

When Does the Fizz Stop? A Reaction as a System

Investigation question: If you keep adding more baking soda to the same amount of vinegar, does the reaction keep making more gas forever, and what decides when it stops?

Collaborative systems modeling

Groups of 3

1 session

Setup 7 · Activity 40 · Cleanup 6 min

MS-PS1-2 · practice

MS-PS1-5 · supports

Scientific purpose

Students treat a cup of vinegar as a system with an input (baking soda), an output that leaves (carbon dioxide gas, measured as mass lost on a balance) and leftovers (whatever did not react). By adding increasing amounts of baking soda to a fixed 50 mL of vinegar and weighing before and after, they find that the mass lost rises and then levels off, and the leftover test tells them which reactant ran out on each side of the plateau. They draw a box model of the system and use it to predict results for amounts and volumes they did not test.

Why this helps students with this chapter

Students explain the end of fizzing as the reaction getting tired or the vinegar going weak. Measuring the output while changing one input turns that story into a testable one: if the fizz simply faded, the mass lost would keep rising with more baking soda; it levels off instead, and the leftover test shows exactly which reactant is gone on each side of the bend. The box model gives them a way to predict, which is what a model is for.

Standards connections

MS-PS1-2 (practice, using a chemical property of the leftover liquid, and the appearance of a gas with mass, as before-and-after evidence): The leftover test compares a chemical property (fizzing with acid, fizzing with baking soda) of the liquid after the reaction with the properties of the reactants, which is the before-and-after reasoning of the PE applied to a reaction the students control. The mass data are the output of the system model rather than a property measurement.

MS-PS1-5 (supports, the idea that a gas leaving the system carries mass away): Students see that the mass lost equals the mass of gas that escaped and that it stops growing when a reactant is used up. Conservation of mass and atom counting are Lesson 13's job; here the data simply prepare the ground, so the role is supports.

Roles (rotate each session)

- **Balance operator:** Zeroes the balance with the empty cup, weighs the vinegar and each baking soda portion, reads the final mass, and keeps the balance dry.

- **Reactor:** Adds the baking soda portion all at once, swirls the cup gently every 30 seconds, runs the leftover test, and rinses the cup between runs.
- **Recorder and modeler:** Records every mass, computes the mass lost, times the run, plots the point as soon as it is known, and leads the box-model drawing.

Materials

Item	Quantity	Per	Note
White vinegar (label says 5% acidity)	350 mL	group	Check the label; 4% and 6% vinegars shift the plateau.
Baking soda	about 25 g	group	
Digital balance reading to 0.1 g (a kitchen scale works)	1	group	0.01 g is better if available. Two groups can share one balance if runs are staggered.
Wide clear cup, about 250 mL	2	group	Wide so the foam from the larger portions does not overflow.
Graduated cup or measuring cup marked at 50 mL	1	group	
Paper squares or weigh boats for baking soda portions	8	group	
Plastic spoons and a dropper	2 spoons, 1 dropper	group	
Timer	1	group	
Splash goggles	1 pair	student	
Graph paper and the recording sheet	1 set	student	
Paper towels and a rinse bucket	1 set	group	

Estimated cost: 15 to 25 per class, or under 5 if balances are stock (an estimate; Estimate. Vinegar (two 1 L bottles, about \$6), baking soda (\$1), cups and paper squares (\$3). A 0.1 g digital kitchen scale is about \$12 if the classroom has none; one per two groups is enough.)

Safety

- Splash goggles on throughout; vinegar stings eyes and foam can spatter when the larger portions go in.
- Never cover, cap or seal the cup while it is fizzing; the gas must leave freely. Nothing is tasted.
- Keep the balance dry: lift the cup off before adding baking soda if foam might spill, and wipe any drips at once.
- All liquids go down the sink with running water at the end; the cups are rinsed between runs, not sealed.

Teacher preparation and setup

1. Run the series once yourself with your vinegar to find where the plateau falls; with 5% vinegar and 50 mL it should start between 3 and 4 g of baking soda.
2. Pre-weigh baking soda portions of 1.0, 2.0, 3.0, 4.0, 5.0 and 6.0 g onto labeled paper squares for each group if balance time is short; otherwise groups weigh their own.
3. Decide how to split runs: each group does all six amounts if balances allow about 5 minutes per run; otherwise group A does 1, 3, 5 g and group B does 2, 4, 6 g and the pair shares data.
4. Print the recording sheet and have graph paper with the axes already drawn for groups who need it.
5. Put a rinse bucket at each table so cups are rinsed without a trip to the sink between runs.

Investigation design

Independent variable	Mass of baking soda added (1.0 to 6.0 g)
Dependent variable	Mass lost from the cup after fizzing stops (grams), and the result of the leftover test
Controlled	50 mL of the same vinegar every run; Same cup, same balance, same swirling routine; Portion added all at once at the start; Same end point: 30 seconds with no bubbles
Trials	One run per amount per group; six to eight groups give several trials of each amount when pooled, and the class plots the averages beside each group's own line.
Comparison	Mass lost at each amount against the previous amount; leftover-test results before and after the plateau.

Student procedure

1. Goggles on. Put the empty wide cup on the balance and zero it. Add 50 mL vinegar and record the mass of the vinegar.
2. Weigh the first baking soda portion (1.0 g) on a paper square and record its mass. Add the vinegar mass and the portion mass to get the starting total.
3. With the cup on the balance, tip the whole portion in at once and start the timer. Swirl gently every 30 seconds. Watch the bubbles.
4. When no bubbles have risen for 30 seconds, read the mass of the cup and contents. Mass lost = starting total minus final mass. Record the time the fizz took.
5. Leftover test, part 1: add a pinch of fresh baking soda to the liquid. Record fizz or no fizz. Part 2: in the same cup, add 1 mL (about 20 drops) of fresh vinegar. Record fizz or no fizz. Decide which reactant was used up and record it.
6. Pour out, rinse the cup, dry the outside, and repeat steps 1 to 5 with 2.0, 3.0, 4.0, 5.0 and 6.0 g of baking soda, always with a fresh 50 mL of vinegar.
7. Plot mass lost (vertical) against baking soda added (horizontal) as each run finishes. Draw a smooth line through the points.

8. Draw the box model: the cup as a system, with arrows for what goes in, what leaves, and what stays, and label which arrow the balance measured.
9. Use the model and your graph to make the two predictions on the recording sheet before you answer the analysis questions. Pool class data on the board.

Expected observations

- With 5% vinegar the mass lost rises roughly in proportion to the baking soda for 1, 2 and 3 g (about 0.4 to 0.5, 0.9 to 1.0 and 1.3 to 1.5 g) and then levels off near 1.6 to 1.8 g for 4, 5 and 6 g.
- Fizzing lasts longer and foams higher for the larger portions; for 5 and 6 g some undissolved baking soda remains visible at the bottom when the fizz stops.
- Leftover test: for 1 to 3 g, added baking soda fizzes and added vinegar does not (acid remained, baking soda was used up); for 5 and 6 g, added vinegar fizzes and added baking soda does not (baking soda remained, acid was used up). The 4 g run may fizz faintly with both, because it is close to the amount that uses up the acid exactly.
- The time until the fizz stops grows with the portion size, from under a minute to several minutes.

Likely difficulties

- Foam spills from the cup for 5 and 6 g if the cup is narrow or the portion is dumped from a height; use a wide cup and tip the portion in at the surface.
- Students read the balance while bubbles are still rising and get a mass lost that is too small; hold to the 30-second no-bubble rule.
- A balance that reads to 1 g cannot resolve the differences; borrow 0.1 g kitchen scales or pool runs so each group does fewer, better-measured amounts.
- Students subtract in the wrong order or forget to add the baking soda mass to the starting total; the sheet's formula line and a worked example on the board prevent most errors.
- Some vinegar brands are 4% or 6%; the plateau moves to about 2.8 g or 4.2 g of baking soda and the plateau height to about 1.5 g or 2.2 g, so compare class data to your own trial run rather than to the key's 5% numbers.

Structured debrief

1. Pool every group's six points on one class graph. The rising part should line up across groups because the rate (mass lost per gram of baking soda) depends only on the reaction; the plateau height should also agree if everyone used the same vinegar. Ask why the bend is the interesting part: it is where the system switches from 'baking soda runs out' to 'acid runs out'.
2. Read the leftover rows aloud for 2 g and 6 g. At 2 g a pinch of baking soda fizzes (acid left) and vinegar does nothing (no baking soda left); at 6 g the reverse. Ask what the liquid at 2 g has in common with vinegar and what the liquid at 6 g has in common with baking soda, and conclude that the leftover liquid's chemical properties tell you what is still in the system.
3. Walk the arithmetic for your vinegar: 50 mL of 5% vinegar holds about 2.5 g of acetic acid, which uses up about 3.5 g of baking soda and can make about 1.8 g of carbon dioxide at most. Compare with the

class plateau and list reasons the measured value runs a bit under (dissolved gas, vinegar strength, timing).

4. Close on the model: the box with arrows predicted the two sheet predictions correctly for most groups. Preview Lesson 13: if the gas that left has exactly the mass the cup lost, and the atoms in that gas came from the reactants, then nothing was created or destroyed, only rearranged.

Recording sheet: what students fill in

Lab 3 recording sheet: When does the fizz stop?

Record every mass to 0.1 g (or 0.01 g if your balance reads it). Mass lost = (vinegar + baking soda) minus the final mass of the liquid in the cup. Run the leftover test after every run.

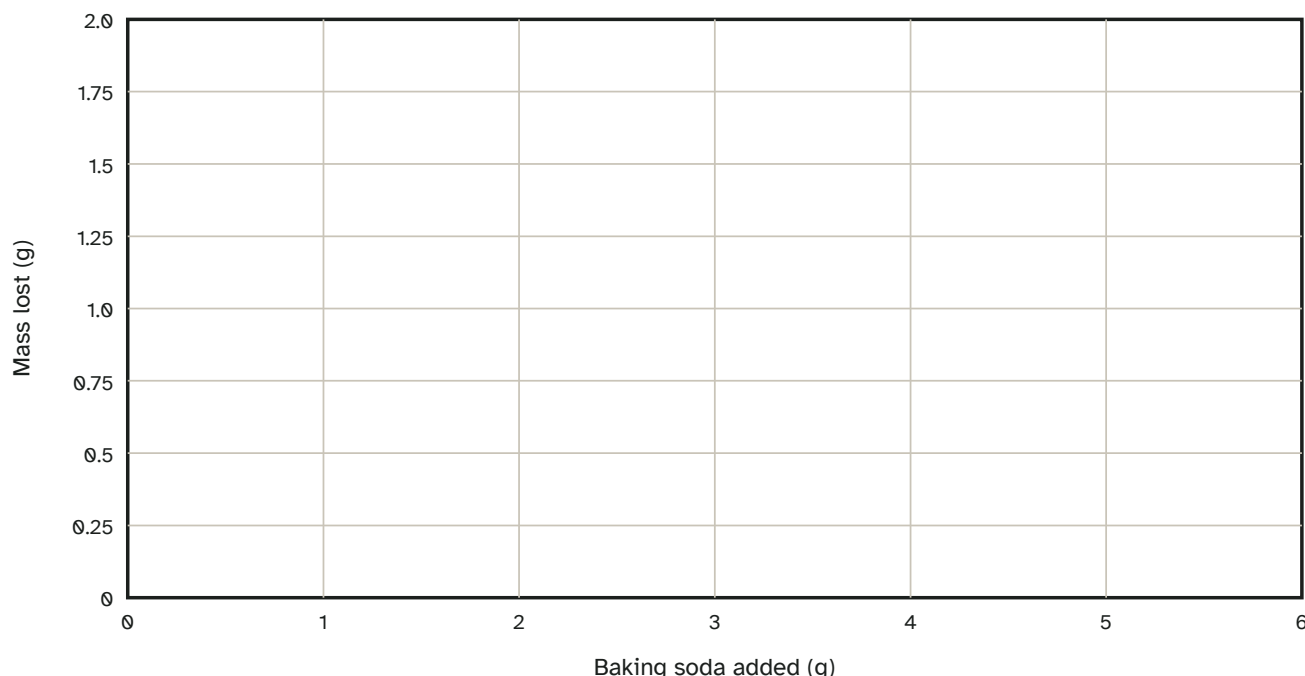
Mass data

Baking soda added (g)	Vinegar mass (g)	Starting total (g)	Final mass (g)	Mass lost (g)	Time until fizz stopped (s)
1.0					
2.0					
3.0					
4.0					
5.0					
6.0					

Leftover test

Baking soda added (g)	Pinch of baking soda added: fizz?	1 mL vinegar added: fizz?	Which reactant was used up?
1.0			
2.0			
3.0			
4.0			
5.0			
6.0			

Mass lost against baking soda added (50 mL vinegar)



-  Draw the cup as a system. Show a box for the cup, an arrow in for the baking soda, an arrow out for what leaves, and labels inside for what stays behind after the fizz stops. Mark the arrow the balance measured, and show how the box changes between a small portion (1 g) and a large portion (6 g).

Answer: A box labeled 'cup: 50 mL vinegar (acetic acid + water)'; an arrow in labeled 'baking soda (1 g or 6 g)'; an arrow out labeled 'carbon dioxide gas: the mass the balance lost'; inside the box after the fizz: 'water, sodium acetate, and the leftover reactant'. For 1 g the leftover is acid (vinegar); for 6 g the leftover is unreacted baking soda. The output arrow for 6 g is at most as big as the plateau, not six times the 1 g arrow.

Why: Checks that the student identified the gas as the measured output and that the leftover changes sides at the bend.

- Input arrow for baking soda and output arrow for gas
- Output arrow marked as what the balance measured
- Leftovers differ between the small and large portion (acid versus baking soda)

1. Prediction 1: 100 mL of vinegar with 3.0 g of baking soda. Mass lost = ____ g. Explain using your model.

Answer: About the same as the 3.0 g run with 50 mL, roughly 1.4 to 1.6 g (theoretical 1.57 g). Doubling the vinegar does not help, because at 3.0 g the baking soda is the reactant that runs out; the extra vinegar just means more acid is left over. Model: the input arrow (3 g) is the same, so the output arrow is the same; only the leftover acid in the box grows.

Why: Theoretical: $3.0 \text{ g baking soda} \times 0.524 \text{ g CO}_2 \text{ per gram} = 1.57 \text{ g}$, and 100 mL of 5% vinegar (about 5 g acetic acid, enough for about 7 g of baking soda) is in excess. Credit a prediction equal to the student's own 3 g result with the 'baking soda runs out' reasoning.

Also acceptable: Accept any value within about 0.2 g of the group's 3.0 g run if the explanation names baking soda as the limiting input.

2. Prediction 2: 25 mL of vinegar with 4.0 g of baking soda. Mass lost = ____ g. Explain using your model.

Answer: About half the plateau value, roughly 0.8 to 0.9 g (theoretical 0.92 g). With 25 mL of vinegar there is only half as much acid, so it is used up by about 1.75 g of baking soda and the rest of the 4.0 g sits unreacted. Model: the acid in the box is halved, so the output arrow is halved, and the leftover is baking soda.

Why: Theoretical: 25 mL of 5% vinegar holds about 1.25 g acetic acid, which makes at most 0.92 g CO₂ (half of the 1.83 g plateau). Students should halve their own plateau value.

Also acceptable: Accept half the group's measured plateau with the 'acid runs out' reasoning.

Analysis questions: answer key

3. Describe the shape of your graph. Between which two amounts of baking soda did the line stop rising, and what happened to the mass lost after that?

Answer: The line rises steadily (close to a straight line) through 1, 2 and 3 g, bends between about 3 and 4 g, and then runs flat; the mass lost for 4, 5 and 6 g is about the same (near 1.6 to 1.8 g with 5% vinegar).

Why: A rising segment followed by a plateau. The bend location depends on vinegar strength; with 5% vinegar it is at about 3.5 g.

- Describes a rise then a plateau
- Locates the bend between two specific amounts from the data
- States the plateau value stays about constant

4. Use the leftover-test rows to say which reactant was used up for the small portions and which for the large portions. How does that explain the bend in the graph?

Answer: For the small portions (1 to 3 g) a pinch of baking soda fizzed and added vinegar did not, so acid was still present and the baking soda had been used up. For the large portions (5 and 6 g) added vinegar fizzed and added baking soda did not, so baking soda was left and the acid had been used up. The bend is where the switch happens: below it, more baking soda means more gas because the acid is waiting; above it, extra baking soda has nothing left to react with, so the gas output cannot grow.

Why: Connects the two leftover results to the two sides of the plateau. Full credit requires both sides and the explanation of the flat part.

- Reads the small-portion leftover result correctly (acid remained)
- Reads the large-portion result correctly (baking soda remained)
- Explains the plateau as the acid being used up

5. Where did the lost mass go? Is 'the cup got lighter' evidence that a new substance formed? Combine it with the leftover test to make the argument.

Answer: The lost mass left as carbon dioxide gas; the bubbles carried it into the air, and gases have mass. 'The cup got lighter' on its own is not proof of a new substance, because mass can also leave by evaporation or spilling. Combined with the leftover test it becomes an argument: a gas appeared that was present in neither the vinegar nor the baking soda, and the liquid left behind lost a chemical property of one reactant (at 6 g it no longer fizzes with baking soda the way vinegar does). A new substance that was not there before, plus a product with different properties from a reactant, is the before-and-after evidence of a reaction.

Why: Students must separate the mass observation (a clue) from the property comparison (the evidence), the chapter's central move.

- Says the mass left as gas
- Says mass loss alone is a clue, not proof
- Uses the leftover test as a property comparison
- Concludes a new substance formed

6. For the 2.0 g run, work out how much mass was lost per gram of baking soda. Then use that rate to predict the mass lost for 2.5 g of baking soda in 50 mL vinegar, and say why the same rate would give the wrong answer for 5.0 g.

Answer: From a typical 2.0 g run that lost about 0.95 g: $0.95 \text{ g} \div 2.0 \text{ g} = \text{about } 0.48 \text{ g of mass lost per gram of baking soda}$ (theoretical 0.52 g per gram). Prediction for 2.5 g: $2.5 \times 0.48 \approx 1.2 \text{ g}$ (theoretical 1.31 g). For 5.0 g the same rate would predict $5.0 \times 0.48 = 2.4 \text{ g}$, but the acid in 50 mL of vinegar runs out at about 3.5 g of baking soda, so the real answer is the plateau value (about 1.7 g); the rate only applies while baking soda is the reactant that runs out.

Why: Use the student's own 2.0 g value for the rate. The point is recognizing the limit of proportional reasoning at the bend.

Also acceptable: Accept any rate computed correctly from the group's own 2.0 g data and a 2.5 g prediction consistent with it, with the plateau named as the reason the rate fails at 5.0 g.

7. A classmate says the fizzing stopped because 'the reaction ran out of energy.' Use two results from this lab to show why that explanation does not fit the data.

Answer: If the reaction ran out of energy, adding more baking soda to a finished cup would do nothing, and adding more vinegar would do nothing either. Instead, one of the two additions always restarted the fizz, which shows the reaction was ready to go as soon as the missing reactant arrived. Second, if energy were the limit, the mass lost would not depend on how much baking soda went in, yet it rose in proportion to the portion until the acid ran out and then stopped at a fixed value set by the amount of vinegar. Both results fit 'a reactant was used up' and neither fits 'energy ran out'.

Why: Two independent lines of evidence against the misconception: the restart test and the shape of the graph.

- Uses the leftover/restart result
- Uses the dependence of mass lost on amount (or the plateau)
- States the reactant-used-up explanation

8. Your measured plateau was probably a little below the value the teacher's key predicts. Give two reasons the measured mass lost could be lower than the mass of gas the reaction actually made.

Answer: Some of the carbon dioxide stays dissolved in the liquid instead of leaving, so the balance does not see it; the fizz may have been stopped early, before the last gas left; the vinegar may be weaker than 5%, so less gas could form; a little foam or liquid may have been lost or wiped away, which would go the other way. Any two of these.

Why: Students should reason about where mass could hide (dissolved gas) and about procedure (timing, vinegar strength).

- Names dissolved gas or an equivalent 'gas still in the liquid' reason
- Names a second plausible reason (timing, vinegar strength, measurement)

9. What does your box model show well, and what does it leave out? Name one thing about the reaction that the model cannot tell you.

Answer: The model shows well what goes into the cup, what leaves (the gas the balance measured) and what is left behind, and it predicts how the output changes when one input is limited. It leaves out what the substances are made of and why they react, how fast the reaction goes, where the energy comes from or goes, and the gas that stays dissolved. One thing it cannot tell you: what the gas is made of or whether its atoms came from the vinegar, the baking soda or both, which is next lesson's question.

Why: A model's limits are part of using it; any honest and specific gap earns credit.

- Names what the model represents (inputs, output, leftovers)
- Names at least one specific thing it cannot show

Individual evidence of learning

Each student submits their own data tables, graph, box-model drawing, two predictions with explanations, and written answers to q3 through q9. The graph with the plateau explained (q3, q4) and the predictions (q1, q2) are the primary evidence; q5 is the evidence that the student can turn mass data and the leftover test into a before-and-after argument.

Assessment criteria

Criterion	Proficient looks like
Data and graph	All six runs recorded with correct subtraction, points plotted accurately, and a line that rises and then levels off.
System model	Drawing shows inputs, the gas output as the measured arrow, and the leftovers; the model is used to make both predictions with correct reasoning (vinegar in excess for prediction 1, baking soda in excess for prediction 2).
Explaining the plateau	States that the mass lost stops rising because the acid in the vinegar is used up, supported by the leftover-test results on both sides of the bend.
Evidence reasoning	Explains that the lost mass is gas that left the cup, and that the leftover liquid's changed chemical property plus the appearance of a gas that was in neither reactant are the before-and-after evidence of a reaction.

Accessibility adaptations

- Pre-weighed portions on labeled paper squares remove the hardest fine-motor step; the balance operator role can then be a reading-and-recording role.
- A talking or large-display balance lets a student with low vision run the measurements; the fizz can be felt as vibration on the cup wall and heard clearly.
- Provide the graph with axes already scaled and the first point plotted, and a box-model template with empty arrows to label.
- Accept spoken explanations for q4, q5 and q7 recorded on a device, and reduce the series to 1, 2, 4 and 6 g for groups that need more time per run.

Low-cost alternative

Share one 0.1 g kitchen scale among three groups by staggering runs, and reduce the series to 1, 2, 4 and 6 g; the plateau still shows. If no balance is available, put 50 mL of vinegar in a small plastic bottle, put the portion inside a balloon, stretch the balloon over the bottle's mouth and tip the powder in, then measure the distance around the balloon with a string. The balloon is the only allowed cover because it stretches; never cap the bottle or seal a bag. The graph rises and levels off the same way, though the numbers are rougher.

Model limitations

The box model treats the cup as a closed system except for the gas arrow, but some carbon dioxide stays dissolved in the liquid and a little water vapor leaves with the gas, so the measured mass lost is slightly less than the gas the reaction made. The model also says nothing about why the two substances react or what the atoms do, which is Lesson 13. The activity has not been physically tested by the authors; the expected masses are computed for 5% vinegar and will shift with vinegar strength, balance precision and how long groups wait before reading.

Teacher notes

Grade the predictions against each group's own data, not the theoretical numbers: a group whose plateau was 1.6 g should predict 0.8 g for prediction 2. The theoretical values in this key assume 5% vinegar (about 2.5 g acetic acid in 50 mL, which consumes about 3.5 g of baking soda and releases about 1.83 g of carbon dioxide, 0.524 g per gram of baking soda). If several groups report fizzing with both additions at 4 g, that is the bend, not an error.