

Fixing Theo's Kitchen Notes: Eight Claims About Particles and States

Learning target: I can find and correct mistakes in someone else's explanation of melting and boiling, and explain what particles really do, and do not do, when a substance changes state.

Error analysis

About 40 min

Individual

MS-PS1-4 · practice

writing

independent practice

Standards connections

MS-PS1-4 (practice): Diagnosing Theo's statements makes students state the particle model precisely: particles move in every state, keep their size during a change of state, and hold the temperature steady at the boiling point while energy is added. Students repair a model rather than build one from scratch, so this is practice toward the PE.

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

Answers with reasoning

Facts Theo could have checked — Air pressure at sea level is about 101 kPa. Mammoth Lakes, in the eastern Sierra Nevada, is about 2,400 m above sea level, where the air pressure is about 75 kPa. Water's boiling point is 100 °C at 101 kPa, about 93.5 °C at 80 kPa, about 92 °C at 75 kPa and about 86 °C at 60 kPa. Water vapor is an invisible gas.

Theo's notebook page

1. The ice cubes in my lemonade looked completely still, so the water particles inside them were not moving at all.
2. As the ice melted, its particles got soft and squishy, and that is why the ice turned runny.
3. The melted water spread out to fill the bottom of the glass because its particles stay close together but can slide past one another.
4. When the kettle boiled, the water particles expanded into bigger steam particles. That is why steam takes up so much more space than water.
5. The big bubbles rising in the boiling water were bubbles of air.
6. The white cloud puffing out of the kettle's spout was water vapor.
7. I left the burner on after the water started boiling, so the water kept getting hotter: 100 °C, then 110 °C, then 120 °C.
8. Water always boils at 100 °C, so my aunt's kettle at her house in Mammoth Lakes boils at 100 °C too.

Theo's drawing. Theo drew three boxes. Box 1, labeled 'ice', shows twelve small circles in neat rows with no motion marks. Box 2, labeled 'water', shows twelve medium circles in a loose pile at the bottom, with short

arrows. Box 3, labeled 'steam', shows six large circles, each about twice as wide as the circles in Box 1, spread far apart, with long arrows.

Part A: Diagnose

1. Complete the table for all eight statements. If a statement is only partly right, mark it incorrect and name only the part that is wrong.

Answer: 1 incorrect: particles in a solid vibrate in place. 2 incorrect: particles do not soften; their arrangement changes. 3 correct. 4 incorrect: particles do not expand; they spread far apart. 5 incorrect: the bubbles are water vapor, not air. 6 incorrect: the white cloud is liquid droplets; water vapor is invisible. 7 incorrect: the temperature stays at the boiling point while boiling. 8 incorrect: the boiling point depends on pressure; lower at Mammoth Lakes.

Why: Seven of the eight statements contain an error; Statement 3 is the control that checks students are not marking everything wrong.

Also acceptable: For 7, accept 'energy goes into boiling, not heating'. For 8, accept 'forgot pressure' or 'it is higher up'.

- Statement 3 marked correct
- All seven others marked incorrect
- A short accurate reason for each incorrect statement

Part B: Explain and rewrite

2. Statements 1 and 2: Explain what the particles in an ice cube are really doing, and what actually changes about them when the ice melts. Then rewrite Statement 2 so it is correct.

Answer: The water particles in ice are packed in a fixed pattern and vibrate constantly around their positions; they never stop moving. When the ice melts, the particles themselves do not change at all; they gain enough energy to break out of the fixed pattern and slide past one another. Rewrite: 'As the ice melted, its particles broke out of their fixed positions and began sliding past one another, and that is why the ice turned runny.'

Why: Softness and runniness are properties of the sample, caused by how the particles are arranged and move, not properties of individual particles.

Also acceptable: Accept 'the particles were freed from their spots' for the arrangement change.

- Particles in ice vibrate in place
- Particles do not soften or change
- Melting is particles leaving fixed positions and sliding
- A correct rewrite of Statement 2

3. Statement 4: Explain why steam takes up so much more space than liquid water, and rewrite the statement correctly.

Answer: Steam (water vapor) takes up much more space because its particles are far apart and move freely, with mostly empty space between them; each particle is the same size as in liquid water. Rewrite: 'When the kettle boiled, water particles separated from one another and moved far apart as a gas, which is why steam takes up so much more space than water.'

Why: The volume of a gas comes from the spaces between particles, not from bigger particles.

Also acceptable: None.

- Says the particles stay the same size
- Explains the extra volume as space between particles
- A correct rewrite

4. Statements 5 and 6: What is inside the big bubbles? What is the white cloud made of? Where is the real water vapor? Rewrite both statements.

Answer: The big bubbles are filled with water vapor: water particles that separated into the gas state inside the liquid. The white cloud is made of tiny droplets of liquid water that formed when the invisible water vapor cooled in the air and condensed. The real water vapor is invisible: inside the bubbles, in the clear gap just outside the spout, and mixed into the air. Rewrites: 5, 'The big bubbles rising in the boiling water were bubbles of water vapor.' 6, 'The white cloud from the spout was tiny droplets of liquid water that condensed from invisible water vapor.'

Why: Two everyday-language errors at once. A small amount of dissolved air comes out as tiny bubbles before boiling, but the large bubbles that keep forming at the boiling point are water vapor.

Also acceptable: Accept 'steam' for the bubbles only if the student says steam here means invisible water vapor.

- Bubbles contain water vapor
- Cloud is condensed liquid droplets
- Water vapor is invisible
- Correct rewrites of both statements

5. Statement 7: The burner really was adding energy the whole time. Where did that energy go once the water was boiling? Rewrite the statement.

Answer: Once the water was boiling, the burner's energy went into separating water particles from one another and letting them escape as gas, not into making them move faster on average, so the temperature stayed at the boiling point (100 °C at sea level) while the water boiled away. Rewrite: 'I left the burner on after the water started boiling, so more water turned into gas, but the temperature stayed at 100 °C.'

Why: This is the boiling plateau of the heating curve. In an open pot at a steady pressure, liquid water cannot get hotter than its boiling point.

Also acceptable: Accept 'the extra energy made it boil faster, not hotter'.

- The energy separates particles into gas
- The temperature stays at the boiling point
- A correct rewrite

6. Statement 8: Use the facts box to rewrite this statement with the right temperature. Then explain in one sentence why lower air pressure lets water boil at a lower temperature.

Answer: Rewrite: 'My aunt's kettle in Mammoth Lakes boils at about 92 °C, because the air pressure there is only about 75 kPa.' With less air pressing down on the water's surface, water particles can escape into bubbles of gas at a lower temperature.

Why: The facts box gives about 75 kPa for Mammoth Lakes and about 92 °C for water's boiling point at 75 kPa. These are real reference values.

Also acceptable: Accept 'about 92 to 93 °C' if the student reasons between the 75 kPa and 80 kPa values.

- About 92 °C
- Mentions lower air pressure
- A one-sentence explanation: less air pushing on the surface or fewer collisions from the air

7. Redraw Theo's three boxes correctly. Keep twelve particles in the ice and water boxes. Label each box with its state and add a one-line description of the motion.

Answer: Three boxes, all circles the same size. Ice (solid): twelve circles packed in neat rows, each with small zigzag vibration marks; 'vibrate in place'. Water (liquid): twelve circles touching but jumbled, with short arrows; 'slide past one another'. Steam (gas): a few circles far apart, with long arrows; 'move fast and freely, far apart'. Each box labeled with its state.

Why: The two fixes that matter are motion marks in the solid and equal particle size in all three boxes. Fewer particles in the gas box is correct: a close-up of a gas contains fewer particles in the same space.

Also acceptable: Accept twelve circles spread out in the gas box if the box is drawn larger.

- Same-size particles in all boxes
- Motion shown in the solid
- Correct spacing for each state
- Each box labeled with state and motion

8. Name the two mistakes in Theo's original drawing and explain why each one matters for the model.

Answer: Mistake 1: no motion marks in the ice box, which shows solid particles as motionless; in fact they vibrate. Mistake 2: the circles grow from ice to water to steam, which shows particles getting bigger; in fact they are the same particles at the same size, only farther apart and moving more freely. Both matter because a model that says particles stop or grow cannot correctly predict what happens when energy is added or removed.

Why: The number of circles in the steam box is not a mistake for a close-up view.

Also acceptable: If a student also flags the six steam particles, accept it only with a sensible reason (for example, the boxes are meant to hold the same amount of water).

- Names the missing motion in the solid
- Names the changing particle size
- Explains why each matters

Part C: The rule behind the mistakes

9. Statements 2 and 4 and Theo's drawing all make the same kind of mistake. Name it. Then write a two-sentence rule Theo could tape inside his notebook that would stop him from making it again, and test your rule on one new example of your own (for example, a puddle drying or butter melting in a pan).

Answer: Theo gives the particles the properties of the whole sample: the ice gets runny, so he says the particles get soft; the steam takes up more space, so he says the particles get bigger. Rule: 'Particles never get soft, runny, hot or big. When a substance changes state, the particles stay exactly the same; only how far apart they are and how freely they move changes.' Example: when a puddle dries, the water particles do not shrink or disappear; the fastest ones escape from the surface and spread out into the air as invisible gas.

Why: Treating particles as tiny pieces of the sample (soft ice, big steam) is a well-documented student idea. Naming it helps students catch it in new situations.

Also acceptable: For the example, butter is a mixture, so accept it if the student describes its particles loosening and sliding without changing size.

- Names the confusion: properties of the sample given to the particles
- A two-sentence rule that says particles do not change, only their spacing and motion
- Applies the rule correctly to a new example

Teacher notes

Every statement targets a misconception listed in chapter.json: motionless solid particles (1), particles softening (2) or expanding (4), the white cloud mistaken for gas (6), the fixed 100 °C boiling point (8), plus two closely related errors about bubbles (5) and the boiling plateau (7). Statement 3 is correct on purpose. The Mammoth Lakes values are real: the town sits at about 2,400 m, standard-atmosphere pressure there is about 75-76 kPa, and water boils at about 92 °C at that pressure; actual pressure varies a little with the weather. Use q9 as a class discussion closer; the rule students write is worth posting. No energy calculations are needed anywhere on the sheet.

Scaffold offered to students: Three questions for every statement

For each statement ask: (1) Is it about the particles or about the whole sample? (2) Does it say the particles themselves change (size, softness, temperature) when really only their spacing and motion change? (3) Does it give a number? If so, check it against the facts box. A statement that passes all three checks is probably correct.

Extension: The invisible gap at the spout

If you look closely at a boiling kettle, there is a short clear gap between the spout and the start of the white cloud. Explain what is in that gap and why the cloud appears only a few centimeters away. Then use the same idea to explain why you can 'see your breath' on a cold morning but not on a warm afternoon. Use the words *water vapor*, *condense* and *droplets*.