Cobalt Catalyst and the Activated Complex

Reaction Pathways

Introduction

What does it take to oxidize a simple organic compound? Will mighty hydrogen peroxide do the trick? No—it takes a little pink catalyst. When cobalt chloride is added to a hot mixture of potassium sodium tartrate and hydrogen peroxide, the solution immediately turns green and begins to bubble vigorously. When the bubbling subsides, the original pink color of the catalyst returns. Follow the path of a cobalt ion catalyst as it gets swept up in the reaction pathway, changes into something different, and reappears.

Concepts

- Kinetics
- Reaction pathway
- Catalyst
- Activated complex

Materials

Cobalt chloride solution, $CoCl_2$, 0.1 *M*, 12 mL

Hydrogen peroxide solution, 6%, H_2O_2, 40 mL

Potassium sodium tartrate, $KNaC_4H_4O_6 \cdot 4H_2O$, 6 g

Water, distilled

Beaker, 500-mL or 1-L

Erlenmeyer flask, 125-mL

Graduated cylinder, 25-mL

Hot plate and magnetic stirrer

Stirring rod (optional)

Thermometer

Safety Precautions

Dilute cobalt chloride solution is slightly toxic by ingestion. (Solid cobalt chloride is a possible carcinogen as a fume or dust.) Hydrogen peroxide is a strong oxidizer and a skin and eye irritant. Avoid contact of all chemical with eyes and skin. Wear chemical-resistant goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the lab. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Preparation

Prepare 0.2 *M* potassium sodium tartrate solution by dissolving 6 g of $KNaC_4H_4O_4 \cdot 4H_2O$ in 100 mL of distilled water.

Procedure

1. Using a graduated cylinder, measure 100 mL of 0.2 *M* potassium sodium tartrate solution and pour it into a 500-mL or 1-L beaker.
2. Place the beaker on a hot plate at a medium setting and slowly warm the solution to 70 °C.
3. Obtain 12–14 mL of 0.1 *M* cobalt chloride solution in a 25-mL graduated cylinder. Show the solution to the class and note the initial pink color of the catalyst.
4. When the temperature of the potassium sodium tartrate solution reaches 70 °C, carefully add 40 mL of 6% hydrogen peroxide solution. Is there any evidence of a chemical reaction? *(There may be a few bubbles here and there.)*
5. Add the pink catalyst solution to the reaction mixture and stir continuously.
6. Observe the rate and the progress of the resulting chemical reaction. (The solution immediately turns brown, but then lightens to a yellow-orange color before turning olive and finally Kelly green. Vigorous bubbling ensues. The mixture begins to froth and foam, then just as suddenly subsides. When the rate of bubbling diminishes, the green color disappears and the solution progresses back through a series of color changes before returning to the original pink

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color of the cobalt chloride solution.)

Disposal

Consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. The final cobalt-containing solution may be disposed of according to Flinn Suggested Disposal Method #27d.

Tips

- The demonstration may be extended to investigate the effect of temperature on the reation rate. (Even catalyzed reactions are affected by the reaction temperature.) Time how long the reaction takes at . Suggested temperatures and corresponding reaction times are: 50 °C—200 seconds, 60 °C—90 seconds, and 70 °C—40 seconds.
- Begin timing the reaction upon addition of the pink catalyst solution. Complete the timing after the vigorous reaction subsides and the original pink color of the cobalt chloride solution has returned. Using a hot plate-magnetic stirrer combination is strongly recommended if you are going to measure reaction times. Otherwise, it will be necessary to continuously stir the reaction mixture.
- The following simple model can be used to demonstrate the action of a catalyst. Remove half the chalk from a new box of chalk and place in a shoe box. Each piece of chalk represents a long molecule, such as a long-chain hydrocarbon. The reaction we want to model involves breaking this long molecule into shorter molecules, similar to the reaction that occurs in petroleum refining to obtain gasoline from crude oil. Close the shoe box and shake vigorously for 15 seconds. Open the box and remove the "products." Did the chalk break down? Take the rest of the new chalk pieces and place them in the shoe box, along with a rock or stone. Close the box and again shake vigorously for 15 seconds. Open the box and compare the products. Which reaction occurred faster? Does the catalyst change the reaction products, or just speed the reaction up? Has the catalyst changed? Could the catalyst be used again and again?

Discussion

The reaction of tartrate ions with hydrogen peroxide is an example of an oxidation–reduction reaction. Hydrogen peroxide is a strong oxidizing agent, resulting in the complete oxidation of tartrate ions to give carbon dioxide and water (Equation 1). The extent of this oxidative decomposition reaction is evident by the production of carbon dioxide gas.

$$C_4H_4O_6^{2-} + 5H_2O_2 \rightarrow 4CO_2 + 6H_2O + 2OH^- \qquad \textit{Equation 1}$$

In the absence of a catalyst, the decomposition reaction, although thermodynamically favorable, is kinetically very slow. Thus, even at 75 °C, the reaction occurs at a barely noticeable rate.

To speed up the reaction, a catalyst must be used. Cobalt ions are known to catalyze the decomposition of hydrogen peroxide. The action of the cobalt catalyst can be followed by observing the color changes of the solution over the course of the reaction. The solution starts out pink, the color of the cobalt(II) aquo complex $[Co(H_2O)_6^{2+}]$. The mixture then quickly turns green, indicating the formation of a cobalt(III) complex. The rapid production of gas bubbles due to oxidation of the tartrate ions occurs almost immediately after the green color has been observed. As the tartrate ions are consumed in the reaction and the amount of gas production subsides, the color of the solution returns back to the original pink color of the cobalt(II) catalyst. The following reaction steps in the reaction pathway have been proposed based on the results of kinetic and mechanistic experiments.

The first step is the formation of a Co(II)-tartrate coordination compound. This is followed by oxidation of the pink Co(II) complex to a green Co(III) complex. The Co(III) complex is most likely a binuclear cobalt containing several tartrate ions. It is this unknown complex that is thought to be the actual catalyst in the oxidation reaction of tartrate ions by hydrogen peroxide to give carbon dioxide and water. In the course of oxidation of the tartrate ions, the Co(III) complex ion is reduced back to Co(II). When all the tartrate has been consumed, the color of the solution reverts back to pink, indicating that only Co(II) ions are present in solution at the end of the reaction. Since the color of the solution is green throughout the reaction, most of the cobalt must be in the form of Co(III) ions during this time. This suggests that the first step, oxidation of Co(II) to Co(III) ions, is very fast compared to the second step, oxidation of the tartrate ions and reduction of the Co(III) complex.

Cobalt ions fit the definition of a catalyst—they are not consumed during the course of the reaction and their addition greatly speeds up the reaction. The cobalt salt could also be isolated from the reaction mixture and reused in future reactions.

Connecting to the National Standards

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

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Constancy, change, and measurement
Content Standards: Grades 9–12
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, structure and properties of matter, chemical reactions
Content Standard G: History and Nature of Science, nature of scientific knowledge

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Cobalt Catalyst and the Activated Complex* activity, presented by Irene Cesa, is available in *Reaction Pathways*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Cobalt Catalyst and the Activated Complex* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in *The Pink Catalyst—Chemcial Demonstration Kit* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP2084	The Pink Catalyst—Chemical Demonstration Kit
C0242	Cobalt Chloride Solution, 0.1 M, 500 mL
P0084	Potassium Sodium Tartrate, 100 g
H0028	Hydrogen Peroxide, 6%, 500 mL
AP7237	Magnetic Stirrer/Hot Plate, Flinn, 79 5 79

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