## 17.1 Silver Salt Solubilities and Formation of complex ions

**Subject:** Solubility-$K_{sp}$, precipitation reactions, complex ions

**Description:** A precipitate of silver chloride is dissolved upon addition of a clear liquid. Adding a second clear liquid gives a second precipitate. Lastly a third clear liquid is added, dissolving the precipitate again.

**Materials:**
200 mL water
600 mL beaker
10 mL 0.1 M silver nitrate‡
30 mL 1.0 M sodium chloride‡
35 mL 6.0 M aqueous Ammonia‡
10 mL 0.1 M Potassium bromide‡
50 mL 0.1 M Sodium thiosulfate‡
Stir bar
Stir plate*
5 graduated cylinders (3 50 ml, 2 10 ml)

‡Solutions are located on the solutions shelves. Ammonia and acetic acid are located in the cabinets under the hood.
*Shared item: located in the top drawer opposite the chemical storage cabinets.

**Procedure:**
1. Place 200 mL of water in a 600 mL beaker.
2. Add 10 mL 0.1 M silver nitrate and 30 mL 1.0 sodium chloride to the beaker to form the AgCl precipitate.
3. Add the ammonia to dissolve the silver chloride and produce the soluble silver ammonia complex ion.
4. Add the sodium bromide to produce silver bromide precipitate.
5. Add the sodium thiosulfate to dissolve the silver bromide and produce the soluble silver thiosulfate complex ion.

**Discussion:**
Step 1: Addition of sodium chloride to the silver nitrate solution forms a precipitate of silver chloride.

$$AgNO_3(aq) \rightarrow Ag^+(aq) + NO_3^-(aq)$$

$$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$$

$$AgCl(s) \Leftrightarrow Ag^+(aq) + Cl^-(aq) \qquad K_{sp} = 1.8 \times 10\text{-}10$$

Step 2: When aqueous ammonia is added the silver chloride precipitate dissolves in favor of formation of the silver ammonia complex ion.

$AgCl(aq) + 2NH_3(aq) \Leftrightarrow [Ag(NH_3)_2]^+(aq) + Cl^-(aq)$

$Ag+(aq) + 2NH_3(aq) \Leftrightarrow [Ag(NH_3)_2]^+(aq)$ $K_f = 1.6 \times 10^7$

$K_{net} = K_{sp} \times K_f = (1.8 \times 10^{-10})( 1.6 \times 10^7) = 2.9 \times 10^{-3}$

$K_{net} = 2.9 \times 10^{-3} = \{[Ag(NH_3)_2]^+)(Cl^-)\}/ [NH_3]^2$

Using a large concentration of $NH_3$ will produce a large concentration of the complex ion in solution and thus the solubility of silver chloride is much higher in an aqueous ammonia solution than in water.

Step 3: Aqueous sodium bromide is added forming insoluble silver bromide, which is more stable than the complex ion:

$[Ag(NH_3)_2]^+(aq) + NaBr(aq) \Leftrightarrow AgBr(s) + Na^+ + 2NH_3$

$AgBr(s) \Leftrightarrow Ag^+(aq) + Br^-(aq)$ $K_{sp} = 5.0 \times 10^{-13}$

Step 4: Sodium thiosulfate is added to the solution. The silver bromide precipitate dissolves in preference to the silver thiosulfate complex ion.

Net chemical equation:
$AgBr(aq) + 2S_2O_3^{2-}(aq) \Leftrightarrow [Ag(S_2O_3)2]^{3-}(aq) + Br^-(aq)$

$Ag^+ + 2S_2O_3^{2-}(aq) \Leftrightarrow [Ag(S_2O_3)_2]^{3-}(aq)$ $K_f = 2.0 \times 10^{13}$

$K_{net} = K_{sp} \times K_f = (5.0 \times 10^{-13})(2.0 \times 10^{13}) = 1.0 \times 10^1$

$K_{net}$ is equal to 1, which predicts a product-favored reaction, and it is observed that the precipitate dissolved and the complex ion is formed.

Note: Relate the use of silver bromide to the application of photography.

**Safety:** Silver nitrate and its solutions and concentrated ammonia solutions can be irritating to the skin and can cause burns. Use proper protective equipment, including gloves and glasses when performing these experiments. Be sure not to add acid to the thiosulfate solutions, as this will produce toxic hydrogen sulfide gas.

**Disposal:** Dispose of solution in an appropriate aqueous waste container.

**References:**
1. B.Z. Shakhashiri; *Chemical Demonstrations: A Handbook for Teachers of Chemistry*; Volume 1; Wisconsin; 1983; p. 307-313 (variation)

2. Kotz, Treichel, Townsend. *Chemistry & Chemical Reactivity, 7th* Ed ;Teachers Ed; Brooks/Cole; 2009; p. 847-848
3. L. Summerlin, C. Borgford, J. Ealy; *Chemical Demonstrations: A Sourcebook for Teachers*; Volume 2; 1987; p. 80 (simpler version producing AgCl and $[Ag(NH_3)_2]^+$ only)