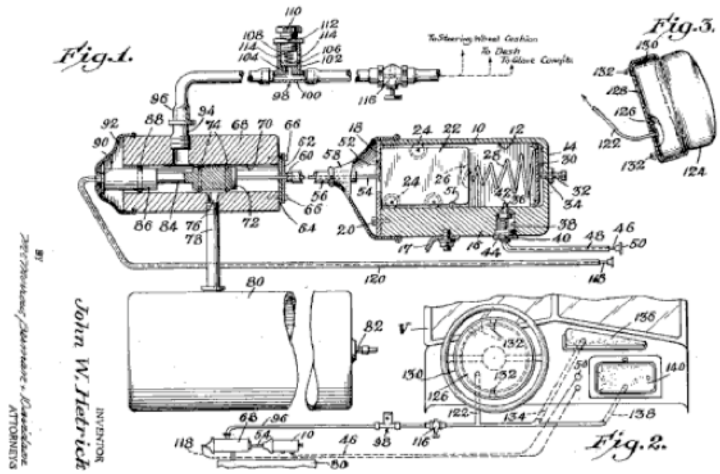
Experiment 12
Airbag Competition



Figures from US Patent 2,649,311

Skills/Concepts:

- Stoichiometry
- Limiting Reagents
- Product Design

Relevant Reading
Hein & Arena 9.1–9.6

Introduction, Part 1
The automobile airbag was first patented in the United States in 1953 by John Hetrick. This mechanical invention used an air reservoir for inflation. Modern airbags use chemical means, which minimize space required by the system. Instead of transferring a pocket of air from a reservoir to the airbag, the modern airbag involves conversion of chemicals from the solid to gaseous state. The primary reaction involves sodium azide:

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

Knowing the stoichiometry of the reaction and the volume of the airbag, engineers can equip cars with just the right enough of sodium azide to all for full inflation of the bag and no excess reagent.

Introduction, Part 2
Model airbags can be built with a range of gas-producing reactions. In this lab, teams will compete to produce the most efficient airbag design. Your aims will be to

- minimize the mass of the pre-deployment airbag
- maximize the amount of gas produced, without bursting the bag
- minimize excess reagents

The airbags will utilize the acid base reaction between hydrochloric acid and sodium bicarbonate:

$$HCl + 2NaHCO_3 \rightarrow CO_2 + NaCl + H_2O$$

Using your stoichiometry skills, design an airbag that will effectively fill the bag with the minimum amount of excess reagents and without exploding the bag. Important steps you will need to do include:

- determining stoichiometric reagent quantities to produce the desired amount of gas,
- engineering a mechanism to avoid initiating the reaction until you want the bag to inflate, and
- analyzing your experimental airbags to improve your design for the final airbag.

Name: ___________________

Pre-Lab

1. One liter is equal to 1.057 quarts. You want to inflate a 1 quart bag. What volume of gas, in metric units, do you want to produce?

2. Under standard conditions (25°C and 1 atm of pressure), 1 mole of gas fills 22.4 L. Assuming standard conditions, how many moles of gas would fill the quart-sized bag?

3. What is the mass of one mole of sodium bicarbonate ($NaHCO_3$)?

4. A solution of 1.0 M HCl has 1.0 moles per 1.0 L. How many moles are in 1.0 mL?

Procedure

Work with your teammates to design an effect airbag. Make sure to note the quantities of reagents to be used and to draw a sketch of your deployment mechanism.

You will be provided with the following materials:
- Five 1-quart sized sealable plastic bags, 4 for experimentation and 1 for the competition
- 1.0 M hydrochloric acid
- 0.50 M hydrochloric acid
- Graduated cylinder
- Weigh paper
- Plastic vials
- Plastic eyedroppers
- Litmus paper

For each of your experimental bags, complete the following analysis:
1. After you assemble your airbag, mass the system.
2. After you deploy the airbag, mass the system while still closed.
3. Deflate the bag and mass the system.
4. Calculate the mass of gas produced.
5. If there are no excess reagents, the remaining solution should be neither acidic nor basic. Dip a piece of litmus paper into the solution, record the pH, and note whether the solution is acidic or basic.
    a. pH values < 7 are acidic
    b. pH values > 7 are basic
    c. If the solution is acidic, you have excess hydrochloric acid.
    d. If the solution is basic, you have excess sodium bicarbonate.

Write out your plan for your airbag design #1:

Design of Airbag:

Mass of $NaHCO_3$		Moles of $NaHCO_3$	
Mass of HCl		Moles of HCl	
Concentration of HCl (1 M or 0.5 M)			
Estimated vol. of CO_2		Moles of CO_2	

Analysis of Airbag:

Mass of Airbag Before deployment		
Remaining solution	pH	
	Acidic, basic, or neutral?	
	Excess reagent: HCl, $NaHCO_3$, or none	
Fullness of airbag after deployment: i.e. Bag did not inflate, Need more gas, or Bag burst		

What do you need to do to improve your airbag design?

Write out your plan for your airbag design #2:

Design of Airbag:

Mass of $NaHCO_3$		Moles of $NaHCO_3$	
Mass of HCl		Moles of HCl	
Concentration of HCl (1 M or 0.5 M)			
Estimated vol. of CO_2		Moles of CO_2	

Analysis of Airbag:

Mass of Airbag Before deployment		
Remaining solution	pH	
	Acidic, basic, or neutral?	
	Excess reagent: HCl, $NaHCO_3$, or none	
Fullness of airbag after deployment: i.e. Bag did not inflate, Need more gas, or Bag burst		

What do you need to do to improve your airbag design?

Write out your plan for your airbag design #3:

Design of Airbag:

Mass of $NaHCO_3$		Moles of $NaHCO_3$	
Mass of HCl		Moles of HCl	
Concentration of HCl (1 M or 0.5 M)			
Estimated vol. of CO_2		Moles of CO_2	

Analysis of Airbag:

Mass of Airbag Before deployment		
Remaining solution	pH	
	Acidic, basic, or neutral?	
	Excess reagent: HCl, $NaHCO_3$, or none	
Fullness of airbag after deployment: i.e. Bag did not inflate, Need more gas, or Bag burst		

What do you need to do to improve your airbag design?

Write out your plan for your airbag design #4:

Design of Airbag:

Mass of $NaHCO_3$		Moles of $NaHCO_3$	
Mass of HCl		Moles of HCl	
Concentration of HCl (1 M or 0.5 M)			
Estimated vol. of CO_2		Moles of CO_2	

Analysis of Airbag:

Mass of Airbag Before deployment		
Remaining solution	pH	
	Acidic, basic, or neutral?	
	Excess reagent: HCl, $NaHCO_3$, or none	
Fullness of airbag after deployment: i.e. Bag did not inflate, Need more gas, or Bag burst		

What do you need to do to improve your airbag design?

Write out your plan for your final airbag design:

Design of Airbag:

Mass of $NaHCO_3$		Moles of $NaHCO_3$	
Mass of HCl		Moles of HCl	
Concentration of HCl (1 M or 0.5 M)			
Estimated vol. of CO_2		Moles of CO_2	

When each team has prepared their final airbag, each team will present their final airbag to the class. Airbags will be ranked based on the following criteria:

- Pre-deployment mass (lower is better)
- Full airbag after deployment
- Absence of excess reagents (as determined by pH)

Analysis of Airbag:

Mass of Airbag Before deployment		
Remaining solution	pH	
	Acidic, basic, or neutral?	
	Excess reagent: HCl, $NaHCO_3$, or none	
Fullness of airbag after deployment: i.e. Bag did not inflate, Need more gas, or Bag burst		

Name: ___________________ Lab Partner: ___________________

Post Lab

Results

Discuss the trial and error that occurred in the development of your airbag. What problems arose and how did you fix them?

Discussion

1. Assume an automobile airbag is designed to have a post-deployment volume of 30.0 L.
   a. How many moles of gas are needed?

   b. What mass of sodium bicarbonate would be needed?

   c. What mass of 1.0 M HCl would be needed?

   d. What would be the total mass of the reagents?

   e. Current airbags use predominantly sodium azide as the gas source. Using the balanced formula from the introduction, how many grams of sodium azide will be needed?

f. Compare the mass of the acid-base airbag and the sodium azide airbag. Which is more efficient in terms of volume of gas produced per gram of reagent?