TEACHER VERSION: Micro scale — How Can We Determine the Actual Percentage of H_2O_2 in a Commercial (Drugstore) Bottle of Hydrogen Peroxide?

This is a micro scale revision of the AP chemistry Guided - Inquiry Lab

Timing and Length of Investigation

20 minutes: Teacher Preparation Time

- Making solutions and gathering materials

80 minutes: Total Student Time

- 25 minutes: Pre-lab guiding questions, whole-class prelab discussion, and animation viewing
- 5 minutes: Practice with instrumentation and procedure
- 20 minutes: Investigation
- 20 minutes: Final calculations and analysis
- 10 minutes: Whole-class wrap-up discussion

This investigation can be broken into two sessions, with the standardization of the $KMnO_4$ solution occurring on the first part (Parts A and B) and the titration of the H_2O_2 solution taking place on the part(Part C).

Central Challenge

This lab has two major tasks. The first task is to standardize the concentration of a $KMnO_4$ solution. This task is necessary in order to complete the second task, which is to evaluate how close commercial H_2O_2 solutions are to their labeled concentrations. Different groups of students will work with different brands and then share their results.

Context for This Investigation

Container labels provide detailed information about the contents present in a given container. Who determines that information? Are there mechanisms taken by manufacturers to verify the information present on those labels? Also, what happens when container seals are broken? Will this have an effect on the contents present in the container? These are questions students will address in this lab.

Alignment to the AP Chemistry Curriculum

Primary Learning Objective

- Learning Objective 3.9: The student is able to design and/or interpret the results of an experiment involving a redox titration. [*See* **SP 4.2, 5.1**]

Secondary Learning Objectives

- Learning Objective 1.20: The student can design, and/or interpret data from, an experiment that uses titration to determine the concentration of an analyte in a solution. [*See* SP **4.2, 5.1, 6.4**]
- Learning Objective 3.3: The student is able to use stoichiometric calculations to predict the results of performing a reaction in the laboratory and/or to analyze deviations from the expected results. [*See* SP **2.2, 5.1**]

Skills

Prior Skills

Students should be able to:

- Evaluate the effectiveness of basic laboratory instruments including a volumetric flask, beaker, and a syringe to accurately measure volume;
- Perform a titration;
- Use stoichiometry and molarity to calculate the moles of a reactant;
- Calculate the molarity of a solution from experimental data and stoichiometric relationships;
- Calculate the percent composition of a solution; and
- Calculate percent error.

Developing Science Practices, Instrumentation, and Procedural Skills

Lab Activities	Associated Science Practice, Instrumentation, Procedure
Standardize a solution, conduct an oxidation-reduction titration	Titration procedure
Calculate the concentration of an unknown solution using oxidation–reduction titration data and stoichiometric ratios	SP 2.1: The student can *justify the selection of a mathematical routine* to solve problems. SP 2.2: The student can *apply mathematical routines* to quantities that describe natural phenomena.
Improve experimental design and critical analysis skills to analyze the H_2O_2 solutions	SP 4.2: The student can *design a plan* for collecting data to answer a particular scientific question. SP 6.1: The student can *analyze data* to identify patterns or relationships. SP 6.4: The student can *make claims and predictions about natural phenomena* based on scientific theories and models.

Preparation

Materials

The materials in the list below should be available for students to choose from while conducting their experiment. Not all materials are listed in the Student Manual, as students were told additional materials may be made available for their use. The additional items may or may not improve their experimental outcomes. To assist students with completing their experiment in the time allotted, you may wish to allocate amounts of each solution for students prior to the beginning of the lab period or have containers already labeled for students to obtain the solutions. Place the materials at one or more central locations so that students can obtain these as needed.

For each student the following is available. A class of 24 students 6 groups working in groups of 4, the following materials are needed:

5 ml Polystyrene Microbeakers beakers (Fisher Scientific) Balance Small vial of Potassium Permaganate Wash Bottle Distilled Water	10 ml Volumetric Flask for peroxide solution Dropper bottle of 6 *M* sulfuric acid (H_2SO_4) Small vials Containing Reagents	3 color coded -1 mL Syringes Red for .100 *M* ammonium iron(III)sulfate ($Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$) ($Fe^{2+}$ solution) Blue- for Potassium Permanganate Solution White-for H_2O_2 solutions Micro spatula Small 10 ml Beaker for Potassium Permanganate Solution

Prelab Preparation

The H_2O_2 solutions can be purchased from a local pharmacy or store that sells over-the-counter medications.

The Fe^{2+} solution can be prepared by dissolving 39.210 g of $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ in 500 mL distilled water in a 1000 mL volumetric flask. Dilute the solution with additional distilled water until it is brought to a final volume of 1 L. Cap the flask and mix the contents thoroughly.

The $KMnO_4$ solution is to be prepared by transferring 200 mL of 0.10 *M* $KMnO_4$ solution to a volumetric flask and adding distilled water until it is brought to a final volume of 1 L. Cap the flask and mix the contents thoroughly. Place into labeled amber vials. You can also have the students prepare the solution as an exercise of lab ware manipulation.

The H_2SO_4 solution can be prepared by adding approximately 500 mL distilled water to a 1000 mL beaker. Place the beaker in an ice bath, as the dilution of concentrated sulfuric acid is very exothermic. Slowly and while stirring, add 333.3 mL of concentrated sulfuric acid to the beaker. Allow the solution to cool to room temperature and place it in a 1000 mL volumetric flask. Add distilled water until it is brought to a final volume of 1 L. Cap the flask and mix the contents thoroughly. The solutions are placed into small dropper bottles.

Parameters of Experiment

Students are told two make two solutions

Solution 1- Weigh out .03 grams of Potassium Permanganate and place into small beaker. Dissolve the solid to the 10ml mark on the beaker.

Solution 2- Transfer 1.00 ml of provided household peroxide into 10.00 ml volumetric flask. Dilute the peroxide to the mark.

Students are told that in order to adhere to "Green Chemistry Fundamentals" and for safety precautions the maximum amount of the following solutions can be used only in your experiment

1.00 ml of Potassium Permanganate Solution

1.00 ml of .100 *M* ammonium iron(III)sulfate ($Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$) ($Fe^{2+}$ solution)

.50 ml of H_2O_2 solutions

5 drops of 6 *M* sulfuric acid (H_2SO_4)- one drop for every .10 ml of solution in beaker to be titrated up to a maximum of 5 drops.

Safety and Disposal

Students should review chemical MSDS for $KMnO_4$, 3% H_2O_2, 6 *M* H_2SO_4, and $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ prior to carrying out the experiment. Online MSDS for these chemicals are located at http://www.ehso.com/msds.php

The sulfuric acid and potassium permanganate solutions require careful handling; gloves are strongly recommended. Solid $KMnO_4$ and H_2SO_4 are not to be mixed, as an explosion could result. Proper ventilation is essential. Both solutions can cause skin burns and eye damage. Teachers and students should take normal laboratory precautions, including wearing splash-proof goggles and aprons at all times. If solutions are spilled on skin, wash those areas immediately with copious amounts of water. Review local and/or state guidelines and specific procedures regarding the disposal of laboratory chemicals and waste materials.

Students are given the following

Standard Electrode (Reduction) Potentials in Aqueous Solution at 25 °C

Reduction Half–Reaction	Standard Potential, E°(V)
Acid Solution	
$F_2(g) + 2e^- \rightarrow 2F^-(aq)$	2.86
$OF_2(g) + 2H^+(aq) + 4e^- \rightarrow H_2O(l) + 2F^-(aq)$	2.1
$O_3(g) + 2H^+(aq) + 2e^- \rightarrow O_2(g) + H_2O(l)$	2.075
$S_2O_8^{2-}(aq) + 2e^- \rightarrow 2SO_4^{2-}(aq)$	2.01
$Ag^{2+}(aq) + e^- \rightarrow Ag^+(aq)$	1.98
$Co^{3+}(aq) + e^- \rightarrow Co^{2+}(aq)$	1.82
$H_2O_2(aq) + 2H^+(aq) + 2e^- \rightarrow 2H_2O(l)$	1.763
$MnO_4^-(aq) + 4H^+(aq) + 3e^- \rightarrow MnO_2(s) + 2H_2O(l)$	1.70
$PbO_2(s) + SO_4^{2-}(aq) + 4H^+(aq) + 2e^- \rightarrow PbSO_4(s) + 2H_2O(l)$	1.69
$Au^{3+}(aq) + 3e^- \rightarrow Au(s)$	1.52
$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightarrow Mn^{2+}(aq) + 4H_2O(l)$	1.51
$2BrO_3^-(aq) + 12H^+(aq) + 10e^- \rightarrow Br_2(l) + 6H_2O(l)$	1.478
$PbO_2(s) + 4H^+(aq) + 2e^- \rightarrow Pb^{2+}(aq) + 2H_2O(l)$	1.455

$ClO_3^-(aq) + 6\ H^+(aq) + 6\ e^- \rightarrow Cl^-(aq) + 3\ H_2O(l)$	1.450
$Ce^{4+}(aq) + e^- \rightarrow Ce^{3+}(aq)$	1.44
$Au^{3+}(aq) + 2\ e^- \rightarrow Au^+(aq)$	1.36
$Cl_2(g) + 2\ e^- \rightarrow 2\ Cl^-(aq)$	1.358
$Cr_2O_7^{2-}(aq) + 14\ H^+(aq) + 6\ e^- \rightarrow 2\ Cr^{3+}(aq) + 7\ H_2O(l)$	1.33
$MnO_2(s) + 4\ H^+(aq) + 2\ e^- \rightarrow Mn^{2+}(aq) + 2\ H_2O(l)$	1.23
$O_2(g) + 4\ H^+(aq) + 4\ e^- \rightarrow 2\ H_2O(l)$	1.229
$2\ IO_3^-(aq) + 12\ H^+(aq) + 10\ e^- \rightarrow I_2(s) + 6\ H_2O(l)$	1.20
$ClO_4^-(aq) + 2\ H^+(aq) + 2\ e^- \rightarrow ClO_3^-(aq) + H_2O(l)$	1.19
$ClO_3^-(aq) + 2\ H^+(aq) + e^- \rightarrow ClO_2(g) + H_2O(l)$	1.175
$NO_2(g) + H^+(aq) + e^- \rightarrow HNO_2(aq)$	1.07
$Br_2(l) + 2\ e^- \rightarrow 2\ Br^-(aq)$	1.065
$NO_2(g) + 2\ H^+(aq) + 2\ e^- \rightarrow NO(g) + H_2O(l)$	1.03
$[AuCl_4]^-(aq) + 3\ e^- \rightarrow Au(s) + 4\ Cl^-(aq)$	1.002
$VO_2^+(aq) + 2\ H^+(aq) + e^- \rightarrow VO^{2+}(aq) + H_2O(l)$	1.000
$NO_3^-(aq) + 4\ H^+(aq) + 3\ e^- \rightarrow NO(g) + 2\ H_2O(l)$	0.956
$2\ Hg^{2+}(aq) + 2\ e^- \rightarrow Hg_2^{2+}(aq)$	0.90
$Cu^{2+}(aq) + I^-(aq) + e^- \rightarrow CuI(s)$	0.86
$Hg^{2+}(aq) + 2\ e^- \rightarrow Hg(l)$	0.854
$Ag^+(aq) + e^- \rightarrow Ag(s)$	0.800
$Hg_2^{2+}(aq) + 2\ e^- \rightarrow 2\ Hg(l)$	0.80
$Fe^{3+}(aq) + e^- \rightarrow Fe^{2+}(aq)$	0.771
$O_2(g) + 2\ H^+(aq) + 2\ e^- \rightarrow H_2O_2(aq)$	0.695
$2\ HgCl_2(s) + 2\ e^- \rightarrow Hg_2Cl_2(s) + 2\ Cl^-(aq)$	0.63
$MnO_4^-(aq) + e^- \rightarrow MnO_4^{2-}(aq)$	0.56
$I_2(s) + 2\ e^- \rightarrow 2\ I^-(aq)$	0.535

 

$Cu^{+}(aq) + e^{-} \rightarrow Cu(s)$	0.520
$H_2SO_3(aq) + 4\ H^{+}(aq) + 4\ e^{-} \rightarrow S(s) + 3\ H_2O(l)$	0.449
$C_2N_2(g) + 2\ H^{+}(aq) + 2e^{-} \rightarrow 2\ HCN(aq)$	0.37
$[Fe(CN)_6]^{3-}(aq) + e^{-} \rightarrow [Fe(CN)_6]^{4-}(aq)$	0.361
$Cu^{2+}(aq) + 2\ e^{-} \rightarrow Cu(s)$	0.340
$VO^{2+}(aq) + 2\ H^{+}(aq) + e^{-} \rightarrow V^{3+}(aq) + H_2O(l)$	0.337
$PbO_2(s) + 2\ H^{+}(aq) + 2\ e^{-} \rightarrow PbO(s) + H_2O(l)$	0.28
$HgCl_2(s) + 2\ e^{-} \rightarrow Hg(l) + 2\ Cl^{-}(aq)$	0.2676
$HAsO_2(aq) + 3\ H^{+}(aq) + 3\ e^{-} \rightarrow As(s) + 2\ H_2O(l)$	0.240
$AgCl(s) + e^{-} \rightarrow Ag(s) + Cl^{-}(aq)$	0.2223
$SO_4^{2-}(aq) + 4\ H^{+}(aq) + 2\ e^{-} \rightarrow SO_2(g) + 2\ H_2O(l)$	0.17
$Cu^{2+}(aq) + e^{-} \rightarrow Cu^{+}(aq)$	0.159
$Sn^{4+}(aq) + 2\ e^{-} \rightarrow Sn^{2+}(aq)$	0.154
$S(s) + 2\ H^{+}(aq) + 2\ e^{-} \rightarrow H_2S(g)$	0.14
$AgBr(s) + e^{-} \rightarrow Ag(s) + Br^{-}(aq)$	0.071
$2\ H^{+}(aq) + 2\ e^{-} \rightarrow H_2(g)$	0.00
Fe3+(aq) + 3 e– → Fe(s)	–0.04
Pb2+(aq) + 2 e– → Pb(s)	–0.125
Sn2+(aq) + 2 e– → Sn(s)	–0.137
AgI(s) + e– → Ag(s) + I –(aq)	–0.152
V3+(aq) + e– → V2+(aq)	–0.255
Ni2+(aq) + 2 e– → Ni(s)	–0.257
H3PO4(aq) + 2 H+(aq) + 2 e– → H3PO3(aq) + H2O(l)	–0.276
Co2+(aq) + 2 e– → Co(s)	–0.277
PbSO4(s) + 2 e– → Pb(s) + SO42–(aq)	–0.356
Cd2+(aq) + 2 e– → Cd(s)	–0.403

$Cr^{3+}(aq) + e^- \rightarrow Cr^{2+}(aq)$	–0.424
$Fe^{2+}(aq) + 2\ e^- \rightarrow Fe(s)$	–0.440
$2\ CO_2(g) + 2\ H^+(aq) + 2\ e^- \rightarrow H_2C_2O_4(aq)$	–0.49
$Cr^{3+}(aq) + 3\ e^- \rightarrow Cr(s)$	–0.74
$Zn^{2+}(aq) + 2\ e^- \rightarrow Zn(s)$	–0.763
$Cr^{2+}(aq) + 2\ e^- \rightarrow Cr(s)$	–0.90
$Mn^{2+}(aq) + 2\ e^- \rightarrow Mn(s)$	–1.18
$Ti^{2+}(aq) + 2\ e^- \rightarrow Ti(s)$	–1.63
$U^{3+}(aq) + 3\ e^- \rightarrow U(s)$	–1.66
$Al^{3+}(aq) + 3\ e^- \rightarrow Al(s)$	–1.676
$Mg^{2+}(aq) + 2\ e^- \rightarrow Mg(s)$	–2.356
$Na^+(aq) + e^- \rightarrow Na(s)$	–2.713
$Ca^{2+}(aq) + 2\ e^- \rightarrow Ca(s)$	–2.84
$Sr^{2+}(aq) + 2\ e^- \rightarrow Sr(s)$	–2.89
$Ba^{2+}(aq) + 2\ e^- \rightarrow Ba(s)$	–2.92
$Cs^+(aq) + e^- \rightarrow Cs(s)$	–2.923
$K^+(aq) + e^- \rightarrow K(s)$	–2.924
$Rb^+(aq) + e^- \rightarrow Rb(s)$	–2.924
$Li^+(aq) + e^- \rightarrow Li(s)$	–3.04

Prelab Guiding Questions/Simulations

Prelab Part I

The prelab assessment is designed to be completed by students independently or in small groups as they read the Explanation to Strengthen Student Understanding section. It will prepare them for developing their own procedure, analyzing their data, and performing lab calculations. After students complete the prelab assessment, their individual or small group responses should be discussed with the entire class.

You may wish to have students work on these questions for homework so that time in class can be spent solely on discussion. Depending on what content has been covered prior to this lab, you may choose to give students skeleton half-reactions to balance for Questions 2–6. If you choose to do this, Question 7 is recommended for in-class discussion only. If reduction potentials have been studied, you may elect to have students use a table of standard reduction potentials to answer Questions 2–7.

1. What measuring devices are used to obtain precise measurements of volumes? What measuring devices are used to obtain approximate measurements of volumes?

[Student answer: volumetric flasks, volumetric pipettes, graduated pipettes; beakers, Erlenmeyer flasks, dropping pipettes]

2. Write a balanced half-reaction for the reduction of permanganate ions in acidic solution. What are the oxidation states of manganese in this reaction?

[Student answer: $MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightarrow Mn^{2+}(aq) + 4H_2O(l)$; Mn is +7 in MnO_4^- and +2 in Mn^{2+}]

3. Write a balanced half-reaction for the oxidation of hydrogen peroxide. What are the oxidation states of oxygen in this reaction?

[Student answer: $H_2O_2(aq) \rightarrow O_2(g) + 2H^+(aq) + 2e^-$; O is -1 in H_2O_2 and 0 in O_2.]

4. What is the balanced reaction for the reduction of permanganate ions by hydrogen peroxide? How many electrons are transferred in this reaction?

[Student answer: $2MnO_4^-(aq) + 5H_2O_2(aq) + 6H^+(aq) \rightarrow 2Mn^{2+}(aq) + 5O_2(g) + 8H_2O(l)$; 10 electrons are transferred]

5. Write a balanced half-reaction for the oxidation of iron (II) ions.

[Student answer: $Fe^{2+}(aq) \rightarrow Fe^{3+}(aq) + e^-$]

6. Write a balanced half-reaction for the reduction of permanganate ions by iron (II) ions. How many electrons are transferred in this reaction?

[Student answer: $MnO_4^-(aq) + 5Fe^{2+}(aq) + 8H^+(aq) \rightarrow Mn^{2+}(aq) + 5Fe^{3+}(aq) + 4H_2O(l)$; 5 electrons are transferred]

7. Besides iron (II) ions and hydrogen peroxide, what are one or two other species that could be used to reduce permanganate ions?

[Student answer: $H_2C_2O_4$, oxalic acid; halides, Cl^-, Br^-, I^-; sulfites, SO_3^{2-}]

8. A sample of oxalic acid, $H_2C_2O_4$, was analyzed using a standardized solution of $KMnO_4$. 25.0 mL of oxalic acid is titrated after heating. 12.30 mL of a 0.0226 M $KMnO_4$ was added to the sample when a faint pink color was observed. The balanced equation for this reaction is shown below:

$$6\ H^+(aq) + 2\ MnO_4^-(aq) + 5\ H_2C_2O_4(aq) \rightarrow 10\ CO_2(g) + 8\ H_2O(l) + 2Mn^{2+}(aq)$$

a. What is the ratio of MnO_4^- ions to $H_2C_2O_4$ molecules in this reaction?

b. How many moles of MnO_4^- ions reacted with the given amount of oxalic acid solution?

c. How many moles of $H_2C_2O_4$ were present?

d. What was the molarity of the oxalic acid solution?

e. If the density of the oxalic acid solution was 1.00 g/mL, what was the percentage by mass of oxalic acid in the solution?

f. What does the faint pink color indicate about the reaction?

[Student answers:

a. 2 MnO_4^-: 5 $H_2C_2O_4$

b. 2.78×10^{-3} mol

c. 6.95×10^{-3} mol

d. 0.278 *M*

e. 2.39%

f. The end point of the reaction has been reached, and the volume of $KMnO_4$ added is assumed to be the volume required to reach the equivalence point.]

 

Prelab Part II-" Framing the Lab"

This animation will help students see the importance of taking care in adding the minimum amount of titrant to the analyte being examined. It will also give them an opportunity to practice stoichiometric calculations used in the experiment.

The “Redox Titration in Acidic Medium” is animated at the following website:

http://group.chem.iastate.edu/Greenbowe/sections/projectfolder/flashfiles/redoxNew/redox.html

Students will be asked to respond to the following questions prior to viewing the simulation using $KMnO_4$ as the oxidizing agent and Fe^{+2} as the reducing agent and again afterward:

1. In your own words, what are the physical and chemical changes that will occur in the system as the titration is performed?
2. How much ~0.02 *M* $KMnO_4$ solution should be needed if the solutions tested have a composition of 3% H_2O_2 by mass?

Explanation to Strengthen Student Understanding

Hydrogen peroxide, H_2O_2, is easily oxidized. It is used in commercial bleaching processes and in wastewater treatment plants as an environmentally friendly alternative to chlorine. Dilute solutions of H_2O_2 are used to bleach hair and to clean wounds. It readily decomposes in the presence of light, heat, or metallic catalysts into water and oxygen. It is important to know the actual concentration of a solution of H_2O_2 as its effectiveness can decrease with smaller concentrations.

Oxidation–reduction (redox) reactions involve a transfer of electrons between the species being oxidized and the species being reduced. The reactions are often balanced by separating the reaction components into two half-reactions: *oxidation* (loss of electrons) and *reduction* (gain of electrons). In a redox reaction, the number of electrons lost by the species being oxidized is always equal to the number of electrons gained by the species being reduced. In the reaction being studied in this lab, solutions of hydrogen peroxide, H_2O_2, and potassium permanganate, $KMnO_4$, will be combined in acidic solution. Deep purple in solution, the Mn in $KMnO_4$ undergoes reduction very easily. In acidic solution, permanganate ions (MnO_4^-) from $KMnO_4$ reduce to nearly colorless Mn^{2+} ions. In the presence of permanganate ions in acidic solution, an aqueous solution of H_2O_2 will undergo oxidation to make oxygen gas and hydrogen ions.

Solutions of $KMnO_4$ are not easily standardized solely by preparation, as solid $KMnO_4$ often contains impurities such as chlorides, sulfates, and nitrates. $KMnO_4$ can be standardized in acidic solution with a known concentration of iron (II) ions. In this oxidation–reduction reaction, manganese (II) ions and iron (III) ions are formed.

Practice with Instrumentation and Procedure

Students should have completed the following Structured Inquiry Lab first:

THE PREPARATION AND STANDARDIZATION OF A 0.1M HCl SOLUTION

See PWISTA APSI LAb Manual for details. Students will have mastered the use of micro scale titrations using syringes in order to complete the structures inquiry lab.

Part A. For the first 15 minutes, students will:

- develop a procedure that will allow them to determine the concentration of the $KMnO_4$ solution;
- collect qualitative and quantitative data that will allow them to determine the concentration of the $KMnO_4$ solution; and
- determine the concentration of the $KMnO_4$ solution.

They will do this using:

- .10 mL of $KMnO_4$ solution that is added in small portions to a .15 mL sample of an acidified 0.100 *M* Fe^{2+} solution;
- .10 mL or less of 6 *M* H_2SO_4 solution is to be added in order to acidify the solution; and
- any of the equipment made available for the lab to collect their data.

The students will then have 1 minute to present their description and reported concentration to the class.

[Student answer: 0.100 M acidified Fe^{2+} solution is light yellow in color. As small amounts of $KMnO_4$ are added, parts of the solution turn a deep red. With stirring, the red color disappears and the solution returns to a light yellow shade. Additional amounts of $KMnO_4$ result in the red color lasting longer but with it still disappearing over time. Eventually, the solution turns pink upon the addition of $KMnO_4$. Additional amounts of $KMnO_4$ deepen the pink, eventually turning the entire solution a deep red color.]

Major errors include adding too little or too much MnO_4^- solution, which will lead to $KMnO_4$ being standardized incorrectly. These issues will need to be addressed in their procedure revisions. Other sources of error include inaccurate measurements and not mixing thoroughly between MnO_4^- additions. Students may also need assistance in determining the concentration of $KMnO_4$ solution, as not all students may account for the stoichiometric ratio of $KMnO_4$ to Fe^{2+} from the balanced equation.

Once students have completed their presentations, ask them questions that will help to develop titration vocabulary. For example, “What did you need to determine the concentration of the $KMnO_4$ solution?” and “What would happen if you didn’t know the quantity of Fe^{2+} solution used?” Assist students in recognizing they have performed an oxidation–reduction titration (method used to determine the exact concentration or amount of a reactant that is used to consume another reactant) by using a titrant (standardized solution of one reactant) to analyze an analyte (reactant of unknown quantity or concentration). Have students identify the titrant and analyte in Part A of their experiment.

Part B. After the presentation discussion, students are to complete the *first part* of the central challenge by designing a procedure in groups of 2 or 3 that will enable them to more accurately standardize the $KMnO_4$ solution. The procedures are to be teacher-reviewed before being conducted. Any additional changes to the procedure also need to be teacher-reviewed.

As students are discussing how to modify their procedure from Part A, listen to their discussions to see if they have identified the major areas of concern. If they have not considered changing how the MnO_4^- solution is added, ask questions that will help them to address those issues. For example, “What measuring device did you use to measure the titrant?” “What caused the molarity of the permanganate solution to be determined incorrectly?” “When do you know that the reaction is completed?” and “How can you change your procedure to account for the reaction’s completion at any volume?”

If you do not have one or more of the materials listed, let students know before they redesign their procedures. Be sure to let students know they are not expected to use all of the available equipment. Tell students the volumes of solutions they will be provided and that they should keep in mind the importance of repeated trials when designing their procedures.

Investigation

Procedure

All of the $KMnO_4$ standardization testing is to be completed before students begin the *second part* of the central challenge: analyzing the H_2O_2 solutions. Students may wish to use the procedure developed to standardize the $KMnO_4$ solution while designing the procedure to analyze the H_2O_2 solutions. Each group should be given two different H_2O_2 solutions to titrate. Students should share their data with each other to obtain additional data for the various H_2O_2 solutions and to compare their results.

The solution of hydrogen peroxide is assumed to be approximately 3%. If students are using hydrogen peroxide solution greater than 3%, you may want them to adjust this ratio. Students may want to do a preliminary test to get an estimate of the ratio of MnO_4^- to H_2O_2. If students develop procedures that include large volumes of H_2O_2, you may wish to remind them of their solution allocations. Also all H_2O_2 measurements need to be performed in one day.

The prelab assessment gives students an opportunity to perform calculations that will be used to analyze their data. The actual lab calculations are not specified further because it is desired that students determine how to do these calculations based on this information. If students struggle with the calculations, refer them to the prelab assessment and Part A of the lab for assistance. Students who are successful in this investigation should have percent error values of 10% or less.

Data Collection and Computation

1. Calculate the moles of $KMnO_4$ solution needed to react with all of the 0.100 *M* $Fe(NH_4)_2(SO_4)_2$ solution for each trial.

[Student answer: moles $KMnO_4$ = volume (L) Fe^{2+} titrated x 0.100 M Fe^{2+} x 1 mol $KMnO_4$/5 mol Fe^{2+}] or [0.0100 L Fe^{2+} x 0.100 M Fe^{2+} x 1 mol $KMnO_4$/5 mol Fe^{2+} = 0.000200 moles $KMnO_4$]

2. Calculate the molarity of the $KMnO_4$ solution for each trial.

[Student answer: *M* $KMnO_4$ = moles $KMnO_4$/volume (L) $KMnO_4$ titrated or 0.000200 mol $KMnO_4$/0.01100 L = 0.0182 *M*]

3. Calculate the average molarity of the $KMnO_4$ solution.

[Student answer: average *M* $KMnO_4$ = sum of *M* $KMnO_4$ from each trial/total number of trials or {0.0182 *M* + 0.0188 *M* + 0.0193 *M*)/3 = 0.0188 *M*]

4. Calculate the moles and mass of H_2O_2 titrated for each trial.

[Student answer: moles H_2O_2 = volume (L) $KMnO_4$ titrated × 0.02× *M* $KMnO_4$ ×5 mol H_2O_2/2 mol $KMnO_4$], [mass H_2O_2 = moles H_2O_2 ×34.02 g/mol or 0.0325 L $KMnO_4$ × 0.0188 *M* $KMnO_4$×5 mol H_2O_2/2 mol $KMnO_4$ = 0.00153 mol H_2O_2], [0.00153 mol H_2O_2× 34.02 g/mol = 0.0520 g H_2O_2]

5. If the density of the H_2O_2 solution titrated was 1.00 g/mL, calculate the percentage of H_2O_2 in solution in each trial.

[Student answer: % H_2O_2 = mass H_2O_2/volume (mL) H_2O_2 titrated ×100 or 0.0520 g/1.70 mL × 100 = 3.06%]

6. Calculate the average percentage of the H_2O_2 solution.

[Student answer: average % H_2O_2 = sum of % H_2O_2 from each trial/total number of trials or (3.06% + 3.10% + 3.02%)/3 = 3.06%]

Sample Student data

	Trial 1
Mass of Potassium Permanganate	**.0355 g**
Volume of Solution	**10.00 ml**
Volume of Potassium Permanganate Titrant	**.190 ml**
Volume of .100 M Fe+2	**.200 ml**
Drops of Sulfuric Acid	**2 drops**
Concentration of Potassium Permanganate	**.021 M**

Volume of Diluted Peroxide Analyte	**.500 ml**
Drops of Sulfuric Acid	**5 drops**
Volume of Potassium Permanganate Titrant	**.970 ml**
Molarity of Diluted Peroxide Solution	**.101 M**
Molarity of House hold peroxide	**1.01 M**
% Peroxide	**3.32 %**

Argumentation and Documentation

1. Are your average values higher or lower than the reported values of the H_2O_2 you tested? What are the likely causes of any errors? Justify your explanations. Be sure to discuss any data values that are outliers.

[Student answer: If values are too low, $KMnO_4$ standardization may have been too low or not all of H_2O_2 was titrated; if values are too high, $KMnO_4$ standardization may have been too high or the H_2O_2 titration was carried out beyond its equivalence point (the pink color was too dark]

2. Why and how did you modify your procedure and materials from Part A? How did these modifications impact your data and/or your calculations?

[Student answer: will vary depending on student modifications]

3. New dietary supplements do not undergo the same rigorous approval process as new medications. You performed a redox titration to determine the percentage of a component in a dietary supplement and in a medication. When you performed repeated trials, your percentages varied widely for the supplement but were very consistent for the medication. Why do you think this happened?

[Student answer: The amount of the component was inconsistent from sample to sample, while the amount in the medication was precise regardless of sample selection.]

Postlab Assessment

If a table of standard reduction potentials has not been studied by the time this lab is completed, Questions 3 and 4 should either be discussed as a class or omitted.

1. What is a titrant? What is an analyte?

[Student answer: A titrant is a standardized solution of a reactant. An analyte is another reactant whose precise concentration has yet to be determined.]

2. In this lab, did a substance serve as both a titrant and an analyte? If so, what was this substance. Support your answer.

[Student answer: Yes. $KMnO_4$. If the concentration of the analyte is determined precisely in one titration, it can then be used as a titrant in another titration.]

3. What might have been the product(s) in the original solution if it had remained neutral (the solution was not acidified with H_2SO_4)? How could you determine this?

[Student answer: Fe^{3+} and MnO_2. A dark solid would form in the solution.]

4. What might have been the product(s) in the original solution if it was alkaline? How could you determine this?

[Student answer: Same as Answer 3]

5. How would the concentrations of the $KMnO_4$ and the H_2O_2 solutions have been affected if the following observations were made about the cup? Justify your answers.

a. When the titration was completed, the cup was colorless.

  a. [Student answer (a): The concentration would have been too low, as the endpoint of the reaction had not been reached and not all of the analyte had been consumed by the titrant.]

b. When the titration was completed, the cup was dark red or purple.

[Student answer (b): The concentration would have been too high, as the endpoint of the reaction would have been exceeded, resulting in a larger amount of calculated analyte than was actually present.]

Connecting the Lab to the Classroom and Beyond

This investigation is related to several topics, including oxidation–reduction reactions and solution stoichiometry. Ideally, it would be performed while students are studying either of these topics. The experiment will enable students to master stoichiometry problems involving molarity or percent composition by mass.

Extension Activity

A quantitative problem using the concepts explored in this lab is described below:

Ethanol, CH_3CH_2OH, is oxidized in an acidic solution of potassium dichromate, $K_2Cr_2O_7$, to ethanoic acid, CH_3COOH. Chromium in the dichromate ion is reduced to Cr^{3+}. The balanced reaction for the redox reaction is: $3CH_3CH_2OH + 2Cr_2O_7^{2-} + 16\ H^+ \rightarrow 3CH_3COOH + 4Cr^{3+} + 11H_2O$. 10.0 mL of an aqueous ethanol solution is titrated with 0.500 M $K_2Cr_2O_7$. 22.6 mL of the $K_2Cr_2O_7$ solution was needed to react completely with the ethanol solution. What is the molarity of the ethanol solution? If the density of the ethanol solution was 1.00 g/mL, what percentage by mass of the solution is ethanol?

[Student answer: 1.70 *M*, 7.81%]

Also, have students draw pictures of what happens when $KMnO_4$ is placed into solution, when it reacts with acidified Fe^{2+} ions, and when it reacts with H_2O_2. These pictures can be used to gauge student comprehension of solution stoichiometry on the particulate level.

Other chemistry content that has connections to this experiment includes acid-base chemistry, as it uses solution stoichiometry, and stoichiometry involving limiting reactants, as the analyte limits the reaction in the redox titration. A subsequent experiment students could perform would be an acid-base titration. Students could then compare and contrast both reaction types and their titrations, along with any related calculations. Additionally, students could perform a gravimetric analysis lab and evaluate the types of calculations performed in it with the two titration labs.

Follow-up Experiment

Hydrogen peroxide solutions are often used periodically in households, with some solutions being opened and not used again for months. Students could test solutions that had been opened and then closed for various intervals of time in order to determine if these events result in a change in their composition.

To examine their experimental design, students could further dilute the concentration of hydrogen peroxide solution used in the titration to collect data about how changes in amounts affect both their observations and calculations. Additionally, students could compare results from the original investigation to this modified procedure and evaluate both advantages and disadvantages.

Another redox titration involves students using conducting the sodium hypochlorite/iodide/thiosulfate reaction to determine the percentage of hypochlorite ions in a solution of bleach. Students would need to explore how quantities of bleach would affect the titration and consider that undiluted samples of the analyte might not always be the limiting reactant.

Students could investigate the thermodynamics involved with the decomposition of hydrogen peroxide by conducting a calorimetry investigation. It would serve to show that the peroxide forms different products when reacted with an oxidizing agent than when it simply decomposes.

Supplemental Resources

[B]Links

"Chemistry Tutorial: Redox." Ausetute. Accessed July 29, 2012. http://www.ausetute.com.au/redoxtitr.html

Chieh, Chung. "Solutions Stoichiometry." University of Waterloo. Accessed July 29, 2012. http://www.science.uwaterloo.ca/~cchieh/cact/c120/sltnstoich.html

"Redox Titration an Animation." Journal of Chemical Education. Accessed July 29, 2012. http://www.jce.divched.org/JCESoft/CCA/CCA3/MAIN/TITREDO/PAGE1.HTM

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Rees, Thomas. "The Stability of Potassium Permanganate Solutions." *Journal of Chemical Education* 64, no. 12 (1987):1058.

Webb, Michael J. "Aqueous Hydrogen Peroxide: Its Household Uses and Concentration Units." *Journal of Chemical Education* 62, no. 2 (1985):152.

Worley, John D. "Hydrogen Peroxide in Cleansing Antiseptics." *Journal of Chemical Education* 60, no. 8 (1983): 678.

Young, J. A. "Hydrogen Peroxide, 3%." *Journal of Chemical Education* 80, no. 11, (2003): 1132.

Young, J. A. "Potassium Permanganate." *Journal of Chemical Education* 80, no. 8 (2003): 873.