A General Chemistry Laboratory Theme: Spectroscopic Analysis of Aspirin

W

Houston Byrd* and Stephen E. O'Donnell
Department of Biology, Chemistry & Mathematics, University of Montevallo, Montevallo, AL 35115;
*byrd@montevallo.edu

There are a variety of ways in which general chemistry laboratories are integrated into the curriculum *(1–5)*. The traditional approach of using the laboratory to enhance the materials covered in lectures is accomplished by developing experiments that are consistent and concurrent with lecture topics. For example, a lecture on acid–base chemistry is often supported by an acid–base titration experiment in lab. A second approach is to use inquiry-based methodology *(2–5)*, in which students are not given step-by-step instructions for a lab exercise, but instead are expected to draw from knowledge learned in lectures. For example, students are given a graduated cylinder and a balance and are asked to determine the density of various liquids and solids by using their knowledge of density from lectures *(5)*. We have noticed two problems in implementing either of these approaches into our laboratories. First, many students never make the connection between the lectures and the laboratory. They view the two as separate entities and therefore the lecture material is not reinforced as expected. The second problem we and others have noticed is that many of the labs are boring to the students *(6)*. This is a serious problem, because general chemistry is the introductory course to our discipline. If the students are not interested in chemistry at this level, most will choose other areas of study. Therefore, in an attempt to increase the interest level while maintaining an intellectual challenge, we have modified the second semester of our general chemistry laboratory to incorporate what we feel are the best aspects of these two different types of laboratory approaches.

In this paper we describe a series of experiments designed for the general chemistry laboratory based on a well-known substance: aspirin. Although labs involving aspirin are common, they are useful because these labs help general chemistry students relate chemistry to real-world problems. What makes our format different is the use of a wide range of spectroscopic techniques as an integral part of the freshman lab. While the step-by-step experimental details are provided to the students, we incorporate the collection and processing of data with open-ended questions in an attempt to let the students discover answers in a small-group environment. We have found that the students respond very favorably to these labs and many get a better sense of how a chemist works. An additional benefit is that the students are introduced to instrumentation early in their academic career, which aids them in their second-year organic and analytical chemistry courses.

The students work in groups of two or three and each of the experiments, with the exception of the synthesis of aspirin, is spread over two weeks. All of the characterization and analysis experiments are performed simultaneously, with each group rotating to a different experiment every two weeks. It should be noted that a lab assistant is needed to help the instructor and students, since all the labs are performed simultaneously. Students are required to turn in one to two page summaries of their accomplishments with their data and results. This summary helps the students make a connection between the data, techniques, and purpose of each lab. Since the labs have been adapted from the literature, all pertinent information (introduction, procedures, data tables, etc.) is provided in *JCE Online*.W

Synthesis of Aspirin

The synthesis of aspirin is a very common and simple reaction that can be found in this *Journal (7, 8)*. In this lab, students learn about synthesis, crystallization, stoichiometry, and percent yield. The students are asked to calculate the theoretical amount of aspirin expected based on the known weight of salicylic acid used in the synthesis. Students then compare the data with the actual amount of aspirin synthesized before and after recrystallization. In the lab summary, students are expected to suggest reasons why the yield drops after recrystallization. This gives the faculty a chance to talk about some practical aspects of chemistry. Once this lab is completed, the students rotate through the series of characterization and analysis experiments.

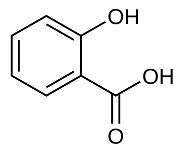
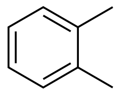
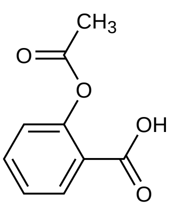
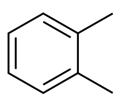
Characterization of Aspirin

In these experiments, students use IR and NMR to determine the purity and structure of their compound by preparing samples of standard aspirin, salicylic acid, and their synthesized aspirin. The students run these samples after a brief tutorial on the instruments and then analyze the results. Obviously, the students do not understand every detail of the instrumental theory. However, they are able to view the spectra and determine the differences between starting materials and the desired product. The introduction to the lab is used to help in this process and details are listed in the supplemental material.W Briefly, students read background information on each technique and are given a table concerning the important regions of analysis. For example, Table 1 lists the NMR data for the different functional groups in each compound. The information in the table and the collected spectra are used by the students to determine if they have made aspirin. Figure 1 shows spectra obtained by our students and how they are able to determine the identity and purity of their product by comparing their data with the aspirin and salicylic acid standards.

Analysis of Aspirin Tablets

Two of the final three experiments are designed around the quantitative analysis of the aspirin synthesized by the student as well as that found in commercial products. For these labs the students use UV–vis spectroscopy *(9)* and HPLC

Table 1. NMR Chemical Shifts for Functional Groups

Compound	Functional Groups	Hydrogens	Reference to TMS/ppm
	—OH	1	10 – 12
	—C(=O)—OH	1	9.5 – 10.5
		4	6.5 – 8
	—O—C(=O)—CH_3	3	2.5 – 2.8
	—C(=O)—OH	1	9.5 – 10.5
		4	6.5 – 8

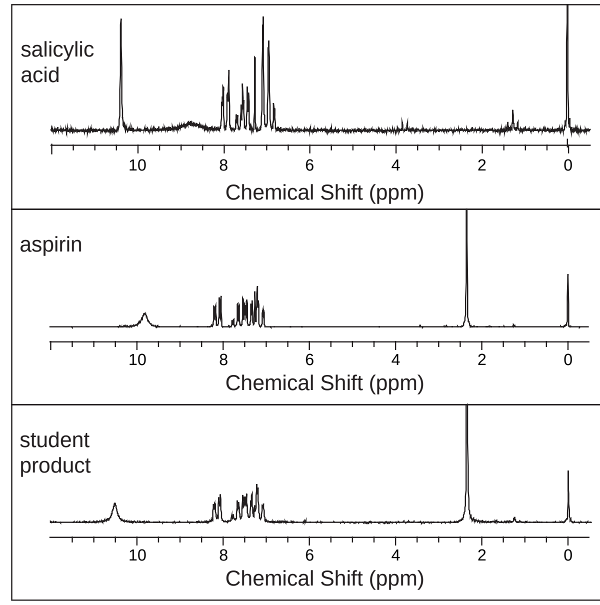


Figure 1. NMR spectra of salicylic acid, an aspirin standard, and student synthesized aspirin in $CDCl_3$. The methyl group (−CH_3) at 2.5 ppm easily distinguishes aspirin from the salicylic acid starting material. Students can also use the aromatic splitting between 6.5–8.0 ppm to determine if any salicylic acid impurity is in the sample.

(10–12). The third lab involves the determination of calcium in buffered commercial aspirins using AAS *(13).* The use of different methods towards the same goal shows students that more than one approach is possible or necessary in solving a problem and it allows them to comment in their summary on advantages and disadvantages of each analysis. Details of the analyses are given in literature *(9–13),* but it is important to note that the published labs were primarily designed for sophomore or higher-level courses. In our general chemistry lab, students routinely determine the amount of aspirin or calcium within 10% of the stated value.

In these experiments the students must first determine the response of the instrument to the concentration of the analyte. Each group prepares its own standards and samples, and generates a calibration curve using Excel to plot the data and fit the standards using regression analysis. As an example, in the HPLC experiment, a calibration curve is constructed from a plot of the peak area of a given standard versus the calculated concentration of that standard. Samples of the synthesized aspirin as well as three commercial products are then analyzed using the previously constructed calibration curve. Students are also able to qualitatively identify other components, such as caffeine, present in the commercial products by comparing measured retention times with those of standard solutions and from the label on the bottle. A student obtained chromatogram is shown in Figure 2.

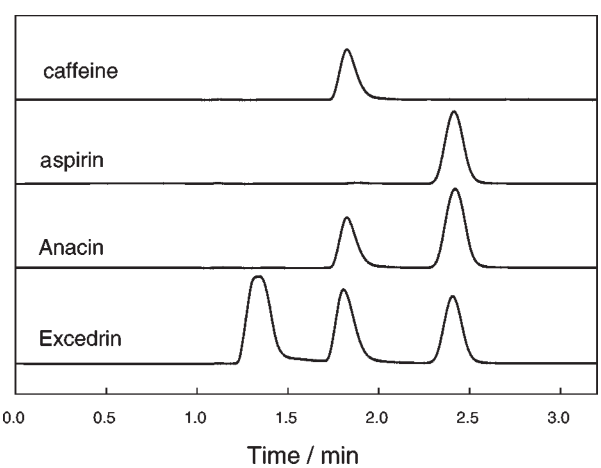


Figure 2. Chromatograms of various analgesic products. Aspirin has a retention time of 2.4 min, caffeine has a retention time of 1.8 min, and acetaminophen has a retention time of 1.4 min. The solvent is a 60%/40% mixture of methanol and 1% acetic acid with a flow rate of 2 mL/min.

Hazards

Caution should be used when synthesizing aspirin. Acetic anhydride (108-24-7) is corrosive, a lachrymator, and reacts violently with water; phosphoric acid (85%, 7664-38-2) is very corrosive. These chemicals need to be kept in the fume hood. Also, gloves should be worn when using chloroform-d, $CDCl_3$ (865-49-6), to prepare the NMR samples.

Conclusions

We have found that this series of labs has been very beneficial to our students. From the course evaluations, 76% of the students (38 out of 49) indicate that they prefer this type of laboratory more than the traditional labs taught in the first semester of general chemistry. These data were obtained from students in the second semester of general chemistry over the past two years. None of the labs discussed in this paper is new, but we believe the concept of introducing general chemistry students to chemical instrumentation through a theme is different. We believe that this approach will enhance the education for our students throughout their undergraduate experience in science.

WSupplemental Material

Introduction, procedures, data tables, and student report forms for each experiment are available in this issue of *JCE Online*.

Acknowledgments

Financial support for these laboratories has been provided through the purchase of equipment. The FT–NMR upgrade was funded by a NSF grant (DUE-9950438) and the University of Montevallo. The University Foundation funded the AAS. The Dean of the College of Arts and Sciences funded the HPLC.

Literature Cited

1. Domin, Daniel S. *J. Chem. Educ.* **1999,** *76,* 543.
2. Gutwill-Wise, Joshua P. *J. Chem. Educ.* **2001,** *78,* 684.
3. Lechtanski, Valerie L. *Inquiry-Based Experiments for Chemistry;* Oxford University Press: New York, 2000.
4. Wilcox, C. Jane. *J. Chem. Educ.* **2001,** *78,* 62.
5. DeMeo, Stephen. *J. Chem. Educ.* **2001,** *78,* 201.
6. Burns, Douglas S.; Berka, Ladisalv H.; Kildahl, Nicholas. *J. Chem. Educ.* **1993,** *70,* A100 and references therein.
7. Olmsted, John A., III. *J. Chem. Educ.* **1998,** *75,* 1261.
8. Pandita, Sangeeta; Goyal, Samta. *J. Chem. Educ.* **1998,** *75,* 770.
9. Pinnell, Robert P.; Motz, Leonard P. A Colorimetric Determination of Aspirin in Commercial Preparations. In *Modular Laboratory Program in Chemistry Anal-126;* Neidig, H. A., Ed.; Willard Grant Press: Boston, MA, 1973; p 1.
10. Beaver, Rodney W.; Bunch, John E.; Jones, Louis A. *J. Chem. Educ.* **1983,** *60,* 1000.
11. Kagel, R. A.; Farwell, S. O. *J. Chem. Educ.* **1983,** *60,* 163.
12. Haddad, Paul; Hutchins, Stephen; Tuffy, Michael. *J. Chem. Educ.* **1983,** *60,* 166.
13. Quigley, Michael N. *J. Chem. Educ.* **1994,** *71,* 800.