Equilibrium
7.13 pH and Solubility
Worksheet Key

1) Solid sodium fluoride is dissolved in distilled water.
   a. Write the chemical equation for this reaction.
   b. Will the final solution be acidic or basic? Justify your answer.

$NaF_{(s)} + H_2O_{(l)} \rightarrow HF_{(aq)} + OH^-_{(aq)} + Na^+_{(aq)}$

The final solution will be basic. F^- is a base, as it is the conjugate base of the weak acid HF. Thus, F^- will react with water to produce OH^- ions. The increased $[OH^-]$ makes the solution basic.

2) Which mixture in each set has the highest pH? Justify your answers.
   a. **1.0 *M* $NaC_2H_3O_2$** or 1.0 *M* $CuNO_3$.

1.0 *M* $NaC_2H_3O_2$ will have the highest pH. Its pH will be greater than 7. CH_3COO^- is the conjugate base of a weak acid, making it a relatively strong base. The following reaction will increase $[OH^-]$ in the solution.

$CH_3COO^-_{(aq)} + H_2O_{(l)} \rightarrow CH_3COOH_{(aq)} + OH^-_{(aq)}$

Increasing $[OH^-]$ increases the pH of the solution.

1.0 *M* $CuNO_3$ will lower the pH of the solution, as Cu^+ is an acidic cation. Its pH will be less than 7.

   b. **2.0 *M* K_2CO_3** or 2.0 *M* LiI

2.0 *M* K_2CO_3 will have the highest pH. Its pH will be greater than 7. The CO_3^{2-} ion is basic, and therefore, it will raise $[OH^-]$ in the solution through the following reaction.

$CO_3^{2-}_{(aq)} + H_2O_{(l)} \rightarrow HCO_3^-_{(aq)} + OH^-_{(aq)}$

Increasing $[OH^-]$ increases the pH of the solution.

2.0 M LiI will have the lowest pH. The pH will be 7. Lithium and iodine are both neutral ions as Li^+ is the conjugate acid of a strong base, and I^- is the conjugate base of a strong acid.

   c. 2.0 *M* NH_4F or **2.0 *M* NaF**

2.0 *M* NaF will have the highest pH. Its pH will be greater than 7. The F^- ion is basic, as it is the conjugate base of a weak acid. The Na^+ ion is neutral, as it is the conjugate acid of a strong base. The basic F^- ion will raise $[OH^-]$ in the solution through the following reaction. $F^-_{(aq)} + H_2O_{(l)} \rightarrow HF_{(aq)} + OH^-_{(aq)}$

Increasing $[OH^-]$ increases the pH of the solution. 2.0 *M* NH_4F will have the lowest pH. Its pH will be close to 7. The F^- ion is basic, as it is the conjugate base of a weak acid. The NH_4^+ ion is acidic as it is the conjugate acid of a weak base. The two ions will work against each other to make the solution more or less neutral.

d. **CaO and water** or NaCl and water

CaO and water will have the highest pH, as metal oxides are basic. Its pH will be greater than 7. CaO reacts with water to form $Ca(OH)_{2(s)}$. $Ca(OH)_{2(s)}$ is slightly soluble, and thus, it increases the $[OH^-]$ in the solution.
NaCl and water produces a neutral solution with a pH of 7, as both ions are neutral. Na^+ is the conjugate acid of a strong base, and Cl^- is the conjugate base of a strong acid.

e. **SiO_2 and water** or $Cu(NO_3)_2$ and water

SiO_2 and water will have the highest pH. Its pH will be 7, as SiO_2 is not water-soluble.
$Cu(NO_3)_2$ and water will have a pH that is lower than 7, as Cu^{2+} is an acidic cation.

3) Which mixture in each set has the lowest pH? Justify your answer.

a. **1.0 *M* $MgSO_4$** or 1.0 *M* Li_2CO_3

1.0 *M* $MgSO_4$ will have the lowest pH. Its pH will be close to 7. Mg^{2+} is an acidic anion, which will lower the pH, and SO_4^{2-} is a slightly basic anion that will raise the pH slightly. K_a for HSO_4^- is 1.2×10^{-2} at 25°C, and therefore, it is a fairly strong acid. The conjugate bases of strong acids have a very limited ability to attract H^+ ions.
1.0 *M* Li_2CO_3 will have the highest pH. Its pH will be greater than 7. Li^+ is the conjugate acid of a strong base, and thus, it is not acidic. CO_3^{2-} is a basic anion, and therefore, it will raise $[OH^-]$ in the solution through the following reaction.

$$CO_3^{2-}{}_{(aq)} + H_2O_{(l)} \rightarrow HCO_3^-{}_{(aq)} + OH^-{}_{(aq)}$$

Increasing $[OH^-]$ increases the pH of the solution.

b. **1.5 *M* NH_4Cl** or 1.5 *M* NaCl

1.5 *M* NH_4Cl will have the lowest pH. Its pH will be less than 7. NH_4^+ is an acidic cation, which will lower the pH; and Cl^- is a neutral anion, which will not affect the pH.
1.5 *M* NaCl will have the highest pH. NaCl and water produces a neutral solution with a pH of 7, as both ions are neutral. Na^+ is the conjugate acid of a strong base, and Cl^- is the conjugate base of a strong acid.

c. **1.0 *M* NaCl** or 1.0 *M* NaF

1.0 *M* NaCl will have the lowest pH. NaCl and water produces a neutral solution with a pH of 7, as both ions are neutral. Na^+ is the conjugate acid of a strong base, and Cl^- is the conjugate base of a strong acid.
1.0 *M* NaF will have the highest pH. Its pH will be greater than 7. The F^- ion is basic as it is the conjugate base of a weak acid. The Na^+ ion is neutral as it is the conjugate acid of a strong base. The basic F^- ion will raise $[OH^-]$ in the solution through the following reaction.

$$F^-{}_{(aq)} + H_2O_{(l)} \rightarrow HF_{(aq)} + OH^-{}_{(aq)}$$

Increasing $[OH^-]$ increases the pH of the solution.

d. **1.0 *M* $Mg(NO_3)_2$** or 1.0 *M* KCl

1.0 *M* $Mg(NO_3)_2$ will have the lowest pH. Its pH will be less than 7, as Mg^{2+} is an acidic cation.
1.0 *M* KCl will have the larger pH. KCl and water produces a neutral solution with a pH of 7, as both ions are neutral. K^+ is the conjugate acid of a strong base, and Cl^- is the conjugate base of a strong acid.

e. **1.0 *M* $Ni(NO_3)_3$** or 1.0 *M* $Ca(NO_3)_2$

1.0 *M* $Ni(NO_3)_3$ will have the lowest pH. Its pH will be less than 7, as Ni^{3+} is an acidic cation.
1.0 *M* $Ca(NO_3)_2$ will have the highest pH. It will form a neutral solution with a pH of 7, as Ca^{2+} and NO_3^- are neutral ions.

f. **CO_2 and water** or O_2 and water

CO_2 and water will form a solution with the lowest pH. Its pH will be less than 7. CO_2 dissolves in water to form carbonic acid (H_2CO_3).
Oxygen gas does not change the pH of water.

4) The acid dissociation constants (K_a values) for hypoiodous acid, HOI, and lactic acid, $HC_3H_5O_3$ at 298 K are 2×10^{-11} and 1.38×10^{-4} respectively. Which solution is more basic: 1.0 *M* NaOI or 1.0 *M* $NaC_3H_5O_3$? Justify your answer.

HOI is the weaker acid, as $2 \times 10^{-11} < 1.38 \times 10^{-4}$. This means that its conjugate base, OI^-, is stronger. Weaker acids have stronger conjugate bases.
The equilibrium for $OI^- + H_2O \rightleftharpoons HOI + OH^-$ lies further to the right than it does in $C_3H_5O_3^- + H_2O \rightleftharpoons HC_3H_5O_3 + OH^-$.
Thus, 1.0 *M* NaOI produces a higher concentration of OH^-, making a more basic solution.

5) In a laboratory experiment, some sodium fluoride was dissolved in distilled water at 25°C. The pH of the final solution was measured to be 8.6 at 25°C. After heating the solution on a hot plate, the pH was measured to be 8.9. Explain why the pH increased after the solution was heated.

$$F^-_{(aq)} + H_2O_{(aq)} \rightleftharpoons FH_{(aq)} + OH^-_{(aq)} \qquad \Delta H^o = +118.4 \text{ kJ/mol}$$

The forward reaction is endothermic. According to LeChatelier's principle, the stress caused by adding heat to a system at equilibrium causes the reaction to shift in the endothermic direction. This shift increased $[OH^-]$, which caused the pH to increase.

6) Mayan and Aztec limestone (calcium carbonate) pyramids are being eroded away by acid rain. Use chemical principals and a balanced net ionic equation to explain why acid rain is a problem for these ancient monuments.

The concentration of H^+ is high in acid rain. The H^+ ions react with solid calcium

carbonate according to the following process:

$$CaCO_{3(s)} + 2\ H^{+}_{(aq)} \rightarrow Ca^{2+}_{(aq)} + H_2O_{(l)} + CO_{2(g)}$$

The solid material, with which the pyramids were built, is converted into aqueous, liquid, and gaseous components.

Write balanced net ionic equations for the reactions that occur in questions 7 – 11.

7) Solid calcium hydroxide is placed in a solution of nitric acid.

$$Ca(OH)_{2(s)} + 2\ H^{+}_{(aq)} \rightarrow Ca^{2+}_{(aq)} + 2\ H_2O_{(l)}$$

8) Solid beryllium carbonate is placed in a solution of 0.5 *M* hydrofluoric acid.

$$BeCO_{3(s)} + 2\ HF_{(aq)} \rightarrow Be^{2+}_{(aq)} + H_2O_{(l)} + CO_{2(g)} + 2\ F^{-}_{(aq)}$$

9) Solid strontium carbonate is placed in a solution of nitric acid.

$$SrCO_{3(s)} + 2\ H^{+}_{(aq)} \rightarrow Sr^{2+}_{(aq)} + H_2O_{(l)} + CO_{2(g)}$$

10) Solid beryllium hydroxide is placed in a solution of acetic acid.

$$Be(OH)_{2(s)} + 2\ CH_3COOH_{(aq)} \rightarrow Be^{2+}_{(aq)} + 2\ H_2O_{(l)} + 2\ CH_3COO^{-}_{(aq)}$$

11) Solid calcium oxide is placed in a solution of hydrobromic acid.

$$CaO_{(s)} + 2\ H^{+}_{(aq)} \rightarrow Ca^{2+}_{(aq)} + H_2O_{(l)}$$