

Three Balances: Lost, Kept, Gained. Where Did the Grams Go?

Investigation question: When the same reaction runs in an open cup and in a sealed bag, and a damp steel pad sits in air for several days, why does the cup lose mass, the sealed bag keep its mass and the pad gain mass, if matter can never be created or destroyed?

Evidence-based mystery

Groups of 4

2 sessions

Setup 10 · Activity 70 · Cleanup 10 min

MS-PS1-5 · assesses

MS-PS1-2 · supports

Scientific purpose

Students run three systems on a balance and get three different results: an open cup of vinegar and baking soda loses mass, the same reaction sealed in a bag keeps its mass, and a damp steel-wool pad left in air for several days gains mass. Each group must define the boundary of each system, predict the reading before they measure, and then explain all three results with one rule: atoms cross boundaries, but they are never made or destroyed. The steel-wool station reproduces the lesson's mass-gain phenomenon with no flame at all.

Why this helps students with this chapter

A single sealed-bag demonstration tells students that mass is conserved, but it does not confront the two results that make them doubt it: a reading that drops and a reading that rises. Putting all three on the table at once forces students to find the one idea that explains every result, and the prediction step before each measurement makes their own misconceptions visible so the data can correct them.

Standards connections

MS-PS1-5 (assesses, using a model of conserved atoms to explain mass data from open and closed systems): Students draw before-and-after atom pictures of the sealed bag and use the same atom model to explain why an open cup reads lower and a rusting pad reads higher. The explanation that mass changes only when atoms cross the system boundary is the evidence this PE asks for, and no atomic masses or symbolic balancing are needed.

MS-PS1-2 (supports, property evidence that a reaction occurred): Fizzing, the bag inflating and the color change on the pad are taken as given evidence of new substances; students are not re-assessed on identifying a reaction.

Roles (rotate each session)

- **Balance reader:** Zeroes the balance, places and removes items the same way every time, and reads each value aloud twice before it is recorded.
- **Mixer:** Measures the vinegar and baking soda, pours and seals, and handles the steel-wool pad with gloves. Wears goggles the whole time, like everyone.

- **Recorder:** Writes the group's prediction before each measurement, records every reading, and computes the change in mass.
- **Boundary checker:** Before each station, says out loud what the system is and what can cross its boundary, and makes sure the group's prediction matches that boundary.

Materials

Item	Quantity	Per	Note
Digital balance reading to 0.1 g (0.01 g if available, for the steel-wool pads)	1	group	Two groups can share a balance if stations are staggered.
White vinegar (5 percent)	about 100 mL	group	
Baking soda	2 level half-teaspoons (about 2.5 g each)	group	
Clear plastic cups, 250 mL or larger	3	group	One for station A, one to hold vinegar inside the bag at station B, one spare.
Gallon-size zip bag	1	group	Must be gallon size; a quart bag can over-inflate with half a teaspoon of baking soda.
Small paper squares or cupcake liners for the baking soda	2	group	
Fine steel wool pads (grade 00 or 0000, no soap)	2	group	One test pad and one control pad. Buy plain steel wool from a hardware store, not soap-filled scouring pads.
Shallow dish or saucer	2	group	
Spray bottle of tap water	1	class	
Disposable gloves and goggles	1 set	student	
Measuring spoons (half teaspoon) and a 50 mL measuring cup or graduated cylinder	1 set	group	
Recording sheet	1	student	

Estimated cost: 12 to 18 per class (an estimate; Estimate for eight groups: one gallon of vinegar (about \$3), one box of baking soda (about \$1), a pack of 12 fine steel wool pads (about \$5), gallon zip bags and cups (about \$4), gloves from stock. Balances, spoons and dishes are standard classroom equipment.)

Safety

- Goggles on for the whole wet part of the lab. Vinegar stings eyes; rinse with water for several minutes if it gets in.

- Use only the pre-measured half teaspoon of baking soda per bag and only gallon-size bags. Students never seal this reaction in a rigid bottle or jar; the gas pressure can pop a lid or burst a thin container. If a bag balloons tightly, open one corner away from faces.
- Handle steel wool with gloves; the fine fibers can splinter into skin. Do not rub eyes after touching it. Keep steel wool away from any flame or heat source and away from batteries; fine steel wool can ignite from a battery short.
- No burning of steel wool by students. If you choose to show the burning phenomenon, do it yourself behind a shield on a heat-proof tray with goggles, with the room's fire plan in mind, or use a video.
- Wipe spills at once; vinegar on a floor is a slip hazard. Wash hands at the end of both sessions.

Teacher preparation and setup

1. Run station A and station B yourself once with the stated amounts so you know the mass change your balances will show; expect roughly 0.8 to 1.2 g lost at station A with half a teaspoon of baking soda and 30 mL of vinegar.
2. Set up station C (the steel-wool pads) at least three school days before session 2. If the schedule is tight, set the pads up as a whole-class task at the end of a previous lesson.
3. Cut or pull each steel-wool pad into two roughly equal halves so the test pad and control pad start alike; label two dishes per group T (test) and C (control).
4. Pre-measure baking soda into paper squares (half a level teaspoon each) so no group uses more than planned; too much baking soda in a bag is the one way to over-inflate it.
5. Choose a warm, humid spot for the rusting pads (near a sink is fine) that will not be disturbed, and a dry spot where the control pads and, later, the test pads can dry out completely.
6. Print the recording sheet; write the three predictions as a required step on the board so no group measures before predicting.

Investigation design

Independent variable	The boundary of the system: open cup, sealed bag, or damp pad in open air (with a dry control pad)
Dependent variable	Change in mass measured on the balance
Controlled	Same amounts: 30 mL vinegar and half a teaspoon of baking soda at stations A and B; Same balance, zeroed before each reading, items placed the same way; Everything that was on the balance 'before' stays on it 'after' (cup, paper square, bag); Test and control pads from the same steel-wool pad, massed completely dry both times
Trials	One run per station per group; the class pools eight or more runs of each station for the average.
Comparison	Open cup versus sealed bag for the same reaction; damp test pad versus dry control pad over the same days.

Student procedure

1. Session 1, station C first (so it can rust all week): put on gloves. Mass the dry test pad and record it. Mass the dry control pad and record it. Both pads must be completely dry.
2. Dip only the test pad in vinegar for about one minute, squeeze it out gently over the sink, rinse it under the tap for ten seconds, squeeze again and set it on dish T. Mist it with water until damp but not dripping. Leave the control pad dry on dish C in the dry spot. Write the boundary and prediction for station C before leaving it: can anything enter or leave the pad over the week?
3. Station A (open cup): place an empty cup on the balance, pour in 30 mL of vinegar, and set one paper square with half a teaspoon of baking soda beside the cup on the same balance. Write the boundary and prediction, then record the total mass as 'before'.
4. Tip the baking soda into the vinegar (drop the paper square beside the cup so it stays on the balance). Watch the fizzing. When bubbling has stopped and the reading has been steady for 30 seconds, record the 'after' mass. Compute the change.
5. Station B (sealed bag): place the empty gallon bag on the balance with a cup inside it. Pour 30 mL of vinegar into the cup inside the bag. Tip the second half teaspoon of baking soda into a bottom corner of the bag, outside the cup, without letting it touch the vinegar. Squeeze most of the air out and seal the bag completely. Write the boundary and prediction, then record 'before'.
6. Keeping the bag sealed, tilt it so the vinegar pours over the baking soda. Let it fizz; the bag will puff up. When it has settled for 30 seconds, place it on the balance, check that the bag is still puffed and that the reading holds steady for one minute, and record 'after sealed'. Compute the change.
7. Now open one corner of the bag away from faces, gently press the gas out, seal it again, and record 'after opened'. Compute the change from 'before'.
8. Make the atom drawing of the bag on the recording sheet: the same atoms before and after, regrouped, inside a boundary nothing crossed.
9. Between sessions: once a day, a volunteer mists the test pads so they stay damp. The control pads are never wetted.
10. Session 2 (three to five school days later): move the test pads to the dry spot one full day before this session so they are completely dry when massed. Mass the dry test pad and the control pad again. Record both and compute the change for each.
11. Pool the class data on the board: average change at station A, at station B (sealed and opened), and for the test and control pads. Answer the analysis questions individually, then compare within the group.

Expected observations

- Station A: the reading drops as the fizzing proceeds and settles about 0.8 to 1.2 g lower with half a teaspoon of baking soda and 30 mL of vinegar (an estimate; the exact loss depends on the amounts and on how much carbon dioxide stays dissolved).
- Station B sealed: the bag inflates noticeably and the reading drops by roughly 0.5 to 0.7 g, then holds steady while the bag stays puffed. That drop is the lift of the puffed-up bag: the gas fills about 0.6 L, and the air it pushes aside has a mass of about 0.7 g (roughly 1.2 g per liter), so it is a measurement

effect, not lost matter. After opening and venting, the reading drops further, to a total close to, often a little less than, station A's loss.

- Station C: after three to five days the damp test pad turns orange-brown and, once fully dry, reads higher than its starting mass; the gain is small, often a few tenths of a gram on a 2 to 3 g half-pad, and varies with humidity and time. The dry control pad stays gray and changes by no more than the balance's last digit.

Likely difficulties

- Groups measure before they predict; the Boundary checker role and the board rule exist to stop this, and a prediction written after the fact teaches nothing.
- At station A, the paper square or a cup is removed from the balance between readings, which produces a false change; everything that was on the balance before must stay on it after.
- Bags leak at the seal or a corner opens during the pour, so 'sealed' bags lose mass; have groups press the seal twice and check it by squeezing gently before the pour.
- Steel pads are massed while still damp on session 2, which adds water mass and swamps the oxygen gain; the pads must be dry to the touch, and the control pad's reading is the check.
- Balance drift and air currents produce changes of 0.1 g that students treat as real; discuss the balance's precision and use the control pad as a sense of 'no change.'
- Students read the sealed bag's drop as 'matter was lost.' Explain the lift of a puffed-up bag (the air outside pushes up on it, as water pushes up on a beach ball; about 0.6 to 0.7 g for this recipe), compare it with the further drop after venting, and treat a reading that keeps falling, a bag that goes soft, or a drop close to the open cup's as a leak.

Structured debrief

1. Put the class averages on the board side by side: station A negative, station B sealed a smaller negative that held steady, station B opened close to station A, test pad positive, control pad near zero. Ask the class to say what the balance 'saw' at each station and what it missed. Every change is atoms crossing a boundary: carbon dioxide out of the cup and out of the opened bag; oxygen (and water) from the air onto the pad.
2. Return to the predictions table. Ask which prediction was most often wrong (usually the steel pad, predicted to lose mass as it 'wears away'). Discuss why that prediction felt right: in everyday experience rust flakes off and disappears, so the gain is hidden.
3. Raise the sealed bags' drop directly: the puffed-up bag is lifted by the air around it, about 1.2 g for every liter of puff, and this recipe makes about 0.6 L of gas, so a perfect seal reads about 0.6 to 0.7 g low. Ask what reading a bag that did not puff up would give (the same as before), and how the class knows the gas was still inside (the reading held steady, the bag stayed puffed, and opening it lowered the reading further). Optional teacher-only demonstration: the same change in a capped 2-liter carbonated-drink bottle, which cannot puff up, reads the same before and after (see the Lab 3 debrief for precautions). Then compare station A with station B after opening. If the opened bag lost less than the cup, ask why: some gas stayed dissolved or trapped in the bag's corners. Use this to make the point that an open system's loss is only a lower limit on the gas produced.

4. Close on q7: one rule, three stations. The law of conservation of matter was never broken; the balance was only ever reading what was inside the boundary. Ask students which station came closest to direct evidence for the law (B, sealed, once the lift is accounted for, or the teacher's capped bottle) and which gave indirect evidence that needed the atom model (A and C).

Recording sheet: what students fill in

Lab 1 recording sheet: Three balances

Rule of the lab — Before every measurement, your Boundary checker says what the system is and what can cross its boundary, and your Recorder writes the group's prediction (up, down or same, and why). Then you measure. Predictions are never erased.

Boundaries and predictions

Station	What is the system? (everything on the balance)	Can matter enter or leave? What kind?	Prediction: reading goes up, down or stays the same	Reason for the prediction
A: open cup				
B: sealed bag				
B: bag after opening				
C: damp test pad in air				
C: dry control pad				

Mass data, stations A and B (session 1)

Station	Mass before (g)	Mass after (g)	Change (after minus before, g)	What you saw
A: open cup				
B: bag, still sealed				
B: bag after opening and resealing				

Mass data, station C (session 1 and session 2)

Pad	Dry mass, day 1 (g)	Dry mass, session 2 (g)	Change (g)	Color and texture on session 2
Test pad (kept damp)				
Control pad (kept dry)				

- ✏ Draw the sealed bag at station B twice: before the vinegar reaches the baking soda, and after the fizzing stops. Use simple circles for atoms (label the kinds you use) and show the bag as the boundary. Your two drawings must contain the same atoms. Write one sentence under them explaining why the total mass inside the bag cannot change.

Answer: Two pictures inside the same bag outline. Before: molecules of vinegar's acetic acid and units of baking soda drawn as labeled circles (for example C, H, O, Na), in the liquid and in the corner. After: the same circles regrouped into carbon dioxide (one C with two O) in the puffed-up space, water (two H with one O) and sodium acetate in the liquid. Sentence: no atoms crossed the bag, every atom keeps its mass, so the total mass cannot change.

Why: The drawing is the model MS-PS1-5 asks for. Exact molecule shapes are not required; what matters is that the atom inventory is identical on both sides and the boundary is shown. Students need not know the formula of sodium acetate; a labeled 'leftover group' of Na, C, H and O atoms is fine.

Also acceptable: Accept pictures that simplify vinegar and baking soda to a few representative atoms as long as the count is identical before and after.

- Same number of each labeled atom in both pictures
- Atoms regrouped into at least one new substance, with the gas shown inside the bag
- The bag drawn as the boundary with nothing crossing it
- Sentence links unchanged atoms to unchanged mass

1. Which of your three predictions was wrong, if any? Copy the prediction and write what the balance actually showed.

Answer: Group-specific. Most commonly the station C prediction was 'down' (rust wears away) and the balance showed a gain; sometimes station A was predicted 'same' because 'matter is conserved' and the balance showed a loss.

Why: The purpose of this item is to make the student confront their own prediction with data. Any honest comparison earns credit.

- Quotes the actual prediction
- States the measured direction and size of the change

2. At station B the bag puffed up, the sealed reading dropped less than the open cup's and held steady, and opening the bag made it drop further. What was in the puffed-up part of the bag, and why did the reading fall again only when the bag was opened?

Answer: Carbon dioxide gas made by the reaction. It stayed inside the sealed bag, so its atoms and their mass stayed on the balance; that mass was already there before the reaction, inside the vinegar and baking soda. The sealed reading still dipped because the puffed-up bag pushes aside air and the air pushes up on it (about 1.2 g per liter of puff, roughly 0.6 to 0.7 g for this much gas). When the bag was opened, the gas itself left, so the reading fell again, to about the open cup's loss.

Why: Students must connect the visible inflation with the invisible gas, see that its atoms were on the balance all along, and use the further drop on opening as evidence that the gas was still inside until then. A student who explains the further drop but not the lift earns most of the credit.

- Names the gas (carbon dioxide, or 'the gas from the reaction')
- Says the gas and its atoms stayed inside the boundary until the bag was opened
- Explains the later drop as the gas leaving through the opened boundary
- Gives the lift of the puffed bag as the reason the sealed reading dipped

Analysis questions: answer key

3. Station A lost mass and station B did not, yet the same reaction ran in both. Use the words 'system' and 'boundary' to explain the difference.

Answer: The system is everything on the balance. At station A the boundary was open: carbon dioxide made by the reaction could leave the cup and escape into the room, so its atoms left the system and the reading dropped. At station B the sealed bag was the boundary and nothing could cross it; the same gas formed but stayed inside, so the mass stayed the same; the smaller, steady dip in the sealed reading is the lift of the puffed-up bag, not gas leaving. Mass was conserved in both; only the open system let some of it leave.

Why: This is the central explanation. Full credit requires the gas to be named as what crossed the boundary and the statement that matter was conserved in both cases.

- Uses system and boundary correctly
- Identifies carbon dioxide leaving at A and staying at B
- States that mass was conserved in both

4. Compare the change at station A with the change at station B after you opened the bag. Should they be about the same? Explain what the opened bag and the open cup have in common.

Answer: They should be similar, since both let the gas escape, but the opened bag often loses a little less. The open cup and the opened bag have the same thing in common: a boundary the gas can cross. The bag can hold back some gas in its corners, and some carbon dioxide stays dissolved in the liquid in both setups.

Why: Students compare two open systems and recognize that an open-system loss measures only the gas that actually left.

- Predicts similar losses
- Identifies the shared open boundary
- Offers a reason for any difference (gas retained in the bag or dissolved)

5. The damp test pad gained mass while the dry control pad did not. Where did the extra mass come from? Name the atoms and where they were before.

Answer: From the air. Oxygen atoms in the air (with water molecules helping the reaction) bonded to iron atoms in the pad to form rust, an iron oxide. Those oxygen atoms were in the room's air before, where the balance could not count them; after the week they were part of the pad, where it could. No atoms were created.

Why: This is the lesson's phenomenon reproduced without flame. The student must name oxygen as the source and locate it before and after.

Also acceptable: Credit answers that also mention water joining the rust; real rust contains water.

- Names oxygen from the air as the added matter
- Says the oxygen atoms bonded to iron atoms (new substance, rust)
- States that nothing was created; atoms moved into the system

6. Why did the lab include a dry control pad at all? What result on the control pad would have made you distrust the test pad's gain?

Answer: The control shows what happens to a pad that was handled and massed the same way but not allowed to rust. If the control pad had also gained mass, the gain could have come from something other than rusting, such as moisture, dust or the balance drifting, and the test pad's result would not be trustworthy.

Why: Assesses whether the student understands a control as the comparison that isolates the variable.

- Explains the control as 'same treatment, no rusting'
- Names a result on the control (a gain) that would undermine the test pad's evidence

7. Write one rule that explains all three results (down, same, up) and show how it applies to each station.

Answer: Rule: atoms are never created or destroyed in a reaction, so the total mass of a system changes only when atoms cross its boundary. Station A: carbon dioxide atoms left the open cup, reading down. Station B: nothing crossed the sealed bag, so its mass stayed the same (the reading dipped only from the lift of the puffed bag and fell the rest of the way only when the gas was let out). Station C: oxygen atoms from the air joined the pad, reading up. In all three the atoms are all still somewhere.

Why: The single-rule answer is the main assessment of the lab. It must apply to all three stations and name the direction of atom movement at each.

- States conservation of atoms or matter
- States that readings change only when matter crosses the boundary
- Applies the rule correctly to A (out), B (none) and C (in)

8. Suppose a group's sealed bag read 0.6 g lower after the reaction. Give two possible explanations and one way to tell them apart.

Answer: Two possible explanations. First, the bag leaked: gas escaped through an incomplete seal or a corner that opened during the pour. Second, the puffed-up bag was lifted by the air around it: about 1.2 g of lift per liter of puff, and this recipe makes about 0.6 L of gas, so even a perfect seal reads about 0.6 to 0.7 g low. To tell them apart: watch the reading for several minutes (a leak keeps falling and the bag goes soft; lift holds steady while the bag stays puffed); open and vent the bag (if the gas was still inside, the reading drops further, to about the open cup's loss; if it had leaked, it barely changes); or squeeze the sealed bag gently under water and look for bubbles.

Why: Students should look for a boundary failure or a measurement effect before doubting the law. Full credit needs both explanations and a test that separates them; the strongest answers use the steady reading or the vent test to decide.

Also acceptable: Accept 'vinegar splashed out when opening' or 'the balance drifted' with a matching test.

- Names a leak and the lift of the inflated bag as possible causes
- Proposes a test that separates them (watch over time, vent and compare, or a bubble check)

9. A classmate says, 'The cup reading dropped by 1.1 g, so the reaction must have made 1.1 g of gas.' Was the mass of gas the reaction made less than 1.1 g, exactly 1.1 g, or 1.1 g or more? Explain.

Answer: 1.1 g or more, most likely a little more. The balance can only show the gas that actually left the cup. Some carbon dioxide stays dissolved in the liquid or lingers in the cup, so the total gas made is at least 1.1 g.

Why: This separates 'mass lost' from 'gas produced' and prepares students for Lab 3, where the goal is to trap all of it. A little water vapor also leaves with the bubbles, but it is usually smaller than the gas that stays dissolved, so 'at least 1.1 g' is the expected reasoning.

- States '1.1 g or more' (at least 1.1 g)
- Explains that some gas stays dissolved or in the cup, so the loss is a lower limit

Individual evidence of learning

Each student submits their own completed boundary and prediction table, both data tables, the atom drawing of the sealed bag with its sentence, and written answers to q1 through q9. The drawing and q7 are the primary evidence for MS-PS1-5; q5 and q6 show whether the student can read the control.

Assessment criteria

Criterion	Proficient looks like
Boundary and prediction	Each station's system is named as everything on the balance, the kind of matter that can cross is identified, and each prediction is written before measuring with a reason that refers to atoms entering or leaving.
Atom model of the closed system	The two bag drawings contain the same labeled atoms regrouped into new substances, with the boundary shown, and the sentence states that no atoms crossed so the mass cannot change.
One rule for three results	q7 states that atoms are conserved and the reading changes only when atoms cross the boundary, and applies it correctly to the lost gas (A), the kept gas (B) and the joined oxygen (C).

Reading the control and the data

Explains the role of the control pad, treats changes within the balance's precision as 'no change,' and explains the difference between an open-cup loss and the total gas made.

Accessibility adaptations

- Provide a prediction word bank (up, down, same) and a sentence frame: 'The reading will go ___ because ___ atoms will ___ the system.'
- Let a partner pour and seal while a student with limited fine-motor control reads the balance aloud and records; accept spoken answers for q3, q5 and q7 recorded on a device.
- Offer a half-completed atom drawing (reactant side drawn, product side blank, atom key given) for students who need more support, and large-print tables.
- Give a printed glossary card for system, boundary, open, closed, reactant and product in English and the student's home language.

Low-cost alternative

Run station A and station B as one class demonstration on a single balance while groups write predictions and readings, and set up a single pair of steel-wool pads for the class. If no balance reads to 0.1 g, the teacher can double the amounts as a demonstration (one teaspoon of baking soda and 60 mL of vinegar, in a gallon bag with the air fully squeezed out), so the open-cup loss is about 2 g and shows on a 1 g balance; expect the sealed bag to read about 1 to 1.5 g low from the lift of its larger puff until it is vented.

Model limitations

A balance only sees what is inside the system you put on it, which is the point of the lab, but it also means small leaks, damp pads and air currents show up as 'mass changes' that have nothing to do with atoms being created or destroyed. The steel-wool station models the lesson's burning phenomenon with slow rusting instead of fast burning: the product is a hydrated iron oxide formed with both oxygen and water, so Fe_2O_3 from the slides is a model of it, not an exact description, and a little vinegar residue could add to the test pad's mass, which is why the control pad matters. A sealed bag that puffs up is also buoyed by the air it displaces, about 1.2 g per liter, so with this recipe the closed system reads about 0.6 to 0.7 g low without any leak, roughly two-thirds of the gas's own mass; a rigid container would avoid this but is not safe for students because pressure builds inside it. This activity has not been physically tested by the authors; the stated mass changes are estimates from the amounts used.

Teacher notes

Insist that predictions are written before every measurement and never erased; the wrong predictions are the most valuable part of the sheet. Expect the sealed bags to read about 0.6 to 0.7 g low from the lift of the inflated bag (about 0.6 L of gas, and each liter of puff lifts about 1.2 g); that is roughly two-thirds of what the open cup loses, so say it plainly before the data go on the board. Treat a reading that keeps falling, a bag that goes soft, or a drop close to station A's as a leak (q8) and, if time allows, let them rerun. The steel-wool gain is small and depends on humidity; if your pads gain less than the balance can resolve, pool all the test pads on one balance against all the control pads, which multiplies the signal by the number of groups. Keep the rusted pads for the slide on burning steel wool; passing a rusted pad and a fresh pad around makes the 'oxygen joined the iron' idea tangible.