Titration Probe

Overview

Description

In this assignment, students will apply the concepts of conductivity and equivalence point to an acid-base reaction. Students will then determine the concentration in molarity of an unknown $Ba(OH)_2$ solution.

Students will first use probeware to collect data as they perform a titration of barium hydroxide with sulfuric acid. They will use the data to support the location of the equivalence point of the reaction between sulfuric acid and barium hydroxide. Using this value and the concentration of the original 0.010 M H_2SO_4 solution, they will determine the molarity of the $Ba(OH)_2$ solution. Finally, they will calculate their percent error and use it to determine the number of moles of Ba^{2+} ions that reacted with SO_4^{2-} ions and with dissolved CO_2.

Final Product: Students will produce a formal laboratory report that includes the following: a title page, an abstract, a materials list, and an explanation of the procedure, results, and conclusions of the laboratory activity. Reports should include any relevant data tables and graphs, as well as written answers to the questions in the Getting Started, Investigating, and Drawing Conclusions sections.

Subject

Chemistry, Chemistry II

Task Level

Grade 10-12

Objectives

Students will:

- Discuss and understand how titrations are used in the preparation and analysis of a wide variety of solutions.
- Set up equipment to collect appropriate data during a chemical reaction.
- Conduct a titration of a barium hydroxide solution with a sulfuric acid solution
- Identify the types and the products of a chemical reaction.
- Determine the equivalence point of an acid-base reaction.

- Locate the equivalence point of a chemical reaction on a graph of conductivity data.
- Locate the equivalence point of a chemical reaction on a graph of pH data.
- Determine the concentration in molarity of the barium hydroxide solution.
- Calculate the percentage error when given the actual concentration of the barium hydroxide solution.
- Calculate the number of moles of Ba^{2+} ions that did not combine with SO_4^{2-} ions.
- Predict what may have happened to the missing Ba^{2+} ions.
- Prepare a formal laboratory report.

Preparation

- Read the Instructor Task Information and the Student Notes.
- Prepare copies of the Student Notes.
- Check that any LabPro® or CBL 2™ interfaces, graphing calculators, and computers to be used by students are in working order and are loaded with the proper software. You may also want to calibrate the probeware in advance.
- Prepare enough of a 0.010 M solution of barium hydroxide, $Ba(OH)_2$, so that each student or team of students can use 50.0 mL for each trial you want them to complete. To prepare a 0.010 M $Ba(OH)_2$ solution, dissolve 3.155 g $Ba(OH)_2 \cdot 8H_2O$ in distilled water to make 1.00 L of solution. Filter the solution the day of the lab because Ba^{2+} ions will combine with dissolved CO_2, causing the precipitation of barium carbonate, $BaCO_3$. Some precipitate may still remain, but shaking the solution will allow students to use a homogeneous mixture for reliable results.
- Prepare enough of a 0.020 M solution of sulfuric acid, H_2SO_4, so that each student or team of students can use up to 25.0 mL for each trial you want them to complete. **CAUTION:** *H_2SO_4 is a strong acid. Add acid to a large volume of water while stirring to dilute. The dilution process is highly exothermic.* To prepare a 0.020 M H_2SO_4 solution, first prepare a 0.200 M H_2SO_4 solution by adding 11.1 mL of concentrated (18.0 M) H_2SO_4 to distilled water to make 1.00 L of solution. Then, dilute 100.0 mL of the 0.200 M H_2SO_4 solution into distilled water to make 1.00 L of solution. You can standardize the H_2SO_4 solution (determine its exact molarity) by titration with a standard solution of sodium hydroxide, NaOH, or you can have students assume the H_2SO_4 solution is exactly a 0.020 M solution. This will provide consistent results, but the actual concentration of the $Ba(OH)_2$ may deviate slightly from the value obtained by the students.

- Place the lab equipment and solutions in an accessible area of the laboratory. Materials needed per student or per team include: safety goggles; lab apron; 0.020 M H_2SO_4 solution; two 250-mL beakers; 0.010 M $Ba(OH)_2$ solution; 100-mL graduated cylinder; buret; funnel; buret clamp; ring stand; magnetic stirrer and stirring bar; conductivity probe; pH sensor; LabPro® or CBL 2™ interface; graphing calculator; two utility clamps; distilled water; and wash bottle.

Prior Knowledge

- Students must know the proper procedures for handling lab equipment and hazardous chemicals safely and for responding to chemical spills.
- Students must have an understanding of ionic solutions, acids and bases, pH, types of chemical reactions, neutralization reactions, chemical equivalence, the mole concept, solutions, net ionic equations, stoichiometry, and how to write balanced chemical equations.
- Students must have a working knowledge of how to use probeware and a graphing calculator or a computer to collect data.
- Students must have a working knowledge of how to set up a titration.

Key Concepts and Terms

- Acid
- Base
- Conductivity
- Equivalence point
- Ion
- Ionic solution
- Neutralization
- pH
- Precipitate
- Titration

Time Frame

This activity should take approximately two hours of in-class time and two to three hours outside of class. Provide up to three 45-minute periods for completing the lab activity part of this assignment during class. Students may complete the analysis of data and generation of the lab report outside of class. This assignment can be modified to meet the needs of different classroom schedules and student ability levels.

Instructional Plan

Getting Started

Learning Objectives

Students will:

- Discuss and understand how titrations are used in the preparation and analysis of a wide variety of solutions.
- Set up equipment to collect appropriate data during a chemical reaction.

Procedure

1. Introduce the assignment to students, and briefly summarize the lab procedures they will be using. Explain that students will fill a buret with a sulfuric acid solution and use it to determine the concentration of the barium hydroxide solution. Also tell students that they will be using probeware, a LabPro® or CBL 2™ interface, and a graphing calculator or computer for data collection.
2. Conduct a class discussion about acids, bases, and acid-base reactions, about the purpose of a titration, and about ionic solutions and stoichiometry. Be sure students understand the meanings of key concepts and terms listed above.
3. Divide the class into teams of two or three students. Encourage team members to work collaboratively and to decide which tasks each team member will be responsible for before they begin the activity. Require team members to perform a different task each time the lab activity is repeated. If there is time for only one titration, be sure team members take turns performing the different tasks involved in the lab activity.
4. Make sure all students wear safety goggles and lab aprons throughout the lab activity. Also, monitor for safety hazards as students conduct the titration.
5. Have students gather all the lab equipment and solutions needed for the lab activity from the designated area of the laboratory.
6. Model the correct use of a buret, including an initial rinse and removing air from the buret tip, as described below:
   a. Pour approximately 60 mL of a 0.02 M H_2SO_4 solution into a 250-mL beaker.
   b. Attach a 50-mL buret to a ring stand, using a buret clamp.
   c. Use a funnel to pour a few milliliters of the H_2SO_4 solution into the buret to rinse it.

d. Fill the buret to just above the 0.00-mL level. Then, use the stopcock to drain a small amount of the H_2SO_4 solution, so that it fills the buret's tip and leaves the H_2SO_4 at the 0.00-mL level. Direct students on how to dispose of the waste H_2SO_4 solution.

7. Read the initial volume of H_2SO_4 in the buret and record to the nearest 0.01 mL.

8. Before students fill the buret with the sulfuric acid solution, tell them that it is *not* necessary for them to start exactly at 0.00 mL for the titration to be successful. Explain that they must keep the starting value in mind when they enter the volume values as the titration proceeds.

9. When students measure 50.0 mL of $Ba(OH)_{2,}$ it is important that they measure accurately and precisely. They can rinse the graduated cylinder with distilled water and add the rinse to the beaker to make sure all of the solution is used.

10. Tell students that they may be asked for calibration data when setting up the data collection device for use with a conductivity probe. If using Vernier probes, explain that the conductivity calibration is in the programming of the interface, so students will need to use the stored information to calibrate.

11. When using a pH sensor, they should be calibrated. Explain that students will use the stored pH calibration in the interface program if using Vernier sensors. Emphasize that they must check the pH sensor first by placing it in a pH-7.0 buffer and that the reading must be a value close to 7.0. If the reading is pH 7.0, have students use the stored calibration for the lab activity.

    If the reading is not pH 7.0, or for better results, have students use pH-4.0 and pH-7.0 buffers to calibrate the pH sensor. Students must select Set-up from the main screen, select the channel the pH sensor is plugged into, select the pH sensor, and then select Calibrate. From the calibration menu, they must select Calibrate Now. If using other pH sensors, they must calibrate as indicted by the manufacturer.

    a. First Calibration: Rinse the pH sensor with distilled water, and place the pH sensor into the pH 4.0 buffer. Wait for the display to stabilize, and select Enter. Key in 4.0 as the pH value.

    b. Second Calibration: Rinse the pH sensor with distilled water, and place the pH sensor into the pH 7.0 buffer. Wait for the display to stabilize, and select Enter. Key in 7.0 as the pH value.

    c. After both calibrations, select OK. Students will be ready to collect data.

12. Caution students that after each addition of 0.020 M H_2SO_4 to the beaker, it is very important to allow a reading to become stable before pressing Enter.

Investigating

Learning Objectives

Students will:

- Conduct a titration of a barium hydroxide solution with a sulfuric acid solution.
- Identify the types and the products of a chemical reaction.
- Determine the equivalence point of an acid-base reaction.
- Locate the equivalence point of a chemical reaction on a graph of conductivity data.
- Locate the equivalence point of a chemical reaction on a graph of pH data.
- Determine the concentration in molarity of the barium hydroxide solution.
- Calculate the percent error when given the actual concentration of the barium hydroxide solution.
- Calculate the number of moles of Ba^{2+} ions that did not combine with SO_4^{2-} ion.
- Predict what may have happened to the missing Ba^{2+} ions.

Procedure

1. Have students write a complete answer or response for each of the questions in this section of the assignment. Explain that by doing so, students will be interpreting and analyzing the data they collected during the titration.
2. Demonstrate how students can use the displays of the graphs produced by entering data in their probeware, graphing calculators, or computers to determine the values for the individual data points used for generating the graphs.
3. Demonstrate, using a different acid-base reaction, how students should use their data to find the values required for this assignment.

Drawing Conclusions

Learning Objectives

Students will:

- Prepare a formal laboratory report.

Procedure

1. Explain how students can use evidence, and reasoning to generate to the conclusion for this laboratory activity

2. Require students to work independently on the Drawing Conclusions section and to develop a formal laboratory report. Explain that they may use copies of tables, graphs, and any solutions generated with lab partners in their reports, but all other parts must be generated independently and submitted for formal assessment of this task.

Scaffolding/Instructional Support

The goal of scaffolding is to provide support to encourage student success, independence, and self-management. Instructors can use these suggestions, in part or all together, to meet diverse student needs. The more skilled the student, however, the less scaffolding that he or she will need. Some examples of scaffolding that could apply to this assignment include:

- Control the use of equations needed for this activity. If needed write equations on the board or give to students a handout.
- Help students to devise data tables based on a careful read of the experimental procedure prior to beginning the lab activity. If necessary, provide data tables for students to use. A sample data table is provided.
- To encourage struggling students, assign lab groups that consist of students from all ability groups. Be sure that students less skilled in the use of probeware, graphing calculators, and computers work with lab partners who are more proficient.
- Devote class time in advance of the activity to discuss the key concepts and terms.
- Average- and low-performing students will find it helpful to read the activity before they begin lab work. Give students an opportunity to develop definitions for the key vocabulary terms.
- A team of students is needed to make the titration go smoothly.
- Closely monitor working lab groups during their first titration. Allow them to work more independently when repeating the titration.
- Students may have questions when they reach steps 2 and 3 of this section. They may need some coaching to reach the conclusion that CO_2 from the air readily dissolves in the barium hydroxide solution when it is exposed to the air. Ask: Did you notice that the barium hydroxide solution you used was cloudy? Explain that barium ions in solution react with dissolved CO_2 to form the precipitate barium carbonate, $BaCO_3$ and that some of this precipitate was filtered out before the solution was used.
- If needed, provide students with a blank data table. Example below:

	Trial 1	**Trial 2**	**Trial 3**
Concentration of H_2SO_4	M	M	M
Volume of H_2SO_4 used	mL	mL	mL
Volume of $Ba(OH)_2$ in beaker	mL	mL	mL

Solutions

The information below is intended to help you assess student's final work products. It may not represent all possible strategies and ideas. The accompanying scoring guide provides specific examples of ways a student might demonstrate content understanding and mastery of cross-disciplinary skills.

Data Table:

	Trial 1	Trial 2	Trial 3
Concentration of H_2SO_4	0.020 M	________M	________M
Volume of H_2SO_4 used	14.58 mL	________mL	________mL
Volume of $Ba(OH)_2$ in beaker	50.0 mL	________mL	________mL

Getting Started

1. Double Replacement: AB + CD → AD + CB

   Precipitation Reaction: $Ba(OH)_2(aq) + H_2SO_4(aq) \rightarrow BaSO_4(s) +$

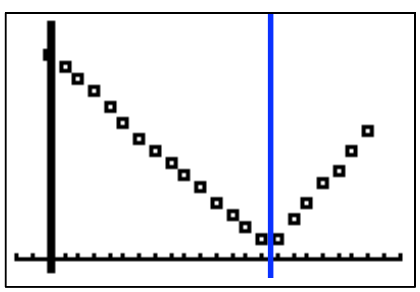
   $H_2O(l)$ Acid-Base Neutralization: $Ba(OH)_2 + H_2SO_4 \rightarrow BaSO_4 + 2H_2O$

   (BASE) + (ACID) → (SALT) + (WATER)

2. $Ba^{2+}(aq) + 2OH^{-1}(aq) + 2H^{+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s) + 2H_2O(l)$

   The presence of ions in a solution will enable the solution to conduct an electrical current. The removal of barium and sulfate ions from a solution to form solid barium sulfate will decrease the solution's conductivity. After the equivalence point of the titration, the addition of sulfuric acid will increase the conductivity of the solution because there will be excess sulfate and hydronium ions in the contents of the beaker. Advanced students may offer the presence of bisulfate ions as a possible prediction for increased conductivity.

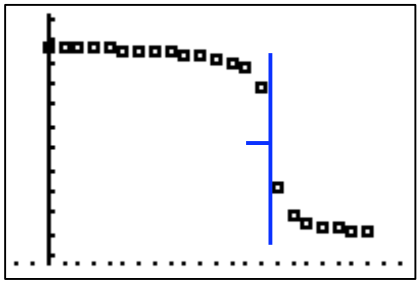
Investigating



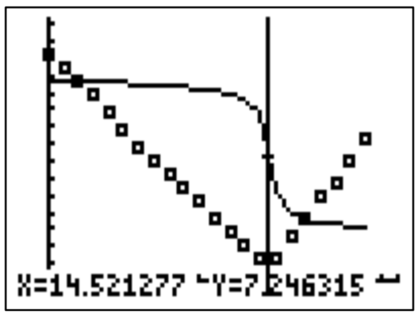
1. Students can examine the data on the displayed graph by moving the cursor right or left. As they move the cursor on the displayed graph, the volume (X) and the conductivity (Y) values are displayed below the graph. They will record the point that has the minimal conductivity value in their data table.
2. The pH changes very little as sulfuric acid is added to the barium hydroxide solution. Then, the pH suddenly drops to about 7 with the addition of a very small amount of

sulfuric acid. After the sudden drop, the drop in the pH gradually begins to slow to a point of very little change with the addition of more sulfuric acid.

3.



4. Students should notice that the equivalence point in the conductivity graph and the equivalence point in the pH graph indicate the same position on the titration.



5. Student data will vary based on individual results. A value of about 0.006 M $Ba(OH)_2$ is expected.

6. 0

$$\frac{14.58\ \cancel{mL}\ H_2SO_4}{} \left| \frac{1\ L}{1000\ \cancel{mL}} \right. = \frac{0.01458\ \cancel{L}\ H_2SO_4}{} \left| \frac{0.020\ mol}{\cancel{L}} \right. = 0.00029\ mol\ H_2SO_4$$

$$\frac{0.00029\ mol\ H_2SO_4}{} \left| \frac{1\ Ba(OH)_2}{1\ H_2SO_4} \right. = 0.00029\ mol\ Ba(OH)_2$$

$$\frac{0.00029\ mol\ Ba(OH)_2}{} \left| \frac{}{0.050\ L} \right. = 0.0058\ M\ Ba(OH)_2$$

.010 M – 0.0058 M = 0.0042

0.0042/0.010 x 100 = 42% (experimental error)

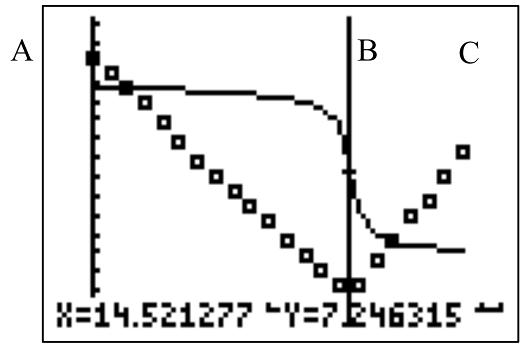
Drawing Conclusions

1. Students' conclusions should consist of a well-written paragraph that summarizes the purpose of a titration, states the hypothesis, provides evidence that supports the conclusion drawn, and highlights the reasoning behind the conclusion.

2. Students should predict that 42% of the barium ions in the barium hydroxide solution reacted with ions of another substance in the solution.

3. The formation of barium carbonate in the solution caused an underestimation of the molarity of the barium hydroxide solution, and therefore, the concentration of bariumions present.

4.



a. $Ba^{2+}(aq) + 2OH^{-1}(aq) + 2H^{+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s) + 2H_2O(l)$.

b. The smooth curve that begins nearly flat and has a sharp drop at B represents pH data. The curve that looks like a *V* represents conductivity data.

c. The addition of sulfuric acid (H_2SO_4) caused Ba^{2+} ions to combine with SO_4^{2-} ions and barium sulfate to precipitate. The H^+ ions reacted with the OH^- ions to form water. Both changes decrease the number of ions in solution, which lowers the conductivity at a rapid rate. The second change reduces the number of hydroxide ions at a much slower rate, so the decrease in pH is not as noticeable.

d. The reaction has reached the equivalence point. The hydrogen ions have neutralized the hydroxide ions because the number of hydrogen ions added equals the number of hydroxide ions originally present.

e. No reaction was occurring. The addition of sulfuric acid added more H^+ and SO_4^{2-} ions, which caused the titrated solution's conductivity to increase and its pH to decrease. Advanced students may offer the presence of bisulfate, as well as the hydrogen in sulfate, as a possible solution.

5. a. Failing to rinse the buret results in a dilution of the acid solution, so the concentration of the acid solution would be slightly less than the value provided by the teacher.

b. The volume of acid recorded will be less than the actual volume used. Some of the volume initially measured filled the tip and was not added to the beaker of base.

6. The volume of strong base needed would be the same (about 25 mL) as the volume of acid used in this activity. The equivalence point is still achieved when equal numbers of hydroxide ions as hydrogen ions have been added. However, the pH at the equivalence point will be greater than pH 7. The titration curve would start at a pH less than 7, have a slight increase and a leveling out of pH, and then have a sharp increase in pH through the equivalence point followed by a plateau. The equivalence point would be located above pH 7 due to hydrolysis of the salt formed from the conjugate base of the weak acid.

7. Student reports will vary. It may be helpful to research styles of technical writing for chemistry to use as a reference point.

TCCRS Cross-Disciplinary Standards Addressed

Performance Expectation	Getting Started	Investigating	Drawing Conclusions
I. Key Cognitive Skills			
A.1. Engage in scholarly inquiry and dialogue.	✓		✓
B.1. Consider arguments and conclusions of self and others.	✓		
B.2. Construct well-reasoned arguments to explain phenomena, validate conjectures, or support positions.	✓		✓
B.4. Support or modify claims based on the result of an inquiry.			✓
D.1. Self-monitor learning needs and seek assistance when needed.	✓	✓	✓
D.3. Strive for accuracy and precision.	✓	✓	✓
D.4. Persevere to complete and master tasks.	✓	✓	✓
E.1. Work independently.	✓		✓
E.2. Work collaboratively.	✓	✓	
II. Foundational Skills			
B.1. Write clearly and coherently using standard writing conventions.			✓
C.5. Synthesize and organize information effectively.		✓	✓
D.1. Identify patterns or departures from patterns among data.		✓	✓
D.3. Present analyzed data and communicate findings in a variety of formats.			✓
E.1. Use technology to gather information.		✓	
E.2. Use technology to organize, manage, and analyze information.		✓	✓
E.3. Use technology to communicate and display findings in a clear and coherent manner.			✓
E.4. Use technology appropriately.		✓	✓

TCCRS Science Standards Addressed

Performance Expectation	Getting Started	Investigating	Drawing Conclusions
I. Nature of Science: Scientific Ways of Learning and Thinking			
A.1. Utilize skepticism, logic, and professional ethics in science.	✓	✓	✓
A.2. Use creativity and insight to recognize and describe patterns in natural phenomena.	✓		✓
A.4. Rely on reproducible observations of empirical evidence when constructing, analyzing, and evaluating explanations of natural events and processes.		✓	✓
C.1. Collaborate on joint projects.		✓	
C.2. Understand and apply safe procedures in the laboratory and field, including chemical, electrical, and fire safety and safe handling of live or preserved organisms.	✓	✓	
C.3. Demonstrate skill in the safe use of a wide variety of apparatuses, equipment, techniques, and procedures.		✓	
D.3. Demonstrate appropriate use of a wide variety of apparatuses, equipment, techniques, and procedures for collecting quantitative and qualitative data.	✓	✓	
E.1. Use several modes of expression to describe or characterize natural patterns and phenomena. These modes of expression include narrative, numerical, graphical, pictorial, symbolic, and kinesthetic.			✓
E.2. Use essential vocabulary of the discipline being studied.	✓	✓	✓
II. Foundation Skills: Scientific Applications of Mathematics			
A.3. Understand ratios, proportions, percentages, and decimal fractions, and translate from any form to any other.	✓	✓	✓
A.4. Use proportional reasoning to solve problems.			✓
A.7. Use calculators, spreadsheets, computers, etc., in data analysis.		✓	✓

B.1. Carry out formal operations using standard algebraic symbols and formulae.		✓	✓
B.2. Represent natural events, processes, and relationships with algebraic expressions and algorithms.	✓		✓
F.1. Select and use appropriate Standard International (SI) units and prefixes to express measurements for real-world problems.	✓	✓	✓
F.2. Use appropriate significant digits.	✓	✓	✓
III. Foundation Skills: Scientific Applications of Communication			
A.1. Use correct applications of writing practices in scientific communication.			✓
B.2. Set up apparatuses, carry out procedures, and collect specified data from a given set of appropriate instructions.	✓	✓	
B.3. Recognize scientific and technical vocabulary in the field of study and use this vocabulary to enhance clarity of communication.	✓	✓	✓
C.1. Prepare and present scientific/technical information in appropriate formats for various audiences.			✓
VII. Chemistry			
E.1. Classify chemical reactions by type. Describe the evidence that a chemical reaction has occurred.	✓		✓
E.2. Describe the properties of acids and bases, and identify the products of a neutralization reaction.	✓	✓	✓
E.4. Understand chemical equilibrium.	✓	✓	✓
G.1. Understand the mole concept.		✓	✓
G.2. Understand molar relationships in reactions, stoichiometric calculations, and percent yield.		✓	✓
I.2. Understand properties of solutions.	✓	✓	✓

TEKS Standards Addressed

Titration Probe - *Texas Essential Knowledge and Skills (TEKS): Chemistry*
112.35.c.1. Scientific processes. The student, for at least 40% of instructional time, conducts laboratory and field investigations using safe, environmentally appropriate, and ethical practices. The student is expected to: 112.35.c.1.A. demonstrate safe practices during laboratory and field investigations, including the appropriate use of safety showers, eyewash fountains, safety goggles, and fire extinguishers; 112.35.c.1.B. know specific hazards of chemical substances such as flammability, corrosiveness, and radioactivity as summarized on the Material Safety Data Sheets (MSDS); and 112.35.c.1.C demonstrate an understanding of the use and conservation of resources and the proper disposal or recycling of materials.
112.35.c.2. Scientific processes. The student uses scientific methods to solve investigative questions. The student is expected to: 112.35.c.2.E. plan and implement investigative procedures, including asking questions, formulating testable hypotheses, and selecting equipment and technology, including graphing calculators, computers and probes, sufficient scientific glassware such as beakers, Erlenmeyer flasks, pipettes, graduated cylinders, volumetric flasks, safety goggles, and burettes, electronic balances, and an adequate supply of consumable chemicals; 112.35.c.2.F. collect data and make measurements with accuracy and precision; 112.35.c.2.G. express and manipulate chemical quantities using scientific conventions and mathematical procedures, including dimensional analysis, scientific notation, and significant figures; 112.35.c.2.H. organize, analyze, evaluate, make inferences, and predict trends from data; and 112.35.c.2.I. communicate valid conclusions supported by the data through methods such as lab reports, labeled drawings, graphs, journals, summaries, oral reports, and technology-based reports.
112.35.c.3. Scientific processes. The student uses critical thinking, scientific reasoning, and problem solving to make informed decisions within and outside the classroom. The student is expected to: 112.35.c.3.A. in all fields of science, analyze, evaluate, and critique scientific explanations by using empirical evidence, logical reasoning, and experimental and observational testing, including examining all sides of scientific evidence of those scientific explanations, so as to encourage critical thinking by the student.
112.35.c.8. Science concepts. The student can quantify the changes that occur during chemical reactions. The student is expected to: 112.35.c.8.A. define and use the concept of a mole; 112.35.c.8.B. use the mole concept to calculate the number of atoms, ions, or molecules in a sample of material; 112.35.c.8.C. calculate percent composition and empirical and molecular formulas; and 112.35.c.8.D. use the law of conservation of mass to write and balance chemical equations.
112.35.c.10. Science concepts. The student understands and can apply the factors that influence the behavior of solutions. The student is expected to: 112.35.c.10.B. develop and use general rules regarding solubility through investigations with aqueous solutions; 112.35.c.10.C. calculate the concentration of solutions in units of molarity; 112.35.c.10.D. use molarity to calculate the dilutions of solutions; 112.35.c.10.G. define acids and bases and distinguish between Arrhenius and Bronsted-Lowry definitions and predict products in acid base reactions that form water; and 112.35.c.10.I. define pH and use the hydrogen or hydroxide ion concentrations to calculate the pH of a solution.

Titration Probe

Introduction

Across the country, teams of people arrive at companies and begin performing titrations. At your local automatic car wash, for example, a team of people will titrate the detergents and waxes used to determine the strength of these agents being applied to cars. Why do they need to titrate? Titration is a method used to determine the concentration of a substance. Titrations are also used to determine the salinity of salt water, the amount of free fatty acids in cooking oil used for making biodiesel fuel, and the amount of dissolved oxygen in water samples.

During a titration, a measured volume of a substance of known concentration, substance A, is added to a specific volume of a substance of unknown concentration, substance B. Just enough of substance A is added so that all of substance B reacts. This point in a titration is called the equivalence point. At the equivalence point, chemically equivalent amounts of A and B have been combined.

The neutralization of a base with an acid does not always have a directly observable end, as the neutralization results in the formation of molecular water with no outward visible sign. Carefully selected indicators, chemicals that change color based on pH, are often used to approximate the equivalence point of an acid-base titration. However, the equivalence point can also be determined by measuring the change in pH of the titrated solution or by measuring the change in the electrical conductivity of the solution. The equivalence point is reached when the number of hydrogen ions equals the number of hydroxide ions. In reactions between a strong acid and a strong base, the pH at the equivalence point is 7. At the equivalence point of an acid-base reaction, the number of moles of H^+ from the acid added is equal to the number of moles of OH^- from the base.

On a graph of pH versus volume of acid added, the equivalence point is indicated by the largest decrease in pH upon the addition of 0.1 mL of the acid. For electrolytes, the equivalence point of a titration is the point at which the electrical conductivity is 0, or very close to it.

The Problem

The purpose of this laboratory activity is to conduct a titration, collect data using a pH sensor and a conductivity probe, analyze the data to determine the equivalence point of the reaction between barium hydroxide, $Ba(OH)_2$, and sulfuric acid, H_2SO_4, and then calculate the moles of sulfuric acid added and the concentration in molarity of the barium hydroxide solution. You will also prepare a laboratory report to organize your work for assessment.

Directions

Getting Started

1. What types of reactions occur during the titration? Explain your answer.
2. Write the balanced equation that represents the overall reaction between sulfuric acid and barium hydroxide, including all states.
3. Predict how you expect the conductivity of the solution in the beaker to change as sulfuric acid is added to barium hydroxide. Summarize the changes you expect to observe.

Set Up a Titration

1. Put on safety goggles and a lab apron.
2. Obtain all materials needed: conductivity probe, pH sensor, LabPro®, CBL 2™, or computer interface, buret, funnel, two 250 mL beakers, magnetic stirrer and bar, buret clamp, ring stand, utility clamp, graphing calculator, 100 mL graduated cylinder, distilled water, and wash bottles.
3. Pour approximately 60 mL of a 0.020 M H_2SO_4 solution into a 250-mL beaker.

   CAUTION: H_2SO_4 is a strong acid. Handle it carefully. If any of the H_2SO_4 solution splashes on your skin or clothing, rinse the area with plenty of water and tell your instructor immediately.

Figure 1

4. Set up a buret with 0.020 M H_2SO_4 solution as demonstrated by your teacher.

   Be sure to use a funnel to fill the buret (Figure 1). If any of the acid splashes on your hands as you fill the buret, rinse them with plenty of water and tell your instructor.
5. Measure to the nearest 0.1 mL approximately 50 mL of a $Ba(OH)_2$ solution of unknown concentration using a 100-mL graduated cylinder.

Pour the solution into a clean, dry 250-mL beaker, making sure to transfer all of the solution.

CAUTION: *$Ba(OH)_2$ is toxic. Do not ingest any of the solution. Handle it carefully. If any of the $Ba(OH)_2$ solution splashes on your skin or clothing, rinse the area with plenty of water and tell your instructor immediately.*

6. Place a magnetic stirrer on the base of the ring stand. Add a stirring bar to the $Ba(OH)_2$ solution, and place the beaker on the magnetic stirrer. (Note: Occasional stirring with a glass stirring rod may be used instead.)

Set Up the Data-Collection Device for Measuring Conductivity and pH

7. Plug the conductivity probe into Channel 1 of a LabPro® or CBL 2™ interface. Set the selector switch on the conductivity probe to the 0–2000 μS/cm range. Use the link cable to connect the graphing calculator to the interface. Firmly press in the cable ends.
8. Plug the pH sensor into Channel 2 of the LabPro® or CBL 2™ interface.
9. Attach the probes to the ring stand, as shown in Figure 2, using utility clamps. Make sure both probes extend down into the $Ba(OH)_2$ solution but do not touch the stirring bar. If the hole in the conductivity probe is not below the level of the solution, add distilled water to the beaker until the hole is completely submerged.
10. Turn on the graphing calculator and the data collection device.
11. Set up the data collection program for a conductivity probe making sure to select the 0–2000 μS/cm setting.
12. Set up for data collection with a pH sensor. If asked to load the calibration file, select "yes."
13. Set up data collection as *Events with Entry* so you can record the volume as you add H_2SO_4 to the $Ba(OH)_2$.

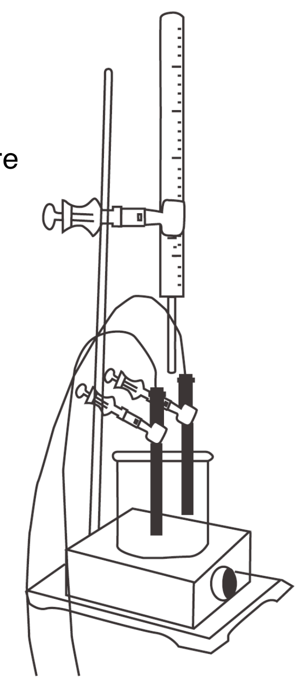


Figure 2

Investigating

Collect Data

1. Start your data collection device.
2. Press ENTER on the calculator, and key in the current buret reading *before* adding any H_2SO_4. Press ENTER again to save this data pair.
3. Add 1.0 mL of 0.020 M H_2SO_4 to the beaker. When the conductivity reading stabilizes, press ENTER and key in the current buret reading. Press ENTER again to save this data pair.
4. Continue adding H_2SO_4 in 1-mL intervals, entering the current buret reading and saving the data pair after each addition, until the conductivity drops below 100 μS/cm.
5. Add 0.5 mL of the H_2SO_4 solution after the conductivity drops below 100 μS/cm. Enter the buret reading, and save the data pair.
6. Start adding H_2SO_4 in 2-drop intervals (approximately 0.1 mL). After each addition, enter the buret reading and save the data pair. Continue until the minimum conductivity has been reached.
7. Continue adding H_2SO_4 and recording data at 2-drop intervals until the conductivity is greater than 50 μS/cm.
8. Begin adding H_2SO_4 at 1-mL intervals. Record data until the conductivity is greater than 1000 μS/cm.
9. Stop the data collection programs, making sure the data are stored.
10. If time permits, repeat the experiment two more times.
11. Print the data tables and graphs generated to observe changes in conductivity and pH during the titration.

Clean Up

12. Rinse off both probes with distilled water and dry them. Place the pH sensor back in the storage solution.
13. Dispose of the solutions as directed by your instructor. Rinse the buret thoroughly with distilled water.

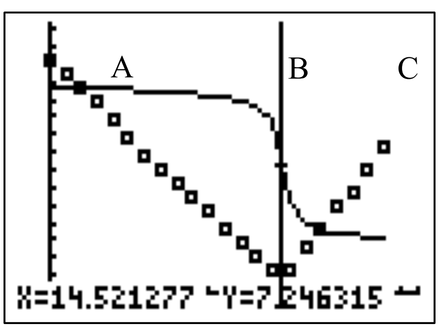
Data Analysis

14. Observe the graph of the conductivity data. Locate the equivalence point of the reaction and mark it with a vertical line.

15. Examine the conductivity graph, and determine the volume of H_2SO_4 needed to reach the equivalence point by moving the cursor on the displayed graph. Record this volume as the volume of H_2SO_4 used.
16. Observe the graph of the pH data. What do you notice about the pH of the solution in the beaker as the titration proceeded?
17. Locate the equivalence point of the reaction and mark it with a vertical line.
18. Overlay the graph of pH data on the graph of conductivity data. Compare the equivalence point of the reaction as determined by each graph.
19. Using the data you collected and the balanced chemical equation for the reaction, calculate the molarity of the $Ba(OH)_2$ solution.
20. Your instructor prepared a 0.010 M solution of $Ba(OH)_2$ for this laboratory activity. Use this value and the value you determined for the molarity of the $Ba(OH)_2$ solution used to calculate the experimental error.

Drawing Conclusions

1. Generate a conclusion for this activity supported by evidence and reasoning.
2. Predict what may have happened to the barium ions that did not react with sulfate ions. (Hint: Carbon dioxide, CO_2, in the air dissolves in water.)
3. How did the formation of barium carbonate affect the value you found for the concentration of the original barium hydroxide solution?
4. Using the graph below, explain what happened during the reaction of barium hydroxide with sulfuric acid.



   a. Write the net ionic equation for the overall reaction.

   b. Identify which curve on the graph represents pH data and which represents conductivity data.

c. Explain what was happening in the solution that resulted in the curves seen in section A.

d. Explain what was happening in the solution during and the significance of point B.

e. Explain what was happening in the solution that resulted in the curves seen in section C.

5. Analyze the following errors to determine the most immediate impact of each error to the data collected.

   a. The buret is rinsed with distilled water but is not rinsed with the acid solution before being filled.

   b. The tip of the buret is filled with air, not acid solution, because the buret is not drained.

6. A student conducts a titration by adding a strong base to a weak acid. The acid and base react in a 1:1 ratio as occurred in this activity. The volume of acid used is 50.0 mL, and the concentration of the acid is 0.010 M. If the concentration of base is 0.020 M, predict how the volume of base needed to reach the equivalence point would compare with the volume of acid that you used in this activity. Predict what the titration curve would look like.

7. Write a laboratory report that includes the following: a title page, an abstract, a materials list, and an explanation of the procedure, results, and conclusions of the laboratory activity. Reports should include any relevant data tables and graphs as well as written answers to the questions in the Getting Started, Investigating, and Drawing Conclusions sections.