GAS LAW INVESTIGATION

INTRODUCTION

Description

This experiment requires two lab periods. In the first lab, students investigate the reaction of an Alka-Seltzer® tablet and water to determine the variables that affect the amount of gas produced from the reaction. Students also become familiar with the use of the gas collection apparatus. In the second lab, students pick from one of two scenarios. Each scenario involves a gas evolution experiment. Students use the gas collection apparatus from the first lab to collect data.

Goals for This Experiment

The goals for this experiment are to have students:

1. work with reporting data in the proper number of significant figures;
2. experience the measurements needed for the determining the amount of gas produced by a chemical reaction;
3. determine the variables that affect the amount of gas produced when an Alka-Seltzer® tablet is dissolved in water;
4. design and modify a procedure in response to a question posed by the scenario;
5. practice good laboratory procedures (GLP) which include keeping a record of everything they do (even though it may not seem important at the time) and the results of their actions;
6. consider the concepts of accuracy, precision, and data analysis; and
7. write a report that details their procedure, results, and any conclusions they make.

Recommended Placement in the Curriculum

The Gas Law Investigation laboratory experiment should be implemented late in the first semester. It is not necessary to have covered the concept of gases in lecture before this laboratory experiment; however, an introduction to gases in lecture is helpful to students. (We used this experiment as the final lab in the first semester of General Chemistry Laboratory.) Prior experience with the design and modification of a procedure is needed. Students should also have experience with burets, significant figures, precision, and accuracy.

GAS LAW INVESTIGATION

BACKGROUND

Evolution of a gas allows you to observe that a chemical or physical change has occurred. With the appropriate equipment, we can measure the volume of gas evolved and use our understanding of the quantitative relationships among volume, temperature, pressure, and the amount of gas to study reactions of chemical systems. In this experiment, you will work to solve laboratory problems that involve gas evolution. In order to accomplish this, you must first become familiar with the laboratory techniques needed to follow a reaction involving gases. Once you have identified the variables that must be considered and have perfected the skills necessary to make quantitative measurements of gases, you will have the scientific tools needed to work on your scenario problem in Part III.

PART I: INVESTIGATION OF A HOUSEHOLD CHEMICAL SUBSTANCE

A scientist who begins a new laboratory project first "messes around" with a known reaction that will provide background knowledge for the new project. Once the scientist has identified the variables to work with, she/he must develop the techniques necessary to control and manipulate those variables in order to gain the kind of data needed in the project.

You will begin your scientific investigation of gas analysis by working with antacid tablets and water. The goal of Part I is to identify the variables that affect the measurement of the amount of gas produced in the chemical reaction and to estimate the volume of gas/tablet ratio value. You should work alone in this part, but have a partner nearby with whom you can share observations and interpretations.

Materials needed:

- balloon
- narrow-mouth Erlenmeyer flask or bottle where the balloon opening can be stretched and fitted over the mouth of the bottle or flask
- graduated cylinder
- water (For Part I, tap water will be fine.)
- 2 packets of Alka-Seltzer® tablets

General Procedure:

To observe the reaction of Alka-Seltzer in water, the following procedure is suggested. You may modify and repeat it as necessary, but you should collect data to help you reach the goal of Part I. **Be sure to take time** to discuss your observations and thoughts with others and your instructor.

1. Pour about 100 mL water in the bottle.

2. Dry the outside and top rim of the bottle. Also be sure your hands and the balloon are dry.

3. Place one dry Alka-Seltzer tablet inside the balloon. It may be helpful to break the tablet into pieces after it is inside the balloon so that the pieces will easily fall into the bottle at the start of the reaction.

4. Make sure that all the Alka-Seltzer pieces are in the bottom of the balloon, and twist the middle of the balloon to keep the Alka-Seltzer away from the water in the bottle. Carefully stretch and fit the opening of the balloon securely on the top of the bottle.

5. After the system is assembled, start the reaction by untwisting the balloon and allowing all of the Alka-Seltzer tablet pieces to fall into the water in the bottle. During the reaction make sure the balloon is securely attached to the neck of the bottle; you may need to hold the balloon in place.

➡ Record the following in your notebook: your set-up, the results you observe, and thoughts you have about what is happening. In this exploratory phase, it is VERY important for you to record details that you may or may not think important. You will use the results of these tests to design an experimental procedure to solve the scenario problem you choose to take on.

6. Repeat the procedure, making any necessary modifications, until you believe you can identify the variables that affect the amount of gas produced and measured by this reaction.

Ask your soon-to-be-partner to help you choose a reasonable estimate of the *volume of gas per tablet* ratio. Record your estimate in your notebook.

Check your list of variables and your estimated ratio with your instructor before going on to the second part of this investigation.

PART II: COLLECTION AND MEASUREMENT OF GASES IN A GAS BURET

The goal of Part II is to develop a technique for gas collection using the apparatus described below. The technique you develop must be *reliable and precise* for measuring the volume of gas evolved during a chemical reaction between Alka-Seltzer® and water. You should work with a partner for Parts II and III.

A. The Collection Apparatus

A gas buret or gas collection apparatus is illustrated in Figure 1.

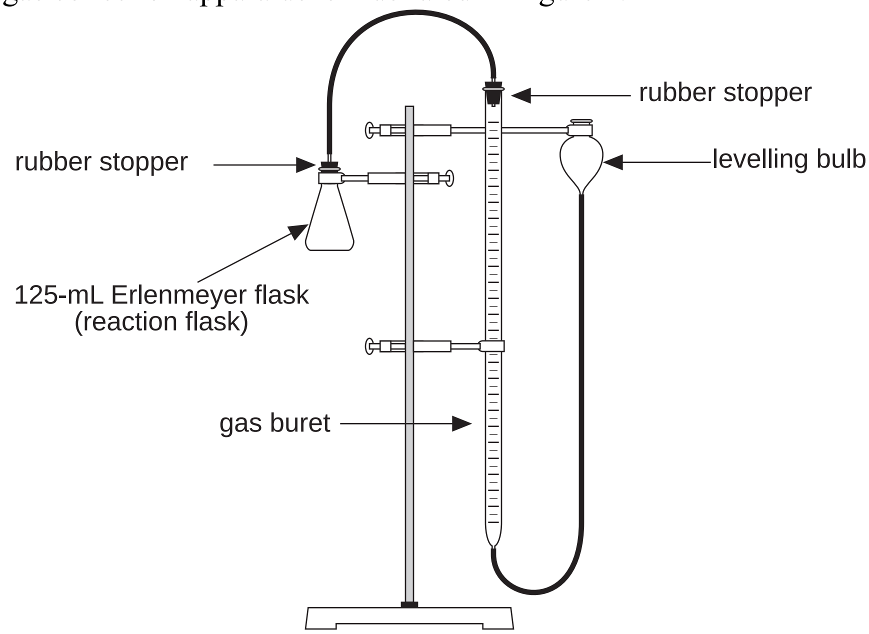

Figure 1: Gas buret apparatus

B. General Information You Need to Think About as You Plan Your Next Step

About the equipment

- Initially, the buret and leveling bulb contain water (or water saturated with the gas to be collected). The gas generated in the flask bubbles into the buret, displacing some of the liquid, which allows the volume of gas produced to be measured.

- Since the volume of gas generated is measured in a buret, the volume accuracy matches that of buret's. (The volume of gas generated can not exceed the buret volume and still be accurately measured. Reagent amounts should be adjusted to give about 40 to 80% of the buret volume.)

- The rubber stoppers at the top of the flask and buret must be tight enough to prevent gas from escaping. (Tight seals give stable liquid levels upon raising or lowering the leveling bulb.)

Some suggested techniques for successful measurements

- Unless you are very fast, a special design is necessary that will allow reagents to be mixed after gas-tight seals are in place. One approach is to place one reactant in a vial or small plastic bag inside the flask. The flask is then tipped to spill the contents, which starts the reaction. Alternatively, a solid such as an Alka-Seltzer tablet might be released from a thread or tissue holder.

- If the levels of liquid in the buret and leveling bulb are equal, the volume measurement is made at the barometric pressure. The pressure of the gas collected also includes the partial pressure of the water over which it is collected. This correction requires knowing the temperature of the water and the values for the vapor pressure of water at that temperature. A Table of Water Vapor Pressures is provided in your lab manual.

- Some gases, such as carbon dioxide, dissolve in water and other liquids to a large extent. Different techniques might be used to correct for this. For example, samples of the gas may be bubbled through the solution to saturate the liquid before analysis. The volume of the solution may be noted and a correction from a handbook applied. The amount of carbon dioxide dissolved in cold water (0°C) is listed as 1.71 mL per mL of cold water; the solubility of carbon dioxide in warm water (20°C) is listed as 0.9 mL per mL of warm water. (CRC Handbook of Chemistry and Physics, 67th Edition, CRC Press, Inc. 1986–7, p. B-82.)

Ask some classmates to help you decide on answers for the following questions.

Q: In what ways is the procedure you used in Part I similar to the task you'll accomplish in Part II?

Q: Based upon the general information given in II.B, what variables in equipment are critical for successful collection of a gas evolved during a chemical reaction?

C. Procedure

1. Design a procedure to use with Alka-Seltzer and water to test the equipment and develop your technical skills.

2. Try your procedure and modify it until you have confidence that your method is reliable for the job at hand.

3. Keep a written record of your methods and results. All these data will be needed for your final project.

PART III. THE SCENARIOS TO BE SOLVED

A. Preliminary Directions

Two laboratory scenarios are described in the following sections. These problems have different settings, but both involve gas evolution experiments. You will work on one scenario with a partner; therefore, you and your partner should begin planning how to approach and solve your chosen problem. All actual laboratory work will be done during the next laboratory period. Although you will work in pairs to solve the problem in your scenario, unless otherwise directed, each person is required to turn in an individual report. The exact form of the report depends upon the instructions from your instructor and the problem in the scenario. General guidelines can be found in your notebook, pages 9–10.

- Present data and results clearly for all scenarios.
  - ➢ Define the task in your own words.
  - ➢ Describe briefly, but completely, the procedure you followed to collect and process the data.
  - ➢ Present your data in a table, if possible.
  - ➢ Discuss the results with respect to your scenario. Be explicit in describing what the data says about the problem. Explain your reasoning as if you were reporting results to a client.

- Following the scenarios are additional readings that will be helpful in planning your laboratory investigations. Read the one relevant to the scenario you will investigate and discuss the information with your partner as you design your experiment. Throughout all of your deliberations, keep in mind the information you gained in your previous procedures regarding the requirements and limitations of your equipment.

B. Scenario Descriptions

1. Amount of Glucose in Cereals

As a dietitian, you have clients that need to know **how much glucose is in a given sample of ready-to-eat breakfast cereal.** Most cereal packages describe sugar collectively by giving the gram amounts of sugar in a single serving; this sugar amount can include sucrose, glucose, fructose, other sugars and, once milk is added, lactose. You know that yeast cells from baker's yeast contain enzymes that ferment glucose to ethanol and carbon dioxide. This reaction might be faster than other enzyme reactions (such as the reaction in which starch is cleaved into glucose), so you use the reaction of yeast with cereal samples to determine how much glucose is in various cereal samples. **How good of an analysis method is this for glucose in cereal?**

2. Is Flooded Alka-Selzer® a Washout?

A warehouse for a large discount chain had standing water on the floor of the warehouse due to spring flooding. The bottom pallet of Alka-Seltzer was directly exposed to water (the packaging is wet) and is definitely a loss. Samples of Alka Seltzer tablets from the pallets that were in the flooded warehouse but not directly exposed to water have been returned to the manufacturer.

Should the tablets on these pallets also be declared a loss? Design an experiment to accurately measure how much sodium bicarbonate is present in the returned tablets so you can **determine whether they are as effective as new or if they must be discarded.**

C. Additional Readings

1. For Scenario 1: Amount of Glucose in Cereal

Yeast cells contain many enzymes. Some of these are catalysts in the fermentation of glucose (a six carbon sugar), which yields ethanol and carbon dioxide. Remember, yeast cells are important in the wine and beer industries where ethanol preserves fruit juice or grain mash, as well as in the baking industry where carbon dioxide evolution provides leavening for baked goods. The overall reaction is:

$$C_6H_{12}O_6 \xrightarrow{\text{enzymes in yeast}} 2CH_3CH_2OH + 2CO_2$$

$$\text{Glucose} \xrightarrow{\text{enzymes in yeast}} \text{Ethanol} + \text{Carbon Dioxide}$$

180.16 g / mole — 46.069 g / mole — 43.999 g / mole

Since this reaction uses enzymes, several factors need to be considered. This reaction may have an optimal temperature (about 40°C). Reactions at temperatures lower than this may be quite slow, while temperatures that are too high may kill the cells and make the enzyme catalysts completely inactive. (A warm water bath might be devised to prevent this.) Another consideration is specificity; the fermentation of glucose to ethanol and carbon dioxide should ideally be fast and complete. (Another researcher has monitored similar reactions using 0.15 grams glucose and 1.0 gram of bakers yeast in about 10 mL water at about 40°C and claims the reaction is complete in 10 to 15 minutes.)

Sources of sweetening in cereal may be table sugar, a disaccharide composed of one glucose and one fructose; honey, often higher in fructose than glucose; and high fructose corn sweetener, also higher in fructose. (Fructose is a ketose, and will not react exactly the same as glucose, an aldose.) Dry active bakers yeast, glucose, and cereal samples including corn flakes and frosted corn flakes will be available in the laboratory. If you want to analyze other ready-to-eat cereals, these samples may be brought to lab for analysis. CEREAL SAMPLES MAY NOT BE CONSUMED IN THE LABORATORY OR BE REMOVED FROM THE LABORATORY AND CONSUMED LATER.

2. For Scenario 2: Is Flooded Alka-Seltzer a Washout?

The walls of the stomach contain cells that produce hydrochloric acid to aid in food digestion and suppress bacterial growth. The acid concentration is approximately 0.14 M. Sometimes, under stress or when extra food is consumed, these cells may produce excess acid which causes discomfort. An antacid is a compound that can decrease the discomfort by neutralizing excess acid.

Antacids need to be mild and/or react only with excess acid since reducing the acid concentration too much can promote greater acid production. One over-the-counter antacid, Alka-Seltzer®, contains solid acids and a solid base that react in water to form a weaker acid and weaker bases. One weak base, sodium citrate, neutralizes the excess stomach acid and provides relief from excess acid. The other weak base, sodium acetylsalicylate, mostly provides pain relief; it is the sodium salt of aspirin. The weaker acid, sodium bicarbonate, spontaneously liberates carbon dioxide, a gas, providing tart tasting bubbles and evidence of the reaction.

Flooded Alka-Seltzer tablets will be available in the laboratory. Solutions already prepared for use include 1.0 M and 6.0 M hydrochloric acid solution. Other solutions may be available upon request.

PLANS FOR YOUR GAS ANALYSIS INVESTIGATIONS
Pre-Lab Assignment for Week 2

GROUP MEMBERS:

SCENARIO PERFORMING:

I. Write a statement of the purpose of your particular investigation.

II.
A. Identify the following:
1. the variable whose values you will manipulate

2. the units in which the variable values will be expressed

3. probable sample sizes you expect to try

B. Identify the following:
1. the responding variable whose values you will measure

2. the units in which the variable values will be expressed

C. Identify the other variables of your procedure whose values you must keep constant.

III. List the expected steps of your investigative procedure.

YOU MUST TURN IN THIS PROCEDURE REVIEW AND PLAN OF ACTION TO YOUR INSTRUCTOR AT THE BEGINNING OF THE LABORATORY PERIOD TO GAIN PERMISSION TO WORK IN THE LABORATORY. Feel free to talk with your instructor before class meets about your plan.

GROUP MATERIALS REQUEST FOR A SCENARIO

Please note: These plans must be returned to the instructor for processing in advance of the time you need the equipment so that lab personnel can do the work needed for all students. For students in a Tuesday laboratory, these plans must be returned by Thursday noon of the week before the experiment is to be performed. You will not be permitted to enter the laboratory if this form is not completed and turned in on time.

Name of group members:

Scenario:

Special Equipment and Materials needed (other than what is in your lab desks):

Reagents and/or solutions needed (please state minimum quantity needed):

GAS LAW INVESTIGATION
INSTRUCTOR NOTES

Time Required
The laboratory experiment is designed to be completed in two weeks. During the first week, students explore the chemical reaction of Alka-Seltzer® and water to become familiar with the gas collection apparatus. Pre-lab discussion takes approximately 30 minutes and students spend around 2–2 $^{1}/_{2}$ hours in the laboratory. The second week's pre lab discussion lasts about 30 minutes and students spend the rest of the time in the laboratory (~2–2 $^{1}/_{2}$ hours) completing and refining their experiment.

Group Size
Students work in teams of two throughout the two-week experiment. The first week, each partner should complete Part I: Investigation of a Household Chemical Substance individually. This gives the team more data to discuss. Both Part II: Collection and Measurement of Gases in a Gas Buret and Part III: The Scenarios to be Solved should be completed as a team. Team members should take turns reading and collecting data so that each student gains experience performing the experiment and feels he or she has ownership of the data.

Materials Needed
First Lab Period
per student:

- 1–2 balloons
- narrow-mouth Erlenmeyer flask or bottle where a balloon opening can be stretched and fitted over the mouth of the bottle or flask
- water
- 100-mL graduated cylinder
- 2 packets of Alka-Seltzer® tablets
- measuring tape (or string and a ruler with metric units)

per team:

- a gas buret collection apparatus, consisting of
    - 50-mL gas-collecting buret
    - leveling bulb
    - 125-mL Erlenmeyer flask
    - 2 ringstand clamps
    - 2 pieces of rubber tubing
    - #5 1-hole rubber stopper (for the Erlenmeyer flask)
    - #00 1-hole rubber stopper (for the buret)
    - L-shaped piece of glass tubing (must fit into the #00 1-hole stopper)

  (For set-up see the diagram in the lab write-up.)

- thermometer
- 2–3 packets of Alka-Seltzer® tablets
- string (have on hand, but let students realize they need this—there are hints in the lab handout) and/or tissue paper

Second Lab Period

Both the materials and the amounts depend on the number of teams that choose each scenario. Amounts listed are per team for each individual scenario. Also, as students experiment, they may request materials that are not listed below. Usually the materials they request are common and are available. Otherwise, substitute a similar item.

Amount of Glucose in Cereals

per team:

- gas collection apparatus (as detailed above)
- 12–15 g Baker's yeast (Most groups use ~1 g per trial and perform 12–15 trials.)
- 100 g unsweetened cereal, i.e., Cheerios®, Corn Flakes. (Most groups use 2–5 g of cereal per trial.)
- 100 g sweetened cereal, i.e., Frosted Cheerios, Frosted Flakes. (Most groups use 2–5 g of cereal per trial.)
- hot plate
- string and/or tissue paper
- thermometer

Is Flooded Alka-Seltzer® a Washout?

per team:

- gas collection apparatus (as detailed above)
- 2 packets of "good" Alka-Seltzer® (possibly more)
- 1 packet of "flooded" Alka-Seltzer® (possibly more)

made available to the class:

- 1 L of 1.0 M acetic acid: To 800 mL of distilled water, ***slowly add*** 60 mL of glacial acetic acid. Dilute to volume with distilled water.
- 1 L of 6 M HCl: To 400 mL of distilled water, ***slowly add*** 500 mL of concentrated hydrochloric acid. Dilute to volume with distilled water.

Notes:

✔ A generic brand can be substituted for the Alka-Seltzer® tablet if cost is an issue.

✔ To "flood" Alka-Seltzer® tablets, open and let them sit out overnight. The "good" Alka-Seltzer® tablets were left unopened.

Safety, Disposal, and Special Handling

Everything from Week 1 can be flushed down the drain. Unreacted yeast and cereal needs to be filtered out of the solution and disposed of in a solid waste container. The solution can then be flushed down the drain.

Points to Cover in Pre-Lab *(First Lab Period)*

- It is not necessary to have covered the concept of gases in lecture before this laboratory experiment; however, an introduction to gases in lecture is helpful to students. You may want to remind students that molecules are very small and elusive, and gas molecules can easily leak out of small spaces or a container if not sealed tightly (an example is the shrinking of a helium balloon over time).
- Suggest that students spend 45 minutes maximum on Part I, then move on to Part II. They need to be sure they understand how to use the gas collection apparatus. Point out that when first developing a technique, precision isn't critical. However, it becomes very important when collecting data.
- Remind students that they should write down everything they do in lab. Even if something doesn't seem important at the time, it may become important later.
- Tap water can be used during the first week since the main goal is to develop a technique for measuring the amount of gas evolved in the reaction.
- Show students an example of the gas collection apparatus and point out to them the leveling bulb. Instruct them on how to use the leveling bulb and tell them that it must be leveled before *every* reading in order to make the reading valid.

Likely Play-Out of Lab *(First Lab Period)*

Part I: Investigation of a Household Chemical Substance

The students will usually begin with one Alka-Seltzer® tablet in the flask. Usually, students will compare the volume of gas produced when they vary the tablet size (i.e., the amount of gas produced with one tablet versus two tablets) and the amount of water. Some students may choose to investigate the effect of the temperature of water. A few students may even explore the effects of re-using water. They need to have you check their list of variables that they have identified as the variables that affect the amount of gas collected. This is a good way for you to ask questions to get the students to think about the solubility of a gas in water (if they haven't thought about it themselves). You can ask leading questions such as:

- What gas do you think is being produced? (They can look at the ingredients for a hint.)
- What do you know about the properties of carbon dioxide? (You can remind them that carbon dioxide gas is responsible for the "fizz" in soft drinks.)

Eventually, the students will realize that some of the carbon dioxide being produced is dissolving in the water. To accurately measure the amount of gas produced, the water must be saturated with carbon dioxide before beginning measurements. This can be done by simply placing a tablet of Alka-Seltzer® into the water and letting it react.

Even though carbon dioxide's solubility in water may be discussed, many times students don't use this information in Part II. Remind them of what they discovered in Part I. Students may not have learned this, however, so leading questions like those mentioned above may need to be asked.

Part II: Collection and Measurement of Gases in a Gas Buret
The main purpose of Part II is to introduce the students to the gas collection apparatus. They need to have time to become familiar and comfortable with the equipment so that it is not an issue the next week when they are trying to solve the scenario. Students usually do the first experiment with an entire tablet of Alka-Seltzer®. However, they quickly find that one tablet produces much more gas than can be measured by the apparatus. Next, they usually try half a tablet or less. An ideal sample size is approximately one quarter (approximately 1 g) of the tablet.

At first, students will simply drop the tablet or piece of tablet into the reaction flask. You may need to ask them if they think the reaction has started before they stopper the flask and remind them that gas particles are extremely small. Ask them if they think any particles could escape before the flask is sealed. Some students will think they are fast enough, but they must have very fast reflexes in order to be quick enough to not let any gas escape. Ask them how they think they could put the tablet in the flask but not have the reaction start until after the flask is sealed. One method could be to tie a string around the tablet and have the tablet suspended above the water. Once the flask is sealed tight, it can be tipped to allow the water to come in contact with the tablet. As the tablet reacts, it will decrease in size until it is small enough to slip out of the string and fall into the water. Students may come up with another method that works just as well.

You may need to remind students of the solubility of carbon dioxide in water and ask them how they can eliminate this problem.

Tip: If the water level in the buret fluctuates up and down, there is a leak somewhere in the apparatus. The most common place a leak occurs is at the top of the buret. We have found that parafilm wrapped around the stopper and the buret will plug the leak.

Points to Cover in Post-Lab *(First Lab Period)*

- Ask students about the solubility of carbon dioxide in water by reminding them of soft drinks. Even though some students may have already thought about this in lab, many still will not have taken this important information into account when using the gas collection apparatus. They must remember that carbon dioxide is fairly soluble in water, and they should take this into account in their experimental design. If they do not, they will not get consistent results the next week.
- Pass out "Part III: The Scenarios to Be Solved." Give students a few minutes to read over the scenarios. You may want to briefly discuss them with the students.
- Pass out the "Plans for Your Scenario Investigation." You will need to tell the students when this information is due. Ideally, they will meet with you before the next lab period so they are

prepared and you can make sure they understand the tasks, approve their procedure, and have all materials they request available in the lab.

Points to Cover in Pre-Lab *(Second Lab Period)*

- Hopefully, students have discussed or have at least been introduced to the concept of gases. If not, a brief discussion in the pre-lab would be helpful.
- Ask students what they learned from last week (that they need to saturate the sample solution with carbon dioxide, how they put the sample into the solution, etc.) This serves to remind them of what they discovered the previous week and it also focuses them on the task at hand.
- If you haven't previously approved the students' procedures, look them over to make sure their plans seem reasonable. One option is to ask the individual teams what their plans are and discuss them as a class.

Likely Play-Out of Lab *(Second Lab Period)*

Part III: The Scenarios to be Solved

1. Amount of Glucose in Cereals

Students have to adjust the sample size and the amount of water to get the desired volume of gas. Students typically performed 12–15 trials. Mostly, the students perfect the procedure by trial and error. Once they get a reproducible procedure, they tend to repeat it for a total of at least three good trials.

Most students start out with too small of a sample. This is not as much of a problem for the sweetened cereals. For Frosted Cheerios, 0.16 g of cereal produced enough gas to be measured (approximately 10 mL of gas). A 1 g sample of Cheerios produced 12 mL of gas. The sample should be crushed to allow the reaction to happen quickly.

2. Is Flooded Alka-Seltzer a Washout?

Again, students have to adjust the sample size and the amount of water to get the desired volume of gas. Students have an easier time with this scenario since it so closely mirrors what they did in lab the week before. Most students performed 6–8 trials and repeated the procedure to yield at least three good trials for both the flooded and the good Alka-Seltzer®.