

Open Cup, Capped Bottle: Tracking Mass Through a Reaction

Learning target: I can graph and calculate from balance readings taken during a reaction to show that mass only leaves or joins a system when matter crosses its boundary, and that a closed system keeps its mass.

Data and graphing

About 40 min

Individual

MS-PS1-5 · practice

data analysis

independent practice

Standards connections

MS-PS1-5 (practice, the mass-is-conserved half, using data rather than a drawn model): Students analyze mass-versus-time data for the same reaction run open and capped, and mass-gain data for burning steel wool, then explain every reading with atoms crossing or not crossing a boundary. This builds the evidence base for the model the PE asks for; the sheet never uses atomic masses or asks students to balance an equation.

Purpose: practice · **Time:** about 40 minutes · **Format:** individual

Answers with reasoning

Part A: The same reaction, two containers

A teacher set up two runs of the vinegar and baking soda reaction. **Open cup:** an empty cup (100.00 g) with 60.00 g of vinegar sat on a balance reading to 0.01 g; at time 0 she tipped in a 2.00 g packet of baking soda. **Capped bottle:** a rigid 2-liter plastic bottle held 60.00 g of vinegar and a small open vial with 2.00 g of baking soda standing upright inside; she screwed the cap on tight, put the whole bottle on a second balance, and at time 0 tipped it to mix. Both mixtures fizzed. The bottle stayed capped for 180 seconds; then she unscrewed the cap, squeezed the bottle gently a few times to push out the gas, left the cap off, and read the balance again at 300 seconds: **164.52 g**.

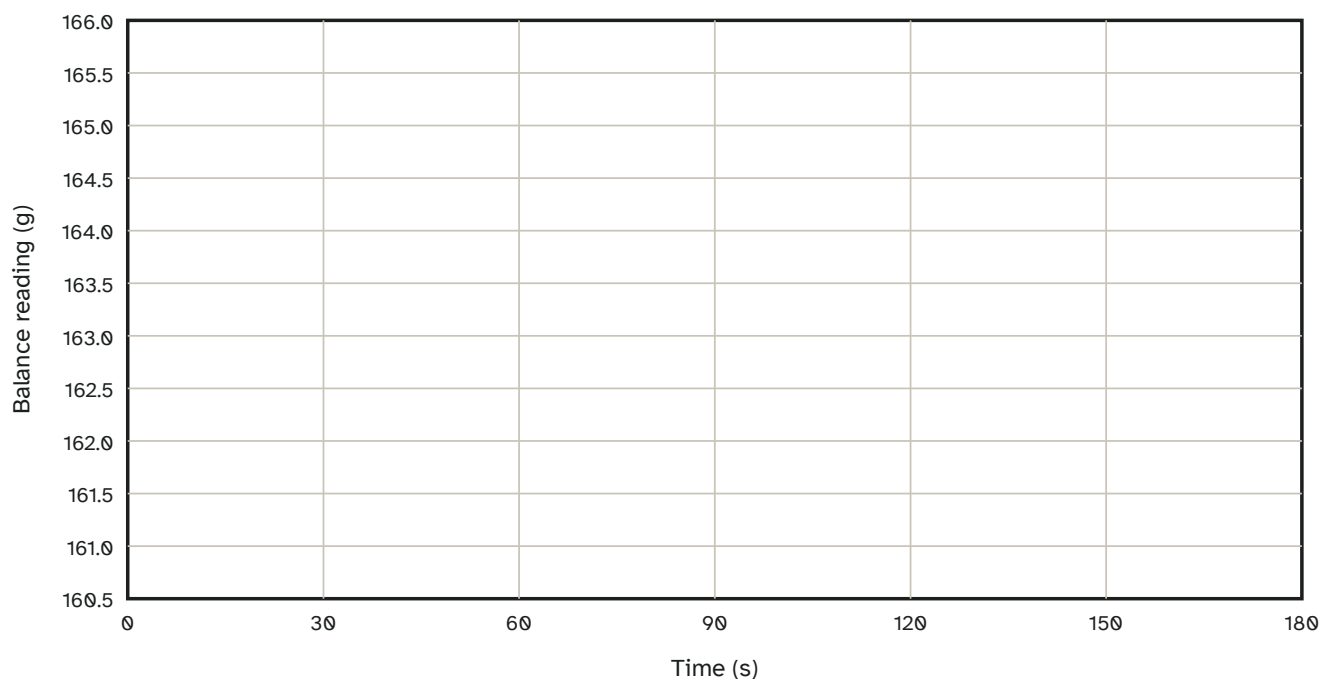
Balance readings during the reaction (teaching dataset)

Simulated teaching dataset: the numbers are invented to be realistic, not measured.

Time (s)	Open cup (g)	Capped bottle (g)
0	162.00	165.50
30	161.42	165.50
60	161.18	165.50
90	161.08	165.50
120	161.03	165.50
150	161.01	165.50
180	161.00	165.50

Simulated data for teaching, realistic for 2.00 g of baking soda in 60 g of vinegar. The bottle was rigid, so its size did not change as gas formed inside.

Mass of each container versus time



1. Calculate the total change in the balance reading from 0 s to 180 s for the open cup and for the capped bottle. Write each change with a sign (+ or –) and units.

Answer: Open cup: $161.00\text{ g} - 162.00\text{ g} = -1.00\text{ g}$. Capped bottle: $165.50\text{ g} - 165.50\text{ g} = 0.00\text{ g}$.

Why: Change is final reading minus starting reading. The cup lost exactly 1.00 g of gas to the room; the bottle let nothing cross its boundary so its total did not change.

Also acceptable: Accept 'lost 1.00 g' and 'no change' in words, as long as the sign is clear.

2. For the open cup, calculate the mass lost during the first 30 seconds and during the last 30 seconds (150 s to 180 s). Then calculate the average rate of loss during the first minute in grams per second.

Answer: First 30 s: $162.00\text{ g} - 161.42\text{ g} = 0.58\text{ g}$ lost. Last 30 s: $161.01\text{ g} - 161.00\text{ g} = 0.01\text{ g}$ lost. Rate during the first minute: $(162.00\text{ g} - 161.18\text{ g}) \div 60\text{ s} = 0.82\text{ g} \div 60\text{ s} \approx 0.014\text{ g/s}$ (about 0.82 g per minute).

Why: Subtracting consecutive readings gives the loss in each interval; the rate is the loss over the first minute divided by 60 s. The two interval losses (0.58 g versus 0.01 g) show the reaction slowing down.

Also acceptable: Accept 0.0137 g/s or 0.014 g/s; accept 0.82 g/min if the student converts units correctly.

3. Describe the shape of each line on your graph. What does the shape of the open-cup line tell you about how fast gas was leaving at the start compared with the end, and why did it change?

Answer: The open-cup line drops steeply at first and then flattens, leveling at 161.00 g by 180 s. The capped-bottle line is flat the whole time. The steep start means gas was leaving quickly at the beginning; the flat end means almost no gas was leaving by 150 s. It changed because the reaction was finishing: as the baking soda was used up, less carbon dioxide was being made, so less left the cup.

Why: The curve's slope is the rate of gas loss. Students should connect the flattening to the reactants running out rather than to the gas 'getting tired'.

Also acceptable: Accept 'the fizzing slowed down because the baking soda was almost gone.'

- Describes the cup line as steep then flat
- Describes the bottle line as flat
- Links the changing slope to the reaction slowing as reactant is used up

4. Calculate how much the bottle's reading dropped after the cap was removed (180 s reading to 300 s reading). Compare this to the open cup's total loss from q1. Give one reason the two numbers are not exactly equal.

Answer: Drop after opening: $165.50\text{ g} - 164.52\text{ g} = 0.98\text{ g}$. The open cup lost 1.00 g. The numbers are nearly equal (difference 0.02 g). Reasons they are not exactly equal: some carbon dioxide stays dissolved in the liquid and leaves slowly, so at 300 s a little gas was still in the bottle; or the two balances read to 0.01 g, so a difference of 0.02 g is close to the limit of what they can tell apart.

Why: The point is that the gas trapped in the bottle had almost exactly the mass the cup lost; the bottle simply delayed the loss until the boundary was opened. Either physical reason earns credit.

Also acceptable: Accept 'the cup had more time for gas to escape' or 'some gas was still inside the bottle.'

5. Explain all three results (the cup's loss, the bottle's steady reading, and the bottle's drop after opening) with one explanation about atoms. Say where the atoms of the 'missing' mass were at 180 s in each container.

Answer: Model response: In both containers, atoms in the vinegar and baking soda regrouped into new substances, including carbon dioxide gas. Every atom still exists, and every atom still has its mass. In the open cup, the carbon dioxide molecules crossed the cup's boundary and spread into the room, so by 180 s the atoms of the missing 1.00 g were in the air of the classroom, and the balance could no longer weigh them. In the capped bottle the same gas formed, but the cap kept it inside the boundary, so at 180 s those atoms were in the air space inside the bottle and the balance was still weighing them; the reading could not change. When the cap came off, the gas crossed the boundary and the reading fell by its mass. Nothing was created or destroyed in either container; the only difference was whether the atoms could leave.

Why: Full credit requires one atom-level explanation that covers all three results, with the location of the escaped atoms named in each case and an explicit statement that atoms were conserved.

Also acceptable: A student who adds that the bottle felt firm because the trapped gas pushed on it is using extra evidence correctly.

- Says the gas is made of atoms that have mass
- Names where the atoms were at 180 s: in the room (cup) and inside the bottle (capped)
- Explains the drop after opening as the gas crossing the boundary
- States that no matter was created or destroyed

6. A classmate says, 'The bottle's reading never changed, so no reaction happened inside it.' Give two observations from the setup or the data that show a reaction did happen in the bottle.

Answer: Any two: the mixture in the bottle fizzed when tipped (a gas was being made); the rigid bottle would feel firm or tight from the gas pressure inside; and the reading dropped by 0.98 g once the cap was removed and the gas let out, which only makes sense if a gas had formed inside while it was capped. A constant reading shows that nothing left, not that nothing happened.

Why: Students must separate 'the system's mass stayed the same' from 'no change occurred inside the system'. The post-opening drop is the strongest quantitative evidence.

Also acceptable: Accept the fizzing plus the pressure, or the fizzing plus the 0.98 g drop.

- Two valid observations
- Distinguishes a steady reading from no reaction

Part B: Steel wool pads that gain mass

In a teacher demonstration (behind a shield; students never handle flame), four pads of fine steel wool of different masses were heated until they glowed, allowed to go dark and cool, and then every crumb was returned to the balance. In a separate described experiment, a 2.00 g pad was sealed inside a glass flask of air, the whole flask was weighed (250.00 g), the pad was heated through the glass until it darkened, and the sealed flask was weighed again: **250.00 g**. When the stopper was then removed, air hissed in and the flask read **250.14 g**.

Steel wool pads heated in open air (teaching dataset)

Simulated teaching dataset: the numbers are invented to be realistic, not measured.

Pad	Mass before heating (g)	Mass after cooling (g)
A	1.00	1.07
B	2.00	2.15
C	3.00	3.21
D	4.00	4.29

Simulated data for teaching. Only part of the iron in each pad reacts, so the gains are smaller than a complete reaction would give.

7. Complete the table. Mass gained = after – before. Gain per gram = mass gained ÷ mass before. Show one full calculation below the table and give the average to three decimal places.

Answer: Pad A: $1.07 - 1.00 = 0.07$ g; $0.07 \div 1.00 = 0.070$ g/g. Pad B: $2.15 - 2.00 = 0.15$ g; $0.15 \div 2.00 = 0.075$ g/g. Pad C: $3.21 - 3.00 = 0.21$ g; $0.21 \div 3.00 = 0.070$ g/g. Pad D: $4.29 - 4.00 = 0.29$ g; $0.29 \div 4.00 = 0.0725$ g/g. Average gain per gram: $(0.070 + 0.075 + 0.070 + 0.0725) \div 4 = 0.2875 \div 4 = 0.072$ g/g (0.0719 rounded).

Why: The gain per gram is nearly constant, about 0.07 g for every gram of pad, which is the pattern that lets students predict in q8. Small scatter is expected because the pads do not all react to exactly the same extent.

Also acceptable: Accept an average of 0.072 or 0.0719; accept 0.07 if the student rounds every row to two decimals and says so.

8. Use your average gain per gram to predict the mass after heating of a 6.00 g pad treated the same way. Show the calculation.

Answer: Predicted gain: $6.00 \text{ g} \times 0.072 \text{ g/g} = 0.43 \text{ g}$. Predicted mass after heating: $6.00 \text{ g} + 0.43 \text{ g} = 6.43 \text{ g}$.

Why: Multiply the starting mass by the average gain per gram and add it to the starting mass. The prediction assumes the larger pad reacts to the same extent as the smaller ones.

Also acceptable: Accept 6.42 g to 6.45 g depending on rounding of the average (0.070 gives 6.42 g; 0.075 gives 6.45 g).

9. Explain the three flask readings (250.00 g sealed before, 250.00 g sealed after, 250.14 g after opening). Where did the pad's extra mass come from, and why did air hiss in?

Answer: Before heating, the sealed flask held the pad plus a fixed amount of air: 250.00 g. While sealed, the iron atoms bonded with oxygen atoms from the air inside the flask to make iron oxide. The pad got heavier by exactly the mass of oxygen it took, and the air inside got lighter by the same amount, so the sealed total stayed 250.00 g; no atoms crossed the glass. When the stopper came off, outside air rushed in to replace the oxygen the pad had used up, and the flask gained 0.14 g, almost exactly the 0.15 g gain Pad B showed in open air. The pad's extra mass came from oxygen atoms that were already inside the flask.

Why: This is the sealed-vessel logic from the reading worksheet applied to the chapter's phenomenon. The refill nearly matches Pad B's gain because the same 2.00 g pad took up the same oxygen. It is a hair less because the air that rushes in only refills the space the used oxygen left, and a liter of air has slightly less mass than a liter of pure oxygen; students do not need to explain the 0.01 g difference, and 'about the same' earns full credit.

Also acceptable: Accept 'the oxygen moved from the air to the pad, so the total inside did not change.'

- Says the sealed total stayed the same because nothing crossed the boundary
- Says the pad's gain came from oxygen in the air inside the flask
- Explains the hiss and the 0.14 g as air replacing the oxygen used

10. Part A shows a reaction whose open reading fell; Part B shows one whose open reading rose. Write one rule about atoms and boundaries that explains all four readings: the open cup, the capped bottle, the open pads and the sealed flask. Then say what a balance reading can and cannot tell you about whether matter was created or destroyed.

Answer: Model rule: Atoms are never created or destroyed in a reaction; they only change partners. A balance reading changes only when atoms cross the boundary of what is on the balance. Open cup: carbon dioxide atoms left, reading fell. Capped bottle: nothing crossed, reading held. Open pads: oxygen atoms from the room joined the iron, reading rose. Sealed flask: oxygen moved from the air inside to the pad, nothing crossed the glass, reading held. A balance can tell you how much matter crossed the boundary and in which direction; it cannot by itself tell you that matter was created or destroyed, because an open system can lose or gain atoms to its surroundings. Only a closed system gives a fair test, and in a closed, rigid system the reading never changes.

Why: Full credit requires one rule that covers both the loss and the gain, applied to all four readings, and a clear statement of what a balance can and cannot show.

Also acceptable: A student who writes the rule as 'mass in + mass out explains every change' and applies it to all four cases has the idea.

- Rule states atoms are conserved and only boundary crossings change the reading
- All four readings explained by the rule
- Says a balance shows matter crossing a boundary, not creation or destruction
- Names the closed system as the fair test

Teacher notes

All numbers are simulated and labeled as such on the sheet. They are consistent with the chemistry: 2.00 g of baking soda reacting completely with excess vinegar makes about 1.05 g of carbon dioxide, and the cup's 1.00 g loss and the bottle's 0.98 g drop are both a little less than that because some gas stays dissolved, which the extension explores. The capped run uses a rigid bottle on purpose: a sealed zip bag that puffs up displaces more air and reads noticeably lighter even though nothing leaves (about 1.2 g for every liter of puff,

roughly 0.65 g for the gas this much baking soda makes; the same effect lifts a balloon); if your Lab 1 bags show a drop, this is why, and a rigid bottle avoids it. Uncapping alone lets out only the extra gas, and carbon dioxide is denser than air and lingers in an upright bottle, which is why the scenario squeezes the bottle before the 300 s reading. The capped run is written as a teacher demonstration because students never seal a reaction in a rigid bottle (Labs 1 and 3); use a carbonated-drink bottle, not a thin water bottle. Steel wool: fine steel wool heated in air gains about 5 to 10 percent of its mass as only part of the iron is converted to iron oxide; a complete reaction would gain much more, and the sheet never asks for that calculation because it would need atomic masses. The sealed-flask experiment is described, not performed: heating a sealed glass vessel is a teacher-only historical demonstration and should not be attempted in a classroom. Common errors: in q2, dividing by 30 instead of 60 for the rate; in q7, dividing gain by the mass after heating instead of before; in q9, saying the pad 'absorbed heat' rather than oxygen. The textbook's figures use grams of reactants and products the same way this sheet does; keep the discussion on mass, never weight.

Scaffold offered to students: Reading the table before you graph

Before plotting, run your finger down the open-cup column and write the drop between each pair of readings in the margin: 0.58, 0.24, 0.10, 0.05, 0.02, 0.01. The drops get smaller, so your curve should be steep at first and nearly flat by the end. The bottle column never changes, so its line is flat. For the rate in q2, $\text{rate} = \text{mass lost} \div \text{time}$, and the unit is grams per second. In Part B, 'gain per gram' means divide the gain by the starting mass, so a 2.00 g pad that gains 0.15 g has $0.15 \div 2.00 = 0.075$ g of gain for each gram of pad.

Extension: The gas that stayed behind

The bottle lost 0.98 g after opening, but the chemistry predicts that 2.00 g of baking soda in this much vinegar should make about 1.05 g of carbon dioxide. Some gas stays dissolved in the liquid, the way carbon dioxide stays in a soda. Design a fair test to find out how much carbon dioxide stayed dissolved: say what you would do to the opened mixture (for example, warm it gently or stir it), what you would measure, and how you would calculate the dissolved amount. Predict the result and explain why stirring a soda makes it go flat.