JOURNAL OF
CHEMICAL EDUCATION

Activity

pubs.acs.org/jchemeduc

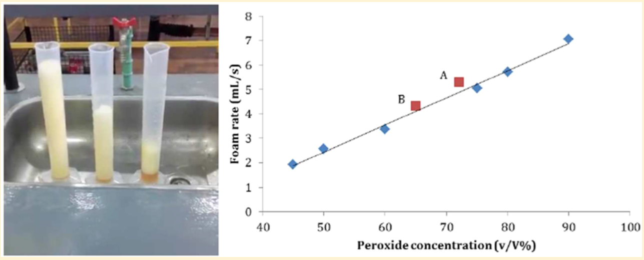
Another Twist of the Foam: An Effective Test Considering a Quantitative Approach to “Elephant’s Toothpaste”

Franco Hernando, Santiago Laperuta, Jeanine Van Kuijl, Nihuel Laurin, Federico Sacks, and Andrés Ciolino*

Departamento de Ingeniería Química (DIQ), Universidad Nacional del Sur (UNS), Avenida Alem 1253, Cuerpo C’ (8000), Bahía Blanca, Argentina

Supporting Information

ABSTRACT: In this work, a new quantitative look at the well-known “Elephant’s Toothpaste” demonstration is proposed. The catalyzed decomposition of H_2O_2 by iodide ion (I^-) is employed to produce foam in a controlled fashion. The time at which the foam reached a known volume in a conventional 500 mL measuring cylinder was registered. A straightforward correlation was observed between foam production and v/V% in a given range. A correlation plot was obtained, and the concentration of unknown solutions “A” and “B” was then estimated from it. This simple and effective laboratory activity is proposed as a learning activity for comparing and analyzing results from both this quantitative approach and titration method reported by scientific literature.



KEYWORDS: *High School/Introductory Chemistry, Laboratory Instruction, Hands-On Learning/Manipulatives, Quantitative Analysis*

INTRODUCTION

Hydrogen peroxide (H_2O_2) is a colorless liquid which looks exactly like water although it is slightly more viscous. It is miscible in water in all proportions and has a well-known oxidizing property, which allows it to work both as a bleaching agent and a disinfectant active on bacteria, viruses, spores, and yeasts. In addition, at high concentrations, H_2O_2 can be used in rocket engines.[1,2]

The decomposition of H_2O_2 catalyzed by iodide ion (I^-) is well-known and documented, and it has been reported that many reaction steps are involved in the process which, in turn, depend on different factors such as pH or temperature.[3−7] Nevertheless, since the required reagents are easy to handle, the reaction offers many alternatives to follow it. For this reason, it is often employed in many undergraduate activities.[8−11] Moreover, a very popular demonstration, called “Elephant’s Toothpaste”, involves the use of this reaction for producing a foamy substance caused by the rapid decomposition of concentrated H_2O_2(aq) solutions in the presence of liquid soap or detergent.[12,13] The production of this foamy substance is so quick and spectacular[14] that many outreach activities in Chemistry employ it for educational purposes.[15,16]

In this paper, we propose a fresh look at the “Elephant’s Toothpaste” test, which goes further than the qualitative demonstration. With this additional examination, the concentration of diluted H_2O_2(aq) solutions was determined by measuring the volume of the foam produced as a function of time. In order to check the precision, we compared the values measured by this method to those obtained by conventional titration. As far as we know, this is the first report in which the popular demonstration is employed for quantitative analysis, with the purpose of collecting experimental data and comparing results with other quantitative techniques (titration). Although the correlation between H_2O_2(aq) concentration and volume of foam produced was already published in this *Journal*,[17] the novelty of this work lies in systematization of this fact as a programmed learning activity.

EXPERIMENTAL SECTION

Reagents

Potassium iodide (KI, Anedra, +99.7% purity) and hydrogen peroxide solution (H_2O_2, Anedra, 100 volumes according to the label) were employed as received. KI solutions were prepared by dissolving the desired amount of salt in distilled water. The same procedure was employed for the dilution of the required volumes of commercial H_2O_2 solution in distilled water [warning: H_2O_2(aq) solutions are strong oxidants and may cause injuries or burn skin. Use fume hood, protective gloves, and laboratory goggles for its manipulation]. Analytical balances, pipettes, and volumetric flasks were employed for such purposes. Solutions were freshly prepared and stored in the dark in order to prevent their decomposition.

Received: January 16, 2017
Revised: May 9, 2017
Published: May 25, 2017

© 2017 American Chemical Society and Division of Chemical Education, Inc.

DOI: 10.1021/acs.jchemed.7b00040
J. Chem. Educ. 2017, 94, 907−910

Sulfuric acid (H_2SO_4, Biopack, 95−98 wt %), ammonium iron(II) sulfate hexahydrate [$Fe(NH_4)_2SO_4{\cdot}6H_2O$, Mohr's salt, Sigma-Aldrich, 99% purity), and potassium permanganate ($KMnO_4$, Biopack, 99% purity] were used for conventional titration methods. Commercial liquid soap (or detergent) was employed as received. A stopwatch (Tressa Crono 10B electronic stopwatch), with centesimal precision, was employed for registering foam evolution. Special care (fume hood) was taken when concentrated H_2SO_4 and solid $KMnO_4$ were employed by wearing laboratory goggles and nitrile gloves and using safety laboratory procedures for the manipulation of strong oxidant agents (please refer to Supporting Information, Chemical Hazards section).

Student Activities

Student activities are planned during four experimental classes (4 h per class) according to the experimental advice given below and in the Supporting Information. Briefly, during the first class, students should be familiar with preparing dilutions from commercial H_2O_2 and $KMnO_4$. Additionally, they should measure the first experimental data with dilutions from H_2O_2 by reproducing the "Elephant's Toothpaste" test in the measuring cylinder.

During the second class, they should be able to complete all the measurements planned and to check the correlation obtained. In the third class, titrations of standard $KMnO_4$(aq) solution and commercial H_2O_2 are carried out together with unknown "A" and "B" samples (see below). Finally, in the fourth class, all data obtained should be analyzed, and suitable corrections should be performed if needed (for further information, please refer to Supporting Information, Instructor's Activities Program section).

Quantitative "Elephant's Toothpaste" Tests

Six experiments were planned by using different concentrations of H_2O_2(aq) solutions at a fixed concentration of KI(aq) (0.06 M). For each concentration of H_2O_2(aq) solution, the following procedure was employed.

In a 500 mL measuring cylinder, 20 mL of H_2O_2(aq) solution was added, followed by 10 mL of liquid soap and a small magnetic bar. The cylinder was placed on a magnetic stirrer. Speed selection was chosen in order to ensure a homogeneous mixture. After 2 min, 20 mL of 0.06 M KI(aq) solution was added. Immediately, the foam production was observed. When the foam produced reached 100 mL inside the measuring cylinder, the stopwatch was started. The stopwatch recorded the time at which the foam reached a known volume inside the cylinder (namely, each 50 mL).

By employing this procedure, a set of experimental data (6 points, 3 repetitions of each) were obtained for correlation purposes. From the data obtained, a master curve was constructed, and two additional experiments ("A" and "B") were performed in order to verify its precision. The v/V% values of the "A" and "B" solutions were calculated from the obtained master curve, and their concentrations were verified by the conventional titration method by using $KMnO_4$(aq).

Standard Titration Method for H_2O_2(aq) Solutions

The $KMnO_4$(aq) solution was prepared according to the recommendations given elsewhere (see Supporting Information). The concentrations of the H_2O_2(aq) solutions were determined using the titration method reported in the chemical literature.[1,18] The same procedure was employed to determine the exact concentration of the commercial solution. The faint pink color of the permanganate ion, MnO_4^-(aq), was employed as an indicator. The concentration of the $KMnO_4$(aq) prepared for this purpose was obtained by using Mohr's salt as standard reagent and titration in acidic medium[19] (for further details, please see Supporting Information).

RESULTS AND DISCUSSION

Figure 1 shows the foam rate evolution of diluted H_2O_2(aq) solutions by keeping the concentration of KI(aq) solution constant.

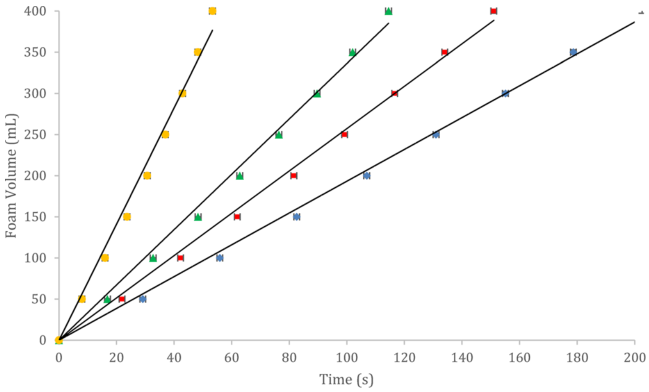


Figure 1. Evolution of the foam volume vs time for different H_2O_2 solutions [KI(aq) 0.06 M in all tests]. Key: 45 v/V% (blue ◆), R^2 = 0.9977; 50 v/V% (red ■), R^2 = 0.9968; 60 v/V% (green ▲), R^2 = 0.9950; 90 v/V% (orange ●), R^2 = 0.9897. Error bars account for uncertainty in measuring time.

As it can be appreciated, a straightforward correlation is evident and follows the same tendency reported previously by Conklin and Kessinger.[17] The slope of the linear correlations observed in Figure 1 was related to v/V% concentration from H_2O_2(aq) solutions,[20] and it can be appreciated that only in the case of high v/V% concentrations does the linear tendency show a slight deviation.

Figure 2 shows the results obtained by taking advantage of the straightforward correlation already discussed between 40 and 90 v/V%. As can be observed, foam rate versus H_2O_2(aq) v/V% shows a linear tendency, and experimental points fits (blue ◆) nicely. Nevertheless, at this point, it is worth mentioning that solutions of the commercial reagent with

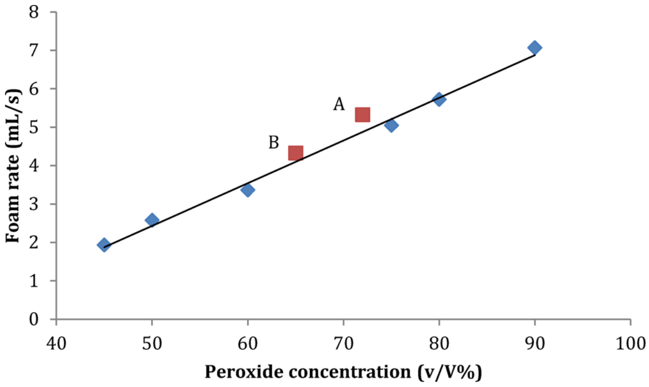


Figure 2. Foam rate as a function of H_2O_2(aq) concentration (R^2 = 0.9939). Key: blue ◆, experimental points (known concentration, foam rate measured); red ■, "A" and "B" solutions (unknown concentration, foam rate measured).

Table 1. Comparison of Relative Error Values for the Unknown Solutions[a]

Solution	Expected v/V, %	Calculated v/V,[b] %	E_r, %	M[c]	M[d]	Difference, E_r, %
A	72	76	+5.6	7.27 ± 0.01	7.90 ± 0.01	+8.66
B	65	67	+3.1	6.48 ± 0.01	6.86 ± 0.01	+5.86

[a] The expected v/V% and the titration values were arbitrarily taken as the real values. [b] Values directly obtained from the master curve shown in Figure 2. [c] Molarity values calculated by the classical titration method. [d] Molarity values calculated by the "foam approach".

dilutions lower than 40 v/V% were also analyzed. The results obtained for these tests did not follow the straightforward tendency observed above, and it might be due to the low $O_2(g)$ evolution that avoids a measurable foam rate. As can be deduced from Figure 2, it seems reasonable to infer that there exist limiting concentrations, and the intercept of the linear regression might denote the minimum foam rate evolution to be employed.

Finally, in order to test the precision of this last correlation, two unknown solutions of $H_2O_2(aq)$ ("A" and "B") were prepared, whose concentrations had to fill the "empty" zone between experimental points. To check this purpose, their concentrations were determined by two different ways: the classical titration method and the straightforward correlation from the master curve already obtained. The results are shown in Figure 2 and reported in Table 1.

As it is appreciated, if the titration values are considered to be exact, the "foam approach" gives quite good results, with a better approximation for v/V%. Despite unavoidable experimental errors (among them, the spontaneous although slow H_2O_2 decomposition is not taken into account throughout the experience), the simplicity of this "foam approach" is out of discussion (at least for those ranges of concentrations in which it might be applicable). Although results were not absolutely exact, at least they give a good approximation by employing an easy setup.

In conclusion, the "foam approach" proposed in this paper is easy to set up, and there is no need for sophisticated equipment or reagents.[21] The method offers the opportunity to describe different chemical topics, such as stoichiometry, gas behavior, chemical decomposition, and volumetric analysis, among others.[16] In addition, it gives the chance to expand this laboratory test with other experimental activities, such as determination of kinetic constants.[22] Last but not least, a quantitative fresh look for the well-known "Elephant's Toothpaste" demonstration is proposed. As a new approach, the now-called "Another Twist of the Foam" offers a simple and effective method to determine $H_2O_2(aq)$ concentrations with the advantage of easy adjustment for teaching purposes.

■ CONCLUSIONS

Decomposition of $H_2O_2(aq)$ catalyzed by $I^-(aq)$ was performed in the presence of liquid soap. From this well-known "Elephant's Toothpaste" demonstration, a straightforward correlation was observed between foam rate production and concentration of commercial H_2O_2 dilutions (at least for the 40−90 v/V% range). From an obtained master curve, the concentrations of unknown solutions "A" and "B" were obtained. In this sense, this "Another Twist of the Foam" is proposed as a new teaching activity for high school students, for which basic chemistry is enough to understand the demonstration and collect data that are useful for quantitative and statistical analysis, depending on the corresponding teaching objectives.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.7b00040.

Additional material for instructors and students regarding the preparation of solutions and foam rate measurements (PDF, DOCX)

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: aciolino@plapiqui.edu.ar.

ORCID

Andrés Ciolino: 0000-0002-9482-3889

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

The authors wish to thank the Departamento de Ingeniería Química (DIQ), and Universidad Nacional del Sur (UNS, Bahía Blanca, Argentina), for their financial support; Gabriela Martínez Ipucha and Miguel Nievas for their technical assistance and aid in laboratory tests; and Claudia Sarmoria for her assistance with English grammar.

■ REFERENCES

(1) *Kirk-Othmer Encyclopedia of Chemical Technology*, 4th ed.; John Wiley & Sons: New York, 1995; Vol. *13*, pp 961−989.

(2) Wisniak, J. Louis-Jacques Thenard. *Revista CENIC Ciencias Químicas* **2002**, *33* (3), 141−149.

(3) (a) Bray, W. C.; Liebhafsky, H. A. Reactions Involving Hydrogen Peroxide, Iodine and Iodate Ion. I. Introduction. *J. Am. Chem. Soc.* **1931**, *53* (1), 38−44. (b) Bray, W. C.; Caulkins, A. L. Reactions Involving Hydrogen Peroxide, Iodine and Iodate Ion. II. The Preparation of Iodic Acid. Preliminary Rate Measurements. *J. Am. Chem. Soc.* **1931**, *53* (1), 44−48. (c) Liebhafsky, H. A. The Catalytic Decomposition of Hydrogen Peroxide by the Iodine-Iodide Couple at 25 °C. *J. Am. Chem. Soc.* **1932**, *54* (5), 1792−1806.

(4) Kolar Anić, L.; Schmitz, G. Mechanism of the Bray-Liebhafsky Reaction: Effect of the Oxidation of Iodous Acid by Hydrogen Peroxide. *J. Chem. Soc., Faraday Trans.* **1992**, *88* (16), 2343−2349.

(5) Milenković, M. C.; Stanisavljev, D. R. The Kinetics of Iodide Oxidation by Hydrogen Peroxide in Acid Solution. *Russ. J. Phys. Chem. A* **2011**, *85* (13), 2279−2282.

(6) Schmitz, G. Iodine oxidation by hydrogen peroxide in acidic solutions, Bray-Liebhafsky reaction and other related reactions. *Phys. Chem. Chem. Phys.* **2010**, *12*, 6605−6615.

(7) Carter, G. E. The Feasibility of Using Hydrogen Peroxide Decomposition Studies for High School Chemistry. *J. Chem. Educ.* **1986**, *63* (2), 159−161.

(8) Hansen, J. The Iodide-Catalyzed Decomposition of Hydrogen Peroxide: A Simple Computer-Interfaced Kinetics Experiment for General Chemistry. *J. Chem. Educ.* **1996**, *73* (8), 728−732.

(9) Teggins, J.; Mahaffy, C. Kinetics Studies Using a Washing Bottle. *J. Chem. Educ.* **1997**, *74* (5), 566.

(10) Ragsdale, R.; Vanderhooft, J.; Zipp, A. Small-Scale Kinetic Study of the Catalyzed Decomposition of Hydrogen Peroxide. *J. Chem. Educ.* **1998**, *75* (2), 215−266.

(11) Sattsangi, P. D. A Microscale Approach to Chemical Kinetics in the General Chemistry Laboratory: the Potassium Iodide Hydrogen Peroxide-Iodine Clock Reaction. *J. Chem. Educ.* **2011**, *88* (2), 184−188.

(12) ChemToddler video: Elephant Toothpaste. https://www.youtube.com/watch?v=ezsur0L0L1c (accessed Apr 2017).

(13) Chemistry experiment 10—Elephant's Toothpaste.https://www.youtube.com/watch?v=UTfMrx7275w (accessed Apr 2017).

(14) Elephant's Toothpaste Geyser with Science Bob on Jimmy Kimmel Live, https://www.youtube.com/watch?v=p1eG2y2mn54 (accessed Apr 2017).

(15) Marzzacco, C. J. The Enthalpy of Decomposition of Hydrogen Peroxide. A General Chemistry Calorimetry Experiment. *J. Chem. Educ.* **1999**, *76* (11), 1517−1518.

(16) Eldridge, D. S. Using Elephant's Toothpaste as an Engaging and Flexible Curriculum Alignment Projec. *J. Chem. Educ.* **2015**, *92* (8), 1406−1408.

(17) We found a previous work with a quantitative approach of this test: Conklin, A.; Kessinger, A. Demonstration of the Catalytic Decomposition of Hydrogen Peroxide. *J. Chem. Educ.* **1996**, *73* (9), 838 In this communication, authors explain the good correlation observed between the volume of the foam formed and $H_2O_2(aq)$ concentration. However, excepting a table with some results, an analysis of the approach and its consequences is not presented..

(18) (a) Huckaba, C.; Keyes, F. The Accuracy of Estimation of Hydrogen Peroxide by Potassium Permanganate Titration. *J. Am. Chem. Soc.* **1948**, *70* (4), 1640−1644. (b) Klassen, N.; Marchington, D.; McGowan, H. H_2O_2 determination by the I_3 Method and by $KMnO_4$ Titration. *Anal. Chem.* **1994**, *66* (18), 2921−2925.

(19) Soule, B. The Determination of Ferrous Iron in Silicate Rocks. I. *J. Am. Chem. Soc.* **1928**, *50* (6), 1691−1694.

(20) The sentence "... the v/V concentration of H_2O_2 solutions..." refers to the solutions prepared by dilution of commercial solution (100 volumes, according to the label) with distilled water, up to 100 mL.

(21) Trujillo, C.; et al. A Modified Demonstration of the Catalytic Decomposition of Hydrogen Peroxide. *J. Chem. Educ.* **2005**, *82* (6), 855.

(22) Cybulskis, V. J.; Ribeiro, F. H.; Gounder, R. Using a Hands-On Hydrogen Peroxide Decomposition Activity To Teach Catalysis Concepts to K−12 Students. *J. Chem. Educ.* **2016**, *93* (8), 1406−1410.