The Chemical Reaction Powered Car

Levels:
Grades 4-5

Content Areas:
Chemistry; Engineering

Lesson Time:
Chemical Reaction: 40 minutes
Designing a Car: 60 minutes

Next Generation Science Standards:
5-PS1-3; 5-PS1-4; 4-PS3-4;
3-5-ETS1-2; 3-5-ETS1-3

Objectives & Outcomes:
- Students will explore the concept of stoichiometry and limiting reagents in a chemical reaction.
- Students will engage in the engienering design and testing process.
- Students will design a car that is powered solely by a chemical reaction.

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Description:
In this lesson, students will learn about chemical reactions and design a car powered by chemical reactions. Students will first explore the effect of different ratios of chemical reactants on the chemical reaction of baking soda and vinegar. Then, students will use the engineering design process to build, test, and re-design a car powered only by this chemical reaction to achievea performance target.

Using This Lesson:
The activities in this lesson are done in small groups. It has two parts: a shorter, chemical reaction activity and a longer car engineering activity.

The background information can be used as reading material for students. Vocabulary words are highlighted in the text and defined. Additionally, leading questions are included to promote discussion and critical thinking.

Introduction to Chemical Reactions:
All things around us are made of tiny particles called **molecules**. Molecules are made of **atoms**. When the atoms in some molecules rearrange, a chemical reaction has occurred. The chemicals before a chemical reaction are called **reactants** and the chemicals after a chemical reaction are called **products**. The ratio of reactants to products is called **stoichiometry**. Chemical reactions occur all around us and within us to keep us alive. Several types of reactions exist.

Combination reactions result when two or more smaller molecules are combined into a larger molecule. Table salt or sodium chloride is made from the combination of sodium and chloride as shown:

$$Na + Cl \rightarrow NaCl$$

Decomposition reactions result when one large molecule is broken down into two or more smaller molecules. Water can be broken into hydrogen and oxygen in a decomposition reaction when electricity is applied. This is represented by:

$$2H_2O \rightarrow H_2 + O_2$$

Single Replacement reactions result when one element replaces another element in a molecule. A single replacement reaction occurs when iron rusts in the presentce of water:

$Fe^{2+} + 2H_2O \rightarrow Fe(OH)_2 + 2H^+$

Double Replacement reactions result when each molcule exchanges an element with another molecule. Double replacement occurs when baking soda reacts with acidic substances:

$NaHCO_3 + H(acid) \rightarrow Na(acid) + H(HCO_3)$

We keep track of molecules in a reaction using a unit called a **mole**.A mole is a unit like a dozen: a dozen is 12 things and a mole is 602,200,000,000,000,000,000,000 things. A mole of donut holes would cover the earth and be 5 miles deep. But a mole of molecules can be a reasonable amount. One mole of water is 18 mL. Moles are used in chemistry because it allows comparisons to be made regardless of the phase or measurement units of a chemical. The number in front of a chemical represents the number of moles of that chemical in the reaction. So, 2 moles of water (H_2O) participate in the example single replacement reaction and 1 mole of iron (Fe^{2+}) is needed. The **molar ratio** is the ratio of moles of one chemical to moles of another chemical, like the ratio of chocolate donut holes to powdered sugar donut holes. The molar ratio of potassium water (H_2O) to iron (Fe^{2+}) in the example single replacement reaction is 2.

Propelling a Car with Chemical Reactions:

This is the well-known chemical reaction of baking soda and vinegar.

Reaction of Baking Soda & Vinegar:

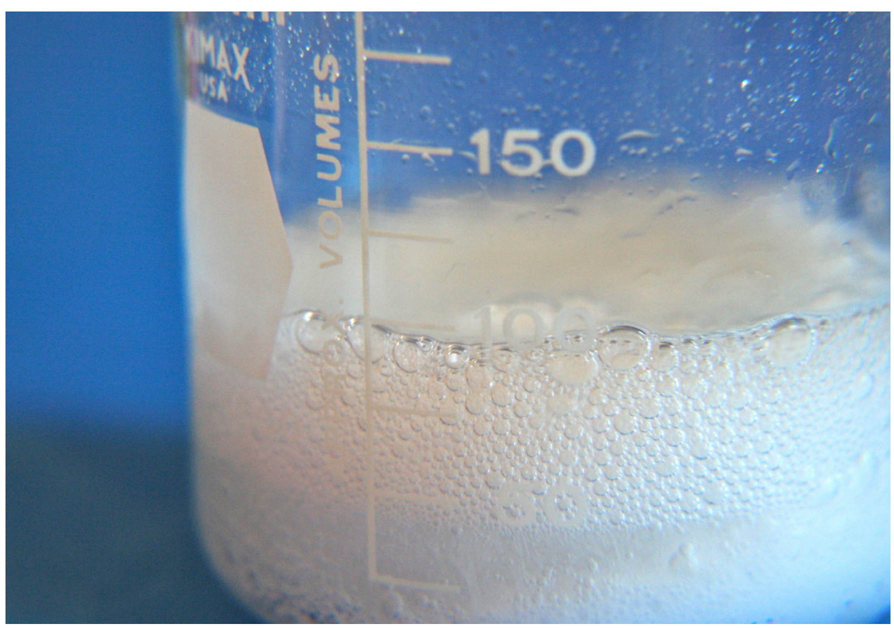
$$[CH_3COOH + H_2O] + NaHCO_3 \rightarrow H_2O + CO_2 + NaCO_3COO$$

Vinegar: $[CH_3COOH + H_2O]$; Baking Soda: $NaHCO_3$; Water: H_2O; Carbon Dioxide: CO_2; Sodium Acetate: $NaCO_3COO$

Mixing baking soda and vinegar producesan exciting foam as carbon dioxide is released. This is a double replacement reaction as hydrogen (H) is transferred to sodium bicarbonate (baking soda) from acetic acid (vinegar) while sodium (Na) is transferred to acetic acid from sodium bicarbonate. As noted, the reaction requires one mole of acetic acid and one mole of baking soda to produce one mole of carbon dioxide gas. For a complete reaction, the molar ratio of acetic acid to sodium bicarbonate must be 1. Baking soda is 100% sodium bicarbonate, but vinegar is only 5% (by volume) acetic acid (the rest is water). If the ratio is not 1, some acetic acid or sodium bicarbonate will be left unreacted, depending on which one there was more of.

The goal in this experiment will be to use a chemical reaction to convert chemical energy to kinetic energy. Once students understand the chemistry, they will attempt different chemical ratios to produce enough carbon dioxide gas to propel their cars:

a) as far as they can,
b) 15 feet exactly, or
c) in a straight line.



The Chemical Reaction Powered Car

Set Up:

To make it easier to manage multiple student groups, create stations where students can get their supplies for conducting the chemical reaction, building their car and testing their car. Drill holes in water bottles before activity. Smaller holes lead to slower cars that run longer and larger holes lead to faster cars with short runs.

Directions:

Part 1: Chemical Reaction Stoichiometry

1. Each group should have an empty water bottle, a balloon, some petroleum jelly and a stopwatch.
2. Add 50 mL vinegar to the water bottle. Mass ~1g of baking soda on a tissue, fold it into a packet, and drop the packet into the water bottle. Quickly cover the bottle opening with a balloon. Rub petroleum jelly around the bottom of the balloon to create a seal. Students may gently shake the bottle to promote mixing.
3. Students should start timing the reaction when bubbles first appear and stop when they disappear. Measure the circumference of the balloon by wrapping a string around the balloon then measuring the length of the string with a ruler.
4. Record the amount of baking soda and vinegar added, time for reaction and balloon circumference.
5. Repeat this procedure for different ratios of baking soda and vinegar.
6. Ask students which ratio of baking soda to vinegar produced the most gas. Students may decide to use that ratio in part 2.

Part 2: Designing a Chemical Reaction Powered Car

1. Design and build a simple car with a water bottle as the "reaction chamber" and to run your reaction to see if you can propel the car forward. Potential materials include popsicle sticks, straws, wooden dowels, rubber bands and hot glue.
2. To build wheels that turn, secure the zombie straws to the car body. Thread the wooden dowel or metal wire through the straw and secure the wheels to dowel or wire.
3. Optimize the car for one of the following goals:
    a. Furthest distance
    b. As close to 15 ft as possible
    c. Travel in a straight line
4. Test the car outside. Add equal parts vinegar and water to the bottle. Create a packet of baking soda using the single ply toilet paper. Drop the baking soda into the bottle, cover the hole with your finger and shake the bottle. Set the car down and release when you feel enough pressure build up.

Part 3: Design Improvements

1. After designing and testing the car, evaluate the results and brainstorm potential design changes to improve car performance. If time permits, modify the car and test it again. Advanced students may redesign their car to meet a different goal or 2 goals at once.

Materials: (per group)

- 5% acetic acid vinegar
- Baking soda
- Water bottles with hole drilled in cap
- 50 mL graduated cylinder (plastic)
- Stopwatch
- Water
- Balloon (medium to large)
- Petroleum Jelly
- String
- Ruler
- Single ply toilet paper
- Popsicle sticks
- 1/4" wooden dowels or metal hanger segments
- Wheels - plastic or wooden rounds
- Duct & masking tape
- Hot glue & hot glue gun
- Zombie straws (large straws)
- Other materials students may use to design a car

Experiment Questions:

Below are basic and advanced level questions and activity enhancements.

BASIC LEVEL

1. What ratio of baking soda to vinegar produced the most gas?
2. At what mass of baking soda did the reaction no longer progress? (if vinegar was held constant)
3. How/when did you potentially lose gas from the balloon and from the car?
4. How close did you come to meeting your goal?
5. What factors did you consider when designing yor car?
6. What improvements to the design would you like to make next? Why?

ADVANCED LEVEL

1. Why are chemical reactions important?
2. How could you improve the experimental design to more accurately measure gas produced by the reaction of baking sode and vinegar?
3. How many moles of sodium bicarbonate and how many moles of vinegar did you react in your most successful combination?
    - To calculate moles of sodium bicarbonate, divide grams of baking soda by the molar mass of sodium bicarbonate (84 g/mol).
    - To calculate moles of acetic acid, multiply the volume of vinegar by 5% to find the volume of acetic acid. Convert the volume of acetic acid to mass by multiplying by the density (1.05 g/mL). Divide the mass of acetic acid by the molecular weight of acetic acid (60 g/mol).

Next Generation Science Standards

DISCIPLINARY CORE IDEAS:

PS1.A: Structure and Properties of Matter

ETS1.B: Developing Possible Solutions

PERFORMANCE EXPECTATIONS:

5-PS1-3: Make observations and measurements to identify materials based on their properties.

5-PS1-4: Conduct an investigation to determine whether the mixing of two or more substances results in new substances.

4-PS3-4: Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.

3-5-ETS1-2: Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

3-5-ETS1-3: Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

PRACTICES:

1. Asking questions and defining problems
3. Planning and carrying out investigations.
6. Constructing explanations and design solutions.

CROSSCUTTING CONCEPTS

3. Scale, proportion, and quantity
5. Energy and matter: flows, cycles, and conservation
6. Structure and function

Resources:

Kitchen Chemistry: The Chemical Reaction Powered Car, Rochefort, Momsen & Hower (March 2004). College of Engineering, Oregon State University. Retrieved from http://engineering.oregonstate.edu/momentum/k12/march04/index.html

Bubble Bomb (1997). Exploratorium Science Explorer. Retrieved from http://www.exploratorium.edu/science_explorer/bubblebomb.html

Why Does Baking Soda and Vinegar React to Each Other? (2015) Science Line, University of California Santa Barbara. Retrieved from http://scienceline.ucsb.edu/getkey.php?key=4147

Additional Resources:

- *Wikibooks Chemistry*. Retrieved from https://en.wikibooks.org/wiki/General_Chemistry/Types_of_chemical_reactions#Single_Replacement_Reactions
- *ChemTutor*. Retrieved from http://www.chemtutor.com/react.htm#what