



Hydrogen Peroxide Analysis

Consumer Chemistry

Introduction

Hydrogen peroxide is regarded as an “environmentally friendly” alternative to chlorine for water purification and wastewater treatment. Because hydrogen peroxide decomposes in the presence of heat, light, or other catalysts, the quality of a hydrogen peroxide solution must be checked regularly to ensure its effectiveness. The concentration of hydrogen peroxide can be analyzed by redox titration with potassium permanganate.

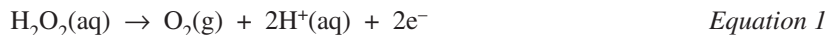
Concepts

- Redox reaction
- Oxidizing and reducing agents
- Titration
- Half-reactions

Background

Titration is a method of volumetric analysis—the use of volume measurements to analyze the concentration of an unknown. The most common types of titrations are acid–base titrations, in which a solution of an acid, for example, is analyzed by measuring the amount of a standard base solution required to neutralize a known amount of the acid. A similar principle applies to redox titrations. If a solution contains a substance that can be oxidized, then the concentration of that substance can be analyzed by titrating it with a standard solution of a strong oxidizing agent.

The equation for an oxidation–reduction reaction can be balanced by assuming that it occurs via two separate half-reactions. In this experiment, potassium permanganate will be used as the titrant to analyze the concentration of hydrogen peroxide in a commercial antiseptic solution. The permanganate ion acts as an oxidizing agent—it causes the oxidation of hydrogen peroxide. The oxidation half-reaction shows that two electrons are lost per molecule of hydrogen peroxide that is oxidized to oxygen gas (Equation 1). The permanganate ion, in turn, is reduced from the +7 oxidation state in MnO_4^- to the +2 oxidation state in Mn^{2+} . The reduction half-reaction shows a gain of five electrons (Equation 2).



Purple

Clear

Experiment Overview

The purpose of this experiment is to analyze the percent hydrogen peroxide in a common “drugstore” solution by titrating it with potassium permanganate. Standard potassium permanganate solution will be added via buret to the hydrogen peroxide solution. As the dark purple solution is added, it will react with the hydrogen peroxide and the color will clear. When all of the hydrogen peroxide has been used up, the endpoint of the titration occurs when the last drop of potassium permanganate that is added causes the solution to stay pink.

Pre-Lab Questions (Answer questions on a separate sheet of paper.)

1. Combine the oxidation and reduction half-reactions for hydrogen peroxide and permanganate ion, respectively, and write the balanced chemical equation for the overall reaction between H_2O_2 and MnO_4^- in acid solution. *Hint:* The number of electrons transferred must “cancel out.”
2. What is the mole ratio of hydrogen peroxide to permanganate ion in the balanced chemical equation determined in Question #1? How many moles of hydrogen peroxide will be oxidized by 0.0045 moles of potassium permanganate in acidic solution?

- Review the procedure. Is it necessary to know the exact volume of: (a) Hydrogen peroxide solution added to the flask in step 7? (b) Water added to the flask in step 8? Why or why not?

Materials

Hydrogen peroxide, H_2O_2 , commercial antiseptic solution, 3 mL	Graduated cylinder, 10- or 25-mL
Potassium permanganate solution, KMnO_4 , 0.025 M, 75 mL	Labels and/or markers
Sulfuric acid solution, H_2SO_4 , 3 M, 30 mL	Pipet, serological, 1-mL
Water, distilled or deionized, 100 mL	Pipet bulb
Beaker, 100- or 150-mL	Ring stand
Buret, 50-mL, with buret clamp	Wash bottle
Erlenmeyer flask, 125-mL	Waste disposal beaker, 250-mL

Safety Precautions

Sulfuric acid solution is severely corrosive to eyes, skin, and other body tissues. Always add acid to water, never the reverse. Notify your teacher and clean up all acid spills immediately. Potassium permanganate solution is a skin and eye irritant and a strong stain—it will stain skin and clothing. Avoid contact of all chemicals with eyes and skin. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the lab.

Procedure

- Obtain about 75 mL of potassium permanganate standard solution, 0.025 M, in a small beaker. Record the precise molarity of the solution in the Data Table.
- Rinse a clean 50-mL buret with two separate 5-mL portions of potassium permanganate solution.
- Clamp the buret to a ring stand with a buret clamp and place a 250-mL waste beaker under the buret.
- Fill the buret with potassium permanganate solution until the liquid level is just above the zero mark.
- Open the stopcock on the buret to allow any air bubbles to escape from the tip. Close the stopcock when the liquid level in the buret is between the 0- and 5-mL mark.
- Record the precise level of the solution in the buret. This is the *initial volume* of the potassium permanganate solution for Trial 1. *Note:* Volumes are read from the top down in a buret. Always read from the bottom of the meniscus and remember to include the appropriate number of significant figures. (See Figure 1 for reading buret level.)
- Using a serological pipet, transfer 1.00 mL of the commercial hydrogen peroxide solution into a 125-mL Erlenmeyer flask.
- Add about 20 mL of distilled or deionized water to the flask.
- Measure 10 mL of 3 M sulfuric acid into a graduated cylinder and carefully add the acid to the solution in the Erlenmeyer flask. Gently swirl the flask to mix the solution.
- Position the flask under the buret so that the tip of the buret is within the flask but at least 2 cm above the liquid surface. Place a piece of white paper under the flask to make it easier to detect the endpoint.
- Open the buret stopcock and allow 5–8 mL of the potassium permanganate solution to flow into the flask. Swirl the flask and observe the color changes in the solution.
- Continue to add the potassium permanganate solution slowly, drop-by-drop, while swirling the flask. Use a wash bottle to rinse the sides of the flask with distilled water during the titration to ensure that all of the reactants mix thoroughly.
- When a light pink color persists in the titrated solution while swirling the flask, the endpoint has been reached. Close the stopcock and record the final volume of the permanganate solution in the Data Table (Trial 1).

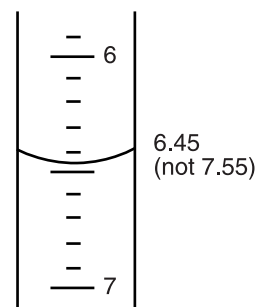


Figure 1.

14. Subtract the initial volume of the permanganate solution from the final volume to obtain the volume of KMnO_4 added. Enter the answer in the Data Table.
15. Pour the titrated solution into a waste disposal beaker and rinse the flask with distilled water.
16. Repeat the titration (steps 6–15) two more times (Trials 2 and 3). Record all data in the Data Table.
17. Dispose of the solution in the waste beaker as directed by your instructor.

Analysis of Hydrogen Peroxide

Data Table

	Trial 1	Trial 2	Trial 3
Molarity of KMnO_4 solution (M)			
Initial volume KMnO_4 solution (mL)			
Final volume KMnO_4 solution (mL)			
Volume of KMnO_4 added to flask (mL)			

Post-Lab Calculations and Analysis (Use a separate sheet of paper to answer the following questions.)

Construct a Results Table to summarize the results of the following calculations (#1–5):

- Multiply the molarity of the KMnO_4 solution by the volume added to the flask to calculate the number of moles of permanganate ion consumed in each trial. *Hint:* What are the units of molarity?
- Multiply the number of moles of permanganate ion by the mole ratio for hydrogen peroxide (see the *Pre-Lab Questions*) to determine the number of moles of hydrogen peroxide for each trial.
- Multiply the number of moles of hydrogen peroxide by the molar mass of hydrogen peroxide to determine the number of grams of hydrogen peroxide for each trial.
- For each trial, divide the number of grams of hydrogen peroxide by the total mass of the hydrogen peroxide solution (see step 7 in the *Procedure*), and multiply the answer by 100. The result is the *percent hydrogen peroxide* in the commercial antiseptic. *Note:* Assume the density of the commercial antiseptic solution is 1.00 g/mL.
- Determine the average value for the percent hydrogen peroxide in the commercial solution and compare the value with the concentration reported on the product label.
- If an insufficient amount of acid is added in step 9, some of the MnO_4^- ions will be reduced to MnO_2 instead of to Mn^{2+} .
 - How would this change the mole ratio for the titration reaction?
 - How would this affect the volume of KMnO_4 solution needed to reach the endpoint?
 - If reduction to MnO_2 were occurring but not being reflected in the calculations, would the calculated percent hydrogen peroxide be too high or too low as a result of this error?

Teacher's Notes

Analysis of Hydrogen Peroxide

Master Materials List (for a class of 30 students working in groups of two)

Hydrogen peroxide, H ₂ O ₂ , commercial antiseptic solution, 50 mL	Graduated cylinders, 10- or 25-mL, 15
Potassium permanganate solution, KMnO ₄ , 0.0250 M, 1.5 L	Labels and/or markers
Sulfuric acid solution, H ₂ SO ₄ , 6 M, 250 mL	Pipets, volumetric or serological, 1-mL, 15
Water, distilled or deionized, 2 L	Pipet bulbs, 15
Beakers, 100- or 150-mL, 15	Ring stands, 15
Burets, 50-mL, and buret clamps, 15	Wash bottles, 15
Erlenmeyer flasks, 125-mL, 30	Waste disposal beakers, 250-mL, 15

Preparation of Solutions (for a class of 30 students working in groups of two)

Potassium Permanganate, 0.0250 M: Obtain about 250 mL of distilled or deionized water in a 1-L volumetric flask and carefully add 3.95 g of potassium permanganate. Stir to dissolve, then dilute to the mark with distilled water. Use quantitative transfer techniques. Repeat once to prepare 2 L of standard potassium permanganate solution. Prepare fresh within 1–2 days of use and store in a dark (amber) bottle, if possible. Avoid exposure to light and heat. *Note:* Potassium permanganate is slow to dissolve—use a magnetic stirrer.

Sulfuric Acid, 6 M: Cool about 100 mL of distilled or deionized water in an ice bath. Carefully add 83 mL of concentrated sulfuric acid (18 M) and stir to mix. Remove the flask from the ice bath, allow to reach room temperature, and dilute to 250 mL with water. *Note:* Always add acid to water.

Safety Precautions

Sulfuric acid solution is severely corrosive to eyes, skin, and other body tissues. Always add acid to water, never the reverse. Keep sodium carbonate or sodium bicarbonate on hand to neutralize acid spills. Potassium permanganate solution is a skin and eye irritant and a strong stain—it will stain skin and clothing. Avoid contact of all chemicals with eyes and skin. 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. Remind students to wash their hands thoroughly with soap and water before leaving the lab.

Disposal

Consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. The waste solutions remaining after the titrations are complete are acidic and contain Mn²⁺ ions. Neutralize the acid with sodium carbonate or sodium bicarbonate according to Flinn Suggested Disposal Method #24b, and add extra hydrogen peroxide (about 5 mL) to the solution to convert the Mn²⁺ ions to MnO₂, a brown solid. Separate the resulting mixture by filtration and dispose of the solid MnO₂ in the trash according to Flinn Suggested Disposal Method #26a.

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, chemical reactions

Lab Hints

- See the *Supplementary Information* section for Bob's alternative microscale titration procedure. The microscale procedure is a gravimetric determination—the mass of the titrant rather than its volume is measured.

Teacher's Notes *continued*

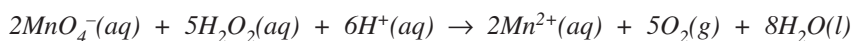
- The actual experimental work for this lab takes about 50 minutes. Students can expect very precise results that are relatively easy to obtain. If students have never used a buret before, however, the experiment will take longer.
- The titration lab teaches students how to use volumetric glassware and encourages them to develop proper laboratory techniques. Review and demonstrate the proper techniques for using a pipet and a buret. See the “Laboratory Techniques Guide” available from Flinn Scientific (Catalog No. AP6248) for a convenient student handout describing 16 common laboratory techniques.
- Have students approximate the amount of potassium permanganate needed to titrate the commercial hydrogen peroxide solution before they begin the titration.
- Students may use Trial 1 as a practice run to estimate the volume of KMnO_4 required for the titration. If the data from Trial 1 are significantly different from those in Trials 2 and 3, students should use only the latter two trials for their calculations.
- Students may feel more confident in the accuracy of the endpoint if they run a “blank” first—add 10 mL of acid to about 30 mL of water, followed by 1 drop of the potassium permanganate solution. Keep the blank next to the titration flask and compare the color at the endpoint.
- Potassium permanganate is not considered a primary standard. Solutions of potassium permanganate are generally standardized by titration with sodium oxalate as the primary standard. If time is available, the teacher may standardize the solution before use. Standardizing the solution would also be a good exercise for students in an honors or advanced chemistry class. See the *Supplementary Information* section for a standardization procedure.
- We have found that preparing the potassium permanganate solution fresh in a volumetric flask using reagent grade potassium permanganate and quantitative transfer techniques gives excellent results without standardization. The difference between the calculated concentration and the standardized molarity is typically less than 3%.

Teaching Tips

- Hydrogen peroxide is a stronger oxidizing agent than potassium permanganate. The standard reduction potential is 1.76 V for hydrogen peroxide versus 1.51 V for permanganate ion. In this experiment, however, hydrogen peroxide is oxidized by potassium permanganate. This is because the permanganate ion cannot be further oxidized—the Mn atom in MnO_4^- is already in the highest oxidation state possible (+7). Hydrogen peroxide can be oxidized further to oxygen gas. Although we tend to think of hydrogen peroxide in terms of its oxidizing ability, hydrogen peroxide can act as both an oxidizing agent and a reducing agent, as seen in this experiment. The well-known decomposition of hydrogen peroxide to give oxygen and water is an example of a disproportionation reaction in which one hydrogen peroxide molecule is oxidized, the other is reduced.
- Increase the “real-world” application or value of this experiment by asking students to bring in old bottles of hydrogen peroxide from home to analyze. The typical drugstore product is labeled with an expiration date, and it is not unusual for students to find, generally in the far reaches of their medicine cabinets, bottles of hydrogen peroxide that are five years past the expiration date. These are great samples to analyze to see if the quality of the solution has deteriorated with age.

Answers to Pre-Lab Questions *(Student answers will vary.)*

1. Combine the oxidation and reduction half-reactions for hydrogen peroxide and permanganate ion, respectively, and write the balanced chemical equation for the overall reaction between H_2O_2 and MnO_4^- in acid solution. *Hint:* The number of electrons transferred must “cancel out.”



2. What is the mole ratio of hydrogen peroxide to permanganate ion in the balanced chemical equation determined in Question #1? How many moles of hydrogen peroxide will be oxidized by 0.0045 moles of potassium permanganate in acidic solution?

The mole ratio is 5 moles of H_2O_2 per 2 moles of MnO_4^- ion.

$$0.0045 \text{ moles } \text{KMnO}_4 \times \frac{5 \text{ moles } \text{H}_2\text{O}_2}{2 \text{ moles } \text{KMnO}_4} = 0.011 \text{ moles } \text{H}_2\text{O}_2$$

Teacher's Notes *continued*

3. Review the procedure. Is it necessary to know the exact volume of: (a) Hydrogen peroxide solution added to the flask in step 7? (b) Water added to the flask in step 8? Why or why not?

a. *It is necessary to know the exact volume of hydrogen peroxide solution added to the flask in step 7 because the concentration of hydrogen peroxide will be determined by dividing the grams of hydrogen peroxide (as calculated from the titration data) by the total mass of the solution. If the precise volume of the solution is not known, it will limit the precision of the results to fewer significant figures.*

b. *It is not necessary to know the exact volume of water added in step 8. The number of moles of hydrogen peroxide in a measured volume of the commercial solution is not affected by how much water is added to dilute it.*

Sample Data Table *(Student data will vary.)*

	Trial 1	Trial 2	Trial 3
Molarity of KMnO_4 solution (M)	0.0250 M		
Initial volume KMnO_4 solution (mL)	4.10 mL	18.75 mL	30.90 mL
Final volume KMnO_4 solution (mL)	18.75 mL	33.55 mL	45.32 mL
Volume of KMnO_4 added to flask (mL)	14.65 mL	14.80 mL	14.42 mL

Answers to Post-Lab Calculations and Analysis *(Student answers will vary.)*

1. Multiply the molarity of the KMnO_4 solution by the volume added to the flask to calculate the number of moles of permanganate ion consumed in each trial. *Hint:* What are the units of molarity?

$$\text{Trial 1: } \frac{0.0250 \text{ moles KMnO}_4}{1 \text{ L}} \times 14.65 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} = 3.66 \times 10^{-4} \text{ moles}$$

See the Sample Results Table for the results of the other calculations.

2. Multiply the number of moles of permanganate ion by the mole ratio for hydrogen peroxide (see the *Pre-Lab Questions*) to determine the number of moles of hydrogen peroxide for each trial.

$$\text{Trial 1: } 3.66 \times 10^{-4} \text{ moles KMnO}_4 \times \frac{5 \text{ moles H}_2\text{O}_2}{2 \text{ moles KMnO}_4} = 9.16 \times 10^{-4} \text{ moles H}_2\text{O}_2$$

See the Sample Results Table for the results of the other calculations.

3. Multiply the number of moles of hydrogen peroxide by the molar mass of hydrogen peroxide to determine the number of grams of hydrogen peroxide for each trial.

$$\text{Trial 1: } 9.16 \times 10^{-4} \text{ moles H}_2\text{O}_2 \times \frac{34.02 \text{ g}}{1 \text{ mole}} = 0.0312 \text{ g H}_2\text{O}_2$$

See the Sample Results Table for the results of the other calculations.

4. For each trial, divide the number of grams of hydrogen peroxide by the total mass of the hydrogen peroxide *solution* (see step 7 in the *Procedure*), and multiply the answer by 100. The result is the *percent hydrogen peroxide* in the commercial antiseptic. *Note:* Assume the density of the commercial antiseptic solution is 1.00 g/mL.

$$\text{Trial 1: } \frac{0.0312 \text{ g H}_2\text{O}_2}{1.00 \text{ g solution}} \times 100\% = 3.12\%$$

See the Sample Results Table for the results of the other calculations.

5. Determine the average value for the percent hydrogen peroxide in the commercial solution and compare the value with the concentration reported on the product label.

The average value for the percent hydrogen peroxide in the commercial solution is 3.1%. This agrees with the concentration reported on the bottle (3%).

Sample Results Table

	Trial 1	Trial 2	Trial 3
Moles of KMnO_4	3.66×10^{-4} moles	3.70×10^{-4} moles	3.61×10^{-4} moles
Moles of H_2O_2	9.16×10^{-4} moles	9.25×10^{-4} moles	9.03×10^{-4} moles
Grams of H_2O_2	0.0312 g	0.0315 g	0.0307 g
Percent H_2O_2	3.12%	3.15%	3.07%
Average Concentration H_2O_2		3.11%	

6. If an insufficient amount of acid is added in step 9, some of the MnO_4^- ions will be reduced to MnO_2 instead of to Mn^{2+} .

a. How would this change the mole ratio for the titration reaction?

If permanganate ions were reduced to MnO_2 instead of to Mn^{2+} ions, the mole ratio for the reaction of hydrogen peroxide with potassium permanganate would change from 5:2 to 3:2 (The change in oxidation state for the Mn atom would be from +7 to +4 instead of from +7 to +2.)

b. How would this affect the volume of KMnO_4 solution needed to reach the endpoint?

The volume of KMnO_4 needed to reach the endpoint would be greater if permanganate ions were being reduced to MnO_2 instead of to Mn^{2+} .

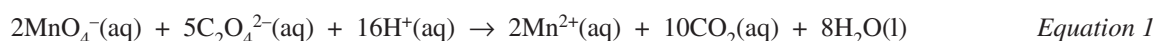
c. If reduction to MnO_2 were occurring but not being reflected in the calculations, would the calculated percent hydrogen peroxide be too high or too low as a result of this error?

The calculated percent hydrogen peroxide would be too high as a result of this error.

Supplementary Information

Standardization of Potassium Permanganate Solution

Equation 1 is the balanced chemical equation for the reaction of permanganate ions with oxalate.



- Using a milligram balance, measure 0.125 g of reagent grade sodium oxalate ($\text{Na}_2\text{C}_2\text{O}_4$) into a weighing dish.
- Using a powder funnel and quantitative transfer techniques, transfer the solid to a 125-mL Erlenmeyer flask. Use a stream of distilled water from a wash bottle to make sure all the solid is transferred to the flask.
- Add more distilled water, if necessary, to the Erlenmeyer flask to obtain a total volume of about 20 mL.
- Using a graduated cylinder, measure and add 10 mL of 3 M sulfuric acid. Swirl the flask to mix the solution.
- Add 5 drops of 1 M manganese(II) sulfate solution to the flask. (The Mn^{2+} ion acts as a catalyst for the reaction.)
- Warm the solution to about 85 °C on a hot plate.
- While the sodium oxalate solution is being heated, prepare and fill a 50-mL buret with nominal 0.025 M potassium permanganate. Record the initial buret volume of potassium permanganate solution.
- Remove the flask from the hot plate and immediately titrate the sodium oxalate solution with potassium permanganate to a pink endpoint. Record the final buret volume of potassium permanganate solution.

Teacher's Notes *continued*

Microscale Titration of Hydrogen Peroxide—A Gravimetric Procedure

1. Fill a thin-stem pipet with commercial hydrogen peroxide solution and label the pipet accordingly.
2. Measure and record the initial mass of the filled H₂O₂ pipet.
3. Fill a second pipet with potassium permanganate solution (dark purple). *Caution:* Avoid contact with skin and eyes. Measure and record the initial mass of the filled KMnO₄ pipet.
4. Record the concentration of the potassium permanganate solution. The units will be moles of KMnO₄ per gram of solution, e.g., 9.05×10^{-5} moles/g. *Note to teachers:* Prepare the standard permanganate solution by adding 1.4–1.5 g of solid KMnO₄ to a pre-weighed beaker. Measure the mass, add about 100 mL of water to the beaker, and then weigh the beaker and the contents again. Determine the concentration of the solution in units of moles of KMnO₄ per gram of solution.
5. Add 20 drops of the hydrogen peroxide solution, followed by 6 drops of 3 M sulfuric acid, to a well on a microscale reaction plate or a small test tube (13 × 100 mm).
6. Measure and record the final mass of the H₂O₂ pipet to determine how much hydrogen peroxide was used.
7. Carefully add the potassium permanganate solution dropwise to the well. Swirl or stir the solution continuously to mix the contents.
8. Continue adding the potassium permanganate solution until a faint pink color persists in the well.
9. Measure and record the final mass of the KMnO₄ pipet to determine how much potassium permanganate solution was added.
10. Repeat the experiment twice for a total of three trials. Use the same pipets, refilling them as needed. Start with new well each time.

Calculations

For each trial, calculate the:

- a. Mass of KMnO₄ solution added
- b. Number of moles of KMnO₄
- c. Number of moles of H₂O₂
- d. Mass of H₂O₂
- e. Mass percent of H₂O₂ in the commercial solution

Reference

This experiment has been adapted from *Flinn ChemTopic™ Labs, Volume 16, Oxidation and Reduction*; Cesa, I. Ed., Flinn Scientific: Batavia, IL (2004).

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Hydrogen Peroxide Analysis* activity, presented by Bob Lewis, is available in *Consumer Chemistry*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for Analysis of Hydrogen Peroxide are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Analysis of Hydrogen Peroxide—Student Laboratory Kit* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP6853	Analysis of Hydrogen Peroxide—Student Laboratory Kit
H0009	Hydrogen Peroxide, 3%, 473 mL
P0077	Potassium Permanganate, 100 g
S0415	Sulfuric Acid Solution, 6 M, 500 mL

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