

Energy Tokens: Act Out Melting and Boiling, Then Graph It

Investigation question: If energy is added to a pure substance at a steady rate, what happens to its particles' motion, its temperature and its state, and where does the energy go when the temperature stops rising?

Collaborative systems modeling

Groups of 4

1 session

Setup 5 · Activity 40 · Cleanup 5 min

MS-PS1-4 · assesses

MS-PS3-4 · supports

Scientific purpose

Four students become the particles of a pure substance inside a container taped on the floor. Paper clips are energy tokens: each round adds one token to every particle, and a rule card decides whether the token becomes motion (a longer chain of clips and faster movement) or goes into a bank that loosens the particles (melting) or separates them (boiling). After every round the group records the model temperature (the average chain length), the bank totals and how many particles are solid, liquid or gas, then plots a heating curve with two flat steps. A short uneven round models evaporation, and an optional second session runs the model backward as cooling.

Why this helps students with this chapter

The flat steps of a heating curve are the hardest part of MS-PS1-4, because students expect any energy added to raise the temperature. Acting as particles makes the rule physical: when your token goes into the bank instead of onto your chain, you can feel that the energy went somewhere other than speed, and you watch your group change state while the thermometer reader's number stays put. Because every token is counted, students can check that no energy vanished. The uneven round shows why a puddle can evaporate below the boiling point and why evaporation cools what is left behind.

Standards connections

MS-PS1-4 (assesses, the whole PE, qualitatively: predicting and describing particle motion, temperature and state as thermal energy is added (and, in session 2, removed)): Students run a model in which each added unit of energy either raises particle motion, and so the temperature, or changes the state while the temperature holds, and they record and graph the result. The heating curve, the state counts and q4 to q9 are direct evidence toward the PE. Tokens are counted only to track where the energy goes; no energy or heat is calculated.

MS-PS3-4 (supports, only the idea that temperature measures the average kinetic energy of the particles): This Grade 6 PE in the California sequence supplies the idea behind the model's thermometer: temperature is the average motion per particle, and Part C shows individual particles differing from that average. Students do not plan the energy, mass and type-of-matter investigation the PE describes.

Roles (rotate each session)

- **Energy source (also particle A):** Hands one token to every particle at the start of each round, keeps the running total of tokens added, and in the cooling run collects tokens into the cold-sink cup.
- **Rule keeper (also particle B):** Reads the rule card aloud each round, says whether tokens go onto chains or into a bank, and calls the state and how each particle should move.
- **Thermometer reader (also particle C):** After each freeze, counts the clips on every particle's chain and works out the model temperature, the average chain length.
- **Recorder (also particle D):** Writes each round's row in the group's data table and checks that the token accounting balances before the next round starts.

Materials

Item	Quantity	Per	Note
Masking tape for a floor container about 2 m by 3 m, a line marking off a liquid strip, and four X marks for the solid positions	about 12 m	group	
Standard paper clips (energy tokens)	50	group	44 are used in the heating run; the rest are spares.
Paper cups labeled 'Energy source', 'Loosening bank (melting)', 'Separating bank (boiling)' and 'Cold sink'	4	group	
Particle name tags A, B, C and D	4	group	
Timer for the 15-second move phase	1	group	
Clipboard or hard surface, recording sheet and pencil	1 each	student	
Clear floor space with desks pushed back (a hallway, gym or blacktop also works)	about 6 square meters per group	class	

Estimated cost: 5 to 10 per class (an estimate; A box of 500 paper clips about \$3, two rolls of masking tape about \$6 and a sleeve of paper cups about \$2; everything except the tape is reusable. Estimated retail prices, not quotes.)

Safety

- This is a walking model: walk only, never run, push or touch. A 'collision' is a turn made at arm's length.
- Clear backpacks, chairs and cords from the floor area, press the tape flat so it is not a trip hazard, and pull it up afterward.
- Paper clips are small and have points. Keep them on chains or in cups, never in mouths, and pick up any that drop.
- Students who cannot move safely in a crowd, or prefer not to, run the tabletop version described under accessibility or take a non-moving role in another group.

Teacher preparation and setup

1. Clear the floor and tape one container per group: a rectangle about 2 m by 3 m. Inside it, along one short end, tape a liquid strip about 1 m deep across the full width, and inside the strip tape four X marks in a 2 by 2 square about 60 cm apart for the solid positions.
2. Count 50 paper clips into each group's energy-source cup and label the three other cups.
3. Print the rule cards (they are on the recording sheet) and the particle tags.
4. Decide and demonstrate the motion signals. Solid: sway in place on your X, with a bigger sway for a longer chain. Liquid: shuffle slowly through the liquid strip, swapping places with neighbors and staying within arm's reach of another particle. Gas: walk in straight lines anywhere in the container, turning away when you come within arm's reach of a wall or another particle. Never run and never touch.
5. Choose a freeze signal (a clap or a timer beep) for the end of each 15-second move phase.
6. If possible, rehearse rounds 1 to 3 with four volunteers before class so you can model the bank rule for everyone.

Investigation design

Independent variable	The energy added, counted as tokens added so far (one token per particle per round).
Dependent variable	The model temperature (average clips per chain), the clips in each bank, and the number of particles in each state.
Controlled	Four particles and the same rule card for every group; One token per particle per round, except in the uneven round; The same model melting point (3) and boiling point (6); A 15-second move phase every round
Trials	One heating run per group (and one cooling run in session 2). Every group follows the same rules, so comparing groups reveals rule-following errors rather than real differences.
Comparison	The rising sections of the heating curve versus its flat steps; the heating curve versus the cooling curve; the liquid's temperature before and after the fastest particle escapes in Part C.

Student procedure

1. Set up: each particle wears a tag and starts with a chain of 1 paper clip, standing on an X mark. The substance is a solid. The energy-source cup holds the remaining clips and the bank cups are empty. Round 0 is already filled in on your table.
2. Read the heating rule card together. In this model the melting point is 3 and the boiling point is 6, measured in clips per chain.
3. Each round: (a) the energy source hands every particle one token; (b) the rule keeper reads the rule and says where each token goes, onto your chain or into a bank; (c) everyone moves for 15 seconds the way the rule card says for their state and chain length; (d) freeze.

4. After each freeze, the thermometer reader works out the model temperature (total clips on chains $\div$ 4), the rule keeper counts the clips in each bank and how many particles are solid, liquid and gas, and the recorder writes the row. Check that the 4 starting clips plus the tokens added so far equal the clips on chains plus the clips in banks.
5. Run rounds 1 to 10. When the loosening bank reaches 4 clips, two particles leave their X marks and become liquid; at 8, all four are liquid. When the separating bank reaches 4, two particles leave the liquid strip as gas; at 8, all four are gas.
6. Plot the heating curve: model temperature against tokens added so far. Circle each flat step and label what the particles were doing during it. Answer q1 and q2.
7. Part C, the uneven round: reset to a liquid with a chain of 4 clips on every particle, 8 clips in the loosening bank and none in the separating bank. Read the uneven-round card, deal the 4 tokens as it says, record the chains and the liquid's temperature, then apply the escape rule and record again. Answer q3.
8. Return the clips to their cups, pull up the tape if the room is needed, and answer the analysis questions individually.
9. Optional session 2, cooling (about 30 minutes): rebuild the end of the heating run (all four particles gas with chains of 7, and 8 clips in each bank). Each round every particle gives one token to the cold-sink cup, following the cooling rule card. Run 10 rounds, fill in the cooling table, and plot the cooling curve on the same graph in a different color.

Expected observations

- Heating run model temperatures: 1 at round 0, then 2, 3, 3, 3, 4, 5, 6, 6, 6, 7 for rounds 1 to 10.
- Loosening bank: 4 clips after round 3 (two particles liquid) and 8 after round 4 (all four liquid).
Separating bank: 4 after round 8 (two particles gas) and 8 after round 9 (all four gas).
- Accounting after round 10: 4 starting clips + 40 added = 44 = 28 on chains + 8 + 8 in the banks.
- Part C: after the deal the chains are 7, 5, 4 and 4 and the liquid temperature is 5; particle A escapes with a chain of 5, leaving B, C and D at 5, 4 and 4, so the liquid temperature drops to about 4.3.
- Cooling run (session 2): 7 at round 0, then 6, 6, 6, 5, 4, 3, 3, 3, 2, 1 for rounds 1 to 10, the heating curve in reverse.

Likely difficulties

- Groups put a melting or boiling token onto a chain, so the temperature keeps rising and the flat step disappears. The rule keeper reads the card aloud every round, and the accounting check catches the error.
- The gas phase speeds up in a small space. Enforce walking and the arm's-length turn; if space is tight, make gas particles walk heel to toe.
- Students think bank clips have 'disappeared'. Point to the cups: the energy is still there, stored in the particles' new arrangement.
- The Part C liquid temperature ($13 \div 3$) is a decimal; accept 4.3 or 'between 4 and 5'.
- Rounds slow down while everyone records. Let the recorder write during the next round's move phase and have teammates copy the table at the end.

Structured debrief

1. Put two or three groups' heating curves side by side. If a curve has no flat steps, walk back through the rule card with that group; usually melting tokens went onto chains. Then ask the class: during the flat steps, was energy still being added? (Yes, 8 tokens each time.) Where did it go?
2. Connect to the real heating curve from the presentation: the same five parts and the same two flat steps. Ask what in the model does not match real water: here both steps took 8 tokens, but real water needs nearly seven times as much energy to boil a sample as to melt it, so its boiling step is far longer.
3. Use Part C to separate boiling from evaporation. Boiling happens all through the liquid at the boiling point; evaporation happens at the surface at any temperature when the fastest particles escape, and it leaves the rest cooler. Ask for examples: sweat, a wet swimsuit, a puddle drying on a cool day.
4. If you ran session 2, lay the cooling curve over the heating curve: the same flat steps at the same model temperatures, with energy now leaving. Ask why the rule card never lets a chain drop below 1 (particles never stop moving).

Recording sheet: what students fill in

Lab 3 recording sheet: Energy tokens

Each student is one particle of a pure substance, and each paper clip is one unit of energy. Clips on your chain are **motion energy**: a longer chain means you move faster. Clips in a bank are energy that **loosened** the particles from their fixed spots (melting) or **separated** them completely (boiling). The **model temperature** is the average chain length: total clips on chains $\div$ 4.

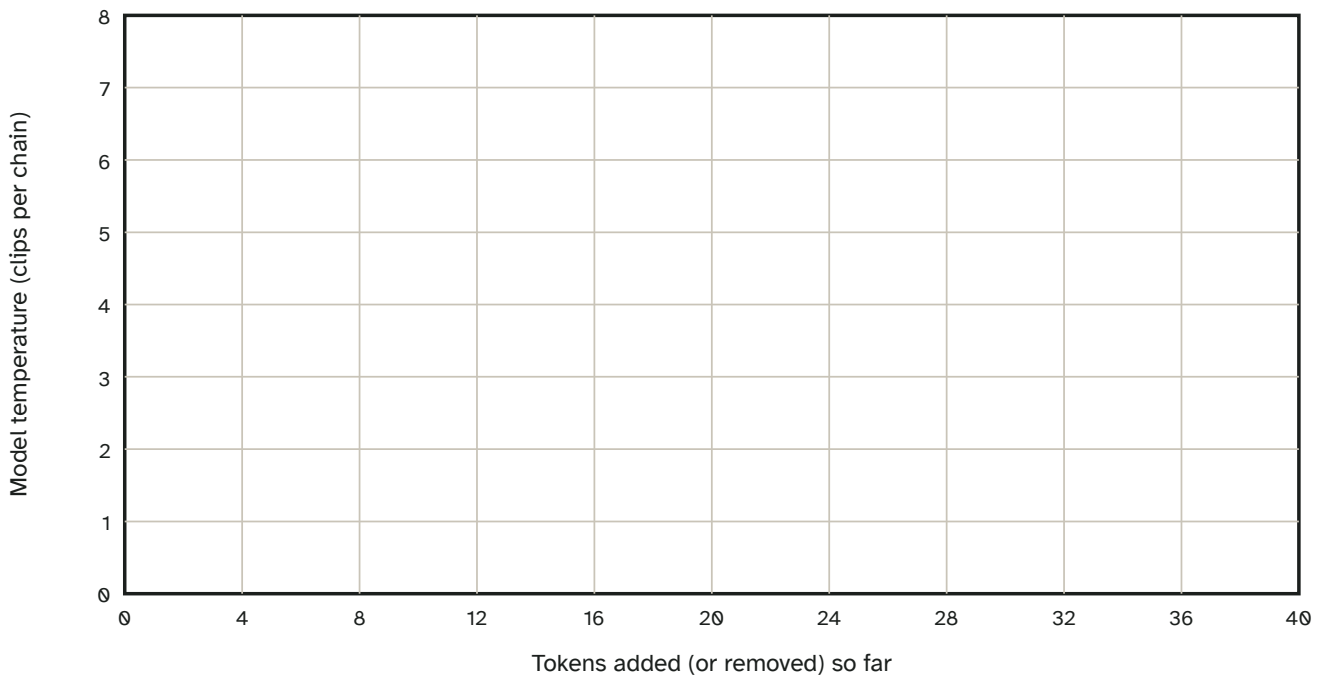
Heating rule card

If the substance is...	Each new token goes...	How the particles move
Solid, chains shorter than 3	Onto your chain	Sway in place on your X; a longer chain means a bigger sway
At the melting point (chains at 3) with any particle still solid	Into the loosening bank. Every 2 clips in the bank free one particle into the liquid	Freed particles shuffle in the liquid strip; the others keep swaying on their X
Liquid, chains shorter than 6	Onto your chain	Shuffle through the liquid strip, swapping places, always within arm's reach of another particle
At the boiling point (chains at 6) with any particle still liquid	Into the separating bank. Every 2 clips in the bank free one particle into the gas	Escaped particles walk in the whole container; the others keep shuffling
Gas	Onto your chain	Walk in straight lines and turn at arm's length from walls and particles; never run

Heating run

Round	Tokens added so far	Model temperature (clips per chain)	Loosening bank	Separating bank	Solid / liquid / gas (particles)	State of the sample
0	0	1	0	0	4 / 0 / 0	solid
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

Heating curve (and cooling curve in session 2)



1. During which rounds did the model temperature stay the same even though tokens were still being added? Where did those tokens go?

Answer: The temperature stayed at 3 during rounds 3 and 4 and at 6 during rounds 8 and 9 (so the curve is flat from round 2 to round 4 and from round 7 to round 9). Those tokens went into the loosening bank during melting and into the separating bank during boiling, not onto chains.

Why: Round 2 brings every chain to 3 and round 7 brings every chain to 6; the next two rounds each add 4 tokens to a bank while the chains stay the same.

- Identifies both flat sections
- States that the tokens went into the loosening and separating banks

2. Check the accounting after round 10: 4 starting clips + tokens added = clips on chains + clips in banks. Write the numbers. Did any tokens disappear?

Answer: $4 + 40 = 44$ clips. On chains: $4 \times 7 = 28$. In banks: $8 + 8 = 16$. $28 + 16 = 44$, so no tokens disappeared; every one is either motion energy on a chain or stored in a bank.

Why: This is bookkeeping in model units, not an energy calculation; it shows that energy is conserved during a change of state.

- Shows 44 on both sides
- Concludes that no tokens disappeared

Uneven-round card. This round, the energy source deals the 4 tokens unevenly: 3 to particle A, 1 to particle B, none to C or D. All dealt tokens go onto chains. **Escape rule:** a liquid particle whose chain is 6 or longer may escape. It puts 2 clips into the separating bank and walks into the gas region. The **liquid temperature** is the average chain length of the particles still in the liquid.

Part C: the uneven round

Moment	Chain A	Chain B	Chain C	Chain D	Liquid temperature	Particles in the gas
Before the deal	4	4	4	4	4	0
After the deal						
After the escape rule						

3. What was the liquid's temperature just before particle A escaped, and just after? Why did the escape change it?

Answer: Just before the escape, the chains were 7, 5, 4 and 4, so the liquid's temperature was $20 \div 4 = 5$. After particle A escaped, the liquid particles had chains of 5, 4 and 4, so the liquid's temperature was $13 \div 3 \approx 4.3$. The particle that left was the fastest one, so the average of the particles left behind went down.

Why: Removing the highest value from a set lowers its average; this is the model's version of evaporative cooling.

- Gives 5 before and about 4.3 after
- Explains that the fastest particle left, lowering the average

Cooling rule card (optional session 2)

If the substance is...	Each round, every particle's token comes from...
Gas, chains longer than 6	Your chain
At the boiling point (chains at 6) with any particle still gas	The separating bank. Every 2 clips removed let one gas particle condense into the liquid strip
Liquid, chains longer than 3	Your chain
At the melting point (chains at 3) with any particle still liquid	The loosening bank. Every 2 clips removed let one particle freeze back onto an X
Solid	Your chain, but no chain ever goes below 1, because real particles never stop moving

Cooling run (optional session 2)

Round	Tokens removed so far	Model temperature (clips per chain)	Loosening bank	Separating bank	Solid / liquid / gas (particles)	State of the sample
0	0	7	8	8	0 / 0 / 4	gas
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

Analysis questions: answer key

4. Describe your heating curve in five parts. For each part, say whether the temperature was rising or flat, which state or states were present, and what the particles were doing.

Answer: (1) Rising from 1 to 3: solid; particles vibrating harder in fixed spots. (2) Flat at 3: solid and liquid together; energy loosening particles from their fixed spots (melting). (3) Rising from 3 to 6: liquid; particles sliding past one another faster. (4) Flat at 6: liquid and gas together; energy separating particles completely (boiling). (5) Rising from 6 to 7: gas; particles flying faster.

Why: This is the qualitative heating curve the PE asks students to model.

- Five parts in the right order
- Correct state or states in each part
- Particle behavior described for each part

5. Explain in particle terms why the temperature stayed flat during melting and boiling even though energy was still being added. Use the word 'average' in your answer.

Answer: Temperature measures the average motion of the particles. During melting and boiling the added energy did not go into faster motion: it went into loosening the particles from their fixed positions, or pulling them completely away from their neighbors. Because the particles' average motion did not change, the temperature stayed the same until the change of state was complete.

Why: The key idea is that the energy changes the particles' arrangement rather than their average speed during a change of state.

- Uses 'average' to define temperature
- Says the energy loosened or separated particles instead of speeding them up
- Says the temperature holds until the change of state is complete

6. After round 3 your group had solid particles and liquid particles at the same time. What real situation does this model? Give an example with water.

Answer: A pure substance at its melting point, where solid and liquid exist together. Example: a glass of ice water stays at about 0 °C while the ice is melting.

Why: Coexistence at the melting point is why the temperature holds steady.

- Names solid and liquid existing together at the melting point
- Gives a correct water example

7. In Part C the liquid's temperature was below the boiling point, yet one particle escaped. What real process does this model, and why was the liquid left behind cooler afterward? Give an everyday example.

Answer: Evaporation. The particles in a liquid have a range of energies, and the fastest ones at the surface can escape even when the average, the temperature, is below the boiling point. Because the escaping particle was the fastest, the average of the particles left behind went down, so the liquid cooled. Everyday examples: sweat cooling your skin, a wet swimsuit feeling cold in a breeze, a puddle drying on a cool day.

Why: Students separate evaporation (surface, any temperature) from boiling and explain evaporative cooling with the average.

- Names evaporation
- Explains that the fastest particles escape below the boiling point
- Explains why the remaining liquid is cooler
- Gives a real example

8. Suppose a group used 8 particles instead of 4 with the same rules. After 5 rounds, would its model temperature be higher, lower or the same as yours? Would it need more tokens to melt the whole sample? Explain what this shows about temperature and thermal energy.

Answer: The same. Each particle still gets one token per round, so after 5 rounds every chain is 4 and the model temperature is 4. But to melt the whole sample the group would need 16 clips in the loosening bank instead of 8, and it adds 8 tokens per round instead of 4. A larger sample at the same temperature holds more thermal energy: temperature is an average per particle, while thermal energy is the total for all of them.

Why: With 8 particles, rounds 3 and 4 put 8 clips each into the loosening bank (16 in all), so the timeline is unchanged but every round needs twice as many tokens.

- The temperature is the same (4)
- More tokens are needed to melt the larger sample
- Distinguishes temperature (average) from thermal energy (total)

9. Sketch the curve you would expect for pure water vapor at 120 °C cooled steadily at 101 kPa until it is ice at -20 °C. Label the temperature of each flat step and the state in each part.

Answer: A curve that starts at 120 °C (gas) and falls to 100 °C; a flat step at 100 °C labeled condensing (gas and liquid together); a fall from 100 °C to 0 °C (liquid); a flat step at 0 °C labeled freezing (liquid and ice together); then a fall to -20 °C (solid). The 100 °C step may be drawn longer than the 0 °C step.

Why: This is the heating curve in reverse at 101 kPa. The temperature holds during condensing and freezing because energy leaves as the particles come together rather than as they slow down.

- Starts at 120 °C and ends at -20 °C
- Flat steps at 100 °C and 0 °C
- States labeled in every part

10. Name two ways this model differs from real particles, and for one of them suggest a rule change that would make the model more realistic.

Answer: Any two, for example: a real sample has trillions of particles with a range of speeds, not four with equal chains; real water needs nearly seven times as much energy to boil as to melt, but the model uses 8 tokens for each; real particles attract one another, and that attraction is why energy is needed to separate them, but the model hides it in a cup; real gas particles are far faster and farther apart than walking students. Rule changes: make the separating bank need about 7 clips per particle so the boiling step is longer; deal each round's tokens randomly so particles have different energies; use more particles.

Why: Credit any two genuine differences and one workable rule change linked to one of them.

- Names two genuine differences
- Proposes a rule change tied to one difference

Individual evidence of learning

Each student submits their own heating table, heating curve, Part C table and answers to q1 through q10, plus the cooling table and curve if session 2 was run. The labeled heating curve, q4, q5 and q9 are the evidence for MS-PS1-4: predicting particle motion, temperature and state as energy is added or removed. q7 and q8 are the evidence that the student treats temperature as an average and separates it from thermal energy.

Assessment criteria

Criterion	Proficient looks like
Data table and accounting	Every round recorded with temperature, banks and state counts, and the token accounting balances ($44 = 28 + 8 + 8$).
Heating curve	Points plotted correctly with two flat steps at 3 and 6, each labeled with the change of state and what the particles were doing.
Explaining the flat steps	States that during melting and boiling the added energy loosened or separated the particles instead of raising their average motion, so the temperature held (q5).
Temperature as an average	Uses Part C to explain evaporation below the boiling point and the cooling of the liquid left behind (q7), and separates temperature from thermal energy (q8).
Prediction and evaluation	Sketches a correct cooling curve for water with flat steps at 100°C and 0°C (q9) and names a real limit of the model with a sensible rule change (q10).

Accessibility adaptations

- Tabletop version: the same rules with four game pieces on a sheet of paper marked with X spots, a liquid strip and a gas region; students move the pieces and add clips to small chains beside each piece.
- Students who need movement can also play the gas in another group's run; students who need a calm role can be the thermometer reader.
- Provide a pre-filled 'tokens added so far' column (0, 4, 8 ... 40) and the rule card as a picture flow chart for students who need support.
- For students with low vision, use large colored clips or wooden beads on string, high-contrast floor tape and a spoken count after each round.
- Offer a tactile heating curve: a string glued to card along the plotted points, with the two flat steps marked by knots.

Low-cost alternative

Use dried beans or folded paper squares as tokens and chalk on the blacktop instead of masking tape. With no floor space at all, run the tabletop version with four coins as particles and the same rule card; it keeps all the data and the graph, though it loses the feeling of being a particle.

Model limitations

A real sample has trillions of particles, not four, and their energies are spread over a range that changes at every collision; in this model every particle gets exactly one token per round except in Part C. The model gives melting and boiling the same 8 tokens, but real water needs nearly seven times as much energy to boil as to melt the same mass, so a real heating curve has a much longer boiling step. Real particles do not choose where energy goes: it goes into loosening or separating them because they attract one another, an attraction the model hides inside the bank cups. Students walking cannot show a real gas's spacing or speed; air molecules average about 470 m/s at room temperature. This activity has not been physically tested by the authors; the timings and token counts assume a group of four following the cards exactly.

Teacher notes

The most common error is putting melting or boiling tokens onto chains; check the first group to reach round 3 and correct it publicly so others catch it. The expected heating temperatures are 1, 2, 3, 3, 3, 4, 5, 6, 6, 6, 7; a row that differs points to a rule error, not a 'different result'. Keep the token arithmetic as bookkeeping only; the chapter asks for no energy or heat calculations. The equal two-clips-per-particle banks are a teaching choice; students ready for extension can redesign them (see the chapter's differentiation notes) and run their rule against the class curve.