

White Powder In, White Powder Out: Did Heating Make a New Substance?

Learning target: I can use before-and-after measurements of mass, solubility and behavior, together with control samples, to argue whether heating turned a substance into a different one, and say which evidence is strongest.

Claim, evidence, reasoning

About 40 min

Individual

MS-PS1-2 · assesses

writing

data analysis

Standards connections

MS-PS1-2 (assesses, interpreting solubility and odor data before and after a substance is heated to decide whether a reaction occurred, and choosing density as the next test): Students receive property data for a powder before and after heating, plus two control samples, and must decide in a written argument whether a new substance formed. Solubility, odor and density are inside the PE's assessment boundary; the mass loss and the fogged plate are treated as clues that need the property data to become a claim.

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

Answers with reasoning

The scenario

Ms. Tran's class is testing a claim from a cookbook: 'Baking soda baked in a dry pan for twenty minutes becomes a different, stronger powder.' Elena, the student running the test, weighs 10.0 g of baking soda into a dry metal pan and heats it on a hot plate set to about 150 °C for twenty minutes (the teacher handles the hot plate). To be fair, she sets up two more samples. Sample 2 is 10.0 g of baking soda in an identical pan that is **not** heated. Sample 3 is 10.0 g of table salt heated exactly like Sample 1. Afterward, every powder is cooled and tested at 20 °C.

Elena's observations during the twenty minutes — Sample 1 (baking soda, heated): a faint hiss for the first few minutes; a cold glass plate held above the pan fogged with tiny droplets during minutes 1 to 6, then stayed clear; gas led through a tube into limewater turned it cloudy; the powder stayed white and gave off no smell. Sample 2 (baking soda, not heated): nothing seen. Sample 3 (table salt, heated): no hiss, the cold plate stayed clear, the limewater stayed clear, the powder stayed white.

Table 1. Tests on each sample before and after the twenty minutes (teaching dataset)

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

Sample	Mass before (g)	Mass after (g)	Solubility before (g per 100 mL)	Solubility after (g per 100 mL)	Fizzes with vinegar: before / after	Odor: before / after	Heated a second time
1: baking soda, heated	10.0	6.3	9.5	21.8	yes / yes	none / none	no fog on the plate, no mass lost
2: baking soda, not heated	10.0	10.0	9.5	9.6	yes / yes	none / none	not tested
3: table salt, heated	10.0	10.0	36	36	no / no	none / none	no fog on the plate, no mass lost

Simulated data for teaching. All solubility tests at 20 °C in 100 mL of water; repeat tests on the same powder agree within 1 g per 100 mL.

Table 2. Reference values for three white powders kept in the stockroom (real values, rounded)

Powder	Density (g/cm ³)	What it does when heated	Solubility at 20 °C (g per 100 mL)
Baking soda (sodium bicarbonate)	2.20	breaks down above about 80 °C instead of melting; gives off water vapor and carbon dioxide	9.6
Washing soda (sodium carbonate)	2.54	melts at 851 °C	about 21.5
Table salt (sodium chloride)	2.17	melts at 801 °C	36

Table 2 is not part of Elena's data. Use it only for q4.

Warm-up: organize the evidence

1. List the three clues Elena noticed for Sample 1 during heating (one from the plate, one from the limewater, one from the balance). For each, say what it **suggests** happened, and why none of them by itself proves a new powder was made.

Answer: Clue 1: the cold plate fogged with droplets, which suggests water vapor left the powder and condensed on the cold glass. Clue 2: the limewater turned cloudy, which suggests carbon dioxide gas came out of the pan. Clue 3: the mass fell from 10.0 g to 6.3 g, which suggests something left the pan as gas. None of these proves that the powder left behind is a different substance: water could have been moisture clinging to the powder, a gas can escape from a mixture without changing the solid, and a mass loss only says something left, not what remains. Proof needs the properties of the powder that is left.

Why: Students must separate 'something left the pan' from 'what remains is different'. The chapter's rule is that clues suggest and property comparisons confirm.

Also acceptable: Accept 'hissing' as a fourth clue; accept 'steam' for the fog.

- Three clues: fog, cloudy limewater, mass loss
- Each paired with what it suggests
- States that clues do not identify the remaining powder

2. Why did Elena include Sample 2 and Sample 3? State what each control sample rules out as an explanation for Sample 1's results.

Answer: Sample 2 (baking soda, not heated) rules out time and handling: baking soda left in a pan for twenty minutes keeps its mass (10.0 g) and solubility (9.5 to 9.6 g per 100 mL), so Sample 1's changes were caused by the heating, not by sitting in a pan. Sample 3 (table salt, heated) rules out the idea that heating itself changes a solubility reading or a mass: salt heated the same way kept its mass and its solubility of 36 g per 100 mL, no plate fog and clear limewater. So heating only changed the powder that could react; it did not change the measuring.

Why: Each control isolates one alternative explanation. The salt control is the stronger one because it shows the heating step does not fake a change.

Also acceptable: Accept 'Sample 3 shows that heating does not change every powder' as the Sample 3 point.

- Sample 2 rules out change from time or handling
- Sample 3 rules out heating changing the measurement itself
- Uses numbers from Table 1

3. Calculate (a) the mass Sample 1 lost and that loss as a percentage of the starting mass, and (b) how many times larger Sample 1's 'after' solubility is than its 'before' solubility. Show your work.

Answer: (a) Mass lost: $10.0\text{ g} - 6.3\text{ g} = 3.7\text{ g}$. Percentage: $3.7 \div 10.0 \times 100 = 37\%$. (b) Solubility ratio: $21.8 \div 9.5 = 2.3$, so the 'after' powder is about 2.3 times as soluble as the 'before' powder at 20 °C.

Why: Both calculations are straightforward; the 37% figure is large enough that moisture alone cannot explain it, and the ratio shows the solubility change is far outside the 1 g repeat spread.

Also acceptable: Accept 2.29 or 'about 2.3 times'; accept 37 percent or 0.37.

Your argument

Answer: Claim: Heating turned the baking soda in Sample 1 into a different substance. The control samples did not change. Evidence: (1) Sample 1's solubility at 20 °C rose from 9.5 g per 100 mL to 21.8 g per 100 mL, a change of 12.3 g per 100 mL when repeat tests agree within 1 g. (2) Sample 1 lost 3.7 g (37%) of its mass while a cold plate fogged and limewater turned cloudy, so water vapor and carbon dioxide left the powder. (3) Heated a second time, Sample 1 lost no mass and fogged no plate, so the powder that remains does not do what baking soda does when heated. (4) Sample 2 kept its mass (10.0 g) and solubility (9.5 to 9.6 g per 100 mL), and Sample 3 kept its mass (10.0 g) and solubility (36 g per 100 mL) with no fog or cloudy limewater. Reasoning: Each pure substance has its own characteristic solubility at a given temperature. The 'before' and 'after' tests were done at the same temperature, 20 °C, so the only way the solubility can more than double is if the powder is now a different substance. The controls make this stronger: Sample 2 shows that time in a pan changes nothing, and Sample 3 shows that heating does not change the mass or solubility of a substance that does not react, so the change in Sample 1 came from the heating acting on baking soda itself. The fog, the limewater and the lost mass fit this: part of the baking soda left as water vapor and carbon dioxide, so what remains cannot be baking soda. I would show a skeptic the solubility numbers first, because they are a measured characteristic property compared under identical conditions, with a difference twelve times larger than the measurement spread. The powder still fizzing with vinegar does not weaken the claim: products differ from reactants in some characteristic properties, not all of them, and the solubility, the mass and the second-heating behavior have all changed.

Why: This is the solved model response. Full credit needs a clear two-part claim, at least three evidence items with sample labels and numbers including one property compared before and after, use of both controls, reasoning that links same-temperature solubility to substance identity, a stated 'strongest evidence' with a reason, and an answer to the fizz objection.

Also acceptable: A student who names the second-heating result as the strongest evidence has made a reasonable choice if the reason given is that the new powder lacks baking soda's chemical property. A student who claims 'no new substance because it still fizzes and looks the same' has ignored the solubility and mass data; that response earns partial credit only for evidence organization.

- Claim: new substance in Sample 1; controls unchanged
- Solubility before/after with numbers at the same temperature
- Mass loss with the fog and limewater clues
- What Samples 2 and 3 showed, with numbers
- Reasoning: characteristic property, same conditions, controls rule out alternatives
- Names the strongest evidence and why
- Explains why the shared fizz does not undo the claim

Follow-up

4. Elena wonders what the new powder is. Compare Sample 1's 'after' results with Table 2. Which stockroom powder matches best, and which property in Table 2 that Elena has **not** measured could she test next to check? Say what result would support the match.

Answer: Washing soda (sodium carbonate) matches best: its solubility at 20 °C is about 21.5 g per 100 mL, close to Sample 1's 21.8 g per 100 mL, and it melts rather than breaking down, which fits 'no mass lost' on the second heating. Baking soda is ruled out by the solubility (9.6) and table salt by the solubility (36). Elena has not measured density. A density close to 2.54 g/cm³ would support the match, while a density near 2.20 g/cm³ would point back to baking soda. (Melting at 851 °C would also fit, but that is far too hot for a classroom.)

Why: The point is to pick a property not yet measured and to say in advance what result would support the identification. Density is inside the assessment boundary; a classroom can measure it by liquid displacement in a liquid the powder does not dissolve in, which is teacher-level detail.

Also acceptable: Accept 'test whether it fizzes with vinegar' only if the student notes that washing soda also fizzes, so that test cannot separate the two; density is the deciding test.

- Picks washing soda using the solubility match
- Names density (or melting behavior) as the untested property
- States the supporting result (about 2.5 g/cm³)

5. A classmate argues: 'Sample 1 is white, has no smell and still fizzes with vinegar, exactly like baking soda, so nothing really changed.' Respond using the idea that a product differs from its reactant in **some** characteristic properties, not necessarily all.

Answer: Sharing some properties does not make two substances the same. Thousands of substances are white, odorless powders, and both baking soda and washing soda fizz with vinegar, so those three traits cannot tell them apart. A product must differ from its reactant in at least some characteristic properties, and Sample 1 does: its solubility at 20 °C more than doubled, 37% of its mass left as gases, and it no longer gives off gas when heated. The matching traits are weak evidence; the differing ones are strong.

Why: This corrects the 'entirely different properties' overstatement from the other direction: products can share properties with reactants, and a few shared traits do not outweigh changed characteristic ones.

Also acceptable: Accept an answer that cites the aspirin example from the chapter (same color and density, different melting point and solubility).

- States that shared properties do not prove sameness
- Cites at least one changed characteristic property
- Explains that products differ in some, not all, properties

Scoring rubric

Criterion	4 • Exemplary	3 • Proficient	2 • Developing	1 • Beginning
Claim	States clearly that Sample 1 became a different substance and that Samples 2 and 3 did not change.	States that Sample 1 became a different substance; the controls are not mentioned in the claim.	Claim is hedged ('something might have changed') or addresses only the gas, not the powder.	No claim, or a claim that contradicts the data.

Evidence	Three or more pieces with numbers and sample labels, including the solubility comparison at the same temperature and what both controls showed.	Three pieces with numbers, but one control is missing or the temperature condition is not mentioned.	One or two pieces, or evidence listed without numbers or sample labels.	Evidence missing, invented, or copied from Table 2 instead of Elena's data.
Reasoning	Links a changed characteristic property under the same conditions to a different substance, explains what each control rules out, names the strongest evidence with a reason, and answers the fizz objection.	Links the property change to a new substance and uses the controls, but omits the strongest-evidence choice or the fizz objection.	Restates evidence without explaining why solubility identifies a substance, or treats the mass loss or fog as proof by itself.	No reasoning, or reasoning that relies on 'it got hot' or 'gas came out' alone.
Scientific language and accuracy	Uses reactant, product, physical and chemical property, solubility, control and characteristic property correctly; no science errors.	Terms mostly correct; one minor slip (for example, 'weight' for mass or 'melted' for broke down).	Several terms used loosely (clue and proof treated as the same; dissolve and react confused).	Scientific language absent or consistently wrong.

Teacher notes

The science is real: sodium bicarbonate breaks down on heating into sodium carbonate, water vapor and carbon dioxide; 10.0 g of baking soda leaves 6.3 g of sodium carbonate, which is why 37% of the mass is lost, and sodium carbonate does not break down further at hot-plate temperatures. Table 1 is a simulated teaching set built around those facts; Table 2 values are real and rounded (densities 2.20, 2.54 and 2.17 g/cm³; sodium carbonate melts at 851 °C and sodium chloride at 801 °C; solubility at 20 °C about 9.6, 21.5 and 36 g per 100 mL). Sodium carbonate also fizzes with vinegar, which is why that test is deliberately uninformative here; its solution is also more strongly basic than baking soda's, which is beyond this lesson. If you run the heating as a demonstration, keep it to the teacher, use a dry pan on a hot plate, and do not exceed about 200 °C; nothing is tasted. The 'cookbook claim' is a framing device; the lesson stays on evidence, not on baking.

Scaffold offered to students: Evidence grid before writing

On scrap paper, draw a grid with the three samples across the top and these rows down the side: mass, solubility, fizz, odor, plate, limewater, second heating. Fill each cell with the number or word from the tables. Circle every cell where 'after' differs from 'before'. The circled cells in Sample 1's column are your evidence; the uncircled cells in Samples 2 and 3 are what your controls show. Sentence frame: 'Before heating, Sample 1 dissolved ____; after, it dissolved ____ at the same temperature, so ____.'

Extension: Where did 3.7 grams go?

The fogged plate and the cloudy limewater show that water vapor and carbon dioxide left the pan.

Design a way to catch and weigh what escaped, using a sealed container with a balloon or a bag, so that you could test whether the mass that left the pan equals the mass that the gases gained. Draw the setup, list what you would weigh before and after, and predict the numbers if the total mass is conserved. Then write two sentences on why this test belongs to the next lesson (tracking atoms) rather than to the question answered here (did a new substance form?).