Stoichiometry: Baking Soda and Vinegar Reactions
Teacher Version

In this lab, students will examine the chemical reaction between baking soda and vinegar, and mix different amounts of these household chemicals to learn about the concept of stoichiometry.

California Science Content Standards:

- **3. Conservation of Matter and Stoichiometry: The conservation of atoms in chemical reactions leads to the principles of conservation of matter and the ability to calculate the mass of products and reactants.**
- 3a. Students know how to describe chemical reactions by writing balanced equations.
- **4. Gases and Their Properties: The kinetic molecular theory describes the motion of atoms and molecules and explains the properties of gases.**
- 4c. Students know how to apply the gas laws to relations between the pressure, temperature, and volume of any amount of an ideal gas or any mixture of ideal gases.
- **4h. (advanced only) Students know how to solve problems by using the ideal gas law in the form of PV=nRT.

Prerequisites:

- Students should be able to do division and multiplication, or have access to a calculator.
- Previous exposure to chemical reactions would be beneficial, but is not required.

Key Concepts:

- **Stoichiometry** is the quantitative balancing of elements in chemical reactions.
- **Conservation of mass** requires that all atoms that enter a reaction as reactants must exit the reaction in the products.
- The **Ideal Gas Law** is used to model equilibrium conditions of most gases, relating the pressure, volume, temperature, and moles of gas.

Introductory Lecture:

Stoichiometry describes the *quantitative* relationship between reactants and/or products in a chemical reaction. In chemistry, reactions are frequently written as an equation, using chemical symbols. The reactants are on the left side of the equation, and the products are on the right.

The law of **Conservation of Mass** tells us that matter is neither created nor destroyed in a chemical reaction. Because of this, a proper chemical equation must be *balanced*; the number of atoms of an element on one side of the equation has to match the number of atoms of that element on the other side.

A **mole** is a unit of measurement just like a “dozen” eggs is 12 eggs. A mole, which was chosen because it is the number of atoms in 12 grams of carbon, is known as Avogadro’s

Number: 6.02×10^{23}. The number of grams in a mole differs from substance to substance – just like a dozen eggs has a different weight than a dozen elephants, a mole of oxygen has a different weight than a mole of hydrogen – even though in each case, there are 6.02×10^{23} atoms.

Using the concept of stoichiometry, the amount of product that results from a chemical reaction can be predicted.

Baking soda is a powdered chemical compound called sodium bicarbonate, and vinegar includes acetic acid. These 2 components react in solution to form carbon dioxide, water, and sodium acetate as shown in the chemical reaction below:

$$\mathbf{NaHCO_3\ (aq) + CH_3COOH\ (aq) \text{ ----> } CO_2\ (g) + H_2O\ (l) + CH_3COONa\ (aq)}$$

Stoichiometry can be used to predict the amount of carbon dioxide released in this process. Conservation of mass requires that all atoms that enter a reaction as reactants must exit the reaction in the products. Consider the example of decomposing water into Hydrogen and Oxygen gas:

$$\mathbf{2H_2O\ (l) \text{ ----> } 2H_2\ (g) + O_2\ (g)}$$

The coefficients in this equation indicate that exactly 2 water molecules are needed to form 2 hydrogen molecules and one oxygen molecules. One can see the necessity of these coefficients by considering their omission:

$$\mathbf{H_2O\ (l) \text{ ----> } H_2\ (g) + O_2\ (g)}$$

In this case, there is only one oxygen atom on the reactant side, with two oxygen atoms in the products. This would violate conservation of mass, as it requires the formation of oxygen out of nowhere, so it is necessary to include a coefficient of 2 on the left side to balance all the oxygen in the equation. Once that is added, though, it is then necessary to incorporate a coefficient of 2 to the hydrogen molecules to balance the hydrogen similarly.

By mixing different amounts of baking soda and vinegar, we should be able to generate different quantities of carbon dioxide in a predictable manner, as this lab demonstrates through the reactivity of two household cooking items, baking soda and vinegar.

Materials:

- 1 clear jar (You will need to use a measuring cup to label volume measurements along the side of the jar.)
- Measuring cup
- Measuring spoons (only ¼ tsp and ½ tsp are necessary)
- Small plastic sandwich bag
- 1 large bucket/tub (14.5” length x 12.2” width x 9” depth is an absolute MINIMUM size – use a considerably larger one if possible)
- 1 empty 20 oz. Gatorade bottle
- 2 cups of vinegar
- ¾ tsp baking soda
- Water source

Pre-Laboratory Instructions:

1. Take the tub/ bucket and fill it with water, leaving well over a liter of space (see picture above).
2. If your jar does not have volume measurements marked along its outside, add them yourself. This can be done with the aid of a measuring cup, pouring in 100 mL quantities, one at a time, and recording the height of the water after each quantity.
3. Fill the jar entirely with water, close it, and set it aside for part 2.

Introduction:

This lab demonstrates the reactivity of two household cooking items, baking soda and vinegar. Baking soda is a powdered chemical compound called sodium bicarbonate, and vinegar includes acetic acid. These 2 components react in solution to form carbon dioxide, water, and sodium acetate as shown in the chemical reaction below:

(baking soda) + (vinegar) → (carbon dioxide) + (water) + (sodium acetate)

$$\mathbf{NaHCO_3\,(aq) + CH_3COOH\,(aq) \rightarrow CO_2\,(g) + H_2O\,(l) + CH_3COONa\,(aq)}$$

Looking closely at this equation, examine whether it is balanced or not.

How many Hydrogen atoms are in the reactants?___5______ In the products?___5______

How many Oxygen atoms are in the reactants?______ 5______ In the products?___ 5______

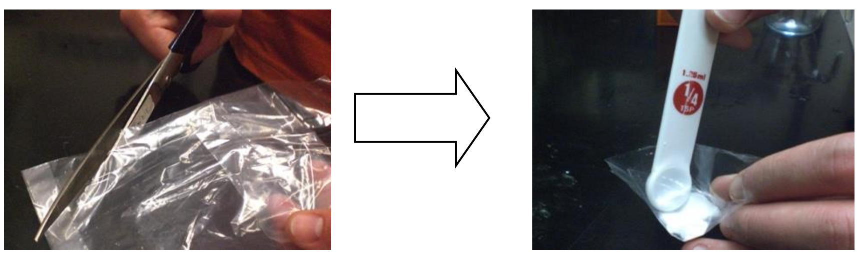
How many Carbon atoms are in the reactants?_____ 3______ In the products?____ 3____

How many Sodium atoms are in the reactants?______ 1______ In the products?___ 1______

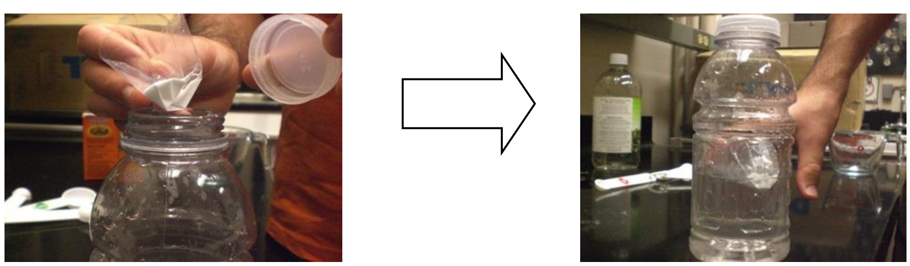
Is this reaction in Equation 1 stoichiometrically balanced?_______ yes________

Part 1

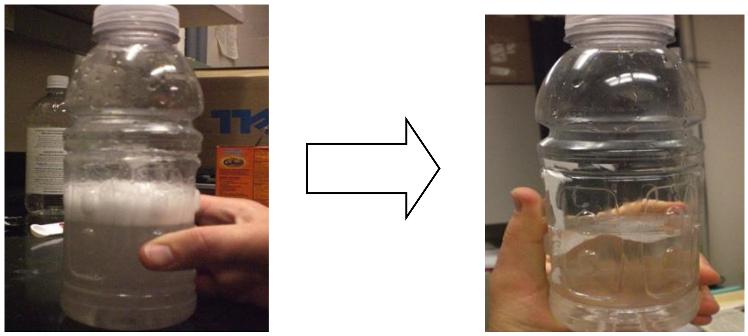
1. Fill the soda bottle with 1 cup of vinegar.
2. Cut a small corner from the clear bag and add ¼ tsp of baking soda into the bag fragment as shown below:



3. Carefully, drop the small bag into the soda bottle with the corner of the bag pointed downwards and quickly close the bottle. The goal is to twist the cap so it is airtight before the baking soda reacts comes into contact with the vinegar.



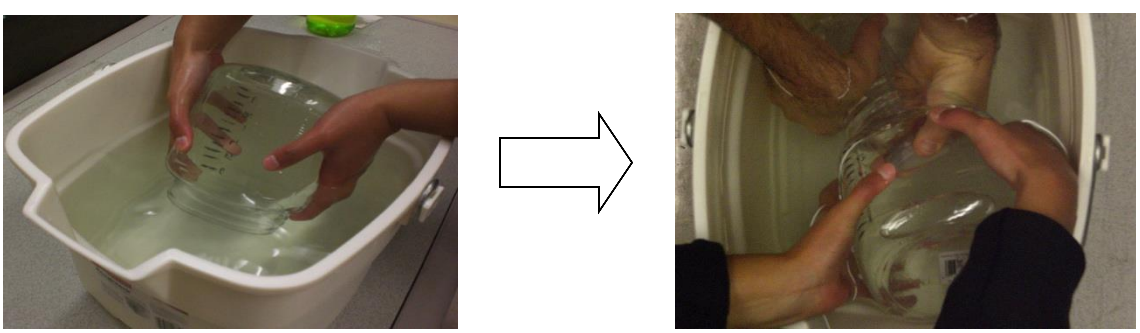
4. Shake the bottle gently until all the baking soda has reacted with the vinegar. Allow the solution to fizz up then gradually settle. Wait until the baking soda has dissolved completely into the vinegar, indicated by no significant bubbling in the bottle. Keep the bottle sealed for Part 2. (Note: The bottle should be stiffening to a squeeze as the reaction proceeds).



Part 2

1. Submerge the closed jar in the water tub with the lid facing downward.
2. Remove the lid while maintaining the jar below water. By maintaining the opening of the jar under water at all times, all of the water will remain inside the jar

3. As your partner holds the jar, place the 20 oz. bottle from part 1 underwater and then slide the top of it inside the opening of the jar. Slowly unscrew the cap to release all of the carbon dioxide into the jar. Note: The water level inside the jar should be slowly decreasing as the gas inside the bottle is released. Be very careful to catch all the carbon dioxide in the jar.



4. Record the amount of trapped air inside the jar. Make sure the water inside and outside the bottle is at the same level before you record.

5. ** To establish a control, repeat the experiment exactly as above but without adding any baking soda to the soda bottle. This will allow you to measure the volume of air in the soda bottle. The volume of gas produced by the baking soda-vinegar reaction is equal to the volume of gas measured with the reaction minus the volume of gas measured without the reaction.

6. Repeat steps 3-10 with ½ tsp of baking soda. Record your results in the table below:

Amount/ tsp	Volume/mL
¼	(Student result)
½	(Student result)

Concept Questions:

Stoichiometry

Determine whether the amount of reaction products you observed agrees with stoichiometric predictions. One underlying assumption is that the baking soda is the only limiting reactant. In other words, there is essentially an unlimited supply of acetic acid in the vinegar bottle, and the reaction output is only dictated by the amount of baking soda you add – every mole added results in a mole of carbon dioxide produced.

Use the following steps to calculate the number of moles of carbon dioxide produced:

Q1. Determine the density of baking soda.

a. *Net weight of the baking soda container (labeled on box): ___454 (e.g.)___g*

b. *Volume in the container (from Nutrition Facts: serving size x number of servings):* ______ *101 (e.g.)*_______ *tsp*

c. *Density = Net weight/volume = ___________4.50__________ g/tsp*

Q2. Mass in ¼ tsp baking soda = ________1.12________ g

Q3. Molecular weight of Sodium Bicarbonate ($NaHCO_3$, get from periodic table) =

Na= __22.99__ H= __1.01__ C= __12.01__ O=__16.0__ ; $NaHCO_3$ = __84.0__ g/mol

Q4. Moles in ¼ tsp baking soda = _________0.0134________ moles $NaHCO_3$

Q4. Moles in ¼ tsp baking soda:

$$\frac{\text{grams of } NaHCO_3 \text{ used}}{\text{molecular weight of } NaHCO_3} = \frac{\_\_\_\_\_\_\_\_\_\_\_\_\_\ \text{g}}{\_\_\_\_\_\_\_\_\_\_\_\_\_\ \text{g/mol}} = \_\_0.0134\_\ \text{moles } NaHCO_3$$

Q5. How many moles of CO_2 do you expect from ¼ tsp $NaHCO_3$? ____0.0134______moles CO_2

Q6. How many moles of CO_2 do you expect from ½ tsp $NaHCO_3$? ___0.0268______ moles CO_2

Gaseous Volume Prediction

The Ideal Gas Law is an equation that roughly models equilibrium properties of most gases:

(pressure) x (volume) = (moles) x (Ideal Gas Constant) x (temperature)

or $pV = nRT$, where R, the Ideal Gas Constant, = 0.0821 L-atm/mol-K

Essentially, this law states that increasing the amount of moles of gas in a system can increase the system's volume and pressure.

Q7. Rearrange the ideal gas law to give an expression for the number of moles of a gas with known temperature, pressure and volume (solve for moles):

Moles = (Pressure x Volume)/(R x Temperature) or; n=pV/RT

Q8. The pressure of the gas when measuring its volume as described in the lab is approximately 1 atm, and the temperature is approximately 300 K. Using the volume of gas you measured in the lab, how many moles of CO_2 did you observe as reaction products:

from ¼ tsp baking soda? _____(Student result)_____

from ½ tsp baking soda?_____ (Student result)______

Q9. Did your stoichiometric predictions agree with the experimental observations?

(Student result)

Q10. Why was it necessary to add the baking soda to the vinegar inside a plastic pouch?

Dropping the baking soda into the vinegar in a plastic pouch prevents the reaction from occurring immediately once the baking soda is added. The plastic acts as a temporary barrier to mixing the two components, giving the experimentalist time to close and seal the bottle.

Q11. Why is it important to have a tight "seal" of the cap on top of the bottle when mixing the two reaction components?

This is necessary to prevent any gaseous reaction products from escaping. If gas was to leak out during the reaction, not all of the products would be observed in the next step, and the resulting moles of products would be measured as less than the expected amount.

QSA12. Why can we not use the volume of the air inside the Gatorade bottle, applied to the ideal gas law, to calculate the moles of carbon dioxide products. (Hint: Which variable in the ideal gas law differs between the conditions in the Gatorade bottle and the conditions in the jar?)

We do not know the pressure inside the Gatorade bottle. The pressure is expected to be higher than 1 atm, because gas is allowed to build up without an increase in the volume. The only way we can know the pressure is to put the system in contact with the atmosphere, as is done using the submerged glass jar.

QSA13. What are the main sources of error that might cause a discrepancy between predictions and observations in this lab, and how could you improve them?

A number of things can lead to experimental error in this lab. For instance, there is always a chance that air leaks out of the bottle during the reaction if the seal is not tight enough. Also, one needs to be careful to trap all of the gas from the plastic bottle in the large glass jar. Also, baking soda tends to deactivate by contact with air over time (which is why you're supposed to keep it in the fridge), so if it's been open for a while, it will be less than optimally reactive.