Lab 6. Comrades, Start Your Airbags

Prelab Assignment

Before coming to lab:

- Use the handout "Lab Notebook Policy" as a guide to complete the following sections of your report for this lab exercise *before* attending lab: Title and Date of Lab, Introduction, Materials/Methods and Data Table(s). The materials/methods may be entered on the left-hand side of the page since your procedure will most likely evolve as you perform the experiment. The finalized procedure should be entered in the right-hand column next to your initial procedure. Ensure that the table of contents of your lab notebook is current.
- Complete the Prelab questions on the last page and hand in at the start of your lab period.

Purpose

Develop a lab protocol while applying the principles of stoichiometry to design a model of an automobile airbag of the *lowest* possible mass containing acetic acid and sodium hydrogen carbonate that fills as completely as possible and as fast as possible when deployed. Each group will hand in their model airbag at least *40 minutes* before the end of the lab period so the performance of each team's model can be judged.

Introduction

Chemists can use concepts like stoichiometry, molar mass, and balanced chemical equations to predict many things about a chemical reaction. You may think that this kind of stuff never leaves the classroom, but virtually everything you can buy at the mall depends on a chemist determining how to mix things up. In industry, where huge amounts of chemicals are used, careful calculations save millions of dollars in chemicals and disposal costs and so they make good economic and environmental sense. The invention of the automobile air bag, for instance, required consideration of not only the chemistry, but economic and environmental factors. Chemists are trained to take this "big picture" approach to problem solving. In this investigation you'll design a model air bag. You'll use the theoretical tools you have learned in class to decide how to optimize the reaction that inflates the bag.

The Chemistry behind Automobile Airbags

The automobile air bag is a remarkable device. It is deceptively simple in concept, but the design requirements of the system are actually very demanding. When a crash occurs, an air bag must inflate rapidly (within about 40 milliseconds), cushioning the occupants against impact. The gas produced must be non-toxic, odorless, and cool enough to avoid burning the occupants. You'd also like the compounds used to be stable, and non-toxic, so they don't expand unexpectedly and are easy and safe to dispose of.

Sensors detect impact and electrically initiate the following reaction to activate modern air bags:

$$2\ NaN_{3\,(s)} \rightarrow 2\ Na_{(s)} + 3\ N_{2\,(g)}$$

Sodium azide (NaN_3) is a stable solid and a small pellet can easily be stored in air bag compartments. The huge volume of nitrogen (N_2) gas is produced rapidly and is non-toxic and relatively cool. Sodium azide itself, however, is pretty nasty. A biologist needs just a few micrograms per liter to prevent bacterial growth in biological preparations. Toxic chemicals like sodium azide are a major concern in landfills where undeployed air bags are discarded.

The sodium metal produced is no peach tree either since it reacts violently with water (and hence your skin!). Fortunately, sodium metal can be transformed into the relatively inert compound $NaFeO_2$ by adding Fe_2O_3 (iron (III) oxide or rust) to the sodium azide pellet. The pellets also contain additives that enhance the rate at which the gas is produced while minimizing the heat. Some formulations are trade secrets, but all require a careful chemical, environmental and economic analysis. These issues, as well as the quest for better and cheaper systems, keep open the search for other compounds and formulations for the gas-producing reaction used in the system.

In this experiment, you will investigate the design of a model airbag system. Because of sodium azide's toxicity, you will be using the reaction of $NaHCO_3$ (sodium hydrogen carbonate or baking soda) with an aqueous solution of CH_3COOH (acetic acid, or vinegar) to produce CO_2 gas. The reaction of acetic acid and sodium hydrogen carbonate is

$$NaHCO_{3\,(s)} + CH_3COOH_{(aq)} \rightarrow CO_{2\,(g)} + CH_3COONa_{(aq)} + H_2O_{(l)}$$

In the lab, the source of $NaHCO_3$ will be baking soda, and the CH_3COOH will be provided by a solution of 3.0 M acetic acid.

Speaking of units... Speaking of 3.0 M acetic acid, the unit 'M' stands for 'Molar' which means, in this case, there are 3.0 moles of acetic acid in every liter of solution. It might also be helpful to know that one mole of any *gas* at room conditions has a volume of approximately *24.4 L at room temperature and pressure (25 ^{o}C and 1 atm pressure)*.

Experimental Design (Work in teams of 2)

The Problem:

Your objective is to use the materials and chemicals listed below to design a model automobile airbag of the lowest possible mass that expands to the *largest possible volume* without breaking the seal on the bag. Before leaving class your team will have to test your design in front of the class. *The best design in the class gets **five bonus points** on their lab write ups, the second place team **two bonus points**, and the third place team **one bonus point**.*

You have limited resources, so plan accordingly. Reserve some of your chemicals and a bag for the final demonstration. All prototype airbag designs must be submitted **at least 40 minutes** before the end of the lab period, must be self-contained, and must be stable enough to not deploy prematurely.

Materials Used per Team of 2	**Chemicals Used per Team of 2**
5 small zip lock bags	100 mL 3.0 M Acetic Acid in a screw-top bottle
Disposable pipettes	Sodium Hydrogen Carbonate (on lab cart)
Metric ruler	
Scoop	
Equipment in your lab drawer	

The Approach

The design is up to you, but here are a few suggestions and things to consider:

1. **Determination of the volume of the Zip-lock Bag**. You will have to devise a way to accurately determine volume of the plastic bag. Neatly record your method in the procedure section of your report and neatly record all your data in a ruled table. Number the table and give it an informative caption.

> **Cautions!** When determining the volume of the plastic bag, remember that nothing in the lab should be placed in or near your mouth. Since you cannot blow up the bag using your lips you must find another way to determine the volume of the bag.
>
> The lab's electronic balance has a *300-gram capacity*: DO NOT place anything above 300 g on the balance as this can cause severe damage to the balance!

2. **Minimum amount of each reactant needed to fill the bag.** Calculate the minimum mass in grams of $NaHCO_3$ and the minimum volume in mL of 3.0 M Acetic Acid that is theoretically required to generate enough carbon dioxide to fill the bag completely. Neatly record all calculations in your notebook using correct significant figures and units.

3. **Perform a trial run or two**:
   a. Use an electronic balance and a plastic weighing boat to carefully measure out the mass of $NaHCO_3$ that you calculated in step 2, above. Be careful to make a quantitative transfer of the $NaHCO_3$ from the weighing boat into one of the plastic bags.

   b. Measure out the amount of acetic acid solution that you calculated in step 2, above—*you need to determine the best way to do this*. Add this solution to the $NaHCO_3$ inside the plastic bag—*you need to determine the most efficient way to do this.* Mix the acetic acid and hydrogen carbonate by squishing and/or shaking the bag to make sure the reaction proceeds as far as possible—*you need to determine the most efficient way to do this.* Don't forget to...
      - ***Measure the total mass of the bag and its contents before mixing!***
      - ***Use a stopwatch to determine how long it takes for the bag to reach maximum inflation!***

   c. Here's a simple and quick way to approximate and compare the *relative* volume of gas produced for each trial run. When the reaction is complete, use a metric ruler to measure the approximate height of the sealed bag in cm as it is lying flat on the bench.

   d. Reexamine your calculations if the bag does not fill to capacity or is over-filled. Chances are your actual gas yield was lower than the theoretical yield you calculated. This may be due to a number of factors including reagent purity, gas solubility in water, the gas pressure not being exactly 1 atm, the gas temperature not being 25 ^oC, humidity etc. As a chemist you need to examine the ratio of reactants carefully to determine the ratio that gives the best yield of CO_2.

e. Make a neat and orderly *ruled* data table in your lab notebook—see table 1, below, for a sample data table. ***Record your observations for each trial***—e.g. Was the bag under-inflated, over-inflated/burst or fill completely without bursting? Did the bag get warmer or cooler to the touch? Did the trial run smoothly? If not, indicate the obstacles or problems you encountered. *As you perform each trial in lab use a pen to neatly record your data and observations directly into your lab notebook using correct significant figures and units*.

Table 1. Sample data table for the results and observations for the each airbag trial.

Trial No.	Mass $NaHCO_3$ (g)	Volume 3.0 M Acetic *Acid* (mL)	Total Mass of Bag and Reactants (g)	Theoretical Volume CO_2 Produced (mL)	Height of Bag after Reaction (cm)	Time needed for maximal inflation (s)	Observations	Moles $NaHCO_3$ Added	Moles CH_3COOH Added	Limiting Reactant

Guidelines to Keep in Mind...

- The trigger and delivery system should not require any external parts (such as the operator injecting acetic acid and then sealing the baggy). That is, you should include the acetic acid *and* the baking soda inside the model airbag in a stable configuration that will survive handling & weighing by you and your lab instructor without deploying prematurely.
- You may use any of the equipment found in the lab to achieve your goals, but you will be limited to the 5 baggies and the 100 mL 3.0 M Acetic Acid in the bottle you were initially given.
- You may use as much of either reagent as you desire in the model airbag you turn in, but you want the mass to be as low as possible since you are in a contest to make the *lightest possible airbag that will fill completely as fast as possible* when deployed, but without breaking seal of the bag.

> **Warning!** You are not allowed to artificially enhance the seal on the bag in any way with the use of glue, tape or another type of adhesive!

- Your team should develop a plan and carefully record results, data and observations in your notebooks *during the experiment*—use a neat and orderly ruled data table—see table 1, above!
- Finally, your team should be ready to submit your prototype airbag to the class at least **40 minutes** before the end of the lab period.
- Empty all air bag chemical waste in the appropriate waste container under the hood. The bags may be rinsed in the sink and disposed of in the regular trash.

Lab Write-Up Checklist

Present your results following the guidelines given in the handout, "Lab Notebook Policy."

Introduction

- Is the goal/purpose of the lab stated clearly?
- Includes summary of background information?
- Has chemical equation for the following reactions....
  - Decomposition of sodium azide, NaN_3?
  - Sodium hydrogen carbonate and acetic acid?

Materials and Methods Section:

- Is the procedure your group followed detailed enough that a competent student could use it to replicate the experiment?

Results:

Make a ruled and neatly organized/easy to read data table(s) that includes all measurements made in this lab experiment and summarizes your major findings. Use units and sig. figs!

- Include a neat and orderly data ruled table(s) for *each trial* that includes—
  - Data for the determination of the volume of the plastic bag
  - Mass sodium hydrogen carbonate used
  - Volume 3.0 M acetic acid used
  - Total mass of bag and reactants
  - Theoretical volume of CO_2 produced
  - Height of the bag after the reaction
  - Time needed for the maximal inflation of the bag
  - Observations
  - Moles of each reactant added
  - Limiting reactant

Analysis of the Results

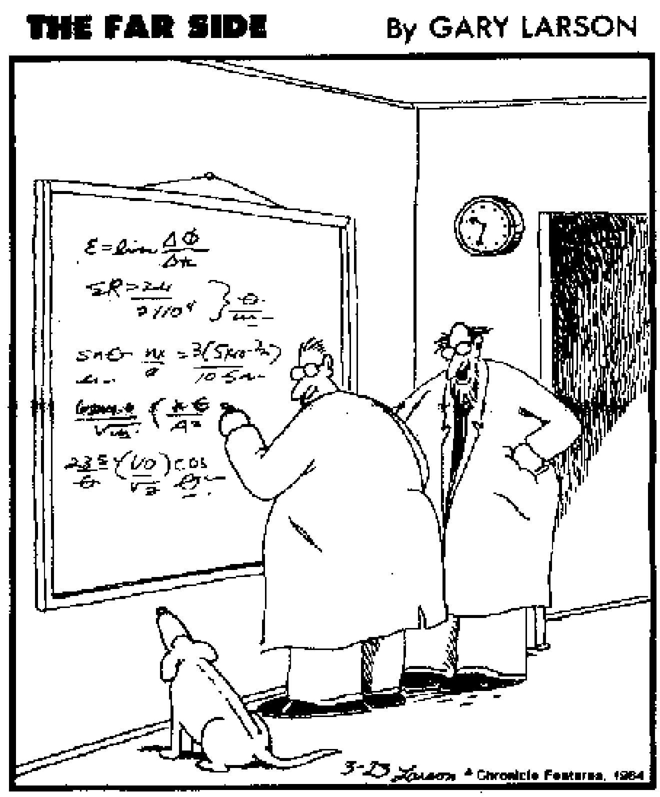
Label all calculations and clearly show work using dimensional analysis, units and sig. figs.

1. Calculate the volume of the Zip-lock Bag
2. Calculate the minimum amount of each reactant needed to fill the bag.
3. Address the following questions for your ***best airbag***.
   a.) For your ***best*** airbag, which reactant was in excess? Which reactant was your limiting reactant? Explain how and why this contributed to it being your best airbag.
   b.) Calculate theoretical volume of CO_2 produced in your ***best*** "airbag?"
   c.) What was the ***approximate*** (estimated) volume of CO_2 produced in your ***best*** "airbag?"
   d.) What was the percent yield for the production of carbon dioxide in your ***best*** airbag?
   e.) What were the major sources of error that account for the % yield of your ***best*** airbag not being 100%.

Conclusion

Use bullets to summarize your major findings and the major sources of error.

"Bunsen, I must tell you how excellent your study of chemical spectroscopy is, as is your pioneer work in photochemistry — but what really impresses me is that cute little burner you've come up with."



"Ohhhhhhh . . . Look at that, Schuster . . . Dogs are so cute when they try to comprehend quantum mechanics."

Lab 6 Prelab Questions **Name** ______________________________
Airbag Lab **Date** ____________ **Section** ___ **Group No.** ____

Instructions: Complete the following questions and hand in at the start of your lab period or when instructed by your instructor. Show your work with units and correct significant figures for all questions that involve a calculation. Circle your numerical answers.

1. The inflated volume of typical automobile airbag is about 130 Liters. Calculate the minimum mass of sodium azide (NaN_3) that is required to react to completely fill a typical airbag at room conditions. Assume the following: 100% sodium azide purity, the reaction goes to completion, the molar volume of a gas room conditions is 24.4 L per mole of gas. Record the balanced chemical equation involved in the space provided below.

   Balanced chemical equation:

2. Calculate the minimum mass of sodium hydrogen carbonate and the minimum volume of 3.0 M acetic acid required to react to completely fill a 1.0 L plastic bag at room conditions. Assume the following: 100% reactant purity, the reaction goes to completion, the molar volume of a gas room conditions is 24.4 L per mole of gas. Record the balanced chemical equation involved in the space provided below.

   Balanced chemical equation: