

Mystery Powders: Reactions as Fingerprints

Investigation question: Can the way a white powder behaves with water, vinegar and a baking soda solution identify it, and how many tests does it take to be sure?

Evidence-based mystery

Groups of 4

1 session

Setup 8 · Activity 35 · Cleanup 7 min

MS-PS1-2 · practice

Scientific purpose

Students build a fingerprint table for three known white powders (baking soda, Epsom salt, calcium chloride) using three tests, then use the table to identify three unknowns, one of which is a mixture of two knowns. The lab makes the chapter's central idea concrete: a substance is known by its properties, and a chemical property such as fizzing with vinegar is as good a fingerprint as a physical property such as solubility. It also forces students to sort each test result into 'a reaction happened' or 'it just dissolved'.

Why this helps students with this chapter

Students tend to think identification means looking harder. Three powders that look the same defeat that, and the only way through is to let each powder interact with something and record what happens. Finding that one unknown fizzes with plain water, which none of the knowns do, pushes students to reason about a mixture whose parts react with each other, which is a genuine mystery rather than a lookup.

Standards connections

MS-PS1-2 (practice, using property data, including how substances behave when they interact, to identify substances and recognize when a reaction has occurred): Students record what happens when each powder meets water, vinegar and a baking soda solution, decide which results are reactions and which are dissolving, and use the pattern to identify unknowns. This builds the before-and-after reasoning of the PE without yet asking for a full reaction-or-not judgment on measured properties, which Lab 2 does.

Roles (rotate each session)

- **Tester:** Measures the level quarter-teaspoon of powder, adds the 10 mL of liquid, and stirs for the same 20 seconds every time.
- **Observer:** Reads the thermometer before and 60 seconds after mixing, watches for fizz and cloudiness, and calls out observations in plain words.
- **Recorder:** Writes every observation in the fingerprint table as it is called out, including 'no change', and makes sure no cell is left blank.
- **Safety and materials captain:** Checks goggles are on before any pouring, labels every cup before it is used, keeps the tray tidy, and runs the cleanup checklist.

Materials

Item	Quantity	Per	Note
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Baking soda (known K1)	about 5 g (1 teaspoon)	group	
Epsom salt (known K2)	about 5 g (1 teaspoon)	group	
Calcium chloride pellets (known K3)	about 5 g (1 teaspoon)	group	Ice-melt or moisture-absorber pellets whose label says calcium chloride only; crush large pellets with a spoon in a bag.
Unknowns X, Y and Z in labeled cups	3 cups, about 1 teaspoon each	group	X = calcium chloride, Y = Epsom salt, Z = a half-and-half mix of baking soda and calcium chloride, mixed dry the same day.
White vinegar	80 mL	group	
Baking soda test solution	80 mL	group	Teacher-made: 1 level teaspoon baking soda stirred into 100 mL warm water until clear.
Tap water at room temperature	100 mL	group	
Small clear plastic cups (30 to 60 mL)	20	group	
Quarter-teaspoon measure and plastic spoons	1 measure, 6 spoons	group	
Graduated cup or syringe marked at 10 mL	1	group	
Digital thermometer (reads to 0.1 °C)	1	group	An inexpensive probe thermometer works; wipe it between cups.
Splash goggles	1 pair	student	
Tray, paper towels, marker for labeling cups	1 set	group	

Estimated cost: 20 to 30 per class, most of it reusable (an estimate; Estimate. Baking soda (\$1), Epsom salt (\$5 for 2 lb), calcium chloride ice melt (\$10 to \$15 for the smallest jug), vinegar (\$3), 200 small cups (\$6). Thermometers and goggles are assumed to be classroom stock; add about \$8 per probe thermometer if not.)

Safety

- Splash goggles on from the first pour to the last rinse. Vinegar and calcium chloride solutions sting eyes.
- Nothing is tasted or smelled up close; waft gently if you must check for a smell. Keep hands away from your face and wash them at the end.
- Calcium chloride is a skin and eye irritant and its solution gets warm. Use only the level quarter-teaspoon, never touch the solution, and tell the teacher if a cup feels hot.
- Unknown Z fizzes in water; keep every cup uncovered and never seal anything that is fizzing.

- Wipe spills at once; wet powders are slippery. All solutions go down the sink with running water; solids and cups go in the trash.

Teacher preparation and setup

1. Mix unknown Z the day you use it: equal spoonfuls of baking soda and calcium chloride stirred dry in a cup. Calcium chloride pulls moisture from the air, so a mix made days ahead can clump and begin to react in the cup.
2. Make the baking soda test solution (1 teaspoon per 100 mL warm water, stir until clear) and pour 80 mL per group into a labeled cup.
3. Run the three tests on the three knowns yourself to learn the temperature changes your pellets give; the calcium chloride warming depends on whether the pellets are anhydrous or hydrated. Adjust the powder amount down if a cup gets uncomfortably hot.
4. Label the unknown cups X, Y, Z and keep the key (X = calcium chloride, Y = Epsom salt, Z = mixture) out of sight; do not use the same letters as last year's class.
5. Print one recording sheet per student; pre-label 18 cups per group if you want to save time (K1-water, K1-vinegar, K1-soda, and so on).

Investigation design

Independent variable	Which powder is tested (K1, K2, K3, X, Y, Z) and which liquid it meets (water, vinegar, baking soda solution)
Dependent variable	What is observed: dissolving, temperature change, fizz, cloudiness
Controlled	Level quarter-teaspoon of powder every time; 10 mL of liquid every time, at the same starting temperature; Same 20 seconds of stirring and same 60-second wait before the temperature reading; Same cups, spoons and thermometer for every test
Trials	One trial per powder-liquid pair; repeat any test the group cannot agree on. Class results are pooled on the board to check that the fingerprints are consistent across groups.
Comparison	Each unknown's row is compared with the three known rows; a match on all three tests identifies it.

Student procedure

1. Put on goggles. Label nine cups for the knowns: K1, K2 and K3 each with 'water', 'vinegar' and 'soda solution'. Label nine more for X, Y and Z the same way.
2. Read the temperature of the water, the vinegar and the soda solution before any mixing and record each as the starting temperature for that liquid.
3. Water test on the knowns: put a level quarter-teaspoon of K1 in its water cup, add 10 mL water, stir 20 seconds. Record whether it dissolves (all, some, none) and the temperature after 60 seconds. Repeat for K2 and K3 with clean spoons.

4. Vinegar test on the knowns: a level quarter-teaspoon of each known in its vinegar cup, 10 mL vinegar, stir 20 seconds. Record fizz (none, slight, strong), whether it dissolves, and the temperature after 60 seconds.
5. Soda-solution test on the knowns: a level quarter-teaspoon of each known in its soda-solution cup, 10 mL baking soda solution, stir 20 seconds. Record whether the liquid turns cloudy, any bubbles, and the temperature after 60 seconds.
6. Look at the fingerprint table. For each cell, mark R if you think a chemical reaction happened (a new substance formed) and P if the powder only dissolved. Discuss until the group agrees.
7. Run the same three tests on unknowns X, Y and Z in the same order, with the same amounts and times. Record everything, including anything that none of the knowns did.
8. Match each unknown to a known fingerprint. If an unknown does not match any single known, ask whether it could be two knowns mixed together and what evidence would show that.
9. Answer the analysis questions on your own, then compare within the group. Rinse the thermometer, pour liquids down the sink with running water, and bin the cups.

Expected observations

- Baking soda: dissolves slowly and only partly in 10 mL water with a small drop in temperature (about 1 to 3 °C); fizzes strongly in vinegar with the cup cooling slightly; no change in the baking soda solution.
- Epsom salt: dissolves fully in water with a small drop in temperature (about 1 to 2 °C); dissolves in vinegar with no fizz; stays clear in the baking soda solution, possibly a faint haze after several minutes.
- Calcium chloride: dissolves in water and the temperature rises clearly (roughly 8 to 15 °C with a level quarter-teaspoon in 10 mL, depending on the pellets); dissolves in vinegar with warming and no fizz; the baking soda solution turns cloudy white within a minute and may show slow small bubbles.
- Unknown Z fizzes, warms and turns cloudy in plain water; in vinegar it fizzes and warms; in the soda solution it clouds and bubbles.

Likely difficulties

- Groups read the thermometer too soon or leave it in the cup from the last test; insist on the 60-second wait and a wipe between cups.
- The baking soda water cup looks like 'did not dissolve' because the amount is near the solubility limit; 'some' is the right answer, and it is a chance to talk about solubility as a measurable property.
- The Epsom salt haze in the baking soda solution, if it appears after a few minutes, tempts students to call it cloudy; compare it with the calcium chloride cup, which clouds fast and heavily, and record the timing.
- Students want to call Z a brand-new fourth powder. Push them to the fingerprint table: which knowns, together, explain all three clues?
- Pellet size varies; a heaped spoon of large pellets is not a level quarter-teaspoon. Crush pellets before class.

Structured debrief

1. Pool the known fingerprints on the board. Every group should have baking soda as the only fizzer with vinegar and calcium chloride as the only warmer and the only one to cloud the soda solution. Ask what it means that six groups got the same fingerprints: properties are characteristic of the substance, not of the group that tested it.
2. Take Z apart in public. Z fizzed, warmed and clouded in plain water. No known did that alone, but baking soda plus calcium chloride does all three once water lets them meet: the warming is the calcium chloride dissolving, and the fizz and cloud are the two dissolved substances reacting. Ask which of Z's three clues were physical and which were a reaction.
3. Sort every cell of the fingerprint table into R or P as a class. Dissolving and temperature changes in water are P; fizzing with vinegar and clouding the soda solution are R. Ask how students knew: in the P cells the original substance could be recovered by drying; in the R cells a gas or a solid appeared that was not there before and that has different properties from the starting solids.
4. Close on q7: one matching test narrows the list, it does not finish the identification. Scientists use several independent properties, which is why the aspirin chemist on the slides measured solubility and melting point rather than stopping at 'white powder'.

Recording sheet: what students fill in

Lab 1 recording sheet: Mystery powders

Starting temperatures: water ____ °C, vinegar ____ °C, baking soda solution ____ °C. Fill in every cell, including 'no change'. After the knowns are done, mark each cell R (reaction) or P (physical change only).

Fingerprints of the known powders

Known powder	Water: dissolves? (all/some/none)	Water: temperature after 60 s (°C)	Vinegar: fizz? (none/slight/strong)	Vinegar: temperature after 60 s (°C)	Baking soda solution: cloudy? bubbles?	R or P for each test
K1 baking soda						
K2 Epsom salt						
K3 calcium chloride						

Unknown powders

Unknown	Water: dissolves? temperature (°C)	Vinegar: fizz? temperature (°C)	Baking soda solution: cloudy? bubbles?	Anything no known did?	Identity	The one test result that ruled out the other knowns
X						
Y						
Z						

- Which of the three tests found a chemical property of a powder? How do you know it was a chemical property and not a physical one?

Answer: The vinegar test (and the baking soda solution test) found chemical properties: whether the powder reacts with an acid to make a gas, and whether it reacts with dissolved baking soda to make a solid. They are chemical properties because you can only see them by letting a reaction happen; a new substance (gas or solid) appears. Dissolving in water and the temperature change are physical, because the powder is still the same substance afterward.

Why: The distinction the chapter needs: physical properties are observed without changing the substance; chemical properties are found by trying a reaction.

- Names the vinegar test (or soda-solution test)
- Explains that a new substance (gas or solid) appearing is what makes it chemical

- Which known powder could you identify with the water test alone? Which pair of knowns needed a second test to tell apart, and which test did it?

Answer: Calcium chloride could be identified by the water test alone because it is the only known that warms the water clearly. Baking soda and Epsom salt both dissolve and cool slightly, so they needed the vinegar test: baking soda fizzes and Epsom salt does not.

Why: Reads the fingerprint table for a unique cell; the key skill is spotting where one test is enough and where it is not.

Also acceptable: Accept 'baking soda could be told by the water test because it did not all dissolve' if the group recorded a clear difference, with the note that solubility differences are less reliable at this amount.

Analysis questions: answer key

3. Unknown Z did something in plain water that none of the three knowns did on its own. Describe what you saw and explain, using the known fingerprints, what Z must be made of.

Answer: Z fizzed, got warm and turned cloudy in plain water. No known did that alone: only baking soda fizzes, only calcium chloride warms water or clouds the baking soda solution. If Z is baking soda and calcium chloride mixed, water lets them meet: the calcium chloride dissolving explains the warming, and the dissolved calcium chloride reacting with the dissolved baking soda explains the fizz and the cloudy solid, exactly what happened when K3 met the baking soda solution. So Z is a mixture of K1 and K3.

Why: Students must combine two fingerprints and recognize that the mixture's parts react with each other once dissolved. Full credit needs both the warming (physical, from calcium chloride) and the fizz-and-cloud (reaction between the two) accounted for.

- Describes all three clues in water
- Attributes the warming to calcium chloride dissolving
- Attributes the fizz and cloud to baking soda and calcium chloride reacting
- Concludes Z is a mixture of K1 and K3

4. In the water test, two cups changed temperature in opposite directions. Did a new substance form in either of them? What evidence from the other tests supports your answer?

Answer: No new substance formed in either cup. Calcium chloride warmed the water and Epsom salt cooled it, but both simply dissolved. Evidence: neither showed a gas or a solid appearing in water, and the drying test (Lab 2) returns the same solids. The temperature changes are indicators that energy moved, not proof of a reaction; the vinegar test showed neither of these two makes a gas with acid, and only the calcium chloride made a solid in the soda solution, which required a second substance to react with.

Why: Targets the 'hot means reaction' misconception. The answer should use the other tests or the recovery idea, not just assert 'dissolving is physical'.

- States no new substance formed in the water cups
- Identifies the temperature change as an indicator, not proof
- Cites a second test or the recovery idea as support

5. When calcium chloride met the baking soda solution, the liquid turned cloudy. Both starting solids dissolve easily in water. What does the cloudiness tell you about the white solid that appeared, and why does that count as evidence of a reaction?

Answer: Both starting solids dissolve well, so the clear solutions could not have 'un-dissolved' into a white solid. The solid that appeared must be a substance that barely dissolves in water, which means it is neither calcium chloride nor baking soda; it is a new substance with a different solubility. A difference in a characteristic property (solubility) between what you started with and what you ended with is the kind of evidence that confirms a reaction.

Why: Solubility is on the assessment-boundary list, and the argument from 'both reactants dissolve, the product does not' is the cleanest precipitate reasoning available with kitchen chemicals. (The solid is calcium carbonate; students do not need its name.)

- Notes both starting solids are soluble
- Infers the new solid has low solubility
- Connects a property difference to evidence of a new substance

6. A classmate says: 'Y fizzed with nothing, so nothing happened to Y and we learned nothing.' Explain what the three 'no fizz' and 'no cloud' results did tell you about Y.

Answer: The 'no' results are evidence too. No fizz with vinegar rules out baking soda; no cloud with the baking soda solution and no warming rule out calcium chloride. Together with dissolving fully and cooling slightly in water, those results match Epsom salt's fingerprint. A result of 'nothing happened' is a property of the substance: Epsom salt does not react with vinegar or baking soda solution, and that is part of how you recognize it.

Why: Students should treat negative results as data; this also previews the slide-task idea that a matching or null result is informative about which tests discriminate.

- States that no-change results rule out other candidates
- Identifies Y as Epsom salt from the combination

7. Suppose a fourth white powder fizzes strongly with vinegar. Can you conclude it is baking soda? What would you need before you could say so?

Answer: No. Fizzing with vinegar shows the powder reacts with acid to release a gas, which baking soda does, but other substances do too (washing soda and crushed antacid tablets, for example). To say it is baking soda you would need more properties to match: how it dissolves in water, its behavior in the baking soda solution, and ideally measured properties such as solubility or density compared with known baking soda.

Why: One matching test narrows the list; several independent matches identify. The named alternatives are optional.

- Answers no
- Explains that other substances share the property
- Names at least one further test

8. Which single test was the most useful for separating the three knowns, and which was the least useful? Use your table to justify both choices.

Answer: Most useful: the water test, because it separated calcium chloride (warms) from the other two in one step and showed a dissolving difference as well; or the vinegar test, because it picked out baking soda uniquely. Least useful: the baking soda solution test, because it only confirmed calcium chloride, which the water test had already identified; its real value was showing what a precipitate looks like. Credit either 'most useful' choice if it is backed by the table.

Why: Students should judge tests by how many candidates each one separates; there are two defensible answers for most useful.

Also acceptable: Accept 'baking soda solution test least useful because it duplicated information' or 'water test least useful because the small cooling was hard to read' with table-based justification.

Individual evidence of learning

Each student submits their own completed fingerprint tables with R/P marks, identities for X, Y and Z with the deciding test named, and written answers to q1 through q8. The Z explanation (q3) and the temperature question (q4) are the primary evidence that the student separates reactions from dissolving.

Assessment criteria

Criterion	Proficient looks like
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Fingerprint data	Every cell filled with a specific observation; temperatures recorded with units; results agree with the class pattern or disagreements are noted and explained.
Identification	X and Y correctly matched to a known with the deciding test named; Z explained as a mixture of baking soda and calcium chloride using at least two of its clues.
Reaction versus physical change	R/P marks correct for all nine known cells; explanation states that dissolving and temperature change alone do not show a new substance while a gas or solid that was not there before, with different properties, does.
Reasoning about evidence	Explains that one matching test narrows but does not settle an identification, and that 'no change' results carry information.

Accessibility adaptations

- Pre-measure powders into labeled cups so no student has to level a spoon; the Tester then only adds liquid.
- Provide a large-print recording sheet and a thermometer with a large digital display; allow a partner to read while the student records on a device.
- Temperature and fizz can be felt (warm cup, vibration of a fizzing cup held lightly) for students with low vision; cloudiness can be checked by whether printed text on paper is visible through the cup.
- Accept a spoken explanation for q3 and q4 recorded on a device, and provide a sentence frame: 'Z did ___, which K1 does, and ___, which K3 does, so Z is ___.'

Low-cost alternative

Drop the thermometer and record 'warmer, cooler or same' by touching the outside of the cup; drop the baking soda solution test and identify with water and vinegar alone, which still separates the three knowns (calcium chloride warms, baking soda fizzes, Epsom salt does neither). Share one set of knowns between two groups.

Model limitations

This is an identification exercise with three candidates, so a fingerprint of three tests is enough; real unknowns need more properties and more candidates. The temperature changes are rough indicators that depend on pellet type, amount and starting temperature, and they are not evidence of reaction on their own. The lab has not been physically tested by the authors; the expected temperature changes are estimates from published heats of solution for a level quarter-teaspoon in 10 mL and should be checked in your room before class.

Teacher notes

Check that R/P marks are consistent with the written answers: a student who marks the calcium chloride water cell R has the 'hot means reaction' idea and should revisit q4. Keep one group's cloudy calcium chloride and soda-solution cup for Lab 2, where the solid is tested for solubility. If a group's Z did not fizz, the mixture was probably made too far ahead and had already reacted in the cup; mix a fresh batch.