

Mercury or Alcohol? A Claim-Evidence-Reasoning Case for a Polar Winter

Learning target: I can write a claim, evidence and reasoning argument that uses a particle model and melting points at a stated pressure to predict what happens to a pure liquid's particle motion, temperature and state as it is cooled.

Claim, evidence, reasoning

About 45 min

Individual

MS-PS1-4 · assesses

writing

data analysis

Standards connections

MS-PS1-4 (assesses, predicting and describing particle motion, temperature and state for a pure substance as thermal energy is removed): The reasoning section requires a particle model that predicts what happens to mercury and ethanol as energy leaves them: slower average motion and falling temperature, then particles settling into fixed positions at a steady temperature while mercury freezes. That is the PE applied to cooling. Evidence comes from real melting points at 101 kPa and a cooling dataset; no energy is calculated.

Purpose: assess · **Time:** about 45 minutes · **Format:** individual

Answers with reasoning

The scenario

A research team is preparing a weather station deep inside Antarctica, where winter air temperatures often fall below $-60\text{ }^{\circ}\text{C}$. Their electronic sensors need a backup: a liquid-in-glass thermometer, the kind in which a thin thread of liquid rises and falls inside a glass tube as the temperature changes. The team has two old thermometers. One is filled with **mercury**, a silvery metal that is a liquid at room temperature. The other is filled with **ethanol**, a pure alcohol dyed red so it is easy to see. Before shipping, an engineer seals a small vial of each liquid, with a temperature probe inside, into a cold chamber at sea-level pressure and slowly lowers the chamber's temperature.

Reference values for three pure substances at 101 kPa (sea-level pressure)

Substance	Melting (freezing) point	Boiling point
Mercury	$-38.8\text{ }^{\circ}\text{C}$	$357\text{ }^{\circ}\text{C}$
Ethanol	$-114\text{ }^{\circ}\text{C}$	$78\text{ }^{\circ}\text{C}$
Water	$0\text{ }^{\circ}\text{C}$	$100\text{ }^{\circ}\text{C}$

Real reference values, rounded. Melting points change by much less than $1\text{ }^{\circ}\text{C}$ with ordinary changes in air pressure; boiling points can change by many degrees. A substance freezes at the same temperature at which it melts.

Cold-chamber test of two sealed vials (teaching dataset)

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

Time (min)	Chamber air (°C)	Mercury vial (°C)	What the mercury looks like	Ethanol vial (°C)	What the ethanol looks like
0	0	0	Shiny liquid; flows when the vial is tipped	0	Clear red liquid; flows
10	-15	-12	Shiny liquid; flows	-12	Flows
20	-30	-27	Shiny liquid; flows	-27	Flows
30	-45	-39	Dull gray crystals forming on the inside wall	-41	Flows
40	-60	-39	About half solid	-54	Flows
50	-60	-39	Almost all solid	-58	Flows a little more slowly
60	-60	-50	Solid; does not move when tipped	-60	Flows slowly
70	-60	-58	Solid	-60	Flows slowly

A teaching dataset; the readings follow the real behavior of mercury and ethanol but were not taken in a specific test. Probe readings are rounded to the nearest degree.

Warm-up: organize the evidence

1. Compare the two vials from 0 to 20 minutes. How did their temperatures change, and what does that tell you about the motion of the particles inside both?

Answer: Both cooled at about the same rate: each fell from 0 °C to -27 °C. Energy was leaving both liquids, so the particles in both were slowing down on average; both stayed liquid and flowed.

Why: Falling temperature means falling average particle motion. Before mercury reaches its freezing point, the two liquids behave alike.

Also acceptable: Accept 'the particles lost energy and moved more slowly'.

- Says both fell by the same amount (0 to -27 °C)
- Links the falling temperature to slower average particle motion

2. For about how many minutes did the mercury vial read -39 °C? Use the first and last times in the table that show this reading.

Answer: From 30 minutes to 50 minutes: $50 - 30 = 20$ minutes, so at least about 20 minutes.

Why: The table shows -39 °C at 30, 40 and 50 minutes and -50 °C at 60 minutes. The true plateau may have started a little before 30 minutes and lasted a little past 50, because readings are only every 10 minutes.

Also acceptable: Accept 'about 20 to 30 minutes' if the student explains the 10-minute gaps.

3. From 30 to 50 minutes the chamber air was colder than the mercury, so energy kept leaving the mercury. Which observations show that something in the mercury was still changing, even though its temperature reading did not change?

Answer: The mercury went from shiny liquid, to crystals forming on the wall at 30 minutes, to about half solid at 40 minutes, to almost all solid at 50 minutes. It was freezing: changing from liquid to solid.

Why: The appearance column shows a change of state in progress while the temperature column is flat.

Also acceptable: None.

- Cites the crystals, half solid and almost all solid observations
- Names freezing (liquid to solid)

Your argument

Answer: Model response. **Claim:** The team should rely on the ethanol thermometer; at -60°C the mercury will be frozen solid, so its thread cannot rise or fall. **Evidence:** Mercury freezes at -38.8°C at 101 kPa, while ethanol does not freeze until -114°C , far below -60°C . In the chamber, the mercury cooled like the ethanol until it reached -39°C , then stayed at -39°C from 30 to 50 minutes while it went from crystals on the wall to almost all solid, and by 60 minutes it was solid and did not move when tipped. The ethanol kept cooling to -60°C and still flowed. **Reasoning:** As energy leaves a liquid, its particles slow down on average, so its temperature falls. When the mercury reached its freezing point, the energy that kept leaving came from the particles settling into fixed positions in a solid pattern instead of from slowing them further, so the temperature held steady until all the mercury had frozen. After that, removing more energy made the particles vibrate less around their fixed positions and the temperature fell again. A solid thread of mercury cannot slide up and down the tube, so the thermometer would be stuck. Ethanol's freezing point is far below -60°C , so at -60°C its particles are slower than at room temperature but can still slide past one another, and the liquid still expands and contracts in the tube.

Why: Score with the rubric. The key reasoning move is explaining the flat stretch: energy is still leaving, but it changes the arrangement of the particles rather than their average motion. Watch for answers that say the mercury 'stopped cooling' or that its particles 'stopped moving'.

Also acceptable: A claim that adds a check of ethanol's lower limit, or notes that mercury is toxic and avoided today, is a stronger answer but not required.

- Claim names ethanol and says mercury will be solid at -60°C
- At least three pieces of evidence with numbers, including the -39°C plateau from 30 to 50 minutes
- Reasoning links falling temperature to slower average motion
- Reasoning explains the plateau as particles settling into fixed positions while energy leaves
- Reasoning explains why ethanol still flows (freezing point -114°C)

Predict with your model

4. The frozen mercury vial ($-58\text{ }^{\circ}\text{C}$) is carried into a $20\text{ }^{\circ}\text{C}$ room. Predict what its temperature will do until it reaches room temperature. Include the temperature where it will pause, and describe what the particles are doing during the pause.

Answer: The temperature will rise from $-58\text{ }^{\circ}\text{C}$ to about $-39\text{ }^{\circ}\text{C}$ (more exactly $-38.8\text{ }^{\circ}\text{C}$), pause there while the mercury melts, and then rise again until it reaches $20\text{ }^{\circ}\text{C}$. During the pause, energy is flowing in from the room, but it is letting the particles break out of their fixed positions and start sliding past one another rather than making them move faster on average.

Why: Melting is freezing in reverse, at the same temperature. The PE model runs both ways.

Also acceptable: Accept $-38.8\text{ }^{\circ}\text{C}$ or 'about $-39\text{ }^{\circ}\text{C}$ '.

- Rises to about $-39\text{ }^{\circ}\text{C}$
- Pauses at about $-39\text{ }^{\circ}\text{C}$ while melting
- Rises again to $20\text{ }^{\circ}\text{C}$
- Particles leave fixed positions during the pause

5. The ethanol thermometer also has a limit. Below what temperature would it stop working, and what would happen to its particles there?

Answer: Below about $-114\text{ }^{\circ}\text{C}$, ethanol's freezing point. There the ethanol particles would settle into fixed positions as solid ethanol forms, and the thread could no longer move.

Why: Every liquid thermometer works only between its liquid's freezing point and its boiling point.

Also acceptable: A student who also mentions the upper limit near $78\text{ }^{\circ}\text{C}$ (boiling) is going further and is correct.

- About $-114\text{ }^{\circ}\text{C}$
- Particles settle into fixed positions or the ethanol becomes a solid

6. The air pressure at an inland Antarctic station is much lower than at sea level. Does that change your claim? Use the note under the reference table.

Answer: No. Lower air pressure changes melting and freezing points by much less than $1\text{ }^{\circ}\text{C}$, so mercury would still freeze at about $-39\text{ }^{\circ}\text{C}$ and ethanol at about $-114\text{ }^{\circ}\text{C}$. Lower pressure would lower the boiling points, but that does not matter for a station at $-60\text{ }^{\circ}\text{C}$.

Why: Pressure has a large effect on boiling points and only a tiny one on melting points, as the table note says.

Also acceptable: Accept 'it only changes boiling points much, so no' if it names the freezing points.

- Says the claim does not change
- Explains that melting points barely change with pressure

Scoring rubric

Criterion	4 • Exemplary	3 • Proficient	2 • Developing	1 • Beginning
Claim	Names ethanol as the reliable liquid and states that mercury will be solid at $-60\text{ }^{\circ}\text{C}$, in one clear statement.	Names ethanol and says mercury will not work, without naming its state.	Names a liquid without saying what happens to the other, or the claim is unclear.	No claim, or chooses mercury.

Evidence	Three or more accurate pieces with numbers from both tables, including the -39°C plateau from 30 to 50 minutes and the observations of crystals forming.	Three pieces with numbers, but one is vague or only one table is used.	One or two pieces of evidence, or evidence without numbers.	No relevant evidence.
Reasoning with the particle model	Explains slower average motion and falling temperature before freezing, particles settling into fixed positions at a steady temperature during freezing, reduced vibration after freezing, and why ethanol's particles still slide at -60°C .	Explains the cooling and the plateau with particles but omits one stage or the ethanol comparison.	Uses particles only loosely (for example 'the particles froze') or explains the plateau without particles.	No particle reasoning, or reasoning that contradicts the evidence (for example 'the particles stopped moving').
Predictions (q4-q6)	All three correct: melting pause at about -39°C with a particle explanation, ethanol's limit near -114°C , and pressure barely changing freezing points.	Two correct, with the particle explanation for the melting pause.	One correct, or predictions without explanations.	Predictions missing or incorrect.

Teacher notes

The reference values are real: mercury melts at -38.83°C and boils at about 357°C ; ethanol melts at about -114°C and boils at 78°C . The cold-chamber readings are invented but realistic; a sealed vial of mercury does hold near its freezing point while it solidifies. Mercury is toxic, and mercury thermometers are no longer used in schools; this is a paper scenario only, so do not bring mercury into the classroom. Liquid-in-glass thermometers for very cold places have long used alcohols or similar liquids for exactly the reason in this case. Keep the reasoning qualitative; the PE's clarification asks for qualitative molecular-level models, and no energy calculation is needed. Use the plateau in q2 and q3 as the bridge to the reasoning box: many students will write that the mercury 'stopped losing energy', and the observation column is the evidence that it did not.

Scaffold offered to students: Sentence frames

Claim: 'The team should use _____, because at -60°C _____ will be a _____.' Evidence: 'The reference table shows that mercury freezes at _____ and ethanol freezes at _____.' 'In the test, the mercury stayed at _____ from _____ to _____ minutes while _____.' Reasoning: 'As energy leaves a liquid, its particles _____, so its temperature _____. When it reaches its freezing point, the particles _____ instead, so the temperature _____ until _____.'

Extension: Colder than ethanol can handle

Some places on the Antarctic plateau have been measured at close to -90°C , and laboratories sometimes need thermometers for even colder conditions. Research the freezing points of pentane and toluene, two other liquids used in low-temperature thermometers. Make a table like the reference table, decide which liquid would cover the widest range of cold temperatures, and write two sentences explaining your choice with the particle model. Note that both are flammable and must stay sealed.