

Introduction to Chemistry

Preparation for General Chemistry · Dr. Karmach

By the end of this unit, you can...

- Classify a scientific statement as a hypothesis, a law, or a theory
- Classify matter as an element, a compound, or a mixture
- Classify a property or a change as physical or chemical
- Distinguish precision from accuracy in measured data
- Name a sample's state from its shape and volume, and describe particle spacing and motion in each state

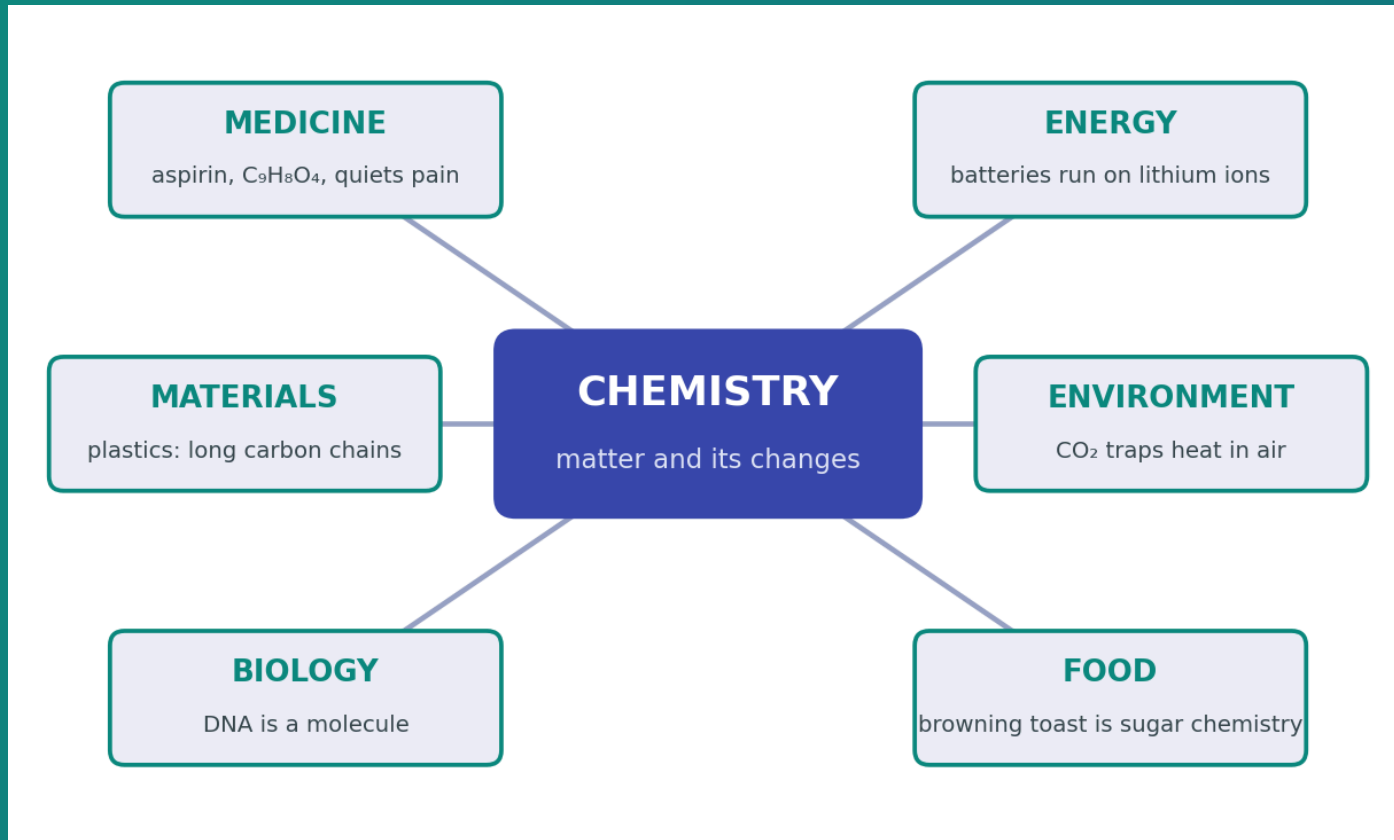
Today's route

1. **Chemistry in Context**
2. **Classifying Matter**
3. **Physical & Chemical Properties**
4. **States of Matter**
5. **Energy**
6. **Precision & Accuracy**

1 • Chemistry in Context

Define matter, read what a test result does to a hypothesis, and classify a scientific statement as hypothesis, law, or theory.

Matter changes all day long



Striking a match, charging a phone, digesting lunch: each is matter changing. One science studies matter and its changes, so medicine, farming, and engineering all lean on it.

The science of matter

Matter is anything that has mass and occupies space. Chemistry studies matter and its changes, and every science that handles material draws on it: the central science.

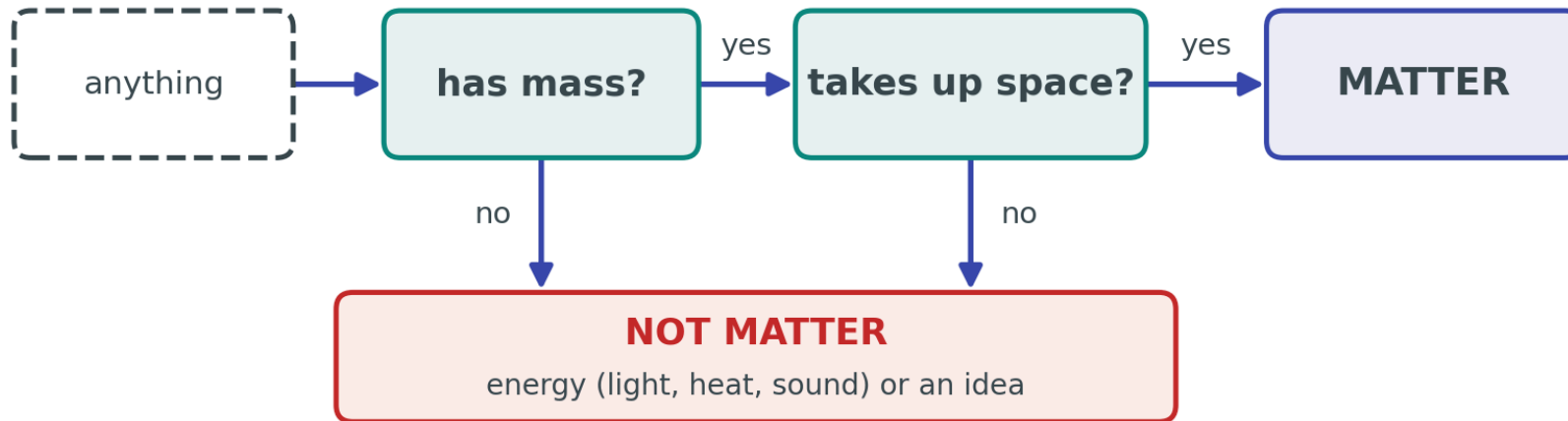
matter: has mass, occupies space

air, rust, salt, seawater: all matter

not matter: light, heat, an idea

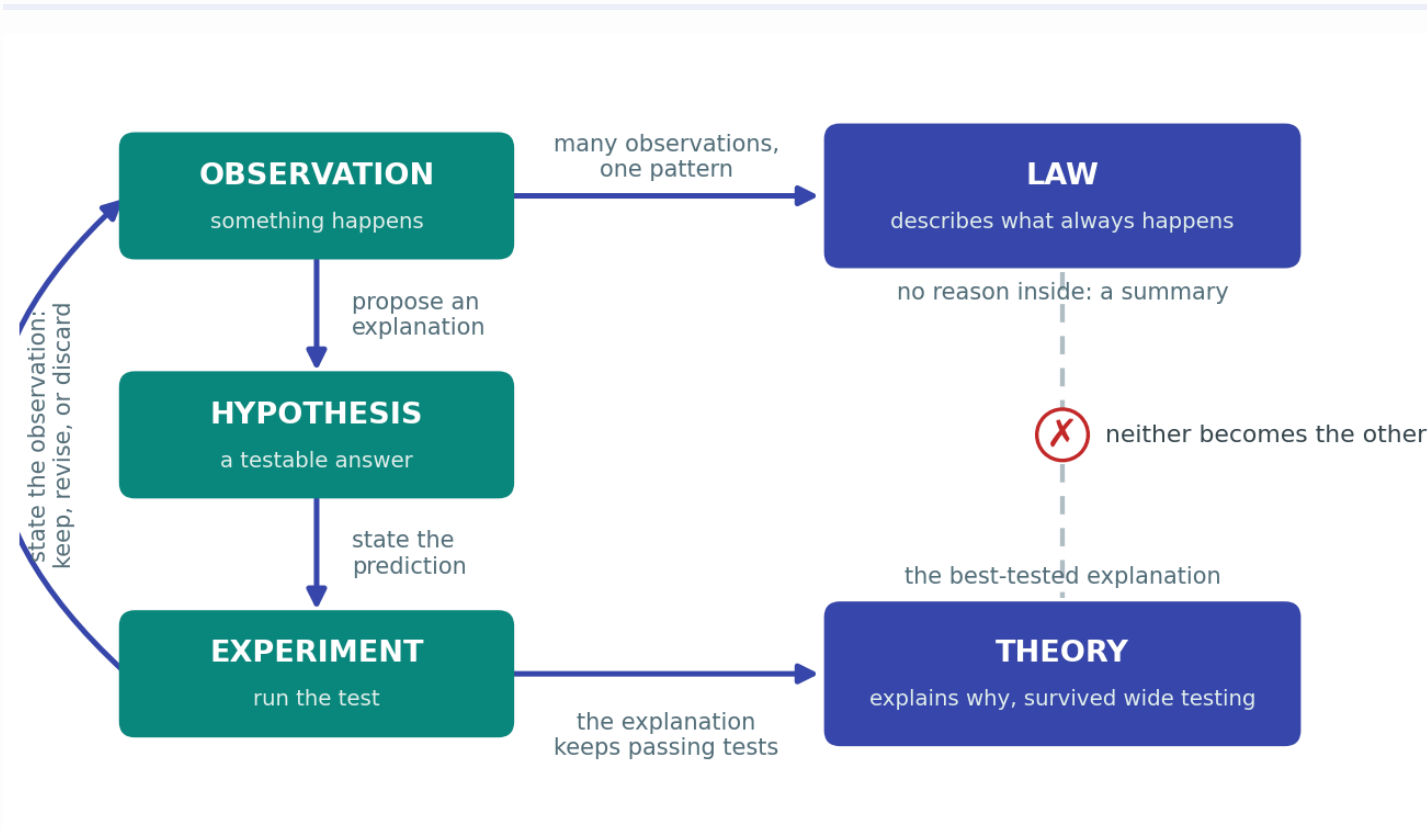
no mass, no space filled: energy and information

Testing for matter: two questions



Matter answers yes twice. Air in a pumped soccer ball has mass: the ball outweighs a flat one. It takes up space: it holds the ball round. A screen's glow has no mass to weigh.

The scientific method



An observation raises a question. A hypothesis proposes a testable answer. An experiment tests it: state the prediction, state the observation, keep or revise. Every answer invites a sharper test.

Hypothesis, law, theory

A hypothesis proposes a testable answer, still on trial. A law summarizes what always happens. A theory explains why, and has survived wide testing. Laws describe; theories explain.

hypothesis: the pond turned green because fertilizer ran in
proposed and testable: sample the water upstream and down

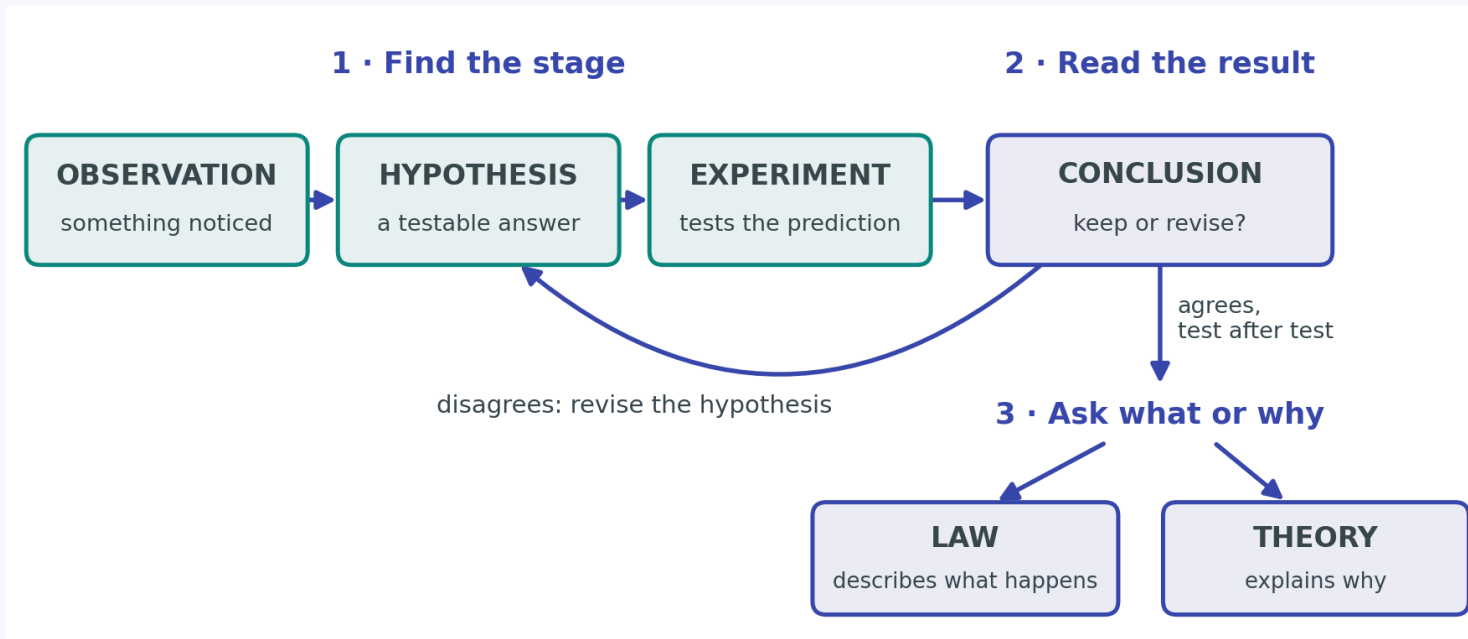
law: every gas held at steady pressure expands when heated
the summary: centuries of thermometers and pistons agree

theory: hot particles move faster and hit harder
the tested explanation standing behind the law



The method

1. **Find the stage:** observation, hypothesis, or experiment.
2. **Read the result:** keep a hypothesis the test agrees with; revise one it contradicts.
3. **Ask what or why:** after wide testing, a law describes what always happens; a theory explains why.





Guided example: brightly colored frogs

four lines from a field notebook

- (1) Birds rarely attack the brightly colored frogs.
- (2) The bright colors warn birds that the frogs taste bad.
- (3) Bright and dull clay frog models sit in the forest for a week; beak marks are counted.
- (4) The dull models collect far more beak marks.

A biologist studies rainforest frogs. Place each line on the map, then decide what line (4) does to line (2).

✓ Guided example: solution

four lines from a field notebook

(1) birds rarely attack bright frogs · (2) the colors warn birds off · (3) clay models for a week · (4) dull models draw more beak marks

Step 1 · Find the stage

(1) observation · (2) hypothesis · (3) experiment · (4) result

(1) something noticed · (2) a testable answer · (3) a test of its prediction · (4) what the test showed, read at the conclusion

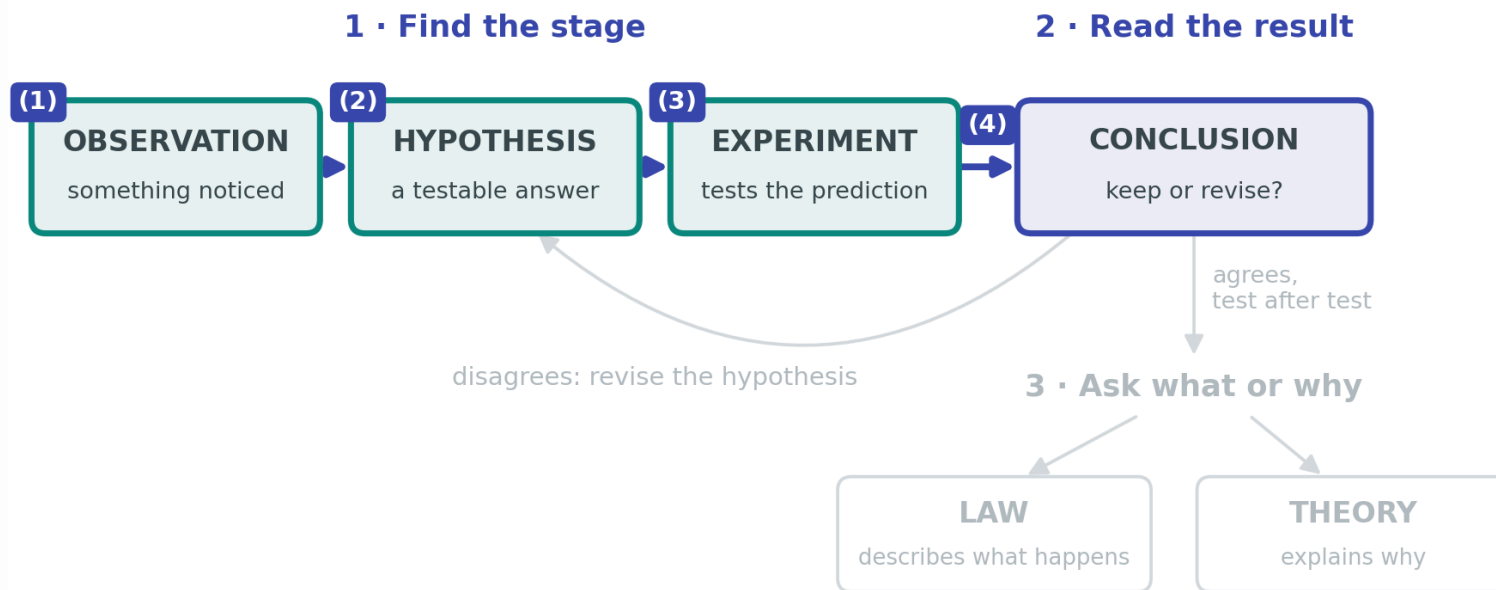
Step 2 · Read the result

Step 3 · Ask what or why

 **Sense check:** Had the bright models drawn as many beak marks, the conclusion would revise (2). An agreeing result keeps a hypothesis; it does not prove it.

✓ Guided example: the route on the map

frogs: observation, hypothesis, experiment; (4) the result → conclusion: keep (2)
found: the result agrees · one forest, one week: test again



🧠 **Sense check:** One test in one forest: the path stops at the conclusion. Law and theory wait on wide testing. ✓



Practice 1

one sunny kitchen

a helium balloon floating at the ceiling · coffee steaming in a mug · a sealed, empty-looking jar on the windowsill

Which of these is not matter?

- A. the helium in the floating balloon
- B. the coffee smell drifting across the room
- C. the air sealed in the jar
- D. the shadow the jar casts on the wall

✓ Practice 1: answer D

shadow → not matter (answer D)

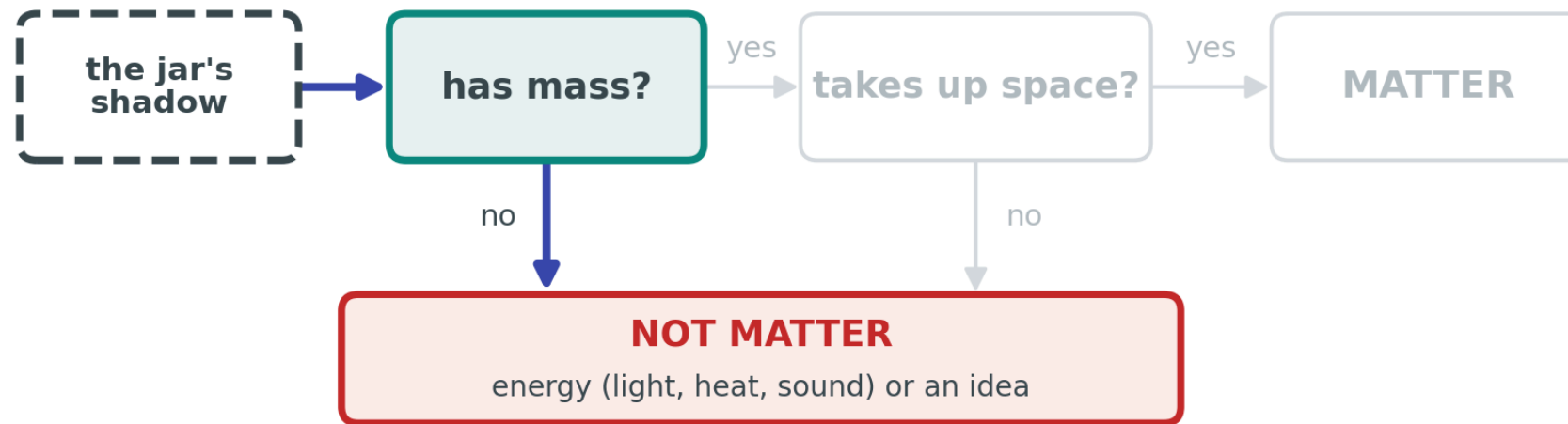
no mass to weigh · fills no space · only a patch of wall the jar keeps the light from

A took floating for weightless. Helium has mass; it is lighter than the air it pushes aside. B took a smell for a feeling: the smell is coffee molecules drifting through the air, and they have mass and fill space. C took invisible for empty: the jar's air has mass and fills the jar.

 **Sense check:** Two questions decide every case. The shadow fails the first; the helium, the coffee vapor, and the jar's air pass both.

✓ Practice 1: the route on the map

the jar's shadow on the wall
has mass? no · found: not matter



🧠 **Sense check:** The shadow stops at the first question. The helium, the coffee vapor, and the jar's air answer yes twice: each has mass and fills space. ✓



Practice 2

hypothesis: salt lowers the temperature at which water boils

test: a plain pot and a salted pot heated side by side · result: the salted pot boils at a higher temperature

A cook tests a claim about salted water. What should the conclusion do with the hypothesis?

- A. Keep it and discard the reading
- B. Revise it to fit the result
- C. Call it a law, since it was measured
- D. Call it a theory, since it was tested

✓ Practice 2: answer B

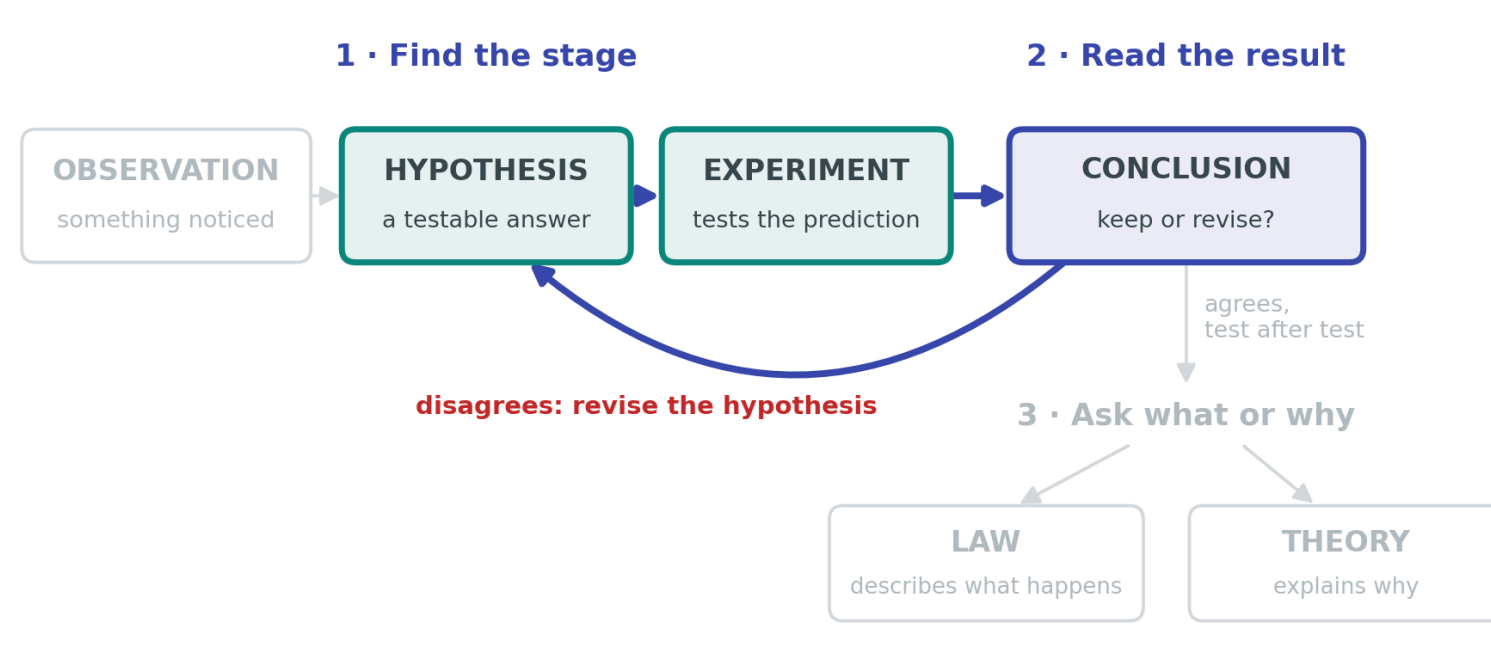
the result contradicts the prediction → revise the hypothesis (answer B)
predicted: the salted pot boils at a lower temperature · observed: it boils at a higher one

A throws out the data to save the hypothesis; a disagreeing result is what a test exists to catch. C: one measurement cannot make a law, and this one contradicts the claim. D: a theory explains why and has survived wide testing; this claim failed its first test.

🧠 **Sense check:** The revised hypothesis, salt raises the boiling point, makes a new prediction, and the loop runs again.

✓ Practice 2: the route on the map

salted water: hypothesis, experiment, conclusion
found: the result disagrees · revise the hypothesis



🧠 **Sense check:** A contradicted prediction sends the path back to the hypothesis, never ahead to law or theory. ✓



Practice 3

"Every compound has a fixed makeup because its atoms always join in the same whole-number ratio."

proposed two centuries ago · confirmed by every careful measurement since

Which label fits this statement?

- A. observation
- B. hypothesis
- C. law
- D. theory

✓ Practice 3: answer D

explains why and survived wide testing → theory (answer D)

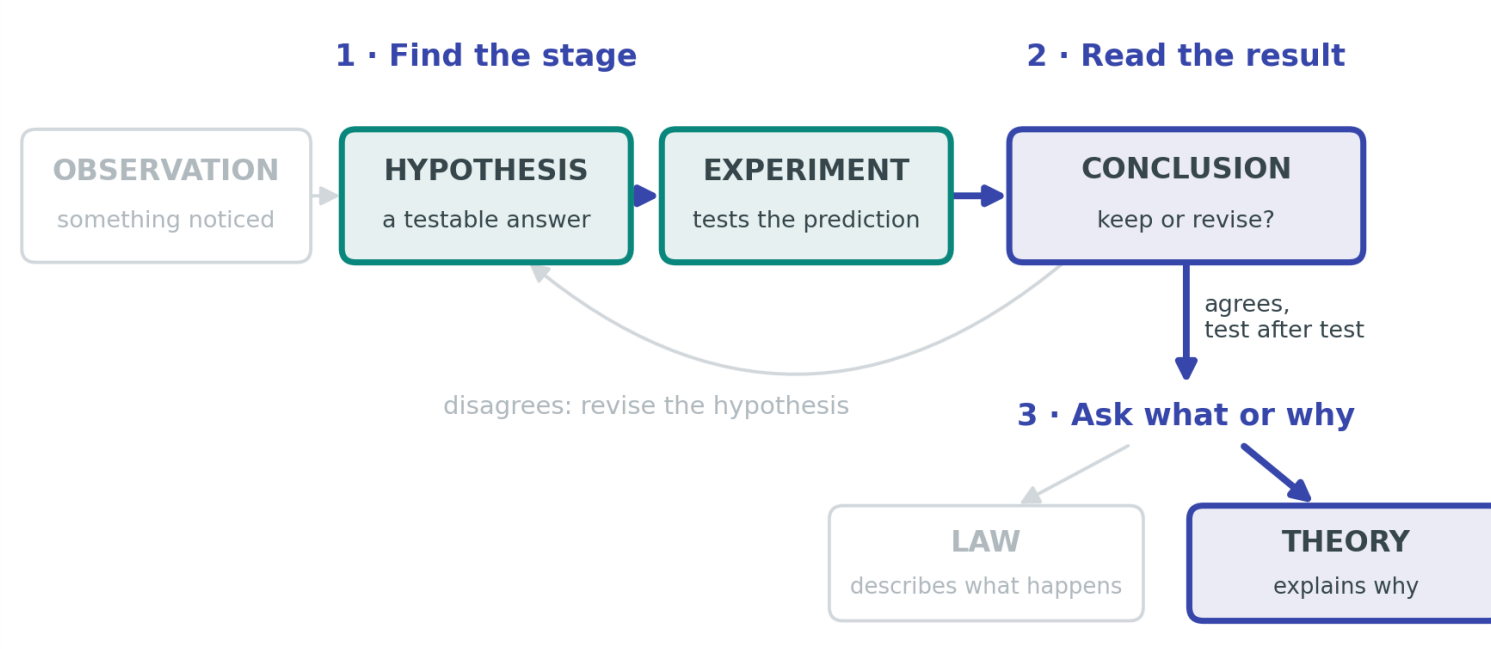
"because" gives a reason · two centuries of confirming measurements

A: no one watches atoms join; the statement is inferred from measurements, not seen. B: a hypothesis is still on trial; this one has passed two centuries of tests. C: "every compound" sounds like a law, but a law stops at what happens; this sentence goes on to say why.

 **Sense check:** Cut the "because" clause and a law remains: every compound has a fixed makeup. The reason behind it is atomic theory.

✓ Practice 3: the route on the map

fixed makeup: hypothesis, experiment, conclusion, then why
found: test after test agrees · the statement gives a reason · theory



🧠 **Sense check:** Test after test carries the path to step 3. A reason, not a summary, picks theory. ✓



Practice 4

three statements about gases

- (1) A balloon left in a hot car popped, probably because heat weakened the rubber.
- (2) For any gas sample at steady temperature, doubling the pressure halves the volume.
- (3) Gas particles move nonstop and strike the walls; in half the space they strike twice as often.

Label statements (1), (2), and (3), in order.

- A. hypothesis, law, theory
- B. hypothesis, theory, law
- C. observation, law, theory
- D. hypothesis, law, hypothesis
- E. theory, law, theory

✓ Practice 4: answer A

(1) hypothesis · (2) law · (3) theory (answer A)

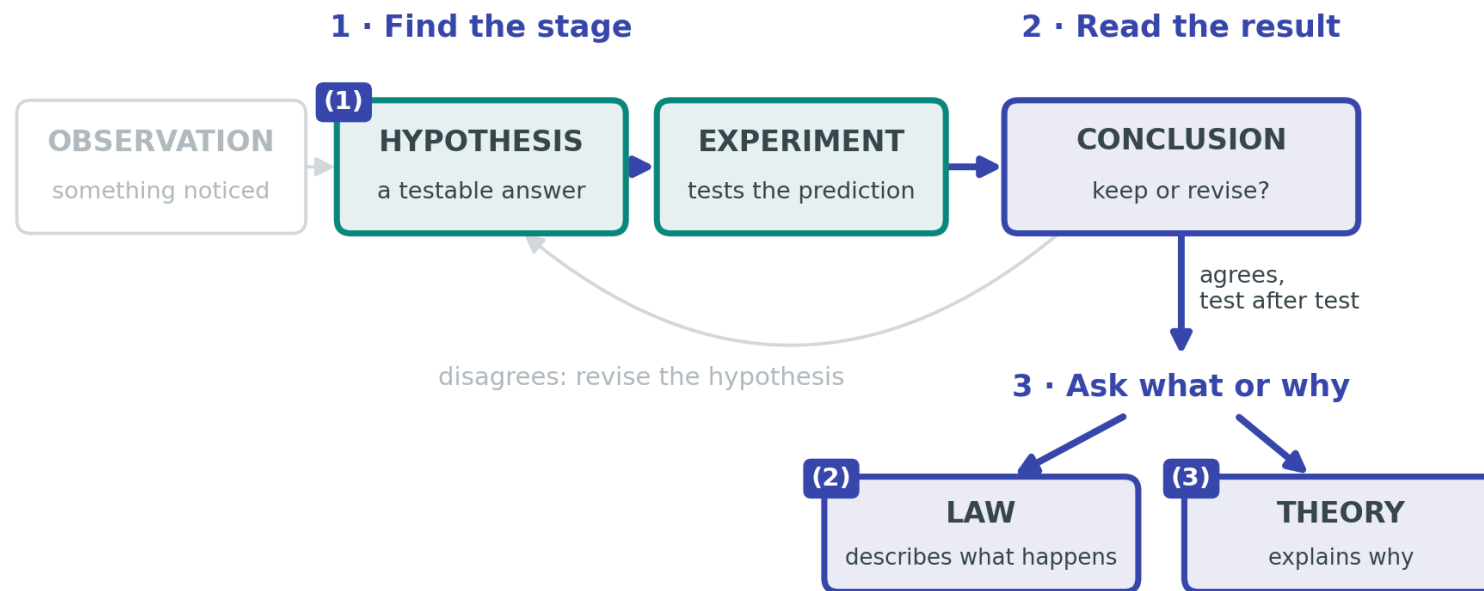
(1) a proposed cause for one event · (2) what always happens, no reason · (3) why (2) happens

B swaps law and theory: (2) gives no reason, and (3) explains. C: the pop was observed, but "probably because" adds an untested cause. D takes unseen particles for a guess; the particle picture has passed wide testing. E calls every explanation a theory; (1) explains one balloon and was never tested.

 **Sense check:** (3) explains (2): half the space, twice the wall hits, twice the pressure. (1) may even be wrong; warm air expanding is a better hypothesis to test.

✓ Practice 4: the route on the map

(1) hypothesis · (2) law · (3) theory
found: (1) untested · (2) and (3) passed test after test



🧠 **Sense check:** (1) waits at the hypothesis. (2) and (3) reach step 3: (2) describes what happens, (3) explains why. ✓



Check yourself

1. State conservation of mass twice: once as the law, once as the theory that explains it. Could more testing ever turn one into the other?
2. Which of these are matter: steam, sunlight, sand, a thought? Say why each one is or is not.

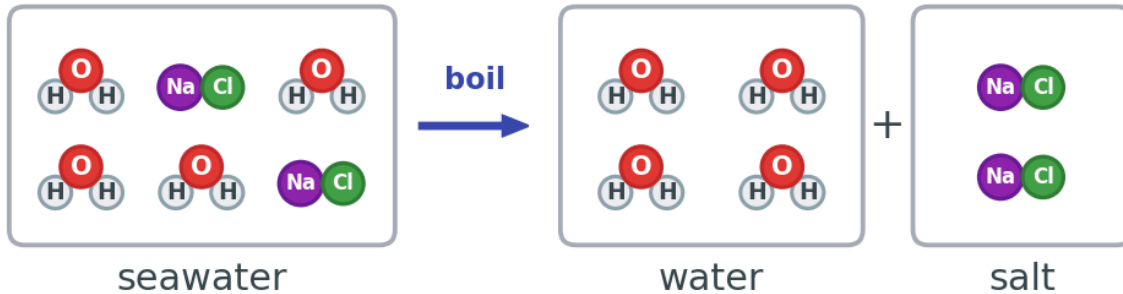
The scientific method built chemistry's biggest ideas: experiments forced the model of the atom itself to be redrawn, twice. And the first job the method hands a chemist is sorting matter, because every sample is an element, a compound, or a mixture, and two counts place it.

2 · Classifying Matter

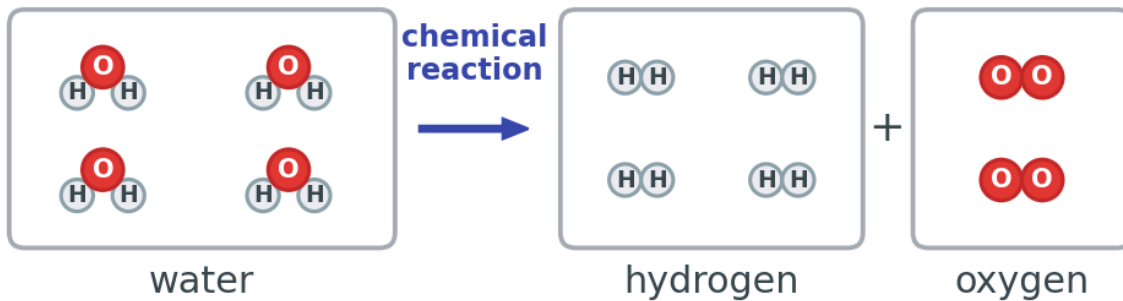
Classify any sample as an element, a compound, or a homogeneous or heterogeneous mixture by counting kinds of particles and phases.

Two ways to take matter apart

boiling separates seawater into water and salt



splitting water takes a chemical reaction



Boiling seawater leaves salt behind. Splitting water takes a chemical reaction. A sample's class tells what can pull it apart, and whether a fixed formula exists.

Sorting matter by what it is made of

zinc · distilled water · apple juice · potting soil

zinc: Zn atoms only · distilled water: H₂O only · apple juice: water, sugars, acids · potting soil: sand, clay, bark, water

Matter sorts first by composition. A pure substance has one fixed composition. A mixture holds two or more substances; boiling or filtering separates them.

Sort the four samples: pure substance or mixture?

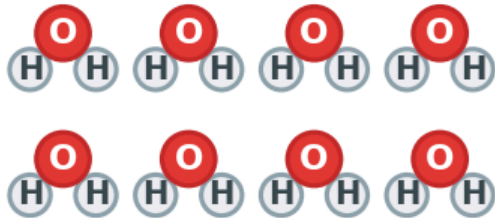
pure substances: zinc · distilled water

mixtures: apple juice · potting soil · each holds more than one substance

Pure substance or mixture

pure substance

one kind of particle

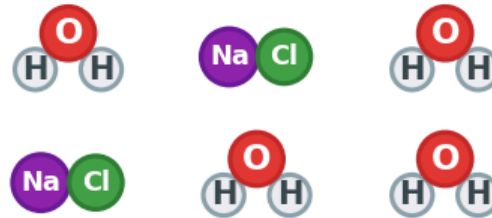


water

every particle identical: composition fixed

mixture

two or more kinds of particles



salt water

more salt or less: composition varies

A **pure substance** contains one kind of particle, so its composition is fixed. A **mixture** contains two or more kinds; its composition can vary, and each component keeps its identity.

Element or compound

Both are pure substances. An **element** contains one kind of atom; no chemical reaction breaks it down. A **compound** contains two or more elements bonded in a fixed ratio; a chemical reaction can take it apart.

elements: Cu · O₂ · S₈

one kind of atom each: 118 elements known

compounds: H₂O · NaCl · CO₂

two or more elements, in a ratio that never changes

Homogeneous or heterogeneous

A **phase** is a uniform region separated from its neighbors by a physical boundary. One phase throughout: homogeneous. Two or more phases: heterogeneous.

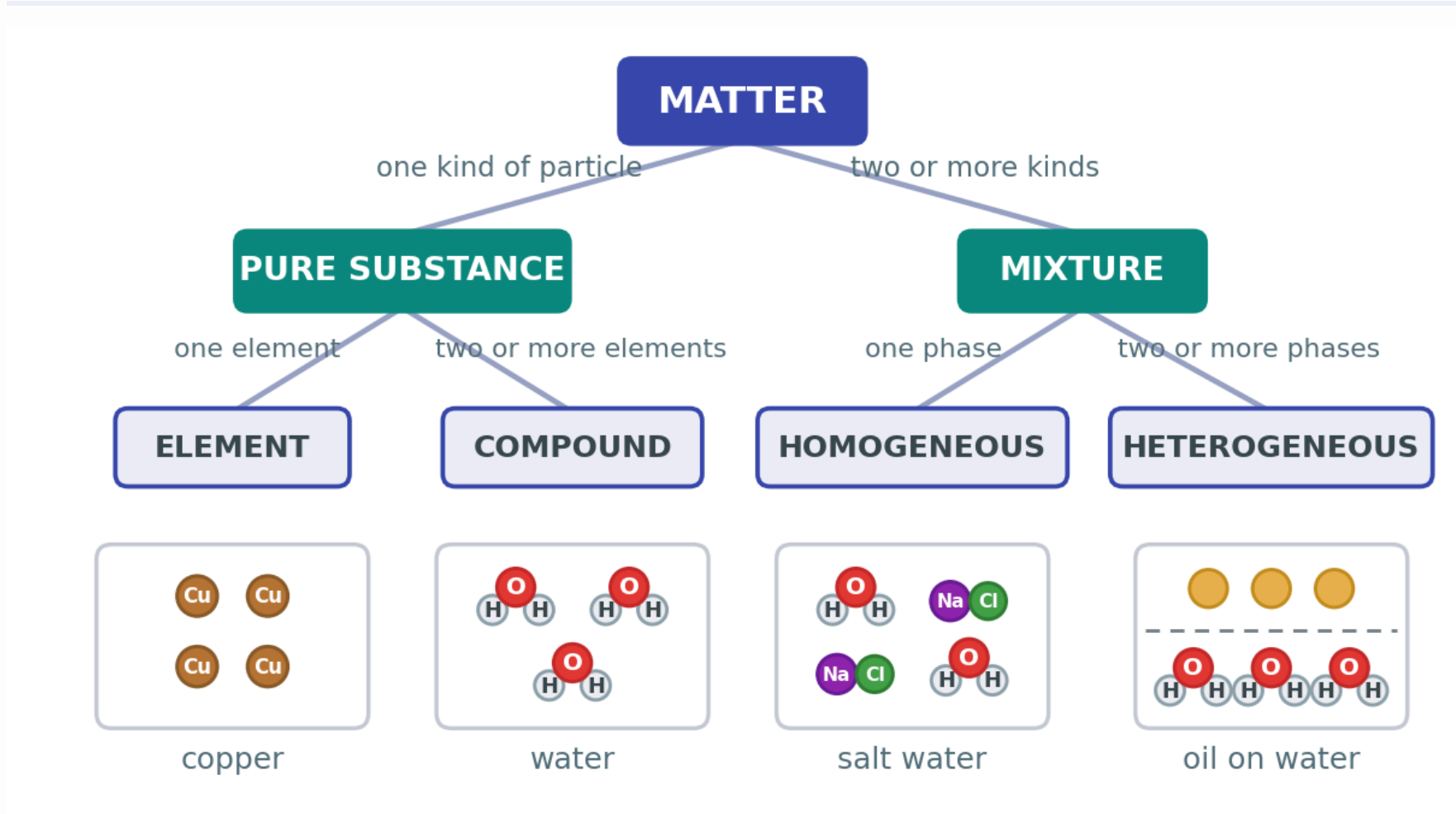
salt water: one phase

homogeneous: any drop matches any other drop

oil on water: two phases

heterogeneous: the top sample is oil, the bottom sample is water

The complete map



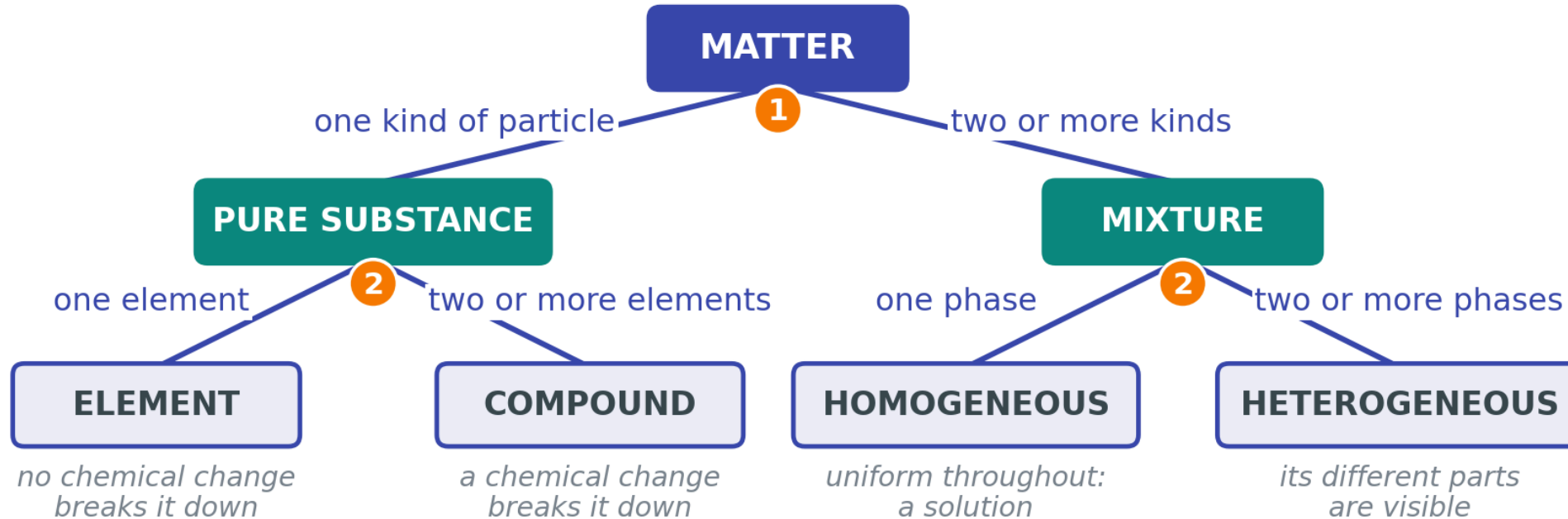
Two counts place any sample: the kinds of particles, then the elements or the phases.



The method

1. **Count the kinds of particles.** One → pure substance; more → mixture.
2. **Count the elements or the phases.** Pure: elements. Mixture: phases.
3. **Name the class.** One element → element. More → compound. One phase → homogeneous. More → heterogeneous.

The method on the map



① count the kinds of particles ② count the elements (pure) or the phases (mixture) ③ name the class

Count 1 picks the side: pure substance or mixture. Count 2 asks a different question on each side: elements for a pure substance, phases for a mixture. The route ends at the class.



Guided example: chlorine gas

Cl_2 gas from a cylinder

every particle: 2 Cl atoms bonded, the same in every molecule

A water-treatment plant draws chlorine gas from a cylinder that holds nothing else. Classify the gas.

On the map, start at matter. Each count picks one branch.

✓ Guided example: solution

Cl_2 gas from a cylinder

every particle: 2 Cl atoms bonded, the same in every molecule

Step 1 · Count the kinds of particles

Step 2 · Count the elements or the phases

Cl_2 : 2 atoms, 1 element

both atoms are chlorine · count the kinds of atoms, not the atoms

Step 3 · Name the class

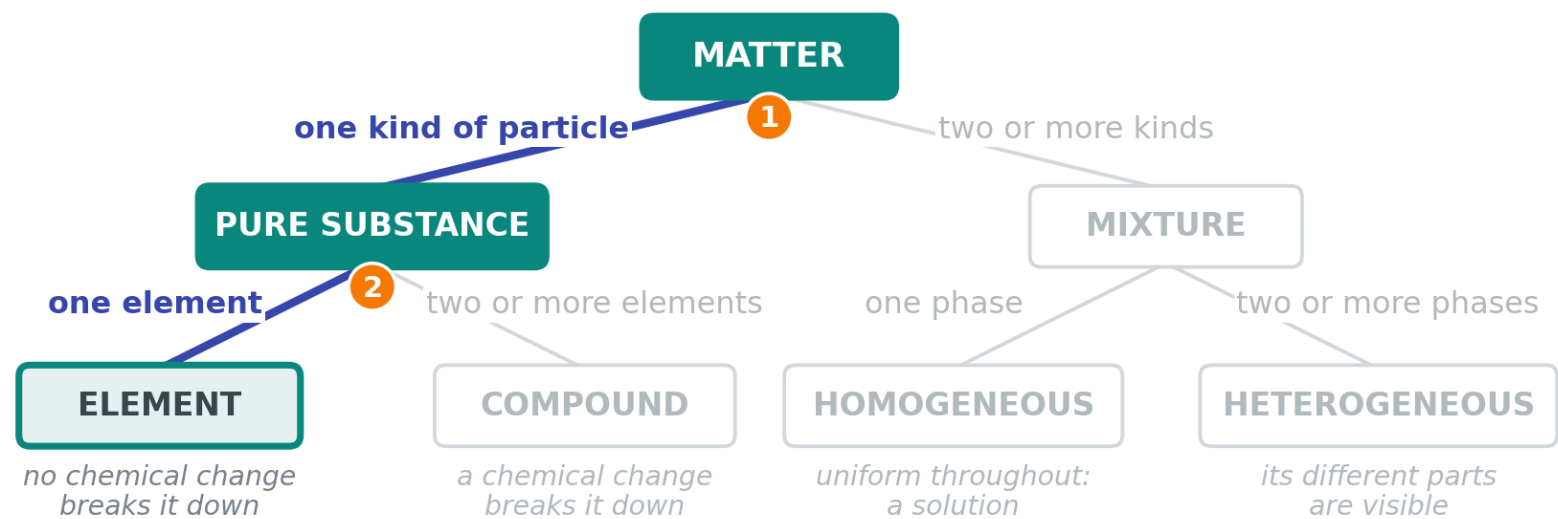
$\text{Cl}_2 \rightarrow$ an element

pure substance · one element · no chemical change breaks it into anything simpler

 **Sense check:** A molecule of an element can hold several atoms: H_2 , N_2 , O_2 , S_8 . Two or more different elements make a compound. Two or more atoms of one element do not.

✓ Guided example: the route on the map

Cl_2 gas from a cylinder
given: every particle is Cl_2 · found: an element



① count the kinds of particles ② count the elements (pure) or the phases (mixture) ③ name the class

 **Sense check:** Count 1: one kind of particle → pure substance. Count 2: one element → element. The two atoms per molecule enter neither count. ✓



Practice 1

white phosphorus: P_4 molecules only
every molecule: 4 P atoms bonded together

A sample of white phosphorus contains nothing but P_4 molecules. How should the sample be classified, and why?

- A. Compound: four atoms are chemically bonded in every molecule
- B. Homogeneous mixture: the solid looks the same at every point
- C. Compound: P_4 has one fixed formula, and a fixed formula marks a compound
- D. Element: all four atoms in each molecule are phosphorus

✓ Practice 1 · answer: D

white phosphorus → an element (answer D)

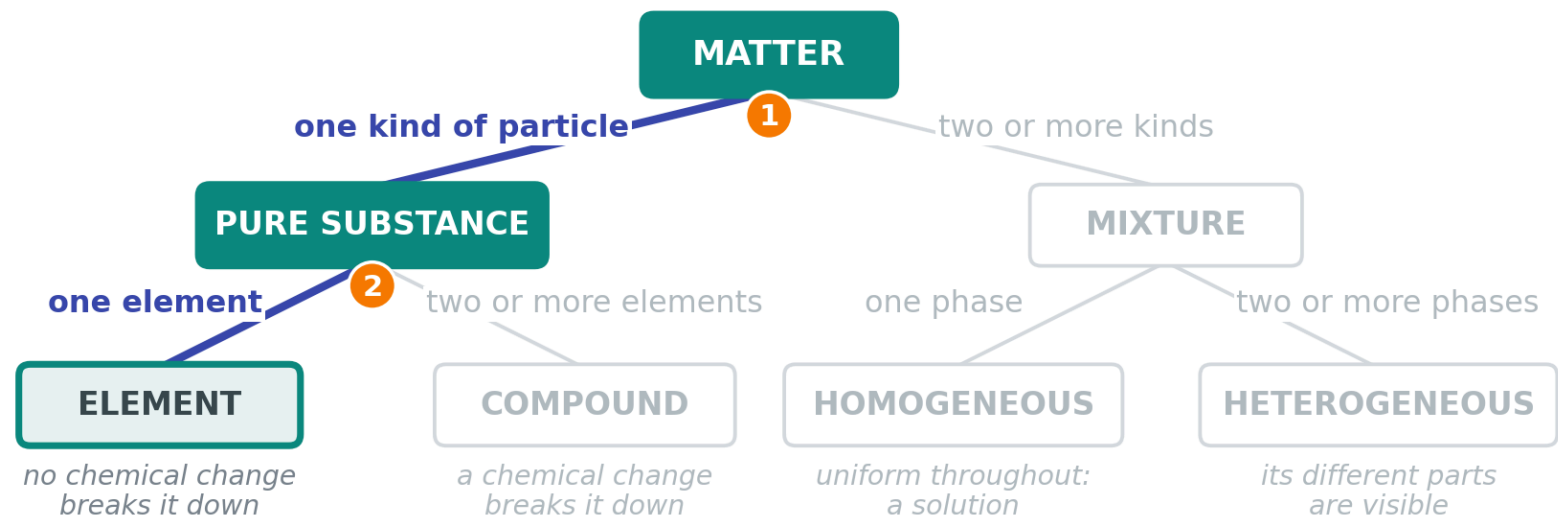
one kind of particle, P_4 · one element, phosphorus · 4 atoms per molecule, all P

A counted atoms, not kinds of atoms: four bonded P atoms are still one element. B: looking the same everywhere shows one phase, and one kind of particle already makes the sample pure. C: every pure substance has a fixed formula, elements included; this formula holds only P.

 **Sense check:** Count the different element symbols in the formula, not the subscript. P_4 shows one symbol: an element.

✓ Practice 1: the route on the map

white phosphorus: P_4 molecules only
given: every particle is P_4 · found: an element



① count the kinds of particles ② count the elements (pure) or the phases (mixture) ③ name the class

🧠 **Sense check:** Count 1: one kind of particle → pure substance. Count 2: one element symbol, P → element. ✓



Worked example 1: carbon dioxide

CO₂ from a fire extinguisher

every particle: 1 C + 2 O = 3 atoms, the same in every molecule

A CO₂ fire extinguisher discharges nothing but carbon dioxide. Classify the gas.

✓ Worked example 1: solution

CO₂ from a fire extinguisher

every particle: 1 C + 2 O = 3 atoms, the same in every molecule

Step 1 · Count the kinds of particles

Step 2 · Count the elements or the phases

Step 3 · Name the class

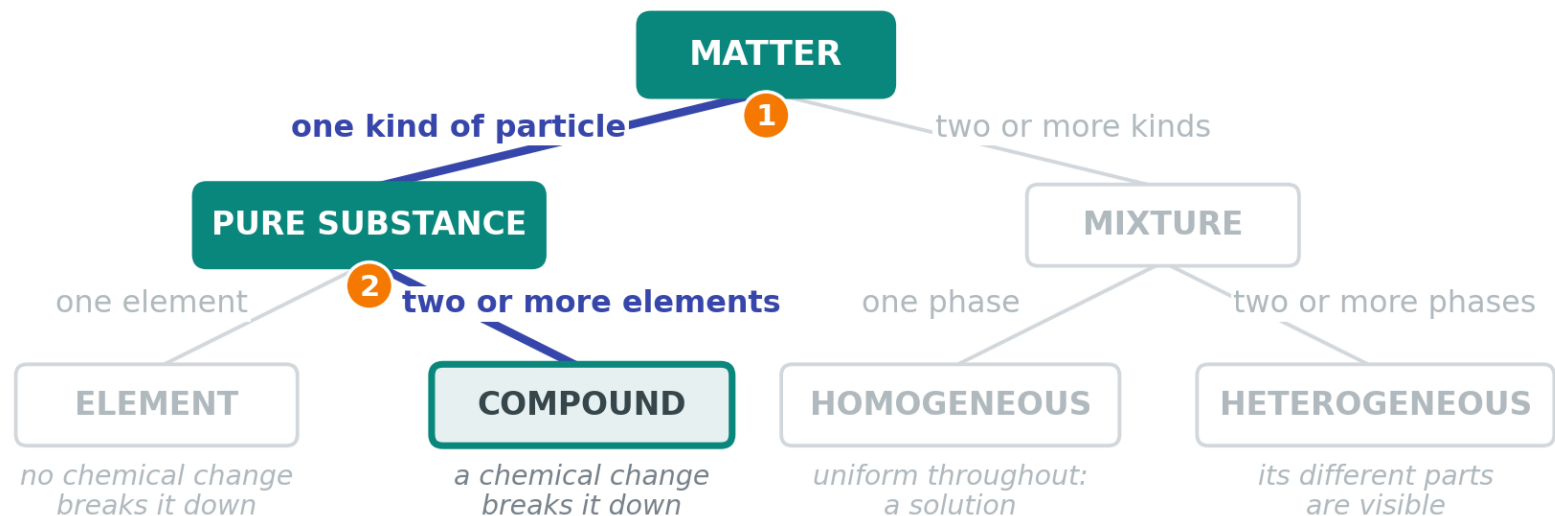
CO₂ → a compound

pure substance · two elements · fixed 1 C : 2 O ratio

 **Sense check:** Every CO₂ molecule carries the same 1 : 2 ratio, and only a chemical reaction separates the carbon from the oxygen. Fixed composition marks a compound.

✓ Worked example 1: the route on the map

CO₂ from a fire extinguisher
 given: every particle is CO₂ · found: a compound



① count the kinds of particles ② count the elements (pure) or the phases (mixture) ③ name the class

Sense check: Count 1: one kind of particle → pure substance. Count 2: two elements, C and O → compound. ✓



Worked example 2: salt water

salt water

one clear liquid: uniform throughout, every drop the same

Ocean water is salt dissolved in water.

A common first attempt: uniform throughout, so a compound. Test it.

✓ Worked example 2: solution

salt water

one clear liquid: uniform throughout, every drop the same

A common first attempt

salt water = a compound?

a compound keeps one fixed ratio; this sample holds however much salt was stirred in ✕

Step 1 · Count the kinds of particles

Step 2 · Count the elements or the phases

Step 3 · Name the class

salt water → a homogeneous mixture

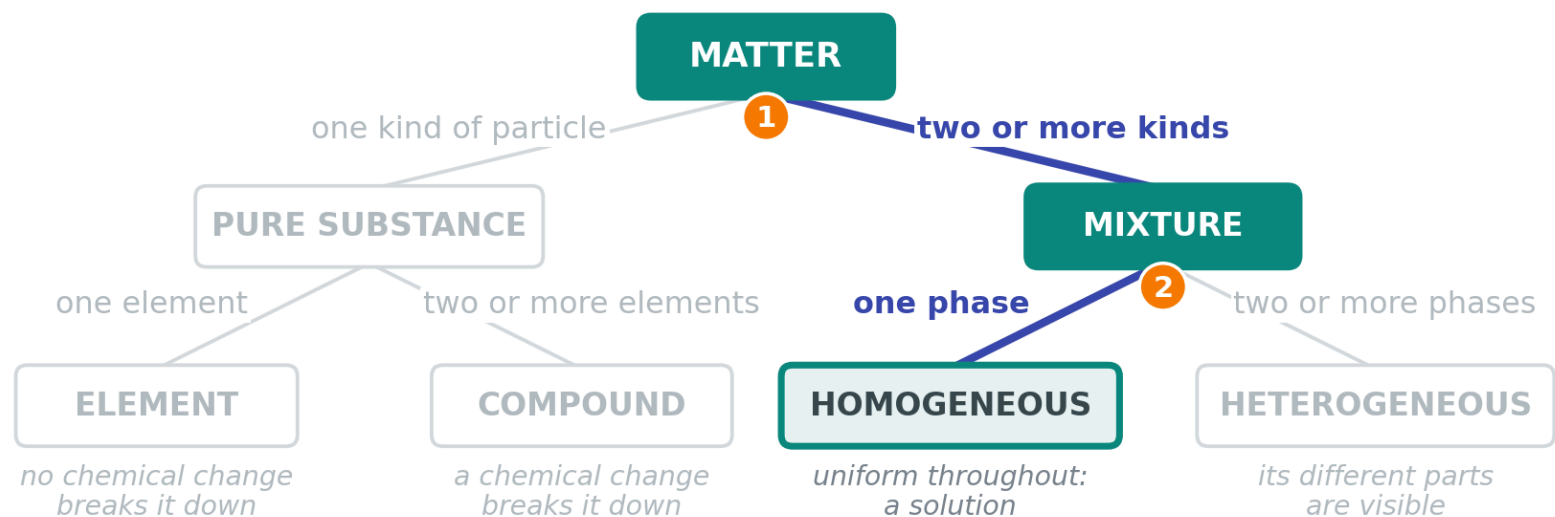
two kinds of particles · one phase · composition varies

 **Sense check:** Uniform answers the phase question, not the purity question. Salt water is uniform and still a mixture.

✓ Worked example 2: the route on the map

salt water

given: water and dissolved salt · found: a homogeneous mixture



🧠 **Sense check:** Count 1: two kinds of particles → mixture. Count 2: one phase → homogeneous. The route never visits the compound box. ✓

Take-home: uniform does not mean compound

water: always 2 H : 1 O

compound: one substance, fixed ratio, separated only by chemical reaction

salt water: any ratio that dissolves

homogeneous mixture: uniform, variable composition, separated by boiling

A compound keeps one fixed ratio. A homogeneous mixture is uniform, but its composition can vary. Uniformity describes phases, never bonding.

Your turn: oil-and-vinegar dressing

oil-and-vinegar dressing
an oil layer floating on a vinegar layer

step	question	answer
1 · kinds of particles	one kind, or more?	more than one → _____
2 · phases	how many phases?	_____ distinct layers
3 · name the class		_____

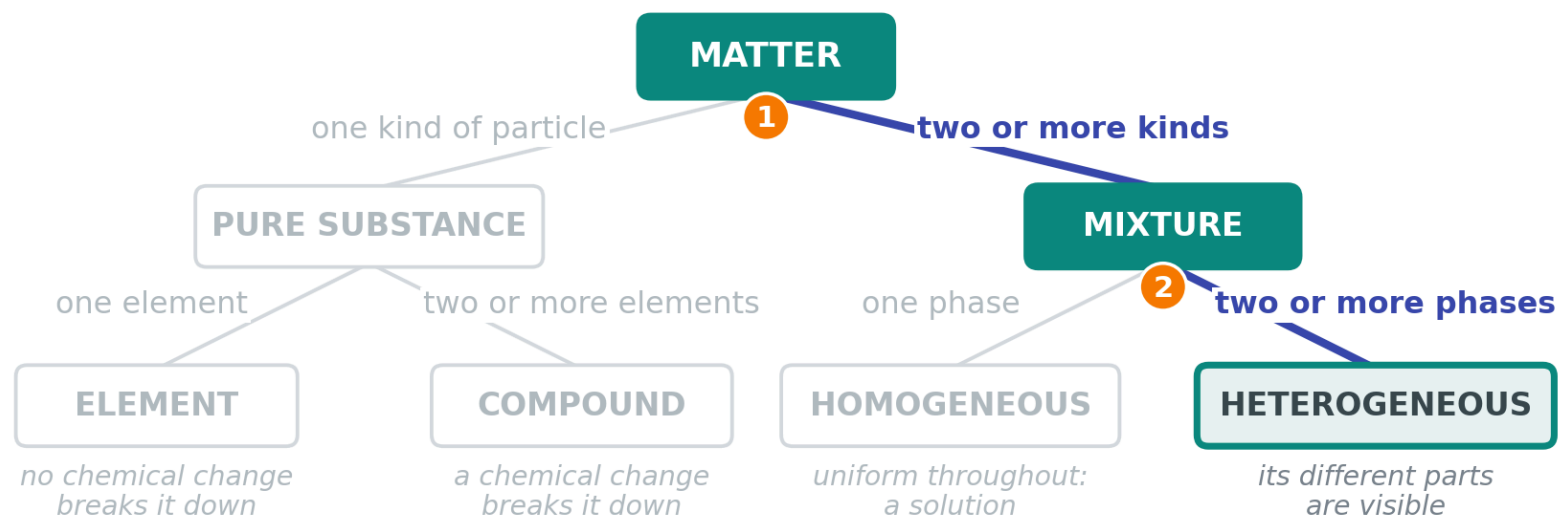
Complete the three counts.

dressing → a heterogeneous mixture
more than one kind of particle · two phases: a top sample is oil, a bottom sample is vinegar

✓ Your turn: the route on the map

oil-and-vinegar dressing

given: an oil layer on a vinegar layer · found: a heterogeneous mixture



① count the kinds of particles ② count the elements (pure) or the phases (mixture) ③ name the class

🧠 **Sense check:** Count 1: more than one kind of particle → mixture. Count 2: two layers, two phases → heterogeneous. ✓

⚠ Where this goes wrong

Calling a uniform mixture a compound. Brass is uniform, but its copper-to-zinc ratio varies batch to batch. A compound keeps one fixed ratio. Uniform appearance does not show chemical bonds.

Calling every multi-substance sample heterogeneous. Air holds nitrogen, oxygen, and argon in one phase. Several substances can share a single uniform phase: homogeneous.

Reading "same properties throughout" as pure. Same everywhere means one phase, nothing more. A pure substance also needs fixed composition, and sugar water's composition can vary.



Practice 2

white vinegar: acetic acid dissolved in water
one clear liquid, uniform throughout

A bottle of white vinegar looks completely uniform. How should it be classified, and why?

- A. Pure substance: it shows the same properties at every point, so it is a single substance
- B. Homogeneous mixture: it is uniform throughout, but its acid-to-water ratio can vary
- C. Compound: a uniform liquid must have its components chemically bonded in a fixed ratio
- D. Heterogeneous mixture: it contains more than one substance, so it cannot be uniform

✓ Practice 2 · answer: B

white vinegar → a homogeneous mixture (answer B)

two kinds of particles · one phase · one bottle can hold more acid than another

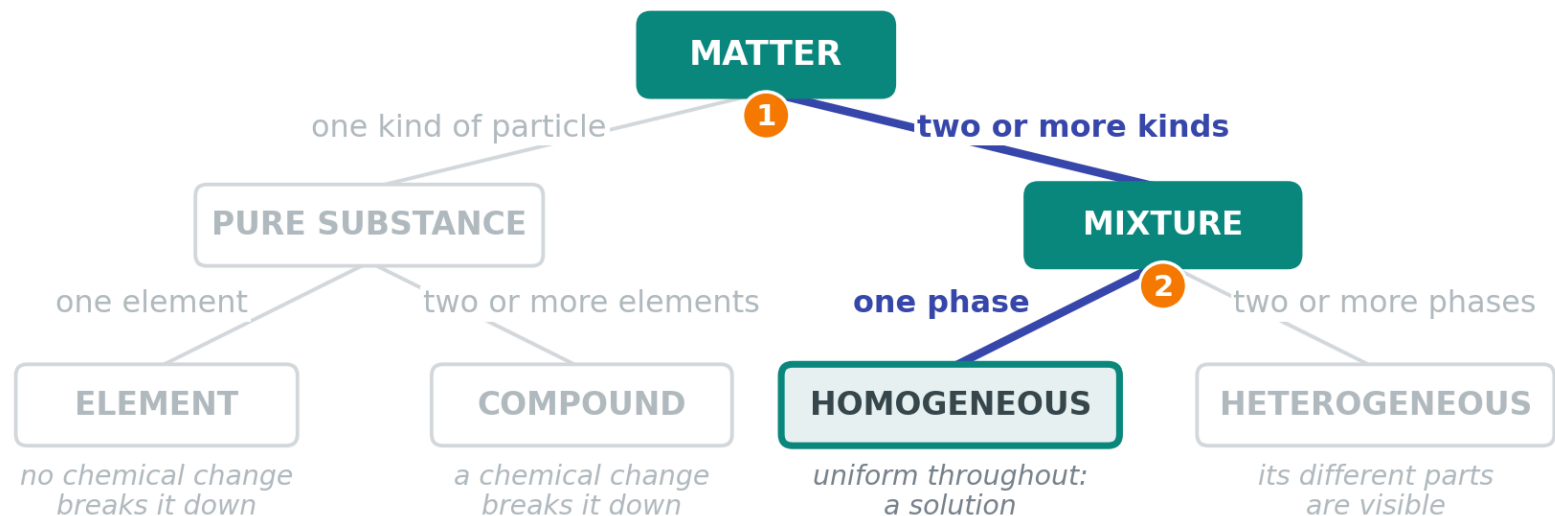
A: same properties throughout shows one phase, not one substance; the composition can still vary. C: uniform appearance does not show bonding; the acid and water separate by distillation, a physical change. D: several substances can share one phase; classification follows the phase count, not the substance count.

 **Sense check:** Uniform → homogeneous. Variable composition → mixture. Both labels apply to the same bottle.

✓ Practice 2: the route on the map

white vinegar: acetic acid dissolved in water

given: one clear liquid, uniform throughout · found: a homogeneous mixture



🧠 **Sense check:** Count 1: acid and water, two kinds of particles → mixture. Count 2: one phase → homogeneous. ✓



Worked example 3: air, brass, milk

air · brass · milk

a gas, a solid, and a liquid

The air in the room, the brass of a doorknob, a glass of milk. Work the three steps on each sample.

✓ Worked example 3: kinds of particles

air · brass · milk
a gas, a solid, and a liquid

Step 1 · Count the kinds of particles

sample	particles
air	N ₂ , O ₂ , Ar, and more
brass	copper atoms and zinc atoms
milk	water, fats, proteins, sugars

Each sample holds more than one kind of particle: three mixtures, in three physical states.

 **Sense check:** A mixture can be a gas, a solid, or a liquid. State does not enter the classification.

✓ Worked example 3: phases and the class

air · brass · milk: three mixtures

Step 2 · Count the elements or the phases

sample	phases
air	one, uniform at every point
brass	one, a uniform solid
milk	two, fat droplets in a watery liquid

Step 3 · Name the class

air → homogeneous · brass → homogeneous · milk → heterogeneous

air: 78% N₂ + 21% O₂ + 1% other = 100% · one phase, variable composition

🧠 **Sense check:** Milk looks uniform; magnified, fat droplets show real boundaries. Phase count, not appearance.



Practice 3

an unlabeled jar of colorless crystals

observation 1: under magnification, every crystal looks identical · observation 2: every sample analyzed has the same composition; strong heating leaves black carbon as water vapor escapes

How should the crystals be classified?

- A. Homogeneous mixture: every crystal looks alike, and heating separates the carbon from the water
- B. Element: every crystal is identical, and every sample has the same composition
- C. Compound: fixed composition in every sample, and heating breaks it into new, simpler substances
- D. Heterogeneous mixture: heating leaves a black solid and a vapor, two phases

✓ Practice 3 · answer: C

the crystals → a compound (answer C)

one kind of particle · fixed composition · a chemical change breaks it down

Step 1: the same composition in every sample means one kind of particle, a pure substance. Step 2: heating turns it into carbon and water, new substances: a chemical change. A pure substance that a reaction breaks down holds more than one element: a compound.

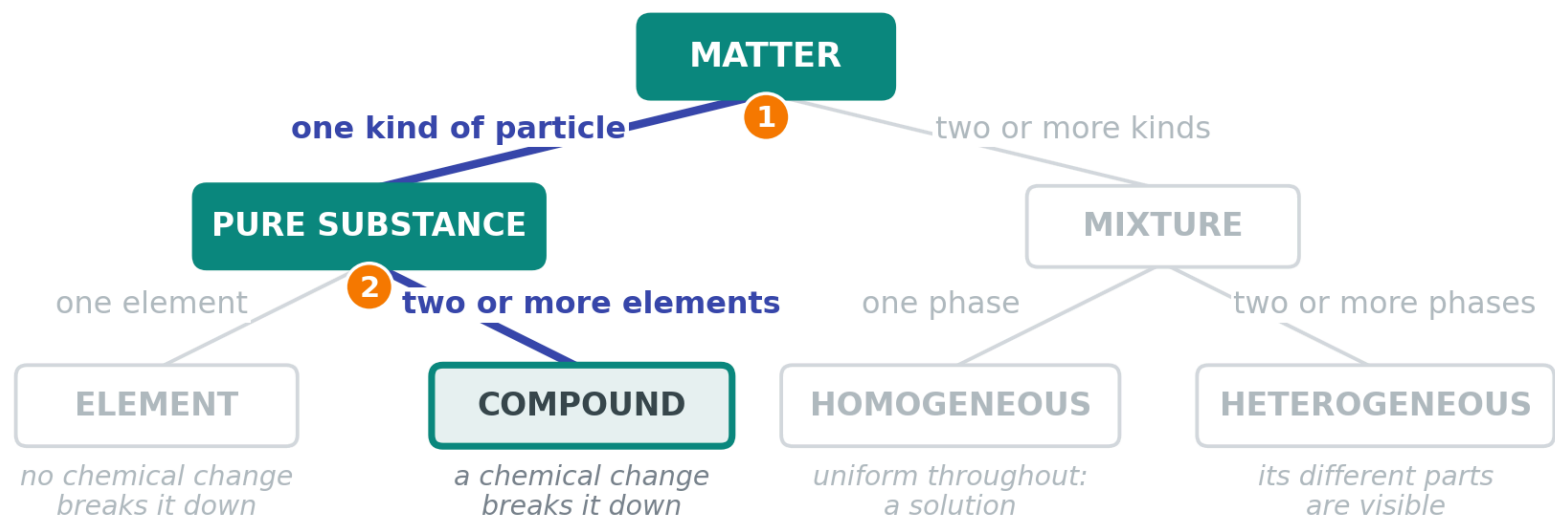
A: a mixture varies in composition and separates by a physical change; charring is chemical. B: fixed composition marks any pure substance, and no reaction breaks an element down. D: counts the phases of the products, not of the sample.

 **Sense check:** Uniform describes phases. Fixed composition says pure. Breakdown by reaction says compound.

✓ Practice 3: the route on the map

an unlabeled jar of colorless crystals

given: fixed composition · heating breaks it into carbon and water · found: a compound



① count the kinds of particles ② count the elements (pure) or the phases (mixture) ③ name the class

Sense check: Count 1: fixed composition → pure substance. Count 2: a reaction breaks it down → two or more elements → compound. ✓



Practice 4

a soft grey metal bead from a stockroom jar

observation 1: cut and magnified, the metal is uniform, and every sample analyzed has the same composition · observation 2: melted in an open crucible and stirred in air for hours, it slowly turns into a yellow powder heavier than the bead; no reaction has ever produced anything simpler from it

How should the bead be classified?

- A. Homogeneous mixture
- B. Element
- C. Compound
- D. Heterogeneous mixture

✓ Practice 4 · answer: B

the bead → an element (answer B)

one phase · fixed composition: pure · heating in air adds oxygen; nothing simpler ever comes out

Step 1: the same composition in every sample means one kind of particle, a pure substance. Step 2: turning into a yellow powder is a chemical change, but the powder outweighs the bead, so oxygen from the air joined the metal. Nothing broke off: one element.

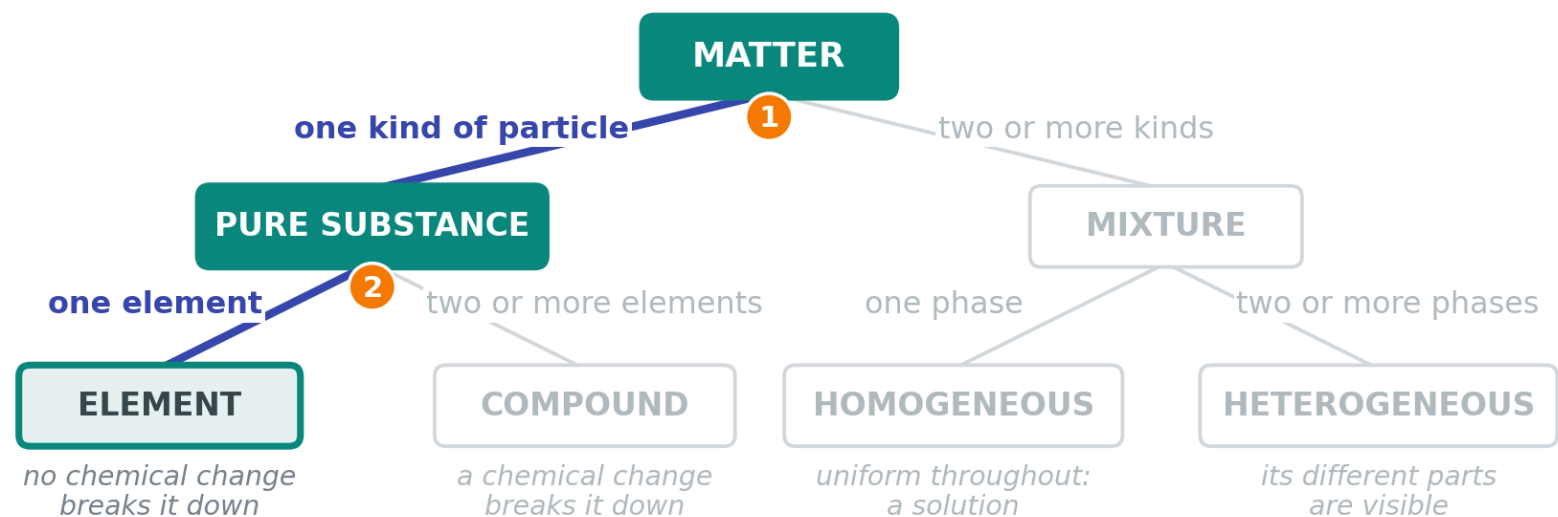
C read every chemical change as a breakdown; this one combines the metal with oxygen. A: uniform shows one phase, and fixed composition rules out a mixture. D counted the bead and the powder after heating, not the phases of the sample.

 **Sense check:** A heavier product means something joined the sample. Simpler products mean the sample broke apart. Only a breakdown marks a compound.

✓ Practice 4: the route on the map

a soft grey metal bead

given: same composition in every sample · heating in air only adds oxygen · found: an element



① count the kinds of particles ② count the elements (pure) or the phases (mixture) ③ name the class

 **Sense check:** Count 1: fixed composition → pure substance. Count 2: no reaction yields anything simpler → one element → element. ✓



Check yourself

1. A sealed bottle of soda water looks uniform throughout. Work the counts: kinds of particles, then phases. What class results?
2. Ice floats in liquid water. How many kinds of particles? How many phases? Is the sample a mixture?

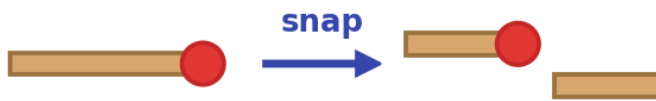
Separating a mixture is a **physical change**: boiling, filtering, settling. Breaking a compound into its elements is a **chemical change**. The same distinction, physical or chemical, classifies every property a substance shows.

3 · Physical & Chemical Properties

Classify any property or change as physical or chemical by asking whether the substance keeps its identity, read the four signals of a chemical change, and judge a change from an equation's formulas.

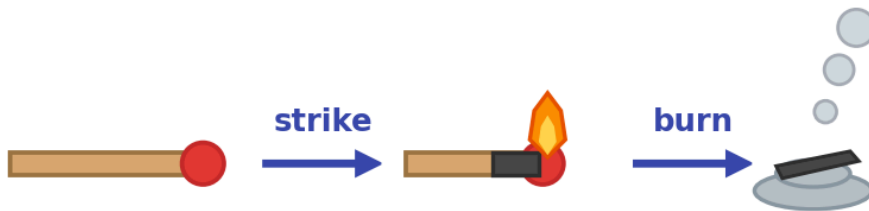
One match, two fates

which change kept the wood?



still wood ✓

two pieces, same substance



wood gone ✗

flame gases + ash: new substances

no cooling, sorting, or gluing brings the wood back

Snap a match: two pieces, still wood. Strike it: flame, smoke, ash, and nothing brings the wood back. Some changes keep a substance. Some end it.

Composition and properties



steam condensing on a cold window · methane burning on a gas stove

Chemistry studies composition, what matter is made of, and properties, the traits that describe it. Every label in this topic asks one question: did the composition change?

Which change keeps the composition?

steam: H_2O before, H_2O after → composition kept

methane: C: 1 = 1 · H: 4 = 4 · O: 4 = 4, the same atoms, but CH_4 and O_2 became CO_2 and H_2O → composition changed

Two kinds of properties

A property describes a substance; the question is what the description costs. Physical properties can be observed with the sample intact. Chemical properties tell what a substance can become, and seeing that takes a reaction.

physical property: observe it, keep the sample

color · odor · density · melting point: the coin survives having its density measured

chemical property: see it only in a reaction

flammable · tarnishes · will not burn: yes or no, the answer takes a reaction test

Two kinds of changes

property or change · physical or chemical

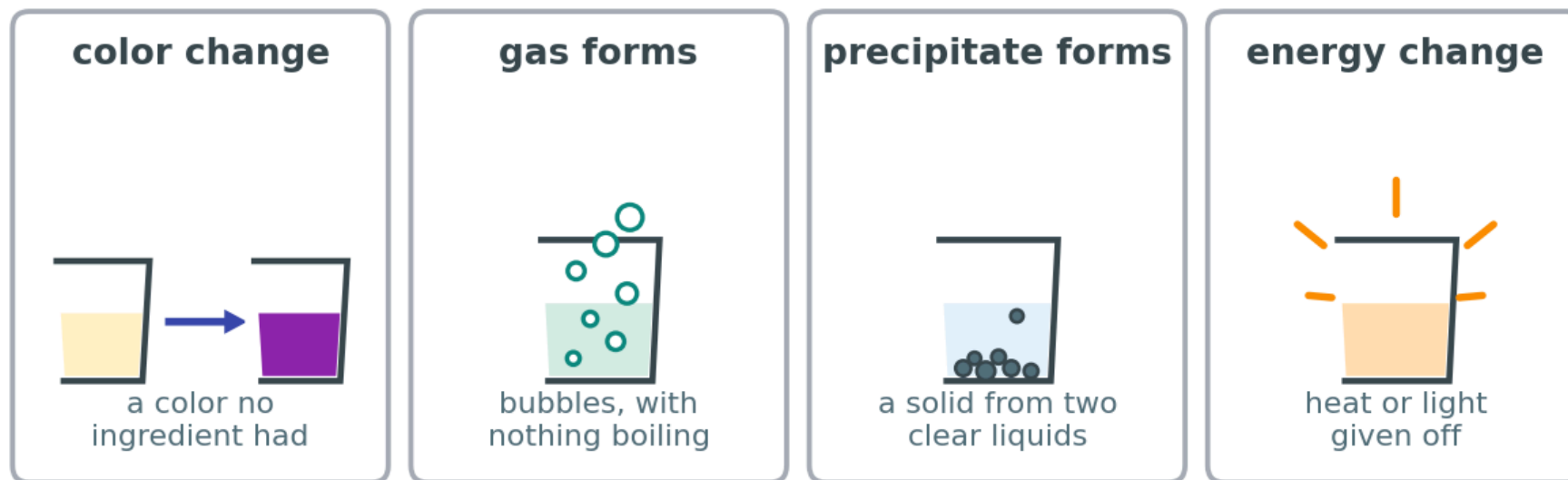
	physical identity kept	chemical identity changed
property a description	melts at 35 °C · 2.70 g/mL measure it, keep the sample	flammable · can rust seen only in a reaction
change an event	ice melts · sugar dissolves same substance, new form	toast browns · iron rusts new substance formed

properties describe, changes happen; both sort by one question: did the substance survive?

Changes get the identity question too. Melt ice, dissolve sugar, tear paper: the substances are all still there, in new forms. Burn paper and it is gone; new substances hold its atoms.

Evidence a new substance formed

four signals that a new substance formed



strong hints, not proof: the bubbles in boiling water are still just water

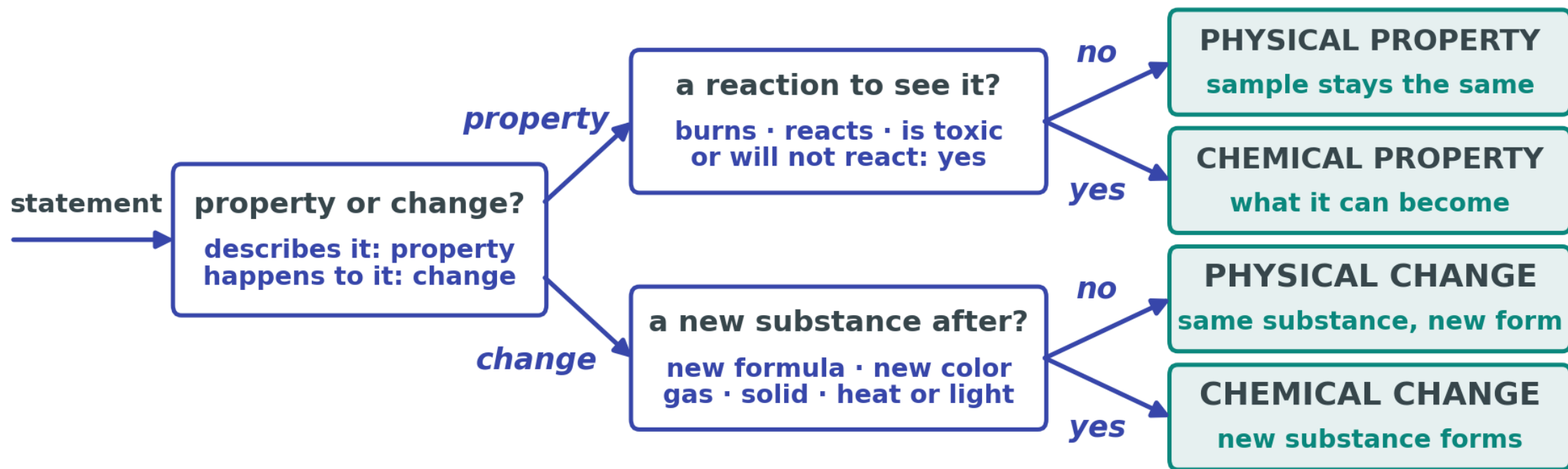
No one watches atoms rebond. What shows up instead: a color no ingredient had, a gas from a mixture that is not boiling, a solid from two clear liquids, heat or light given off.



The method

1. **Name the substance before and after.** Same substance → physical. New substance → chemical.
2. **Check the evidence.** New color, gas, solid, or energy change → new substance.

One map for every property and change



Two questions sort every statement. First: a property, which describes, or a change, which happens? Second: does a new substance form, in the change or in the test that shows the property?



Guided example: ethanol's boiling point

ethanol, $\text{C}_2\text{H}_5\text{OH}$: boils at $78\text{ }^\circ\text{C}$

one entry on a data sheet · wanted: physical or chemical property

A data sheet for ethanol, the alcohol in hand sanitizer, lists: **boils at $78\text{ }^\circ\text{C}$** . Classify the entry.

On the map, answer the first question before the second.

✓ Guided example: solution

ethanol, $\text{C}_2\text{H}_5\text{OH}$: boils at $78\text{ }^\circ\text{C}$

one entry on a data sheet · wanted: physical or chemical property

Property or change?

Step 1 · Name the substance before and after

$\text{C}_2\text{H}_5\text{OH}(\text{l}) \rightarrow \text{C}_2\text{H}_5\text{OH}(\text{g})$ at $78\text{ }^\circ\text{C}$

C: $2 = 2$ · H: $6 = 6$ · O: $1 = 1$ · ethanol before · ethanol after

Step 2 · Check the evidence

boils at $78\text{ }^\circ\text{C} \rightarrow$ a physical property

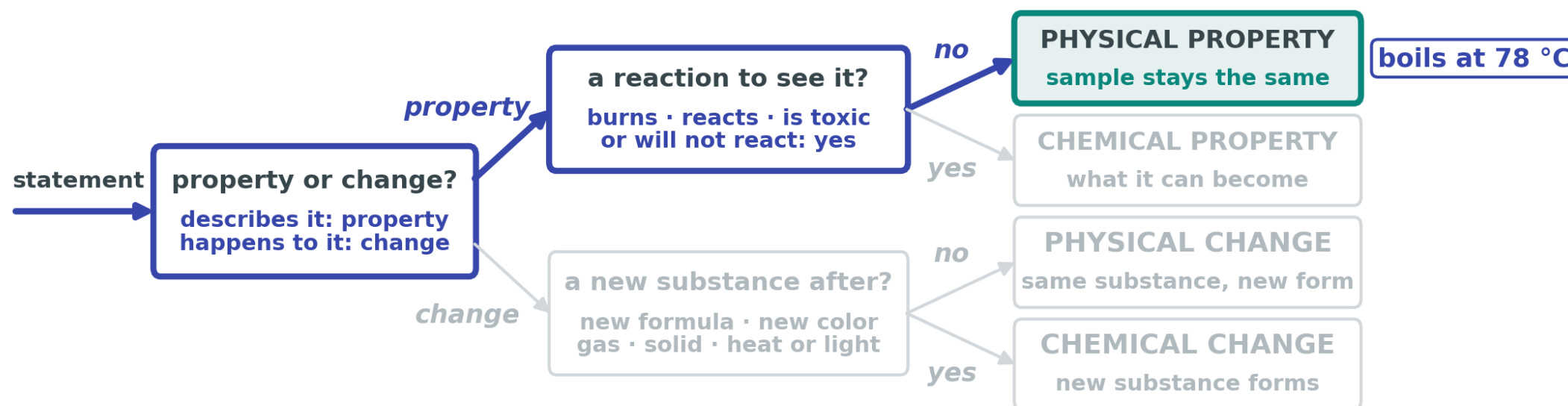
bubbles appear, but the gas is ethanol · no new color, solid, or substance

 **Sense check:** Observing the property left ethanol as ethanol. Bubbles from a boiling liquid are that liquid's own vapor, never a new gas.

✓ Guided example: the route on the map

ethanol, $\text{C}_2\text{H}_5\text{OH}$: boils at $78\text{ }^\circ\text{C}$

property · no reaction needed to see it · found: a physical property



🧠 **Sense check:** Two questions, two answers: a property, and no reaction to see it. Physical property. ✓



Practice 1

vinegar poured onto baking soda

the mixture foams over as bubbles of carbon dioxide escape

Vinegar poured onto baking soda foams as carbon dioxide bubbles out. Is this a physical or a chemical change?

- A. Physical, because the bubbles are a gas, as in boiling water
- B. Chemical, because any change that can be seen is chemical
- C. Physical, because the baking soda only dissolves in the vinegar
- D. Chemical, because carbon dioxide is a new substance, in neither starting material

✓ Practice 1 · answer: D

vinegar + baking soda → carbon dioxide gas + new dissolved substances (answer D)
CO₂ before: none · CO₂ after: bubbling out · a gas from a mixture that is not boiling → chemical change

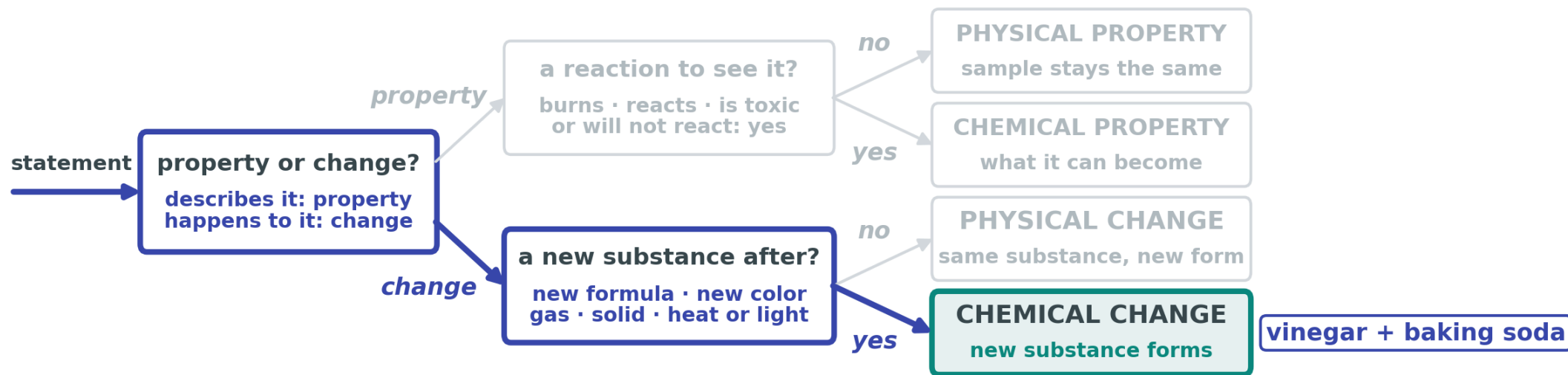
A: boiling bubbles are the liquid's own vapor; nothing here boils, and CO₂ is neither vinegar nor baking soda. B: right verdict, false rule; melting ice is seen too, and it is physical. C: dissolving makes no gas; the foam is a new substance leaving the bowl.

🧠 **Sense check:** One question settles it: is the gas a new substance? CO₂ was in neither bottle. ✓

✓ Practice 1: the route on the map

vinegar poured onto baking soda

change · new substance after: CO_2 · found: a chemical change



🧠 **Sense check:** A change, and a new substance after it: chemical change. The bubbles are the evidence. ✓



Worked example 1: butter in a pan

butter in a hot pan: melts, then browns and smokes

event 1: solid → clear yellow liquid · event 2: liquid → brown residue + smoke + sharp smell

Butter dropped in a warm pan melts. Left on the heat, it browns, smokes, and turns bitter. Two events, one pan. Classify each.

✓ Worked example 1: solution

butter in a hot pan: melts, then browns and smokes

Step 1 · Name the substance before and after

melting → a physical change

same butter · new form · fully undone by cooling

Step 1 · Name the substance before and after, again

Step 2 · Check the evidence

browning → a chemical change

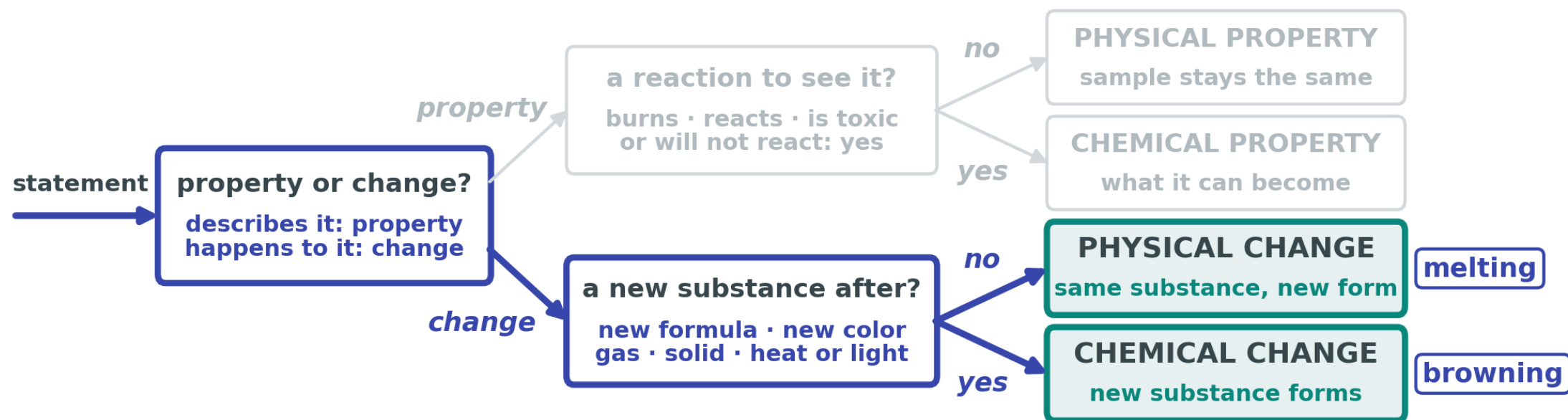
color change · gas and smoke · new smell · not undone by cooling

 **Sense check:** The pan ran the identity test twice. Cooling reverses melting; nothing on a stove has ever unbrowned toast, and butter follows the same rule.

✓ Worked example 1: the route on the map

butter in a hot pan: melts, then browns and smokes

melting: same butter → physical change · browning: brown solids, smoke, new smell → chemical change



🧠 **Sense check:** One pan, two exits. Both events are changes; only browning made a new substance. ✓



Worked example 2: changes written as equations

two changes, each ending in a gas

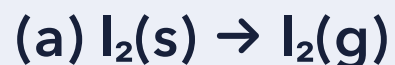


Iodine crystals warmed in a flask give off violet vapor. Hydrogen peroxide poured on a cut foams. A common first claim: a gas appeared, so both changes are chemical. Classify each from its formulas.

✓ Worked example 2: solution

two changes, each ending in a gas · (a) $\text{I}_2(\text{s}) \rightarrow \text{I}_2(\text{g})$ · (b) $2 \text{H}_2\text{O}_2(\text{l}) \rightarrow 2 \text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g})$

Step 1 · Name the substance before and after



I_2 before · I_2 after · only the state label changed → physical

Step 1 · Name the substance before and after, again



H: $4 = 4$ ✓ · O: $4 = 4$ ✓ · H_2O_2 before · H_2O and O_2 after → chemical

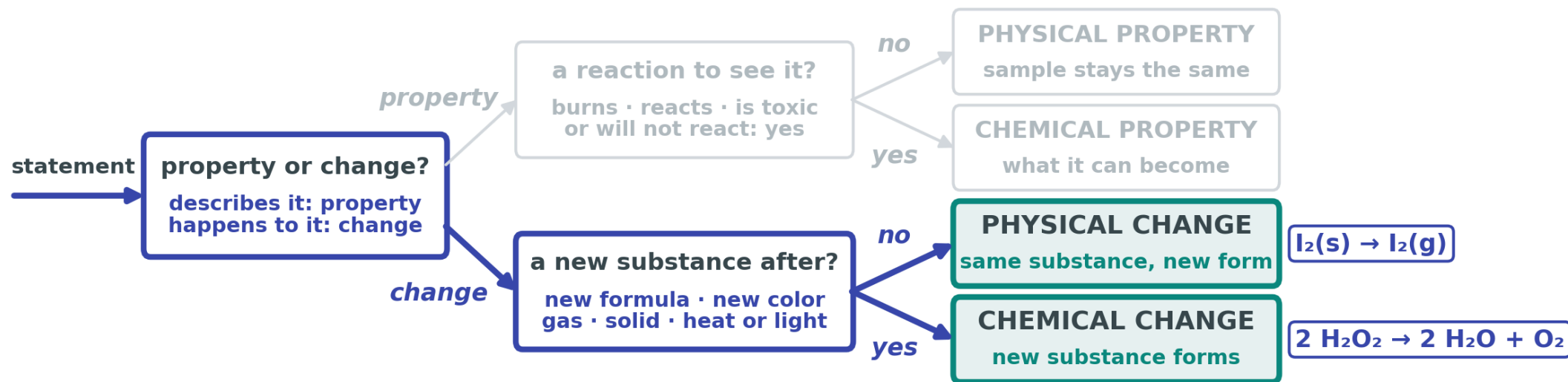
Step 2 · Check the evidence

 **Sense check:** A (g) shows up on the right of both equations, so a gas counts as evidence only when it is a new substance. Iodine vapor is still iodine; O_2 is new.

✓ Worked example 2: the route on the map



(a) I_2 on both sides → physical change · (b) new formulas H_2O and O_2 → chemical change



 **Sense check:** In an equation, the formulas answer the second question: same formula, physical; new formula, chemical. ✓

Take-home: one question does the sorting

identity kept → physical

melting, dissolving, cutting: the substance survives in a new form

identity lost → chemical

burning, rusting, browning: new substances hold the old atoms

Every label in this topic rides on one question: is the original substance still there? Yes, in any shape or state: physical. No: chemical, and the evidence usually announces it.

Your turn: a nail in the rain

an iron nail, weeks outdoors: an orange-brown, flaky coat
the coat scrapes off as a brittle powder, nothing like the shiny metal beneath

step	question	answer
1 · substance after	is the coat still iron?	no, a new orange solid → _____ change
2 · evidence	which signals appear?	a _____ change and a new solid
3 · undo it	does scraping restore the iron?	_____

Complete the three rows.

rusting → a chemical change

iron + air + water → rust · color change, new brittle solid · scraping removes rust and restores nothing

⚠ Where this goes wrong

Calling dissolving a chemical change. Sugar vanishes into tea, but boil the tea away and the sugar is back, unchanged. Out of sight is not out of existence: the sugar kept its identity. Physical.

Reading every bubble as a reaction. Boiling water bubbles furiously, and the gas is water vapor: the same substance. Gas counts as evidence when it is a new substance appearing from a mixture that is not boiling.

Confusing a property with a change. "Melts at 35 °C" is a physical property, a number that sits on a label. "The butter melted" is a physical change, an event in a pan. Properties describe; changes happen.

Judging a change by how dramatic it looks. A beaker hits the floor and bursts into shards with a loud crack: still glass, in smaller pieces. Physical. A silver spoon darkens quietly over a month as a new black solid coats it. Chemical. A new substance is the evidence, never the size of the show.



Practice 2

gasoline: a liquid · floats on water · evaporates fast · flammable
four descriptions of one substance

Four descriptions of gasoline. Which one is a chemical property?

- A. It is a liquid at room temperature
- B. It floats on water
- C. It evaporates quickly from an open container
- D. It is flammable

✓ Practice 2 · answer: D

flammable → a chemical property (answer D)

observing it turns the gasoline into carbon dioxide and water: the description costs the sample

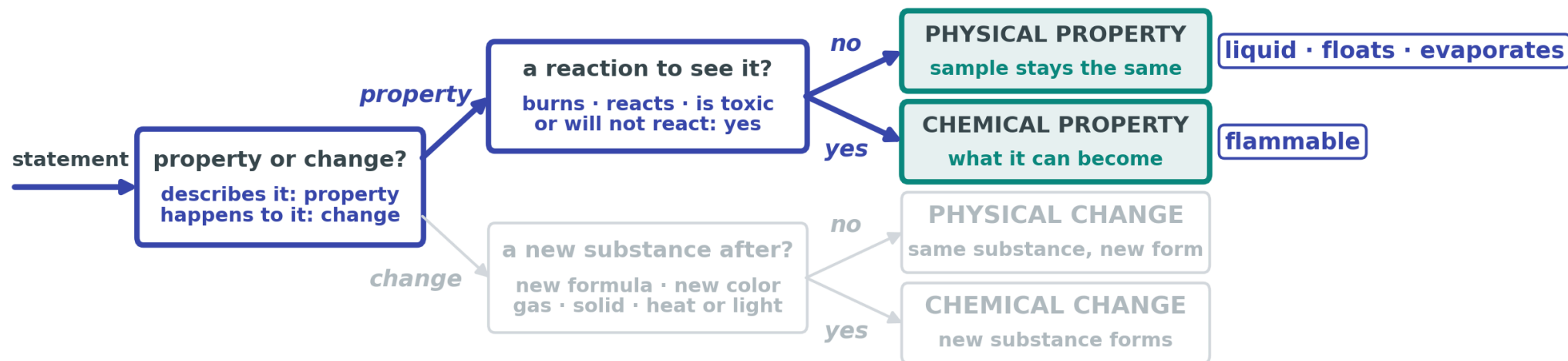
A: state is observed by looking; the liquid stays gasoline. B: floating compares two densities, and both liquids survive the comparison. C: evaporation trades liquid for vapor, still gasoline; chill the vapor and it condenses right back.

 **Sense check:** Three descriptions leave the gasoline in the can. The fourth can be confirmed once, from a distance.

✓ Practice 2: the route on the map

gasoline: a liquid · floats on water · evaporates fast · flammable

three seen with the sample kept → physical properties · flammable → chemical property



🧠 **Sense check:** All four are properties. Only flammability takes a reaction to see. ✓

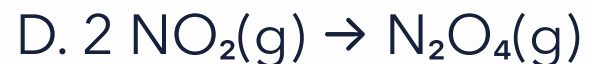
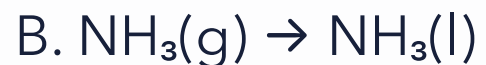
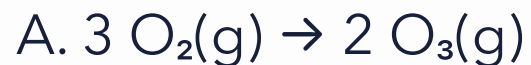


Practice 3

four changes, each written with formulas and state labels

A, B, C, D · wanted: the one physical change

Which equation shows a physical change?



✓ Practice 3 · answer: B

$\text{NH}_3(\text{g}) \rightarrow \text{NH}_3(\text{l})$: NH_3 on both sides $\rightarrow$ physical change (answer B)

N: $1 = 1$ · H: $3 = 3$ · only the state label changes: ammonia gas condenses

A: $3 \text{ O}_2 \rightarrow 2 \text{ O}_3$ · C: $\text{NH}_4\text{Cl} \rightarrow \text{NH}_3 + \text{HCl}$ · D: $2 \text{ NO}_2 \rightarrow \text{N}_2\text{O}_4$

a new formula on the right in each $\rightarrow$ chemical change

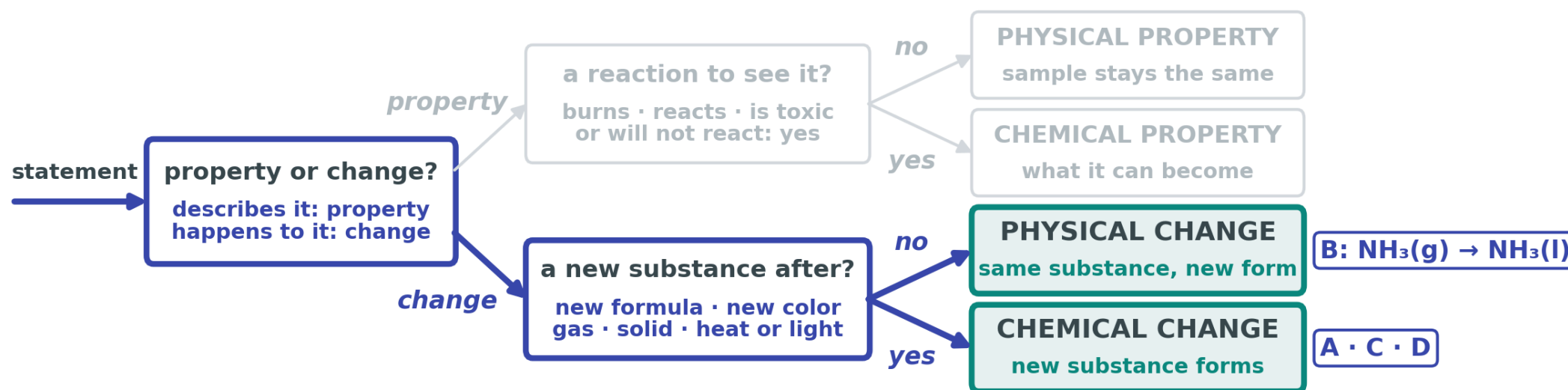
A: only oxygen on both sides, but O_3 is a different substance from O_2 . C: a solid turning into gases looks like sublimation, yet two new formulas form. D: counts match, N: $2 = 2$ · O: $4 = 4$, as in every balanced equation; NO_2 still became N_2O_4 .

 **Sense check:** Compare formulas, not state labels or atom counts. Only a formula kept across the arrow makes a change physical. ✓

✓ Practice 3: the route on the map

B: $\text{NH}_3(\text{g}) \rightarrow \text{NH}_3(\text{l})$ · A, C, D: a new formula after the arrow

B: same formula $\rightarrow$ physical change · A, C, D: new substance $\rightarrow$ chemical change



🧠 **Sense check:** Four changes, one question each: a new formula after the arrow? Only B says no. ✓



Practice 4

chlorine, four entries in a lab notebook

(1) a greenish-yellow gas · (2) $\text{Cl}_2(\text{g}) \rightarrow \text{Cl}_2(\text{l})$ at $-34\text{ }^\circ\text{C}$ · (3) $\text{Cl}_2(\text{g}) + 2\text{Na}(\text{s}) \rightarrow 2\text{NaCl}(\text{s})$ · (4) does not burn in air

Which entries are chemical, either a chemical property or a chemical change?

- A. (3) and (4)
- B. (3) only
- C. (2) and (3)
- D. (2), (3), and (4)

✓ Practice 4 · answer: A

(3) and (4) are chemical (answer A)

(1) color: physical property · (2) Cl_2 on both sides: physical change · (3) NaCl is new: chemical change ·
(4) a failed burn test: chemical property

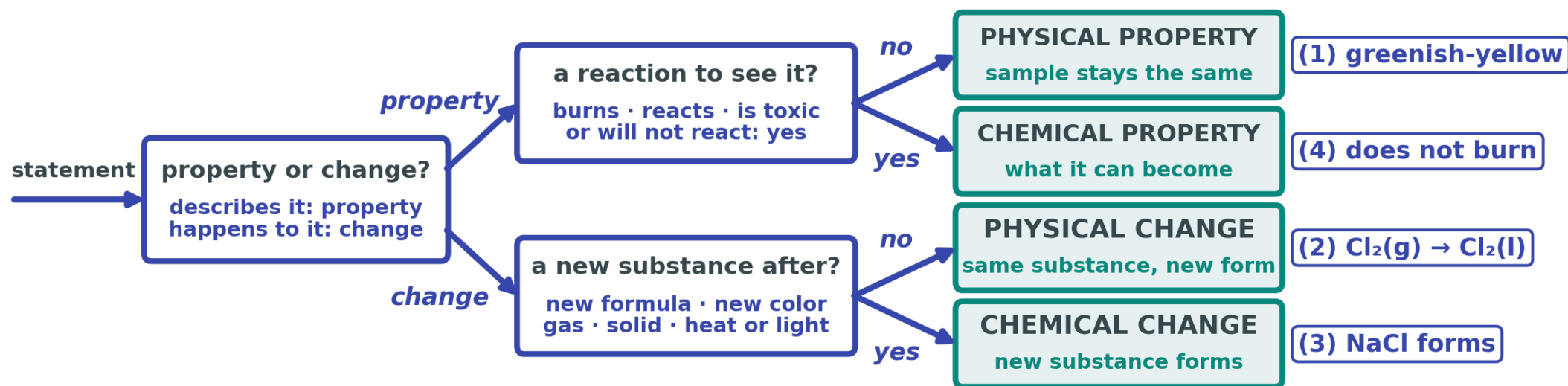
B: "does not burn" still reports what a reaction test found, so it is a chemical property. C: (2) keeps the same formula, Cl_2 , and only the state label changes; condensing is physical. It also drops (4). D: counts the condensation as a reaction because it is written as an equation.

 **Sense check:** An arrow does not make a reaction; a new formula does. A burn test answers yes or no, and either answer is chemistry.

✓ Practice 4: the route on the map

chlorine, four entries in a lab notebook

(1) physical property · (2) physical change · (3) chemical change · (4) chemical property



🧠 **Sense check:** Four entries, four different exits. The first question split them; the second decided each one. ✓



Practice 5

calcium oxide (lime), three entries on a data sheet

(1) melts at 2613 °C · (2) 56.1 g of CaO combines with 18.0 g of water · (3) density: 3.34 g/cm³

A data sheet for lime, calcium oxide, lists the three entries above. Which entries are chemical properties?

- A. (1) and (2)
- B. (2) and (3)
- C. (2) only
- D. (1), (2), and (3)

✓ Practice 5 · answer: C

(2) only is a chemical property (answer C)

(1) melted, still CaO: physical · (2) $\text{CaO(s)} + \text{H}_2\text{O(l)} \rightarrow \text{Ca(OH)}_2\text{(s)}$: chemical · (3) sample kept: physical

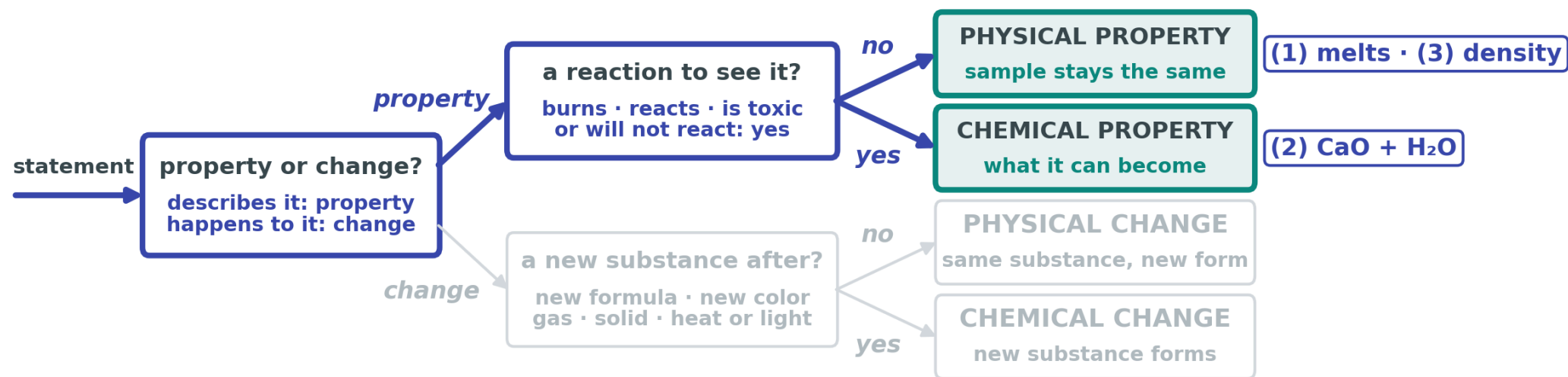
A: melting-as-reaction slip; 2613 °C is extreme, but the liquid that forms is still CaO. B: density-as-reaction slip; density identifies lime, yet weighing and measuring a sample leaves it CaO. D: reads "a property of a chemical" as "a chemical property"; a data sheet lists both kinds, and a number with units never decides which.

🧠 **Sense check:** 56.1 g + 18.0 g = 74.1 g of calcium hydroxide. Only (2) tells what lime can become; (1) and (3) describe lime as it is. ✓

✓ Practice 5: the route on the map

calcium oxide (lime), three entries on a data sheet

all three are properties · (1), (3) no reaction to see them: physical · (2) Ca(OH)_2 forms: chemical



🧠 **Sense check:** Three numbers, one branch. Units do not decide the exit; whether seeing it takes a reaction does. ✓

Check yourself

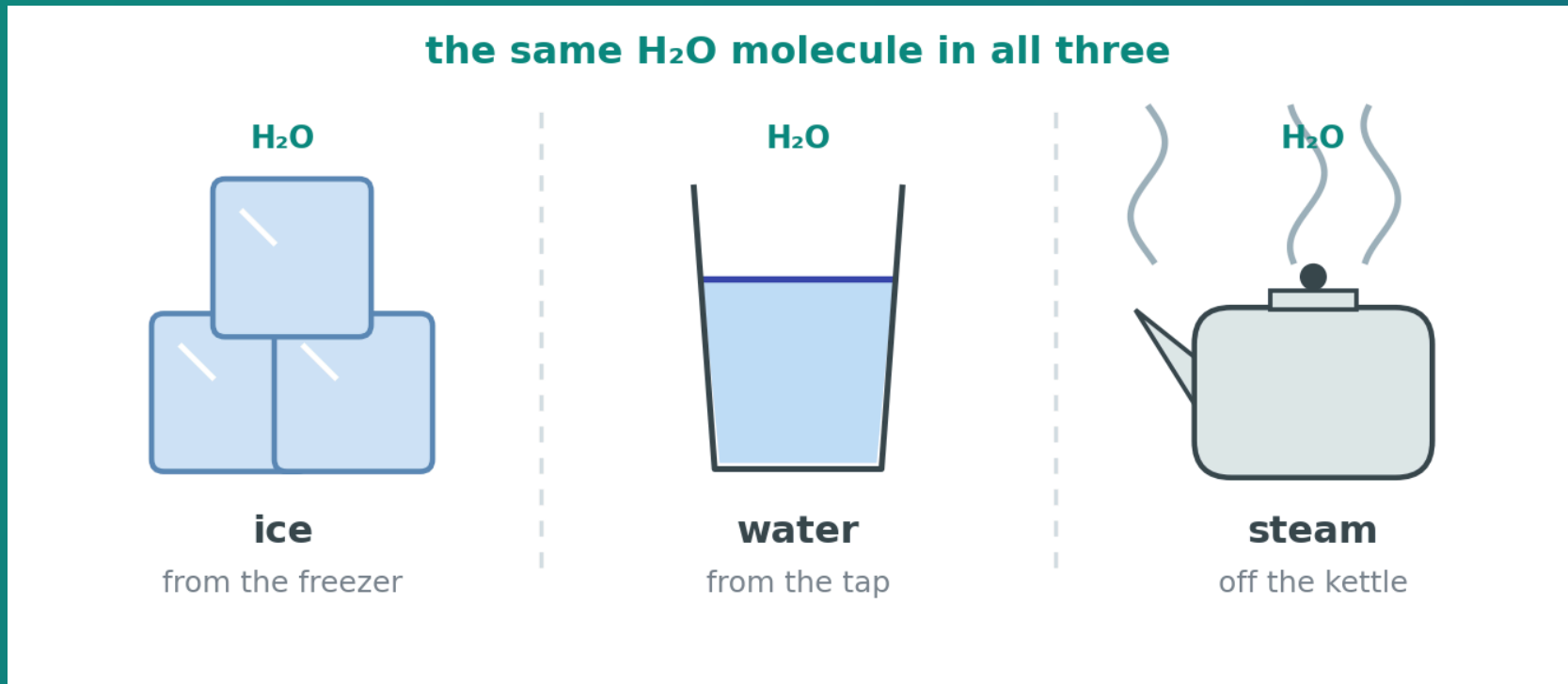
1. A tablet dropped in water fizzes, the glass cools, and the tablet shrinks away. List every signal you can, then classify the change.
2. Dry ice turns straight to gas, $\text{CO}_2(\text{s}) \rightarrow \text{CO}_2(\text{g})$. Heated limestone gives off a gas too, $\text{CaCO}_3(\text{s}) \rightarrow \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$. Classify each change and name the clue in the formulas.

Physical or chemical, property or change: every label here comes from one habit. Ask what survived the event, and what the observation cost.

4 · States of Matter

Name a sample's state from two checks, its shape and its volume, and back the call with the particle picture of spacing and motion.

One substance, three states



Ice, tap water, steam off the kettle: all H_2O , the same molecule down to the last atom. What changed is how the molecules sit and how fast they move.

Solid, liquid, gas, and plasma

solid · liquid · gas

the three states on the bench: ice, tap water, steam

plasma: a fourth state

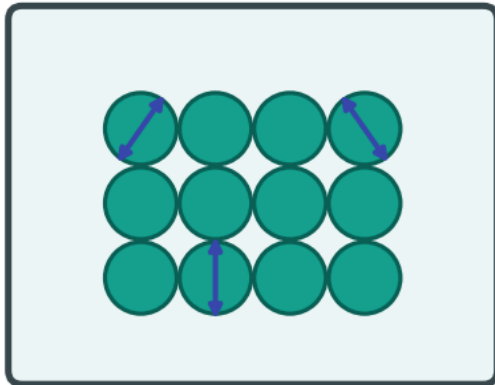
lightning, neon signs, the Sun: a gas so hot its atoms break into charged particles

Matter has mass and takes up space, and it comes in states. Plasma needs extreme temperatures. Every sample in this course is a solid, a liquid, or a gas.

The particle view

same particles, three arrangements

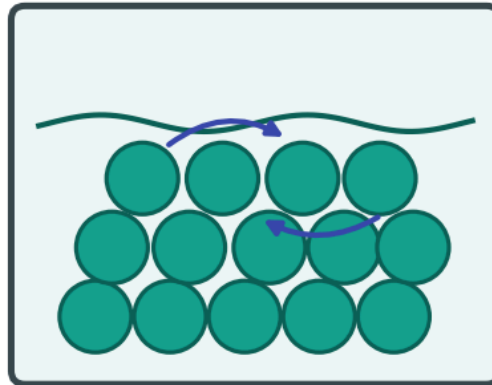
solid



particles vibrate in place

**own shape
own volume**

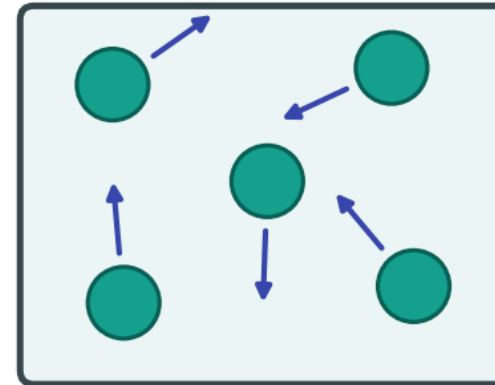
liquid



particles slide past one another

**container's shape
own volume**

gas



particles fly between collisions

**container's shape
container's volume**

spacing and motion name the state

Matter is particles in motion. Solid: the particles touch and vibrate in place. Liquid: they touch but slide past one another. Gas: they fly apart, mostly empty space between them.

Shape and volume follow the particles

solid: its own shape, its own volume

definite shape · definite volume · incompressible: locked particles hold both

liquid: the container's shape, its own volume

indefinite shape · definite volume · incompressible: touching keeps the volume, sliding loses the shape

gas: the container's shape, the container's volume

indefinite shape · indefinite volume · compressible: far-apart particles spread to fill the container, and a push packs them closer

Two questions sort every sample: does it keep its own shape, and does it keep its own volume. The particle picture answers both.

Naming the changes of state

solid $\rightleftharpoons$ liquid

melting: solid $\rightarrow$ liquid, energy in · freezing: liquid $\rightarrow$ solid, energy out

liquid $\rightleftharpoons$ gas

evaporation (boiling): liquid $\rightarrow$ gas, energy in · condensation: gas $\rightarrow$ liquid, energy out

solid $\rightleftharpoons$ gas

sublimation: solid $\rightarrow$ gas, energy in · deposition: gas $\rightarrow$ solid, energy out

Every change of state runs both ways, and each direction has a name. Toward gas, the sample takes energy in. Toward solid, it gives energy out. Dry ice sublimates. Frost deposits on a cold window.

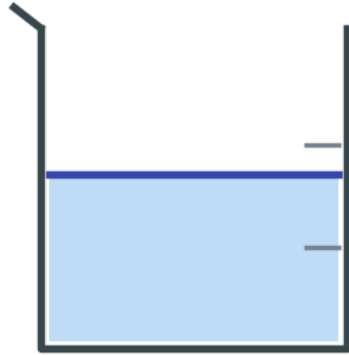
The three states in glassware

three states on the bench



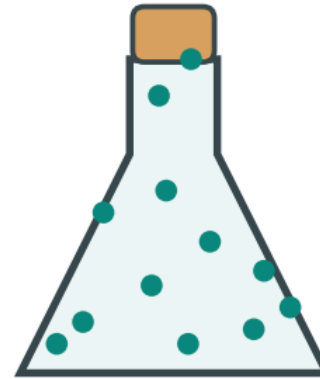
solid

the powder keeps its heap



liquid

levels flat, takes the beaker's shape



gas

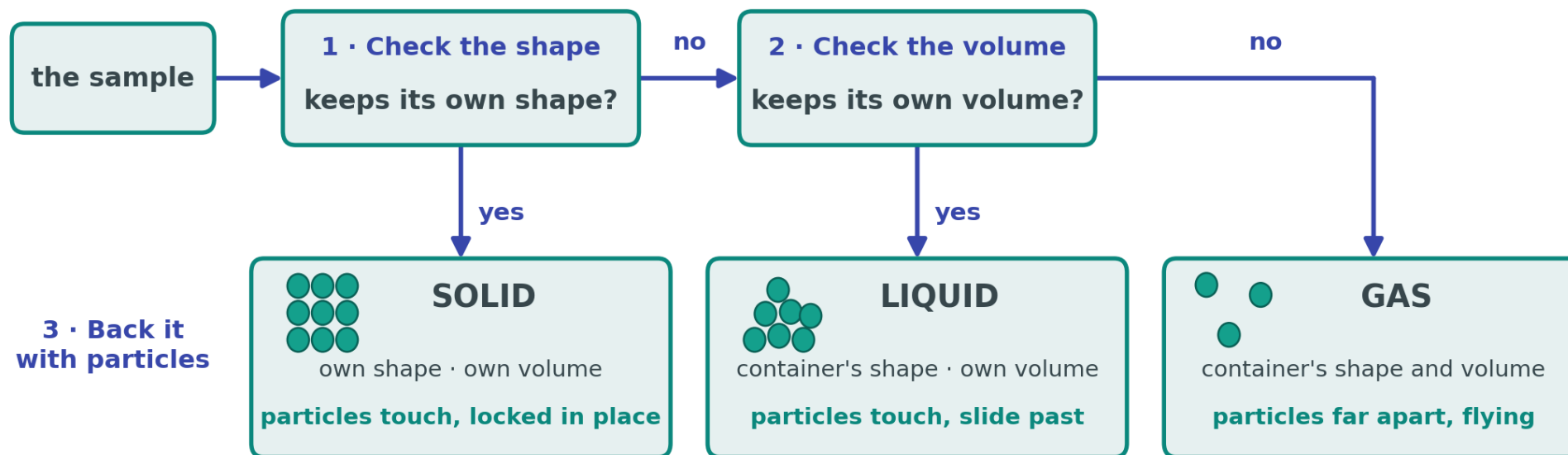
fills the flask, neck included

The bench shows all three daily. A powder holds its heap on the watch glass. A liquid levels flat against the beaker walls. A gas fills a stoppered flask completely, neck included.



The method

1. **Check the shape:** keeps its own shape → solid.
2. **Check the volume:** keeps its own volume → liquid. Fills the container → gas.
3. **Back it with particles:** locked in place, sliding, or far apart.





Guided example: honey

250 mL of honey, poured from a jar into a wide bowl
it creeps out slowly · minutes later it lies flat across the bowl's bottom · still 250 mL

Honey pours so slowly that a common first call is solid. Name its state with the two checks, then back the call with particles.

✓ Guided example: solution

250 mL of honey, jar → wide bowl
lies flat across the bowl's bottom · still 250 mL

Step 1 · Check the shape

Step 2 · Check the volume

jar: 250 mL → bowl: 250 mL
container's shape · own volume → liquid

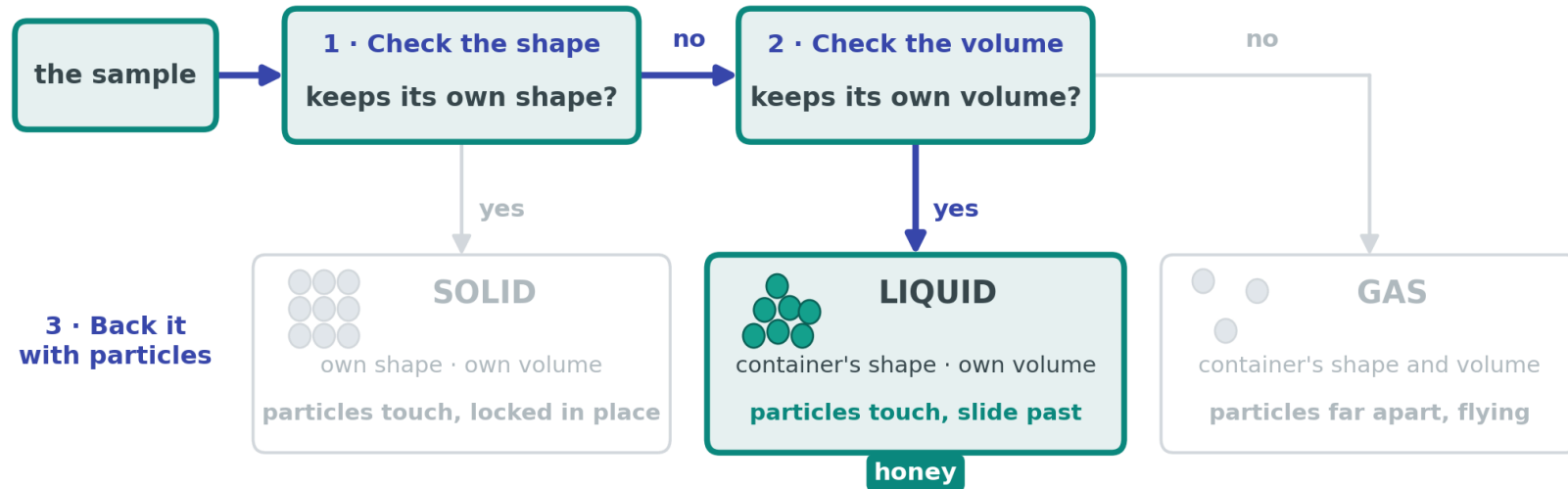
Step 3 · Back it with particles

Honey's particles touch, which holds the 250 mL. They slide past one another, which gives up the shape. They just slide slowly.

🧠 **Sense check:** Slow flow is still flow. Thickness sets how fast a liquid pours, never which state it is. ✓

✓ Guided example: the route on the map

250 mL of honey, jar → wide bowl
container's shape · own volume · found: liquid



🧠 **Sense check:** Both checks ran: no to its own shape, yes to its own volume. The particle row backs the call. ✓



Practice 1

particles that touch one another and slide past one another
wanted: the state

In which state do the particles touch but slide past one another?

- A. Solid
- B. Liquid
- C. Gas
- D. Both solid and liquid

✓ Practice 1 · answer: B

touch + slide → liquid (answer B)

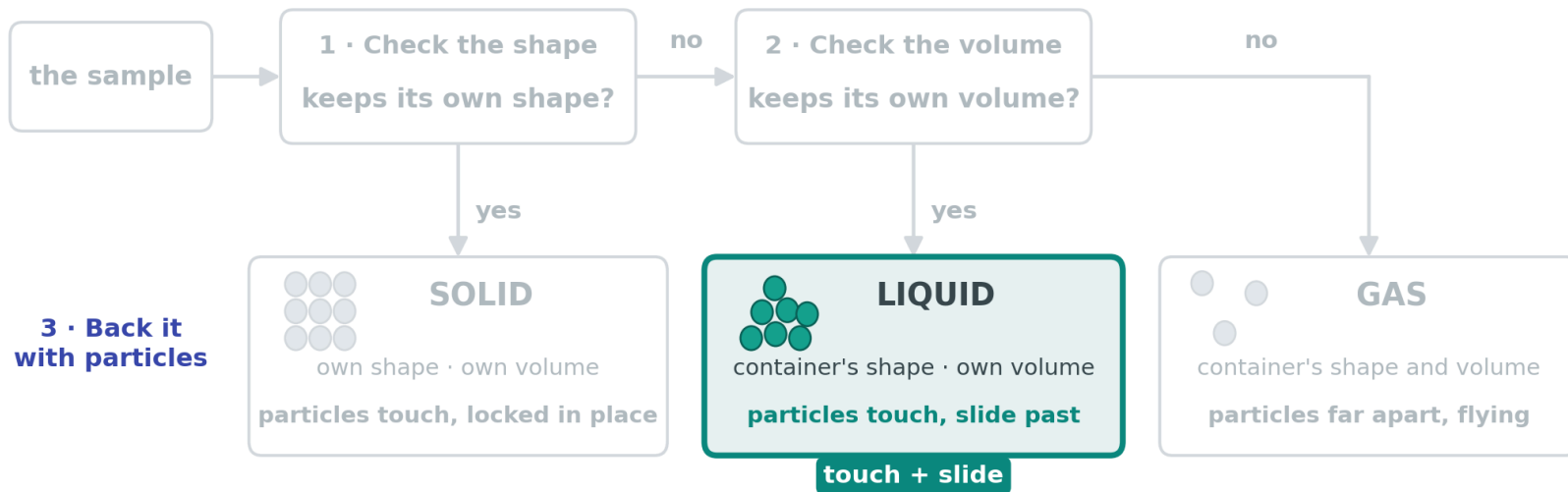
solid: touch, locked in place · liquid: touch, slide · gas: far apart, flying

A matched only the touching: solid particles touch but stay locked in place. C matched only the motion: gas particles move freely, but far apart, not touching. D matched only the touching too: a solid's particles do not slide, so a solid keeps its own shape.

 **Sense check:** Two features, one state. Touching holds the volume; sliding gives up the shape. ✓

✓ Practice 1: the route on the map

particles touch and slide
found: liquid



🧠 **Sense check:** The particle row reads both ways: from a state to its particles, or from the particles back to the state.





Practice 2

liquid water boils into steam



When liquid water boils into steam, what happens to its particles?

- A. They swell to many times their size
- B. They break apart into hydrogen and oxygen
- C. They move far apart, each keeping its size
- D. They stay touching but slide faster

✓ Practice 2 · answer: C

$\text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_2\text{O}(\text{g})$: same formula, new spacing (answer C)

liquid: particles touch · gas: far apart, mostly empty space · each H_2O molecule unchanged

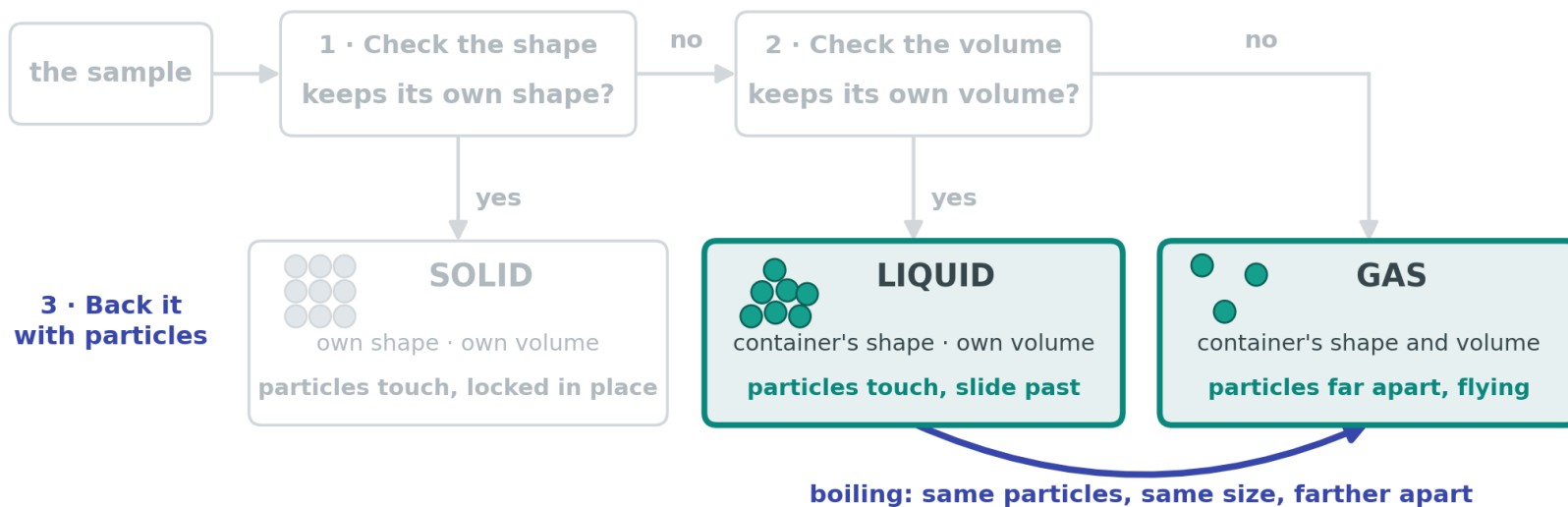
A resized the particles: particles keep their size in every state, and only the space between them grows. B made a new substance: the bubbles are water vapor, and H_2O sits on both sides of the arrow. D describes hot liquid water: touching particles would keep their own volume, and steam fills its container.

 **Sense check:** Boiling changes spacing, never size or identity. Condense the steam and the same water returns. ✓

✓ Practice 2: the route on the map



liquid: touching · gas: far apart · found: same particles, farther apart



 **Sense check:** Boiling moves a sample from the liquid leaf to the gas leaf. Only the particle row changes: touching becomes far apart. ✓



Practice 3

two samples, each moved into its own empty, sealed 6.0 L jug
1.5 L of helium from a balloon · 0.50 L of liquid water from a bottle

A balloon holds **1.5 L** of helium and a bottle holds **0.50 L** of water. Each sample is moved into its own empty, sealed **6.0 L** jug. What total volume do the two samples fill, in liters?

- A. 6.5
- B. 2.0
- C. 12.0
- D. 7.5

✓ Practice 3 · answer: A

helium: a gas, the container's volume · water: a liquid, its own volume

given: 1.5 L helium, 0.50 L water, two 6.0 L jugs · wanted: total L

Two checks, one per sample. The helium fills its jug; the water keeps its 0.50 L.

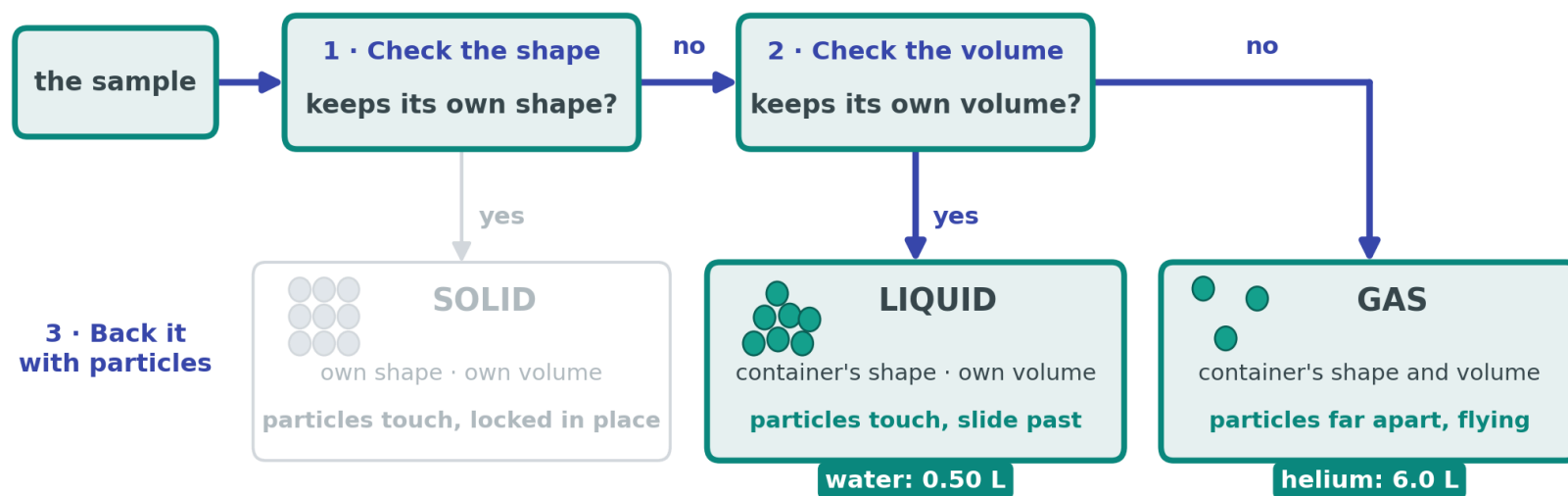
$$6.0 \text{ L helium} + 0.50 \text{ L water} = \mathbf{6.5 \text{ L (answer A)}}$$

B kept both volumes: $1.5 + 0.50 = 2.0$, the helium treated as a liquid. C filled both jugs: $6.0 + 6.0 = 12.0$, the water treated as a gas. D swapped the rules: $1.5 + 6.0 = 7.5$, the gas kept its volume and the liquid spread.

 **Sense check:** The helium's starting 1.5 L never enters the sum. A gas takes its container's volume, whatever it came from. ✓

✓ Practice 3: the route on the map

helium: container's volume · water: own volume
given: 1.5 L helium, 0.50 L water, two 6.0 L jugs · found: 6.5 L



🧠 **Sense check:** Both samples fail the shape check. The volume check splits them: water keeps its own, helium fills the jug. ✓



Practice 4

three 40 mL samples, each moved into its own empty 250 mL piston cylinder

X: spreads through all 250 mL, and pushing the piston squeezes it into 125 mL · Y: lies flat across the bottom, still 40 mL · Z: keeps the block shape it came in, still 40 mL

In which samples do the particles touch one another?

- A. Z only
- B. X and Y
- C. Y and Z
- D. X, Y, and Z

✓ Practice 4 · answer: C

X: indefinite shape and volume, compressible → gas · Y: indefinite shape, definite volume → liquid · Z: definite shape and volume → solid
touching: solid and liquid · far apart: gas → Y and Z (answer C)

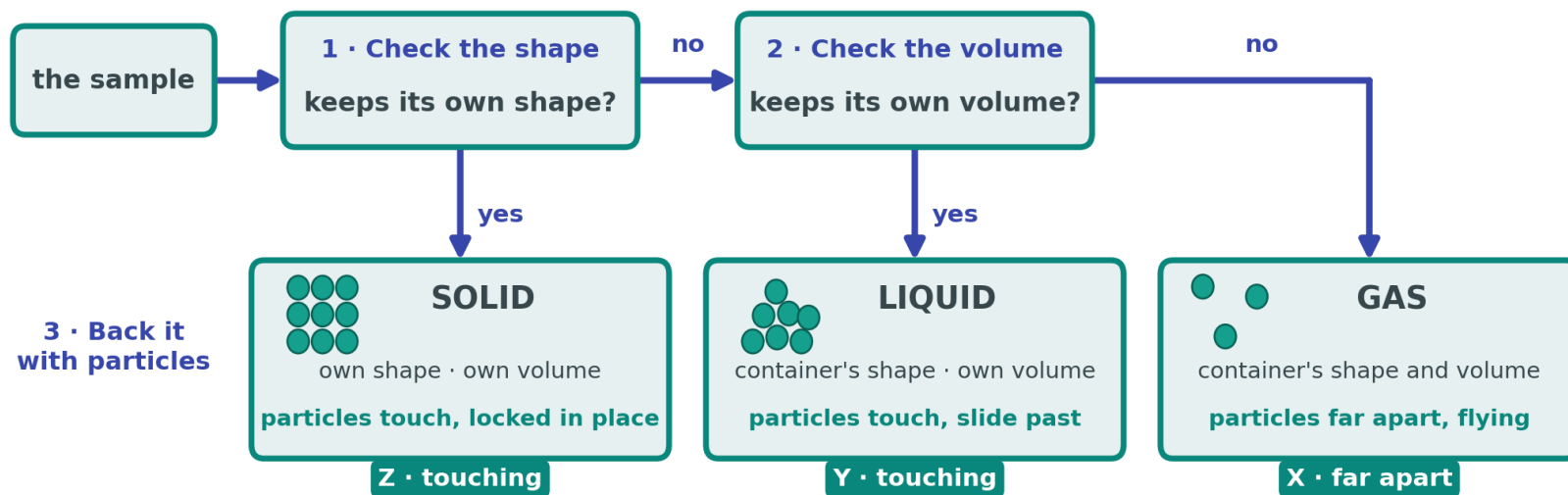
A stopped at locked particles: liquid particles touch too, which is why Y kept its 40 mL. B sorted by shape: X and Y both took the cylinder's shape, but shape follows sliding, not touching. D read the full cylinder as packed: X spread from 40 mL to 250 mL and then squeezed into 125 mL, so its particles sit far apart.

 **Sense check:** The volume check is the touching test. A sample that keeps its own volume has touching particles; one that fills any container does not. ✓

✓ Practice 4: the route on the map

three 40 mL samples in 250 mL piston cylinders

X: gas · Y: liquid · Z: solid · found: Y and Z touch



🧠 **Sense check:** All three paths through the chart, then the particle row: the two leaves that keep their own volume are the two whose particles touch. ✓



Check yourself

1. A sealed syringe of air squeezes to half its size; a sealed syringe of water barely gives at all. Explain both results with particle spacing.
2. Dry sand pours into a bucket and takes the bucket's shape. Run the two checks on one grain, then on the pile. Why is sand still a solid?

Every change of state carries an energy cost: melting and boiling take energy in, freezing and condensing give it back. Measuring that energy is its own topic, and it starts from this particle picture.

5 • Energy

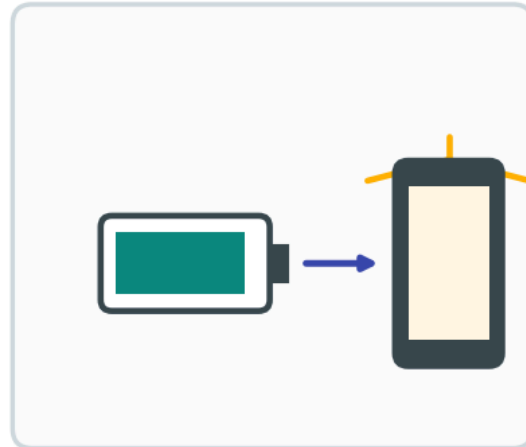
Say what energy is, sort stored energy from energy of motion in chemical settings, name heat and work as the two ways energy transfers, and keep temperature distinct from heat.

Energy on an ordinary day

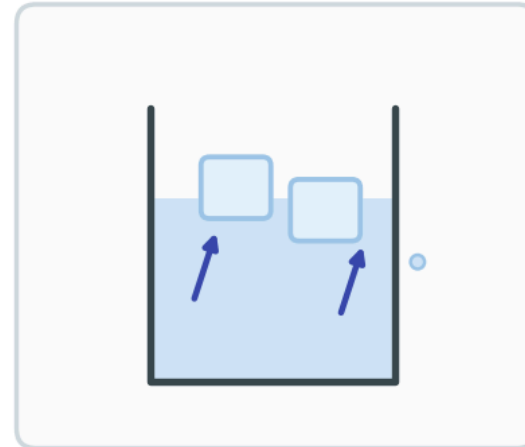
three ordinary sights, one thing changing hands



burning wood pours out
heat and light



a charged battery
runs a phone



melting ice draws warmth
from the drink

A campfire pours out heat and light. A charged battery runs a phone. Ice melting in a glass draws warmth from the drink. Chemistry tracks all of it.

Energy: the capacity to do work or transfer heat

energy: the capacity to do work or to transfer heat
never created or destroyed · it changes form and changes place

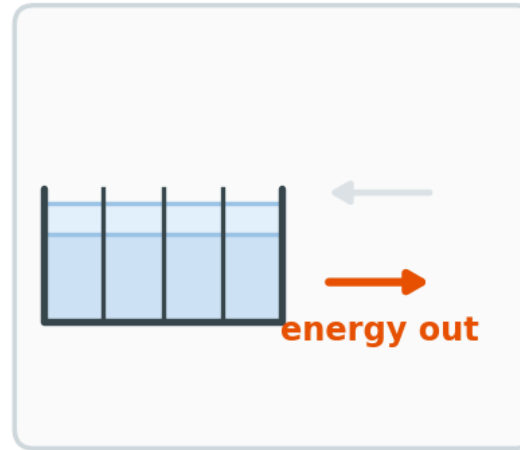
A campfire creates no energy; it releases energy the wood already held. Every process moves energy from one place to another or converts it from one form to another.

Changes in matter move energy

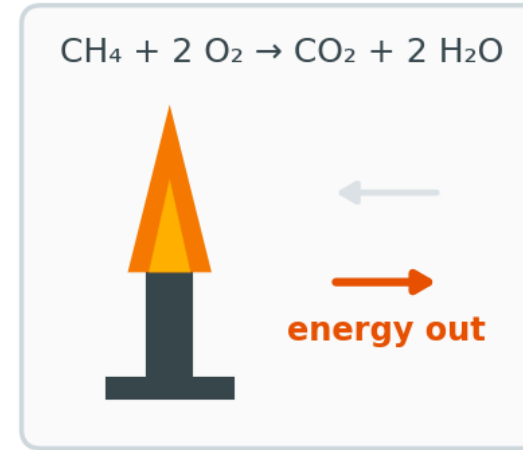
every change in matter moves energy: in or out



melting iron
physical change



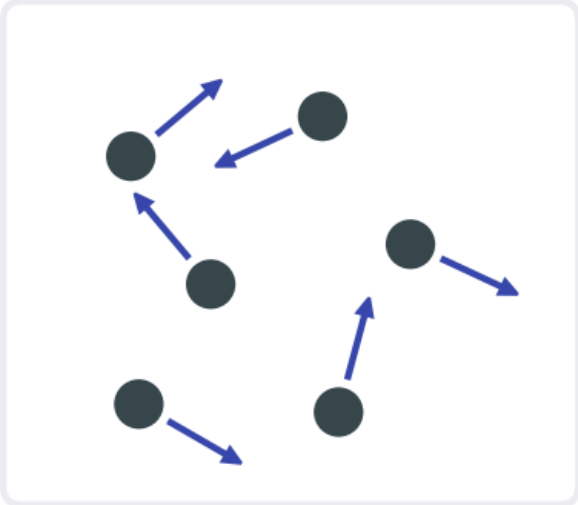
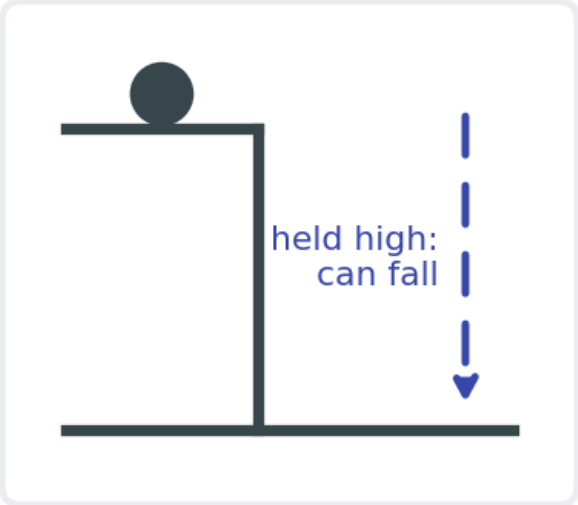
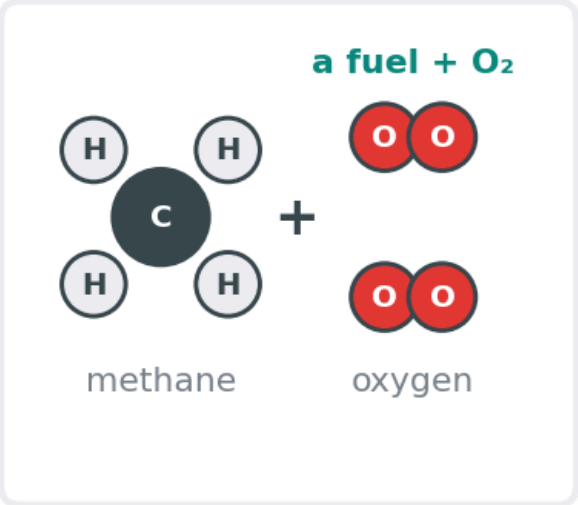
freezing water
physical change



combustion of CH_4
chemical change

Physical and chemical changes both move energy. Melting iron takes energy in. Freezing water and burning methane give energy out. The direction depends on the particular change, not on whether it is physical or chemical.

Kinetic and potential energy

kinetic energy	potential energy	chemical potential energy
		
energy of motion	stored by position	stored in the arrangement of atoms

Kinetic energy is energy of motion: molecules never stop moving. **Potential energy** is stored by position or arrangement. Chemical bonds store potential energy; burning rearranges the atoms and releases it.

Heat and work: the two ways energy moves

heat: energy moving because temperatures differ
a hot pan warms the water poured into it

work: energy moving because a force pushes something
expanding gases push a car's piston down the cylinder

Energy passes between things through exactly two channels. Heat needs a temperature difference; work needs a push. Every transfer, however complicated, is one, the other, or both.

Temperature is not heat

a cup of tea and a bathtub, both at 40 °C

same temperature · the tub holds far more energy and gives up far more as it cools

Temperature measures how fast the particles are moving, on average. **Heat** is an amount of energy in transfer. A cup and a bathtub can match in temperature and still differ enormously in energy.



Energy: forms and transfers

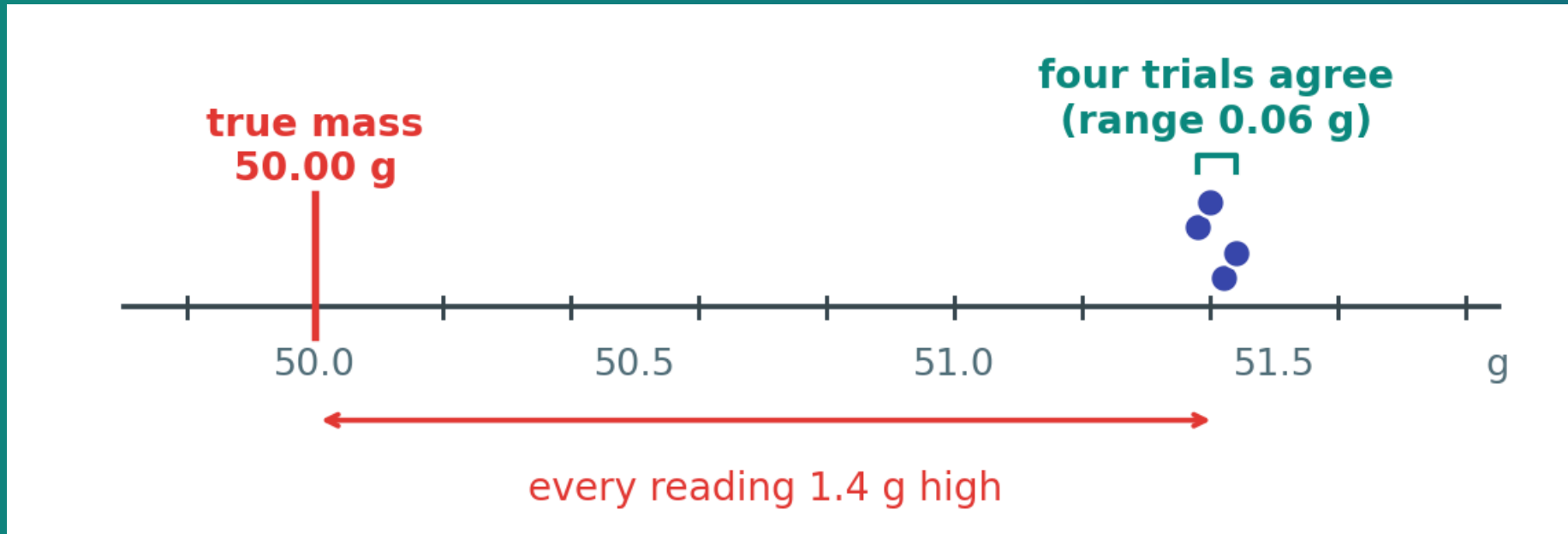
kinetic: energy of motion · potential: energy stored by position or arrangement
heat and work move energy between things · temperature measures average particle motion, not an amount of energy

Energy comes in counted amounts, and the units carry names: the joule, the calorie, and the food Calorie. Thermochemistry measures the heat a reaction releases or absorbs.

6 · Precision & Accuracy

Judge a set of repeated measurements two ways: precision from the trials' relative range, accuracy from their average's percent error, each verdict decided against the 2% bar.

The same wrong answer, four times



A 50.00-g standard is weighed four times. Every reading lands near 51.4 g. The trials agree with one another; not one of them is right.

Close to each other, close to the true value

standard: 30.00 g · two balances, three trials each

check 1: are the trials close to each other? · check 2: are they close to 30.00 g?

balance 1: 30.01 · 29.99 · 30.00 g → close to each other ✓ close to 30.00 g ✓

balance 2: 30.91 · 30.89 · 30.90 g

Run both checks on balance 2.

balance 2 → close to each other ✓ every trial 0.89 to 0.91 g high ✗

Close to each other is **precise**. Close to the true value is **accurate**. Balance 1 is both; balance 2 is precise only.

Two questions about repeated measurements

Repeated trials form a set, and the set is judged twice. Each verdict comes from its own comparison.

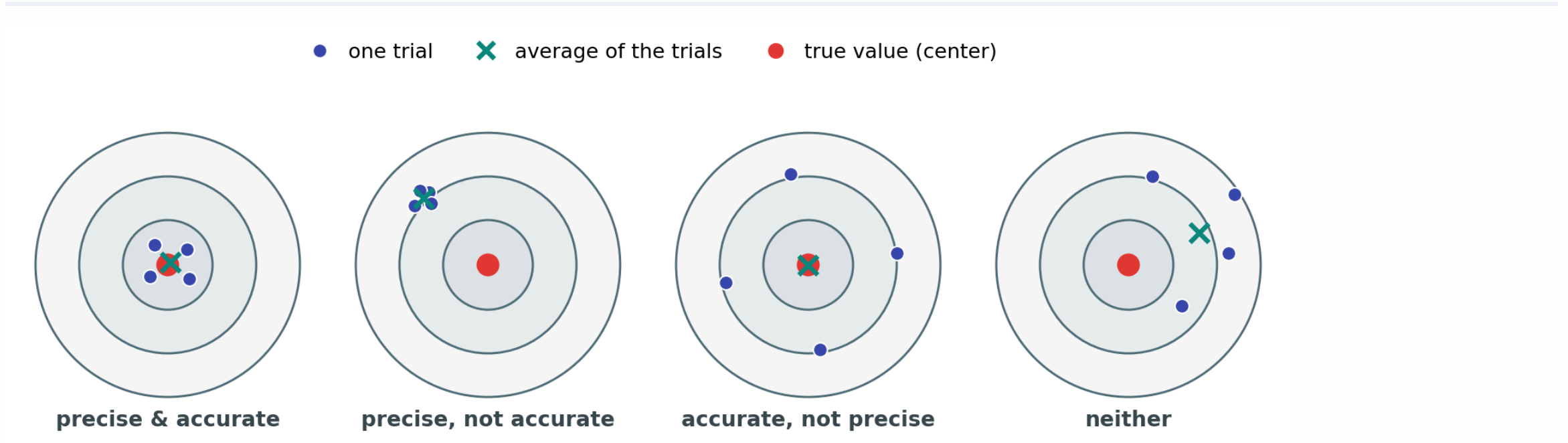
precise = the trials agree with one another

uses only the trials themselves · pRecise: Repeatable

accurate = the average lands on the true value

uses the average and the accepted true value · aCcurate: Correct

The four outcomes



The center is the true value; ✕ marks the average. A shared flaw, a miscalibrated balance, shifts the whole cluster together: precise but wrong. Random scatter cancels in the average: accurate but imprecise. The verdicts are independent.

A number for each verdict

Each verdict has its own number. The range measures agreement among the trials. The error measures how far the average sits from the true value.

range = highest trial – lowest trial

range ÷ average × 100 = relative range (precision's number)

error = average – true value

error ÷ true value × 100 = percent error (accuracy's number)

The 2% standard

"Close" and "consistent" are not measurements. Compute both percentages; test each against the same bar: 2%.

relative range = range ÷ average × 100; at most 2% → precise
above 2%, the trials disagree: not precise

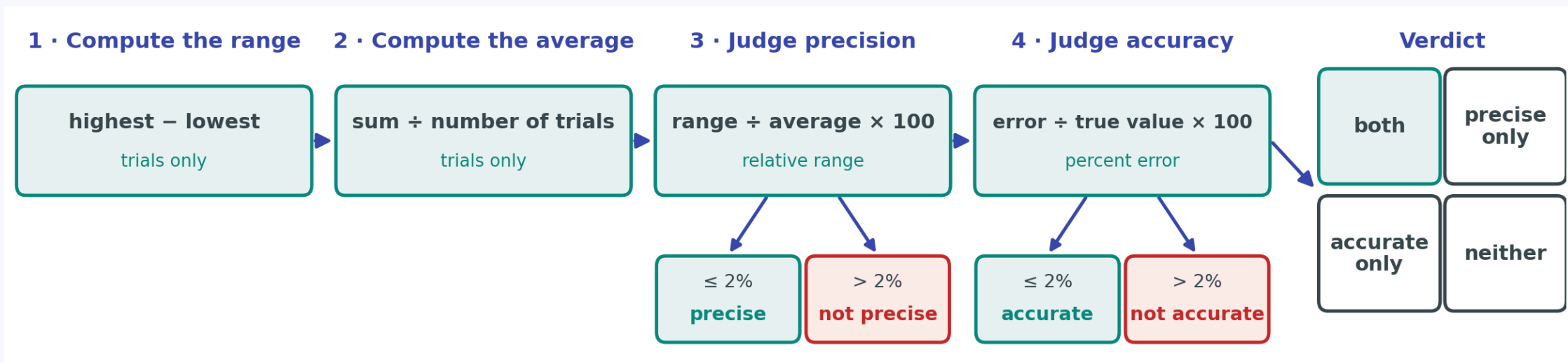
percent error = |average – true value| ÷ true value × 100; at most 2% → accurate
above 2%, the average misses: not accurate

The 2% bar is a course convention, not a law of nature; other labs draw the line elsewhere.



The method

1. **Compute the range**: highest trial – lowest.
2. **Compute the average** of the trials.
3. **Judge precision**: relative range at most 2%.
4. **Judge accuracy**: percent error at most 2%. State both verdicts.





Guided example: the density of copper

trials: $8.85 \cdot 8.97 \cdot 8.91 \text{ g/cm}^3$

true value: 8.96 g/cm^3 (copper) · wanted: both verdicts

A student measures the density of a copper sample three times.

Run the four steps of the method. Judge the set: precise? accurate?

✓ Guided example: solution

Step 1 · Compute the range

range: $8.97 - 8.85 = 0.12 \text{ g/cm}^3$

Step 2 · Compute the average

average: $(8.85 + 8.97 + 8.91) \div 3 = 26.73 \div 3 = 8.910 \text{ g/cm}^3$

Step 3 · Judge precision

relative range: $0.12 \div 8.910 \times 100 = 1.3\% \rightarrow$ at most 2%: precise

Step 4 · Judge accuracy

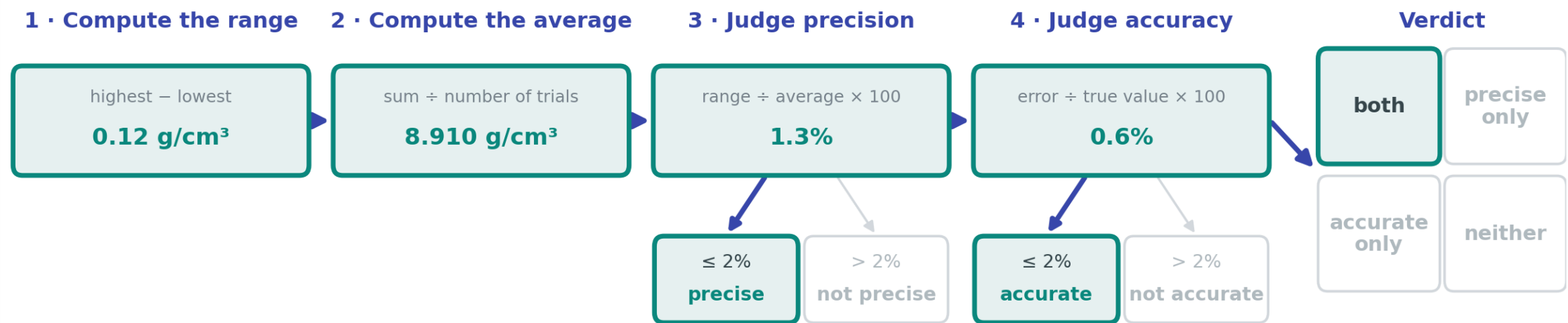
percent error: $(8.96 - 8.910) \div 8.96 \times 100 = 0.6\% \rightarrow$ at most 2%: accurate

 **Sense check:** Precise and accurate: both percentages pass the 2% bar. The average sits only 0.05 g/cm^3 below copper's true density. ✓

✓ Guided example: the route on the map

trials: 8.85 · 8.97 · 8.91 g/cm³ · true value: 8.96 g/cm³

found: range 0.12 g/cm³ · average 8.910 g/cm³ · relative range 1.3% · percent error 0.6%



Sense check: All four steps, in order. Both percentages fell under 2%, so both forks took the ≤ 2% branch and the set lands in "both". ✓



Practice 1

balance	readings (g)
W	5.49 · 5.85 · 5.68
X	5.81 · 5.83 · 5.82
Y	5.513 · 5.802 · 5.695
Z	5.67 · 5.91 · 5.44

Each balance weighs the same 5.670-g quarter three times. Which balance is precise?

- A. Balance W
- B. Balance X
- C. Balance Y
- D. Balance Z

✓ Practice 1 · answer: B

true mass of the quarter: 5.670 g · relative range at most 2% → precise

W: $(5.85 - 5.49) \div 5.673 \times 100 = 6.3\%$ not precise

X: $(5.83 - 5.81) \div 5.820 \times 100 = \mathbf{0.3\%}$ precise → **answer B**

Y: $(5.802 - 5.513) \div 5.670 \times 100 = 5.10\%$ not precise

Z: $(5.91 - 5.44) \div 5.673 \times 100 = 8.3\%$ not precise

🧠 **Sense check:** Precision compares the trials with one another. Balance X agrees with itself within 0.3%, yet its average sits 0.15 g above the true mass: precise, not accurate. ✓

✓ Practice 1: the route on the map

balance X: 5.81 · 5.83 · 5.82 g

found: range 0.02 g · average 5.820 g · relative range 0.3%

1 · Compute the range

2 · Compute the average

3 · Judge precision

4 · Judge accuracy

Verdict

highest – lowest
0.02 g

sum ÷ number of trials
5.820 g

range ÷ average × 100
0.3%

error ÷ true value × 100
percent error

≤ 2%
precise

> 2%
not precise

≤ 2%
accurate

> 2%
not accurate

both
precise only

accurate only
neither

 **Sense check:** Precision only: steps 1 to 3. The question asked only about precision, so step 4 and the verdict grid stay unused. ✓



Worked example 1: checking a balance

trials: 51.42 g · 51.38 g · 51.44 g · 51.40 g

true value: 50.00 g (calibration standard) · wanted: both verdicts

A balance is checked with a standard of known mass, weighed four times.

Judge the set: precise? accurate?

✓ Worked example 1: solution

Step 1 • Compute the range

Step 2 • Compute the average

range: $51.44 \text{ g} - 51.38 \text{ g} = \mathbf{0.06 \text{ g}}$

average: $(51.42 + 51.38 + 51.44 + 51.40) \div 4 = 205.64 \div 4 = \mathbf{51.41 \text{ g}}$

Step 3 • Judge precision

Step 4 • Judge accuracy

relative range: $0.06 \div 51.41 \times 100 = \mathbf{0.12\%} \rightarrow$ at most 2%: precise

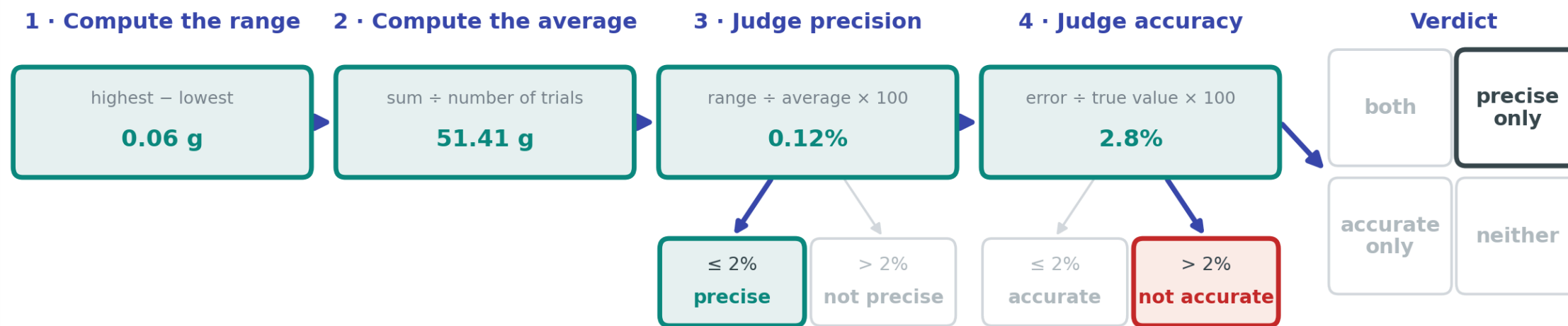
error: $51.41 \text{ g} - 50.00 \text{ g} = \mathbf{1.41 \text{ g high}}$

$\rightarrow$ percent error $1.41 \div 50.00 \times 100 = \mathbf{2.8\%}$, above 2%: not accurate

 **Sense check:** Precise but not accurate. All four trials carry the same 1.41-g error; agreement cannot expose it.

✓ Worked example 1: the route on the map

trials: 51.42 · 51.38 · 51.44 · 51.40 g · true value: 50.00 g
found: range 0.06 g · average 51.41 g · relative range 0.12% · percent error 2.8%



🧠 **Sense check:** The forks split: under 2% at precision, above 2% at accuracy. The set lands in "precise only". ✓



Worked example 2: boiling water

trials: $97.9\text{ }^{\circ}\text{C}$ · $102.1\text{ }^{\circ}\text{C}$ · $99.6\text{ }^{\circ}\text{C}$ · $100.4\text{ }^{\circ}\text{C}$

true value: $100.0\text{ }^{\circ}\text{C}$ (water boils at sea level) · wanted: both verdicts

A thermometer is read four times in boiling water at sea level.

A common first answer: the readings all land near the true $100.0\text{ }^{\circ}\text{C}$, so they are precise.
Test it against the 2% standard.

✓ Worked example 2: solution

Step 1 · Compute the range

range: $102.1\text{ }^{\circ}\text{C} - 97.9\text{ }^{\circ}\text{C} = 4.2\text{ }^{\circ}\text{C}$

Step 2 · Compute the average

average: $(97.9 + 102.1 + 99.6 + 100.4) \div 4 = 400.0 \div 4 = 100.0\text{ }^{\circ}\text{C}$

Step 3 · Judge precision

relative range: $4.2 \div 100.0 \times 100 = 4.2\%$ → above 2%: not precise

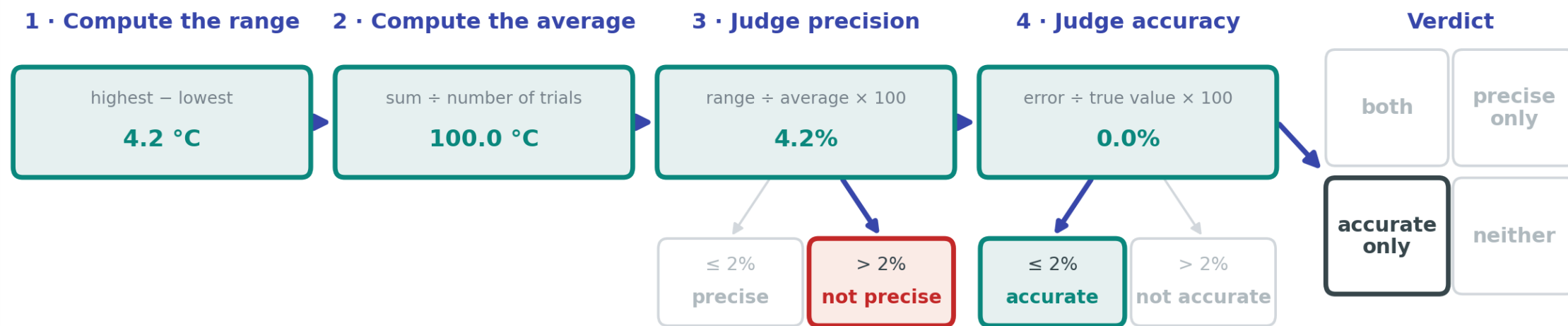
Step 4 · Judge accuracy

percent error: $(100.0 - 100.0) \div 100.0 \times 100 = 0.0\%$ → at most 2%: accurate

 **Sense check:** Accurate but not precise. Random errors land high and low with equal chance; in the average they cancel.

✓ Worked example 2: the route on the map

trials: 97.9 · 102.1 · 99.6 · 100.4 °C · true value: 100.0 °C
 found: range 4.2 °C · average 100.0 °C · relative range 4.2% · percent error 0.0%



🧠 **Sense check:** The opposite split: above 2% at precision, under 2% at accuracy. The set lands in "accurate only". ✓

Take-home: two separate comparisons

trials: 97.9 · 102.1 · 99.6 · 100.4 °C; true value 100.0 °C

relative range 4.2%, above the 2% bar → not precise · percent error 0.0%, under it → accurate

Precision compares the trials with one another and never mentions the true value. Accuracy compares the average with the true value and never mentions the spread. Swapping the two comparisons flips the verdict.

Your turn: density of an aluminum sample

trials: 2.41 · 2.43 · 2.40 · 2.42 g/mL

true density of aluminum: 2.70 g/mL

range: $2.43 - 2.40 = \underline{\hspace{1cm}}$ g/mL · average: $(2.41 + 2.43 + 2.40 + 2.42) \div 4 = \underline{\hspace{1cm}}$ g/mL

range: $2.43 - 2.40 = \mathbf{0.03 \text{ g/mL}}$

→ relative range $0.03 \div 2.415 \times 100 = \mathbf{1.2\%}$, at most 2%: precise

average: $9.66 \div 4 = \mathbf{2.415 \text{ g/mL}}$

→ percent error $0.285 \div 2.70 \times 100 = \mathbf{10.6\%}$, above 2%: not accurate

Precise but not accurate.



Practice 2

trials: 11.98 · 12.09 · 12.04 g/cm³

accepted density of lead: 11.34 g/cm³

A student measures the density of a lead sample three times. What is the percent error of the set?

- A. 0.91
- B. 5.6
- C. 5.8
- D. 6.2

✓ Practice 2 · answer: D

trials: $11.98 \cdot 12.09 \cdot 12.04 \text{ g/cm}^3$
accepted density of lead: 11.34 g/cm^3

average: $(11.98 + 12.09 + 12.04) \div 3 = 36.11 \div 3 = 12.04 \text{ g/cm}^3$

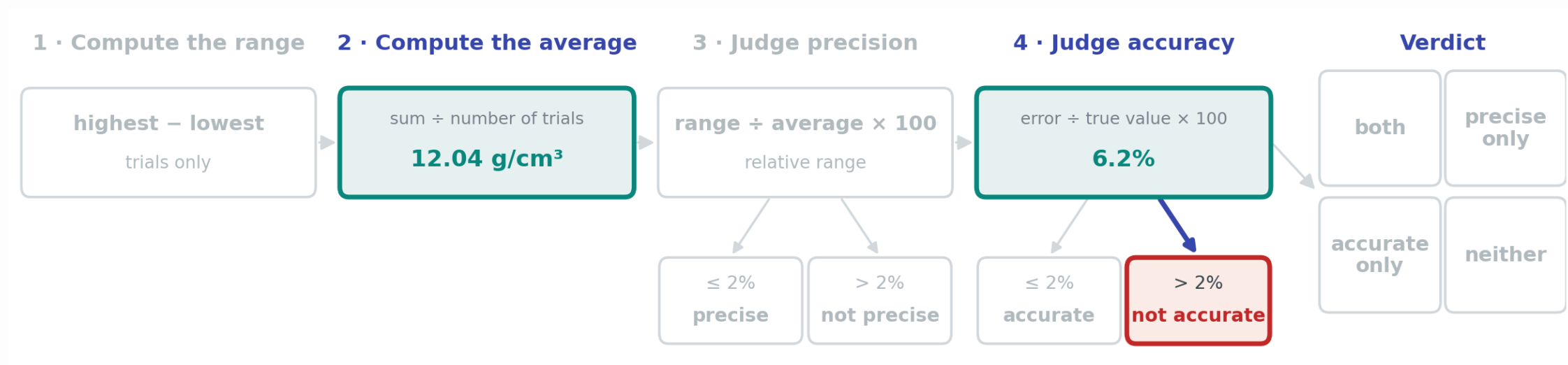
percent error: $(12.04 - 11.34) \div 11.34 \times 100 = 0.70 \div 11.34 \times 100 = 6.2\% \rightarrow \text{answer D}$

C divided by the average, not the true value: $0.70 \div 12.04 \times 100 = 5.8$. B judged the set by one trial: $(11.98 - 11.34) \div 11.34 \times 100 = 5.6$. A computed precision's number, the relative range: $(12.09 - 11.98) \div 12.04 \times 100 = 0.91$.

🧠 **Sense check:** 6.2% is above the 2% bar: not accurate. Every trial reads high, so the average does too. ✓

✓ Practice 2: the route on the map

average: 12.04 g/cm^3 · accepted density of lead: 11.34 g/cm^3
found: percent error 6.2%



Sense check: Accuracy only: the average and the true value. The range never entered, so steps 1 and 3 stay unused. ✓

⚠ Where this goes wrong

Swapping the definitions. Trials of 97.9–102.1 °C averaging 100.0 °C get called "precise, since the average is right." An average on the true value is accuracy. Precision is agreement among the trials: relative range 4.2%, above 2% → not precise.

Judging the set by one trial. In 51.42, 51.38, 51.44, 51.40 g against a true 50.00 g, trial 2 sits 51.38 – 50.00 = 1.38 g from the true mass, yet the set is precise: relative range 0.12%, well under 2%. Both verdicts describe the whole set, never one reading.

Counting digits as accuracy. A caliper reads 14.42 cm, four digits, on a rod whose true length is 15.00 cm: the reading is 0.58 cm short. Digits show how finely the scale reads, not whether the reading is right.

Treating precise as accurate. Four readings within 0.06 g of one another all sit 1.41 g above the true mass: percent error 2.8%, above the bar. Agreement rules out scatter; it cannot rule out an error shared by every trial.



Practice 3

trials: 26.32 mL · 26.28 mL · 26.34 mL · 26.30 mL

true volume: 25.00 mL

A pipette made to deliver 25.00 mL is tested four times. Which statement gives both verdicts?

- A. Precise but not accurate: the trials agree within 0.06 mL, and their average of 26.31 mL is 1.31 mL above the true volume.
- B. Not precise: trial 2, at 26.28 mL, sits 1.28 mL from the true volume, and one reading that far off rules out precision.
- C. Accurate but not precise: agreement within 0.06 mL makes the trials accurate, and the 1.31-mL gap from the true volume makes them imprecise.
- D. Accurate: every reading carries four digits, and digits that fine mean accuracy.

✓ Practice 3 · answer: A

trials: 26.32 mL · 26.28 mL · 26.34 mL · 26.30 mL

true volume: 25.00 mL

range: $26.34 - 26.28 = 0.06 \text{ mL}$

→ relative range $0.06 \div 26.31 \times 100 = 0.23\%$, at most 2%: precise

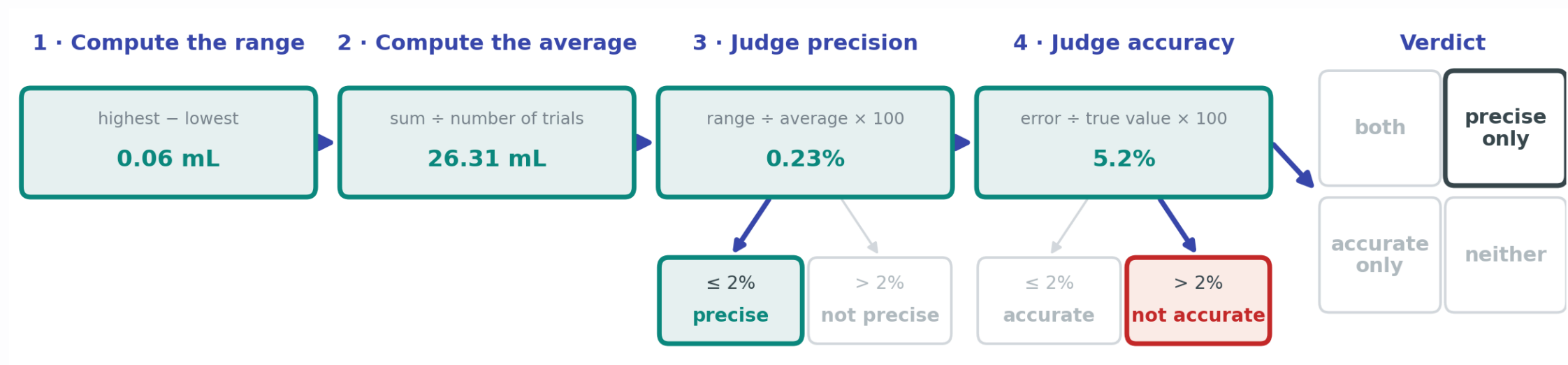
average: $(26.32 + 26.28 + 26.34 + 26.30) \div 4 = 26.31 \text{ mL}$

→ percent error $1.31 \div 25.00 \times 100 = 5.2\%$, above 2%: not accurate → **answer A**

 **Sense check:** All four deliveries run high by nearly the same amount. A flaw in the pipette itself repeats identically in every trial. ✓

✓ Practice 3: the route on the map

trials: 26.32 · 26.28 · 26.34 · 26.30 mL · true volume: 25.00 mL
 found: range 0.06 mL · average 26.31 mL · relative range 0.23% · percent error 5.2%



Sense check: The forks split: under 2% at precision, above 2% at accuracy. Precise only: a flaw in the pipette repeats in every delivery. ✓



Practice 4

readings: 4.91 g · 5.09 g · 4.98 g · 5.06 g
true mass: 5.00 g

A 5.00-g brass check weight goes on a pocket scale four times. Which verdict is correct?

- A. Precise and accurate: the readings spread only 0.18 g and the average misses by only 0.01 g, both well under 2
- B. Precise but not accurate: the 0.2% figure shows the readings agree, and the 3.6% figure shows the average misses
- C. Neither: a 3.6% spread fails the bar, and readings that scatter cannot average onto the true value
- D. Accurate but not precise: the relative range, 3.6%, fails the 2% bar; the percent error, 0.2%, passes it

✓ Practice 4 · answer: D

range: $5.09 - 4.91 = 0.18 \text{ g}$

→ relative range $0.18 \div 5.01 \times 100 = 3.6\%$, above 2%: not precise

average: $20.04 \div 4 = 5.01 \text{ g}$

→ percent error $0.01 \div 5.00 \times 100 = 0.2\%$, at most 2%: accurate → **answer D**

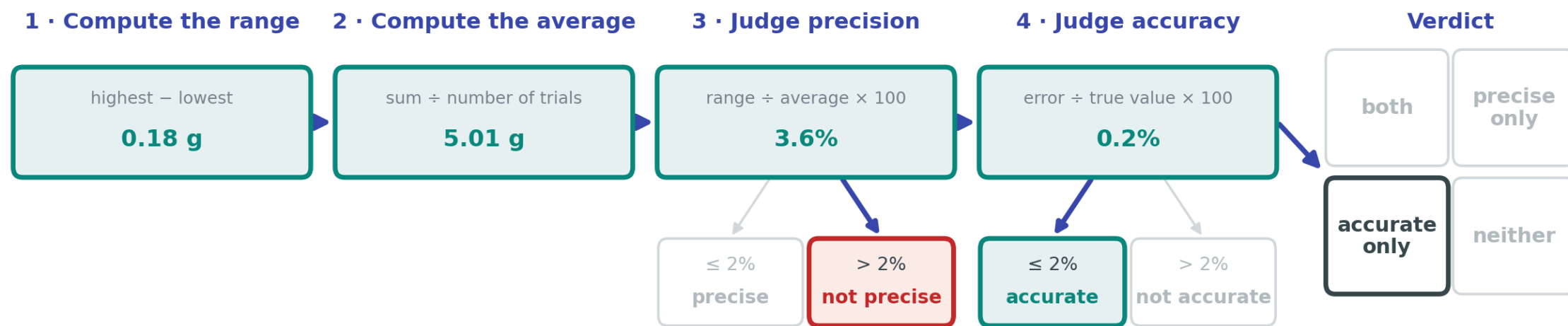
A treated the 2% bar as 2 grams: 0.18 g is small only next to a large mass, and on a 5-g weight it is 3.6%. B swapped the definitions: relative range judges precision, percent error judges accuracy. C let one verdict answer both: high and low readings cancel in the average.

🧠 **Sense check:** A small mass makes a small spread large in percent. Divide before judging. ✓

✓ Practice 4: the route on the map

readings: 4.91 · 5.09 · 4.98 · 5.06 g · true mass: 5.00 g

found: range 0.18 g · average 5.01 g · relative range 3.6% · percent error 0.2%



🧠 **Sense check:** Accurate only. In grams, 0.18 g looks small; as a percent of 5.01 g it fails the bar. ✓



Practice 5

set	trials	true value
1 · analytical balance	2.062 · 2.066 · 2.064 g	2.000 g
2 · pipette	9.89 · 10.12 · 10.04 mL	10.00 mL
3 · kitchen scale	247.1 · 246.8 · 247.4 g	250.0 g

Classify each set as precise only, accurate only, both, or neither. Which line gives sets 1, 2 and 3, in order?

- A. both · both · precise only
- B. accurate only · precise only · both
- C. precise only · accurate only · both
- D. precise only · neither · both

✓ Practice 5 · answer: C

1: 2.062 · 2.066 · 2.064 g 2: 9.89 · 10.12 · 10.04 mL 3: 247.1 · 246.8 · 247.4 g
 true values: 2.000 g · 10.00 mL · 250.0 g · averages: 2.064 g · 10.02 mL · 247.1 g

set 1: $0.004 \div 2.064 \times 100 = 0.2\%$ precise · $0.064 \div 2.000 \times 100 = 3.2\%$ not accurate

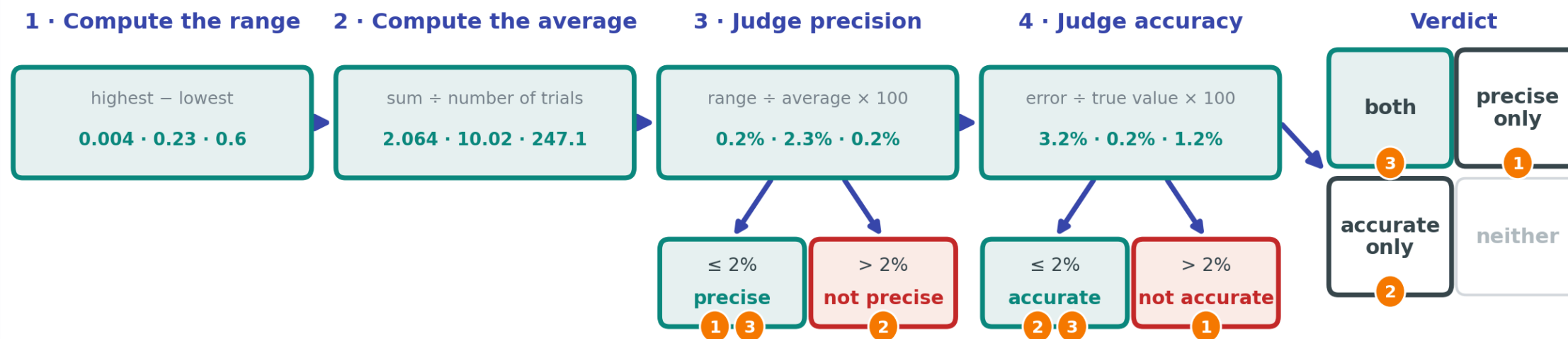
set 2: $0.23 \div 10.02 \times 100 = 2.3\%$ not precise · $0.02 \div 10.00 \times 100 = 0.2\%$ accurate

set 3: $0.6 \div 247.1 \times 100 = 0.2\%$ precise · $2.9 \div 250.0 \times 100 = 1.2\%$ accurate → **answer C**

🧠 **Sense check:** Grams and milliliters never meet the bar directly. Divide first, then compare with 2%. ✓

✓ Practice 5: the route on the map

sets 1 · 2 · 3, all four steps run on each
found: precise only · accurate only · both



🧠 **Sense check:** The orange badges mark the branch each set took at each fork and the cell where it landed. ✓

Check yourself

1. Four trials of a 20.00-g standard have a range of 0.04 g, and their average, 17.90 g, sits 2.1 g below the true value. Compute both percentages and give both verdicts.
2. A single reading lands exactly on the true value. What does that establish about the set's precision?

Averages return with atoms. The atomic mass printed on the periodic table is a weighted average of the masses of an element's isotopes.

Can you...?

- ☐ classify a scientific statement as a hypothesis, a law, or a theory?
- ☐ classify matter as an element, a compound, or a mixture?
- ☐ classify a property or a change as physical or chemical?
- ☐ distinguish precision from accuracy in measured data?
- ☐ name a sample's state from its shape and volume, and describe particle spacing and motion in each state?

If any box stays empty, the practice site has a drill for it. 