Airbag

Project-Based Learning Module

High School Chemistry

PASCO®

PASCO Engineering Design Process

PASCO's STEM Modules guide students through the multi-step engineering design process outlined below. Students work individually and in groups to design, build, test, and evaluate their engineering prototype.

1 Initial Design Ideas

Students work individually to develop design ideas based on the design requirements and constraints of the engineering challenge.

2 Research

Students work in groups to carry out the science and math activities of the module. In carrying out these standards-based activities, students investigate fundamental concepts that apply to the engineering challenge and acquire skill using the standard tools and techniques they will need to complete the challenge successfully.

3 Revise Design

Students work individually to revise, improve, or confirm their initial designs based on the science and math concepts explored in the research stage.

4 Develop Group Design

Students work in groups to produce a collaborative design based on the best elements of the various individual designs, observing the original design requirements and constraints.

5 Build a Prototype

Students work in groups to build a prototype of their group design.

6 Test and Evaluate

Using a standard test bed, students test their prototype and evaluate its success.

7 Design Review

Students analyze and evaluate the test results and propose changes to increase the effectiveness of their design.

Challenge: Airbag

Design and build an airbag that will inflate to exactly 5 kilopascals more than atmospheric pressure as quickly as possible within 3 minutes.

Activity: Understanding Pressure

Describe how temperature, volume, and the amount of a gas affect pressure.

PASCO Absolute Pressure Sensor and PASCO Stainless Steel Temperature Sensor

Graphical analysis, inverse and direct proportionality, deriving an equation

List three variables that affect the pressure inside your airbag and describe the affect each one has on the pressure.

Activity: Mole-to-Mole Ratios

Determine the amount of sodium bicarbonate needed to completely react with 10 mL of 0.50 M acetic acid and use these values to determine the mole-to-mole ratios in the balanced chemical equation.

PASCO Absolute Pressure Sensor

Graphical analysis, lines of best fit, ratios, word problems, solving one-variable equations

Determine and use the balanced chemical equation to ensure that the reactants in the airbag are mixed in exact mole-to-mole ratios to avoid wasting chemicals.

Activity: Variable Volumes

Determine the volume of gas and the amount of gas (in moles) needed to fill bags of various sizes.

PASCO Absolute Pressure Sensor and PASCO Stainless Steel Temperature Sensor

Graphical analysis, solving literal equations for a given variable

Determine the volume of your airbag and the number of moles of carbon dioxide needed to inflate the airbag to the required pressure.

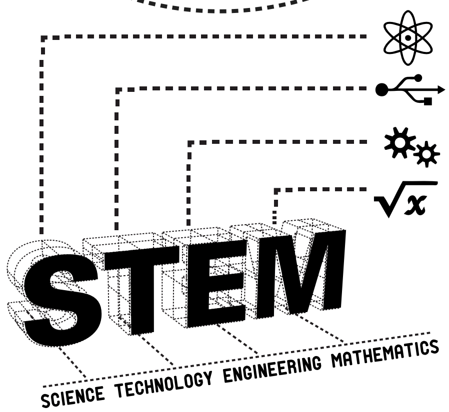
Construct an airbag that satisfies the design requirements and constraints using the information learned in the activities.

Activity: Stoichiometric Calculations

Calculate the amounts and concentrations of reactants needed to produce a certain number of moles of product without wasting any chemicals.

Word problems, solving 1-variable equations, solving literal equations for a given variable

Calculate the amount and concentration of each reactant required in the airbag.



Activity: Reaction Rate

Determine how stirring and reactant concentration affect the reaction rate between acetic acid and sodium bicarbonate.

PASCO Absolute Pressure Sensor

Graphical analysis, calculating average rates

Design the airbag to ensure it inflates as quickly as possible.

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Published by
PASCO scientific
10101 Foothills Blvd.
Roseville, CA 95747-7100
800-772-8700
916-786-3800
916-786-8905 (fax)
www.pasco.com

ISBN 978-1-886998-70-4
First Edition
Part Number: 012-12747
Catalog Number: PS-2983

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Contents

***NOTE:** Headings in bold type indicate student handouts.*

What Is STEM?

STEM education is a trans-disciplinary curriculum connecting **S**cience, **T**echnology, **E**ngineering, and **M**athematics, the combination of which promotes students' understanding of each of these fields and develops their abilities to become self-reliant researchers, innovators, and inventors. When faced with an idea or a problem, students learn how to develop solutions, how to analyze and evaluate different solutions, and how to collaborate with others to construct and test a product.

What this looks like in the classroom, however, is not always clear. In some cases, "S" is presented but not "M"—the math that explains the science. In other cases, STEM curriculum and materials focus on the "S" and the "M," leaving out the "T" and "E"—the technology element that generates solutions and gives rise to a deeper understanding of the science and math components, and the engineering element that centers on solving problems. The four parts of STEM have historically been taught separately and most of the time independently from each other; with STEM, science, technology, engineering, and math all play an important part in teaching these subjects as a whole.

PASCO's Project-Based Learning Modules

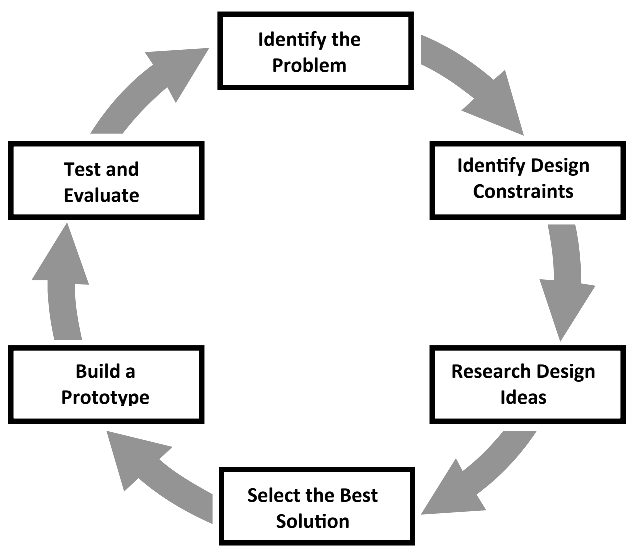
Module Principles

PASCO's Project-Based Learning Modules focus on all four components of S-T-E-M and are guided by various elements, including national standards; activity-, inquiry- and problem-based learning; the expectation of a tangible product or process as an outcome; and formative and summative assessments. They incorporate both independent and collaborative work, and rely on the engineering design process to bring all the pieces together.

A PASCO Project-Based Learning Module is centered on an open-ended Challenge in which students are given the task of designing, constructing, and implementing the solution to an engineering problem. The Challenge is based on fundamental science concepts in one or more genres of science: physics, chemistry, biology, and environmental science, and simulates a real-world problem that a modern engineer may encounter, with similar design constraints. Inside each Challenge are activities that focus on some or all of the key science and mathematics concepts of the Challenge and are part of the students' engineering design research.

These activities provide an opportunity for students to explore and research scientific concepts using PASCO's 21st Century Probeware and data collection systems. Students can then support their engineering designs with quantitative results from the activities. Through the activities, they obtain the science understanding, math skills, and familiarity with the techniques and tools of the field—background necessary to design and build the model or prototype.

Prototype development for a Challenge follows an engineering design process: students independently create initial solutions, they revise these solutions based on the results of the structured group activities, they analyze and evaluate the approaches of the students in their group, they finalize a group design, and they build a model or prototype for testing. Using the results of the test, they review their design and propose improvements.



Although the PASCO Engineering Design Process is shown (on the back of the title page) as a linear process that ends at the Design Review stage, engineering design is an iterative process, as shown in the circular diagram to the right. If time permits, students can use their analysis of the test results to begin again, creating an improved initial design, doing additional research, and building, testing, and analyzing the revised prototype.

Module Organization

A Project-Based Learning Module contains the student handouts and related information to assist the teacher in presenting, guiding, and assessing the students' work. Material is organized in a chronological manner, with the teacher information immediately following the handouts. For example, the pre-assessment handout is followed by the pre-assessment answer key and includes information that suggests ways to use the results and how to overcome misconceptions.

Each section of the student Challenge—Initial Design Ideas, Research, Revise Design, Develop Group Design, Build a Prototype, Test and Evaluate, and Design Review—conveys both the students' and the teacher's role for that stage of the engineering design process. The science and math activities (both student handouts and teacher notes) are included in the Research section. The Concluding the Module section provides wrap-up questions to use for discussion and lists possible misconceptions in order to look for changed understanding. The module concludes with a post-assessment handout for the students and answer key for the teacher.

The Challenge and Activity handouts are designed to be copied and used for multiple classes. Students should record all work in their notebook. If desired, you can change the handouts to be used to record the data by modifying the Microsoft® Word documents provided.

Paper versus SPARKlab™ Activities

In addition to the conventional paper format found in the Research section of this module, each activity in the Airbag STEM Module is available on the accompanying storage device in an electronic SPARKlab format (".spk"). The content found in both the paper format and the SPARKlab format is nearly identical, with some small changes to the step sequence and wording. This provides you, the teacher, an opportunity to choose the format that will be best received by your students.

The SPARKlab activities are presented as fully configured, stand-alone activities used with either a SPARK Science Learning System™ or a computer running SPARKvue™ software. All instructions, procedural steps, data displays, and questions are pre-configured and included in the electronic file. There are two sets of electronic SPARKlabs provided on the accompanying storage device. The two sets of labs have identical content but different resolution.

SPARKlab folder	Airbag SPARK Science Learning System	Airbag SPARKvue
Sample file name	HS STEM Understanding Pressure.spk	HS STEM Understanding Pressure Sv.spk
Images	The images are optimized for the size of the SPARK screen.	The images have a higher resolution to take advantage of the size of a computer screen.
Copying files	Refer to your SPARK Science Learning System User's Guide, in the "Saving and Sharing" section under "Managing Files and Folders".	The files can be saved anywhere in your normal filing system. The labs are "read-only" to protect students writing over them.

For information on the different methods for submitting student work when using the SPARK Science Learning System or SPARKvue software, refer to the "Saving and Sharing" section of the appropriate User's Guide.

Projecting SPARKlab™ Activities Using the SPARKvue Emulator

The SPARKvue emulator can be used to demonstrate the SPARK Science Learning System interface. To model opening a SPARKlab, first save the SPARKlabs in the locations described below.

Windows XP :	C:\Documents and Settings\All Users\Documents\My SPARK Data\Experiments
Windows Vista/7:	C:\Users\Public\Documents\SPARK Data\Experiments
Mac OS X:	HD>Users>Shared>SPARK>Experiments

The Data Collection System

All activities are carried out on a PASCO data collection system. "Data collection system" refers to the data collection, display, and analysis device used to carry out the various PASCO Module activities. These include PASCO's DataStudio®, the Xplorer GLX®, SPARKvue™, and SPARK Science Learning System™.

Detailed explanations for using the data collection system to carry out these procedures are found in the Tech Tip file corresponding to your data collection system. You can find these files on the storage device that accompanies this printed module, on the stand-alone storage device, and available for download with the module content.

Data Collection System	Tech Tip File
SPARK Science Learning System™	SPARK Tech Tips.pdf
SPARKvue™	SPARKvue Tech Tips.pdf
Xplorer GLX®	Xplorer GLX Tech Tips.pdf
DataStudio®	DataStudio Tech Tips.pdf

Using Project-Based Learning Modules with PASCO's 21st Century Science Guides

Science is a process of inquiry; an ongoing search to explain what goes on around us. PASCO's 21st Century Science Guides focus on students learning science through inquiry-based activities—presenting concepts in a way that develops critical thinking, procedural expertise, proficiency in design and construction, and analytical skills.

Using the Project-Based Learning Modules in conjunction with the 21st Century Science Guides further increases student skills and understanding. Students working on the Project-Based Learning Module Challenge are exercising the highest levels of critical and creative thinking: synthesis and evaluation—students design their prototypes by integrating the skills and knowledge gained in the activities, by comparing and discriminating between their own designs and those of others, and by appraising the strengths and weaknesses of their creation.

Teachers can use the Project-Based Learning Modules together with the 21st Century Science Guides in several ways. They can

- use only the Project-Based Learning Module to teach the unit
- extend a science unit with the activities in the Project-Based Learning Module after students complete related activities from the 21st Century Science Guide
- include additional activities from the 21st Century Science Guide to enhance the module
- use the Project-Based Learning Module as a capstone to review and integrate the topics already covered from the 21st Century Science Guide

In all of these approaches, challenging students with a Project-Based Learning Module enables them to apply their inquiry skills as they combine the science concepts and math skills to engineer something entirely new.

Content and Skills

The Airbag Project-Based Learning Module provides students an opportunity to learn about gas laws, chemical reactions, balancing chemical equations, stoichiometry, and reaction rate. After learning these individual concepts, the students apply and synthesize them as they design, build, and test a model airbag using a plastic bag and an acid-base reaction involving acetic acid and sodium bicarbonate. In this module, students develop the following skills and explore the following concepts:

Concepts	Skills
Pressure	Determine if variables are directly or inversely proportional
Kinetic molecular theory	Use a pressure sensor and a temperature sensor
Ideal Gas Law	Determine the maximum pressure from a graph of pressure versus time
Chemical reactions	Determine the reaction rate from a pressure versus time graph
Limiting reactants and excess reactants	Solve algebraic equations for given variables
Stoichiometry	Experimentally determine mole-to-mole ratios
Controlling the rate of chemical reactions	Perform stoichiometric calculations

The Airbag module includes a short pre-assessment to determine the students familiarity with the concepts and skills required to successfully complete this module. The pre-assessment starts with questions students should already be able to answer relating to balancing chemical equations, moles, and molarity. If the students answer these questions incorrectly, you may need to weave additional instruction throughout the module to make sure the students can successfully complete the activities.

The rest of the pre-assessment asks the students about content they will be learning during the activities. It is expected that most students will not do well on these questions. However, students who do well may benefit from additional challenges during the module or they can be paired with weaker students in order to help them.

The Airbag module also includes a post-assessment to help assess how much material students learned as a result of the module.

Prerequisites

The prerequisites listed below consist of terms and concepts used in the module, but never directly explained.

- Concentration
- Moles
- Molarity
- Law of Conservation of Matter
- Balanced chemical equations
- Ratios
- Line of best fit

Pacing Guide

Each lab-based activity is designed to fit one 45-minute block of time (one "Day"), unless otherwise noted. The table below indicates a recommended pacing for all lessons and activities within the module, in chronological order. Lessons and activities with the same number in the Day column can be carried out on the same day. Lessons or activities requiring an entire 45-minute block of time are the only ones listed on that day.

The module is designed to be completed in 14 "Days." The pacing guide lists what the students will be doing on each day. Days 1–12 are designed to be done consecutively. After day 12, the students may benefit from having additional time to plan and construct their airbags outside of class. Then the remaining two days, Day 13 and 14, can be done consecutively.

This module could be accelerated to be completed in fewer days, but the recommended pacing laid out below gives students time to think about and digest the concepts they learn before applying them. If time is a problem, the Stoichiometric Calculations activity can be done as homework, but some time in class should be used to review it before starting the Reaction Rate lab.

This module is designed to be completed in 14 "Days"

14-Day Sequence	Lessons/Activities	Instr. Led	Indiv. Work	Group Work	Lab Work
1	Pre-Assessment (assemble groups based on the results)		✓		
1	Introducing Students to the Challenge	✓			
1	Airbag Challenge: Initial Design Ideas		✓		
2–4	Activity: Understanding Pressure			✓	✓
5–6	Activity: Mole-to-Mole Ratios			✓	✓
7	Activity: Variable Volumes			✓	✓
8	Activity: Stoichiometric Calculations		✓		
9–10	Activity: Reaction Rate			✓	✓
11	Airbag Challenge: Revise Design		✓		
11–12	Airbag Challenge: Develop Group Design			✓	
13*	Airbag Challenge: Test and Evaluate	✓			
13	Airbag Challenge: Design Review		✓		
14	Concluding the Module	✓			
14	Post-Assessment		✓		

* The students may need one or two days outside of class to complete their airbags before testing and evaluating them. Depending on their design, they may need glue to dry or may have other design features that need additional time.

Safety

All normal safety procedures should be followed when performing the Airbag module. Most of the activities involve collecting data under pressurized conditions. It will be necessary to teach your students safety procedures related to pressurized systems including the possibility of stoppers and chemicals being expelled from sampling bottles.

Safety information is provided in each lab activity. However, the activities provided are templates. Each teacher should read through the entire activity and change the procedure as needed to ensure student safety.

Refer to the Normal Laboratory Safety Procedures appendix for a detailed list of safety precautions.

Pre-Assessment

Answer each question to the best of your ability.

1. There are two bags on a table. Bag A contains exactly one mole of carbon atoms and bag B contains exactly one mole of liquid water molecules. Both bags have the same ______________.

   A. volume B. number of particles C. mass D. all (A, B, and C)

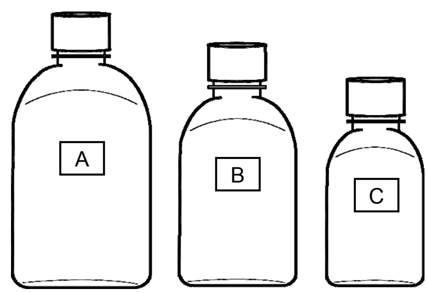
2. How do you make a 2.0 M solution of sodium bicarbonate?
   A. Add 168 grams of sodium bicarbonate to one liter of water.
   B. Add 2.0 moles of sodium bicarbonate to 100 milliliters of water.
   C. Add 2.0 grams of sodium bicarbonate to one liter of water.
   D. Add 0.23 moles of sodium bicarbonate to 100 milliliters of water.

3. Airbags in most automobiles inflate due to the incredibly fast decomposition of sodium azide. How many moles of nitrogen gas are formed to balance the following chemical reaction?

$$2NaN_3(s) \rightarrow 2Na(s) + \_\_\_\_ N_2(g)$$

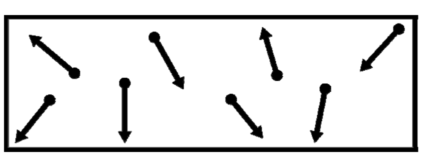
   A. 4 B. 3 C. 2 D. 1

4. If each sampling bottle is at the same temperature and contains the same number of molecules, which one has the highest pressure?
   A. Bottle A
   B. Bottle B
   C. Bottle C
   D. All the sampling bottles will have the same amount of pressure.

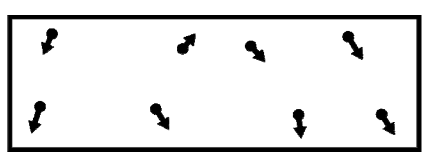


5. In the following diagrams, the volume is represented by the rectangles, each gas molecule is represented by a dot, and the speed each molecule is traveling is represented by the arrow. The longer the arrow, the faster the molecule is traveling.

   Which of the following statements is true about gaseous Sample A when compared to gaseous Sample B? The gas in both samples is the same.



Sample A



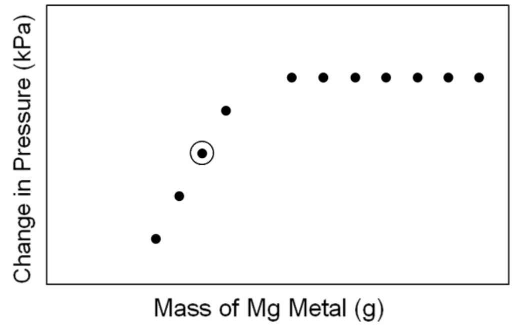
Sample B

   A. They occupy the same volume and have the same pressure, but have different temperatures.
   B. They have the same temperatures and the same pressure, but occupy different volumes.
   C. They have the same temperature and occupy the same volume, but have different pressures.
   D. They occupy the same volume, but they have different temperatures and pressures.

6. In a closed container, what change will cause the pressure to decrease?
   A. An increase in temperature
   B. The addition of more particles to the container
   C. An increase in the volume of the container
   D. All of the above

7. Various reactions were performed in which increasing amounts of magnesium metal were mixed with a constant amount of hydrochloric acid. The change in pressure for each reaction was measured and a graph of the change in pressure versus the mass of magnesium is shown below. Which best describes the data point that is circled?

A. Magnesium is the excess reactant and hydrochloric acid is the limiting reactant.
B. Magnesium is the limiting reactant and hydrochloric acid is the excess reactant.
C. There was exactly the right amount of reactants and neither was in excess or limiting.
D. There was an excess of each reactant in this trial.



8. What does it mean if two reactants are combined using their mole-to-mole ratio?

A. Equal numbers of moles of each reactant are combined to produce the most product.
B. One mole of each reactant is added to produce two moles of product.
C. The amount of one reactant is determined precisely and a large excess of the other reactant is added to ensure a maximum amount of product is formed.
D. A precise amount of each reactant is combined to form the maximum amount of product with the least amount of unused or wasted excess material.

9. How many moles of carbon dioxide gas are required to fill a 1.2 L plastic bag to its maximum volume? Use the data given below to determine your answer.

P = 101.1 kPa; T = 300.2 K; R = 8.314 (L·kPa)/(mol·K)

A. 0.027 mol CO_2 B. 0.049 mol CO_2 C. 0.54 mol CO_2 D. 20.5 mol CO_2

10. How many moles of sodium bicarbonate are in 10 mL of a 3 M sodium bicarbonate solution?

A. 0.03 mol $NaHCO_3$ B. 30.0 mol $NaHCO_3$ C. 0.003 mol $NaHCO_3$ D. 3 mol $NaHCO_3$

11. How many liters of hydrogen gas will form if you completely react 0.30 g of magnesium metal (Mg) with an excess of hydrochloric acid (HCl) at 298.2 K and 101.3 kPa according to the following reaction?

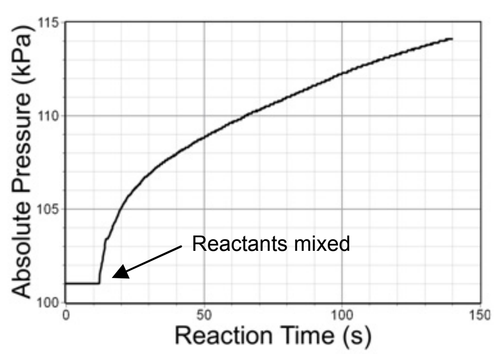
R = 8.314 (L·kPa)/(mol·K); the molar mass of Mg is 24.31 g/mol

$$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$$

A. 0.012 L H_2 B. 0.30 L H_2 C. 0.60 L H_2 D. 7.92 L H_2

12. What is the average rate of reaction for this run of data?

A. 0.10 kPa/s
B. 0.88 kPa/s
C. 140 kPa/s
D. 10 kPa/s



13. Which of the following reactants would magnesium metal react with the most quickly?

A. 1 M HCl B. 2 M HCl C. 3 M HCl D. 4 M HCl

Pre-Assessment Answer Key

The pre-assessment consists entirely of multiple choice questions to aid teachers with large class sizes or those who want to use a “clicker” response system for recording answers. The pre-assessment is available in an editable electronic format (HS STEM Airbag PreAssessment.doc) so you may edit questions to make them open-ended or to add or customize questions based on your students’ familiarity with the curriculum.

The results of the pre-assessment may be used in several ways:

- To identify areas of weaknesses. These may be supplemented with extra class discussions or lab activities.
- To identify student strengths and adapt the activity accordingly.
- To place students in groups with similar skills and conceptual understanding or mixed skills and levels of understanding.
- To introduce students to the applicable concepts.
- Use the results of a specific question to start a class discussion after students carry out the corresponding activity. For example, tell students, “Half of the class said that answer ‘a’ was correct. How many of you agree with this answer now?” Then have students explain their reasoning using data from the activities.
- The answer key includes an explanation of each correct answer and in some cases explains what wrong answers may mean about a student’s current conceptual understanding. The assessment information also indicates the activity in the module that addresses the concept assessed.

Question	Correct Answer	Assessment Information
1	B	A mole is 6.0×10^{23} particles. It is similar to using the word “dozen” to signify 12 of something. If you have a dozen cars and a dozen mice you have very different volumes and masses, but the number of objects is the same. A “mole” is similar. The molecules of a mole of water and a mole of carbon have different sizes and mass, but a mole of either contains the same number of molecules. Students who did not get this correct have not yet understood the concept of moles and will likely be confused with the more advance concepts required in this module. A review of this concept can be included during the Understanding Pressure activity, which asks the students to look at both volume and the amount of a gas (number of moles) as two different variables.
2	A	Sodium bicarbonate has a molecular weight of 84 g. To make a 2.0 M solution, add 168 g of sodium bicarbonate to one liter of water. Students may have to calculate the mass of solute needed for a specified volume of solution and then make the solution so it can be used in their airbag. Instruction for preparing a solution in the lab is not taught in this module, but depending on their airbag design, students may need to prepare solutions. If students struggle to answer this question, additional instruction may be required to teach them how to do this. Students who got the wrong answer may have forgotten the unit: molarity (M), which is "moles of solute per liter of solution."
3	B	$2NaN_3(s) \rightarrow 2Na(s) + 3N_2(g)$ Following the Law of Conservation of Matter, this equation shows 2 Na and 6 N atoms on both the reactant and product sides of the equation. It is expected that students already understand this concept before starting the module. Students will need review if they missed this question.
4	C	Bottle C has the smallest volume so the particles in it will collide with the sides of the container the most often, resulting in the highest pressure. The concept of pressure and how it varies with volume is addressed in the Understanding Pressure activity.
5	D	In these diagrams, the volume is represented by the rectangles, each gas molecule is represented by a dot, and the speed each molecule is traveling is represented by the arrow. The longer the arrow, the faster the molecule is traveling. As the molecules in Sample A are traveling faster, Sample A has a higher temperature and a higher pressure than Sample B. In this module, the students are asked to draw molecular level diagrams to illustrate different amounts of gas, temperatures of gas, and volume of gas. The students do not have to use the method shown here, but they should be able to explain their illustrations. These concepts are addressed in the Understanding Pressure activity.
6	C	Increasing the volume of a container will cause the pressure inside that container to decrease. Choices A and B will both cause an increase in pressure inside the container. These concepts are addressed in the Understanding Pressure activity.

7	B	Magnesium is the limiting reactant. This can be determined by looking at the data points that come after the one that is circled. The data points to the right of the circled data point, each representing a larger amount of magnesium, produced a greater change in pressure even though the same amount of hydrochloric acid was added. This means that, for the circled data point, the reaction ended when it ran out of magnesium. The graph shows that as more magnesium was added, the reaction produced more gas, showing a greater change in pressure, until there was an excess of magnesium and hydrochloric acid became the limiting reactant. The change in pressure didn't alter after that, regardless of the amount of magnesium used. The concept of limiting reactant and excess reactant is addressed in the Mole-to-Mole Ratios activity.
8	D	If reactants are combined using their mole-to-mole ratio, then the ideal amount of each reactant is used to obtain the maximum amount of product with the least amount of unused or wasted material. Answer A states that equal numbers of moles of each reactant are used. This could apply to an equation with a 1:1 mole ratio. While this can be the case, it is not always the case, depending on the chemical reaction. There could be any number of mole-to-mole ratios, including 1:2, 2:3, 4:7, etc. Students who answered B (one mole of each reactant is added to produce two moles of product) may be confusing a mathematical equation with a chemical equation. Answer C is restating the procedure of the experiment described in the previous question. If one reactant is in excess then the reactants were not combined using their exact mole-to-mole ratio. The concept of mole-to-mole ratios is addressed in the Mole-to-Mole Ratios activity.
9	B	The ideal gas law, $PV = nRT$, can be used to solve this problem. $n = \frac{PV}{RT}$ $n = \frac{(101.1\ \text{kPa})(1.2\ \text{L})}{\left(8.314\ \frac{\text{L kPa}}{\text{mol K}}\right)(300.2\ \text{K})}$ $n = 0.049\ \text{mol}\ CO_2$ Students derive the Ideal Gas Law in the Understanding Pressure activity and Ideal Gas Law calculations will be performed in the Variable Volumes and the Reaction Rate activities.
10	A	$10\ \text{mL} \times \frac{1\ \text{L}}{1000\ \text{mL}} \times \frac{3\ \text{mol NaHCO}_3}{1\ \text{L}} = 0.03\ \text{mol NaHCO}_3$ This type of calculation is not taught in these activities, but the students use it in the Stoichiometric Calculations activity.
11	B	$0.30\ \text{g Mg} \times \frac{1\ \text{mol Mg}}{24.31\ \text{g Mg}} = 0.012\ \text{mol Mg}$ $0.012\ \text{mol Mg} \times \frac{1\ \text{mol H}_2}{1\ \text{mol Mg}} = 0.012\ \text{mol H}_2$ $V = \frac{nRT}{P}$ $V = \frac{(0.012\ \text{mol})\left(8.314\ \frac{\text{L kPa}}{\text{mol K}}\right)(298.2\ \text{K})}{(101.3\ \text{kPa})}$ $V = 0.29\ \text{L H}_2$ Multi-step stoichiometry problems are practiced in the Stoichiometric Calculations activity.
12	A	$\text{Rate} = \frac{\Delta P}{\Delta t}$ $\text{Rate} = \frac{114\ \text{kPa} - 101\ \text{kPa}}{140\ \text{s} - 10\ \text{s}} = \frac{13\ \text{kPa}}{130\ \text{s}} = 0.10\ \text{kPa/s}$ This concept is covered in the Reaction Rate activity.
13	D	The higher the concentration, the faster the reaction occurs. The affect of concentration on reaction rate is explored in the Reaction Rate activity.

Introducing Students to the Challenge

Begin by engaging your students in a discussion of automobile safety features, why they are designed, and how they help people. Focus the discussion on airbags and show your students a video of an airbag being activated. Have the students discuss how chemistry is involved in this process. After this discussion, distribute the Airbag Challenge handout and give the students some time to read through it.

The stages described on the handout follow, chronologically, the stages of the engineering design process, as listed in the Pacing Guide activities and lessons. Each stage is identified by title in the Challenge handout, which includes instructions or questions, or both, that require students to respond in their notebooks. When beginning the Challenge, make certain that students are aware of this and that they each have a notebook for their responses and data.

The first section of the Challenge handout (Identify the Problem) outlines the real world challenges engineers face when designing airbags. Discuss these challenges and then introduce the modified Challenge the students will solve. Be certain to discuss the design requirements and constraints (outlined on the Challenge handout) with your students, being clear that failure to stay within those requirements and constraints will affect their overall grade.

Students will work individually and in groups throughout the Airbag Challenge. After introducing the Challenge, it is a good idea to assign students to groups for the stages of the Challenge that are carried out in groups (Research, Develop Group Design, Build a Prototype, Test and Evaluate, and Design Review). Although you, as the teacher, will know what grouping method best suits your class, the Pre-Assessment results may provide additional insight. For example, if the Pre-Assessment reveals that your students have a variety of prior concept knowledge, they may benefit from being in groups that distribute this knowledge. We suggest that these groups be the same throughout all the stages of the Challenge where students work in groups.

Challenge Rubric

To give students a better understanding of what is expected of them throughout the Challenge, you may choose to pass out the Challenge Rubric with the Challenge handout, which will indicate the suggested grading criteria. If you feel that these grading criteria are not suitable for your class, the rubric is available in an editable electronic format (HS STEM Airbag Challenge Rubric.doc) that allows you to change it as you find necessary.

This rubric gives equal weight to each part of the engineering design process. The bulk of the class time, however, will be spent on the Research section. In addition to giving an overall grade for the entire project, you may also decide to give additional points to each individual activity.

Materials

Each student group will need the following materials to build its airbag:

- A plastic bag that does not exceed a maximum volume of 1.5 L.
- A maximum of 100 mL of 3 M acetic acid and 10 g of sodium bicarbonate.
- A 10-cm piece of tubing.
- Other materials will also be needed, including materials to seal the airbag around the attached tubing and materials to separate the reactants inside their airbag.

The Challenge handout is available in an editable electronic format (HS STEM Airbag Challenge.doc), making it easy to change material constraints in the Design Requirements and Constraints section.

The materials required for each activity of the module are listed in each activity handout and in the Master Materials and Equipment appendix. The Materials and Equipment appendix also includes a list of all the materials needed to complete the airbag module.

Challenge: Airbag

***NOTE**: Record all work, including data, diagrams, and answers, into your notebook.*

Identify the Problem

Since 1998, all new cars sold in the United States must have both driver and passenger airbags. According to the latest statistics, the risk of dying in a head-on collision has decreased because of airbags. However, airbags only decrease risk in head-on collisions. Side-impact collisions are also common and can result in serious injury or death. While carmakers have tried to make car doors stronger to improve vehicle safety, side door airbags are also being designed, tested, and even offered in some cars.

Designing side door airbags is significantly more difficult for engineers than front airbags because of the speed the airbag must inflate. In a head-on crash, energy from the collision is absorbed by the bumper, hood, and engine before it reaches the occupant. This takes approximately 35 to 40 milliseconds and thus the front airbag must be deployed in less than this amount of time. In a side collision there is less material to absorb the energy and thus the airbag must be deployed in about 5 or 6 milliseconds! [1]

To inflate so quickly, airbags contain a highly toxic chemical called sodium azide (NaN_3). When the car's airbag sensor detects a head-on collision, an electrical circuit ignites the sodium azide and causes it to rapidly decompose into sodium metal (Na) and nitrogen gas (N_2). The nitrogen gas fills the airbag to a maximum pressure and openings in the airbag release the gas so that the occupant hits the airbag as it is deflating. Additional chemicals are added to the airbag to react with the highly reactive sodium metal that is formed.

Your challenge is to design an airbag similar to those engineers and scientists are working on, except rather than using toxic and explosive chemicals, your airbag will deploy using the reaction between acetic acid and sodium bicarbonate.

[1] Rachel Casiday, Regina Frey. Gas Laws Save Lives: The Chemistry Behind Airbags, Department of Chemistry. 2000. Washington University, St. Louis, MO. Retrieved January 27, 2012 from http://www.chemistry.wustl.edu/~edudev/LabTutorials/Airbags/airbags.html.

Challenge

Design and build an airbag that will inflate to exactly 5 kilopascals more than atmospheric pressure as quickly as possible within 3 minutes.

Design Requirements and Constraints

- When inflated, the airbag's volume should not exceed 1.5 L.
- The airbag must be inflated by the product of the chemical reaction between sodium bicarbonate and acetic acid. You can use a maximum of 100 mL of 3 M acetic acid and 10 g of sodium bicarbonate.
- Provide mathematical evidence that the amounts of chemicals used in your design are appropriate to meet the requirements and constraints without reactants being wasted.
- The airbag must be attached to the pressure sensor. You will be provided with a 10-cm piece of tubing to build into your design. On the day of testing, a quick-release connector will be used to attach the tubing to the pressure sensor.
- The airbag with the tubing attached must be airtight. Materials for making it airtight must be supplied by each group.
- You will have 10 minutes on the day of testing to prepare your airbag. Then you have 1 minute to attach the sensor to the airbag, seal it, and start data collection. You will collect absolute pressure data for 20 seconds before activating the airbag.
- Standard lab materials needed for separating the reactants may be used. Materials other than standard lab materials needed for this must be supplied by the group.

1 Initial Design Ideas

☐

If you were to design your airbag right now, how would you construct it and what materials would you use? How will you make sure your design fulfills the design requirements and constraints?

1. Sketch two possible designs and explain your proposals.
2. List three reasons for choosing each design.
3. List three questions you would like to know the answer to in order to finalize your design.

2 Research

☐

Carry out the activities listed below. These will help you revise or validate your initial design ideas in order to complete the challenge successfully. After completing an activity, answer the questions following its description. All questions must be answered before you proceed to the Revise Design portion of the Challenge.

NOTE: When you see the symbol "�" with a number following a step in an activity, refer to the Tech Tip with that number for detailed instructions as needed. Tech Tips will be provided by your teacher.

Understanding Pressure

☐

What is pressure and what factors cause changes in pressure? In this activity you will explore pressure and explain how macroscopic changes are caused by changes at the molecular level.

1. What is the pressure inside an airbag before it is activated? How does the pressure inside the airbag change during activation?
2. List three variables that may affect the pressure inside your airbag and describe the affect each one has on the pressure.
3. What is the Ideal Gas Law? List one way you could use this law to help you design your airbag.

Mole-to-Mole Ratios

☐

In this activity you will explore how gas production varies when different amounts of sodium bicarbonate are mixed with the same amount of acetic acid (10 mL of 0.50 M acetic acid). You are to experimentally determine the mole-to-mole ratio between the reactants and complete the balanced chemical equation.

1. How can you control the amount of gas that will be produced inside your airbag?
2. Give an example of how an airbag design would result in chemicals being "wasted"? How can you avoid this mistake?
3. What gas will inflate your airbag?
4. How is your airbag similar to and different from the sampling bottle you used in this activity?

Variable Volumes

☐

How will you determine the size of the bag you will use to construct your airbag? How much gas will your airbag hold? In this activity you will determine the volume of various size bags and calculate the number of moles of gas needed to fill them.

1. What size airbag will you use? Why?
2. Will the design of your airbag and method of inserting the pressure sensor tubing change the volume inside your airbag? If so, how will it change and how will you account for this difference?
3. How many moles of gas must be produced inside your airbag to meet the Challenge requirements? Explain your reasoning.
4. How will you control the production of this amount of gas?

Stoichiometric Calculations

☐

In this activity you will practice the chemical calculations necessary to calculate the quantity and concentration of reactants you will use in your airbag to produce the amount of gas required.

1. How many moles of carbon dioxide will you need to fill your airbag to 5 kPa above atmospheric pressure?
2. Describe two ways you can produce the number of moles of carbon dioxide you need by reacting sodium bicarbonate with acetic acid. Be sure to give the volume and concentration of each solution used and the mass of any solid substances used.
3. What factors will help you decide which procedure to use in your final airbag?

Reaction Rate

☐

Your goal is to inflate your airbag as quickly as possible within 3 minutes. In this activity you will investigate factors that affect the rate of reactions.

1. List one factor that you investigated in this activity and describe how you could use it to design your airbag.
2. Based on the results of this activity, which of the two methods of increasing the rate of carbon dioxide production, stirring or adjusting the reactant concentration, do you plan on using? Why?
3. How do you plan to separate the reactants in your airbag? How does the rate of reaction influence your decision?

3 Revise Design

☐

After completing the five activities in this Challenge, you should have the conceptual tools necessary to construct an airbag that will inflate to exactly 5 kPa more than atmospheric pressure as quickly as possible within 3 minutes.

1. How have your initial design ideas changed? Explain your reasons for making those changes.
2. Sketch your revised design in your notebook and explain your proposal, indicating the important components of the design including quantities, concentrations, and your plan for separating the reactants.
3. Include a description of the materials you will use in your proposed design and list any safety concerns.

4 Develop Group Design

☐

Discuss as a group the different designs made by each group member and agree on a collaborative design that will be most effective. After deciding on an approach, draw the group's final design and have your teacher approve your group's proposal. Every group member should have a copy of the proposal.

1. Record in your notebook a sketch of the group design, the important design points, and explain why you chose this design.
2. Include a description of the materials you will use in your proposal and list any safety concerns and precautions needed.
3. Record in your notebook the mathematical evidence showing that the amounts of the chemicals used in your design meet the requirements and constraints without reactants being wasted.

5 Build a Prototype

☐

Using your collaborative design, prepare your airbag. Make sure you follow all the safety precautions you have identified.

1. List your specific responsibilities during the construction of your airbag prototype.
2. Often a prototype will not exactly match its design due to some unforeseen construction challenges. Were any design points changed during the construction process? Does your group's prototype exactly match the original design? If you did make changes, list those changes in your notebook and explain why your group made those changes.
3. Record in your notebook the mass and volumes of reactants used.

6 Test and Evaluate

☐

As directed by your teacher, attach your airbag to the pressure sensor being used for testing. Start data collection, wait 20 seconds and then activate your airbag. Stop data collection when the airbag has reached and maintained its maximum pressure or three minutes have passed.

1. List your specific responsibilities during the testing of your airbag prototype.
2. Record the room temperature.
3. Record the following data points and calculate the change in pressure and the time of inflation:
   - Starting pressure
   - Final pressure
   - Change in pressure
   - Time activated
   - Time fully inflated
   - Time to inflate
4. As each group takes its turn, record information about its airbag design and the results.

7 Design Review

☐

Analyze the result of your group's prototype. Based on the requirements and constraints, compare it with other prototypes you observed and suggest ways to make your design more successful.

1. How successful was your design? Did you meet all the design requirements and constraints? What data supports your assessment?
2. How could you have constructed it differently to be more effective? Explain why this would help.
3. Look at another group's designs. What was different about their design and how do you think those differences affected their performance relative to yours?

Congratulations! You have finished the Airbag Challenge. Complete the information in your notebook and turn it in to your teacher.

Challenge Rubric: Airbag

	Excellent			Good			Fair		
Initial Design Ideas	▪ Included two detailed sketches with labels explaining them ▪ Included three reasons for each design ▪ Asked at least three pertinent questions about their designs			▪ Included two sketches with labels explaining them ▪ Included two reasons for each design ▪ Asked at least two pertinent questions about their designs			▪ Included one or two rough sketches ▪ Included at least one reason for each design ▪ Asked at least one question about the design(s)		
	9	8	7	6	5	4	3	2	1
Research	▪ Completed all research activities ▪ Answers to activity and Challenge questions were complete and correct ▪ Answers showed an excellent understanding of the concepts			▪ Completed most research activities ▪ Answers to activity and Challenge questions were mostly complete. ▪ Answers showed a good understanding of the concepts			▪ Completed some research activities ▪ Answers to activity and Challenge questions were incomplete ▪ Answers showed a partial understanding of the concepts		
	9	8	7	6	5	4	3	2	1
Revise Design	▪ Provided several explanations for the design change ▪ Revised design sketch was clearly explained and included labels, measurements, and units ▪ Provided a complete list of materials and safety concerns			▪ Provided at least one explanation for the design change ▪ Revised design sketch included labels and measurements ▪ Provided a partial list of materials			▪ Didn't include explanations for changing the design ▪ Provided a roughly drawn revised design ▪ Included a brief explanation of the design		
	9	8	7	6	5	4	3	2	1
Develop Group Design	▪ Worked well in the group to draw a design based on solid reasoning ▪ The group design included a full explanation, labeled sketch, and accurate mathematical evidence ▪ Provided a complete list of materials and safety concerns			▪ Participated in the group to devise a group design ▪ The group design included mathematical evidence and a labeled sketch ▪ Provided a partial list of materials			▪ Had limited involvement in the group design ▪ Has a hasty copy of the group design and proposal ▪ Did not include materials or safety concerns		
	9	8	7	6	5	4	3	2	1
Build a Prototype	▪ Took responsibility to ensure the prototype was built as designed ▪ Had complete notes on the prototype development ▪ Recorded reactant measurements and recalculated expected results			▪ Participated in building the prototype ▪ Had notes on the prototype development ▪ Recorded reactant measurements			▪ Had limited involvement in building the prototype ▪ Had minimal notes on the prototype development or reactant measurements		
	9	8	7	6	5	4	3	2	1
Test and Evaluate	▪ Took responsibility to ensure activating and testing the airbag followed the prescribed protocol ▪ Recorded all data and took notes describing the other prototypes tested			▪ Participated in activating and testing the airbag, according to the prescribed protocol ▪ Appropriate data was recorded ▪ Most requirements and constraints were met			▪ Had limited involvement in testing the airbag ▪ Recorded some data ▪ Some requirements and constraints were met		
	9	8	7	6	5	4	3	2	1
Design Review	▪ Evaluated the success of the design and supported it with data ▪ Included a thorough description for prototype changes and supported it with evidence ▪ Included redesign ideas based on ideas learned from other groups			▪ Evaluated the success of the design ▪ Included notes on how the design could have been more effective ▪ Referred to other groups' designs			▪ Evaluation of the design was incomplete ▪ Included few ideas on designing a more effective prototype ▪ Did not refer to other groups' designs		
	9	8	7	6	5	4	3	2	1
	Total Score								

1 Initial Design Ideas

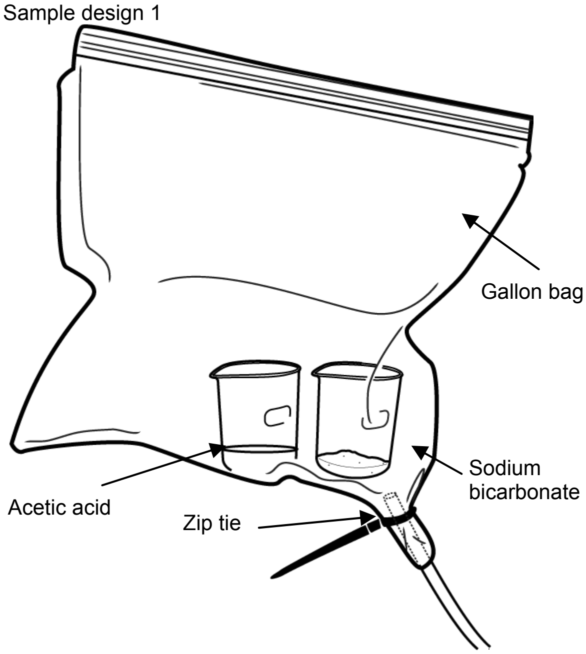
This stage provides an opportunity for students to display their creative and critical thinking skills. Students should be encouraged to draw their initial design ideas based on their prior knowledge of how the chemicals used in this lab can be used to inflate a bag.

Students are expected to individually answer the three questions found in the Challenge. In their responses and drawings, have the students include measurements, with units, and have them explain why they chose each design. Two sample student designs are shown below. There is no right answer and it is likely that the students will change their design as they work through the activities.

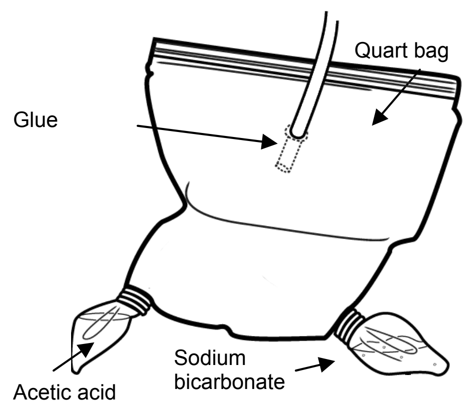
While there is not a right answer, some students will be focused on the car crash and how people interact with an airbag instead of the challenge to build an airbag. These students may need to be reminded about the specific challenge and related constraints and requirements. It is important to make sure the students differentiate between the context and the actual challenge.

Possible Student Designs

Sample design 1



Sample design 2



SAMPLE RESPONSES TO THE QUESTIONS IN THE INITIAL DESIGN IDEAS SECTION OF THE CHALLENGE

Question	Sample Response
1	**Sketch two possible designs and explain your proposals.** Sample design 1 ▪ Each reactant will be held in a beaker and the beakers will be inside a sealed bag. The tubing will be attached on the bottom of the bag using a zip tie. Sample design 2 ▪ Each reactant will be held in a corner of the bag. Rubber bands will be used to make sure the reactants stay in these locations until it is time to mix them. The tubing will come out the top center of the bag. I will use glue to attach this.
2	**List three reasons for choosing each design.** Sample design 1 ▪ The beakers will be used to separate the reactants until it is time to activate the airbag. ▪ A large bag will be used so that the beakers can fit inside. ▪ The tubing will come out of the corner of the bag because it will be easy to make a small hole here and seal it well. Sample design 2 ▪ The rubber bands will be used to keep the reactants in their own area so they don't mix until it is time to activate the airbag. ▪ A small bag will be used because it will fill up with gas the quickest. ▪ The tubing will come out of the top of the bag so the solution does not block the tubing.
3	**List three questions you would like to know the answer to in order to finalize your design.** ▪ How much sodium bicarbonate and acetic acid should I use? ▪ What is a “kPa”? ▪ What can be done to make the reaction occur as quickly as possible?

Addressing Preconceptions

The Initial Design Ideas stage provides a good opportunity to ask students questions about their designs in order to identify preconceptions about how airbags work and how to control chemical reactions. Identifying these preconceptions early will allow you to enhance the activities that may require additional explanation. Examples of some preconceptions are:

- Chemicals are always completely used up during a chemical reaction.
- Pressure will increase immediately inside a sealed bag.
- An airtight seal is easy to create with tape or a rubber band.
- There is no pressure inside an “empty” bag.
- There is no way to predict how much product will form when reactants are mixed.

2 Research

Engineering research and development is usually an iterative process: the engineering research determines how something can be made to function for a given purpose, and development is the process of building and testing prototypes or working models based on this research. While engineering research includes exploring other people's research, reading articles in journals, and investigating what has been done before, this section directs students to carry out scientific research activities which explore the science concepts and math skills related to the engineering challenge—building an airbag that inflates as quickly as possible within 3 minutes. In carrying out these activities, students will also become familiar with some of the standard tools and techniques of this field of study.

During the research process, the students are expected to learn the science required to effectively design and build an airbag. Four of the research activities are designed to be carried out in small groups in the lab. The students will work together to explore the topic, but students will record answers in their own notebooks. One activity, Stoichiometric Calculations, does not have a lab component and students will complete this activity independently.

At the end of each activity, the students should answer the questions on the Challenge handout related to that activity. These questions are intended to help the student connect each topic to their airbag design. After each activity, provide time for students to alter their airbag designs.

During the research process, the teacher's role is to introduce activities, informally assess conceptual understanding during the activity, and help students interpret and draw appropriate conclusions from each activity. Prior to each activity, the teacher should set the stage by relating the topic to the construction of an airbag. A sample introduction is provided in the Teacher Notes for each activity. As students are working, the teacher should ask questions about the meaning of the data being collected. This is also a good time to focus on students with weaknesses in the area of study identified in the Pre-Assessment or the Initial Design Ideas phase. At the end of each class period, the teacher should allow students to share their data and help all the groups interpret the data and relate it to the airbag design.

How Do the Activities Prepare Students for the Challenge?

In the Understanding Pressure activity, students learn how temperature, volume, and amount of a gas affect pressure. By the end of this activity, the students will have derived the Ideal Gas Law, which they will use to calculate the number of moles of product needed to reach the desired pressure in the airbag. In the Mole-to-Mole Ratios activity, students experimentally determine the coefficients that balance the chemical equation for the reaction between sodium bicarbonate and acetic acid. With these coefficients, students can determine the number of moles of reactants needed based on the amount of product required.

In the Variable Volumes activity, the students use water to determine the volume of various size bags they may select for their airbag, after which they use the Ideal Gas Law to determine the number of moles of gas needed to inflate the bag to the required pressure. Knowing the amount of carbon dioxide gas needed and having determined the mole-to-mole ratio of reactants and product, the Stoichiometric Calculations activity helps students calculate the exact mass or concentration of each reactant to use. Finally, the Reaction Rate lab introduces students to variables that can increase the speed of the reaction so they can more quickly inflate their airbag.

Completing the Research Questions

All Research activities and Research questions should be answered before students proceed to the Revise Design portion of the Challenge.

NOTE: *Students use a variety of technical procedures in the activities. Detailed explanations for using the data collection system* to carry out these procedures are found in the Tech Tip file corresponding to your data collection system. Please make copies of these instructions available for your students. (Tech Tips are identified in the activities by the "�" symbol followed by the Tech Tip number.)*

You can find these files on the storage device that accompanies this printed module, on the stand-alone storage device, and available for download with the module content.

Data Collection System	Tech Tip File
SPARK Science Learning System	SPARK Tech Tips.pdf
SPARKvue	SPARKvue Tech Tips.pdf
Xplorer GLX	Xplorer GLX Tech Tips.pdf
DataStudio	DataStudio Tech Tips.pdf

**Data collection system refers to the data collection, display, and analysis device used to carry out the various activities and includes PASCO's DataStudio, the Xplorer GLX, SPARKvue, and SPARK Science Learning System.*

SPARKlab Activities

In addition to the conventional paper format found in this section of the airbag module, each activity is available in an electronic SPARKlab format. All electronic SPARKlab files can be found on the accompanying storage device with a .spk file extension and the title of each activity within the filename, for example, "Understanding Pressure" and "HS STEM Understanding Pressure.spk".

For instructions on how to move the electronic SPARKlab files from the storage device to your SPARK Science Learning System, please refer to your SPARK Science Learning System User’s Guide, "Managing Files and Folders" section.

For information on the different methods for submitting student work when using the SPARK Science Learning System, refer to the "Saving and Sharing" section of the SPARK Science Learning System User's Guide.

Activity: Understanding Pressure

Objective

Describe how temperature, volume, and the amount of a gas affect pressure in a closed system.

Materials and Equipment

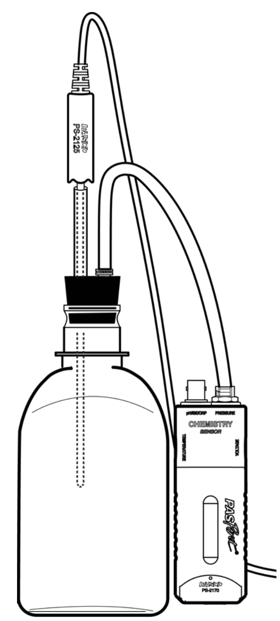
- Data collection system
- Absolute pressure sensor
- Stainless steel temperature sensor with blue tubing
- Syringe with quick-release connector attached
- Sampling bottle, plastic, 500-mL
- Beaker, 1000-mL
- Rubber stopper, two-hole, to fit the sampling bottle and fitted with a 50-cm piece of tubing with a quick-release connector at the end
- Stopcock connected to a tubing connector
- Crushed ice, 500 mL
- Paper towels

Safety

- Wear safety goggles.
- To minimize the risk of injury or damage to the equipment, do not exceed 400 kPa when compressing air in the syringe.
- Do not point the top of the sampling bottle toward yourself or anyone else.

NOTE*: Record all work, including tables, data, diagrams, calculations, and answers, into your notebook.*

Procedure – Part 1: How does temperature affect pressure?



☐ 1. Connect the absolute pressure sensor and the stainless steel temperature sensor to your data collection system. �(2.2) Create a new file �(1.2) with a graph that displays pressure (kPa) on the *y*-axis and temperature (K) on the *x*-axis. �(7.1.1)

☐ 2. Place a 3- to 4-cm piece of blue tubing onto the stainless steel temperature sensor and then insert the sensor into the open hole in the stopper. Push the sensor all the way through the stopper so that some of the blue tubing is in the stopper's hole and an airtight seal is formed.

☐ 3. Attach the quick-release connector at the end of the tubing coming from the stopper to the pressure sensor and then firmly place the stopper into the sampling bottle so the tip of the temperature probe is in the middle of the sampling bottle.

☐ 4. List the independent and dependent variables in this experiment and then explain what you think will happen to the air pressure inside the bottle when the temperature decreases and increases.

☐ 5. Place a layer of crushed ice at the bottom of the 1000-mL beaker. Place the sampling bottle on the ice in the beaker and pour crushed ice all around the bottle. Allow the air in the sampling bottle to adjust to its new environment for 2 minutes.

☐ 6. Start collecting data �(6.2) and continue to collect data until you have determined how decreasing temperature affects pressure. Once you detect the trend, stop collecting data.�(6.2)

☐ 7. Ensure that the stopper remains in the sampling bottle as you carefully remove the sampling bottle from the beaker of ice and pat it dry with a paper towel. Lay the bottle on its side and allow the bottle to adjust to its new environment for 2 minutes. Start collecting data.�(6.2) Continue to collect data until you detect the trend, then stop collecting data. �(6.2)

☐ 8. The following questions apply to your observations for both cooling and warming the sampling bottle:

a. What happens to the pressure in the bottle as the temperature of the air in the bottle decreases?

b. What happens to the pressure in the bottle as the temperature of the air in the bottle increases?

c. Explain why these trends occur and draw diagrams that show the gas molecules' positions, speed (long arrows for faster speeds; short arrows for slower speeds), and relative number in both a warm and a cool environment.

☐ 9. In your notebook,

a. Sketch both runs of the data collected onto a graph of pressure versus temperature.

b. Label each run and then state whether or not your predictions were correct and explain any differences.

☐ 10. Describe the relationship you observed between pressure and temperature.

a. Is pressure directly proportional ($P \propto T$) or inversely proportional ($P \propto 1/T$) to temperature? How do you know?

b. What variables must be held constant to observe this relationship?

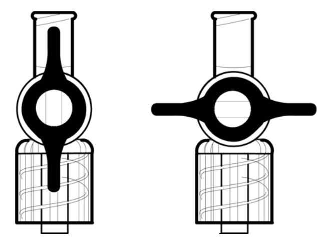
c. Assuming this is the correct relationship, what will happen if the temperature is reduced by half?

☐ 11. Disassemble the setup and disconnect and remove the sensors from your data collection system.

Procedure – Part 2: How does the amount of gas (*n*) affect pressure?

☐ 12. Connect the pressure sensor to your data collection system�(2.1) and create a new file.�(1.2)

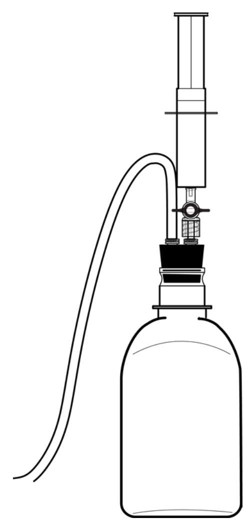
☐ 13. Configure the data collection system to manually collect pressure (kPa) and amount of air (syringes) in a table. Define "amount of air" as the manually entered data set with units of "syringes". �(5.2.1)



☐ 14. Insert the tubing connector, with the stopcock attached, into the empty hole of the stopper. Make sure the stopcock is in the "closed" position.

☐ 15. Attach the quick-release connector at the end of the tubing coming from the stopper to the pressure sensor and then firmly place the stopper into the bottle.

☐ 16. List the independent and dependent variables in this experiment and then explain what you think will happen to the air pressure inside the bottle when air is added and when air is removed.



☐ 17. Start a manually sampled data set �(6.3.1), record the pressure, and enter "0" as the number of syringes of air added. �(6.3.2)

☐ 18. Record the pressure with 1, 2, and 3 syringes of air added using the following procedure:

a. Pull the plunger of the syringe out as far as possible (so it fills with air) and then attach the syringe to the stopcock (still in the closed position).

b. Open the stopcock and then push the plunger of the syringe down to force the air molecules from the syringe into the sampling bottle.

c. Close the stopcock, remove the syringe from the stopcock, and record the data point (both pressure and the total number of syringes of air added at this point). �(6.3.2)

d. Repeat this process until you have added three syringes of air to the bottle, then stop the manually sampled data set. �(6.3.3)

☐ 19. Open the stopcock to allow the pressure inside the sampling bottle to return to atmospheric pressure, then close the stopcock. Record the pressure for 0, –1, –2, and –3 syringes of air using the following procedure:

NOTE: the negative sign indicates that air is being removed from the container.

a. Start a manually sampled data set �(6.3.1), record the pressure, and enter "0" as the number of syringes of air removed. �(6.3.2)

b. Position the plunger of the syringe so there is no air inside the syringe and then attach the syringe to the stopcock (still in the closed position).

c. Open the stopcock and then pull the plunger away from the sampling bottle until the syringe is full of air.

d. Close the stopcock, remove the syringe from the stopcock, and record the data point (both the pressure and the total number of syringes of air removed at this point). �(6.3.2)

e. Repeat this process until you have removed three syringes of air from the bottle, then stop the manually sampled data set. �(6.3.3)

☐ 20. Display a graph of pressure (kPa) versus the amount of air (syringes). �(7.1.1)

a. What happened to the pressure in the bottle when air was added?

b. What happened to the pressure in the bottle when air was removed?

c. Explain why these trends occurred and draw diagrams that show the gas molecules' positions, speed, and relative number when there is a large amount of gas and when there is a small amount of gas in the bottle.

☐ 21. In your notebook,

a. Sketch both runs of the data collected onto a graph of pressure versus amount of air.

b. Label each run and then state whether or not your predictions were correct and explain any differences.

☐ 22. Describe the relationship you observed between pressure and the amount of a gas.

a. Is pressure directly proportional ($P \propto n$) or inversely proportional ($P \propto 1/n$) to the amount of a gas (n)? How do you know?

b. What variables must be held constant to observe this relationship?

c. Assuming this is the correct relationship, what will happen to the pressure if the amount of gas is doubled?

☐ 23. Disassemble the setup and disconnect and remove the sensors from your data collection system.

Procedure – Part 3: How does volume affect pressure?

☐ 24. Connect the pressure sensor to your data collection system �(2.1) and create a new file. �(1.2)

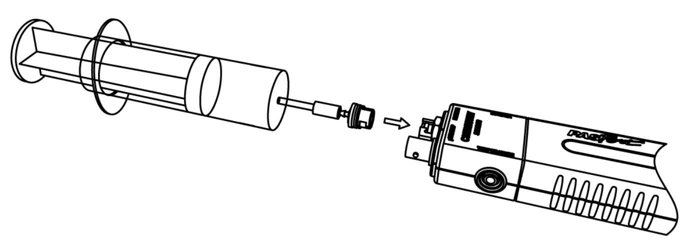
☐ 25. Configure the data collection system to manually collect pressure (kPa) and volume (mL) in a table. Define "volume" as a manually entered data set with units of milliliters (mL). �(5.2.1)

☐ 26. List the independent and dependent variables in this experiment and then explain what you think will happen to the air pressure inside the syringe as the volume of the syringe decreases and increases.

☐ 27. Collect one run of data as you decrease the volume in the syringe using the procedure below. You will determine the pressure of the starting volume and of four additional volumes that become sequentially smaller, such as 30 mL, 25 mL, 20 mL, 15 mL, and 10 mL. Use these data points to determine how pressure changes as volume decreases.

a. Start a manually sampled data set. �(6.3.1)

b. Adjust the plunger so air occupies half the syringe and then attach the syringe to the sensor using the quick-release connector.



c. Record the pressure and volume of the first data point. �(6.3.2)

d. Adjust the plunger to the next volume and then record this data point. �(6.3.2) Repeat this step until all the data points have been recorded.

   e. Stop the manually sampled data set �(6.3.3) and disconnect the syringe from the sensor.

☐ 28. Collect one run of data as you increase the volume in the syringe using the procedure below. You will determine the pressure of the starting volume and of four additional volumes that become sequentially larger, such as 30 mL, 35 mL, 40 mL, 45 mL, and 50 mL. Use these data points to determine how pressure changes as volume increases.

   a. Start a manually sampled data set. �(6.3.1)
   b. Adjust the plunger so air occupies half the syringe and then attach the syringe to the sensor.
   c. Record the pressure and volume of the first data point. �(6.3.2)
   d. Adjust the plunger to the next volume and then record this data point. �(6.3.2) Repeat this step until all the data points have been recorded.
   e. Stop the manually sampled data set �(6.3.3) and disconnect the syringe from the sensor.

☐ 29. Display a graph of pressure (kPa) versus volume (mL). �(7.1.1)

   a. What happened to the pressure as the volume decreased?
   b. What happened to the pressure as the volume increased?
   c. Explain why these trends occur and draw diagrams that show the gas molecules' positions, speed, and relative number in both a large and a small volume.

☐ 30. In your notebook,

   a. Sketch both runs of the data collected onto a graph of pressure versus volume.
   b. Label each run and then state whether or not your predictions were correct. Explain any differences.

☐ 31. Describe the relationship you observed between pressure and volume.

   a. Is pressure directly proportional ($P \propto V$) or inversely proportional ($P \propto 1/V$) to the volume of a gas (V) in a container? How do you know?
   b. What variables must be held constant to observe this relationship?
   c. Assuming this is the correct relationship, what happens to pressure if the volume of a container is reduced by half?

Questions

1. Define "pressure" and describe how gases exert pressure at the molecular level (use the word "molecules" in your answer).
2. List the mathematical relationships you determined, in the above procedures, between pressure and each independent variable (V, n, T), using "P" for pressure and the corresponding symbols for the other variables.
3. Combine these three mathematical relationships into one that includes all the variables.
4. A mathematical relationship can be changed into a mathematical equation by adding a proportionality constant, that is, a constant that will result in the two sides of the equation being equal. For example, $a \propto b$ can be changed into an equation by writing $a = kb$, where k is the proportionality constant.

   Use "R" as your proportionality constant and change the mathematical relationship in your answer to the previous question to an equation.
5. The Ideal Gas Law is often written as $PV = nRT$. Does the equation in your answer to the previous question agree with the Ideal Gas Law? Explain your reasoning.

Teacher Notes: Understanding Pressure

Learning Objectives

Describe pressure at the molecular level and explain how temperature, volume, and the amount of a gas affect pressure in a closed system.

- Use the kinetic molecular theory to explain the properties of gases.
- Explain that the collisions of molecules with a surface create the observable pressure on that surface.
- Become familiar with the kilopascal (the International System of Units unit of pressure).
- Derive the Ideal Gas Law ($PV = nRT$).

Safety

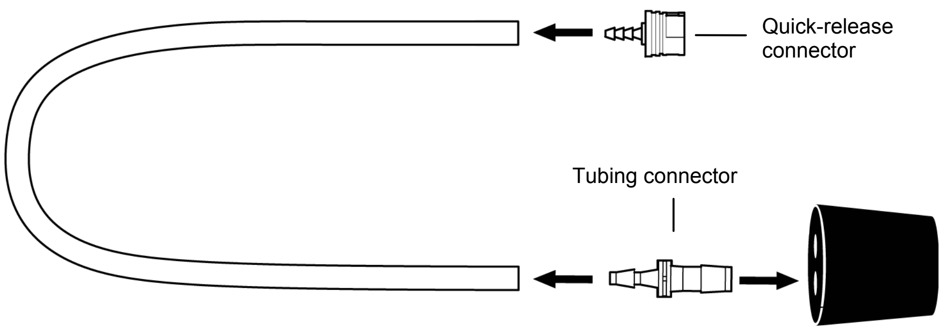
In this activity, the students will be working with pressurized systems. The absolute pressure sensor has an upper limit of 700 kPa, but there is no reason for students to create pressures near this value. When working with the syringe, the students will likely try to get the sensor to read as high a pressure as possible. There is an increased chance of both injury and damage to the equipment at high pressures, so over-compressing the air in the syringe should be avoided.

When working with the sampling bottle, the stopper may pop out and chemicals inside the container could spray out of the container. Make sure students are wearing eye protection.

Activity Preparation

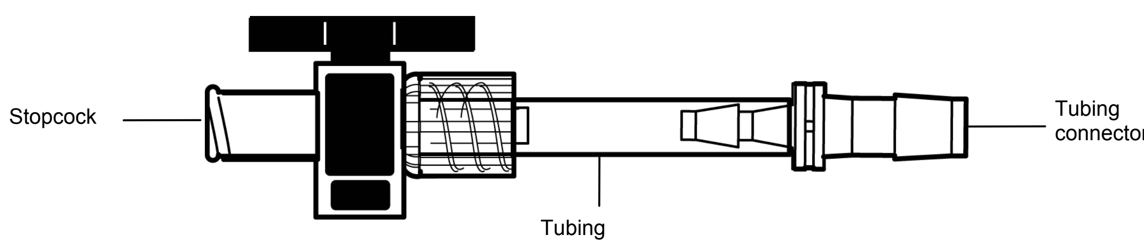
PREPARATION OF THE RUBBER STOPPER

1. Insert the wider end of the tubing connector into one hole of the rubber stopper. If this is difficult, add a drop of glycerin.
2. Connect a 50-cm piece of tubing to the other, narrower end of the tubing connector.
3. Insert the barbed end of the quick-release connector into the open end of the 50-cm piece of tubing. If this is difficult, add a drop of glycerin.



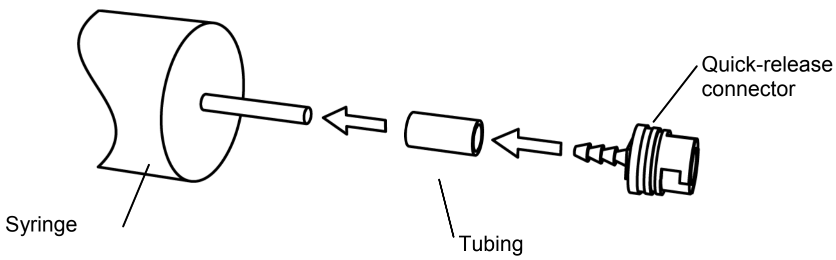
PREPARATION OF THE STOPCOCK

1. Attach one end of a 2-cm piece of tubing around the small tube surrounded by the plastic casing on the stopcock.
2. Connect the other end of the 2-cm piece of tubing to the narrower end of the tubing connector.



PREPARATION OF THE SYRINGE

1. Connect the syringe to the quick-release connector using a 2-cm piece of tubing. Put a drop of glycerin on the connecting pieces as necessary.



Activity Timeline

The Understanding Pressure activity is designed to take three "days" (45 minutes periods).

- ***1st day:*** Introduce the activity using the Activity Introduction below and then have students complete Part 1. At the end of the class period have student groups share their data and use it to determine whether the relationship between pressure and temperature is directly or inversely proportional.
- ***2nd day:*** Have the students complete Part 2 and Part 3.
- ***3rd day:*** Have the students share their data and then answer the questions at the end of the activity.

  If your students need assistance with the mathematics, you may need to walk them through the derivation of the Ideal Gas Law.

  Use the second half of this class period to discuss how this activity helps students with their airbag design. Before having students answer the Research questions on the Challenge handout, use the discussion questions provided in the Connecting the Activity to the Challenge below to help them make the connection between the activity and their airbag design.

Activity Introduction

To introduce this activity, Understanding Pressure, ask the students questions related to this challenge, such as:

- **What is pressure?**

  Pressure is the force exerted over a given area. A newton is a force and a meter squared is an area.
- **What is atmospheric pressure?**

  Atmospheric pressure is the force exerted on a surface due to air molecules colliding with the surface.
- **What are kilopascals?**

  A kilopascal (kPa) is a unit of pressure. A “pascal” is 1 newton per meter squared.

To help all the students understand the answers to these questions, project a graph of pressure (kPa) versus time (s) for the class to see. Hold up the pressure sensor and show the students the opening on the sensor that measures the pressure. Have the students predict what the pressure in the room will be.

- **What is the pressure in the classroom? Make a prediction. Be sure to note the units are kPa.**

  If you are at sea level, the pressure will be approximately 101.3 kPa.
- **Who thinks the pressure will be zero? Larger than zero? Smaller than zero?**

  Have the students commit to their answers. Have two or three students explain their predictions.

Collect pressure data for one minute and then stop data collection. Use the kinetic molecular theory to discuss the concept of pressure with your students.

- **What is the pressure in the classroom today?**

  Read the pressure from the data collected.
- **Why is the pressure not zero?**

  Air molecules are continuously colliding with each other from high in the atmosphere all the way to the surfaces on Earth, which are the ones that create a measurable force over the area they contact.

- **What is pressure? How have you heard the word pressure used in your daily life?**

  The word “pressure” has several different meanings. It means the act of being pressed, an urgent claim or demand, and an oppressive condition. In science, pressure is defined as the force exerted over a given area.

- **What is exerting a force on the pressure sensor?**

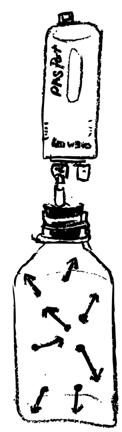
  Air particles exert a force on the pressure sensor as they collide into it.

- **Why is the pressure in the room staying the same?**

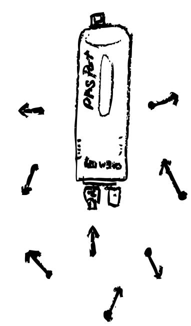
  The conditions in the room are relatively stable and thus the air is constantly colliding with the same amount of force.

Use a simulation to show the students that molecules exert pressure by colliding with a surface. Use the simulation and the sensor data to ensure the students understand the following:

- Pressure is force exerted over a specific area
- The SI unit of pressure is the pascal (Pa) which is equal to one newton (force) per square meter (area). In this lab the kilopascal, (abbreviated "kPa") is the unit used. There are many units of pressure. Students may be more familiar with other units, such as pounds per square inch (psi), inches or millimeters of mercury, or bars (1 bar = 100 kPa).
- How to sketch a molecular level diagram of pressure in open and closed systems



Closed System



Open System

Teacher Tips

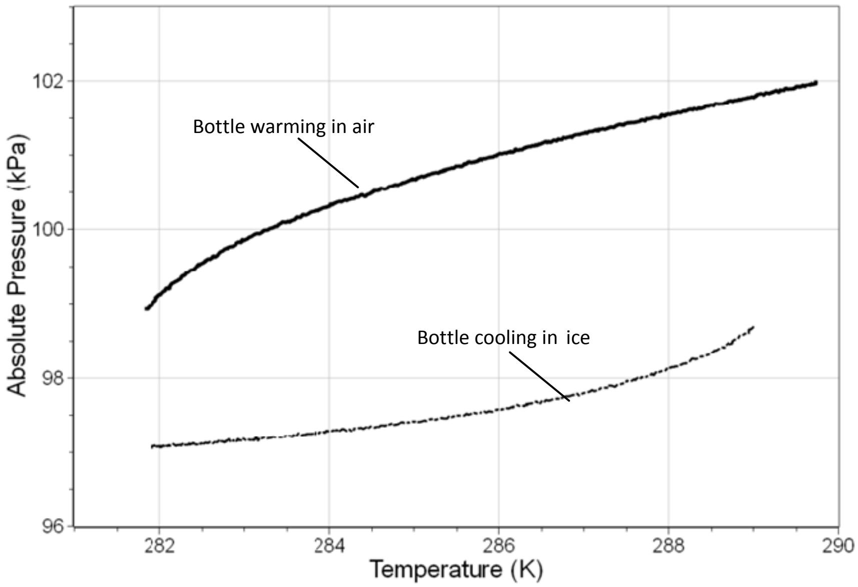
- To use the absolute pressure sensor:

  Insert the quick-release connector into the port of the absolute pressure sensor and turn the connector clockwise until the fitting “clicks” onto the sensor (about one-eighth turn).

- At the end of this activity, leave the stopcock attached to the two-hole rubber stopper. The remaining research activities in the module use the two-hole stopper fitted with both the quick-release connector and the stopcock.
- It is recommended that students using the SPARK Science Learning System or SPARKvue software use the accompanying SPARKlabs created for this activity. If you do have your students build their own pages, make sure they turn the "Use same value for all runs" feature off when they create their own user-entered data sets.
- The graph of absolute pressure versus temperature that the students collect could, theoretically, be used to extrapolate to absolute zero. However, the data will produce very poor results because the absolute pressure sensor measures changes in pressure more quickly than the stainless steel temperature sensor measures changes in temperature.

Sample Data

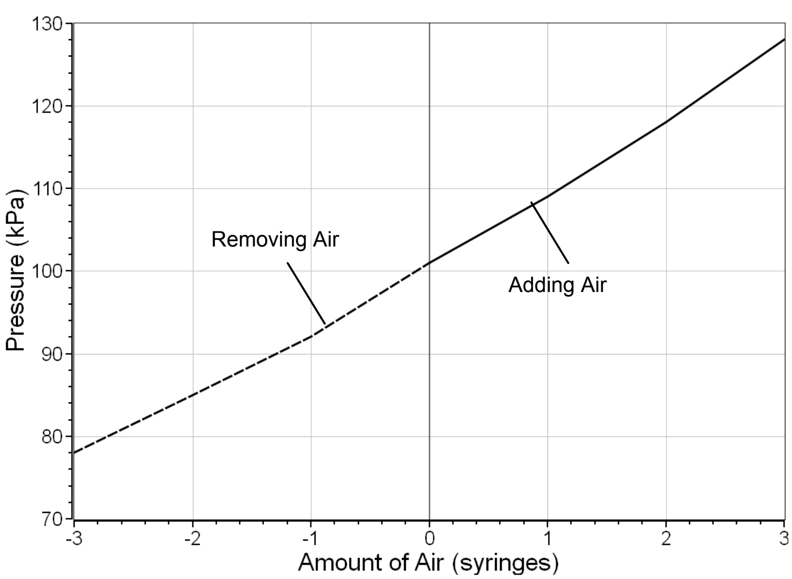
PRESSURE VERSUS TEMPERATURE GRAPH (PART 1)



NOTE: The "Bottle cooling in ice" data run starts on the right and moves to the left as data is collected, since the temperature in the bottle is decreasing while the temperature on the graph scale increases from left to right. The "Bottle warming in air" data starts on the left and moves toward the right, since the temperature is increasing.

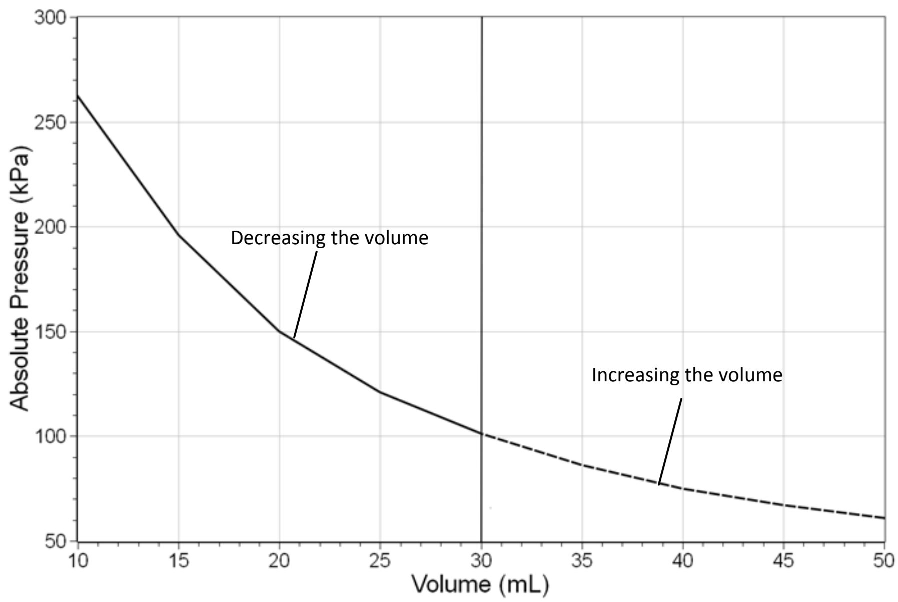
PRESSURE VERSUS THE AMOUNT OF GAS, DATA TABLES AND GRAPH (PART 2)

Run 1: Adding air to the sample bottle		Run 2: Removing air from the sample bottle	
Amount of Air (syringes)	**Absolute Pressure (kPa)**	**Amount of Air (syringes)**	**Absolute Pressure (kPa)**
0	101	0	101
1	109	–1	92
2	118	–2	85
3	128	–3	78



PRESSURE VERSUS VOLUME, DATA TABLES AND GRAPH (PART 3)

Run 1: Increasing the volume		Run 2: Decreasing the volume	
Volume (mL)	**Absolute Pressure (kPa)**	**Volume (mL)**	**Absolute Pressure (kPa)**
30	101	30	101
25	121	35	86
20	150	40	75
15	196	45	67
10	262	50	61

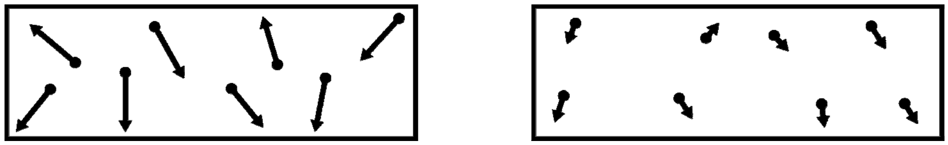
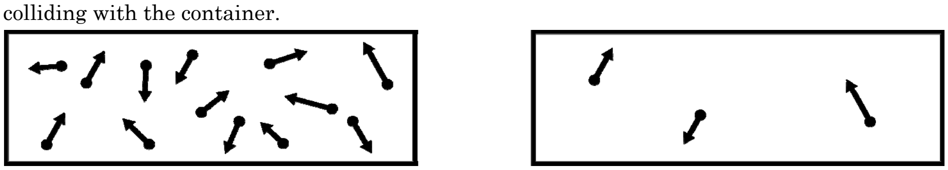


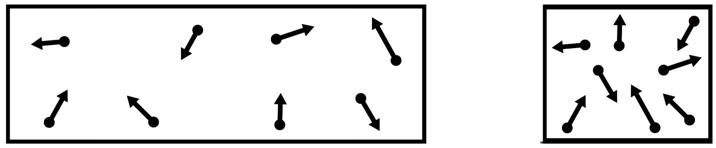
Answer Key

Below are sample responses to the questions found in either the Procedure steps or the Questions section of the Understanding Pressure activity. The handout and SPARKlab questions may be numbered differently, and are therefore listed in separate columns. The SPARKlab question numbers begin with an "S" to further differentiate them. As this activity has multiple parts, the step or question number begins with the part number, for example, "P2:3" under "Procedure" indicates the sample response is for the question in step 3 of the Procedure in Part 2 of the activity.

SAMPLE RESPONSES TO THE QUESTIONS IN THE UNDERSTANDING PRESSURE ACTIVITY HANDOUT

Procedure		Sample Response
Handout	**SPARKlab**	
		Part 1
4	S P1:4	For *Part 1: How does temperature affect pressure?* the variables are: Independent variable: Temperature Dependent variable: Pressure When the temperature increases, I think the pressure will increase because the molecules will move faster and hit the walls more often and with more force. When the temperature decreases, the pressure will decrease because the molecules will move slower and hit the wall less often and with less force.
8a	S P1:12	As the temperature in the sampling bottle decreases, the pressure decreases.
8b	S P1:13	As the temperature in the sampling bottle increases, the pressure increases.

Procedure		Sample Response
Handout	SPARKlab	
8c	S P1:14	When the temperature increases, the pressure also increases because the molecules move faster and hit the walls more often and with more force. When the temperature decreases, the pressure also decreases because the molecules move slower and hit the wall less often and with less force.  Warm Environment Cool Environment
9a		See the pressure versus temperature graph in the Sample Data section above.
9b	S P1:15	My predictions were correct.
10a	S P1:16	Pressure is directly proportional to temperature ($P \propto T$); when one increases the other increases and when one decreases, the other decreases, as shown on the graph.
10b	S P1:17	This relationship is observed when both the volume of the container and the amount of gas inside the container are held constant.
10c	S P1:18	In a closed system, if the temperature is reduced by half, the pressure will also be reduced by half.
Part 2		
16	S P2:4	For *Part 2: How does the amount of gas affect pressure?* the variables are: Independent variable: Amount of gas Dependent variable: Pressure When the air is added, I think the pressure will increase because there will be more molecules colliding with the container. When air is removed, I think the pressure will decrease because there will be fewer molecules colliding with the container.
20a	S P2:20	When air was added to the sampling bottle, the pressure increased.
20b	S P2:21	When air was removed from the sampling bottle, the pressure decreased.
20c	S P2:22	When air was removed, the pressure decreased because there were fewer molecules colliding with the container. When the air was added, the pressure increased because there were more molecules colliding with the container.  More Air Molecules Fewer Air Molecules
21a		See the pressure versus amount of gas data tables and graph in the Sample Data section above.
21b	S P2:23	My predictions were correct.
22a	S P2:24	Pressure is directly proportional to the amount of gas in the bottle ($P \propto n$). I know this because the data shows that when one increases the other increases and when one decreases, the other decreases.
22b	S P2:25	This relationship is observed when the volume of the container the gas occupies and the temperature of the gas are both held constant.
22c	S P2:26	In a closed system, if the amount of gas is doubled, the pressure will also double.
Part 3		
26	S P3:1	For *Part 3: How does volume affect pressure?* the variables are: Independent variable: Volume Dependent variable: Pressure I think when the volume in the syringe decreases, the pressure will increase. This is because the molecules hit the syringe walls more often. When the volume in the syringe increases, the pressure will decrease. This is because the molecules hit the syringe walls less often.
29a	S P3:16	As the volume in the syringe decreased, the pressure increased.
29b	S P3:17	As the volume in the syringe increased, the pressure decreased.

Procedure		Sample Response
Handout	SPARKlab	
29c	S P3:18	As the volume in the syringe decreased, the pressure increased because there was less space for the molecules to move and they hit the walls of the container more often. As the volume increased, the pressure decreased because there was more space for the molecules to move and they hit the walls of the container less often.  Large Volume Small Volume
30a		See the pressure versus volume graph in the Sample Data section above.
30b	S P3:19	My predictions were correct.
31a	S P3:20	Pressure is inversely proportional to the volume ($P \propto 1/V$);I know because the data shows that when one increases the other decreases and vice versa.
31b	S P3:21	The number of moles of gas and the temperature are the variables held constant in order to observe this relationship.
31c	S P3:22	If the volume of a container is reduced by half, the pressure would double.

Questions		Sample Response
Handout	SPARKlab	
1	S P3:1	Pressure is defined as a force exerted over an area. Gases exert pressure when gas molecules collide with a surface.
2	S P3:2	$P \propto T$ $P \propto n$ $P \propto 1/V$
3	S P3:3	$P \propto Tn/V$
4	S P3:4	$P = RTn/V$
5	S P3:5	Yes, the equation $P = RTn/V$ is the same as $PV = nRT$. All you have to do is multiply both sides of the equation by V and then rearrange the values RTn to be nRT. Since this is multiplication, the written order does not matter.

Connecting the Activity to the Challenge

In the Understanding Pressure activity, students have measured changes in pressure due to temperature, amount of gas, and volume; they have explained these changes at the molecular level; and they have mathematically summarized the behavior of gases in the Ideal Gas Law. The goal now is to help the students connect their understanding of pressure with how airbags work and realize that the Ideal Gas Law can help them design their airbags. Use the following questions as a guide to help the students make some of these connections.

- **What was the pressure inside the sampling bottle or syringe before you started each investigation? What caused this pressure?**

  If you are at sea level, the pressure will be approximately 101.3 kPa. This pressure is due to the molecules in the air.

- **What do you think the initial air pressure will be inside the airbag you construct? Why?**

  Students may say there is no pressure initially, but pressure inside the airbag will start at atmospheric pressure because it will have air particles inside. If they don't understand this at first, you might demonstrate, using a vacuum to draw out the air from an empty storage bag (some are made for this purpose with a hole for inserting a vacuum hose) and then ask students what was removed.

- **What will happen to the pressure inside your airbag if the number of gas molecules inside your airbag increases? How do you know? Could you predict the exact change in pressure without actually performing the experiment?**

  If the volume and temperature remain the same, the pressure inside the airbag will increase. The data shows that there is a direct relationship between pressure and the number of gas molecules. The exactly change in pressure could be calculated using the Ideal Gas Law. However, since this is an airbag and not a rigid container, something else happens first.

- **If the number of gas molecules inside your airbag increases, what other change would occur? How would this affect the pressure?**

  The volume would increase. When volume increases the pressure decreases. Thus the two changes could cancel each other out. The final pressure would depend on how great the change of each was. The Ideal Gas Law can be used to predict the exact change.

- **Why is the Ideal Gas Law a valuable tool for engineers and chemists?**

  The Ideal Gas Law allows engineers and chemists to predict what will happen when a certain change is made without actually having to physically perform the task.

After this discussion, have students answer the Research Questions for the Understanding Pressure activity on the Challenge handout.

Sample Responses to the Understanding Pressure Research Questions

Question	Sample Response
1	**What is the pressure inside an airbag before it is activated? How does the pressure inside the airbag change during activation?** The pressure inside the airbag will initially be the same as atmospheric pressure. On activation, the airbag will quickly fill with gases from the chemical reaction and the volume will increase. The pressure will be the same until the airbag is fully expanded and then the pressure will increase.
2	**List three variables that may affect the pressure inside your airbag and describe the affect each one has on the pressure.** Temperature, volume, and the amount of gas will all affect the pressure inside the airbag I design. Temperature and the amount of gas are both directly proportional to pressure, so if I increase either of them, the pressure should increase. Volume is inversely proportional, so if the volume increases then the pressure will decrease.
3	**What is the Ideal Gas Law? List one way you could use this law to help you design your airbag.** The Ideal Gas Law is $PV = nRT$. I can use this law to calculate the amount of gas I need in my airbag to obtain a specific pressure, volume, and temperature.

Activity: Mole-to-Mole Ratios

Objective

Determine the ideal amount of sodium bicarbonate to completely react with 10 mL of 0.50 M acetic acid and use these values to determine the mole-to-mole ratio in the balanced chemical equation.

Materials and Equipment

- Data collection system
- Absolute pressure sensor
- Sampling bottle, plastic, 500-mL
- Beaker, 100-mL
- Rubber stopper, two-hole, to fit the sampling bottle and fitted with a 50-cm piece of tubing with a quick-release connector, and a stopcock
- Syringe
- Balance, readability: 0.01 g
- Sodium bicarbonate ($NaHCO_3$), 1.2 g
- 0.50 M Acetic acid ($HC_2H_3O_2$), 40 mL
- Waste container
- Tap water to rinse the sampling bottle between trials

Safety

- The gas being generated causes an increase in pressure which may expel the stopper from the bottle. Because of this, eye protection should be worn during this experiment to prevent injury due to flying objects or splashed chemicals.
- Do not point the sampling bottle toward yourself or anyone else.

***NOTE**: Record all work, including tables, data, diagrams, calculations, and answers, into your notebook.*

Procedure

☐ 1. Copy Table 1 into your notebook. Fill in the following values for the approximate mass of sodium bicarbonate ($NaHCO_3$): 0.10 g, 0.20 g, 0.30 g, 0.40 g, 0.50 g, and 0.60 g.

Table 1: Pressure change due to increasing amounts of sodium bicarbonate

Approximate Mass of $NaHCO_3$ (g)	Exact Mass of $NaHCO_3$ (g)	Initial Pressure (kPa)	Final Pressure (kPa)	Change in Pressure (kPa)
	RECORD THE DATA IN YOUR NOTEBOOK.			

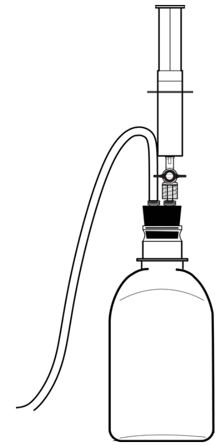
☐ 2. Two lab groups will work together to collect data in this activity; one will collect data for 0.10 g, 0.30 g, and 0.50 g of $NaHCO_3$ and the other will collect data for 0.20 g, 0.40 g, and 0.60 g of $NaHCO_3$. When finished, record the other group's data in your notebook.

In your notebook, indicate the set of data your group is collecting, Data Set 1 (0.10 g, 0.30 g, or 0.50 g) or Data Set 2 (0.20 g, 0.40 g, or 0.60 g).

☐ 3. What do you think will happen to the pressure in the sampling bottle as increasing amounts of $NaHCO_3$ are added to the same amount (10 mL of 0.50 M) of acetic acid ($HC_2H_3O_2$)? Explain your reasoning.

☐ 4. Connect the absolute pressure sensor to your data collection system �(2.1) and create a new file �(1.2) with a pressure (kPa) versus time (s) graph and a digits display of pressure (kPa). �(7.1.1)(7.3.1) Change the pressure measurement to display the tenths value. �(5.4)

☐ 5. Use a balance to obtain the mass of your first sample of $NaHCO_3$. Record the exact mass in Table 1.



☐ 6. Set up the bottle:

a. Place the $NaHCO_3$ you just measured into the bottle.

b. Attach the pressure sensor to the stopper using the quick-release connector.

c. Firmly place the stopper into the bottle.

d. Expel all the air from the syringe and place the syringe in a 100-mL beaker containing the 0.50 M $HC_2H_3O_2$. Pull the plunger out until the syringe contains 10.0 mL of solution (with no air bubbles).

e. Make sure the stopcock is closed and attach the syringe to the stopcock.

☐ 7. Start collecting data �(6.2), open the stopcock, and inject the $HC_2H_3O_2$ into the bottle. Immediately turn the stopcock to the closed position.

☐ 8. Hold the stopper in place and gently swirl the bottle to help the reactants mix. Stop collecting data when the reaction is complete: no gas bubbles form and the pressure has stabilized. �(6.2)

☐ 9. Remove the syringe from the stopcock and then release the pressure from the bottle by slowly removing the stopper from the bottle.

NOTE: Hold the sampling bottle away from yourself and others because some of the solution will probably spurt out.

☐ 10. Find the initial pressure, final pressure, and change in pressure for this run of data and record these values in Table 1. �(9.2)

☐ 11. Pour the solution in the bottle into the waste container. Clean the bottle by rinsing it with water.

☐ 12. Repeat this procedure for the remaining amounts of $NaHCO_3$ in your group's set.

☐ 13. Exchange data with the lab group you are working with so you have data for all 6 reactions.

☐ 14. When the ideal amount of each reactant is combined, the maximum amount of product is formed with the least amount of unused or wasted material. What is the ideal amount (in grams) of $NaHCO_3$ required to react with the 10 mL of 0.50 M $HC_2H_3O_2$? Follow the steps below to find this answer:

a. Plot a graph of maximum change in pressure (kPa) versus mass of $NaHCO_3$ in your notebook. Include the origin in your plot. Why should the origin be included?

b. Draw a line of best-fit through the data points that are increasing.

c. Draw a second line of best-fit through the data points that are approximately the same.

d. Find the mass of $NaHCO_3$ at the point where the two best-fit lines intersect and record the value in your notebook.

e. Explain why this mass is the ideal mass even though other amounts of $NaHCO_3$ may have reacted to form a similar amount of product.

Questions

1. Each trial used the same amount of $HC_2H_3O_2$. What happened as you added increasing amounts of $NaHCO_3$? Why did this happen?
2. Was your prediction correct? Explain any differences.
3. In a chemical reaction, the reactant used up first is called the "limiting reactant." The other reactant is called the "excess reactant." When you added 0.10 g of $NaHCO_3$ to 10 mL of 0.50 M $HC_2H_3O_2$, which was the limiting reactant and which was the excess reactant? How do you know?
4. When you added 0.60 g of $NaHCO_3$ to 10 mL of 0.50 M $HC_2H_3O_2$, what was the limiting reactant and what was the excess reactant? How do you know?

5. In a balanced chemical equation, the coefficients indicate the ideal mole ratio between reactants and products. This ratio is called the "mole-to-mole" ratio (or stoichiometric ratio). According to your data, what is the mole-to-mole ratio in the chemical reaction between $NaHCO_3$ and $HC_2H_3O_2$? The following questions will guide you to finding this ratio:
   a. What is the ideal amount of $NaHCO_3$ that can be added to 10 mL of 0.50 M $HC_2H_3O_2$ to produce the greatest amount of gas? Report your answer in grams and in moles. (The molar mass of $NaHCO_3$ is 84.01 g/mol.)
   b. How many moles of $HC_2H_3O_2$ are in 10 mL of the 0.50 M solution?
   c. Compare the number of moles of $HC_2H_3O_2$ to the ideal amount of $NaHCO_3$ that released the maximum amount of gas. Use the following format:
      ______ mol $HC_2H_3O_2$ **:** ______ mol $NaHCO_3$
   d. Simplify this experimental data to a whole number ratio.
6. When acetic acid and sodium bicarbonate react, the products are sodium acetate, water, and carbon dioxide. Write the balanced chemical equation using the simplest whole number mole ratio values as coefficients for the reactants and use the Law of Conservation of Matter to determine the coefficients for the products. Include state-of-matter symbols in your balanced chemical equation.
7. The smallest amount of sodium carbonate (Na_2CO_3) that reacts with all 10 mL of 0.50 M $HC_2H_3O_2$ is 0.26 grams. What is the mole-to-mole ratio between sodium carbonate and acetic acid? (The molar mass of Na_2CO_3 is 105.98 g/mol). Using the simplest mole-to-mole ratio values as coefficients, write the balanced chemical reaction between Na_2CO_3 and $HC_2H_3O_2$.
8. In your own words, explain the importance of a mole-to-mole ratio in a chemical equation.

Teacher Notes: Mole-to-Mole Ratios

Learning Objectives

Determine the ideal amount of sodium bicarbonate to completely react with 10 mL of 0.50 M acetic acid and use these values to determine the mole-to-mole ratio in the balanced chemical equation.

- Explain the term “mole-to-mole ratio.”
- Differentiate between a limiting reactant and an excess reactant.

Safety

In this activity the students will be working with pressurized systems. The absolute pressure sensor has an upper limit of 700 kPa, but there is no reason for students to create pressures near this value.

The stopper may pop out and any chemicals inside the container could spray out of the container. Make sure students are wearing eye protection.

Activity Preparation

PREPARE 500 ML OF 0.50 M ACETIC ACID ($HC_2H_3O_2$) STARTING FROM EITHER CONCENTRATED (GLACIAL 17.4 M) OR DILUTE (6 M) ACETIC ACID. THIS IS ENOUGH FOR 12 LAB GROUPS.

Starting with concentrated (glacial, 17.4 M) acetic acid:

1. Place a stir bar in a 500-mL beaker, and add approximately 250 mL of distilled water.
2. Slowly add 14.4 mL of 17.4 M acetic acid to the beaker, stirring continuously.
3. Allow the solution to cool, then carefully pour the solution into a 500-mL volumetric flask and dilute it to the mark with distilled water.
4. Cap and invert the flask three times carefully to ensure complete mixing.

Starting with dilute (6 M) acetic acid:

1. Add approximately 250 mL of distilled water to a 500-mL volumetric flask.
2. Add 41.7 mL of 6 M acetic acid to the water, and dilute it to the mark with distilled water.
3. Cap and invert the flask three times carefully to ensure complete mixing.

PREPARATION OF THE RUBBER STOPPER

1. Connect a 50-cm piece of tubing to one hole in the stopper using a tubing connector.
2. Insert the barbed end of the quick-release connector into the open end of the 50-cm piece of tubing. If this is difficult, add a drop of glycerin.
3. Connect the stopcock to the other hole in the stopper using a 2-cm piece of tubing and a tubing connector.

Activity Timeline

The Mole-to-Mole Ratios activity is designed to take two "days" (45 minutes periods).

- ***1st day:*** Introduce the activity and have the students complete the procedure.
- ***2nd day:*** Have students complete the lab questions, share their data, and complete the Research questions on the Challenge handout for this activity.

Activity Introduction

Having obtained an understanding of pressure and the Ideal Gas Law from the previous activity, the students are ready to explore the chemical reaction they will use to fill their airbags. Introduce this activity by asking the following questions.

NOTE: The students should think about these questions, but they should not be answered during this discussion.

- **What chemicals will be used to fill your airbag?**

  Carbon dioxide gas will fill the airbag. Carbon dioxide gas is one of the products formed when acetic acid and sodium bicarbonate react.

- **How much of each chemical should be used?**

  The amount of each chemical used depends on the size of the airbag. One goal is to have no wasted materials so reactants must be added in the correct stoichiometric ratio.

- **Is there an ideal ratio that should be used when combining these reactants?**

  Yes. The ideal ratio will follow the Law of Conservation of Matter.
- **How can the balanced chemical equation for this reaction be determined experimentally?**

  That is what students will do in this lab.

Now write the following on the board for all the students to see:

______ $HC_2H_3O_2$ **+** ______ $NaHCO_3 \rightarrow$ products

Tell the students that the goal of this activity is to experimentally determine the ideal ratio (the mole-to-mole ratio or stoichiometric ratio) between the reactants. Discuss with the students how they will be able to determine the ideal ratio. Use the following questions as a guide:

- **How will you know if you have mixed an ideal amount of reactants?**

  The maximum amount of product will be formed without either reactant being left unused (wasted).
- **How will you measure the amount of product formed? Why does this work?**

  Students will use a pressure sensor to measure how much product is formed. This will work because a gas, carbon dioxide, is produced during the reaction. If the reaction takes place in a closed system, then the change in pressure will be due to the product of the reaction. The amount of product can be calculated using the Ideal Gas Law.
- **What will happen if you have too little of one reactant?**

  That reactant will be used up first and when it is, the reaction will stop.
- **What will happen if you have too much of one reactant?**

  It will not all be used and is wasted.

Conclude this discussion by explaining that the ideal ratio can be found by determining the smallest amount of one reactant (sodium bicarbonate) that, when added to a fixed amount of the second reactant (acetic acid), will produce the greatest amount of product (carbon dioxide gas). The amount of each reactant will then be converted to moles and compared to one another to find the mole-to-mole ratio.

Teacher Tips

This activity requires two lab groups to work together. Each lab group will perform three of the six trials. One group should collect data for the 0.10 g, 0.30 g, and 0.50 g trials and the other group will collect data for 0.20 g, 0.40 g, and 0.60 g. trials. Splitting the data collection by every other trial, as described, will allow both groups to see at least one data run that results in the maximum pressure achieved as well as one that does not reach the maximum pressure. The groups will need to exchange their data to complete their data analysis.

At the end of this activity, leave the stopcock attached to the two-hole stopper. The remaining activities use the two-hole stopper fitted with both the quick-release connector and the stopcock.

Sample Data

PRESSURE VERSUS TIME DATA FOR DIFFERENT AMOUNTS OF $NaHCO_3$ ADDED TO 10 ML OF 0.50 M $HC_2H_3O_2$

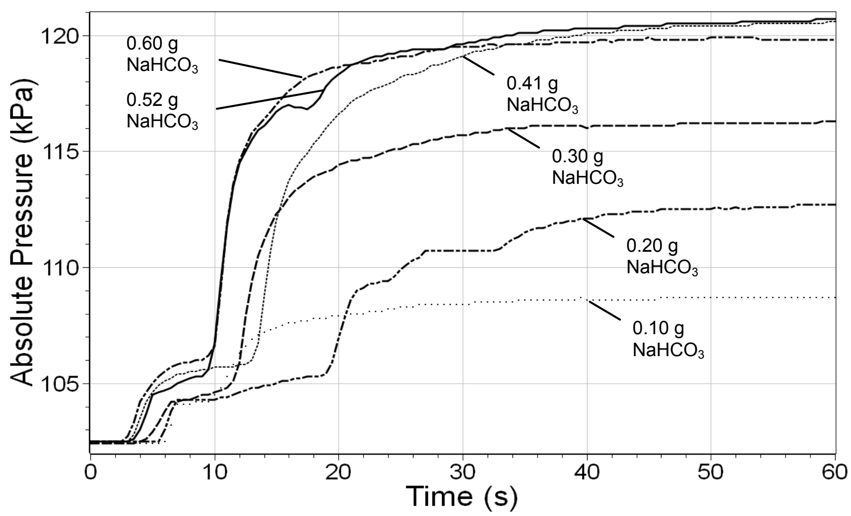


TABLE 1: PRESSURE CHANGE DUE TO INCREASING AMOUNTS OF SODIUM BICARBONATE

Approximate Mass of Sodium Bicarbonate (g)	Exact Mass of Sodium Bicarbonate (g)	Initial Pressure (kPa)	Final Pressure (kPa)	Change in Pressure (kPa)
0.10	0.10	102.4	108.7	6.3
0.20	0.20	102.5	112.9	10.4
0.30	0.30	102.4	116.5	14.1
0.40	0.41	102.4	120.7	18.3
0.50	0.52	102.5	120.8	18.3
0.60	0.60	102.5	120.0	17.5

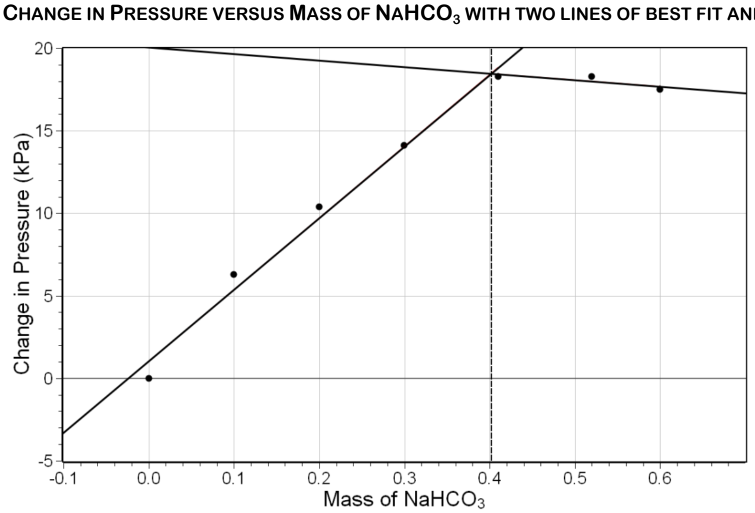
SAMPLE CALCULATIONS

Change in pressure:

Final Pressure – Initial Pressure = Change in Pressure

0.10 g $NaHCO_3$: 108.7 kPa – 102.4 kPa = 6.3 kPa

CHANGE IN PRESSURE VERSUS MASS OF $NaHCO_3$ WITH TWO LINES OF BEST FIT AND THEIR INTERSECTION



Answer Key

Below are sample responses to the questions found in either the Procedure steps or the Questions section of the Mole-to-Mole Ratios activity. The handout and SPARKlab questions may be numbered differently, and are therefore listed in separate columns. The SPARKlab question numbers begin with an "S" to further differentiate them.

SAMPLE RESPONSES TO THE QUESTIONS IN THE MOLE-TO-MOLE RATIOS ACTIVITY HANDOUT

Procedure		Sample Response
Handout	SPARKlab	
2	S 1	This is either Data Set 1 or Data Set 2, depending on the groups' allocation.
3	S 2	I think the amount of pressure will increase as larger amounts of sodium bicarbonate are mixed with acetic acid. It will increase because the reaction produces a gas which will increase the pressure in the bottle. As more sodium bicarbonate is added, more and more gas will form.
14a–d	S 41, 42	Refer to the graph showing change in pressure versus mass of $NaHCO_3$ in the Sample Data section above.
14a		If zero grams of sodium bicarbonate are added to the acetic acid, there will be no (zero) change in pressure. The origin should be included to show this data point.
14d	S 43	The mass determined at the intersection of the two best-fit lines on the Sample Data graph: 0.40 g
14e	S 44	This amount of sodium bicarbonate will react with the acetic acid completely to give a maximum amount of product without either sodium bicarbonate or acetic acid being wasted (unreacted).

Questions		Sample Response
Handout	SPARKlab	
1	S 1	In the first few trials with increasing amounts of sodium bicarbonate, the pressure inside the bottle increased. Eventually, however, a maximum change in pressure was reached and even when I added more sodium bicarbonate, the pressure didn't increase further. I think the pressure increased as the amount of sodium bicarbonate added increased until the particular reaction where both the sodium bicarbonate and acetic acid were completely used. In the reactions after that, the reaction stopped when the acetic acid was used up and the same maximum pressure was reached regardless of the amount of sodium bicarbonate added.
2	S 2	My prediction was not correct. The amount of pressure did not keep increasing as larger amounts of sodium bicarbonate were mixed with the same amount of acetic acid because in the reactions after the one in which both reactants were consumed, acetic acid was used up before the sodium bicarbonate was used up and the change in pressure for each reaction was about the same.
3	S 3	In the chemical reaction using 0.10 g of $NaHCO_3$ and 10 mL of 0.50 M $HC_2H_3O_2$, the limiting reactant was sodium bicarbonate and the excess reactant was acetic acid. I know this because more gas was produced in the next trial when a greater amount of sodium bicarbonate was added. Since both of these trials had the same amount of acetic acid, the first reaction must have run out of sodium bicarbonate.
4	S 4	In the chemical reaction using 0.60 g of $NaHCO_3$ and 10 mL of 0.50 M $HC_2H_3O_2$,the limiting reactant was acetic acid and the excess reactant was sodium bicarbonate. I know this because the previous trial using less $NaHCO_3$ (0.52 g) resulted in a similar change in pressure (caused by the gas produced). The reaction with 0.60 g $NaHCO_3$ didn't produce more gas than the reaction using 0.52 g, indicating that the reaction stopped before using all the sodium bicarbonate.
5a	S 5a	The ideal amount of $NaHCO_3$ that can be added to 10 mL of 0.5 M $HC_2H_3O_2$ to reach the maximum change in pressure is 0.40 g, which is 0.0048 moles of $NaHCO_3$. $0.40\text{ g} \times \frac{1\text{ mol}}{84.01\text{ g}} = 0.0048\text{ mol NaHCO}_3$
5b	S 5b	0.0050 moles of $HC_2H_3O_2$ are in 10 mL of 0.50 M $HC_2H_3O_2$. $\frac{0.50\text{ mol}}{\text{L}} \times 10.0\text{ mL} \times \frac{1\text{ L}}{1000\text{ mL}} = 0.0050\text{ mol HC}_2\text{H}_3\text{O}_2$
5c	S 5c	0.0050 mol $HC_2H_3O_2$: 0.0048 mol $NaHCO_3$
5d	S 5d	1 mol $HC_2H_3O_2$: 1 mol $NaHCO_3$
6	S 6	$HC_2H_3O_2(aq) + NaHCO_3(s) \rightarrow NaC_2H_3O_2(aq) + CO_2(g) + H_2O(l)$ (if no coefficient appears, it is assumed to be "1")

Questions		Sample Response
Handout	SPARKlab	
7	S 7	To find the mole-to-mole ratio between sodium carbonate and acetic acid , first calculate the number of moles of each reactant used: $0.26\text{ g} \times \frac{1\text{ mol}}{105.98\text{ g}} = 0.0025\text{ mol } Na_2CO_3$ $\frac{0.50\text{ mol}}{\text{L}} \times 10.0\text{ mL} \times \frac{1\text{ L}}{1000\text{ mL}} = 0.0050\text{ mol } HC_2H_3O_2$ Compare the number of moles of each reactant: 0.0050 mol $HC_2H_3O_2$: 0.0025 mol Na_2CO_3 Convert the ratio to whole numbers: 2 mol $HC_2H_3O_2$: 1 mol Na_2CO_3 Write the balanced equation: $2\ HC_2H_3O_2(aq) + Na_2CO_3(s) \rightarrow 2\ NaC_2H_3O_2(aq) + CO_2(g) + H_2O(l)$
8	S 8	A mole-to-mole ratio represents the ideal amount of each reactant that, when combined, will give the largest amount of product with the least amount of wasted (or unused) chemicals.

Connecting the Activity to the Challenge

The students should connect the idea of mole-to-mole ratios, limiting reactants, and excess reactants when they plan how much of each reactant to include in their airbag. Start by asking the students how the Mole-to-Mole Ratios activity helps them with their airbag design. If the students cannot make any connections on their own, use the following questions to help the students see how the activities are related.

- **What is a mole-to-mole ratio and how does it relate to your airbag challenge?**

  A mole-to-mole ratio represents the ideal amount of each reactant, that when combined, will give the largest amount of product with the least amount of wasted (or unused) chemicals. When students design their airbag, they will need to make sure they combine acetic acid and sodium bicarbonate in a 1:1 mole ratio, which they should have determined by the experiment.

- **What will happen if you mix a random amount of acetic acid with sodium bicarbonate? How will this violate the requirements and constraints for this project?**

  If a random amount of each reactant is mixed, then one of the reactants will run out (limiting reactant) before the other one does. Since the other reactant is not used up, it is wasted (excess reactant). The requirements specify that chemicals should not be wasted and that mathematical evidence needs to be provided to support this requirement.

  Another reason a random amount of reactants should not be mixed is because there is no way to know how much carbon dioxide gas will form and so there will be no way to control the pressure in the airbag.

- **How were you able to determine the mole-to-mole ratio for the reaction between sodium bicarbonate and acetic acid? Why is this ratio useful to the airbag Challenge?**

  The mole-to-mole ratio between sodium bicarbonate and acetic acid was determined by repeating the reaction several times using the same amount of acetic acid and slowly increasing the amount of sodium bicarbonate. The mole-to-mole ratio was obtained at the point at which the most product was formed (largest change in pressure) with the fixed amount of acetic acid used.

  This ratio is useful because it provides the balanced chemical reaction for the reaction between sodium bicarbonate and acetic acid. This is the reaction that can be used in the airbags to produce a known number of gas molecules (CO_2).

After the discussion, direct the students to answer the Research questions listed in the Mole-to-Mole Ratios section on the Challenge handout.

Sample Responses to the mole-to-mole ratios Research Questions

Question	Sample Response
1	**How can you control the amount of gas that will be produced inside your airbag?** The amount of gas produced depends on the amount (determined by the mole-to-mole ratio) of each reactant I use inside my airbag.
2	**Give an example of how an airbag design would result in chemicals being "wasted"? How can you avoid this mistake?** An airbag would waste chemicals if the quantities of the reactants used deviated from the reactants' mole-to-mole ratio. Once the limiting reactant (the one used up first) was used up, the reaction would end, no more gas would be produced, and the chemical provided in excess would be wasted. I can avoid this mistake by using the same number of moles of each reactant because there is a one-to-one mole ratio between them needed for the reaction.
3	**What gas will inflate your airbag?** Carbon dioxide gas will fill my airbag.
4	**How is your airbag similar to and different from the sampling bottle we used in this activity?** My airbag is similar to the sampling bottle because it is a closed system. The gas produced is trapped inside the airbag just like it is trapped inside the bottle. My airbag is different than the sampling bottle because it is not a rigid container.

Activity: Variable Volumes

Objective

Determine the volume of gas and the amount of gas (in moles) needed to fill bags of various sizes to a specific pressure.

Materials and Equipment

- Data collection system
- Absolute pressure sensor
- Temperature sensor
- Syringe
- Rubber stopper to fit the balloon, two-hole, fitted with a 50-cm piece of tubing with a quick-release connector, and a stopcock
- Graduated cylinder, 1000-mL
- Beaker, 400-mL
- Plastic bags, sealable, various sizes (3)
- Balloon, large
- Tub, plastic
- Tap water
- Paper towels

Safety

- Wear safety goggles.
- Do not point the balloon toward yourself or anyone else.

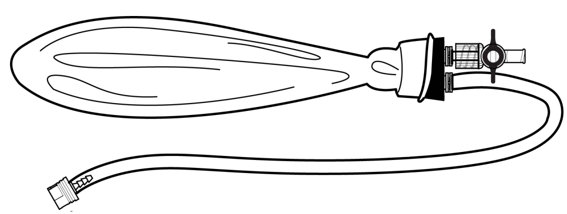
NOTE*: Record all work, including tables, data, diagrams, calculations, and answers, into your notebook.*

Procedure – Pressure inside a large balloon as it fills with air

☐ 1. What do you think will happen to the pressure inside a large balloon as air is added? Explain your prediction.

☐ 2. Test your prediction by adding 3 to 4 syringes of air to the large balloon as follows:

a. Place the balloon around the stopper fitted with a quick-release connector and stopcock. Make sure the opening of the balloon is centered around the two openings on the stopper and that the balloon is kept either completely horizontal or completely vertical throughout the experiment.



b. Connect the pressure sensor to your data collection system [2.1] and create a new file [1.2] with a pressure (kPa) versus time (s) graph and a digits display of pressure (kPa). [7.1.1][7.3.1]

c. Attach the stopper to the pressure sensor using the quick-release connector.

d. Pull the plunger of the syringe out as far as possible (so it fills with air) and then attach the syringe to the stopcock (set in the closed position).

e. Start collecting data, [6.2] open the stopcock, and push the plunger of the syringe down to force the air in the syringe into the balloon. Close the stopcock, remove the syringe from the stopcock, re-fill the syringe with air, and reattach it to the stopcock. Open the stopcock again and fill the balloon with a second syringe full of air. Repeat this process two more times and then stop data collection. [6.2]

☐ 3. Describe how the following variables were affected when you added air to the large balloon and explain how you know:

a. The pressure inside the balloon

b. The amount of air inside the balloon

c. The volume inside the balloon

☐ 4. How is adding air to a balloon different from adding air to a bottle?

Procedure – Maximum Volume of a Bag

☐ 5. When a gas is added to a plastic bag, when will the pressure inside the bag increase? Explain your reasoning.

☐ 6. The Ideal Gas Law can be used to calculate the number of moles of gas needed to fill each bag (and to fill each bag to 5 kPa higher than atmospheric pressure). Describe the values you will use for each variable in the Ideal Gas Law.

☐ 7. Copy Table 1 into your notebook.

Table 1: Determine the amount of gas needed to fill bags of different sizes

Type of Bag	Maximum Volume (mL)	Maximum Volume (L)	Amount of Gas Needed to Fill the Bag (mol)	Amount of Gas Needed to Increase Pressure by 5 kPa (mol)
	RECORD YOUR ANSWERS IN YOUR NOTEBOOK.			

☐ 8. Use water to determine the volume of three different size bags when they are sealed. Record the volumes in Table 1 in units of milliliters and liters.

☐ 9. Use the temperature sensor and pressure sensor to determine the temperature and atmospheric pressure in your classroom and record them in your notebook. Record both atmospheric pressure and 5 kPa higher than atmospheric pressure.

☐ 10. Use the Ideal Gas Law to calculate the number of moles of gas needed to fill each bag at the classroom temperature and pressure. Show your work, including units, and record your answers in Table 1.

$(R = 8.314 \frac{\text{L} \cdot \text{kPa}}{\text{mol} \cdot \text{K}})$

☐ 11. For each bag, determine the number of moles of gas needed to increase the pressure by 5 kPa. Record your answers in Table 1.

Questions

1. Does the number of moles of gas needed depend on the gas you use to fill the bag? For example, does it matter if you use oxygen gas or carbon dioxide gas or air? Explain your reasoning.
2. When gas is added to a closed system, does the pressure always increase? Explain your reasoning.
3. When you add a gas to a large balloon, what happens to the pressure? Was your prediction correct? Explain any differences.

Teacher Notes: Variable Volumes

Learning Objectives

Determine the volume of gas and the amount of gas (in moles) needed to fill bags of various sizes to a specific pressure.

Safety

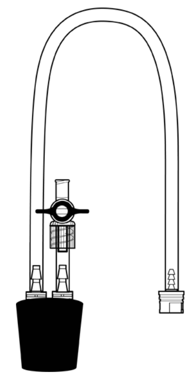
Students should not point the balloon toward themselves or anyone else.

Activity Timeline

The Variable Volume activity is designed to take one "day" (45 minutes). The students should be able to complete the lab procedure and questions in this timeframe, including the discussion suggested in the Activity Introduction section for the second part. The Research questions for this activity on the Challenge handout can be assigned as homework.

Activity Preparation

PREPARATION OF THE RUBBER STOPPER



1. Connect a 50-cm piece of tubing to one hole in the stopper using a tubing connector.
2. Insert the barbed end of the quick-release connector into the open end of the 50-cm piece of tubing. If this is difficult, add a drop of glycerin.
3. Connect the stopcock to the other hole in the stopper using a 2-cm piece of tubing and a tubing connector.

PREPARATION OF THE BALLOON

The balloons used in this activity need to be large and the end must fit over the rubber stopper. They also need to be inflated prior to being used with the students, so the plastic has been stretched. If this is not done, students may observe a pressure increase before the balloon is fully expanded.

PLASTIC TUB

Students may find it easier to pour the water that fills the bag into the tub and then into the graduated cylinder, rather than directly into the graduated cylinder, so the tub must be large enough to hold the water from any of the bags being used, as well as to catch spills.

Activity Introduction

Introduce the activity by holding up a balloon and a sampling bottle for the class to see. Discuss the similarities and differences between these containers.

- **How are these two containers similar and different?**

  The balloon is flexible and can change size. The sampling bottle is fixed at one size and volume.

- **If each of these containers were sealed, would they hold air?**

  Yes, each container could be sealed and would hold air.

- **Could we force more air into each of these containers?**

  Air can be added to both.

- **Which of the two containers behaves more like an airbag? Why?**

  The balloon behaves more like an airbag because the airbag gets larger when it is activated, just like a balloon gets larger when it is inflated.

- **What happens to the pressure inside as air is added to the balloon and to the sampling bottle? Why?**

NOTE: The point of this lab is to learn this particular concept, so it is fine if students disagree or get the answer to this question wrong. This issue is being brought to their attention here.

  When air is added to the sampling bottle, the pressure will increase. When air is added to a balloon (that has been previously stretched) the pressure will not increase because the volume increases.

- **Describe the volume of each container.**

  The volume of the balloon can change. The volume of the bottle is fixed.

DISCUSSION AFTER THE FIRST PART AND PRIOR TO THE SECOND PART

Send the students to the lab to determine what happens when air is added to a balloon. After the first part you may want to stop the class and have a short discussion. Make sure the students have understood that because the volume of the balloon increased, the pressure did not increase. Remind them that pressure is directly proportional to the amount of a gas when the volume of the container is held constant. In this case the volume also changed.

Prior to the second part of the procedure, ask the following questions:

- **If you kept adding air to the balloon, what would eventually happen to the pressure? Why?**

  If we kept adding air to the balloon, the pressure would eventually increase. The pressure would increase once the balloon reached its maximum volume. Eventually, the air pressure in the balloon would exceed the strength of the balloon and the balloon will pop.

- **Once you activate your airbag, the pressure should increase 5 kPa above atmospheric pressure. As the reaction proceeds and carbon dioxide is produced, will the pressure go up immediately? Explain why or why not.**

  No, the pressure will not increase until the bag expands to its maximum volume. After that is achieved, additional gas will cause an increase in pressure.

- **How does the Ideal Gas Law, $PV = nRT$, help us determine how much gas we need to fill our airbag?**

  If we know the final pressure, volume, and temperature in the airbag then the Ideal Gas Law can be used to calculate the number of moles of gas in the airbag.

- **How can you find the volume, in liters, of these different bags? (hold up 3 different size plastic bags)**

  Fill them with water, seal them, and then measure the volume of water using a graduated cylinder.

After students present ideas, send them back to the lab to determine the volumes of different bags. The lab will guide the students to make these measurements and then they will use the Ideal Gas Law to determine the number of moles they need to fill each bag with a gas.

Sample Data

EFFECT ON PRESSURE OF ADDING AIR TO THE BALLOON

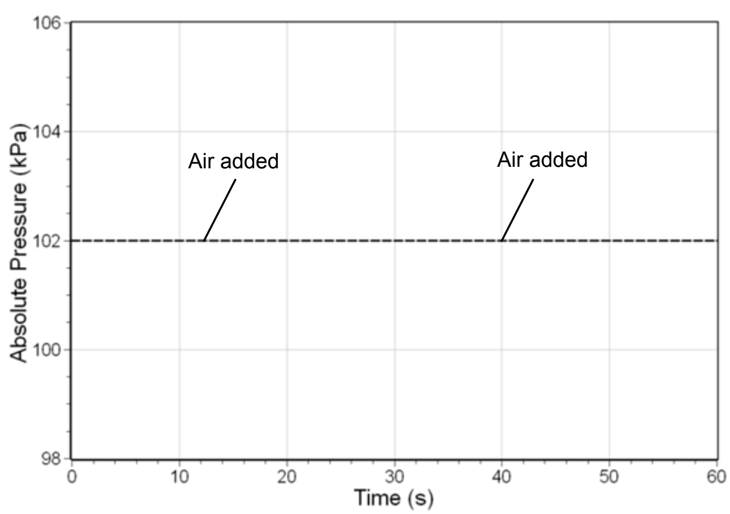


TABLE 1: DETERMINE THE AMOUNT OF GAS NEEDED TO FILL BAGS OF DIFFERENT SIZES

Type of Bag	Maximum Volume (mL)	Maximum Volume (L)	Amount of Gas Needed to Fill the Bag (mol)	Amount of Gas Needed to Increase Pressure by 5 kPa (mol)
Sandwich	730	0.73	0.030	0.032
Quart	1200	1.2	0.050	0.052
Gallon	3810	3.81	0.158	0.165

SAMPLE CALCULATIONS

Amount of gas (in moles) that will fill the sandwich bag:

$$PV = nRT$$

$$n = \frac{PV}{RT}$$

$$n = \frac{(102.0\ \text{kPa})(0.73\ \text{L})}{\left(8.314\ \frac{\text{L}\cdot\text{kPa}}{\text{mol}\cdot\text{K}}\right)(296.6\ \text{K})}$$

$n = 0.030$ mol of gas needed to fill the sandwich bag

Amount of gas (in moles) that will cause a 5 kPa increase in pressure in the sandwich bag:

$$P_{\text{atm}} = 102.0\ \text{kPa}$$

$$P_{\text{atm+5 kPa}} = 107.0\ \text{kPa}$$

$$n = \frac{P_{\text{atm+5 kPa}}V}{RT}$$

$$n = \frac{(107.0\ \text{kPa})(0.73\ \text{L})}{\left(8.314\ \frac{\text{L}\cdot\text{kPa}}{\text{mol}\cdot\text{K}}\right)(296.6\ \text{K})}$$

$n = 0.032$ mol of gas is needed to fill the sandwich bag to 5 kPa greater than atmospheric pressure

Answer Key

Below are sample responses to the questions found in either the Procedure steps or the Questions section of the Variable Volumes activity. The handout and SPARKlab questions may be numbered differently, and are therefore listed in separate columns. The SPARKlab question numbers begin with an "S" to further differentiate them.

SAMPLE RESPONSES TO THE QUESTIONS IN THE VARIABLE VOLUMES ACTIVITY HANDOUT

Procedure		Sample Response
Handout	SPARKlab	
1	S 1	I predict that the pressure inside the balloon will not increase when air is added. This is because the volume of the balloon will increase and the extra air particles will fill the extra space so there is nothing to cause the pressure to change, like less space for the particles to move or hitting the walls of the container more often.
3a	S 11	The pressure inside the balloon remains constant. I know this from the sensor data.
3b	S 12	The amount of air inside the balloon has increased. I know this because I have added air using the syringe.
3c	S 13	The volume inside the balloon has increased. I know this because I can see the balloon get larger.
4	S 14	Adding air to the balloon is different than adding it to a bottle because the volume of the balloon changes and the pressure is constant until the maximum volume of the balloon is reached whereas the volume of the bottle is fixed and adding air increases the pressure.
5	S 15	When a gas is first added to a plastic bag, the pressure will not increase because the volume of the bag will increase. Once the bag has reached its maximum volume, additional gas will cause the pressure to increase. At maximum volume, the bag is like a sampling bottle; it has a fixed volume.
6	S 16	I will obtain the data for the variables as follows: *P:* atmospheric pressure (to fill the bag) and atmospheric pressure plus 5 kPa (to fill the bag to a pressure 5 kPa higher than atmospheric pressure). *V*: maximum volume of the sealed bag *T*: room temperature *n*: number of moles of gas produced, needs to be calculated. *R*: universal gas constant
9	S 19, 20	The temperature and pressure in my classroom: Temperature = 23.4 °C (296.6 K) Atmospheric pressure = 102.0 kPa; Atmospheric pressure + 5 kPa = 107.0 kPa
10	S 21	Refer to the Sample Data section above.
11	S 22	Refer to the Sample Data section above.

Questions		Sample Response
Handout	SPARKlab	
1	S 1	The number of moles of gas needed does not depend on the gas used to fill the bag, because the unit "mole" refers to a number of particles (6.02×10^{23}). It does not matter whether the bag is filled with oxygen gas molecules, carbon dioxide gas molecules, or any other gas molecules; the number of moles needed is the same for each.
2	S 2	When gas is added to a closed system, the pressure does not always increase. If the container is a rigid container the pressure will increase, but if the container can increase its volume, the pressure will not increase until it has expanded to its maximum volume.
3	S 3	When I add a gas to a bag, its pressure will not increase initially. When enough gas has been added so the bag has expanded to its maximum volume, then any additional gas will cause an increase in pressure. My prediction was correct. I knew the pressure would not change because the volume increases.

Connecting the Activity to the Challenge

The students will need to perform the steps of this lab when designing their airbag. To help the students make the connection, ask them the following questions.

- **When carbon dioxide is formed in your airbag, will the pressure increase immediately? How do you know?**

  The pressure will not increase immediately. The pressure will remain the same until the maximum volume of the airbag is achieved and then the pressure will increase. Students should know this because the bag expands like the balloon did. When air was added to the balloon, the pressure did not increase until the balloon had reached its maximum volume. But when air was added to a rigid sampling bottle, it did not expand so the pressure did increase.

- **How can you calculate how much gas you need to produce inside your airbag in order to get it to inflate to 5 kPa above atmospheric pressure (according to the design requirements and constraints)?**

  It is necessary to determine the volume of the airbag, the maximum pressure desired, and the temperature in the room. Once they are known, plug them into the Ideal Gas Law to determine the number of moles of carbon dioxide (or any gas) needed to produce these parameters.

- **How will you produce the calculated numbers of moles of gas inside your airbag?**

  Use the balanced chemical equation to calculate the number of moles of each reactant needed to produce this number of moles of carbon dioxide.

Following the Variable Volumes activity, direct the students to answer the Research questions on the Challenge handout. The students should apply what they have learned in the Variable Volume activity to their airbag design. At this point, each student should be able to determine the volume of their airbag and the number of moles of gas to be produced to obtain the required pressure in the airbag.

SAMPLE RESPONSES TO THE VARIABLE VOLUMES RESEARCH QUESTIONS

Question	Sample Response
1	**What size airbag will you use? Why?** I will use a sandwich size bag (about 730 mL volume). This bag is the smallest so it should be able to fill with carbon dioxide the fastest.
2	**Will the design of your airbag and method of inserting the pressure sensor tubing change the volume inside your airbag? If so, how will it change and how will you account for this difference?** My airbag design uses a hole cut in the bag for inserting the tubing into the bottom of a plastic bag. It is sealed with glue and a zip tie. I do not expect the volume of my airbag to be significantly different than the volume of the bag.
3	**How many moles of gas must be produced inside your airbag to meet the Challenge requirements? Explain your reasoning.** Using the Ideal Gas Law to calculate n (with T = 296.6 K, P = 107.0 kPa, and V = 0.730 L), I will need to produce 0.032 moles of gas to fill the airbag so it is 5 kPa above atmospheric pressure. It will take 0.30 moles of gas just to fill the airbag and the rest will increase the pressure.
4	**How will you control the production of this amount of gas?** I will have to mix the correct mole-to-mole ratio of reactants to produce this amount of gas.

Activity: Stoichiometric Calculations

Objective

Calculate the amounts and concentrations of reactants needed to produce a certain number of moles of a product without wasting any chemicals.

Stoichiometric Calculation Steps

How can you determine the quantity of each reactant you need to produce a given amount of product? The stoichiometric ratio given in a balanced chemical formula provides the mole-to-mole ratio, but chemicals aren't physically measured in moles. It is generally necessary to convert physical measurements (such as grams or milliliters) to moles (a specific number of particles), make sure the correct mole ratios are used, and then convert the number of moles needed back into grams or milliliters.

These calculations involve many steps, so it is easiest to break down the steps and complete them one at a time:

A. Write the balanced chemical equation.

B. Convert the amount measured of the given substance to the number of moles of that substance.

C. Use the mole ratio to convert from the number of moles of the given substance to the number of moles of the wanted substance.

D. Convert the number of moles needed of the wanted substance to the units needed for measurement.

Sample Calculations

How many liters of carbon dioxide gas will form if you burn 5.0 grams of methane gas in an excess of oxygen gas at room temperature (298.15 K) and atmospheric pressure (101.3 kPa)?

A. Balanced chemical equation: $CH_4(g) + 2O_2(g) \rightarrow 2H_2O(l) + CO_2(g)$

B. Convert 5.0 grams of methane to moles of methane: $5.0\text{ g CH}_4 \times \dfrac{1\text{ mol CH}_4}{16.04\text{ g CH}_4} = 0.31\text{ mol CH}_4$

C. Convert moles of methane to moles of carbon dioxide gas: $0.31\text{ mol CH}_4 \times \dfrac{1\text{ mol CO}_2}{1\text{ mol CH}_4} = 0.31\text{ mol CO}_2$

D. Convert moles of carbon dioxide gas to liters using the Ideal Gas Law ($R = 8.314\ \frac{\text{L} \cdot \text{kPa}}{\text{mol} \cdot \text{K}}$):

$$PV = nRT$$

$$V = \frac{nRT}{P}$$

$$V = \frac{(0.31\text{ mol})\left(8.314\ \frac{\text{L} \cdot \text{kPa}}{\text{mol} \cdot \text{K}}\right)(298.15\text{ K})}{101.3\text{ kPa}} = 7.6\text{ L}$$

***NOTE**: Record all work, including tables, diagrams, calculations, and answers, into your notebook.*

One-Step Problems

☐ 1. Write the balanced chemical equation for acetic acid reacting with sodium bicarbonate.

☐ 2. How many moles of acetic acid are needed to react with an excess of sodium bicarbonate in order to produce 0.50 moles of carbon dioxide?

☐ 3. Convert 0.90 g of sodium bicarbonate to moles of sodium bicarbonate.

☐ 4. How many moles of acetic acid are in 20.0 mL of a 4.0 M acetic acid solution?

☐ 5. How many moles of sodium bicarbonate are in 10.0 mL of a 3.0 M sodium bicarbonate solution?

☐ 6. How many milliliters of a 2 M sodium bicarbonate solution are needed to have 0.60 moles of sodium bicarbonate?

Multi-Step Problems

- ☐ 7. How many grams of sodium bicarbonate are required to react with an excess of acetic acid to form 0.75 moles of carbon dioxide?
- ☐ 8. How many liters of carbon dioxide will form if you completely react 0.30 g of sodium bicarbonate with an excess of acetic acid? (The gas will stay at a pressure of 101.3 kPa and a temperature of 298.15 K the entire time.)
- ☐ 9. You need to produce 0.50 L of carbon dioxide at 101.3 kPa and 298.15 K. How many moles of acetic acid and sodium bicarbonate do you need to react together?
- ☐ 10. When 20.0 mL of 4.0 M acetic acid is mixed with 10.0 mL of 4.0 M sodium bicarbonate:
    - a. How many moles of carbon dioxide will be produced?
    - b. How many liters of carbon dioxide will be produced if it is kept at room temperature (298.15 K) and atmospheric pressure (101.3 kPa)?
    - c. What reactant limited the amount of carbon dioxide formed? How do you know?
    - d. Was any chemical wasted (not used) in this reaction?
- ☐ 11. Describe two ways you can place 0.30 moles of sodium bicarbonate in a reaction vessel.
- ☐ 12. Describe two ways you can produce 0.500 moles of carbon dioxide by reacting sodium bicarbonate with acetic acid. Be sure to give the volume and concentration of each solution used and the mass of any solid substances used.

Questions

1. Why is a balanced chemical equation needed when performing chemical calculations involving substances in a reaction?
2. What is a limiting reactant in a chemical reaction?
3. The results of the calculations above are theoretical. Reacting 0.50 grams of sodium bicarbonate with 10.0 mL of 0.50 M acetic acid will theoretically produce 41 mL of carbon dioxide gas at 101 kPa and 25 °C. When you perform this in the lab, what are some reasons the experimental results may not match the theoretical values?

Teacher Notes: Stoichiometric Calculations

Learning Objectives

Calculate the amounts and concentrations of reactants needed to produce a certain number of moles of a product without wasting any chemicals.

- Determine the number of moles required or produced of a reactant or product based on the number of moles of another reactant or product using a balanced chemical equation.
- Convert between moles and mass using molecular weight.
- Use the Ideal Gas Law to convert from moles to volume of a gas at atmospheric pressure (101.3 kPa) and room temperature (273.15 K)
- Use the molarity of a solution to determine the volume of solution required to have a certain number of moles.
- Perform multi-step calculations that involve two or more of the calculations listed above.

Activity Timeline

The Stoichiometric Calculations activity is designed to take one "day" (45 minutes). The students should be able to complete the problems, the questions, and the Research questions for this activity on the Challenge handout. Students who struggle with math may need extra time.

Activity Introduction

Hold up one of the plastic bags the students studied in the previous activity and discuss with the students how they can get the necessary amount of gas into the bag.

- **How many moles of gas are needed to fill the bag?**

  This was calculated in the previous activity using the Ideal Gas Law and should be reviewed.
- **What gas will you fill your airbag with if you react acetic acid with sodium bicarbonate?**

  Carbon dioxide gas will fill my airbag.
- **Would the number of moles change if you used a different gas?**

  No. It will be the same for all gases.
- **What pieces of information do you have that can help you determine how to get the specified amount of gas into the bag?**

  The balanced chemical equation provides the mole ratios, the atmospheric pressure and temperature, the molar mass of each reactant and product involved, and the volume of the airbag.

NOTE: Students will answer the following questions in the activity. They can be asked now to get the students thinking, but should not be answered.

- **How much sodium bicarbonate and how much acetic acid should I combine together to get this exact amount of gas?**
- **Are their different combinations of reactant concentrations that can produce the same amount of gas?**

Go over the stoichiometric calculation steps and the sample calculations on the activity handout to review the mole-to-mole ratios in the balanced chemical equation. Show how molecular weight, mole-to-mole ratios, molarity, and the Ideal Gas Law can help to determine the number of moles needed.

Teacher Tips

Depending on the students skill with stoichiometric calculations, this assignment could take more than once class period. Have students who finish sooner work on the design of their airbag. Have them think about how to separate the reactants and how to seal their airbags with the tubing in it that attaches to the pressure sensor.

Answer Key

Below are sample responses to the questions found in either the Problems or the Questions section of the Stoichiometric Calculations activity handout. This activity does not have a corresponding SPARKlab because there is no data collection.

SAMPLE RESPONSES TO THE QUESTIONS IN THE STOICHIOMETRIC CALCULATIONS ACTIVITY HANDOUT

Problems	Sample Response
1	$HC_2H_3O_2(aq) + NaHCO_3(s) \rightarrow NaC_2H_3O_2(aq) + CO_2(g) + H_2O(l)$
2	Use the one-to-one relationship between acetic acid and carbon dioxide shown in the equation. $0.50 \text{ mol } CO_2 \times \frac{1 \text{ mol } HC_2H_3O_2}{1 \text{ mol } CO_2} = 0.50 \text{ mol } CH_4$
3	$0.90 \text{ g } NaHCO_3 \times \frac{1 \text{ mol } NaHCO_3}{84.01 \text{ g } NaHCO_3} = 0.011 \text{ mol } NaHCO_3$
4	$20.0 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} \times \frac{4.0 \text{ mol } HC_2H_3O_2}{1 \text{ L}} = 0.080 \text{ mol } HC_2H_3O_2$
5	$10.0 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} \times \frac{3.0 \text{ mol } NaHCO_3}{1 \text{ L}} = 0.030 \text{ mol } NaHCO_3$
6	$0.60 \text{ mol } NaHCO_3 \times \frac{1 \text{ L}}{2 \text{ mol } NaHCO_3} \times \frac{1000 \text{ mL}}{1 \text{ L}} = 300 \text{ mL of 2 M } NaHCO_3 \text{ solution}$
7	Use the balanced chemical equation to find the mole ratio between sodium bicarbonate and carbon dioxide to determine the number of moles of sodium bicarbonate required. Then convert that number of moles of sodium bicarbonate to grams using its molar mass. $0.75 \text{ mol } CO_2 \times \frac{1 \text{ mol } NaHCO_3}{1 \text{ mol } CO_2} = 0.75 \text{ mol } NaHCO_3$ $0.75 \text{ mol } NaHCO_3 \times \frac{84.01 \text{ g } NaHCO_3}{1 \text{ mol } NaHCO_3} = 63 \text{ g } NaHCO_3$
8	First determine the number of moles of sodium bicarbonate used in the reaction. Then use the balanced chemical equation to find the mole ratio between sodium bicarbonate and carbon dioxide and determine the number of moles of carbon dioxide that will be produced. Finally, use the Ideal Gas Law to convert the number of moles of carbon dioxide produced to liters at the given temperature and pressure. $0.30 \text{ g } NaHCO_3 \times \frac{1 \text{ mol } NaHCO_3}{84.01 \text{ g } NaHCO_3} = 0.0036 \text{ mol } NaHCO_3$ $0.0036 \text{ mol } NaHCO_3 \times \frac{1 \text{ mol } CO_2}{1 \text{ mol } HC_2H_3O_2} = 0.0036 \text{ mol } CO_2$ $PV = nRT$ $V = \frac{nRT}{P} = \frac{(0.0036 \text{ mol CO})\left(8.314 \frac{\text{L} \cdot \text{kPa}}{\text{mol} \cdot \text{K}}\right)(298.15 \text{ K})}{101.3 \text{ kPa}} = 0.088 \text{ L}$
9	Use the Ideal Gas Law to find the number of moles of carbon dioxide produced. Then use the balanced chemical equation to find the mole ratio between carbon dioxide and each reactant. $PV = nRT$ $n = \frac{PV}{RT} = \frac{(101.3 \text{ kPa})(0.50 \text{ L } CO_2)}{\left(8.314 \frac{\text{L} \cdot \text{kPa}}{\text{mol} \cdot \text{K}}\right)(298.15 \text{ K})} = 0.020 \text{ mol of } CO_2 \text{ are needed}$ There is a 1:1 ratio between all the reactants and products, so 0.020 moles of acetic acid must be reacted with 0.020 moles of sodium bicarbonate to produce 0.020 moles of CO_2.
10a	Convert the volume of the solution with the specified concentration to moles and then use the balanced chemical equation to find the mole ratio between carbon dioxide and sodium bicarbonate. $20.0 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} \times \frac{4.0 \text{ mol } HC_2H_3O_2}{1 \text{ L}} = 0.080 \text{ mol } HC_2H_3O_2$ $10.0 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} \times \frac{4.0 \text{ mol } NaHCO_3}{1 \text{ L}} = 0.040 \text{ mol } NaHCO_3$ $0.040 \text{ mol } NaHCO_3 \times \frac{1 \text{ mol } CO_2}{1 \text{ mol } NaHCO_3} = 0.040 \text{ mol } CO_2$

Problems	Sample Response
10b	Knowing the number of moles of carbon dioxide produced, use the Ideal Gas Law to determine the volume of the carbon dioxide produced. $PV = nRT$ $V = \frac{nRT}{P} = \frac{(0.040\text{ mol }CO_2)\left(8.314\frac{L \cdot kPa}{mol \cdot K}\right)(298.15\text{ K})}{101.3\text{ kPa}} = 0.98\text{ L of }CO_2$ 0.040 moles of CO_2 will occupy 0.98 L at atmospheric pressure and room temperature.
10c	Sodium bicarbonate limited the reaction because there were only 0.040 moles of it, but there were 0.080 moles of acetic acid. There is a one-to-one mole ratio between the two reactants, so the 0.040 moles of sodium bicarbonate will be used up first.
10d	There were 0.040 moles of acetic acid not used in the reaction.
11	I can add 25 g of $NaHCO_3$ or 75 mL of a 4.0 M $NaHCO_3$ solution. Both contain 0.30 moles of sodium bicarbonate. $0.30\text{ mol }NaHCO_3 \times \frac{84.01\text{ g }NaHCO_3}{1\text{ mol }NaHCO_3} = 25\text{ g }NaHCO_3$ $0.30\text{ mol} \times \frac{1\text{ L}}{4.0\text{ mol }NaHCO_3} \times \frac{1000\text{ mL}}{1\text{ L}} = 75\text{ mL of }4.0\text{ M }NaHCO_3\text{ solution}$ Other answers may also be correct.
12	Two ways I can produce 0.500 moles of carbon dioxide, which requires 0.500 moles of reactants (determined by using the balanced chemical equation to find the mole ratio between the reactants and carbon dioxide): 1) By reacting 42.0 grams of sodium bicarbonate with 167 mL of 3.00 M acetic acid. $0.500\text{ mol }NaHCO_3 \times \frac{84.01\text{ g }NaHCO_3}{1\text{ mol }NaHCO_3} = 42.0\text{ g }NaHCO_3$ $0.500\text{ mol} \times \frac{1\text{ L}}{3.00\text{ mol }HC_2H_3O_2} \times \frac{1000\text{ mL}}{1\text{ L}} = 167\text{ mL of }3.00\text{ M }HC_2H_3O_2\text{ solution}$ 2) Or I could get 0.500 moles of carbon dioxide by reacting 167 mL of 3.00 M sodium bicarbonate with 333 mL of 1.50 M acetic acid. $0.500\text{ mol} \times \frac{1\text{ L}}{3.00\text{ mol }NaHCO_3} \times \frac{1000\text{ mL}}{1\text{ L}} = 167\text{ mL of }3.00\text{ M }NaHCO_3\text{ solution}$ $0.500\text{ mol} \times \frac{1\text{ L}}{1.50\text{ mol }HC_2H_3O_2} \times \frac{1000\text{ mL}}{1\text{ L}} = 333\text{ mL of }1.50\text{ M }HC_2H_3O_2\text{ solution}$ Other answers may also be correct.

Questions	Sample Response
1	A balanced chemical equation is needed when performing calculations because all the calculations are based on the mole-to-mole ratio between the reactants and products. The balanced chemical equation shows the mole-to-mole ratios between reactants and products.
2	A limiting reactant is the reactant that is used up first in a chemical reaction. It limits the amount of product that can form because when it is used up, the reaction stops.
3	When performing reactions in the lab, we may not see the theoretical values we calculated because the temperature and pressure may be different from the ones we used in our calculations, chemicals may not have reacted completely, or we could make mistakes when measuring the reactants. Any of these situations will result in our calculations being different from our experimental data.

Connecting the Activity to the Challenge

After completing the Stoichiometric Calculations activity, have the students return to the Challenge handout and answer the questions in the Research section. The Challenge handout Research questions direct the students to calculate two different ways they could combine sodium bicarbonate and acetic acid to inflate their airbag. If students are struggling on their own, you can use the following questions to guide their thinking.

- **How can you determine how many moles of carbon dioxide you will need to fill your airbag to 5 kPa above atmospheric pressure?**

  Use the Ideal Gas Law, as in the Variable Volumes activity.

- **The design requirements and constraints limit you to using 10 grams of sodium bicarbonate. Does that mean you have to use the sodium in a solid form? What are some alternatives?**

  Students could make different concentrations of sodium bicarbonate solution by dissolving it in water.

- **The design requirements and constraints limit you to using 100 mL of 3 M acetic acid. Does this mean you have to use this concentration? What are some alternatives?**

  Students could dilute the 3 M acetic acid by adding water.

- **What other design requirements and constraints are important when deciding how to design your airbag? Why?**

  There are many correct answers to this question. The goal is to get the students thinking about the different constraints together, for example:

  The reactants must mix as quickly as possible. Also, the pressure of the gas produced must not exceed the 5 kPa above atmospheric pressure limit.

SAMPLE RESPONSES TO THE STOICHIOMETRIC CALCULATION QUESTIONS

Question	Sample Response
1	**How many moles of carbon dioxide will you need to fill your airbag to 5 kPa above atmospheric pressure?** My airbag has a volume of 0.73 L and will be activated at room temperature (23.5 °C) and atmospheric pressure (102.0 kPa). $P_{atm} = 102.0 \text{ kPa}$ Final pressure based on the design requirements: $P_{atm+5\,kPa} = 107.0 \text{ kPa}$ $n = \frac{P_{atm+5\,kPa}V}{RT}$ $n = \frac{(107.0 \text{ kPa})(0.73 \text{ L})}{\left(8.314 \frac{\text{L} \cdot \text{kPa}}{\text{mol} \cdot \text{K}}\right)(296.6 \text{ K})}$ $n = 0.032 \text{ mol}$ I will need 0.032 moles of carbon dioxide to fill my airbag.
2	**Describe two ways you can produce the number of moles of carbon dioxide you need by reacting sodium bicarbonate with acetic acid. Be sure to give the volume and concentration of each solution used and the mass of any solid substances used.** To produce 0.032 moles of carbon dioxide, I can mix 2.7 g of solid sodium bicarbonate with 11 mL of 3 M acetic acid: $0.032 \text{ mol } NaHCO_3 \times \frac{84.01 \text{ g } NaHCO_3}{1 \text{ mol } NaHCO_3} = 2.7 \text{ g } NaHCO_3$ $0.032 \text{ mol} \times \frac{1 \text{ L}}{3 \text{ mol } HC_2H_3O_2} \times \frac{1000 \text{ mL}}{1 \text{ L}} = 11 \text{ mL of 3 M } HC_2H_3O_2 \text{ solution}$ Or I could mix 11 mL of 3 M sodium bicarbonate with 16 mL of 2 M acetic acid: $0.032 \text{ mol} \times \frac{1 \text{ L}}{3 \text{ mol } NaHCO_3} \times \frac{1000 \text{ mL}}{1 \text{ L}} = 11 \text{ mL of 3 M } NaHCO_3 \text{ solution}$ $0.032 \text{ mol} \times \frac{1 \text{ L}}{2 \text{ mol } HC_2H_3O_2} \times \frac{1000 \text{ mL}}{1 \text{ L}} = 16 \text{ mL of 2 M } HC_2H_3O_2 \text{ solution}$
3	**What factors will help you decide which procedure to use in your final airbag?** I will have to think about how I plan to separate the chemicals in my airbag. I will also consider which one will make the reaction occur more quickly.

Activity: Reaction Rate

Objective

Determine how stirring and reactant concentration affect the reaction rate between acetic acid and sodium bicarbonate.

Materials and Equipment

- Data collection system
- Absolute pressure sensor
- Sampling bottle, plastic, 500-mL
- Rubber stopper, two-hole, to fit the sampling bottle and fitted with a 50-cm piece of tubing with a quick-release connector, and a stopcock
- Graduated cylinder, 100-mL
- Beaker, 100-mL
- Balance, readability: 0.01 g
- Syringe
- Magnetic stirrer with stirring bar
- Sodium bicarbonate ($NaHCO_3$), 2 g
- 0.50 M acetic acid ($HC_2H_3O_2$), 60 mL
- Waste container
- Tap water, 180 mL plus water to rinse the sampling bottle between trials

Safety

- The gas being generated causes an increase in pressure, which may expel the stopper from the bottle. Wear eye protection during this experiment to prevent injury due to flying objects or splashed chemicals.
- Do not point the sampling bottle toward yourself or anyone else.

***NOTE**: Record all work, including tables, data, diagrams, and answers, into your notebook.*

Procedure – Part 1: No stirring versus stirring

☐ 1. In the steps below, you will react 0.40 g of sodium bicarbonate ($NaHCO_3$) with 10.0 mL of 0.50 M acetic acid ($HC_2H_3O_2$) in the 500-mL sampling bottle. Before beginning the reaction, use the Ideal Gas Law to calculate the maximum pressure (kPa) you expect to obtain when the reaction is complete.

HINTS: a) Does your sampling bottle hold more than 500 mL? b) Watch the units carefully. c) Don't forget to include air pressure already in your sampling bottle. d) R = 8.314 $\frac{\text{L·kPa}}{\text{mol·K}}$.

☐ 2. Will the reaction between $NaHCO_3$ and $HC_2H_3O_2$ occur faster with or without stirring? Explain your prediction.

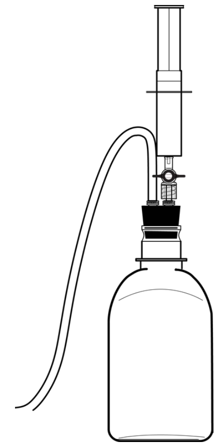
☐ 3. Copy Table 1 into your notebook.

Table 1: Reaction rate comparison: with and without stirring, collected data

Reaction Conditions	Mass of $NaHCO_3$ (g)	Volume of 0.50 M $HC_2H_3O_2$ (mL)	Initial Pressure (kPa)	Final Pressure (kPa)	Time Reaction Started (s)	Time Reaction Stopped (s)
Without stirring	RECORD THE DATA IN YOUR NOTEBOOK.					
With stirring						

☐ 4. Connect the pressure sensor to your data collection system �(2.1) and create a new file �(1.2) with a pressure (kPa) versus time (s) graph and a digits display of pressure (kPa). �(7.1.1)(7.3.1)

☐ 5. Determine if the reaction occurs faster with or without stirring. To do this, follow the steps listed below once while constantly swirling the sampling bottle (stirring) and once without swirling (no stirring).



a. Use a balance to obtain 0.40 g of $NaHCO_3$. Record the exact mass in Table 1.

b. Place the $NaHCO_3$ you just measured into the 500-mL sampling bottle.

c. Firmly place the stopper into the sampling bottle. Turn the stopcock to the closed position.

d. Attach the absolute pressure sensor to the sampling bottle using the quick-release connector.

e. Expel all the air from the syringe and place the syringe in a 100-mL beaker containing the 0.50 M $HC_2H_3O_2$. Pull the plunger out until the syringe contains 10.0 mL of solution (with no air bubbles). Record the exact volume in Table 1.

f. Twist the syringe onto the stopcock.

g. Start collecting data �(6.2) and after 10 seconds, turn the stopcock to the open position and inject the $HC_2H_3O_2$ into the sampling bottle. Immediately turn the stopcock to the closed position.

h. Collect data until the reaction is complete (the data stabilizes at the maximum pressure) or until the reaction has run for two minutes and then stop data collection. �(6.2)

g. Record in Table 1 the initial pressure, the time the reactants were mixed, the final pressure, and the time the reaction was stopped. �(9.1)

h. Remove the syringe from the stopcock and then release the pressure from the bottle by slowly removing the stopper from the bottle.

i. Pour the solution in the bottle into the waste container. Clean the bottle by rinsing it with water.

☐ 6. Copy Table 2 into your notebook and complete it by calculating the change in pressure, change in time, and the average rate of the reaction for each trial.

NOTE: "Average rate of reaction" equals the change in pressure (product formation) divided by the change in time.

Table 2: Reaction rate comparison: with and without stirring, calculated data

Reaction Conditions	Change in Pressure (kPa)	Change in Time (s)	Average Rate of Reaction (kPa/s)
Without stirring	RECORD THE DATA IN YOUR NOTEBOOK.		
With stirring			

☐ 7. Did the reaction occur faster with stirring or without stirring? Support your answer with data.

☐ 8. Was your prediction correct? Explain any differences.

Procedure – Part 2: Changing reactant concentration

☐ 9. In this part of the procedure you will react 10 mL of 0.50 M $HC_2H_3O_2$ with different concentrations of $NaHCO_3$. In each trial you will use 0.40 g of $NaHCO_3$ but you will dissolve it in different amounts of water (30 mL, 60 mL, and 90 mL) to create different concentrations.

a. Which solution will be the most concentrated?

b. Which solution will be the most dilute?

☐ 10. Predict how concentration will affect the rate of the chemical reaction. Explain your reasoning.

☐ 11. Copy Table 3 into your notebook.

Table 3: Reaction rate comparison: different concentrations of sodium bicarbonate, collected data

Volume of Water Added to $NaHCO_3$ (mL)	Mass of $NaHCO_3$ (g)	Volume of 0.50 M $HC_2H_3O_2$ (mL)	Initial Pressure (kPa)	Final Pressure (kPa)	Time Reaction Started (s)	Time Reaction Stopped (s)
30.0						
60.0	RECORD THE DATA IN YOUR NOTEBOOK.					
90.0						

☐ 12. Determine how concentration (with constant stirring for all trials) affects the reaction rate by performing the reaction 3 times, each with a different starting concentration of $NaHCO_3$, as follows:

a. Use a balance to obtain the mass of 0.40 g of $NaHCO_3$. Record the exact mass in Table 3.

b. Place the $NaHCO_3$ you just measured in the 500-mL sampling bottle and then add the specified amount of water.

c. Place the sampling bottle on a magnetic stirrer, add a stir bar to the bottle, and set the stirrer to medium speed. Allow the $NaHCO_3$ to dissolve before continuing with the next step. Continue stirring throughout the reaction.

d. Firmly place the stopper into the sampling bottle.

e. Attach the pressure sensor to the sampling bottle using the quick-release connector.

f. Fill the syringe with 10.0 mL of 0.50 M acetic acid ($HC_2H_3O_2$). Record the exact volume in Table 3.

g. Twist the syringe onto the stopcock.

h. Start collecting data �(6.2) and after 10 seconds, turn the stopcock to the open position and inject the $HC_2H_3O_2$ into the sampling bottle, keeping the magnetic stirrer at medium speed the entire time. Immediately turn the stopcock to the closed position.

i. Collect data until the reaction is complete (the data stabilizes at the maximum pressure) or until the reaction has run for two minutes, and then stop data collection. �(6.2)

j. Record in Table 3 the initial pressure, the time the reactants were mixed, the final pressure, and the time the reaction was stopped. �(9.1)

h. Remove the syringe from the stopcock and then release the pressure from the bottle by slowly removing the stopper from the bottle.

i. Pour the solution in the bottle into the waste container. Clean the bottle by rinsing it with water.

☐ 13. Copy Table 4 into your notebook. Complete it by calculating the number of moles and molarity of $NaHCO_3$ in each trial as well as the change in pressure, change in time, and the average rate of the reaction for each trial.

Table 4: Reaction rate comparison: different concentrations of sodium bicarbonate, calculated data

Volume of Water Added to $NaHCO_3$ (mL)	Moles of $NaHCO_3$ (mol)	Molarity of $NaHCO_3$ (M)	Change in Pressure (kPa)	Change in Time (s)	Average Rate of Reaction (kPa/s)
30.0					
60.0	RECORD THE DATA IN YOUR NOTEBOOK.				
90.0					

☐ 14. How does the concentration affect the reaction rate? Support your answer with data.

☐ 15. Was your prediction correct? Explain any differences.

Questions

1. Sketch the data you collected on a graph of pressure (kPa) versus time (s). Label each data run.
2. Describe what is meant by the rate of a chemical reaction. Use the terms "reactants" and "products" in your answer.
3. Why does measuring the pressure measure the rate of the reaction between $NaHCO_3$ and $HC_2H_3O_2$?
4. Describe two ways you can increase the rate of a chemical reaction.

Teacher Notes: Reaction Rate

Learning Objectives

Determine how stirring and reactant concentration affect the reaction rate between acetic acid and sodium bicarbonate.

Safety

In this activity the students will be working with pressurized systems. The absolute pressure sensor has an upper limit of 700 kPa, but there is no reason for students to create pressures near this value.

When using a sampling bottle and a stopper, do not have the students hold the stopper beyond a pressure of 125 kPa (1.2 atm). The stopper may pop out and any chemicals inside the container could spray out of the container. Make sure they are wearing eye protection.

Activity Preparation

PREPARE 500 ML OF 0.50 M ACETIC ACID ($HC_2H_3O_2$) STARTING FROM EITHER CONCENTRATED (GLACIAL 17.4 M) OR DILUTE (6 M) ACETIC ACID. THIS IS ENOUGH FOR 8 LAB GROUPS.

Starting with concentrated (glacial, 17.4 M) acetic acid:

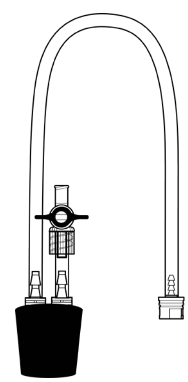
1. Place a stir bar in a 500-mL beaker, and add approximately 250 mL of distilled water.
2. Slowly add 14.4 mL of 17.4 M acetic acid to the beaker, stirring continuously.
3. Allow the solution to cool, then carefully pour the solution into a 500-mL volumetric flask and dilute it to the mark with distilled water.
4. Cap and invert the flask three times carefully to ensure complete mixing.

Starting with dilute (6 M) acetic acid:

1. Add approximately 250 mL of distilled water to a 500-mL volumetric flask.
2. Add 41.7 mL of 6 M acetic acid to the water, and dilute it to the mark with distilled water.
3. Cap and invert the flask three times carefully to ensure complete mixing.

DISPENSING THE ACETIC ACID

Each group will need the acetic acid in a 100-mL beaker. You can prepare a beaker for each group in advance or have a few graduated cylinders set out at a dispensing station for students to obtain it themselves.



PREPARATION OF THE RUBBER STOPPER

1. Connect a 50-cm piece of tubing to one hole in the stopper using a tubing connector.
2. Insert the barbed end of the quick-release connector into the open end of the 50-cm piece of tubing. If this is difficult, add a drop of glycerin.
3. Connect the stopcock to the other hole in the stopper using a 2-cm piece of tubing and a tubing connector.

SENSORS

The activity uses the absolute pressure sensor. The students also need to know room temperature. You may decide to provide each group with a temperature sensor or you can write the room temperature on the board for all students to see.

Activity Timeline

The Reaction Rate activity is designed to take two "days" (45 minutes periods).

- ***1st day:*** Introduce the activity and have students complete Part 1: No stirring versus stirring.
- ***2nd day:*** Have students complete Part 2: Changing reactant concentration and then have them answer the questions in the lab and the Research questions on the Challenge handout for this activity.

Activity Introduction

In addition to having the airbag inflate to 5 kPa above atmospheric pressure, the airbag has to inflate as quickly as possible. Students have calculated two different ways to produce the amount of carbon dioxide needed to increase the pressure. Which of these methods will inflate the airbag the fastest?

Discuss with your students the variables they think will affect the reaction time. Use the questions below as a guide.

- **At the molecular level, what has to happen in order for reactants to form a product?**

  The molecules of reactants have to collide with each other with enough energy and with the correct orientation in order to form product.

- **What factors do you think will affect how quickly the reaction between acetic acid and sodium bicarbonate occur? Why?**

  Students are likely to mention the following:

  Temperature: at higher temperatures the molecules move more quickly, have more energy, and collide more often.

  Concentration: the more concentrated the solution, the more molecules are nearby to collide with.

  Surface area: the greater the surface area the molecules reside on, the more likely the molecules will collide.

  Mixing: the more the reactants are mixed, the more likely the molecules will collide.

- **Which of these factors are appropriate to control for your airbags? Which are not?**

  The temperature and the reaction being used are not applicable in this case. Airbags have to sit at atmospheric conditions and this Challenge is limited to one specific chemical reaction. However, the concentration, surface area, and mixing (or stirring) are variables that can be changed.

- **How many of you have proposed using solid sodium bicarbonate in your airbag? Why might this be good? Why bad?**

  Solid sodium bicarbonate could be good because it is concentrated and it is a powder, so it is easy to keep separate from the other reactant.

  Solid sodium bicarbonate could be bad because if it gets stuck in one corner it might never react with the acetic acid. The design of the airbag is important when addressing this possible problem.

Although there are several conditions that affect reaction rate, tell the students that the two they will explore are stirring and reactant concentration.

Teacher Tips

The reaction between acetic acid and sodium bicarbonate occurs quickly. The concentrations used in this experiment are very low (0.05 M to 0.16 M). If students are using greater concentrations, they probably will not find a difference in the rate because the reaction is so fast.

In the Changing Concentration portion of this activity, it is assumed that the volume of the container stays the same throughout the experiment. This is not exactly true, because different volumes of liquid are used so the volume of gas in the sampling bottle is different for each reaction. This assumption is not addressed in the lab, but can be discussed as necessary in your class.

The first question in the activity procedure (copied below) is fairly long. You may have the students do this as homework the day before or do it together as a class to save time:

> *In the steps below, you will react 0.40 g of sodium bicarbonate ($NaHCO_3$) with 10 mL of 0.50 M acetic acid ($HC_2H_3O_2$) in your 500-mL sampling bottle. Before beginning the reaction, use the Ideal Gas Law to calculate the maximum pressure (kPa) you expect to obtain when the reaction is complete.*
>
> *HINTS: a) Does your sampling bottle hold more than 500 mL? b) Watch the units carefully. c) Don't forget to include air pressure already in your sampling bottle. d)* $R = 8.314\ \frac{\mathrm{L \cdot kPa}}{\mathrm{mol \cdot K}}$.

Sample Data

REACTION RATE WITH STIRRING AND WITHOUT STIRRING, GRAPH AND DATA TABLES (PART 1)

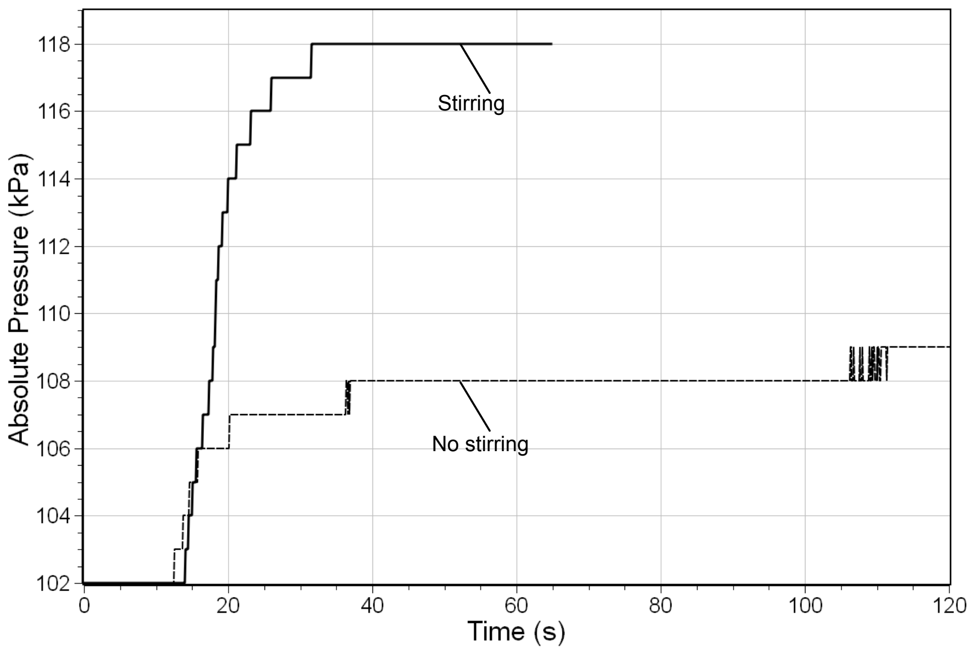


TABLE 1: REACTION RATE COMPARISON: WITH AND WITHOUT STIRRING, COLLECTED DATA

Reaction Conditions	Mass of NaHCO3 (g)	Volume of 0.50 M $HC_2H_3O_2$ (mL)	Initial Pressure (kPa)	Final Pressure (kPa)	Time Reaction Started (s)	Time Reaction Stopped (s)
Without stirring	0.40	10.0	102	109	12.0	121.4
With stirring	0.40	10.0	102	118	13.9	43.4

TABLE 2: REACTION RATE COMPARISON: WITH AND WITHOUT STIRRING, CALCULATED DATA

Reaction Conditions	Change in Pressure (kPa)	Change in Time (s)	Average Rate of Reaction (kPa/s)
Without stirring	7	109.4	0.06
With stirring	16	29.5	0.54

REACTION RATE WHEN CHANGING REACTANT CONCENTRATION, GRAPH AND DATA TABLES (PART 2)

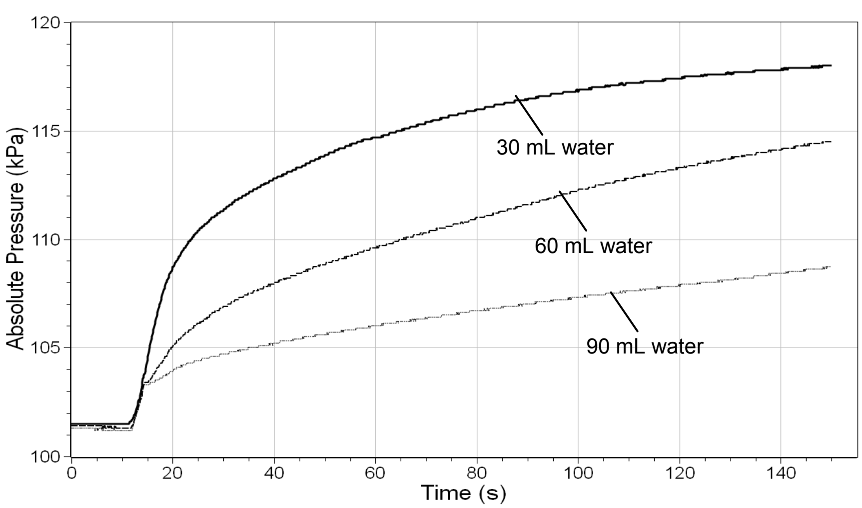


TABLE 3: REACTION RATE COMPARISON: DIFFERENT CONCENTRATIONS OF SODIUM BICARBONATE, COLLECTED DATA

Volume of Water Added to $NaHCO_3$ (mL)	Mass of $NaHCO_3$ (g)	Volume of 0.50 M $HC_2H_3O_2$ (mL)	Initial Pressure (kPa)	Final Pressure (kPa)	Time Reaction Started (s)	Time Reaction Stopped (s)
30.0	0.40	10.0	101	118	11.9	149.8
60.0	0.40	10.0	101	115	11.9	164.7
90.0	0.40	10.0	101	110	11.9	179.7

TABLE 4: REACTION RATE COMPARISON: DIFFERENT CONCENTRATIONS OF SODIUM BICARBONATE, CALCULATED DATA

Volume of Water Added to $NaHCO_3$ (mL)	Moles of $NaHCO_3$ (mol)	Molarity of $NaHCO_3$ (M)	Change in Pressure (kPa)	Change in Time (s)	Average Rate of Reaction (kPa/s)
30.0	0.0048	0.16	17	137.9	0.12
60.0	0.0048	0.080	14	152.8	0.092
90.0	0.0048	0.053	9	167.8	0.05

SAMPLE CALCULATIONS (THESE APPLY TO CALCULATED DATA IN TABLES 1 – 4)

Change in pressure:

$$\text{Change in pressure} = P_{\text{final}} - P_{\text{initial}} = 109\text{ kPa} - 102\text{ kPa} = 7\text{ kPa}$$

Change in time:

$$\text{Change in time} = T_{\text{final}} - T_{\text{initial}} = 121.4\text{ s} - 12.0\text{ s} = 109.4\text{ s}$$

Average rate of reaction:

$$\text{Average rate of reaction} = \frac{\text{change in pressure}}{\text{change in time}}$$

$$\text{Average rate of reaction} = \frac{7\text{ kPa}}{109.4\text{ s}} = 0.06\text{ kPa/s}$$

Calculating moles of $NaHCO_3$:

$$0.40\text{ g NaHCO}_3 \times \frac{1\text{ mol NaHCO}_3}{84.01\text{ g NaHCO}_3} = 0.0048\text{ mol NaHCO}_3$$

Calculating molarity of $NaHCO_3$:

$$30\text{ mL: } \frac{0.0048\text{ mol NaHCO}_3}{0.030\text{ L}} = 0.16\text{ M NaHCO}_3\text{ solution}$$

Answer Key

Below are sample responses to the questions found in either the Procedure steps or the Questions section of the Reaction Rate activity. The handout and SPARKlab questions may be numbered differently, and are therefore listed in separate columns. The SPARKlab question numbers begin with an "S" to further differentiate them. As this activity has multiple parts, the step or question number begins with the part number, for example, "P2:3" under "Procedure" indicates the sample response is for the question in step 3 of the Procedure in Part 2 of the activity.

SAMPLE RESPONSES TO THE QUESTIONS IN THE REACTION RATE ACTIVITY HANDOUT

Procedure		Sample Response
Handout	SPARKlab	
1	S P1:1	Calculate the expected final pressure. $PV = nRT; P = \frac{nRT}{V}$ $V = 0.60$ L (The 500-mL sampling bottle holds more than 500 mL. Fill the bottle with water, insert the rubber stopper, and then measure the volume of water to find the exact volume of the bottle.) $R = 8.314 \frac{\text{L kPa}}{\text{mol K}}$ $T = 296.6$ K $n = ?$ Determine the limiting reactant and the amount used, in moles. $0.40\text{ g NaHCO}_3 \times \frac{1\text{ mol NaHCO}_3}{84.01\text{ g NaHCO}_3} = 0.0048\text{ mol NaHCO}_3$ (the limiting reagent) $10.0\text{ mL} \times \frac{1\text{ L}}{1000\text{ mL}} \times \frac{0.50\text{ mol HC}_2\text{O}_3\text{H}_2}{1\text{ L}} = 0.0050\text{ mol HC}_2\text{O}_3\text{H}_2$ Calculate the pressure, using the number of moles of the limiting reagent. This will be the same number of moles of product due to the one-to-one ratio between reactants and product in the balanced chemical equation. $P = \frac{nRT}{V} = \frac{(0.0048\text{ mol})\left(8.314\frac{\text{L kPa}}{\text{mol K}}\right)(296.6\text{ K})}{0.60\text{ L}} = 20.\text{ kPa}$ *NOTE: Trailing zeros that follow the last non-zero digit are only significant if there is a decimal point in the number. In this case, the answer has two significant figures, indicated by the decimal point after the "20". (The number "20.0" has three significant figures, which would be incorrect.)* 20. kPa is the pressure due to the gas produced. This is in addition to the starting atmospheric pressure. The final pressure is the starting atmospheric pressure plus the pressure due to the gas produced: 101 kPa + 20. kPa = 121 kPa
2	S P1:2	I predict the reaction will occur faster with stirring. Stirring will help the molecules collide with each other so they can react.
5,6	S P1:3–28	Refer to Table 1 and Table 2 in the Sample Data section above.
7	S P1:29	The reaction occurred faster with stirring. The reaction occurred at an average rate of 0.54 kPa per second with stirring, but only went at 0.06 kPa per second without stirring.
8	S P1:30	Yes, my prediction was correct.
9a	S P2:1a	The most concentrated solution will be the one with the least amount of water (30 mL).
9b	S P2:1b	The most dilute solution will be the one with the greatest amount of water (90 mL).
10	S P2:2	I predict that the higher the reactant concentration is, the faster the reaction rate will be. It will be faster because the molecules of sodium bicarbonate will make up a larger percentage of the solution and thus will be more likely to collide with the acetic acid.
12,13	S P2:3–48	Refer to Table 3 and Table 4 in the Sample Data section above.

Procedure		Sample Response
Handout	SPARKlab	
14	S P2:49	The higher the concentration, the faster the reaction rate. The solution with the highest concentration (0.16 M) had a reaction rate of 0.12 kPa per second while the solution with the lowest concentration (0.053 M) had a reaction rate of only 0.05 kPa per second.
15	S P2:50	My prediction was correct.

Questions		Sample Response
Handout	SPARKlab	
1		Refer to the two graphs in the Sample Data section above.
2	S P2:1	The rate of a chemical reaction refers to how fast the reactants turn into products.
3	S P2:2	Measuring the pressure allows us to measure the rate of reaction between $NaHCO_3$ and $HC_2H_3O_2$ because one of the products is a gas (carbon dioxide). In a closed, rigid container, this gas will cause an increase in pressure. Since the increase in pressure is due solely to the newly formed gas, we can determine how fast the reaction occurs by how fast the pressure in the bottle increases.
4	S P2:3	I can increase the rate of a reaction by stirring the reactants and by using reactants in solutions of high concentrations.

Connecting the Activity to the Challenge

The students have explored two of several different factors that affect reaction rate. Have the students complete the questions on the Challenge handout to relate what they have learned about reaction rates to the design of their airbag. The following questions can be used to help students who need extra guidance.

- **What did you learn about the rate of a chemical reaction in this activity?**

  Students should have learned that stirring a reaction causes it to react faster and that the more concentrated the solution of a reactant is, the faster the chemical reaction occurs.

- **When you mix the chemicals in your airbag, what could make them react slowly? How can you design your airbag to avoid this behavior?**

  The reaction could occur really slowly if the sodium bicarbonate was stuck on one side and the acetic acid was on the other side or if one of the chemicals got caught in the folds of the airbag. Students can avoid this by using solutions instead of solids and making sure the reactants mix thoroughly.

SAMPLE RESPONSES TO THE REACTION RATE RESEARCH QUESTIONS

Question	Sample Response
1	**List one factor that you investigated in this activity and describe how you will use it to design your airbag.** In this activity I investigated how stirring and concentration affect reaction rate. I found that consistent stirring has the greatest affect on increasing the reaction rate. Therefore, I am going to make sure that my chemicals are stirred well when I activate my airbag.
2	**Based on the results of this activity, which of the two methods of increasing the rate of carbon dioxide production, stirring or adjusting the reactant concentration, do you plan on using? Why?** I plan on using both methods. Stirring had the greatest affect on increasing the reaction rate, but increasing the concentration of the reactants also speeds the reaction. Based on the results of this activity and my calculations of the amount of reactants needed for a 0.73 L sandwich bag, I think it will be best to mix 11 mL of 3 M $NaHCO_3$ with 11 mL of 3 M $HC_2H_3O_2$. I will use this concentration of $HC_2H_3O_2$ because it is the most concentrated solution provided. Since the reactant mole ratio is 1:1, I will make the same concentration of $NaHCO_3$ and use the same volume. I do not want to use solid sodium bicarbonate because it may get trapped and not mix well.
3	**How do you plan to separate the reactants in your airbag? How does the rate of reaction influence your decision?** I plan to store each reactant in a beaker. The beakers will be inside the airbag. When it is time to activate the airbag, I will pour the contents of each beaker out into the bag and have them mix in one corner of the bag. I will gently shake the bag to ensure continuous mixing.

3 Revise Design

During the research phase, your students were continually thinking about and revising their airbag design. Now it is time to have each student update their initial ideas with what they have learned in the research phase to improve their design. At this point, students work on their own original design. (After individual designs are created, students will work in groups to develop a group design, the Develop Group Design phase).

Prior to having them begin their revisions, revisit the engineering design process as a class and discuss how research should support the design phase. Emphasize to the students that unlike their initial designs, which were based on prior knowledge, their revised design should be data driven and include mathematical evidence.

Also review the design requirements and constraints. The students should keep in mind these constraints as they evaluate their initial design. The students may choose to change their initial design slightly or they may choose to completely start over. The revised design that is created should be supported with evidence from the concepts covered in the research section.

Encourage the students to think about the decisions that need to be made when considering the design of their airbag. Then have them look through their notebooks for how the different activities could help them make each decision. Use the questions below to help prompt the students as necessary.

BASIC AIRBAG DESIGN QUESTIONS

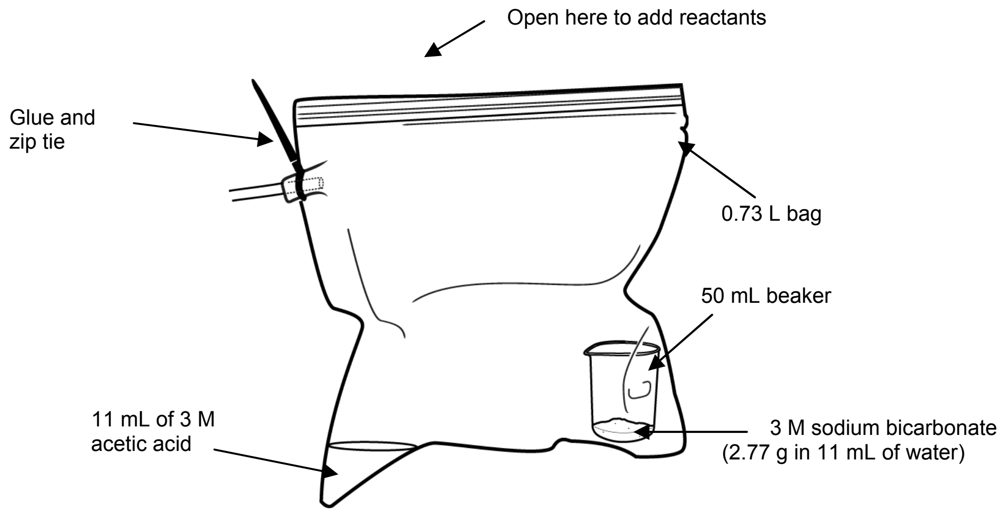
Design Questions	Answers Based on Design Requirements and Constraints and Research Activities
What size bag should I use for my airbag?	▪ The airbag has to be 1.5 L or smaller. (Constraint) ▪ The airbag must be inflated as quickly as possible. A smaller bag will fill up faster and inflate to the necessary pressure faster. (Understanding Pressure) ▪ The airbag must be large enough to hold the reactants required.
How will the reactants be separated?	▪ Reactants initially need to be separate (constraint), but they also have to mix easily. (Reaction Rate) ▪ Reactants could be kept in separate containers or in the corners of the bag (this is where the students can get creative).
How much of each reactant needs to be used?	▪ A maximum of 100 mL of 3 M acetic acid and 10 g of sodium bicarbonate can be used. (Constraint) ▪ Mathematical evidence must be presented that shows reactants are not being wasted. (Constraint) ▪ The amount of each reactant can be calculated once the volume of the bag is decided. (Understanding Pressure, Variable Volumes) ▪ Once volume is decided, then the Ideal Gas Law can be used to calculate the number of moles of carbon dioxide that must be produced. (Understanding Pressure: students derived $PV = nRT$; Variable Volumes: students applied this calculation) ▪ Once the number of moles of carbon dioxide needed is determined, then stoichiometric calculations are used to determine the number of moles of each starting reactant required. (Mole-to-Mole Ratios: students balanced the chemical equation; Stoichiometric Calculations: students determine the number of moles of the reactants needed.) ▪ Once the number of moles of each reactant is known, the students must decide what form to use the reactants in. The acetic acid can be used as a 3 M or less concentrated solution and the baking soda can be used in its solid form or as a solution (in a concentration determined by the student). (Stoichiometric Calculations)

How can I make the airbag inflate as quickly as possible?	▪ When using solutions, more concentrated solutions react more quickly. (Reaction Rate) ▪ Continuous stirring of reactants significantly increases the reaction rate. (Reaction Rate) ▪ Using solid sodium bicarbonate can be slow if the sodium bicarbonate gets stuck in a clump. (Mole-to-Mole Ratios and Reaction Rate)
How will I attach the tubing to my airbag?	▪ The system must be completely sealed so the air and carbon dioxide from the reaction cannot escape. Students may need to test their seal (placing it under water works well). (Understanding Pressure) ▪ Strong glue and zip ties can be used to seal the tube into the airbag. (This is another area where the students can be creative). ▪ Does the position of the tubing matter?

At the end of the Revise Design process, the students should have a good understanding of their design and data to support their design decisions.

SAMPLE RESPONSES TO THE QUESTIONS IN THE REVISE DESIGN SECTION OF THE CHALLENGE

Question	Sample Response
1	**How have your initial design ideas changed? Explain your reasons for making those changes.** My initial ideas are a lot more quantitative now. I have learned how I can calculate the exact amount of each reactant I need. At first I just said we needed some of each and now I know exact quantities. I have also learned that the size of the bag will affect the time it takes for the bag to inflate and therefore a smaller bag is the better choice. Since the small bag requires less gas to be filled up, the smaller quantity of reactants will not take up very much space.

2	**Sketch your revised design in your notebook and explain your proposal, indicating the important components of the design including quantities, concentrations, and your plan for separating the reactants.**  I am planning the reaction so 0.32 moles of gas form. This can be done by mixing 11 mL of 3 M acetic acid with 11 mL of 3 M sodium bicarbonate. Since the reaction between sodium bicarbonate and acetic acid has coefficients of 1 before every chemical, the number of moles of each reactant needs to be the same. I will mix exactly 0.32 moles of acetic acid with exactly 0.32 moles of sodium bicarbonate and if everything reacts, 0.32 moles of carbon dioxide gas should be produced. Because exact amounts will be used, no chemical should be wasted. I determined I need 0.32 moles of carbon dioxide gas because that is how many moles will cause the pressure in a bag with a volume of 0.73 liters to reach 107.0 kPa (which is exactly 5 kPa higher than the classroom atmospheric pressure). The 0.32 moles was calculated using the Ideal Gas Law ($PV = nRT$). Using a solution of sodium bicarbonate instead of a solid should cause the reaction to proceed faster. This is because the ions are distributed in the solution and will not get clumped up and inaccessible the way a solid dumped in a small amount of liquid might. Finally, I decided to move the tubing for the pressure sensor to the top of the bag. This way I will be able to quickly combine the reactants and mix them without having the tubing in the way. Mixing is important because it increases the rate of the reaction and will make the bag inflate more quickly.
3	**Include a description of the materials you will use in your proposed design and list any safety concerns.** The materials for the airbag: Sealable sandwich bag, 0.73 L Zip tie and glue to attach the tubing to the bag 11 mL of 3 M acetic acid 11 mL of 3 M sodium bicarbonate (2.77 g of sodium bicarbonate in 11 mL of water) 50 mL beaker to hold one of the solutions Safety: I will be creating a pressurized system so it will be important to wear safety goggles and not to point the bag at others.

4 Develop Group Design

Once students have developed their own design, put the students into groups and have the group come up with a single design. This group design is what will be built and tested during the rest of the module. Have each group member explain their design and the rationale for each part of their design. Once each member has participated, the group members should discuss the strengths and weaknesses of each approach.

The group may elect to take the best design and modify it, or start from scratch and create a new design that integrates individual approaches. Each group member should sketch a picture of the final design in their notebook along with an explanation as to why this design was chosen.

This stage of the project helps students learn to critically evaluate others' work, a crucial skill in any kind of research.

The teacher's role in this phase is to monitor the groups as they develop their group's design. The teacher should help students answer new questions that arise as well as provide questions to direct student thinking. Questions could include:

- What in your design ensures that the pressure inside the airbag will increase 5 kPa within three minutes?
- What are some advantages of using solid sodium bicarbonate versus a solution of sodium bicarbonate?
- How will you separate your reactants?
- How will you make sure your bag is completely sealed?

Design Approval

Once each group has finalized its design, the teacher should approve it before the students begin to construct the airbag. When approving designs, make certain that each design conforms to the design requirements and constraints and that the design is safe. Allow the students time to fix any designs that do not meet your approval. It is, however, fine to approve designs you think may not work as long as they are safe and the students have addressed the requirements and constraints.

Engineering research is not necessarily a linear process. There are many different and equally valid ways to solve the same problem, so expect a variety of proposed solutions.

SAMPLE RESPONSES TO THE QUESTIONS IN THE DEVELOP GROUP DESIGN SECTION OF THE CHALLENGE

Question	Sample Response
1	**Record in your notebook a sketch of the group design, the important design points, and explain why you chose this design.** Students should provide a drawing of the final design. Important design points: ▪ The number of moles of sodium bicarbonate and acetic acid should be equal to avoid wasting materials. ▪ The number of moles of carbon dioxide formed needs to create enough pressure to raise the pressure inside the bag 5 kPa. The Ideal Gas Law should be used to calculate this number based on typical conditions in the classroom. ▪ The bag must be completely sealed, including the area around the tubing as well as any other openings. ▪ The reactants need to be separated in a way that it is easy to mix them. ▪ Reaction rate should be considered in the design to ensure that the reaction occurs in less than 3 minutes and as quickly as possible.
2	**Include a description of the materials you will use in your proposal and list any safety concerns and precautions needed.** Materials list: ▪ Bag (with exact volume) ▪ Acetic acid (not to exceed 100 mL of 3 M acetic acid) ▪ Sodium bicarbonate (not to exceed 10 g) ▪ Materials to attach the tubing (glue, zip tie, etc.) ▪ Materials to separate the reactants Safety concerns: We are creating a pressurized system so it is important to wear safety goggles and to make sure that the bag is not pointed at individuals.

3	**Record in your notebook the mathematical evidence showing that the amounts of the chemicals used in your design meet the requirements and constraints without reactants being wasted.** The following calculation specifies the number of moles we need to inflate our airbag to 5 kPa above atmospheric pressure: $P_{atm} = 102.0\ kPa$ $P_{atm+5\ kPa} = 107.0\ kPa$ $n = \frac{P_{atm+5\ kPa}V}{RT}$ $n = \frac{(107.0\ kPa)(0.73\ L)}{\left(8.314\ \frac{L \cdot kPa}{mol \cdot K}\right)(296.6\ K)}$ n = 0.032 mol of gas needed to fill the sandwich bag at 5 kPa more than atmospheric pressure These calculations determine the amount of each reactant required so that nothing is wasted: $HC_2H_3O_2(aq) + NaHCO_3(s) \rightarrow NaC_2H_3O_2(aq) + CO_2(g) + H_2O(l)$ $0.32\ mol\ CO_2 \times \frac{1\ mol\ HC_2H_3O_2}{1\ mol\ CO_2} = 0.32\ mol\ HC_2H_3O_2$ $0.32\ mol\ HC_2H_3O_2 \times \frac{1\ mol\ NaHCO_3}{1\ mol\ HC_2H_3O_2} = 0.32\ mol\ NaHCO_3$ $0.032\ mol \times \frac{1\ L}{3\ mol\ HC_2H_3O_2} \times \frac{1000\ mL}{1\ L} = 11\ mL$ of 3 M $HC_2H_3O_2$ solution $0.032\ mol \times \frac{1\ L}{3\ mol\ NaHCO_3} \times \frac{1000\ mL}{1\ L} = 11\ mL$ of 3 M $NaHCO_3$ solution

5 Build a Prototype

After finalizing their group design (with teacher approval), students build the prototype. The students will need some time outside of class to gather their supplies. They will also need time in class to make their solutions and measure the exact amount of each reactant. Each student in the group should have equal responsibility in building the prototype. The students should also use this time to test their prototype in different ways (does the bag seal completely? Do the reactants cause the expected change in pressure?). You will have to decide if you will allow extra supplies for testing or if only those listed in the design requirements and constraints can be used).

Your role in this phase is to walk around the class providing support and encouragement to the groups. You will likely have to help groups solve unforeseen problems that arise. You will also want to remind the students to document the building process and include an explanation for any deviations from their design.

The students should have their airbag assembled and ready to go by the end of the class period. The students will have 10 minutes on the day of testing to finish any assembly required on the day of the event.

SAMPLE RESPONSES TO THE QUESTIONS IN THE BUILD A PROTOTYPE SECTION OF THE CHALLENGE

Question	Sample Response
1	**List your specific responsibilities during the construction of your airbag prototype.** My responsibility was to attach the tubing to the airbag and to test it to make sure it was airtight. I tested it by dunking it under water and making sure no air bubbles formed.
2	**Often a prototype will not exactly match its design due to some unforeseen construction challenges. Were any design points changed during the construction process? Does your group's prototype exactly match the original design? If you did make changes, list those changes in your notebook and explain why your group made those changes.** The biggest challenge was to get the tubing into the airbag. The white glue we started with did not work very well. We decided to use super glue instead, which worked better. The glue took much longer than expected to dry, so we did not have time to test our airbag as much as we wanted to.
3	**Record in your notebook the mass and volumes of reactants used.** Volume of 3 M acetic acid: 11.0 mL Mass of sodium bicarbonate: 2.77 g Volume of 3 M sodium bicarbonate: 11.0 mL

6 Test and Evaluate

On the day of testing, you will need to set up a testing station which includes a data collection system with a pressure sensor attached. A graph of pressure (kPa) versus time should be displayed. You may also have a digits display running to make the pressure reading easy to see from the back of the room. Ideally, this testing station would be attached to an LCD projector so the entire class could see the data being collected. Have each group collect its data in a separate trial. Keep track of which group corresponds to which trial.

On the day of testing, give each student group a maximum of 10 minutes to construct its airbag. They will probably need to measure and prepare their reactants. (They may have already measured the necessary amount of sodium bicarbonate.) Have each group set its airbag on a side counter or table next to the testing station. One at a time, have the groups come to the testing station and attach its airbag to the sensor. They have one minute to do this. Then they should start data collection and after 20 seconds have passed, they should activate their airbag. The group should stop data collection when the reaction has stopped or when 3 minutes and 20 seconds have elapsed.

Each group should record its airbag's starting pressure, final pressure, time activated, and time it became fully inflated. These values can be used to calculate the change in pressure and time the airbag took to inflate.

After each group tests its airbag, the other groups should make notes about what worked well and what did not work well. These notes will be used for the final portion, Design Review, of this module.

During the period in which testing takes place, you will be responsible for organizing each group test. While the students will do all the hands-on work, you need to keep the groups moving at a rapid pace. You will also need to time each group and make sure they stop data collection after the time period has passed.

SAMPLE RESPONSES TO THE QUESTIONS IN THE TEST AND EVALUATE SECTION OF THE CHALLENGE

Question	Sample Response
1	**List your specific responsibilities during the testing of your airbag prototype.** I was responsible for measuring the $NaHCO_3$ and recording the data
2	**Record the room temperature.** Room temperature: 296.6 K
3	**Record the following data points and calculate the change in pressure and the time of inflation:** Starting pressure: 101 kPa — Time activated: 20 s Final pressure: 105 kPa — Time fully inflated: 160 s Change in pressure: 4 kPa — Time to inflate: 140 s
4	**As each group takes its turn, record information about its airbag design and the results. I was responsible for measuring the $NaHCO_3$ and recording the data.** Group 1: Used solid sodium bicarbonate. Used epoxy to seal the tubing. Change in pressure: 6 kPa. Time to inflate: 125 s

7 Design Review

In this stage, students will use the observations made during the Test and Evaluate state to review where their model succeeded and where it failed. Students are expected to answer the Design Review questions in the Challenge handout. The teacher's role is to facilitate questioning and discussion, direct students to compare their results with those of other groups in the class, and have students propose explanations for any differences in the outcome of their evaluation.

Based on their reviews, students could re-enter the engineering process at several points in the Engineering Design Process if time allows. They may wish to pursue additional avenues of research, or revise their design and construct a new model based solely on the results of their test and evaluations. Extensions for advanced students may include investigating a better (and still safe) chemical reaction to use or a way to activate their airbag in a "crash" type situation.

SAMPLE RESPONSES TO THE QUESTIONS IN THE DESIGN REVIEW SECTION OF THE CHALLENGE

Question	Sample Response
1	**How successful was your design? Did you meet all the design requirements and constraints? What data supports your assessment?** Our design was good but not entirely successful. We met most of the design requirement: we used 11 mL of acetic acid and 2.77 g of sodium bicarbonate. The pressure increased by 4 kPa in less than 3 minutes. The airbag, unfortunately, was not airtight.
2	**How could you have constructed it differently to be more effective? Explain why this would help.** To make it more successful, we need to find out where our airbag leaked and fix it. The pressure increased, but when it got to 105 kPa it started to decrease. This means there must have been a leak. The most likely location is around the tubing. More glue to seal the opening better may help. We didn't use a zip tie. That might help to hold the bag and glue in place to create a better seal. If the gas had not escaped, the pressure probably would have increased by the full 5 kPa.
3	**Look at another group's designs. What was different about their design and how do you think those differences affected their performance relative to yours?** Some groups used solid sodium bicarbonate. This was good because it reacted really fast, but sometimes it formed a clump and the reaction did not finish within the 3 minutes.

Concluding the Module

To conclude the Airbag Module, have a class discussion about aspects of the designs that worked and those that did not work. Discuss how well the mathematical calculations resulted in the expected changes in pressure. For those airbags that failed, were the calculated values wrong or was there a flaw in the design of the airbag that did not allow the reaction to occur?

Review with the students the chemistry involved in their airbag. Have the students draw a molecular level diagram of the airbag before activation and after activation. Have the students describe their diagrams to the class and discuss any differences.

Finally, end with a discussion about what real airbag engineers do on a daily basis. Do you think their designs always work? How do they test the airbags? What chemical reaction is used? How does that reaction compare to acetic acid and sodium bicarbonate? End by generating a list of questions they would like to ask an airbag engineer. If time allows, have students research some of these questions and report on their findings.

Have students review and complete their notebooks and submit them for assessment.

Post-Assessment

Answer each question to the best of your ability.

1. A mole of sucrose and a mole of iron have the same ______________.

   A. mass B. volume C. number of particles D. all (A, B, and C)

2. How many moles are in 30.0 mL of a 2.0 M solution of sodium bicarbonate?

   A. 0.015 mol B. 0.15 mol C. 0.60 mol D. 0.060 mol

3. Airbags in most automobiles inflate due to the incredibly fast decomposition of sodium azide. How many moles of sodium are formed to balance the following chemical reaction?

   $$2NaN_3(s) \rightarrow \_\_\_\_Na(s) + 3N_2(g)$$

   A. 4 B. 3 C. 2 D. 1

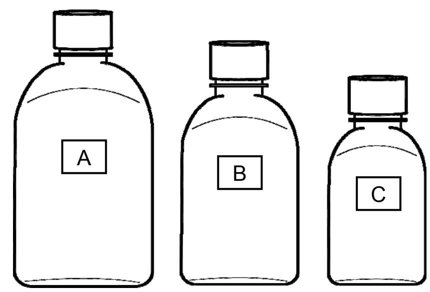
4. If each sampling bottle is at the same temperature and contains the same number of molecules, which one has the lowest pressure?

   A. Bottle A

   B. Bottle B

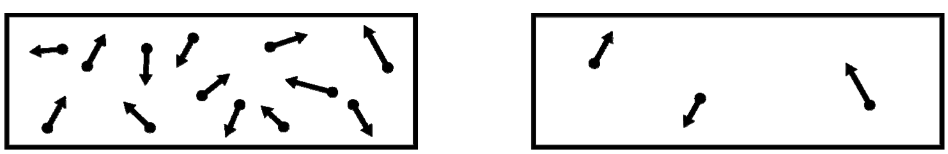
   C. Bottle C

   D. All the sampling bottles will have the same amount of pressure.



5. In the following diagrams, the volume is represented by the rectangles, each gas molecule is represented by a dot, and the speed each molecule is traveling is represented by the arrow. The longer the arrow, the faster the molecule is traveling.

   Which of the following statements is true about gaseous Sample A when compared to gaseous Sample B? The gas in both samples is the same.

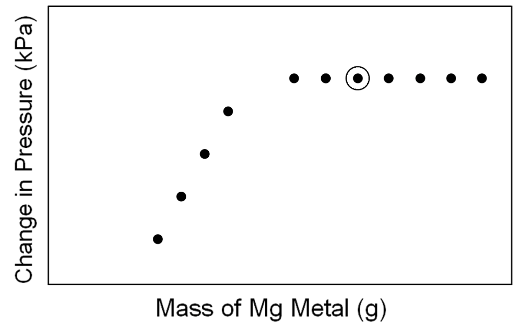


   A. They occupy the same volume and have the same pressure, but have different temperatures.
   B. They have the same temperatures and the same pressure, but occupy different volumes.
   C. They have the same temperature and occupy the same volume, but have different pressures.
   D. They occupy the same volume, but they have different temperatures and pressures.

6. In a closed container, what change will cause the pressure to increase?
   A. An increase in temperature
   B. The removal of particles from the container
   C. An increase in the volume of the container
   D. All of the above

7. Various reactions were performed in which increasing amounts of magnesium metal were mixed with a constant amount of hydrochloric acid. The change in pressure for each reaction was measured and a graph of the change in pressure versus the mass of magnesium is shown below. Which best describes the data point that is circled?

    A. Magnesium is the excess reactant and hydrochloric acid is the limiting reactant.
    B. Magnesium is the limiting reactant and hydrochloric acid is the excess reactant.
    C. There was exactly the right amount of reactants and neither was in excess or limiting.
    D. There was an excess of each reactant in this trial.



8. What does it mean if two reactants are combined using their mole-to-mole ratio?

    A. Equal numbers of moles of each reactant are combined to produce the most product.
    B. One mole of each reactant is added to produce two moles of product.
    C. The amount of one reactant is determined precisely and a large excess of the other reactant is added to ensure a maximum amount of product is formed.
    D. A precise amount of each reactant is combined to form the maximum amount of product with the least amount of unused or wasted excess material.

9. How many moles of carbon dioxide gas are required to fill a 0.50 L plastic bag to its maximum volume? Use the data given below to determine your answer.

    P = 101.1 kPa; T = 300.2 K; R = 8.314 (L·kPa)/(mol·K)

    A. 49.0 mol CO_2 B. 0.049 mol CO_2 C. 0.20 mol CO_2 D. 0.020 mol CO_2

10. How many milliliters of 3.0 M sodium bicarbonate are needed to have 0.080 moles of sodium bicarbonate?

    A. 0.24 mL B. 27 mL C. 24 mL D. .027 mL

11. How many liters of hydrogen gas will form if you completely react 0.45 g of magnesium metal (Mg) with an excess of hydrochloric acid (HCl) at 298.2 K and 101.3 kPa according to the following reaction?

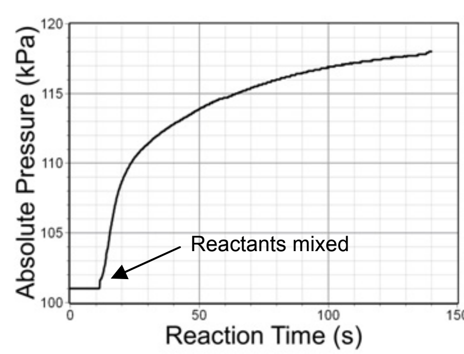
    R = 8.314 (L·kPa)/(mol·K); the molar mass of Mg is 24.31 g/mol

$$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$$

    A. 0.019 L H_2 B. 0.47 L H_2 C. 4.64 L H_2 D. 11.0 L H_2

12. What is the average rate of reaction for this run of data?

    A. 7.6 kPa/s
    B. 17 kPa/s
    C. 130 kPa/s
    D. 0.13 kPa/s



13. Which of the following reactants would magnesium metal react with the most quickly?

    A. 2 M HCl B. 1 M HCl C. 0.80 M HCl D. 0.30 M HCl

Post-Assessment Answer Key

Questions from the Post-Assessment handout are identified by the number in the first column in the table below. The second column indicates the correct answer to each question. A detailed description of the answer is provided in the assessment information.

Question	Correct Answer	Assessment Information
1	C	A mole is 6.0×10^{23} particles, so a mole of sucrose contains 6.0×10^{23} molecules of sucrose and a mole of iron contains 6.0×10^{23} atoms of iron.
2	D	$(0.0300\text{ L})\left(\frac{2.0\text{ mol}}{\text{L}}\right) = 0.060\text{ mol of }NaHCO_3$
3	C	$2NaN_3(s) \rightarrow 2Na(s) + 3N_2(g)$
4	A	Bottle A has the largest volume so the particles in it will collide with the sides of the container the least often, resulting in the lowest pressure.
5	C	There are more molecules in Sample A than there are in Sample B, but the temperature in both samples is the same (the arrows are the same length). Sample A therefore has the same volume and same temperature, but a higher pressure than Sample B.
6	A	Increasing the temperature of the air in the container will cause the pressure inside that container to increase. Choices B and C both cause a decrease in pressure inside the container.
7	A	Hydrochloric acid is the limiting reactant. The graph shows that as more magnesium was added, the reaction produced more gas, showing a greater change in pressure, until there was an excess of magnesium and hydrochloric acid became the limiting reagent. The change in pressure didn't alter after that point, regardless of the amount of magnesium used. The circled data point is in the region of the graph where the pressure did not alter regardless of the amount of magnesium used. This means the reaction ended when it ran out of hydrochloric acid.
8	D	If reactants are combined using their mole-to-mole ratio, then the ideal amount of each reactant is used to obtain the maximum amount of product with the least amount of unused or wasted material.
9	D	The ideal gas law, $PV = nRT$, can be used to solve this problem. $n = \frac{PV}{RT}$ $n = \frac{(101.1\text{ kPa})(0.50\text{ L})}{\left(8.314\ \frac{\text{L kPa}}{\text{mol K}}\right)(300.2\text{ K})}$ $n = 0.020\text{ mol }CO_2$
10	B	$0.080\text{ mol} \times \frac{1\text{ L}}{3.0\text{ mol }NaHCO_3} \times \frac{1000\text{ mL}}{1\text{ L}} = 27\text{ mL}$
11	B	$0.45\text{ g Mg} \times \frac{1\text{ mol Mg}}{24.31\text{ g Mg}} = 0.019\text{ mol Mg}$ $0.019\text{ mol Mg} \times \frac{1\text{ mol }H_2}{1\text{ mol Mg}} = 0.019\text{ mol }H_2$ $V = \frac{nRT}{P}$ $V = \frac{(0.019\text{ mol})\left(8.314\ \frac{\text{L kPa}}{\text{mol K}}\right)(298.2\text{ K})}{(101.3\text{ kPa})}$ $V = 0.47\text{ L }H_2$
12	D	$\text{Rate} = \frac{\Delta P}{\Delta t}$ $\text{Rate} = \frac{118\text{ kPa} - 101\text{ kPa}}{140\text{ s} - 10\text{ s}} = \frac{17\text{ kPa}}{130\text{ s}} = 0.13\text{ kPa/s}$
13	A	The higher the concentration, the faster the reaction occurs.

Appendix – Master Materials and Equipment List

Equipment by Activity

Teachers can conduct some lab activities with sensors other than those listed here. For assistance with substituting compatible sensors for a lab activity, contact PASCO Teacher Support (800-772-8700 inside the United States or http://www.pasco.com/support).

NOTE: Italicized entries indicate items not available from PASCO. The quantity indicated is per student or group.

Act	Title	Materials and Equipment	Qty
1	**Understanding Pressure (p. 23)** Use a pressure sensor and a temperature sensor to determine how temperature, volume, and amount of a gas affect pressure in a closed system.	Data Collection System	1
		PASPORT Absolute Pressure Sensor	1
		PASPORT Stainless Steel Temperature Sensor with blue tubing	1
		Syringe with quick-release connector attached	1
		Sampling bottle, plastic, 500-mL	1
		Beaker, 1000-mL	1
		Rubber stopper, two-hole, to fit the sampling bottle and fitted with a 50-cm piece of tubing with a quick-release connector at the end	1
		Stopcock connected to a tubing connector with a 2-cm piece of tubing	1
		Crushed ice	500 mL
		Paper towels	several
2	**Mole-to-Mole Ratios (p. 35)** Use a pressure sensor to determine the ideal amount of sodium bicarbonate to completely react with 10 mL of 0.50 M acetic acid and use these values to determine the mole-to-mole ratio in the balanced chemical equation.	Data Collection System	1
		PASPORT Absolute Pressure Sensor	1
		Sampling bottle, plastic, 500-mL	1
		Beaker, 100-mL	1
		Rubber stopper, two-hole, to fit the sampling bottle and fitted with a 50-cm piece of tubing with a quick-release connector, and a stopcock	1
		Syringe	1
		Balance, readability 0.01 g	1
		Sodium bicarbonate ($NaHCO_3$)	1.2 g
		Acetic acid ($HC_2H_3O_2$)*, 0.50 M*	40 mL
		Waste container	1
		Tap water to rinse the sampling bottle between trials	
3	**Variable Volumes (p. 45)** Use a pressure sensor and a temperature sensor to determine the volume of gas and the amount of gas (in moles) needed to fill bags of various sizes to a specific pressure.	Data Collection System	1
		PASPORT Absolute Pressure Sensor	1
		PASCO Stainless Steel Temperature Sensor	1
		Syringe	1
		Rubber stopper, two-hole, to fit the balloon and fitted with a 50-cm piece of tubing with a quick-release connector, and a stopcock	1
		Graduated cylinder, 1000-mL	1
		Beaker, 400-mL	1
		Plastic bags, sealable, various sizes	3
		Balloon, large	1
		Tub, plastic	1
		Tap water	
		Paper towels	several

Act	Title	Materials and Equipment	Qty
4	**Stoichiometric Calculations (p. 51)** Calculate the amounts and concentrations of reactants needed to produce a certain number of moles of a product without wasting any chemicals.	*Calculator*	1
5	**Reaction Rate (p. 57)** Use a pressure sensor to determine how stirring and reactant concentration affect the reaction rate between acetic acid and sodium bicarbonate.	Data Collection System	1
		PASPORT Absolute Pressure Sensor	1
		Sampling bottle, plastic, 500-mL	1
		Rubber stopper, two-hole, to fit the sampling bottle and fitted with a 50-cm piece of tubing with a quick-release connector, and a stopcock	1
		Graduated cylinder, 100-mL	1
		Beaker, 100-mL	1
		Balance, readability 0.01 g	1
		Syringe	1
		Magnetic stirrer with stirring bar	1
		Sodium bicarbonate ($NaHCO_3$)	2 g
		Acetic acid ($HC_2H_3O_2$), 0.50 M	60 mL
		Waste container	1
		Tap water	

Equipment for Airbag Construction

NOTE: Italicized entries indicate items not available from PASCO. The quantity indicated is per student or group

Items Provided by Teacher	Qty
3.0 M acetic acid ($HC_2H_3O_2$)	100 mL
Sodium bicarbonate ($NaHCO_3$)	10 g
Tubing, 10-cm	1
Standard lab materials	
Items Provided by Student Groups	**Qty**
Plastic bag with a volume of 1.5 L or less	1
Materials to attach the tubing to the airbag, for example, glue and zip ties	
Materials to separate reactants in the airbag, for example, rubber bands	

Equipment for Airbag Module

The following is a list of all the materials needed for the entire Airbag module. The quantity listed is the total needed for the entire module. To find the quantity used in each activity, refer to the Equipment by Activity and Equipment by Airbag Construction listed above.

NOTE: Italicized entries indicate items not available from PASCO. The quantity indicated is per student or group.

Materials	Qty	Activity Where Used
Data Collection System	1	1, 2, 3, 5
PASPORT Stainless Steel Temperature Sensor (with blue tubing)	1	1, 3
PASPORT Absolute Pressure Sensor	1	1, 2, 3, 5
Balance, readability: 0.01 g	1	2, 5
Balloon, large	1	3
Beaker, 1000-mL	1	1
Beaker, 100-mL	1	2, 5
Magnetic stirrer with stirring bar	1	5
Rubber stopper, two-hole, to fit the sampling bottle and fitted with a 50-cm piece of tubing with a quick-release connector	1	1, 2, 3, 5
Sampling bottle, plastic, 500-mL	1	1, 2, 5
Stopcock connected to a tubing connector	1	1, 2, 3, 5
Syringe (with quick-release connector attached)	1	1, 2, 3, 5
Tubing, 10-cm	1	Airbag construction
Acetic acid ($HC_2H_3O_2$), 0.50 M	100 mL	2, 5
Acetic acid ($HC_2H_3O_2$), 3.0 M	100 mL	Airbag construction
Beaker, 400-mL	1	3
Calculator	1	4
Crushed ice	500 mL	1
Graduated cylinder, 1000-mL	1	3
Graduated cylinder, 100-mL	1	5
Paper towels	Several	1, 3
Plastic bags, sealable, various sizes	1	3
Sodium bicarbonate ($NaHCO_3$)	13.2 g	2, 5, Airbag construction
Tap Water	unlimited	2, 3,5
Tub, plastic	1	3
Waste container	1	2, 5
Standard lab materials		Airbag construction

Appendix – Normal Laboratory Safety Procedures

Overview

PASCO is concerned with your safety and because of that, we are providing a few guidelines and precautions to use when performing the Activities and the Challenge. This is a list of general guidelines only; it is by no means all-inclusive or exhaustive. Of course, common sense and standard laboratory safety practices should be followed.

Regarding chemical safety, some of the substances and chemicals referred to in this manual are regulated under various safety laws (local, state, national, or international). Always read and comply with the safety information available for each substance or chemical to determine its proper storage, use and disposal.

Since handling and disposal procedures vary, our safety precautions and disposal comments are generic. Depending on your lab, instruct students on proper disposal methods. Each of the lab activities also has a Safety section for procedures necessary for that activity.

General Lab Safety Procedures and Precautions

- Follow all standard laboratory procedures
- Absolutely no food or drink is allowed in the lab.
- Wear protective equipment (for example, safety glasses, gloves, apron) when appropriate.
- Do not touch your face with gloved hands. If you need to sneeze or scratch, take off your gloves, wash your hands, and then take care of the situation.
- Wash your hands after handling samples, glassware, and equipment.
- Know the safety features of your lab such as eye-wash stations, first-aid equipment or emergency phone use.
- Insure that loose hair and clothing are secure when in the lab.
- Handle glassware with care.
- Ensure you have adequate clear space around your lab equipment before starting an activity.
- Do not wear open-toe shoes in the laboratory.
- Allow heated objects and liquids to return to room temperature before moving.
- Never run or joke around in the laboratory.
- Do not perform unauthorized experiments.
- Students should work in teams of 2 or more in case of trouble and help is needed.
- Keep the work area neat and free from any unnecessary objects.

Water Related Safety Precautions and Procedures

- Keep water away from electrical outlets.
- Keep water away from all electronic equipment.

Chemical Related Safety Precautions and Procedures

- Consult the manufacturer's Material Safety Data Sheets (MSDS) for instructions on handling, storage, and disposing of chemicals. (You can find these on the Internet.) Keep these instructions available in case of accidents.
- Many chemicals are hazardous to the environment and should not be disposed of down the drain. Always follow local regulations for disposing of chemicals. When it is appropriate to dispose of chemicals in a sink, always flush them with large amounts of water.
- Sodium hydroxide, hydrochloric acid, and acetic acid are corrosive irritants. Avoid contact with the eyes and wash your hands after handling.
- Always add acids and bases to water, not the other way around, as the solutions may boil vigorously.
- Diluting acids and bases creates heat; be extra careful when handling freshly prepared solutions and glassware, as they may be very hot.
- Handle concentrated acids and bases in a fume hood; the fumes are caustic and toxic.
- Be sure that all acids and bases are neutralized before being disposed of down the drain.
- Wear eye protection, lab apron, and protective gloves when handling acids. Splash-proof goggles are recommended. Either latex or nitrile gloves are suitable.
- Read labels on all chemicals and pay particular attention to Hazard icons and safety warnings.
- Wash your hands before and after a laboratory session.

- If acid solutions come in contact with skin or eyes, rinse immediately with a copious amount of running water for a minimum of 15 minutes.
- Follow the teacher's instructions for disposing of chemicals and handling substances.
- Check the label to verify it is the correct substance before using it.
- Never point the open end of a test tube containing a substance at yourself or others.
- Use a wafting motion when smelling chemicals
- Do not return unused chemicals to their original container.

Safety Precautions When Working with Systems under Pressure

- Never point the opening of a container with a substance under pressure at yourself or others.
- To minimize the risk of injury or damage to the equipment, do not exceed 400 kPa when compressing air in the syringe.
- Be aware that a gas being generated in a closed system causes an increase in pressure which may cause the system to burst or cause loosely attached pieces, such as a stopper, to be expelled. Eye protection should be worn during this type of experiment to prevent injury due to flying objects as well as splashed chemicals.

Other Safety Precautions

- Any injury must be reported immediately to the instructor. An accident report must be completed by the student or a witness.
- If you are suffering from any allergy, illness, or are taking any medication, you must inform the instructor. This information could be important in an emergency.

Additional Resources

- Flinn Scientific
- The Laboratory Safety Institute (LSI)
- National Science Education Leadership Association (NSELA)/Safe Science Series