You are a food chemist who works for the Sweet Tooth Cola Company. You are responsible for testing a chemical reaction that will produce the gas, carbon dioxide, for carbonating the Company’s cola soft drink. The reaction must produce large amounts of carbon dioxide but cannot be very expensive.

The chemical reaction that has been used by your co-worker is:

\[
\text{CH}_3\text{CO}_2\text{H} + \text{NaHCO}_3 \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{NaCH}_3\text{CO}_2
\]

Acetic Acid | Sodium bicarbonate | Carbon dioxide | Water | Sodium acetate

The company has decided that one way to reduce the cost of producing the carbon dioxide is by using vinegar instead of pure acetic acid. Vinegar contains acetic acid but is less expensive. Costs can also be reduced by using baking soda which is the chemical sodium bicarbonate.

Your co-workers were able to produce some carbon dioxide using the baking soda and vinegar.

The different amounts of reactants that your coworkers tried and the volume of carbon dioxide gas they were able to produce are shown in the graph that follows.

However, the company still needs to produce carbon dioxide for the soda and also company needs to keep its costs down. They ask you to take over the project. The goals of your project are shown following the graph.
Goals

1. To keep costs down, design an experiment that produces as large a volume of CO₂ gas as possible using as small a mass of sodium bicarbonate as possible. Your experiment should create a larger volume of CO₂ gas than that of your co-workers.

2. Explain why you chose the conditions for your experiment.

3. Test your experiment and provide data that shows the results of the experiment. Your results must include a graph showing your data.

4. Explain whether the volume of carbon dioxide you produced is more than the carbon dioxide produced by your co-workers and why.

5. Report the volume of vinegar used and the mass of sodium bicarbonate that you recommend using to produce the largest amount of carbon dioxide at the lowest cost.

6. Explain why your recommendations are the best method for producing the carbon dioxide at the lowest cost.
Guidelines For Your Experiment

1. To reduce costs you may not use more than 30 ml of vinegar for any one reaction.

2. To reduce costs, you may not use more than 5 grams of baking soda in any one reaction.

3. You must use the balloon and flask procedure to conduct your experiment and test the amount of carbon dioxide produced. The procedure is described in the Background.
Background

You will use the same procedure that your coworkers developed to test the reaction. The procedure that was used is shown below:

1. Pour the liquid reactant into a 500ml Erlenmeyer flask.

2. Use a lab scoop to add the solid reactant to a large balloon.

3. Stretch the open end of the balloon over the mouth of the Erlenmeyer flask until the balloon securely covers the mouth of the flask. Do not allow any solid reactant to fall into the flask.

4. Making sure that the balloon does not come off the mouth of the flask, hold the balloon and shake the solid reactant out of the balloon until all of it has fallen into the liquid reactant.

5. Gently swirl the flask so the solid reactant stays in contact with the liquid. After approximately 5 minutes, the production of the product will have stopped. Do not remove the balloon.

6. Use the metric ruler to measure the diameter of the balloon.

7. Calculate the volume of gas produced using the following procedure. Since the balloon is a sphere, the formula for the volume of a sphere can be used.

   In the following equations:
   \[ \pi = 3.14 \]
   \[ r = \text{the radius of a sphere in centimeters} \]
   \[ d = \text{the diameter of a sphere in centimeters} \]
   \[ d^3 = (d \times d \times d) \]

   The volume of a sphere \( V \) = \[ \frac{4}{3} \pi r^3 \]

   This can be simplified to:

   Volume of a sphere = 0.52 \( \times d^3 \) = 0.52 \( \times (d \times d \times d) \)
1. Design an experiment that produces as large a volume of carbon dioxide as possible using the smallest amount of baking soda. The volume of carbon dioxide must be greater than that of your co-workers.

a. Describe the design for your experiment.

To produce the most carbon dioxide, five Trials would be performed. The Trials would use 30 ml of vinegar but different amounts of baking soda. The first Trial would use 1 g of baking soda. The amount of baking soda would be increased to 3 grams in the second Trial, and increased to 5 grams in the third Trial. The vinegar would be placed in a flask for each Trial and the baking soda in a balloon. The balloon would be attached to the flask and the baking soda added to the flask by holding it above the flask. After each reaction, the diameter of the balloon would be measured and used to calculate the volume of carbon dioxide produced.

b. Explain why you chose the conditions for your experiment.

The data from my co-workers showed that they were able to produce approximately 113 ml of CO₂ gas. Their graph showed that increasing the vinegar more than this did not produce a greater amount of carbon dioxide. This is likely because all of the vinegar had reacted with the 5 g of baking soda. This indicates that there is a point in the reaction in which one reactant can be used up even though there is an excess of another reactant. The guidelines for the experiment indicate that 30 ml of vinegar must be used for the experiment. The data from my co-workers graph shows that 30 ml of vinegar with 1 g of baking soda will not
produce more carbon dioxide than 10 ml of vinegar. Therefore in order to increase the amount of carbon dioxide, the amount of baking soda must need to increase the product of the reaction, carbon dioxide. However, there is probably a point at which all of the vinegar in the reaction will react with the baking soda and no more carbon dioxide will be produced. By increasing the amount of baking soda in five Trials, I should be able to find that point.

2. Test your experiment and record data from the experiment in the space below. Your results must include a graph that shows your data.

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Volume of Vinegar (ml)</th>
<th>Mass of NaHCO₃ (g)</th>
<th>Unreacted NaHCO₃ Remaining</th>
<th>Diameter of Balloon (cm)</th>
<th>Volume of Balloon (ml)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
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<td>No</td>
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<td>5</td>
<td>Yes</td>
<td>8.9</td>
<td>375</td>
</tr>
</tbody>
</table>

Note:
All trials used 30ml of vinegar.
3. Explain whether the volume of carbon dioxide you produced is greater than your co-workers. Support your explanation with data from your experiment.

*The volume is greater than the volume produced by the coworkers based on 375ml of carbon dioxide produced from 3g of sodium bicarbonate and 30 ml of vinegar. The coworkers produced only 115ml using 1 of sodium bicarbonate and 10ml of vinegar.*

4. Report the volume of vinegar and the mass of baking soda that you recommend to produce the greatest of carbon dioxide at the lowest cost.

*3g of baking soda and 30ml of vinegar produce the greatest amount of carbon dioxide gas at the lowest cost. Any mass greater than 3 g does not produce any more gas.*

5. Explain why your recommendations are the best method for producing the carbon dioxide at the lowest cost.

*The production of carbon dioxide gas by the coworkers was limited by using 1g of baking soda and 10ml of vinegar. In my procedure, I produced more gas because I used 3g of baking soda and 30ml of vinegar. The increase in the amount of the two reactants increased the amount of the products.*