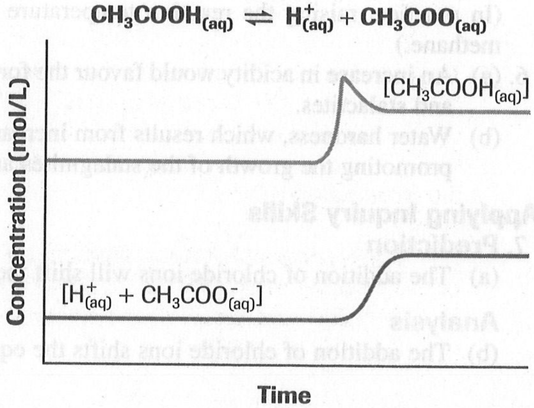
(c) $CaCO_{3(s)} + \text{energy} \rightleftharpoons CaO_{(s)} + CO_{2(g)}$



(b) $H_2O_{(l)} \rightleftharpoons H^+_{(aq)} + OH^-_{(aq)}$

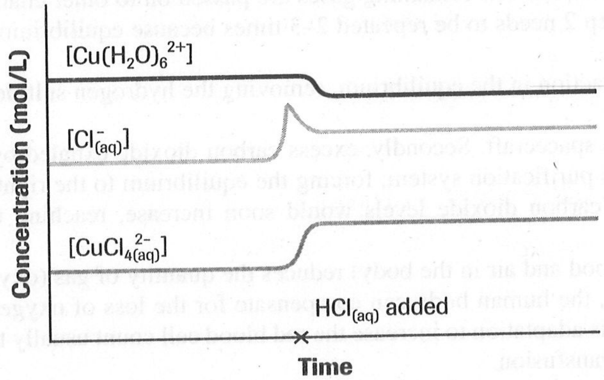


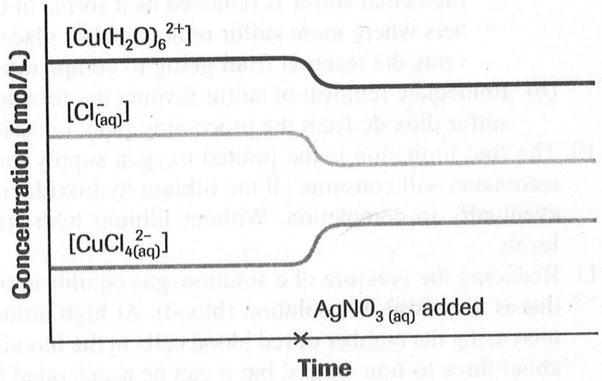
(d) $CH_3COOH_{(aq)} \rightleftharpoons H^+_{(aq)} + CH_3COO^-_{(aq)}$



3. (a) When oxygen is added, the rate of the forward reaction is greater than that of the reverse, shifting the equilibrium to the right.
   (b) When the system is heated, the rate of the reverse reaction is greater than that of the forward, shifting the equilibrium to the left.
   (c) When $NO_{(g)}$ is removed, the rate of the forward reaction is greater than that of the reverse, shifting the equilibrium to the right.
   (d) When the volume of the reaction vessel is decreased, the rate of the reverse reaction is greater than that of the forward, shifting the equilibrium to the left.
   (e) When an inert gas is added (without changing the volume), the amount/L of reactants and products doesn't change, and no equilibrium shift occurs.

4. $CuCl_{4(aq)}^{2-} + 4\ H_2O_{(l)} \rightleftharpoons Cu(H_2O)_{4(aq)}^{2+} + 4\ Cl^-_{(aq)}$





5. Hydroxide ions combine with hydrogen ions to form water. The removal of $H^+_{(aq)}$ results in the equilibrium shifting to the right.
6. At A, the pressure of the system is decreased by increasing the volume.
   At B, the temperature is increased.
   At C, $C_2H_{6(g)}$ is added to the system.
   At D, no change is apparent (although it is possible that a catalyst or an inert gas was added.
   At E, $H_{2(g)}$ is added to the system.

Applying Inquiry Skills

7. **Question**
   (a) How does increasing the pressure affect the nitrogen–dinitrogen tetroxide equilibrium?

   Prediction
   (b) The nitrogen–dinitrogen tetroxide equilibrium is represented by the equation

$$N_2O_{4(g)} + \text{energy} \rightleftharpoons 2\ NO_{2(g)}$$

   According to Le Châtelier's principle, increasing the pressure of the nitrogen–dinitrogen tetroxide equilibrium causes the equilibrium to shift to the left, which decreases the number of gas molecules. (Two moles of $NO_{2(g)}$ produce one mole of $N_2O_{4(g)}$.)

   Experimental Design
   (c) A sample of nitrogen dioxide gas is compressed in a syringe and the intensity of the colour is used as evidence to test the prediction.

   Evaluation
   (d) The experimental design should give reproducible qualitative results for this experiment. Given the toxicity of the gases involved, this experiment should only be conducted in a fume hood. The experimental design produced results that provided clear evidence that pressure does affect the nitrogen–dinitrogen tetroxide equilibrium. One flaw in the experimental design is that the experiment should be conducted in a fume hood, given the toxicity of the chemicals involved.

8. **Prediction**
   (a) (i) The equilibrium shifts to the right, changing colour from yellow to orange.
   (ii) The equilibrium shifts to the left, becoming more yellow.
   (iii) A yellow precipitate of barium chromate is produced, shifting the equilibrium to the left. The solution becomes more yellow.

Synthesis

(b) An addition of acid to the test tube shifts the equilibrium to the right, dissolving the precipitate. Note: Barium dichromate is much more soluble than barium chromate.

Making Connections

9. (a) The Claus method is one of the most common methods of removing foul-smelling hydrogen sulfide during the processing of crude oil and natural gas. The Claus method occurs in two steps:
   1. In the "thermal step," hydrogen sulfide is burned with oxygen temperatures in excess of 850°C.
   2. During the "catalytic step," the combustion products from step 1 are cooled and passed over an aluminum oxide catalyst, where the following reaction takes place:

   $$2\ H_2S_{(g)} + SO_{2(g)} \rightleftharpoons 3\ S_{(s)} + 2\ H_2O_{(g)}$$

   Elemental sulfur is removed as it forms in the process. The remaining gases are passed on to other chambers where more sulfur removal takes place. Step 2 needs to be repeated 2–3 times because equilibrium prevents the reaction from going to completion.

   (b) Immediate removal of sulfur favours the forward reaction in the equilibrium, removing the hydrogen sulfide and sulfur dioxide from the processing plant emissions.

10. The first limitation is the limited oxygen supply on the spacecraft. Secondly, excess carbon dioxide exhaled by the astronauts will consume all the lithium hydroxide in the purification system, forcing the equilibrium to the right and eventually to completion. Without lithium hydroxide, carbon dioxide levels would soon increase, reaching toxic levels.
11. Reducing the pressure of a solution–gas equilibrium (blood and air in the body) reduces the quantity of gas (oxygen) that is dissolved in a solution (blood). At high altitudes, the human body can compensate for the loss of oxygen by increasing the number of red blood cells in the blood. This adaptation to increase the red blood cell count usually takes about three to four weeks, but it can be accelerated by transfusion.
12. Get the victim to fresh air as soon as possible. Administer oxygen with a bottle-fed breathing mask. Breathing 100% oxygen would shift the given equilibrium to the left, displacing carbon monoxide from hemoglobin.

7.4 CASE STUDY: THE HABER PROCESS: AMMONIA FOR FOOD AND BOMBS

PRACTICE

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Understanding Concepts

1. Factors increasing production include:
   - removing $NH_{3(g)}$
   - adding $N_{2(g)}$
   - adding $H_{2(g)}$
   - reducing the temperature slightly
   - raising the pressure
   - adding a catalyst (which will have the effect of speeding up both forward and reverse reactions)

Making Connections

2.