

10, 9, 8, 7, 6, 5, 4, 3, 2, 1 ...

**BLAST OFF!**



# **Pop Rocket Inquiry and Engineering Design Challenge**

***A Three-Phase STEM Lesson Designed for  
Honors Chemistry***

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## STEM Middle and High School Lesson Template

**Title:** Pop Rocket Inquiry and Engineering Design Challenge

**Grade Level:** High School – Honors Chemistry (reaction rate, balanced equations, stoichiometry)<sup>1</sup>

### Lesson Design Questions:

#### 1. What are the essential questions for the lesson?

- *What factors affect the rate of a chemical reaction?*
- *How does the mass of a reactant affect the launch time of a rocket?*
- *Design, build, and test a rocket that will launch in exactly 10 seconds.*

##### a. Why are these questions relevant?

*This lesson enables students to explore, investigate, understand, and apply the core chemical concepts of reaction rate, balanced chemical equations, chemical change, gas behavior, and molar relationships. This lesson addresses several core learning goals for chemistry in an engaging, guided inquiry format. Upon completion of this lesson, students will understand how reaction rates affect things in their daily lives and how the quantities of chemical reactants can affect the behavior of a real-world object such as a rocket.*

##### b. What is the connection to real life?

*In phase one of the inquiry, students will consider the real-world applications of reaction rate including launching a rocket, keeping food fresh, and the use of medications. In phase two of the inquiry, students will use technology to analyze their data and generate a best-fit line. In phase three of the inquiry, students will learn how engineers solve problems and employ the Engineering Design Cycle to tackle the challenge of designing a pop rocket that will launch in exactly 10 seconds.*

#### 2. What techniques are used to make the lesson:

##### a. inquiry-based?

*This lesson is designed in three parts to enable a scaffolded approach to inquiry. Each phase of the inquiry begins with an experimental question. Phase 1 is designed as a **structured inquiry** lesson. Students are given the exact steps to follow to obtain data that will enable them to answer the experimental question. Phase 2 is designed as a **guided inquiry** lesson. Students are provided some introductory steps for the investigation but then must make choices as to the amounts of reactant to use for their final tests. Phase 3 is designed as an **open inquiry** lesson. Students are challenged with designing, building, testing, and improving a rocket with the target of a 10-second launch. Students are given design parameters but must design their own method, materials, and procedure.*

##### b. project-based?

*The three phases of this lesson culminate with the challenge of designing a 10-second rocket. A teacher may select to use all three phases of this lesson or only one or two, depending on the needs and abilities of the students. Students will use their experimental observations, graphical analysis, and knowledge of chemical principles to create their rocket. Success on this project will be measured by a class competition at the end of phase 3.*

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<sup>1</sup> This lesson could also be used with Active Chemistry. The second phase of the inquiry would need to be modified to remove the stoichiometric calculations.

### 3. What are the lesson outcomes?

- *Students will explain the effect of temperature, concentration, and surface area on the rate of a chemical reaction.*
- *Students will understand the relationship between the molar quantities of reactant and product.*
- *Students will construct a graph of launch time versus reactant concentration, generate an equation of the line of best fit, and use the equation to solve for a particular launch time.*
- *Students will apply the Engineering Design Cycle to solve a real-world problem.*

### 4. How is participant discourse promoted?

*Students should work in collaborative teams of 2-3 on this inquiry lesson. Students are asked to reflect upon their learning using a C-E-I framework following each phase of the inquiry. In this framework, students first make an experimental claim. They next provide evidence to support that claim. Finally, they reflect upon the significance of the experiment and interpret the results. Students will be asked to share their responses to the C-E-I conclusions with team members as well as in the whole class format.*

### 5. How are science, technology, engineering, and mathematics addressed in the lesson?

**Science:** *This lesson addresses multiple core learning goals for chemistry, including reaction rate, stoichiometry, and balanced chemical equations. It also addresses multiple goals in the “Skills and Process” domain including safe lab procedures, use of laboratory equipment, data analysis, and graphical interpretation.*

**Technology:** *In phase 2 of this inquiry lesson, students use Excel or a graphing calculator to create a scatter plot of their data and determine the equation for the line of best fit. Students will use calculators to determine stoichiometric ratios. Students will also be using stopwatches to measure the launch time. This could also be modified to include the use of a photogate.*

**Engineering:** *In phase 2 of this inquiry lesson, students learn about and use the Engineering Design Cycle (Idea-Design-Build-Test-Improve) to solve the problem of the 10-second rocket.*

**Mathematics:** *In phase 2 of this inquiry lesson, students collect data, calculate the mean from multiple trials, and assess the precision of their data sets. They will also create a scatter plot of their data and determine the equation of the line of best fit. Students will then use this equation to solve for the amount of reactant needed to create a specific launch time.*

Standard	Standard Number (s)	Activity
<b>Common Core Standard for Mathematical Practice</b>	4 5 6	Model with mathematics (phase 2) Use appropriate tools strategically (phases 1-3) Attend to precision (phase 2)
<b>International Technology Education Association Standards for Technological Literacy</b>	3 9 10 11 18	Relationships among technologies and other fields (phase 1,3) Engineering Design (phase 3) Role of troubleshooting, experimentation in problem solving Apply the design process (phase 3) Transportation technologies (phase 3, rocket design)
<b>Common Core Reading Standards for Literacy in Science and Technical Subjects</b>	1 4	Read closely and cite textual evidence (phases 1-3, elaboration) Interpret words and phrases as they are used in text (phases 1-3, elaboration)
<b>Common Core Writing Standards for Literacy in History/ Social Studies, Science and Technical Subjects</b>	1 4 5 7 9	Write arguments focused on content (phases 1-3, C-E-I) Produce clear and coherent writing (phases 1-3, C-E-I) Develop and strengthen writing (phases 1-3, C-E-I) Conduct short research projects to answer a question (3) Draw evidence from informational texts to support analysis (phases 1-3, elaboration)
<b>Skills and Processes Core Learning Goals for Science</b>	3 4 5 6 7	Carry out scientific investigations effectively (phases 1-3) Demonstrate that data analysis is vital aspect of the process of scientific inquiry (phases 1-3) Use appropriate methods for communicating in writing and orally the processes and results of scientific investigation Use mathematical processes (phase 2) Show connections between sciences and other fields (phase 1,3)
<b>Content Standard</b>	4.5.4 4.5.3.2 4.4.3.2 1.1.2, 1.2.3-1.2.6, 1.3.2, 1.3.3, 1.4.7, 1.4.9, 1.5.1, 4.4.3, 4.5.3, 4.5.4	Recognize that chemical reactions occur at different speeds (1) Demonstrate that changing the amount of reactants may change the amount of products formed (phase 2) Use relationships between moles and mass (phase 2) Skills and process core learning goals (phase 3)

5E Model – STEM lessons will use the 5E Model

5E Lesson Components	Description of Activity
<p style="text-align: center;"><b>Engagement</b></p> <p>The activities in this section capture the participants' attention, stimulate their thinking, and help them access prior knowledge.</p>	<p>Initiate a whole class discussion by showing pictures of different chemical changes such as a rusting gate and an exploding firework. Ask <i>“Which chemical change happens faster? Why? How could we make the gate rust faster? How could we slow down the explosion? What can you do to control how fast a chemical change happens?”</i> Introduce the experimental question for Phase 1 of the Pop Rocket inquiry and have students brainstorm ideas with their lab partners and then share with the class.</p>
<p style="text-align: center;"><b>Exploration – Phase 1</b></p> <p>In this section, participants are given time to think, plan, investigate, and organize collected information.</p>	<p>Read the “Introduction” to Phase 1 of the Pop Rocket Inquiry. Discuss lab safety and behavioral expectations. Have students work in lab teams of 2-3 to follow the experimental procedure and collect their data.</p>
<p style="text-align: center;"><b>Explanation – Phase 1</b></p> <p>Participants are now involved in an analysis of their exploration. Their understanding is clarified and modified because of reflective activities.</p>	<p>Instruct students to complete the C-E-I conclusion framework for phase 1 of the inquiry lesson. Following phase 1 of the inquiry, have students share their experimental claims and what data they have to support those claims. Address any conflicting pieces of evidence and discuss possible sources of error.</p>
<p style="text-align: center;"><b>Exploration – Phase 2</b></p> <p>In this section, participants are given time to think, plan, investigate, and organize collected information.</p>	<p>Read the experimental question and “Introduction” to Phase 2 of the Pop Rocket Inquiry. Have students work collaboratively on the Pre-Inquiry questions and then share the answers as a whole class. Discuss lab safety and behavioral expectations. Have students work in lab teams of 2-3 to follow the experimental procedure and collect their data.</p>
<p style="text-align: center;"><b>Explanation – Phase 2</b></p> <p>Participants are now involved in an analysis of their exploration. Their understanding is clarified and modified because of reflective activities.</p>	<p>Instruct students to complete the data analysis and C-E-I conclusion framework for phase 2 of the inquiry lesson. Following phase 2 of the inquiry, have students share their graphs, equations of best fit, experimental claims, and what data they have to support those claims. Address any conflicting pieces of evidence and discuss possible sources of error.</p>

<p style="text-align: center;"><b>Extension</b></p> <p>This section gives participants the opportunity to expand and solidify their understanding of the concept and/or apply it to a real world situation.</p>	<p>Introduce the design challenge for phase 3 of the inquiry. Discuss the Engineering Design Cycle. Have students work collaboratively on the Pre-Inquiry questions and then share the answers as a whole class. Discuss lab safety, behavioral expectations, and design parameters. Have students work on the Design/Build/Test/Improve stages of the design cycle for 30 minutes. Then, instruct them to measure out their materials for the design challenge class competition.</p>
<p style="text-align: center;"><b>Evaluation</b></p> <p>Evaluation occurs throughout the lesson. Scoring tools developed by teachers and participants target what participants must know and do. Consistent use of scoring tools improves learning.</p>	<p>Conduct the class competition. The teacher should measure and record the exact time for each rocket launch and declare a competition winner. Have students complete the C-E-I framework for the design challenge and share/discuss their responses in small group and whole class format.</p> <p>Informal assessment will occur throughout the 3 phases of the lesson via discussion questions, small group interactions, and monitoring during the lab. Students should submit their inquiry reports for formal assessment. The class competition may be used as a portion of the inquiry grade – for example, if the launch time is +/- 2 seconds, they receive 10 points.</p>
<p style="text-align: center;"><b>Elaboration</b></p> <p>This section gives participants the opportunity to further explore the underlying concepts and make connections to other fields of study.</p>	<p>Based upon student interest or the desired depth of the inquiry, the teacher may opt to use selected sections of the “Rocket Propulsion” article to explore some of the chemistry and physics related to rocket design and launch. Students could read text, highlight key terms, generate questions, and then share their ideas in small groups.</p>

Name: \_\_\_\_\_

**CLG 4.5.4:** Recognize that chemical reactions occur at different speeds.

## Phase 1 Rocket Inquiry: Pop Rocket Reaction Rate

**Experimental Question:** *What factors affect the rate of a chemical reaction?*

### Introduction:

You may have noticed that chemical reactions occur at different rates. The explosion of fireworks is instantaneous; the rusting of an iron gate is relatively slow. A **rate** is measure of change per unit time. For example, the rate of change of distance over time is called speed. The rate of a chemical reaction is studied in terms of changes in concentration of a reactant or product over time.

Chemists study rates of reaction in order to control the progress of a chemical reaction. In order to understand how the rates of chemical reactions can be controlled, it is necessary to understand the factors that influence the rates of chemical reactions. We will study some of these factors by launching film canister rockets.



**Procedure:** *Check off each step as it is completed.*

- 1. Put on safety goggles. They must be worn correctly at all times during this investigation.
- 2. Obtain a film canister, a stopwatch, a plastic bin ("launching pad"), and 1 pack of Alka Seltzer.
- 3. Take out one Alka Seltzer tablet and place on a dry paper towel.
- 4. Cut or break the tablet into four equal pieces.
- 5. Measure exactly 15 mL of tap water and add to the film canister.
- 6. Get the stopwatch ready.
- 7. Quickly place the tablet into the canister, snap on the lid and place cap-side down into the launching pad. Start the timer, **stand back**, and record how long it takes to launch.
- 8. Empty the reaction products into the sink.
- 9. Repeat steps #5-8 using warm water from the hot plate.
- 10. Repeat steps #5-8 using cold water (beaker with ice water).
- 11. Use the mortar and pestle to grind the remaining  $\frac{1}{4}$  tablet into a fine powder. Transfer the powder onto a piece of paper.
- 12. Repeat steps #5-8 using regular tap water and this powdered tablet. (*Work very quickly with this one!*)
- 13. Break the second tablet into four equal pieces.
- 14. Repeat steps #5-8 using vinegar in the canister instead of tap water.
- 15. Use remaining  $\frac{1}{4}$  tablets to repeat trials or try a new experiment.
- 15. Rinse out the film canister and clean up your lab area.

<b>Variable</b>	<b>Time to Launch (seconds)</b>
<b>Room Temp Water</b>	
<b>Warm Water</b>	
<b>Cold Water</b>	
<b>Powdered Tablet</b>	
<b>Tablet with More Acid (vinegar)</b>	

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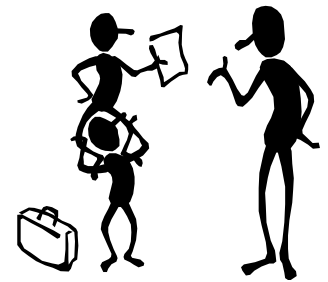
# Conclusion for Phase 1 Rocket Inquiry: Pop Rocket Reaction Rate

Answer each of the following in complete sentences.

**CLAIM** – Answer the experimental question.



**EVIDENCE** – Provide at least three specific experimental observations or pieces of data to support your claim.



**INTERPRETATION** –

Use your experimental observations to explain why food is kept fresh by storing it in the refrigerator.

Use your experimental observations to explain why powdered sugar might dissolve faster in iced tea than a cube of sugar.

Use your experimental observations to explain why two aspirin tablets can often cure a headache faster than one aspirin tablet.





**CLG 4.5.3.2:** Demonstrate that changing the amount of reactants may change the amount of products formed.

**CLG 4.4.3.2:** Use relationships between moles and mass.

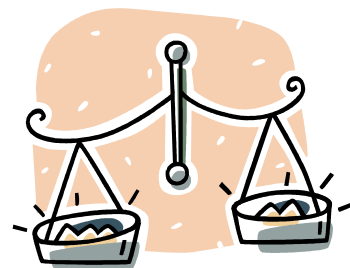
Name: \_\_\_\_\_

## Phase 2 Rocket Inquiry: Pop Rocket Stoichiometry

**Experimental Question:** *How does the mass of reactant affect the launch time of a rocket?*

### Introduction:

**Stoichiometry** is the study of chemical quantities. We use stoichiometry to investigate the relative amounts of reactants and products. When investigating these relationships, don't forget the golden rule of stoichiometry -- **all quantitative relationships in chemistry are based on the mole!** When comparing amounts of reactants and products, we don't talk about grams, liters, or molecules ... we always compare molar amounts.



In today's investigation, you will explore how the amount of a reactant affects the launch time of a rocket. Our two reactants are acetic acid (vinegar) and sodium hydrogen carbonate (baking soda).

### Pre-Inquiry Question #1:

Write the balanced equation for the reaction between acetic acid and sodium hydrogen carbonate:



### Pre-Inquiry Question #2:

A 15 mL sample of vinegar contains 0.72 grams of acetic acid. Convert this value to moles of acetic acid.

### Pre-Inquiry Question #3:

Determine the number of grams of sodium hydrogen carbonate needed to react completely with the moles of acetic acid from question #2.

**Procedure:** *Check off each step as it is completed.*

- 1. Put on safety goggles. They must be worn correctly at all times during this investigation.
- 2. Obtain a film canister with lid, a launching pad, a few pieces of tissue, and a stopwatch.
- 3. Cut a piece of tissue into 4 equal squares.
- 4. Place one of the squares of tissue on the electronic balance and hit "zero". Add exactly 1.0 gram of baking soda to the center of the tissue and take it back to your lab station.
- 5. Measure exactly 15.0 mL of vinegar using a graduated cylinder and add it to your film canister.
- 6. Fold up the corners of the tissue and twist together to make a little "baking soda bomb".

- 7. When you're ready, have one lab partner start the stopwatch while the other adds the baking soda bomb to the canister, snaps on the lid tightly, gives it one good shake, and places it upside down on the launching pad. **Stand back** and record the time it takes for the pop rocket to launch.
- 8. Rinse and dry the film canister.
- 9. Repeat steps #4-8 to obtain two more trials for 1.0 gram of baking soda.

<b>Reaction with 1.0 g of NaHCO<sub>3</sub></b>	<b>Time to Launch (seconds)</b>
<b>Trial 1</b>	
<b>Trial 2</b>	
<b>Trial 3</b>	
<b>Average Time</b>	

**STOP AND THINK**



*What effect do you think changing the amount of baking soda would have on the time it takes for the rocket to launch? If you keep the amount of vinegar constant, do you think there is a maximum amount of baking soda that would work? Do a mass-mole calculation in the space below to support your reasoning.*

- 10. Select three additional masses of baking soda and run steps #4-9 to obtain three trials for each.

<b>Mass of NaHCO<sub>3</sub></b>	<b>Time to Launch (seconds)</b>			
	<b>Trial 1</b>	<b>Trial 2</b>	<b>Trial 3</b>	<b>Average</b>

**Data Analysis:**

- Use Microsoft Excel or a graphing calculator to graph your data. Create a scatter plot of mass of NaHCO<sub>3</sub> (x-axis) versus time to launch (y-axis). Be sure to plot your average data for 1.0 gram as well as the three additional masses you selected.
- Create a best fit line and write the equation for the line below:

**Equation of Best-Fit Line:** \_\_\_\_\_

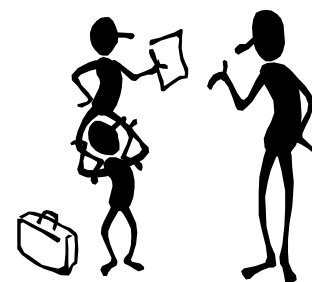
## Conclusion for Phase 2 Rocket Inquiry: Pop Rocket Stoichiometry

Answer each of the following in complete sentences.

**CLAIM** – Answer the experimental question.



**EVIDENCE** – Provide at least three specific experimental observations or pieces of data to support your claim.



**INTERPRETATION** –

Was your experimental data precise? Give an example to support your answer.

What was the mathematical relationship between the mass of  $\text{NaHCO}_3$  and the launch time?



Use your equation of the best fit line to determine the exact mass of  $\text{NaHCO}_3$  needed to create a rocket that would launch in 8 seconds. Show your work below.

Name: \_\_\_\_\_

**Chemistry CLG:** 1.1.2, 1.2.3-1.2.6,  
1.3.2, 1.3.3, 1.4.7, 1.4.9, 1.5.1, 4.4.3,  
4.5.3, 4.5.4

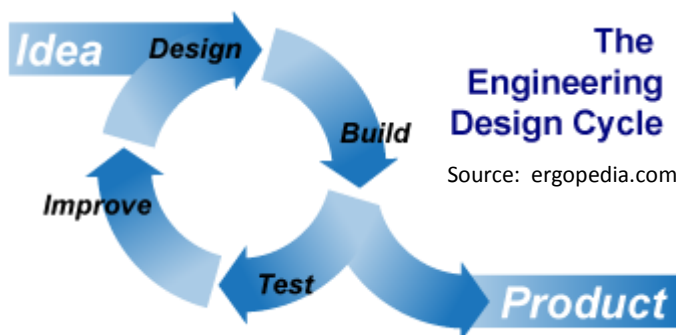
## Phase 3 Rocket Inquiry: Pop Rocket Design Challenge

**Challenge:** *Design, build, and test a rocket that will launch in exactly 10 seconds.*

### Introduction:

**10, 9, 8, 7, 6, 5, 4, 3, 2, 1 ... BLAST OFF!**

Can you use your knowledge of chemical reactions, reaction rates, and stoichiometry to build a rocket that will launch in exactly 10 seconds? That is your engineering design challenge today. We will wrap up this design challenge with a class competition – the team that submits the rocket that launches closest to the 10 second target will win! 😊



Engineers apply their knowledge of science and mathematics to solve real world problems. They employ a systematic approach to problem solving called the **Engineering Design Cycle**.

### Pre-Inquiry Question #1:

Describe each step of the Engineering Design Cycle as shown in the figure above.

### Pre-Inquiry Question #2:

Why is this process called a “cycle”?

### Design Parameters:

- You will have the following materials available for your entire design cycle:

<i>Film canister (“pop rocket”)</i>	<i>Launching Pad</i>
<i>20 grams of baking soda, <math>\text{NaHCO}_{3(s)}</math></i>	<i>Room Temperature, Warm, and Cold <math>\text{H}_2\text{O}_{(l)}</math></i>
<i>100 mL of vinegar, <math>\text{HC}_2\text{H}_3\text{O}_{2(aq)}</math></i>	<i>Stopwatch</i>
<i>2 tablets of Alka Seltzer</i>	<i>Graduated Cylinder</i>
<i>4 sheets of tissue</i>	<i>Balance</i>
- You will have 30 minutes to design, build, test, and improve your rocket before submitting a rocket for the class competition.
- You must wear goggles correctly at all times during this design challenge. You are also responsible for cleaning up all materials and surfaces when you are finished.

# Engineering Design Cycle for 10 Second Pop Rocket

**Design:** *In the space provided below, list the specific materials and quantities you plan to use. You must have teacher initials before proceeding to the "Build" phase.*

**Build:** *Measure out the amounts for your rocket as specified above.*

**Test:** *Record the launch time for your rocket in the space provided below. Repeat the same amounts to obtain three sets of data.*

**Trial 1 Launch Time =** \_\_\_\_\_

**Trial 2 Launch Time =** \_\_\_\_\_

**Trial 3 Launch Time =** \_\_\_\_\_

**Improvement #1:** *Make one change to your rocket design. Describe the change below.*

**Test #1:** *Record the launch time for your rocket in the space provided below. Repeat the same amounts to obtain three sets of data.*

**Trial 1 Launch Time =** \_\_\_\_\_

**Trial 2 Launch Time =** \_\_\_\_\_

**Trial 3 Launch Time =** \_\_\_\_\_

**Improvement #2:** *Make one change to your rocket design. Describe the change below.*

**Test #2:** *Record the launch time for your rocket in the space provided below. Repeat the same amounts to obtain three sets of data.*

**Trial 1 Launch Time =** \_\_\_\_\_

**Trial 2 Launch Time =** \_\_\_\_\_

**Trial 3 Launch Time =** \_\_\_\_\_

**Design/Build:** *Use what you have learned to design your 10 second rocket. List the materials and amounts below and set up the rocket for the class competition.*

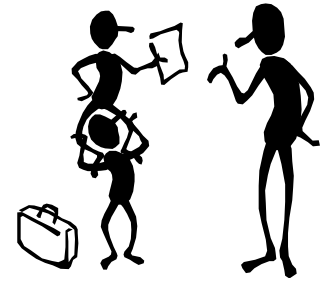
# Conclusion for Phase 3 Rocket Inquiry: Pop Rocket Design Challenge

Answer each of the following in complete sentences.

**CLAIM** – Record the exact time of your launch for the class competition.



**EVIDENCE** – Describe how you used the Engineering Design Cycle to solve this challenge.



**INTERPRETATION** –

How successful was your rocket design?

Discuss three potential sources of error that could have affected your final launch time.



Explain how the chemical reaction that you did in the film canister turned it into a rocket.

# Teacher Notes for Pop Rocket Inquiry Lesson

## Safety

All three phases of this inquiry lesson use relatively safe, readily available “kitchen chemicals” including Alka Seltzer (effervescent tablets), vinegar, and baking soda. Students must wear goggles correctly at all times during experimentation due to the risk of projectiles and chemical splashing. All reaction products can be rinsed down the drain. To minimize clean up issues, students should launch their rockets from a small bin (“launching pad”). This lab may also be done outdoors weather permitting.



## Materials

The only type of film canister that works well for these pop rockets is a translucent plastic with a cap that snaps inside the canister. The black canisters with the grey lids do not hold a seal well enough and tend to leak. I obtained a whole bag of free used film canisters from the photo-processing area at Target. You can also purchase these canisters from [www.teachersource.com](http://www.teachersource.com).



In phase 2 of the inquiry lesson, students are directed to make a “baking soda bomb” out of tissue paper. This is a simple procedure that gives them enough time to snap the lid on the container, give it a shake, and place it in the launch pad before it explodes. All that is needed for this is a small square of Kleenex-style tissue. The baking soda is placed in the middle of the tissue and the ends are then folded up and twisted to make a little packet that can be placed into the film canister. Make sure none of the tissue gets trapped in the lid or the canister will leak and not launch.



## Sample Experimental Data

The following graph shows experimental data collected for phase 2 of the inquiry. It represents the average data from three trials for each of the designated mass values. The equation of the line of best fit and the  $R^2$  value are shown. Generally, students produce a linear fit with an upper limit showing the limiting reactant. (the value above which baking soda is in excess).

