Redox and the Goddess of Beauty

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. The beautiful colors of vanadium ions and oxidation states show why vanadium was named after Vanadis, the Norse goddess of beauty.

Concepts

- Redox reactions
- Oxidation states
- Transition metals

Materials

Ammonium metavanadate solution, NH_4VO_3 in dilute H_2SO_4, 140 mL

Hydrogen peroxide, H_2O_2, 6%, 7 mL

Zinc, granular, Zn, 5 g

Erlenmeyer flasks, 500-mL, 2

Graduated cylinder, 250-mL

Magnetic stirrer and stir bar

Powder funnel, large

Stopper to fit the Erlenmeyer flask

Pipet, Beral-type

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

Prepare the acidic ammonium metavanadate solution by dissoving 2.6 g of NH_4VO_3 in 400 mL of 1 M sulfuric acid solution. Dilute to 500 mL with distilled 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. Place a magnetic stir bar into the flask.
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 begin stirring on the magnetic stirrer 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 10-15 minutes.)*
5. After the solution has turned purple, decant the solution into another 500-mL Erlenmeyer flask, leaving the zinc in the first flask. Do not transfer any zinc.
6. Using a Beral-type pipet, add 6% hydrogen peroxide to the purple solution in 1–2 mL increments, swirling after each addition. *(The solution will cycle back through a series of color changes, from purple to blue-green to blue to dark green to brownish red. The entire sequence of color changes will require about 7 mL of H_2O_2.)*
7. The resulting vanadium solution may be recycled through both the reduction and oxidation sequences to repeat the

demonstration. Pour the solution remaining from step 6 back into the flask containing the original zinc, and repeat steps 4–6.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. The ammonium metavanadate solution may be disposed of according to Flinn Suggested Disposal Method #27f. Excess hydrogen peroxide solution may be disposed of by diluting it with water to a concentration of less than 3% and rinsing it down the drain with excess water according to Flinn Suggested Disposal Method #26b.

Tips

- This demonstration has been available for years using zinc (mercury) amalgam as the reducing agent. Given the toxicity and hazard of working with mercury, we retested the procedure using other sources of zinc. We found that granular zinc gives excellent results, as described herein. Use only fresh, high quality, granular zinc. Do NOT use mossy zinc or zinc dust.
- Dissolving metavanadate ions (VO_3^-) in acidic solution produces VO_2^+ ions according to the following reaction:

  $VO_3^-(aq) + 2H^+(aq) \rightarrow VO_2^+(aq) + H_2O$
- As noted in step 7, both the vanadate solution and the zinc may be recycled to repeat the demonstration. The color changes may take a little longer the second time around, but all of the colors will be observed.
- 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

Answers to Worksheet Questions

1. Describe what happened in this demonstration.

A yellow ammonium metavanadate solution was poured into a flask containing zinc. The solution immediately turned green. While swirling the flask, the solution went through a series of color changes, from green to blue to blue-green to dark blue to purple. When the solution was decanted off and hydrogen peroxide was added, the solution went through another set of color changes, from purple to blue-green to blue to dark green to brownish red.

2. What is an oxidation–reduction reaction?

An oxidation–reduction (or "redox") reaction occurs when one or more electrons are transferred between molecules. Oxidation refers to a loss of electrons (and rise in oxidation state), and reduction refers to a gain of electrons (and subsequent decrease in oxidation state).

3. The initial yellow solution contains VO_2^+ ions, which include vanadium(V). In the first part of this demonstration, vanadium(V) was reduced stepwise by zinc to vanadium(IV), then vanadium(III), and then vanadium(II). Write a balanced chemical equation for the each of the steps in this reaction. *Hint:* Include hydrogen ions in the first two reactions.

a. V(V) to V(IV)

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

b. V(IV) to V(III)

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

c. V(III) to V(II)

$$Zn(s) + 2V^{3+}(aq) \rightarrow 2V^{2+}(aq) + Zn^{2+}(aq)$$

4. VO_2^+ ions are yellow, while VO^{2+} ions are blue. Knowing this, explain the green color that was generated when the ammonium metavanadate solution was poured over the zinc.

The green was an intermediate color, due to the combination of yellow VO_2^+ *ions from the ammonium metavanadate solution and blue* VO^{2+} *ions that the zinc was already producing.*

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Redox and the Goddess of Beauty* activity, presented by Irene Cesa, is available in *Oxidation States*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Redox and the Goddess of Beauty* 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
A0245	Ammonium Metavanadate, Reagent, 10 g
H0028	Hydrogen Peroxide, 6%, 500 mL
Z0028	Zinc, Granular, Reagent, 100 g
GP3050	Erlenmeyer Flask, Borosilicate Glass, 500-mL
GP2025	Graduated Cylinder, Borosilicate Glass, 250-mL

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

Redox and the Goddess of Beauty Worksheet

Discussion Questions

1. Describe what happened in this demonstration.

2. What is an oxidation–reduction reaction?

3. The initial yellow solution contains VO_2^+ ions, which include vanadium(V). In the first part of this demonstration, vanadium(V) was reduced stepwise by zinc, to vanadium(IV), then vanadium(III), and then vanadium(II). Write a balanced chemical equation for the each of the steps in this reaction. *Hint:* Include hydrogen ions in the first two reactions.

   a. V(V) to V(IV)

   b. V(IV) to V(III)

   c. V(III) to V(II)

4. VO_2^+ ions are yellow, while VO^{2+} ions are blue. Knowing this, explain the green color that was generated when the ammonium metavanadate solution was poured over the zinc.