The “Air Bag” Problem—Solving an “Actual” Problem Experimentally
(and then rationalizing your result)

Background.
When any acid is combined with an ionic solid whose anion is hydrogen carbonate (HCO$_3^-$) or carbonate (CO$_3^{2-}$) there is the potential for a double displacement reaction to occur to generate H$_2$CO$_3$(aq), which can split into H$_2$O(l) and CO$_2$(g). As the CO$_2$ gas is generated, bubbles can be seen to form in the liquid. Recall that you may have observed this phenomenon during the “bottles” experiment when you were trying to figure out which solution had Na$_2$CO$_3$. In this experiment, you will combine baking soda (NaHCO$_3$) and H$_2$SO$_4$(aq) in order to generate some CO$_2$(g) inside of a plastic baggie. The balanced "molecular" equation describing the reaction is:

$$2 \text{NaHCO}_3(s) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow [\text{Na}_2\text{SO}_4(\text{aq}) + 2 \text{H}_2\text{CO}_3(\text{aq})] \rightarrow \text{Na}_2\text{SO}_4(\text{aq}) + 2 \text{H}_2\text{O}(\text{l}) + 2 \text{CO}_2$$

Prelab. Write answers the following questions on a separate sheet as your prelab for this experiment.
1. What is your experimental goal?
2. List all types of raw data you will collect.
3. Assume your first trial (using A g of solid and B mL of acid solution) results in the bag not filling completely. Assuming ONE of the two reactants is in excess and one is limiting, how could you figure out which one is in excess and which one is limiting by doing exactly one more trial? Explain in detail what you would do and how you would interpret the possible outcomes of the trial.
4. If 86. g of NaHCO$_3$(s) are combined with 322. mL of 0.800 M H$_2$SO$_4$, how many moles of CO$_2$(g) would be produced if reaction occurred as completely as possible? (Hint: calculate the number of moles of both reactants first, then figure out which one will run out first.)

Part 1. Getting the bag filled.
Your primary goal this lab period will be to figure out amounts of two reagents, solid baking soda (NaHCO$_3$) and a 0.8 M solution of H$_2$SO$_4$(aq) which, if combined inside of a given “1-quart” resealable baggie, will just fill up the baggie with enough gas to be considered “full” (bag is taut, but does not explode or leak!).

I expect most pairs to use a "trial and error" approach. However, you must follow these guidelines:
a) Each trial must be documented (which means amounts must be listed and observations must be written down). Note: Make sure to dry the baggie between trials with a paper towel.
b) For each trial, you must give a bit of reasoning for using the amounts that you do (if you use trial and error, you need not be too specific for the first trial, but you must say something). c) It could be very dangerous if you explode your bag (you WILL be wearing safety goggles, but still….). Therefore, you may lose points if you explode your bag (so be careful!). If you need a new bag, you must ask the instructor. For your first trial, err on the side of caution!
d) When you believe you have a “winner”, you must show it to your instructor to get an official “okay”.
e) After you have a ‘winner’, analyze your data and try to determine which reactant is in excess. Then make a final trial in which you add 20% more of what you believe to be the excess reactant, and write down your observations. Did your result make sense? Is your conclusion correct about which reactant is limiting?
f) Measure the volume of the filled bag (come up with a method with your partner). Report on p.2 of report form.

Part 2. Making Sense of the Experiment
**AFTE R YOU HAVE GOTTEN SUCCESSFUL TRIALS** you will do the following on your report form:
1) State which one of your reagents is in excess in your final trial. Give reasoning for your conclusion.
2 (a) Figure out, via calculations, what amounts you should use to get the baggie filled without there being any significant amount of EITHER reactant left over. That is, find amounts such that there would be NO limiting reagent; all of both would be completely used up. NOTE: You must consider the stoichiometry of the reaction to answer this (look at the balanced chemical equation)! Also recall what 0.8 M means.
   (b) (If there's time) Mix those calculated amounts in the baggie, and record what you observe. Did it “work”?
3) Show via calculation and verbal explanation that your results above are reasonable (see report form).
   Note: you must consider stoichiometry as well as use the ideal gas law in order to receive full credit. You may also need to make some assumptions about values of P$_{gas}$ and T$_{gas}$, as part of your explanation. Recall that you have determined the volume of the baggie! (How does this relate to the volume of CO$_2$ you produced in your “winner” trial?)
4) Answer the “final questions” on the report form.
Report Form—Air Bag Experiment

Part 1. (NOTE: You need not fill in every line; different groups may make a different # of trials. However, you MUST make at least five trials, including the “20% more of excess” trial)

<table>
<thead>
<tr>
<th>Trial #</th>
<th>g NaHCO₃</th>
<th>mL of 0.8 M H₂SO₄</th>
<th>Reasons for Amounts Chosen</th>
<th>Observations/Result</th>
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Part 2.
1) Which reactant did you conclude was "in excess" in your "winner" trial? ______________

Was there any significant difference in the results of your "winner" trial and the trial in which you added 20% more of the supposed “excess” reactant? If so, describe:

Does your result above make sense? Is your conclusion about which reactant was in excess correct? Explain. (If you need to change your conclusion, then make an additional final trial in which you use 20% more of the "correct" excess reagent. Ask if necessary).

(Just to make sure!) Reagent that was in excess in your "winner" trial: ______________

2) Use the amount of your presumed limiting reactant in your "winner" trial to calculate the amount of the other reagent that would be needed to react with all of the first reagent.

Results of above calculation ("NO EXCESS" CASE): ____________ g NaHCO₃; ____________ mL H₂SO₄
(If there was time): Describe the results of the trial in which the above amounts were combined:
3) (a) Actual (Measured) Volume of filled baggie (see p. 1): __________ How did you determine this? ________

(b) (i) Calculate a theoretical (predicted) volume of CO\(_2\) that "should" be generated assuming that all of the NaHCO\(_3\)(s) in a "no excess" trial would react (see the value you calculated at the bottom of prior page ("no excess case" calculation). You must consider stoichiometry (note the balanced chemical equation!) as well as the ideal gas law in order to calculate the volume asked for here.

NOTE: You must make some reasonable assumptions about the temperature and pressure of the gas in your bag. State these here: T\(_\text{gas}\)(estimate): ______ P\(_\text{gas}\)(estimate):_______

(ii) Compare the theoretical volume from (b)(i) to the actual volume of gas generated. Are these values reasonably close? Consider the possible errors in the experiment, as well as the assumptions made.

4) Final Questions: (a) Calculate the density (in g/mL and g/L) of the CO\(_2\) in the bag at the end of your final successful trial. (Use the actual bag volume, not the theoretical volume.)

(b) Which has the greater density, the CO\(_2\) you generated (see (a)) or liquid water? How many times larger is it? **Hint: Make sure to compare the two density values using the same units!**

(c) Draw one nanoscopic picture representing a sample of gas and another representing a sample of liquid (water). Refer to these pictures in your answer to the following question: Does your calculated result in (b) make sense based on your nanoscopic pictures of gases and liquids?