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ARTICLE *in* JOURNAL OF CHEMICAL EDUCATION · FEBRUARY 1994

Impact Factor: 1.11 · DOI: 10.1021/ed071p153

1 AUTHOR:

Stephen Demeo

City University of New York - Hunter College

edited by
JAMES O. SCHRECK
University of Northern Colorado
Greeley, CO 80639

A Laboratory Activity for Distinguishing between K_2SO_4 and NaCl

Stephen DeMeo
Barnard College, Columbia University, New York, NY 10027

It is difficult for chemistry teachers to devise activities that challenge students but remain within their technical skills and intellectual abilities. Chemistry students often are asked to discover for themselves various chemical concepts and principles without having the prerequisite background to accomplish such tasks. Even when students are prepared for a task, they usually are given an "unknown" and are told to replicate a battery of procedural steps that they have just learned. More often than not, if students do not use the one correct procedure, or if they name or quantify the unknown incorrectly, the students will fail the activity. These routines lead to frustration and boredom, thus "turning off" students to the excitement and relevance of chemistry. This article introduces a problem using an "unknown" that has one correct solution, but, many ways to argue for that solution. These arguments cover a wide range of concepts and techniques and rely on the skill and creativity of the student. The following problem is the focus of a laboratory activity that uses two chemicals as "unknowns," potassium sulfate and sodium chloride.

The Problem

In a laboratory, a chemist is busy filling small bottles with chemicals from large stock containers. After many interruptions, the chemist is not sure that the containers have been labeled correctly. The chemist is sure that each bottle contains only one of the two salts, potassium sulfate (K_2SO_4) or sodium chloride (NaCl).

Create as many arguments as you can based on observation and laboratory tests to determine the contents of the two bottles. Work independently and write up your experiments. Include the methodological and theoretical basis for the experiments you construct. Your scores will be based on the quality of the experimental procedures devised, the theory upon which your experiments are based, and on the number of your arguments. Any references on reserve, class notes, and information from past laboratory activities may be used.

- **Caution: Tasting of any chemicals in the lab is strictly forbidden.**

Solutions

These salts can be distinguished from each other in various and interesting ways by considering solubility, density, crystalline form, electrolysis, melting point, flame tests, and qualitative cation and anion tests. The means of distinguishing these two salts involve lab skills and concepts commonly taught in an introductory chemistry course. It is most appropriate to use this activity near the end of a course or at a time when these particular skills and concepts have been mastered by the students. Because knowledge of experimental design should be demonstrated, samples of the known salts are not given out unless the student requests them.

The success of this activity depends in part on the nature of the chemicals. They both are readily available, inexpensive, nontoxic, and can be disposed of down the sink after dilution. Moreover, because potassium sulfate and sodium chloride are white crystalline, odorless substances, students readily accept the argument that other tests are needed to differentiate between the two chemicals. For a cost-saving measure, noniodized table salt can be used in lieu of reagent grade sodium chloride. At a time when laboratory expenses and safety concerns are becoming major considerations when designing lab activities, these chemicals are appropriate for students, instructors, and society alike.

Solubility

Potassium sulfate and sodium chloride have different solubilities (*1*) in water at 25 °C. One gram of potassium sulfate dissolves in 8.3 mL of water, while 1 g of sodium chloride dissolves in only 2.8 mL of water. The salts can be distinguished from each other simply by placing 1 g of each salt in 3–4 mL of tap water. The complete dissolution of one salt (NaCl) is apparent, while the other salt (K_2SO_4) remains visible as an undissolved solid. This simple test qualitatively confirms the literature citation. The conceptual framework of solubility includes the concepts of chemical bonding and dissociation, atomic structure, solute, solvent, and chemical change.

Density

Potassium sulfate and sodium chloride can be differentiated by determining their density using the method of displacement of water. A 10-mL graduated cylinder partially filled with water is used. Because the two salts are water soluble, this method requires a saturated solution of salt. After saturating the water in the cylinder with one salt, a known mass of that salt is added to the graduated cylinder. From the mass of the salt added and the volume displacement of the saturated solution, the density of each salt can be estimated. After three trials, an average experimental value of 2.1 g/mL (standard deviation = 0.02 g/mL) was determined for sodium chloride. This correlates well with the literature value of 2.17 g/mL (*2*). For potassium sulfate, an average value of 2.6 g/mL (standard deviation = 0.07 g/mL) was found, which also compares well with the literature value of 2.66 g/mL.

These densities agree with the literature values because they do not form hydrated compounds in water. If they did, a discrepancy between the literature and experimental values would be evident. Instead of water, mineral oil or other solvents in which these salts are insoluble work nicely. Another advantage of using these salts is the fairly wide range between their density value. This makes it easy for students to discern between the two salts. Concepts that relate to the density determination include solubility, atomic structure and mass, and volume.

Crystalline Form

Observing the salts under a microscope of modest power (i.e.; 40×) is another simple and effective way to discern between these two salts (*2*). The cubic geometry of sodium chloride is strikingly apparent and clearly contrasts with the non-cubic geometry of potassium sulfate. A mixture of hexagonal and rhombic geometries is observed with crystalline potassium sulfate under the microscope. Atomic structure and bonding are involved in the conceptual framework of this method.

Electrolysis

When an electrical current is passed through aqueous sodium chloride, a chemical change takes place. The electrolysis of aqueous sodium chloride produces chlorine gas at the anode. Most students who have gone swimming in chlorinated pools recognize the familiar "sharp" odor of chlorine. In contrast, the electrolysis of potassium sulfate produces no chemical substances having detectable odors, enabling the two salts to be distinguished from each other. A simple and inexpensive electrolysis apparatus has been described (*3*). Electrolysis involves the concepts of electricity, atomic structure, solubility, chemical change, bonding and dissociation, and ions.

Melting Point and Flame Tests

Determination of the salts' melting points and their colors in a flame can strengthen the argument for identification. When a few crystals of sodium chloride on a metal spatula are held just above the blue cone of a Bunsen burner's flame, slow melting and congealing of the salt is observed. Slow melting occurs when the spatula's tip is red-hot for about 15 s. A prolonged, bright yellow flame is noted when heating is initiated. A Bunsen burner flame is not hot enough to melt potassium sulfate. Small crystals are observed to bump and to remain solid minutes after the spatula tip is red-hot. Upon heating, a violet flame is seen only for a short time. *The Merck Index* (*1*) cites the melting points of sodium chloride as 804 °C and potassium sulfate as 1067 °C. Flame tests for various cations often are found in students' textbooks or investigated in separate laboratory manuals. Melting points and flame tests involve an understanding of physical change, heat, atomic structure, and energy.

Qualitative Cation Tests for Potassium, Chloride, and Sulfate Ions

Identifying the ions in the salts can lead to the identification of the respective salts. This is done easily by performing specific chemical tests that have been documented in texts on qualitative analysis of inorganic chemicals (*4*, *5*). These tests involve the conceptual ideas of chemical change, writing equations, nomenclature, reaction classification, acids and bases, and solubility. Once again these tests should be done prior to this activity so that students understand the reactions, know how to carry out the procedures, and know which observations indicate a positive test.

Conclusion

Because there are many ways to know and construct knowledge, students should be given a chance to solve a chemical problem in a variety of ways using what they have learned and the science materials they have used in their chemistry class. Given an opportunity to work in such a manner, most students seem to enjoy being creative and devising their own solutions if the challenges are within their capabilities. With this in mind, an activity has been devised that allows students to draw upon a myriad of concepts and techniques in order to construct arguments to solve a grade-appropriate problem. By doing so, students are made aware of the importance of the argument and how the nature of the argument gives meaning to the solution. In this activity, students construct experiments to test their ideas, then discuss the concepts that underlie their methods, and finally find other ways to reaffirm their hypotheses through the literature and by other experiments. After the experimental work, students can be steered into discussion and debate about which arguments are the most persuasive—an activity that is characteristic of the scientific community. More specifically, a discussion concerning a test's reliability, sensitivity, experimental design, and the concepts of uncertainty, precision, and accuracy can be raised. Lastly, deciding which tests are more efficient can be argued.

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