

Temperature or Pressure? A Twelve-Card Evidence Sort on Changing States

Learning target: I can work with my group to sort real observations by whether temperature or pressure caused a change, explain each with particle collisions and motion, and build part of water's state diagram from evidence.

Collaborative investigation

About 50 min

Small group

MS-PS1-4 · practice

collaboration

discussion

data analysis

Standards connections

MS-PS1-4 (practice, the pressure strand of the particle model (PS1.A: changes of state with variations in temperature or pressure)): Groups explain twelve real observations with particle motion and collisions and build water's boiling line from the cards, extending the heating-and-cooling model to include pressure. This practices the model the PE describes; the sheet does not ask for a full predictive model of adding or removing energy, so it is not used as PE evidence.

Purpose: practice · **Time:** about 50 minutes · **Format:** small-group

Answers with reasoning

Twelve evidence cards (real observations and reference values)

1 Bottle from the summit

A hiker finishes her water on the summit of Mount Whitney, where the air pressure is about 58 kPa, and screws the cap tightly onto the empty plastic bottle. When she reaches the trailhead far below, where the air pressure is much higher, the bottle has caved in.

2 Noodles on the summit

On the same summit, a camp-stove pot of water boils hard at about 85 °C. The noodles take noticeably longer to soften than they do at home near sea level.

3 Pressure cooker

A sealed pressure cooker traps water vapor, so the pressure inside rises to about 200 kPa. The water inside does not boil until it reaches about 120 °C, and dry beans cook in a fraction of the usual time.

4 Dry ice on a plate

A block of solid carbon dioxide sits on a plate at sea level. It stays at about −78.5 °C, gives off cold, invisible gas and shrinks steadily, but it never leaves a puddle.

5 Fire extinguisher

A carbon dioxide fire extinguisher at room temperature holds liquid carbon dioxide that sloshes when the tank is shaken. The pressure inside the tank is more than 50 times sea-level air pressure.

6 Gallium in a hand

A small bar of pure gallium sits solid on a desk in a 22 °C room. Held in a closed hand, it slowly turns into a silvery liquid. Gallium's melting point is about 30 °C at sea-level pressure.

7 Squeezed syringe

A student seals the tip of a plastic syringe full of air and pushes the plunger halfway in. The farther it goes, the harder it is to push. When she lets go, the plunger springs back.

8 Warm tires

A driver checks her tire pressure on a cold morning and again after an hour of highway driving. The tires feel warm, and the pressure reading is about one tenth higher, even though no air was added.

9 Boiling at room temperature

A teacher puts a beaker of 22 °C water inside a sealed chamber and pumps most of the air out. When the pressure inside falls to about 2.6 kPa, the water begins to boil, even though nothing has heated it.

10 Propane tank

A barbecue's propane tank holds liquid propane under pressure. At sea-level pressure, propane boils at about -42 °C, so when the valve opens and the pressure on it drops, liquid propane turns into the gas that feeds the flame.

11 Melting iron

In a foundry at sea level, a block of pure iron in a furnace glows red, then orange, and stays solid until it reaches about 1,538 °C. Then it melts into a liquid that can be poured into molds.

12 Ice tray

Water in an ice-cube tray in a -18 °C freezer at sea level cools to 0 °C, stays at 0 °C while it turns to ice, and then keeps cooling toward -18 °C.

Part A: Expert round (on your own)

1. For each of your three cards, write what changed (the cause), what happened (the effect), and whether a change of state happened.

Answer: Set A: 1 cause lower outside pressure on the summit, then higher pressure lower down; effect bottle caves in; no change of state. 2 cause lower air pressure; effect water boils at about 85 °C; yes (liquid to gas). 3 cause higher pressure inside the cooker; effect water boils only at about 120 °C; yes. Set B: 4 cause warming above -78.5 °C at sea-level pressure; effect solid turns straight to gas; yes (sublimation). 5 cause very high pressure; effect carbon dioxide stays liquid at room temperature; yes, compared with the gas it would be at sea level. 6 cause warming from 22 °C to hand temperature, above 30 °C; effect gallium melts; yes. Set C: 7 cause squeezing the same air into less space; effect harder to push, springs back; no. 8 cause warming the air in the tires; effect pressure about one tenth higher; no. 9 cause lowering the pressure to about 2.6 kPa; effect water boils at 22 °C; yes. Set D: 10 cause pressure drop when the valve opens; effect liquid propane boils into gas; yes. 11 cause heating to about 1,538 °C; effect iron melts; yes. 12 cause cooling to 0 °C; effect water freezes while the temperature holds; yes.

Why: Each student answers only for their own set. Check that the cause and effect are not reversed and that the state-change column is right.

Also acceptable: Card 5 may be marked 'no' if the student explains that nothing in the tank is changing state right now; accept either answer with a reason.

- Cause and effect identified for each of the three cards
- Change of state column correct

Part B: Group task

1. Teach your three cards to the group in one minute each. Listeners may ask one question per card.

2. Sort all twelve cards into three groups: (1) a change of state caused by a temperature change at about the same pressure; (2) a change of state, or the temperature at which it happens, set by pressure; (3) no change of state, but the pressure of a gas changes. Record the sort in q2.
 3. Find the four cards or facts that tell you a pressure and a temperature at which water boils. One is a fact you already know: 100 °C at 101 kPa. Plot all four points on the group graph and draw one smooth curve through them.
 4. Label the side of your curve where water is a liquid and the side where it is a gas, then answer q3 to q5 together.
2. Group record: write the card numbers in each group and what the cards in that group have in common.

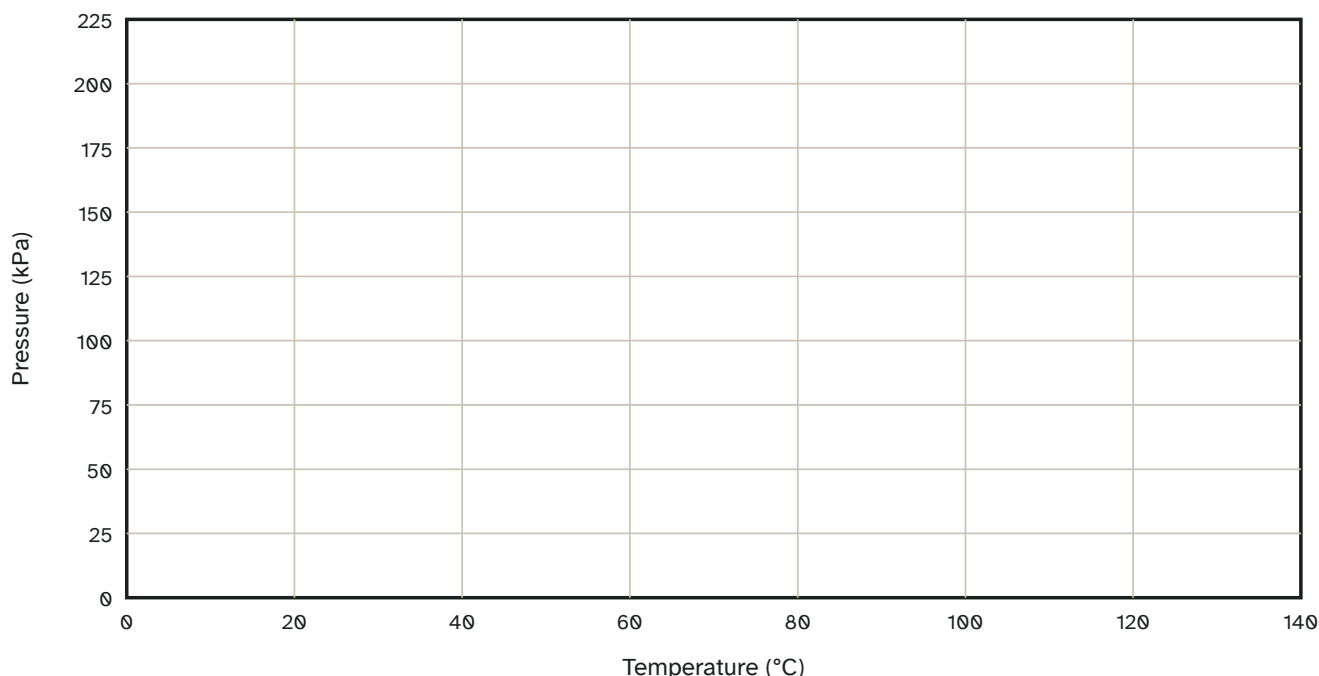
Answer: Group 1 (temperature change causes a change of state): cards 4, 6, 11, 12; in common, the pressure is about sea level and heating or cooling past a melting, freezing or sublimation temperature changes the state. Group 2 (pressure sets the change of state): cards 2, 3, 5, 9, 10; in common, raising or lowering the pressure shifts a liquid's boiling temperature or keeps a substance liquid. Group 3 (no change of state; gas pressure changes): cards 1, 7, 8; in common, a gas stays a gas while the push of its particle collisions on the walls changes.

Why: Card 4 is in group 1 because the dry ice changes state as it warms at constant sea-level pressure. Card 8 is in group 3 because, although temperature is the cause, the effect is a pressure change in a gas with no change of state.

Also acceptable: Accept card 4 in group 2 if the group argues that carbon dioxide skips the liquid state only because the pressure is low; that is a strong, defensible argument.

- Cards 4, 6, 11, 12 in group 1
- Cards 2, 3, 5, 9, 10 in group 2
- Cards 1, 7, 8 in group 3
- A sensible statement of what each group has in common

Water's boiling line, built from the cards



3. Group answer: Describe the curve your group drew. Which side is liquid and which side is gas? Explain how your group decided.

Answer: Points at (22 °C, 2.6 kPa), (85 °C, 58 kPa), (100 °C, 101 kPa) and (120 °C, 200 kPa). The curve rises slowly at first and then more and more steeply as temperature increases. Above and to the left of the curve (higher pressure or lower temperature) water is a liquid; below and to the right (lower pressure or higher temperature) it is a gas. We decided because the cards show that water below its boiling point at a given pressure stays liquid, and above it boils into gas.

Why: This is the liquid-gas boundary of water's state diagram, built from real boiling conditions. The real curve bends upward; groups who draw a straight line through the top three points should be asked whether it fits the 22 °C point.

Also acceptable: A curve that is close to straight between 85 °C and 120 °C is fine if it still passes near the 22 °C point.

- All four points plotted correctly
- A smooth curve that bends upward
- Liquid on the high-pressure or low-temperature side, gas on the other

4. Group answer: Use your curve to decide whether water at 100 °C is a liquid or a gas at 200 kPa, and at 58 kPa. Explain each answer.

Answer: At 200 kPa, 100 °C is a liquid: the point is left of (above) the curve, because water at 200 kPa does not boil until about 120 °C. At 58 kPa, 100 °C is a gas: the point is right of (below) the curve, because water at 58 kPa boils at about 85 °C.

Why: Both points are at least 15 °C away from the boundary, so a hand-drawn curve gives a clear answer.

Also acceptable: None.

- Liquid at 200 kPa with the boiling point comparison
- Gas at 58 kPa with the boiling point comparison

5. Group answer: Cards 1, 7 and 8 show pressure changing without any change of state. Explain each one using collisions of gas particles.

Answer: Card 1: the air sealed inside the bottle on the summit has fewer particles per space than the air lower down, so on the way down more particles collide with each area of the outside of the bottle than the inside, and the outside push wins and caves the bottle in. Card 7: pushing the plunger crowds the same particles into less space, so more of them hit each area of the walls and plunger every second, which raises the pressure and pushes back harder. Card 8: driving warms the air in the tires, so its particles move faster on average and hit the tire walls harder and more often, raising the pressure with no air added.

Why: All three are explained by collisions per area: more particles in the same space (cards 1, 7) or faster particles (card 8).

Also acceptable: For card 1, accept 'the outside air pressure is higher than the trapped air's pressure' with collisions mentioned.

- Card 1 compares collisions outside and inside
- Card 7 links crowding to more collisions
- Card 8 links higher temperature to faster particles and more forceful or frequent collisions

Part C: Individual accountability (complete alone)

6. Card 9: Explain, using particles, how water can boil at 22 °C. Why doesn't the same water boil on a classroom desk?

Answer: Removing the air takes away most of the gas particles that were colliding with the water's surface and pushing down on it. With so little pressure on the surface, water particles moving at their ordinary 22 °C speeds can escape and form bubbles of gas inside the liquid, so the water boils. On a desk, about 101 kPa of air pushes on the surface, so the water would have to reach 100 °C before bubbles of vapor could form; at 22 °C it only evaporates slowly from the surface.

Why: Boiling begins when bubbles of vapor can form against the pressure on the liquid. Lower the pressure enough and room-temperature water boils.

Also acceptable: Accept 'its boiling point drops to 22 °C at 2.6 kPa' with a particle sentence.

- Says the pressure on the surface is very low
- Explains that particles can then escape or form gas bubbles at 22 °C
- Explains that on the desk the air pressure is too high for boiling at 22 °C

7. Cards 4 and 5 are both about carbon dioxide. Why is carbon dioxide a liquid inside the extinguisher but never a liquid on a plate at sea level?

Answer: At sea-level pressure carbon dioxide cannot be a liquid at any temperature: it goes straight from solid to gas at -78.5°C (card 4). Inside the extinguisher the pressure is more than 50 times higher, which squeezes the particles close enough together that carbon dioxide can stay a liquid at room temperature (card 5).

Why: Real carbon dioxide needs a pressure of about five times sea-level air pressure before a liquid can exist at all; extinguishers hold it far above that. Students need only the pressure comparison.

Also acceptable: Accept 'it needs high pressure to be a liquid' with reference to both cards.

- Says carbon dioxide skips the liquid state at sea-level pressure
- Says the very high pressure in the tank lets it be a liquid

8. Which statement best explains why a boiling point should always be reported with a pressure?

Answer: B. The pressure pushing on a liquid's surface changes the temperature at which its particles can escape into bubbles of gas.

Why: A is false; thermometers are not the cause. C is false because particles are not squeezed smaller. D is false because the cards show pressure changing the boiling point of liquid water.

Also acceptable: None.

9. Lena says, 'Temperature decides a substance's state. Pressure only matters for gases in containers, like tires.' Use evidence from at least **two** cards to argue against her, and name **one** card she could fairly use to support part of her idea.

Answer: Lena is partly wrong. Card 9 shows water boiling at 22°C just because the pressure was lowered, so pressure decided the state of a liquid with no change in temperature. Card 3 shows that raising the pressure keeps water liquid all the way to about 120°C , and card 5 shows carbon dioxide kept liquid at room temperature only by high pressure. Lena could fairly use card 6 or card 11, where heating at an unchanged pressure is what caused melting, or card 8, where pressure in a gas container changes. Both temperature and pressure decide a substance's state.

Why: A strong answer uses specific cards against the claim and is fair about where the claim is partly right.

Also acceptable: Any two of cards 2, 3, 5, 9 and 10 can be used against her.

- At least two cards that show pressure changing a liquid's state or boiling point (2, 3, 5, 9 or 10)
- Explains how each card contradicts Lena
- Names one card that supports part of her idea (4, 6, 8, 11 or 12)
- Concludes that temperature and pressure both matter

Scoring rubric

Criterion	4 • Exemplary	3 • Proficient	2 • Developing	1 • Beginning
Sorting the evidence (q2)	All twelve cards placed correctly (or card 4 placed in group 2 with a strong argument), with an accurate statement of what each group has in common.	One or two cards misplaced, or one group description vague.	Three or four cards misplaced, or groups described only by topic (for example 'water cards').	Cards sorted without reference to cause and effect.

Building the boiling line (graph, q3, q4)	Four points plotted correctly, a smooth upward-bending curve, liquid and gas sides labeled correctly, and both q4 predictions correct with reasons.	Points and curve correct; one label or one prediction missing a reason.	Points plotted with errors, or sides of the curve reversed.	No curve, or a curve unrelated to the card data.
Particle explanations (q5, q6, q7)	Every explanation uses collisions per area or particle speed and spacing correctly, and the group can explain all three gas-pressure cards aloud.	Explanations mostly correct; one leans on 'pressure' without particles.	Explanations restate the card without a particle cause.	Explanations missing or contradict the particle model (for example particles shrinking under pressure).
Individual argument (q9)	Uses two or more specific cards correctly against the claim, names a fair supporting card, and reaches a balanced conclusion.	Uses two cards correctly but does not name a supporting card, or the conclusion is one-sided.	Uses one card, or cards are named without explaining how they apply.	No evidence from the cards.

Teacher notes

All card values are real or rounded reference values: water boils at about 85 °C near 58 kPa (Mount Whitney's summit, about 4,420 m, in a standard atmosphere), at about 120 °C at 200 kPa, and at 22 °C when the pressure falls to about 2.6 kPa; carbon dioxide sublimates at −78.5 °C at 101 kPa and cannot be liquid below about 518 kPa, while an extinguisher at 20 °C holds it at about 5,700 kPa; gallium melts at 29.76 °C; propane boils at −42 °C; iron melts at 1,538 °C. Two cautions for discussion: in card 9 the first small bubbles are often dissolved air coming out, and boiling water in a vacuum chamber cools itself as it boils. Print the card sheet on card stock and shuffle each deck. If time is short, assign the graph as the only group product and move q5 to homework. Keep all reasoning qualitative; no gas-law or energy calculations are expected.

Scaffold offered to students: Cause, effect, particles

For every card, finish three sentence starters before you sort it: 'The thing that changed was ____.' 'Because of that, ____ happened.' 'At the particle level, ____.' If the thing that changed is how hard something is pushing on an area, the cause is pressure. If the thing that changed is how hot or cold the sample got, the cause is temperature. A card can show temperature causing a pressure change (look at card 8).

Extension: Add the solid

Your graph shows only the boundary between liquid and gas. Water's boundary between solid and liquid is almost a straight up-and-down line at about 0 °C over the whole pressure range on your graph. Draw it in, label the solid region, and use card 12 to justify where it goes. Then explain why the solid-liquid line is nearly vertical while the liquid-gas line slants, and predict whether a pressure cooker at 200 kPa would change the temperature at which ice melts by much.