THE FLOATING EGG PROBLEM
INTRODUCTION

Description
Students work in groups of four to make a salt solution that will "float" an egg (according to their definition of "float"). Each student then determines the density of the group's salt solution by using both a pipet and a graduated cylinder. They compare the results to determine the effect that the volume-measuring device has on calculating the density. Students also explore how the freshness of the raw egg affects their results.

Goals for This Experiment
The goals for this experiment are to have students:
1. practice skills of measuring masses on a balance, measuring volumes with pipets, and making solutions;
2. experience the measurements needed to determine density;
3. compare the design of a simple procedure in response to a question posed by the scenario (For many students this will be their first real experience with experimental design and they may show or express discomfort with the task);
4. report data with the proper number of significant figures;
5. consider the concepts of accuracy, precision, and data analysis; and
6. begin to realize that procedures carried out within an experiment do not "pop from the sky fully formed," but are developed to meet specific experimental goals.

Recommended Placement in the Curriculum
The Floating Egg Problem lab would be best implemented very early in a General Chemistry Laboratory course. This is a good lab to introduce basic laboratory skills (measure, compare, make a solution, use significant figures correctly, analyze data). Very little prior knowledge by the student is required.

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PURPOSE

(1) To answer a question of historical interest using modern measurements.
(2) To determine the way in which different measuring instruments influence the answer obtained.

AN HISTORICAL QUESTION

For many years soap was made at home from a variety of recipes. Usually, tallow or another fat was cooked with a lye solution. Lye was obtained from wood ashes and water. Some lye recipes involved heating wood ashes in water, pouring off the lye solution, and adding this solution to the fat. Another method involved pouring warm water over a barrel (which had been fitted with a drain) filled with ashes and collecting the lye solution that drained through. Both methods required the user to test the concentration of the lye solution before use. One simple test was to try to "just float" a raw egg in the solution. If the egg sank, the concentration of lye in the solution was too low, and it would be poured through the ashes again in hopes of increasing the concentration. If the egg floated too high, the concentration was too great, and water was added before adding the fat.

Your task is to find the answers to the following questions by using the procedures described below.

QUESTION # 1: What is the density (in grams/mL) of the "ideal" solution that the homemade soap makers were aiming to achieve?

QUESTION # 2: In what way does each of the following affect the calculated density or the precision of the calculated density:

(a) the type of volume measuring device used: small graduated cylinder, large graduated cylinder, or pipet?
(b) the degree of freshness of the raw egg?

PROCEDURE

Because lye is caustic and corrosive to the skin, substitute sodium chloride (table salt) for lye in your investigation. Salt, eggs, standard glassware, balances, and distilled water will be available. Other items may be available on request.

Safety note: Sodium chloride solution is not harmful unless it gets into the eyes. If this occurs, flush the eyes with large amounts of water for 15 minutes. All solutions may be poured down the drain with water after use.

I. Preparation of the test solution

Work in a group of four to make a solution that fits the "ideal" criterion.

- Make at least 500 mL of solution.
- Use only one egg for testing.

1: When your group's solution is acceptable, describe briefly in your notebook the procedure you used.

II. Measurements of solution properties

Each person in a group should use a pipet and a 25- or 50-mL graduated cylinder for measuring the volume of solution. Each person in a group should have a different size pipet. You should all use an electronic balance for mass measurements. **Note:** Be sure to record all measurements using the number of significant figures allowed by that instrument.

A. Make at least three separate sets of mass/volume measurements with each piece of volume equipment. (Remember your solution is reusable if you keep it clean.)

B. When using the graduated cylinder, measure the mass of the empty cylinder. Then add some solution, record the volume, and measure the new mass. Repeat this procedure until you have your three sets of measurements.

C. When using the pipet, first weigh a clean, dry beaker. Add measured samples of solution, record the volume, and weigh again. Repeat this procedure until you have at least three good sets of data.

III. Data manipulation (Do before leaving class.)

- Calculate the density from each set of your measurements. Do not combine values for the two types of volume measuring devices. Calculate the mean and standard deviation for each set of data. Be sure to record these values using the proper number of significant figures.

- Collect the calculated density data from the other members of your group into a table. Calculate the group mean and standard deviation for the values obtained by each volume measuring device.

- Collect mean density values and standard deviations from other groups, keeping the graduated cylinder data separate from the pipet data. Also record the degree of freshness of each egg used.

POINTS TO PONDER (Please put answers in your notebook.)

Q 1: What was the density of the "ideal" solution the homemade soap makers were aiming to achieve, based on the data obtained with your egg?

Q 2: How valid is the assumption that aqueous sodium chloride is an adequate replacement for aqueous sodium hydroxide as a means of finding an answer to question #1? Explain your reasoning.

Q 3: What specifically was the effect of the freshness of the egg on the density of the "ideal" solution?

(You might want to refresh your memory about *quality* in measurements by rereading the pages given in the lab materials before you answer the next few questions.)

Q 4: What were the advantages/disadvantages of using each of the different volume measuring devices?

Q 5: Scientists are very careful to report their numerical values to a particular number of significant figures. What was the "proper" number of significant figures to use in each part of your group's report and why?

You were asked to make at least three separate sets of measurements for the volume measuring instrument.

Q 6: How much variation did you find within your own data sets?

Q 7: How did the amount of variation in your data sets compare to what was found by others in your group? the different groups?

Q 8: What is the purpose of repeating measurements?

Q 9: How reliable is this historical process of solution preparation for making soap? How does it compare with modern methods of production?

THE FLOATING EGG PROBLEM
INSTRUCTOR NOTES

Time Required
The laboratory experiment should take approximately $2^1/_2$–3 hours. (The last 30–45 minutes is used for data analysis and sharing of group data.) If necessary, data analysis can be done outside of class.

Group Size
Students work in teams of four to make the "ideal" solution. Each student then works individually to determine the density of the solution and pools data with the rest of the team. Each person in the team should use both a pipet (each person works with a different size pipet—10, 15, 20 and 25 mL are suggested) and a 25- or 50-mL graduated cylinder.

Materials Needed
per team:
- ~ 500 mL of tap water
- 1 egg (fresh or old)
- ~ 200 g kosher salt (see note below)
- 600-mL beaker
- four 25- or 50-mL graduated cylinders
- one volumetric pipet each measuring 10, 15, 20, and 25 mL

Notes:
✔ For best results, use either kosher salt or chemistry lab salt rather than table salt. Table salt has an anti-caking agent (silica) that will not completely dissolve.

✔ Provide raw eggs of differing degrees of freshness, and make sure to mark with a permanent marker which eggs are old and which are fresh. Using eggs of varying degrees of freshness will provide a range of densities for the class to compare. For comparisons to be valid, all groups must use the same definition of "just float."

✔ If students find an egg that floats before any salt has been added to the water, the egg is very old and should be disposed of. (The older the egg, the more gas it contains, and the less dense it is.)

Safety, Disposal, and Special Handling
Eggs can be re-used for another lab section if needed. Review the Material Safety Data Sheets of any chemical used in the experiment for information regarding safety and handling. Dispose of waste according to your local ordinances.

Points to Cover in Pre-Lab

- Introduce the "historical" significance of the scenario.
- Explain what it means "to just float" the egg in the solution. (We have found that some students think "float" means to suspend the egg in the middle of the solution, rather than at the surface.)
- Review or introduce the correct use of a balance and a pipet and pipet bulb.
- Show students the way to read a meniscus.
- Explain to students the difference in accuracy between the graduated cylinder (read to ±1% of the total volume) and the pipet (read to the nearest ±0.02 mL), and the resulting difference in significant figures in measurements.
- Remind students about proper disposal of broken glass.

Likely Play-Out of Lab

This lab includes numerous opportunities to assist students in learning various skills and concepts. Several are described below.

Part I: Preparation of the Test Solution

The teams may go to elaborate lengths to measure the mass of salt that goes into the initial solution. This may slow the progress of the experiment. If this happens, ask students WHY they are measuring the mass...what useful information about the solution will this provide? They may reply that knowing the mass of salt will be useful in determining the density. In this case, clarify the concept of density as a solution property rather than a property of the substances comprising the solution. (Density is a ratio of the mass of salt *solution* to solution volume.)

Part II: Measurements of Solution Properties

Because this is apt to be the first time many of the students will have used pipets, encourage them to practice pipetting with plain water until they can pipet repeatedly without pulling water into the bulb and master the control of liquid flow with their finger so that the meniscus rests on the volume mark. When students understand that the development of this skill is a major goal of the lab, they tend to relax and work to learn the skill without as much stress.

Help the students understand the cumulative nature of the task of using the graduated cylinder. Make sure students understand that while they don't need to use exactly the same volume of solution for each trial, they do need to read the volumes accurately within the limits of the device, and record these volumes.

Some students may use the pipet to fill the graduated cylinder, and then place the graduated cylinder on the balance to get the mass of the solution. You need to remind them that the pipet and the graduated cylinder are both measuring devices and the volume only needs to be measured once, using either the pipet **or** the graduated cylinder.

Part III: Data Manipulation
The directions for calculating the mean and standard deviations are provided on page 6 of the lab book (in the section titled "A Look at *Quality* in Calculations Made From Measurements").

At the End of the Data Collection
Make sure students have the necessary corresponding mass/volume data. Check to see that students subtract the mass of the cylinder each time and that they use the accumulated volume if they are measuring the accumulated mass.

Make sure students use the correct method for calculating the standard deviation of the team's results. Students often want to average the standard deviations found by each member of the group. They need to realize the standard deviation of the team is calculated using each member's individual mean and the deviation from the group mean.

Possible Answers to the Questions

1. **What was the density of the "ideal" solution the homemade soap makers were aiming to achieve, based on the data for your egg?**
   Answers will vary. Typical student data range from 1.05-1.10 g/mL for new eggs.

2. **How valid is the assumption that aqueous sodium chloride is an adequate replacement for aqueous sodium hydroxide as a means of finding an answer to question #1? Explain your reasoning.**
   Assuming no reaction occurs between the egg and either of the two solutions, you would expect the egg (whose density is not altered in the process) to exhibit the same physical behavior in two solutions with the same density.

   In reality, few students will have the degree of chemistry knowledge to express the above response. Our goal in asking the question is to challenge students to begin thinking about these details. We tend to accept a variety of responses, as long as their reasoning makes some sense.

3. **What, specifically, was the effect of the freshness of the egg on the density of the "ideal" solution?**
   Extremely old eggs will float in water when little or no salt has been added. The older the egg, the more gas it contains and the less salt needed to make it float. Therefore, older eggs will tend to require a solution with a lower density to "just float" them.

4. **What were the advantages and disadvantages of using each of the different volume measuring devices?**

graduated cylinder

advantages
- easy to use
- quick

disadvantages
- not as accurate as a pipet

pipet

advantages
- accurate

disadvantages
- difficult to use for beginners
- skill is needed to get precision
- time involved in getting a good measurement

5. **Scientists are very careful to report their numerical values in a particular number of significant figures. What was the "proper" number of significant figures to use in each part of your group's report and why?**

   If the students use electronic balances and record the mass of the solution up to the hundredths place, the students can include up to four significant figures in their answers.

   The answers to this question will vary depending on the size of pipet and cylinder used. Students should recognize the relationship between the number of significant figures in the measurement and in the reported density value.

6. **How much variation did you find within your own data sets?**
7. **How did the amount of variation you found compare to what was found by the others in your group? The different groups?**

   Answers will vary. Students should be consistent with the data reported and should provide a meaningful number. This gives you and the students a chance to reflect on the numbers obtained in relation to the quality of measuring done.

8. **What is the purpose of repeating measurements?**

   Repeating measurements provides more data to compare. Students can examine their precision and relate this to their technique (the better their technique, the more precise their measurements should be).

9. **How reliable is this historical process of solution preparation for making soap? How does it compare with modern methods of production?**
   - The method is not very precise and often leads to a large excess of lye in the soap. Modern soap manufacturers typically employ a procedure that considers the stoichiometry of the system, thus minimizing the excess of lye.
   - In the old method, several variables are difficult to control (e.g., the concentration of the solution, the impurities in the solution).
   - Using the old method, the process would vary in yield of soap and amount of excess lye.

Students will probably recognize the lack of reproducibility of measurement here. They may not be able to compare with modern methods if they do not know or cannot imagine what the modern methods are.

Instructor Suggestions

- We suggest that you use 10-, 15-, 20-, and 25-mL volumetric pipets. If 5-mL volumetric pipets and electronic balances are used, the calculated density will only have three significant figures (since the pipet measures 5.00 mL of solution). This may create confusion when calculating the group mean since all densities will have four significant figures except the density calculated using the 5-mL pipet. Since this lab is early in the course, it is best to avoid the confusion altogether by not using 5-mL pipets.

- An essential element to the success of this lab is the availability of a variety of volumetric measure devices. Comparisons of variance will be much more meaningful if a variety of devices are employed. For example, a volumetric pipet has more accuracy than a graduated cylinder (they read to the nearest ±0.02 mL and ±0.1 mL respectively).

- Perhaps the largest source of frustration comes from the students' inability to actually perform the necessary procedures to determine the ideal density (e.g., they failed to realize that all they needed to do was "dump" in salt until the egg floated). Students often become absorbed in attempting to determine the exact mass of salt added to the solution, which is not even needed to determine the density.