

Density Determination by Water Displacement and Flotation: An Introductory Experiment in Forensic Chemistry

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We present an experiment that explores several methods of density analysis and their practical applications in criminal investigations. The experiment is designed for a non-majors course in forensic chemistry; however, it requires little specialized equipment, so it could be implemented in general chemistry or high-school laboratory courses.

Since the mid-1980s, several introductory experiments involving the densities of liquids and solids have been published in this *Journal* (1–6), including recent applications to bowling balls (1) and beverages (2, 3). This subject presents a unique opportunity to enter the world of the forensic scientist. It is employed as the first experiment in the forensic course, because it introduces students to common laboratory equipment and measurements.

The density (d) of an object can be determined by dividing its mass by its volume (m/V). Students in most introductory laboratories have access to the analytical balances required for accurate, precise measurement of mass. Direct calculation of density works well for regularly shaped objects, whose volumes can be calculated directly. In the case of an irregularly shaped object, an indirect method is required. This experiment introduces students to two such methods: water displacement and flotation.

Archimedes's principle states that an object immersed in a fluid displaces a volume of fluid equal to the object's volume. If the density of an object is greater than that of water, then it is possible to determine the object's volume by immersing it in a known volume of water and measuring the change in volume due to displacement of water by the object.

The forensic scientist is often faced with the challenge of determining whether two very small pieces of evidence, such as slivers of glass, have a common origin (7). One approach is by determining the relative densities of the two objects. This comparative method, known as flotation, is a precise and rapid method capable of distinguishing glass particles that differ in density by 0.001 g/mL (7). The first step in a flotation analysis is to prepare a liquid mixture whose density matches one of the pieces of evidence. A second piece of evidence of approximately the same size and shape is then added to the liquid. If both particles remain suspended in the liquid, their densities are equal, indicating a possible common origin. If the second particle either sinks or floats, the possibility of a common origin is ruled out.

Experimental Procedures and Results

This is designed to be a 2.5-hour laboratory experiment. Each student keeps a detailed lab notebook.

Density Determination by Water Displacement

The first part of the lab involves calculating the density of some common, irregularly shaped objects such as rubber

stoppers, pen caps, and jewelry by water displacement. Each group of students selects two such samples from an assortment of items, some of which are inappropriate for this method of analysis and are included to draw students' attention to its limitations. As they make measurements, the students become familiar with the use of the laboratory balances, graduated cylinders, and other common laboratory equipment, as well as simple calculations of density. Students also discover there are drawbacks to the water-displacement method.

Students quickly notice that it is difficult to measure the volume of water displaced by a small object such as a silver earring using conventional graduated cylinders. Consequently, they can report density values for some objects to one digit only, which is of little use.

When a student group chooses an item that floats on water, it prompts the group members to discuss whether it is appropriate to use the displacement method. Most student groups conclude that the entire object must be submerged in order for the water displacement to equal its volume. Whether the group deduces this on their own or with instructor assistance, we then introduce the idea that one could use a different liquid, of lower density than the object itself; however, we do not do this experiment with liquids other than water. Instead, the group is allowed to choose another, denser object for the displacement analysis.

Comparison of Simulated Tire Evidence by Flotation

Students are given evidence bags from a hit-and-run accident. Each group is told that they have tire samples from the "accident scene" and from a "suspect vehicle". The "tire" samples are actually small (3 mm \times 5 mm) pieces of two different types of black rubber laboratory tubing. Berry has published an experiment where students match the density of pieces of rubber tubing by mixing water and alcohol (8), but we take a simpler approach.

Students examine the evidence visually, sketch the tire fragments and look for common physical characteristics prior to performing the flotation analysis. We note that, although the students know that the samples do not come from a real crime scene, they accept without question that the samples are tire fragments. cursory visual examination of these samples by someone with experience with tires would indicate otherwise.

Students then place each sample in a graduated cylinder containing a 50% (v/v) solution of 95% ethanol and water (solution density = 0.90 g/mL). One sample floats and the other sinks, demonstrating that the samples are not of the same density and, therefore, could not have originated from a common source. This simple illustration of density comparison by flotation is followed by a more complex analysis of glass and clear polymers.

Comparison of Simulated Headlamp Evidence by Flotation

The objective of this part of the experiment was for students to match “suspect” samples to “crime scene” evidence by flotation analysis. We use glass and clear rigid polymers to represent car headlamp fragments obtained from a simulated hit-and-run accident. The polymer sources come from a car headlamp, a polystyrene cuvette, and an audiocassette case cover. Glass sources are a large test tube and a piece of plate window glass. Because the densities of the glass fragments differ significantly from nonglass polymers, a two-part analysis, demonstrating two different methods of flotation comparison, has been developed.

The first step is a visual examination of the evidence. Students note, for example, that the widths of some fragments differ, some of the samples “look like plastic” and others “look like glass”. The density analysis then begins with sequential immersion of fragments in a saturated solution of sodium chloride. All of the polymer samples float; all of the glass fragments sink.

Next, polymer samples are analyzed via a density-matching flotation method. Students begin by placing a sample in a saturated NaCl solution in a large test tube: the sample floats. Deionized water is then added slowly, with stirring, until the density of the solution matches the density of the polymer fragment, at which point the fragment becomes suspended in the solution. (Students often overshoot this point, their samples sink, and they have to add more NaCl solution.) Once a “crime scene” fragment is suspended, the students can match it with one of the fragments from “suspect” vehicles, by adding fragments from different evidence bags until one is suspended alongside the fragment from the “crime scene”. We note that it would be possible for students to measure the density of the resultant solutions; however, this would require introduction to the accurate use of volumetric pipets that would lengthen the experimental time required, so we have not included this in the experiment.

The glass samples are analyzed via a modified flotation method. Bromoform ($d = 2.89 \text{ g/mL}$) and bromobenzene ($d = 1.52 \text{ g/mL}$) are commonly used in flotation analyses of glass fragments (8–10). Because these chemicals pose human health hazards, we do not have students mix them. Instead, a density-graduated series of seven bromoform–bromobenzene solutions was prepared (9, 10). Working in a fume hood, students add a sample of glass to each of the bromoform–bromobenzene solutions and note whether the sample floats or sinks. For the glass samples employed in this experiment, separation occurs in the 67% bromoform solution. If appropriate safety precautions either cannot be taken or are unlikely to be followed in a particular laboratory classroom, this part of the experiment should be omitted.

Hazards

Ethanol has an NFPA health rating of 3: flammable liquid. The flash point of ethanol is 13°C , so it is a Class 1B flammable liquid. Its vapor mixes easily with air, and explosive mixtures can result. Bromoform is known to be toxic to the human nervous system; it is an irritant, lachrymator, and cancer suspect agent. It has an NFPA health rating of 2: may

be harmful if inhaled or absorbed. Bromobenzene has an NFPA health rating of 2 (see above), and flammability rating of 2: combustible liquid. Students must perform the glass flotation analysis involving bromoform–bromobenzene mixtures in a fume hood, wearing gloves and goggles.

Students are warned that the glass and plastic “headlamp” shards might be sharp and that handling these pieces wrapped in lab towels or tissue minimizes the risk of small abrasions.

Conclusions

While performing this experiment, students gain a solid understanding of density and, arguably more important, experience with basic lab skills. Students are introduced to the proper use of lab equipment, including analytical balances, graduated cylinders, and test tubes. They gain experience in manipulating samples, including work in a fume hood, and making careful observations about physical evidence. Students can find the density-matching experiments to be tedious, and many are surprised how careful one must be to obtain reliable results, but the “crime scene” aspect of the experiment appeals to them. Indeed, no negative comments on this experiment have appeared on end-of-course evaluations in either of the two terms in which the course has been taught.

Densities of liquids vary with temperature. Although we present this information to the students in postlab discussion, we do not make any effort to control temperature during the experiment.

Another application of flotation involves the use of a density-gradient tube, prepared by filling a large tube with layers of two liquids mixed in varying proportions so that each layer has a different density value (7, 9, 10). Samples of soil are often analyzed using gradient tubes; each soil particle sinks to the area of the tube that has equivalent density. A distribution pattern results that can then be compared with another soil sample to determine whether they had a common origin (7). Because of the time required to prepare a gradient tube, this method was not included in the experiment.

It is important to note that comparison of the density of two pieces of evidence establishes only the **possibility** of common origin; while quite useful in ruling out commonality, it cannot establish a common origin with certainty.

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^wSupplemental Material

Instructor notes and the student handout, with detailed experimental procedures, are available in this issue of *JCE Online*.

Literature Cited

1. Holley, Kathleen; Mason, Diana S.; Hunter, Kirk J. *Chem. Educ.* **2004**, *81*, 1312A–1312B.
2. Herrick, Richard S.; Nestor, Lisa P.; Benedetto, David A. *J. Chem. Educ.* **1999**, *76*, 1411–1413.
3. Henderson, Susan K.; Fenn, Carol A.; Domijan, John D. *J. Chem. Educ.* **1998**, *75*, 1122–1123.
4. Richardson, W. S.; Teggin, J. E. *J. Chem. Educ.* **1988**, *65*, 1013.
5. Hill, William D., Jr. *J. Chem. Educ.* **1987**, *64*, 92.
6. Harris, Arlo D. *J. Chem. Educ.* **1986**, *63*, 718–719.
7. Saferstein, Richard. *Criminalistics: An Introduction to Forensic Science*, 8th ed.; Prentice Hall: Upper Saddle River, NJ, 2004; Chapter 4.
8. Berry, Keith O. *J. Chem. Educ.* **1985**, *62*, 1060–1064.
9. Meloan, Clifton E.; James, Richard E.; Saferstein, Richard. Lab Manual for *Criminalistics: An Introduction to Forensic Science*, 7th ed.; Prentice Hall: Upper Saddle River, NJ, 2001; pp 5, 8, 13, 39–42.
10. Kaplan, Lawrence J. *Chemistry and Crime From Sherlock Holmes to Modern Forensic Science: A Laboratory Manual for an Introduction to the Crime Lab*; Williams College: Williamstown, MA, 2001; pp 44–48.