Teacher Guide: What the Fizz?!

STATE OF MICHIGAN CONTENT STANDARDS:
- C4.6a: Calculate the number of moles of any compound or element given the mass of the substance.
- C5.2d: Calculate the mass of a particular compound formed from the masses of starting materials.
- C5.2A: Balance simple chemical equations applying the conservation of matter.
- C5.7B: Predict products of an acid-base neutralization.
- C5.7C: Describe tests that can be used to distinguish and acid from a base.
- C1.1D: Identify patterns in data and relate them to theoretical models.
- C1.1E: Describe a reason for a given conclusion using evidence from an investigation.
- C1.1f: Predict what would happen if the variables, methods, or timing of an investigation were changed.
- Extension: C5.2e: Identify the limiting reagent when given the masses of more than one reactant.
- Extension: C5.2f: Predict the volumes of product gases using initial volumes of gases at the same temperature and pressure.

NSES
Level 9-12 Physical Science Standard: Understanding Chemical Reactions

TYPE OF INQUIRY
Guided

TIME
Prep time: 30 minutes
Pre-lab: 15 minutes
Lab time: Two 45-minute class periods or one 75-minute class period
Clean up time: 10 minutes
Post lab: 20 minutes

EDUCATIONAL OBJECTIVES
The learner will be able to:
- Calculate the correct molar ratios of substances in a chemical reaction.
- The learner will calculate the mass of a particular compound formed from the masses of starting materials.
- The learner will apply principles of stoichiometry to food science.
- The learner will identify patterns in data and relate data to theoretical models.
• The learner will describe a reason for a given conclusion using evidence from an investigation.
• The learner will describe the difference between mass (grams) and moles.

CONCEPTS ADDRESSED
• Stoichiometry
• Acid/base neutralization and properties

MISCONCEPTIONS
• Students unable to use ratio and proportional reasoning needed for molar problems.
• Students fail to apply reacting mass reasoning and assume all inputs.
• Students are confused about whether to treat a mole as a number or a quantity of matter.
From Fach, M., de Boer, T., and Parchmann, I. (2007):
• Students equate the mass ratio of atoms in a molecule with the ratio of the number of these atoms, and the mass ratio with the molar mass ratio.
• Students calculate the molar mass of a given substance by summing up the atomic masses and then multiplying or dividing this sum by the coefficient of the substance in the chemical equation; others do not understand the significance of the coefficients in a chemical equation.
• Students confuse the concepts of conservation of atoms or do not take into account the conservation of atoms or mass at all.

These misconceptions will be addressed in this activity by allowing students to develop the knowledge based on their observations and needs. Students will observe how using grams as a unit is not equally proportional to using particles or moles, so they will need to resolve this discrepancy.

PREREQUISITE KNOWLEDGE
Students must:
• know how to calculate molar mass and the proper units.
• be familiar with using molar mass as a conversion factor between grams and moles.
• be able to balance equations.
• be able to identify the occurrence of a chemical reaction using laboratory evidence.
Students should:
• know simple acid and base properties.
• be familiar with the concept of acid/base neutralization. This can be deleted from lab if desired.
TEACHER BACKGROUND

- This lab mimics a candy from the 1950’s and 60’s called Fizzies Drink Tablets, a candy that when placed in water created a fruity, fizzy product. Read about it at this website: http://www.oldtimecandy.com/fizzies.htm.

- While grams and other units of mass or volume are used most typically in food science, the chemistry behind the recipes relies on proper mole ratios. In this experiment, citric acid reacts with baking soda to produce sodium citrate, water, and carbon dioxide, according to the following reaction:

\[ \text{H}_3\text{C}_6\text{H}_5\text{O}_7 + 3\text{NaHCO}_3 \rightarrow \text{Na}_3\text{C}_6\text{H}_5\text{O}_7 + 3\text{H}_2\text{O} + 3\text{CO}_2 \]

- The citric acid in this reaction is an acid and tastes sour. Acids also release \( \text{H}^+ \) in solution, have a pH less than 7, turn litmus paper red, and react with metals. It is reacting with baking soda, a base. Bases taste bitter, release \( \text{OH}^- \) in solution, have a pH greater than 7, turn litmus paper blue, and are slippery. When acids and bases react, they can neutralize each other because the \( \text{H}^+ \) of the acid and the \( \text{OH}^- \) of the base to form \( \text{H}_2\text{O} \). Neutralization often creates water, a salt, and depending on the reaction, carbon dioxide.

- When balanced properly, the reaction reveals the ratio at which the citric acid and baking soda will react completely. The reaction releases carbon dioxide as a gas to make the beverage “fizzy.” If the acid and base are not mixed in the correct ratio, one of them will be in excess—excess acid creates a sour taste, and excess base creates a bitter taste and oily/slippery feel.

SAFETY

- The quality of the materials for this lab is of the utmost concern. Supplies must be stored in a “kitchen-like” atmosphere and NEVER in a typical chemical storage. No substances from a laboratory should be consumed under any circumstances.

- This activity should not be performed in a chemical laboratory; make sure balances are cleaned before use.

- Proper care must be taken to shield students from any possible dangers of contamination:
  - Do not use laboratory tools to perform the activity
  - Clean all surfaces prior to beginning activity
  - Use a protective barrier such as wax paper, butcher paper, or other suitable work surface to perform activity
  - Perform the activity in a non-laboratory environment if possible to avoid any potential contamination

- All substances used in this activity may be disposed of down the drain.

MATERIALS, PREPARATION, AND DISPOSAL

- Wax paper/butcher paper
- Paper muffin cups (could also use mini cups)
- Food beakers or large plastic cups (pre-measure to find out where 200-250 mL falls on the cups used)
- Spoons and/or stir sticks
• 5 oz. mini cups
• Citric acid, \( \text{H}_3\text{C}_6\text{H}_5\text{O}_7 \): Use a food grade source. Citric acid can be purchased from health food stores, or True Lemon crystallized lemon is a functional substitute available in grocery stores, although you may want to use Lemonade Kool-aid with the True Lemon so the taste is consistent. About 4 packets of True Lemon is 3 grams of “citric acid”, ignoring the mass of any other substance present. Students may need about 8 packets per group to complete the activity.
• Baking soda, \( \text{NaHCO}_3 \)
• Sugar or sugar substitute: If using aspartame sweetener, change amount to approximately 3 g
• Kool-aid – preferably only one flavor; cherry seems to yield best results (teachers guide follows cherry)
• Consumable water source; do not assume lab sinks are safe
• Mass balance
• Wipes handy for Kool-aid splashes

All surfaces need to be cleaned before performing this experiment. The wax paper or butcher paper is used to cover the work surface, as well as the surface of the balances used for this activity as an extra measure of safety. Masking tape may be helpful to hold paper in place.

A group of 2 students will need one large cup, two mini-cups, two spoons, and two muffin cups. Use one spoon for dry ingredients and the other for stirring. Use the muffin cups as a weigh boats for the ingredients. For scooping Kool-aid, I recommend the Portage Northern Kool-aid Scoop, made with a plastic pipet and scissors by cutting off the top half of a pipette bulb, shown below:

These make it easier to scoop out of the narrow Kool-aid envelopes effectively and to measure the small amounts necessary for the experiment.

The lab runs most smoothly when two groups can share a set of ingredients and a balance, but depending on facilities more groups per balance may be necessary.

To prepare, divide up portions of the sugar, citric acid, and baking soda in food safe containers such as labeled mini cups or color-coded muffin cups. One packet of Kool-aid per station would be the easiest, so that it does not need to be emptied out of the package and become a mess.

Have some clean-up wipes readily available as any substances spilled will probably leave a sticky mess or stain surface not covered by paper.
PRELAB ENGAGEMENT

- Discuss the pre-lab activities about the Fizzy Drink tablets and the potential to recreate this in the laboratory.
  - What were Fizzy Drink tablets?
  - What chemistry do you think could be involved in the candy?
- Discuss with students the safety rules being broken by this experiment and why it is acceptable this time.

PROCEDURE 1 – Try this!

1. Measure out 0.45 g of drink mix and 12 g of sugar into the container.
2. Add about 200 – 250 mL cold water and stir to dissolve, this is the “starter solution”.
3. Have a taste-test (using mini cups) and adjust sweetener if necessary. It should taste just like Kool-aid. Taste a very small amount (less than 10%).
4. Now, let’s see what happens when we add the first ingredient, citric acid. Add approximately 3 grams to the container, dissolve, and taste-test. Here, you may consume as much as you like.

DATA AND OBSERVATIONS for Procedure 1

5. Describe how your solution looks and tastes:
   Solution is red (for cherry), transparent, and tastes sour.
6. This solution contained an excess of citric acid. What are some characteristics of acids?
   Acids taste sour, have a pH less than 7, and release H⁺ in solution.
7. Dispose of the rest of your solution down the drain and rinse out your containers.

PROCEDURE 2 – Dare you to!

8. Try another: Remake the starter solution.
9. Add approximately 3 grams of baking soda. Dissolve it and taste-test as much as you’d like.

DATA AND OBSERVATIONS for Procedure 2

10. Describe how your solution looks and tastes.
    Solution may be cloudy or clear, red, tastes bitter, oily/slippery. Students may not recognize weak bitter flavor of the baking soda.
11. This solution contained an excess of baking soda, which is a base. What are some characteristics of bases?
    Bases taste bitter, have a pH of greater than 7, and release OH⁻ in solution.
12. What do you think happens when acids and bases react with each other?
    They will neutralize each other to form salt and water. Students may report this as canceling each other out.
13. Dispose of the rest of your solution down the drain and rinse out your containers.
PROCEDURE 3
14. Make another starter solution.
15. This time both the acid and base will be used. Choose one of the following recipes below to see if you can make a tasty beverage. Circle the one you will prepare:

1 gram citric acid + 1 gram baking soda (1:1) 1.5 grams citric acid + 0.5 grams baking soda (3:1)
0.5 grams citric acid + 1.5 grams baking soda (1:3) 1 gram citric acid + 0.5 grams baking soda (2:1)

These ratios are all by mass – make sure that approximately equal groups of students make each ratio so they can collect data from all combinations. Assigning students to one may be helpful.

DATA AND OBSERVATIONS 3
16. Now make your solution based on your chosen recipe. Record what you observe when the two solids are added to the solution.
The two components should cause the formation of a gas and release bubbles or “fizz” when added. This is caused by the acid/base neutralization, much like baking soda and vinegar. The True Lemon substitute will yield less fizz than the citric acid.

17. What do you think is happening in the solution to cause this?
The acid and base are reacting and a gas is produced (carbon dioxide).
18. Describe how your solution looks and tastes. Taste-test only a small amount; you will need to share with other groups. Do you taste one of the ingredients more than the others?
Solution may be clear or cloudy due to amount of fizz. One ingredient should be in excess in each case, making it taste bitter or sour.
19. Find at least 1 group that made a different recipe than yours and perform a taste-test (try to find each combination). Make a table showing the combination and how the solutions look and taste:

<table>
<thead>
<tr>
<th>Solution (acid:base)</th>
<th>Look</th>
<th>Taste</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:1</td>
<td>Red, clear, fizzing</td>
<td>Slippery, oily, soapy, bitter</td>
</tr>
<tr>
<td>3:1</td>
<td>Red, clear, fizzing</td>
<td>Sour, biting</td>
</tr>
<tr>
<td>1:3</td>
<td>Red, may be cloudy, fizzing</td>
<td>Slippery, oily, soapy, bitter</td>
</tr>
<tr>
<td>2:1</td>
<td>Red, clear, fizzing</td>
<td>Sour</td>
</tr>
</tbody>
</table>

20. Use your observations and describe why none of the combinations tasted like perfect Kool-aid.
In each solution there was either too much acid or too much base; one component was always in excess; some of the citric acid or baking soda did not react.
21. Predict what should be added to each of the combinations to make it taste better. Explain your choices.
1:1 needs more citric acid to react with the extra baking soda, same with 1:3
3:1 needs more baking soda to react with the extra acid, same with 2:1
22. Dispose of the rest of your solution down the drain and rinse out your containers.
PROCEDURE 4
Sometimes recipes help when making foods. For example, to properly make a gravy, the fat-to-flour ratio by volume (in tablespoons) should be 1:1. To make a vinaigrette, the vinegar-to-oil ratio is usually 1:3 by volume.

23. If 3 tablespoons of vinegar are used, how much oil would you use to make a vinaigrette? Explain how you knew this.
   **9 tablespoons of oil would be needed, because the ratio of vinegar to oil must be 1:3.**

24. Here is the equation/recipe for the reaction between citric acid and baking soda:
   $$H_3C_6H_5O_7 + NaHCO_3 \rightarrow Na_3C_6H_5O_7 + H_2O + CO_2$$

25. Balance the equation in the space above, and rewrite your final answer below:
   $$H_3C_6H_5O_7 + 3NaHCO_3 \rightarrow Na_3C_6H_5O_7 + 3H_2O + 3CO_2$$

26. Using the balanced equation, decide what ratio the citric acid and baking soda should be added to make the perfect fizzy drink where all the citric acid reacts with all the baking soda. Explain your decision.
   *The ratio by moles should be 1:3 acid to base, however the grams must first be converted into moles to achieve the correct combination.*

27. The ratio of the coefficients in the balanced equation matches one of the ratios that was made during Procedure 3, but it probably didn’t taste very good (check your observations). If the ratio matches, why didn’t it work?
   *The ratio in the equation is a ratio of particles or moles, and not mass. Since each of the particles has a different mass, a gram to gram ratio will not work.*

28. Is there a unit we could use besides mass (grams) that would allow us to compare our experimental results to the balanced chemical equation? What is it?
   *Yes, moles.*

29. If you used 0.90 g of $H_3C_6H_5O_7$, how many grams NaHCO$_3$ should you add to make the reaction work best and react completely? Show your work and explain.
   $$0.90 \text{ g } H_3C_6H_5O_7 \times \frac{1 \text{ mole } H_3C_6H_5O_7}{192 \text{ g } H_3C_6H_5O_7} \times \frac{3 \text{ moles } NaHCO_3}{1 \text{ mole } H_3C_6H_5O_7} \times \frac{84 \text{ g } NaHCO_3}{1 \text{ mole } NaHCO_3} = 1.2 \text{ g } NaHCO_3$$

   *This is the key part of the experiment. Students must recognize that the coefficients in the balanced equation correspond to quantities in moles and not in grams. It is vital to the students’ conceptual understanding that each group has a chance to discuss this and arrive at the correct conclusion. A large-group discussion may be used to do this, or individually in lab groups.*

30. Make a starter solution, and add your calculated amounts.
DATA AND OBSERVATIONS 4

31. Describe how your solution looks and tastes:
   Should be slightly salty, but not acidic or basic if the calculations were correct.
   Should also be quite fizzy.

32. Was more or less or the same fizz produced from this mixture than others? Why
    might this be?
   More fizz should be observed because optimal amounts of acid and base were
   combined to produce as much product as possible.

33. Dispose of the rest of your solution down the drain and rinse out your containers. All
    paper/plastic products can be thrown away.

RESULTS

- Students could just turn in worksheet with all of the following questions answered,
  or the information can be put into a laboratory write up.
- Students are instructed to summarize qualitative data in a table:

<table>
<thead>
<tr>
<th>Solution (acid:base)</th>
<th>Look</th>
<th>Taste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only citric acid</td>
<td>Red, clear</td>
<td>Sour</td>
</tr>
<tr>
<td>Only baking soda</td>
<td>Red, cloudy to clear</td>
<td>Slippery, oily, soapy, bitter</td>
</tr>
<tr>
<td>1:1</td>
<td>Red, clear, fizzing</td>
<td>Slippery, oily, soapy, bitter</td>
</tr>
<tr>
<td>3:1</td>
<td>Red, clear, fizzing</td>
<td>Sour, biting</td>
</tr>
<tr>
<td>1:3</td>
<td>Red, may be cloudy, fizzing</td>
<td>Slippery, oily, soapy, bitter</td>
</tr>
<tr>
<td>2:1</td>
<td>Red, clear, fizzing</td>
<td>Sour</td>
</tr>
</tbody>
</table>

DISCUSSION

Either in a classroom discussion or report, students should discuss the following points:

Write a paragraph that explains the solutions and reactions you made in this lab (the
chemistry, what was going on?) You should write this explanation as you would explain
your results to a freshman.

This will allow students to simplify the chemistry and focus on the key concepts. In order
for the student to demonstrate understanding of the lab, I would look for correct
interpretation of the acid-base chemistry, the idea that the balanced reaction yielded the
correct “recipe” by providing a mole ratio of how the substances actually react, and that
using the balanced equation yielded the best solution because all of the acid and base
reacted together so neither could be tasted by itself.
Refer back to question 27. Why didn’t our recipe ratios in grams work? Explain in detail.
The 1:3 ratio of citric acid to baking soda that the chemical equation provides is a ratio of particles or amount of moles, not mass or amount of grams. Because citric acid is a heavier molecule (larger molar mass) than baking soda, a 1:3 ratio by mass will not allow for a complete reaction.

What evidence was there in the lab that a chemical reaction was taking place?
A gas was formed during the reaction and caused the fizz. Also, the reaction can be observed by taste, because after a complete reaction, neither the acid or base is left in solution.

What effects did changing the amounts of citric acid and baking soda have on the properties of your solutions, as well as the reaction? What effects would changing the amount of water in our procedure have on the results? Explain.
As the amount of citric acid or baking soda changed, the reaction changed, either by having excess acid or base, or causing a complete reaction. Too much acid made it taste sour; too much base made it taste bitter, and when they reacted all together it tasted like normal Kool-aid. Water is not a reactant and so changing the amount would not change the reaction, but it would dilute the flavor of the Kool-aid, a physical change.

If instead, we were baking chocolate chip cookies, which ingredients would ruin the taste of the cookies if you changed the amounts? Which could you change and still have delicious cookies?
When baking cookies, key ingredients like oil/butter, sugar, flour, salt, and baking soda should not be changed, because they are key in the chemical reactions that make the cookies. Changing the amounts would lead to very different tasting cookies. Other ingredients like the chocolate chips or nuts do not react, so varying the amount will still yield good cookies.

GOING FURTHER
1. Using the following shapes to represent the chemicals and ratios in the balanced equation, draw a particulate representation of the chemical reaction for this experiment.

- H$_3$C$_6$H$_5$O$_7$
- Na$_3$C$_6$H$_5$O$_7$
- ▲ CO$_2$
- □ NaHCO$_3$
- ● H$_2$O

- + □ + □ + □ → ○ + ● + ● + ● + ▲ + ▲ + ▲

2. Calculate the molar masses of the particles. Does each of these particles have the same mass?
The masses are all different:

- H$_3$C$_6$H$_5$O$_7$ = 192 g/mol
- Na$_3$C$_6$H$_5$O$_7$ = 258 g/mol
- CO$_2$ = 44 g/mol
- NaHCO$_3$ = 84 g/mol
- H$_2$O = 18 g/mol
3. How does this help you relate the best tasting “formula” to the balanced chemical
equation? Explain and show calculations to support your answer.
Since the different substances/particles each have a different mass, grams cannot be
used alone to measure the amounts necessary to react completely, moles must also
be considered.

4. Which of the substances is responsible for the fizz? Look back at the recipes in
Procedure 3. Which of the formulas should produce the least fizz? The most? Show
calculations to support your answer.
This question is a little advanced for a regular, introductory setting. You may want to
come back to it later, or avoid it entirely, except in an advanced course.

The carbon dioxide creates the fizz. The combination that has a mole ratio closest to
1 mole acid:3 moles base should make the most product.

Citric acid conversions:
\[1 \text{ g} \text{H}_3\text{C}_6\text{H}_5\text{O}_7 \times \frac{1 \text{ mole} \text{H}_3\text{C}_6\text{H}_5\text{O}_7}{192 \text{ g} \text{H}_3\text{C}_6\text{H}_5\text{O}_7} = 0.0052 \text{ molesH}_3\text{C}_6\text{H}_5\text{O}_7\]
\[0.5 \text{ g} \text{H}_3\text{C}_6\text{H}_5\text{O}_7 \times \frac{1 \text{ mole} \text{H}_3\text{C}_6\text{H}_5\text{O}_7}{192 \text{ g} \text{H}_3\text{C}_6\text{H}_5\text{O}_7} = 0.0026 \text{ molesH}_3\text{C}_6\text{H}_5\text{O}_7\]
\[0.5 \text{ g} \text{H}_3\text{C}_6\text{H}_5\text{O}_7 \times \frac{1 \text{ mole} \text{H}_3\text{C}_6\text{H}_5\text{O}_7}{192 \text{ g} \text{H}_3\text{C}_6\text{H}_5\text{O}_7} = 0.0078 \text{ molesH}_3\text{C}_6\text{H}_5\text{O}_7\]
Baking soda conversions:
\[1 \text{ g} \text{NaHCO}_3 \times \frac{1 \text{ mole} \text{NaHCO}_3}{84 \text{ g} \text{NaHCO}_3} = 0.012 \text{ molesNaHCO}_3\]
\[0.5 \text{ g} \text{NaHCO}_3 \times \frac{1 \text{ mole} \text{NaHCO}_3}{84 \text{ g} \text{NaHCO}_3} = 0.0060 \text{ molesNaHCO}_3\]
\[1.5 \text{ g} \text{NaHCO}_3 \times \frac{1 \text{ mole} \text{NaHCO}_3}{84 \text{ g} \text{NaHCO}_3} = 0.018 \text{ molesNaHCO}_3\]

Therefore,
1:1 by mass = \frac{0.0052}{0.012} = 0.43
3:1 by mass = \frac{0.0078}{0.060} = 0.13
1:3 by mass = \frac{0.0026}{0.018} = 0.14
2:1 by mass = \frac{0.0052}{0.0060} = 0.86

The 1:1 by mass solution, with the ratio closest to 0.33, should have made the most
fizz.
5. Research the proper recipe to make ice cream from scratch (just vanilla will do). Copy the recipe and turn it into a chemical equation trying to use chemical formulas when possible. Otherwise just use words. Make sure to pick a unit to be your “mole” in the equation (what will the coefficients represent?) and balance!

\[ 1 \text{ tablespoon sugar} = 3 \text{ teaspoons} \times 4 = 12 \]
\[ \frac{1}{2} \text{ cup milk} = 24 \text{ teaspoons} \times 4 = 96 \]
\[ \frac{1}{4} \text{ teaspoon vanilla extract} = \frac{1}{4} \text{ teaspoons} \times 4 = 1 \]

\[ 12C_{12}H_{22}O_{11} + 96\text{milk} + C_8H_8O_3 \rightarrow 96\text{ice cream!} \]
(sugar, sucrose)               (vanillin)

All of the information used to create this answer was found on the internet in about 5 minutes with a few Google searches: “baggie ice cream”, “ice cream in a bag”, “teaspoons in a tablespoon”, “teaspoons in a cup”, “chemical formula of vanilla” are some examples.

6. If we had 3072 teaspoons of sugar how many cups of ice cream could be made?
Using to the balanced equation:

\[
3072\text{teaspoons} - \text{sugar} \times \frac{96\text{icecream}}{12\text{sugar}} = 24576\text{teaspoons} - \text{ice cream} \times \frac{1\text{cup}}{48\text{teaspoons}} = 512\text{cups}
\]

GOING FURTHER – Teacher Extension Ideas
Other possible extensions that could be added include a calculation of the volume of gas released during each reaction or determining the limiting reactant in the different recipes and calculating the amount of excess reagent left over, or amounts of either product. Students also may do another trial where the citric acid is dissolved and the baking soda is added slowly to observe the changes in reaction and taste as the baking soda moves from a limiting reagent to an excess reagent.

REFERENCES