The Mellow-Yellow Reaction

Transition Metal Complex Ions

Introduction

Add water from a large beaker into another beaker and from that beaker to the next! Your students will observe a variety of color changes until at the very end the large beaker contains "lemonade."

Concepts

- Complex ions
- Precipitates

Materials

Ammonium thiocyanate solution, 12 drops
Iron(III) chloride solution, 25 drops
Oxalic acid solution, 10 mL
Tannic acid solution, 12 drops
Water, distilled, 600 mL
Beakers, 1000-mL, 6
Graduated cylinder, 10-mL
Pipets, Beral-type, 3

Safety Precautions

Iron(III) chloride is a skin/tissue irritant. Ammonium thiocyanate is toxic by ingestion and dangerous when heated to decomposition (170 °C) or when in contact with acids since fumes containing cyanides may be produced. Tannic acid is toxic by ingestion and inhalation, and is a suspected carcinogen. Oxalic acid is a skin and eye irritant, and is toxic by ingestion with an LD_{50} of 375 mg/kg. Wear chemical-resistant gloves, a chemical-resistant apron, and chemical splash goggles. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Procedure

1. Arrange five 1000-mL beakers in a row across the demonstration table. Set a sixth beaker behind the row.
2. Place 25 drops of iron(III) chloride solution into Beaker 1.
3. Place 2 drops of ammonium thiocyanate solution into Beaker 2 and 10 drops of ammonium thiocyanate solution into Beaker 3.
4. Place 12 drops of tannic acid solution into Beaker 4.
5. Using a 10-mL graduated cylinder, measure out 10 mL of oxalic acid solution and transfer it to Beaker 5.
6. Fill the last beaker (Beaker 6) with 600 mL of distilled or deionized water.
7. Pour the water from Beaker 6 into Beaker 1. Swirl to mix the contents. Pour the solution back into Beaker 6. The solution should be pale yellow, like the color of lemonade.
8. Pour the solution from Beaker 6 into Beaker 2. Swirl to mix the contents. Pour the solution back into Beaker 6. The solution should be orange-red, like the color of iced tea.
9. Pour the solution from Beaker 6 into Beaker 3. Swirl to mix the contents. Pour the solution back into Beaker 6. The solution should be dark red, like the color of wine.
10. Pour the solution from Beaker 6 into Beaker 4. Swirl to mix the contents. Pour the solution back into Beaker 6. The solution should be blue-black, like the color of grape juice.
11. Pour the solution from Beaker 6 into Beaker 5. Swirl to mix the contents. Pour the solution back into Beaker 6. The solution should be yellow. Use your imagination to describe the final yellow solution!

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Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. The resulting solution may be rinsed down the drain with excess water according to Flinn Suggested Disposal Method #26b.

Tips

- In the video Peg Convery uses slightly different chemicals than are listed in this write-up (i.e. potassium thiocyanate instead of ammonium thiocyanate). However, the reaction mechanisms are the same.
- If the solution in Beaker 1 is too pale, add a few more drops of iron(III) chloride solution.
- Be creative when doing this demonstration and make up a funny story to go along with each of the colors. Your story may include a very thirsty person ordering various drinks (lemonade, iced tea, red wine, grape juice) and then because he/she drank too much he/she had to go to the bathroom.
- Use only distilled or deionized water in order to obtain the best results.
- An alternate idea is to use various types of glasses (i.e., wine glass, beer mug, etc.) in place of the large beakers.

Discussion

Beaker 1: Hydrated iron(III) ions, $[Fe(H_2O)_6]^{3+}$, are present in the solution in Beaker 1. The initial solution is orange at a concentration of 2 M. Upon dilution with 600 mL of water from Beaker 6, the solution becomes pale yellow.

$$Fe^{3+}(aq) + H_2O(l) \rightarrow \underset{\text{2 M (orange)}}{[Fe(H_2O)_6]^{3+}(aq)} \rightarrow \underset{\text{0.003 M (pale yellow)}}{[Fe(H_2O)_6]^{3+}(aq)}$$

Beaker 2 : Thiocyanate ions, SCN–, are present in Beaker 2 in a limited quantity. When mixed with an excess of hydrated iron(III) ions from Beaker 1, a small amount of iron(III) thiocyanate complex ions are formed.

$$\underset{\text{(pale yellow)}}{[Fe(H_2O)_6]^{3+}(aq)} + \underset{\text{limited quantity}}{SCN^-(aq)} \rightarrow \underset{\text{(orange-red)}}{[Fe(H_2O)_5SCN]^{2+}(aq)}$$

Beaker 3: When additional thiocyanate ions from Beaker 3 are added to Beaker 2, they react with the excess hydrated iron(III) ions from Beaker 2 which did not react in the previous step. The color of the solution becomes a deeper red as more of the iron(III) thiocyanate complex ions are formed.

$$[Fe(H_2O)_6]^{3+}(aq) + SCN^-(aq) \rightarrow \underset{\text{(blood-red)}}{[Fe(H_2O)_5SCN]^{2+}(aq)}$$

Beaker 4: When the mixture of iron(III) ions in Beaker 3 is mixed with the tannic acid solution in Beaker 4, iron(III) tannate is formed. The chemical formula of iron(III) tannate is not given because the composition is variable. The formation of iron(III) tannate imparts a bluish-black color to the final solution in Beaker 4.

$$Fe^{3+}(aq) + \underset{\text{tannic acid}}{C_{76}H_{52}O_{46}(aq)} \rightarrow \underset{\text{(bluish-black)}}{\text{iron(III) tannate(aq)}}$$

Beaker 5: An iron(III) oxalate complex is formed when the iron(III) tannate solution in Beaker 4 is mixed with the oxalic acid solution in Beaker 5. This final complex is yellow in color.

$$\text{iron(III) tannate(aq)} + \underset{\text{oxalic acid}}{H_2C_2O_4(aq)} \rightarrow \underset{\text{(yellow)}}{[Fe(C_2O_4)_3]^{3-}(aq)}$$

Note: The actual formula of this final complex is unknown, but the formula given above is likely. The iron(III) ions may also have waters surrounding them. In fact, by this point, so many components are present in solution that several of them may be contributing to the final yellow color.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Constancy, change, and measurement
Content Standards: Grades 5–8
Content Standard B: Physical Science, properties and changes of properties in matter
Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter, chemical reactions

Answers to Worksheet Questions

1. Note the initial contents of each beaker, as well as the final color.

Beaker 1 – *Contents: Iron(III) chloride solution. Color: Pale yellow*

Beaker 2 – *Contents: Ammonium thiocyanate solution. Color: Orange-red*

Beaker 3 – *Contents: Ammonium thiocyanate solution. Color: Dark red*

Beaker 4 – *Contents: Tannic acid solution. Color: Bluish-black*

Beaker 5 – *Contents: Oxalic acid solution. Color: Yellow*

2. Write the following balanced chemical equations for the reactions that occurred in this demonstration. Note the formation of iron(III) tannate in Beaker 4 and the iron(III) oxalate complex in Beaker 5 are not included, due to their unknown compositions.

a. The combination of iron(III) ions with water (Beaker 1)

$$Fe^{3+}(aq) + H_2O(l) \rightarrow [Fe(H_2O)_6]^{3+}(aq)$$

b. Hydrated iron(III) ions reacting with thicocyanate ions (Beaker 2)

$$[Fe(H_2O)_6]^{3+}(aq) + SCN^{-}(aq) \rightarrow [Fe(H_2O)_5SCN]^{2+}(aq)$$

3. The same reaction occurs in Beaker 2 as in Beaker 3 – Beaker 3 reacts with the excess hydrated iron(III) ions from Beaker 2. Why, then, is Beaker 3 a different color?

Beaker 3 is a different color than Beaker 2 because of the higher concentration of iron(III) thiocyanate complex ions. The ions are reddish in color, but because there are more in Beaker 3, the color of Beaker 3 is a darker, deeper red than Beaker 2.

References

Rohr, W., Eastchester High School, personal communication.

Shakhashiri, B. Z. *Chemical Demonstrations, A Handbook for Teachers of Chemistry;* University of Wisconsin Press: Madison, WI, 1983; Vol. 1, pp 341–343.

Summerlin, L. R., Ealy J. L. *Chemical Demonstrations, A Sourcebook for Teachers,* 1st Ed., American Chemical Society, 1985, Vol. 1.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of *The Mellow-Yellow Reaction* activity, presented by Peg Convery, is available in *Transition Metal Complex Ions*, *There's Magic in Chemistry*, and *Open House Demonstrations* part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *The Mellow-Yellow Reaction* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in *The Chemical Kidney* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP8461	The Chemical Kidney—Chemical Demonstration Kit
A0213	Ammonium Thiocyanate
F0069	Iron(III) Chloride Solution, 1.0 M, 100 mL
Q0005	Oxalic Acid, 100 g
T0002	Tannic Acid, 100 g

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

The Mellow-Yellow Reaction Worksheet

Discussion Questions

1. Note the initial contents of each beaker, as well as the final color.

   Beaker 1 –

   Beaker 2 –

   Beaker 3 –

   Beaker 4 –

   Beaker 5 –

2. Write the following balanced chemical equations for the reactions that occurred in this demonstration. Note the formation of iron(III) tannate in Beaker 4 and the iron(III) oxalate complex in Beaker 5 are not included, due to their unknown compositions.

   a. The combination of iron(III) ions with water (Beaker 1)

   b. Hydrated iron(III) ions reacting with thicocyanate ions (Beaker 2)

3. The same reaction occurs in Beaker 2 as in Beaker 3 – Beaker 3 reacts with the excess hydrated iron(III) ions from Beaker 2. Why, then, is Beaker 3 a different color?