The Redox Rainbow

Oxidation States

FLINN SCIENTIFIC CHEM FAX!

Introduction

A yellow solution containing vanadium(V) ions goes through a series of beautiful color changes as it is swirled and shaken with zinc metal. The final purple solution, which contains vanadium(II) ions, miraculously cycles back through the entire series of color changes when hydrogen peroxide is added.

Concepts

- Redox reactions
- Oxidation states
- Transition metals

Materials

Ammonium metavanadate solution, NH_4VO_3 in dilute H_2SO_4, 140 mL

Zinc, granular, Zn, 5 g

Demonstration tube

Erlenmeyer flasks, 500-mL

Magnetic stirrer and stir bar (optional)

Pipet, Beral-type

Powder funnel, large

Rubber stopper, size 2

Rubber stopper, size 7

Weighing dish

Safety Precautions

Ammonium metavanadate solution is highly toxic and corrosive to eyes, skin, and other tissue. Hydrogen peroxide is corrosive to the skin, eyes, and respiratory tract and is a very strong oxidant. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Preparation

1. To prepare the ammonium metavanadate solution measure 75 mL of distilled or deionized water in a graduated cylinder and transfer it to a 250-mL beaker.
2. Add 6.75 mL of concentrated (18 M) sulfuric acid to the 75 mL of DI water. Mix throughly.
3. Measure 0.75 g of ammonium metavandate and add to the acidified DI water.
4. Mix until ammonium metavandate has dissolved.
5. Dilute to 150 mL using DI water.

Procedure

1. Measure 5 g of granular zinc into a weighing dish and transfer the zinc into a 500-mL Erlenmeyer flask using a large powder funnel.
2. Using a 250-mL graduated cylinder, measure out 140 mL of the acidic ammonium metavanadate solution. *(Observe the initial yellow color of the solution.)*
3. Pour the ammonium metavanadate solution into the Erlenmeyer flask. *(The solution will turn green.)*
4. Stopper the flask and gently shake the solution to reduce the vanadium (VO_2^+) ions. *(The solution will gradually change color from green to blue to blue-green to dark green to dark blue to purple. The entire sequence of color changes will take about eight minutes. The solution may have to be shaken vigorously to reach the purple color.)*
5. Place a size 2 rubber stopper in one end of the demonstration tube.
6. After the solution has turned purple, decant the solution into the demonstration tube, leaving the zinc in the first flask.

Do not transfer any zinc. The demonstration tube contains the vanadium(II) ions.

7. Add ammonium metavanadate in one end of the demonstration tube. This contains the vanadium(V) ions.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures, and review all federal, state and local regulations that may apply, before proceeding. The ammonium metavanadate solution may be disposed of according to Flinn Suggested Disposal Method #27f.

Tips

- Dissolving metavanadate ions (VO_3^-) in acidic solution produces VO_2^+ ions according to the following reaction:

  $VO_3^-(aq) + 2H^+(aq) \rightarrow VO_2^+(aq) + H_2O$

- The purple solution containing V^{2+} ions is very stable and will not change color, even after several hours.

Discussion

The initial yellow ammonium metavanadate solution contains VO_2^+ ions and illustrates vanadium in the +5 oxidation state, vanadium(V). The yellow vanadium(V) is reduced stepwise by zinc through the following oxidation states—vanadium(IV) in VO^{2+} (blue), vanadium(III) in V^{3+} (blue-green), and finally vanadium(II) in V^{2+} (purple). The balanced equations for the stepwise reduction of vanadium by zinc are shown below.

Reduction of vanadium by zinc:

V(V) to V(IV): $Zn(s) + 2VO_2^+(aq) + 4H^+(aq) \rightarrow 2VO^{2+}(aq) + Zn^{2+}(aq) + 2H_2O(l)$

Yellow *Blue*

V(IV) to V(III): $Zn(s) + 2VO^{2+}(aq) + 4H^+(aq) \rightarrow 2V^{3+}(aq) + Zn^{2+}(aq) + 2H_2O(l)$

Blue *Blue-green*

V(III) to V(II): $Zn(s) + 2V^{3+}(aq) \rightarrow 2V^{2+}(aq) + Zn^{2+}(aq)$

Blue-green *Purple*

The intermediate green color observed when the yellow solution is initially poured into the flask containing zinc is due to the combination of the yellow VO_2^+ and the blue VO^{2+} ions.

Vanadium in the +2 oxidation state, V^{2+}, is reoxidized using hydrogen peroxide. The various oxidation states are observed by the gradual addition of hydrogen peroxide. In a strongly acidic solution, hydrogen peroxide will convert the vanadium all the way to the red-brown peroxovanadium cation, VO_2^{3+}, in which vanadium in the (+5) oxidation state is combined with the peroxide anion, O_2^{2-}.

Oxidation of vanadium by hydrogen peroxide:

$$V^{2+}(aq) + H_2O_2(aq) \rightarrow V^{3+}(aq) \rightarrow VO^{2+}(aq) \rightarrow VO_2^+(aq) \rightarrow VO_2^{3+}(aq)$$

Purple *Blue-green* *Blue* *Yellow (green)* *Red-brown*

Vanadium, element 23, was named after Vanadis, the Norse goddess of beauty, because of its beautiful, multicolored compounds. The principal oxidation state of vanadium is +5, which is found in compounds such as the orange vanadium(V) oxide, V_2O_5, an industrial catalyst. In aqueous solution, vanadium can exist in many different oxidation states, from +5 to +2. Each oxidation state has a different representative color. Many transition metal ions form complexes to give a rainbow of colors. The colors arise because transition metal ions have incompletely filled *d* subshells. The *d* electrons can be excited from a lower energy state to a higher energy state by absorbing light of the appropriate wavelength and energy.

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 9–12
Content Standard B: Physical Science, structure and properties of matter, chemical reactions, interactions of energy and matter

References

Davis, J. M. *J. Chem. Educ.* 1968, *45*, 473.

Grant, A. W. *J. Chem. Educ.* 1977, *54*, 500.

Greenwood, N. N.; Earnshaw, A. *Chemistry of the Elements* Pergamon Press, 1984, 1157.

Hentz, F. C.; Long, G. G. *J. Chem. Educ.* 1978, *55*, 55.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *The Redox Rainbow* activity, presented by John Little, is available in *Oxidation States*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *The Redox Rainbow* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Redox and the Goddess of Beauty—Chemical Demonstration Kit* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP8472	Redox and the Goddess of Beauty—Chemical Demonstration Kit
AP2229	Rubber Stopper, Size 7
AP2224	Rubber Stopper, Size 2
GP9146	Demonstration Tube
A0245	Ammonium Metavanadate, 10 g

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