This segment allows students to investigate chemical reactions and consider a range of factors in order to predict reaction products, to develop particle drawings that represent the rearrangement of atoms during a reaction type, and to develop a strategy for balancing and classifying chemical equations.
Student Science Performance

Grade or course: 9-12 Chemistry	**Title:** Chemical Stoichiometry
Topic: Chemical Reaction Stoichiometry	

Performance Expectation for GSE:
SC3. Obtain, evaluate, and communicate information about how the Law of Conservation of Matter is used to determine chemical composition in compounds and chemical reactions.

c. Use mathematics and computational thinking to apply concepts of the mole and Avogadro's number to conceptualize and calculate
   - percent composition
   - empirical/molecular formulas
   - mass, moles, and molecules relationships
   - molar volumes of gases

d. Use mathematics and computational thinking to identify and solve different types of reaction stoichiometry problems (i.e., mass to moles, mass to mass, moles to moles, and percent yield) using significant figures.
   (Clarification statement: For elements c and d emphasis is on use of mole ratios to compare quantities of reactants or products and on assessing students' use of mathematical thinking and not on memorization and rote application of problem-solving techniques.)

e. Plan and carry out an investigation to demonstrate the conceptual principle of limiting reactants.

Performance Expectations for Instruction:
- Use mathematics and computational thinking to solve different types of reaction stoichiometry.
- Plan and carry out investigations to demonstrate limiting reactants.

Additional notes on student supports

Materials
Introductory Phenomenon Activity
Mars Lander Airbag Video
Airbag materials:
Sodium bicarbonate, vinegar, sandwich baggies, small plastic cup, duct tape, hard-boiled egg

Students will continuously obtain, evaluate, and communicate information. This is not a linear process. Students will communicate through writing and discussions to allow for formative assessment. This benefits the teacher, student, and whole group to guide instruction to clarify misconceptions or extend content.

Engaging Learners	**Phenomenon** Introductory Activity: Show students short video of Mars Rover airbag landing The link to close up image is: Mars Rover Airbag.
	Obtaining 1. Students perform the experiment in groups of 2-3. 2. Students groups explore the commercial use of airbags in the automotive industry. *3.* Student groups explore the chemistry behind the commercial airbag.
	Evaluating In groups, students will write a paragraph that summarizes their research.

	Teacher Notes: Their paragraph should include a balanced equation and should identify that the components of the reaction including reactant, products, and mole ratio in the balanced chemical equation.
	Communicating Students share their paragraphs with other groups. Students may revise their conclusions and explanations based on input from other groups.
Exploring	*Obtaining* 1. Teachers will provide students with the [Airbag Egg Drop Challenge activity sheet.] 2. Students will work in a group of two students through the activity. 3. Students will perform preliminary calculations for the chemical reaction using the questions in the activity sheet.
	Communicating ● Students will share their pre-lab calculations prior to beginning their design ● Each group should critically compare their calculations with other student calculations.
	Evaluating The teacher should evaluate students' ability to calculate molar conversions, molar volume calculations, and limiting reactants.
Explaining	*Obtaining* Groups of 2-3 students should utilize their research, pre-lab calculations, and prior knowledge of chemical stoichiometry to begin designing their airbag.
	Evaluating The commercial should include: ● Stoichiometric calculations of the volume of their airbag ● Cost of their airbag based on the materials used ● Effectiveness of their airbag based on the trial data
	Communicating The students produce an initial plan for their design including a diagram, list of supplies, and cost calculations
Elaborating	*Obtaining* Students will build and test their designs at least twice before a final test at the maximum height available. It is suggested that the test site be a large set of bleachers in a gym or stadium. *Teacher Notes: Protect bleacher and floor surfaces with trash bags or tarps.* As students build understanding of stoichiometry in the airbag challenge, an extension to connect to limiting reactants is the Limiting Reactant Lab.
	Evaluating ▪ Students will evaluate their airbag design ▪ Students will critically compare their design to the design of other students

	▪ Students will evaluate the effectiveness of their design as compared to other students
	Communicating Students will share their findings with other students via a commercial or poster of their design. Poster can be on paper or via slideshow. All student groups must include the following data in their commercial/poster: ● Final design diagram or picture of final design ● Final cost of design ● Data collected from trials including calculations of volume and moles ● Data about effectiveness of design ● Student thoughts on improving design
Evaluation	***Assessment of Student Learning***
	Formative Assessment ● Paragraph summarizing research and calculations. ● Calculations in pre-lab for stoichiometric quantities ● Data table for lab--monitored by teacher to ensure students are following procedure correctly. ● Post lab analysis for the limiting reactant lab. ● Student communication of research at each stage with teacher monitoring to correct any misconceptions as they arise or guide the students in a different direction. ● Summative Assessment ○ Analysis questions. ○ Poster or commercial of design
SEP, CCC, DCI	**Science Essentials**
Science and Engineering Practices	● Planning and carrying out investigations ● Using mathematics and computational thinking. ● Obtaining, evaluating and communicating information.
Crosscutting Concepts	● Patterns ● Scale, proportion, and quantity ● Systems and system models
Disciplinary Core Ideas	From A Framework for K-12 Science Education: ● PS1.A: Structure and Properties of Matter ● PS1.B: Chemical Reactions ● PS2.B: Types of Interactions

Additional Supports for struggling learners:

The following supports are suggestions for this lesson and are not the only options to support students in the classroom. These supports target students that struggle with science material, this lesson or a previous lesson. These are generalized supports and do not take the place of IEP accommodations as required by each student's Individualized Education Program.

General supports for the following categories:

Reading:	Writing:	Math:
1. Provide reading support by reading aloud or doing partner reads 2. Have the teacher model what they are thinking when reading the text 3. Annotate the text with students so that they may refer to it as they work through the lab	1. The teacher can provide a sentence starter for the students. 2. The teacher can give students an audience to write to (i.e. Write a letter to your sibling explaining this topic). 3. The teacher can provide constructive feedback during the writing process to help students understand the expectations.	1. Provide calculators as needed. 2. Provide graph paper as needed.

Supports for this specific lesson if needed:

Performance expectations for instruction:

1. The teacher should provide information to students in various formats to reach as many students as possible.
2. The students should be given adequate time to complete each part of the lesson.
3. The students should be allowed to express their knowledge in various formats.
4. The teacher should be sure to provide multiple ways for the students to communicate their knowledge of the material.

Engage:

1. The teacher should show the video and have students make observations.
2. The class can then discuss the observations that were made during the video.
3. The teacher should have clear and consistent guidelines for class discussions. This should make students feel more comfortable and be more likely to participate.
4. The teacher should use intentional and flexible grouping to assign student groups. Best practice is to use data to drive student grouping.
5. The teacher should consider giving sources for students to use when doing research.
6. The teacher should consider providing an organizer for students to record questions, research and begin thinking about a summary of their research.
7. The teacher should consider doing a gallery walk or other method of presentations so that students can get more information about airbags.
8. Students may need additional time to revise their conclusions and explanations.

Exploring:

1. The teacher should explain directions and review materials that the students may use in their design.
2. The teacher should consider providing an organizer to help students begin planning their air bag design.
3. The teacher should use flexible and intentional grouping to group students. Best practice is to use data to drive student grouping.
4. The teacher may need to provide calculators for any calculations that students may be performing.
5. The teacher should have students share their designs at some point during the design process and have students use that information to revise their design if they feel the need.
6. The teacher should consider a formative assessment and then re-teach, review or enrich as needed.
7. Students may need additional time to complete their assignments.

Explaining:

1. The teacher should use intentional and flexible grouping to group students. Best practice is to use data to group students.
2. The teacher should provide calculators as needed for calculations.
3. The teacher may need to explicitly show students how to do the calculations, have students practice in groups and then provide time for students to practice individually.
4. The teacher should consider giving students an organizer to record data, observations and the design of their airbag.
5. The teacher should consider giving students a template for the final product that they will need to evaluate.
6. The teacher should consider providing students with a rubric to evaluate their work. This will increase student ownership of the work.

Elaborating:

1. The teacher should give the students an organizer to record data and observations as the different airbags are tested.
2. The teacher should then remind students that the data and observations from the tests can be used as evidence for revising their own design later.
3. The teacher should use intentional and flexible grouping to group students. Best practice is to use data to group students.
4. Students may need additional time to revise their work.
5. The teacher should remind students to evaluate their final product based on the rubric that was provided earlier in the lesson.

Evaluating:

1. The teacher should consider providing multiple ways for students to communicate their knowledge of the material. These formats could include writing, drawing or designing a presentation.
2. Students may need additional time to complete their assignments.

Airbag Egg Drop Challenge

Challenge:

In groups of 3, you act as chemists and engineers as part of an air bag company to design an airbag that will protect a passenger (an egg) from a drop of 12 meters (top of the stadium). Your group will need to stoichiometrically calculate the best quantities needed for this reaction. Your company works on a limited budget for supplies. You will compete against other companies (your classmates) for the car company's bid.

Background Research:

Conduct research to determine how airbags save lives and to understand the chemistry of airbags.

Here is a slow motion video that shows a car crash with and without an airbag.

1) Write the reaction that occurs in airbags.

2) Classify this reaction.

3) Why is more than one reaction necessary for a safe airbag system?

4) How is stoichiometry important in designing airbags?

Pre-Lab Calculations:

Because of the toxicity of the compounds used in airbags, you will use another gas-producing reaction to construct your airbag - the reaction of $NaHCO_3$ with an aqueous solution of CH_3COOH.

$$CH_3COOH(aq) + NaHCO_3(aq) \rightarrow NaCH_3COO(Aq) + CO_2 (g) + H_2O(l)$$

This creates the harmless products of a salt solution in water along with the CO_2, which will inflate your air bag. It is very important, that as airbag designers, you use stoichiometry to ensure that your airbag does not overinflate or under inflate. Underinflated bags do not provide enough protection and over inflated bags can cause injuries.

5) Calculate the volume of your "airbag" – sealable plastic bag.

6) The gas law formula **PV = nRT** will help calculate the number of moles of CO_2 required to fill the volume of the airbag. P = Pressure (measured in atmospheres); V = volume (liters); T = temperature (Kelvin). During your experiment, we will record the temperature and pressure of the lab on that particular day. R = the universal gas constant is 0.0821 atm. L/mole.K. and n = moles.

7) Once the number of moles of CO_2 is calculated, then use your balanced equation and stoichiometry to calculate the grams of baking soda required for the reaction.

8) Once the moles of CO_2 is calculated, then use your balanced equation and stoichiometry to calculate the grams of acetic acid required for the reaction.

9) Turn grams of CH_3COOH into milliliters of CH_3COOH (assume the density of CH_3COOH is 1g/mL). We are using vinegar and not pure acetic acid. Vinegar only contains 5% acetic acid and you will need to multiply your moles of acetic acid by 20 to account for this.

Airbag Challenge and Materials:

Each group will use the following materials for three trials – this is enough for two prototypes and one final airbag. You have a budget of $2000 and your materials cost money. Your bag needs to expand to the largest possible value without breaking the seal on the bag.

Material	Maximum Quantity	Cost
Sodium bicarbonate	10 g	$5 per gram
Acetic acid	100 mL	$10 per 5 mL
Sealable sandwich baggies (airbag)	6 (one bag will enclose the egg for clean-up)	$100 each (can be reused for subsequent trials)
Small plastic cup (acts as car seat)	3	$200 each (can be reused)
Duct tape	10 cm	$5 per cm
Hard boiled Egg (passenger dummy)	1	$500 (can be reused)

In addition, a meter stick, and balance are provided at no charge. For your final drop from the stadium, a non-hard boiled egg is provided at no charge. **Caution:** CH_3COOH is corrosive so handle with caution. Goggles should be worn at all times and hands washed after handling acid.

Initial Design:

In your group brainstorm ideas for your airbag design. Sketch your initial design below. Label all the elements you plan to include:

Planned Budget Expense:

Develop a table listing the supplies you plan to use, their cost and the final cost of your airbag development.

*Planned total budget expense: $*____________________

Procedure:

Get goggles and then record in the table below, based on your calculations and experimentation, the amount of materials used for each trial. After you have constructed your airbag, your group needs to attach your passenger to the airbag with the plastic cup and tape. Begin testing at a small distance above the ground and keep testing at different drop heights. If your passenger does not survive (becomes cracked or broken), you will need to discontinue your tests and revise your design.

Data:

Trials	Mass $NaHCO_3$ (g)	Moles $NaHCO_3$	Volume CH_3COOH (mL)	Moles CH_3COOH
1				
2				
Final Drop				

Conclusion:

1. How effective was your airbag design? Did it protect your passenger? In your answer, compare to other airbags dropped by competing teams and compare the effectiveness of those designs with yours.

2. How would you improve your design if you had to start over?

Analysis Questions:

1. Airbags in many cars use the following reaction:

$$\mathbf{10NaN_3 + 2KNO_3 \rightarrow K_2O + 5Na_2O + 16\ N_2}$$

The driver's side airbags in a large SUV is approximately 63.2 L when fully inflated. Assuming the nitrogen gas (N_2) is at STP (it is not actually): *Show all calculations*

a. What mass of sodium azide is needed to inflate the airbag?

b. What mass of potassium nitrate in needed to inflate the airbag?

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Limiting Reactant Lab

Purpose

Design and carry out an investigation to determine the limiting reactant in a reaction between copper (II) chloride dihydrate and aluminum.

Safety

Wear goggles during this experiment. Avoid skin contact with copper (II) chloride dihydrate. Wash your hands before leaving the laboratory.

Prelab Questions:

1. Aluminum metal reacts with aqueous copper(II) chloride dihydrate ($CuCl_2 \cdot 2H_2O$) to form copper metal, aqueous aluminum chloride, and water. Write the balanced equation for this reaction.

2. Create a data table to contain the data you will collect in this activity. (This requires you to read through the lab procedure)

Materials:

- Copper(II) chloride dihydrate
- Aluminum foil
- 250-mL Erlenmeyer flask
- Balance
- Graduated cylinder
- Distilled water
- Filter paper

Procedure

1. Choose the following amounts of each reactant:

Mass of Al (g)	Mass of $CuCl_2 \cdot 2H_2O$ (g)
0.25g - 1.00g	0.5g-2.00g

2. Mass the copper(II) chloride dihydrate in a 250-mL Erlenmeyer flask and record the actual mass in your table.

3. Using a graduated cylinder, measure 100 mL of distilled water and add it to the flask containing the copper (II) chloride dihydrate. Stir until dissolved completely. Note the color of the solution.

4. Mass the appropriate mass of aluminum foil and record the actual mass of aluminum in your data table. Loosely crumple it up into a few small pieces and add it to the copper (II) chloride solution. Swirl the solution gently and then allow it to sit undisturbed for 5-10 minutes. Record observations in your table.

5. While allowing the reaction to proceed, answer the following questions. Show all work below. Note: when calculating the molar mass of the $CuCl_2 \cdot 2H_2O$, don't forget to add the mass of two moles of water!

Calculations:

Your group should brainstorm and determine how you will calculate the answers to the following:

- Which is your limiting reactant?
- What is your theoretical yield (in grams) of copper metal?
- What is your theoretical yield (in grams) of aluminum chloride?
- What mass of the excess reactant will remain when the limiting reactant is consumed?

6. If your solution is still blue at the end of the reaction, which was your limiting reactant?

7. If you can't see any blue in your flask at the end of the reaction, can you be certain about which reactant was the limiting? Why or why not?

8. Think carefully about your limiting and excess reactants and the products you have formed. Which of the two products will you be able to isolate and calculate a percent yield for? Consult with your teacher if you are not sure which product you should isolate.

Isolation Procedures:

Isolation of copper: Find the mass of a piece of filter paper. Filter the mixture through the filter paper (see your teacher if you need to be reminded of the correct set-up). Wash the copper well with distilled water to remove the dissolved aluminum chloride. Discard the filtrate (liquid) and let the copper in the filter paper dry overnight. Weigh the dry copper & filter paper.

Isolation of aluminum chloride: Find the mass of a clean, dry beaker. Separate the solids from the dissolved aluminum chloride through filtration, catching the filtrate in your clean, dry beaker. Wash the solids three times with 2.00 ml distilled water to get all the aluminum chloride into the beaker. Discard the solids. Then proceed to separate the water from the aluminum chloride using evaporation (set it in the drying oven overnight). Find the mass of the cool, dry aluminum chloride and beaker.

9. Isolate the correct product for your particular lab activity and calculate your percent yield. Show your calculation.

10. Does your percent yield seem reasonable? What are some possible sources of error?

11. Draw a particle diagram to represent your reaction in the space below.

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