

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

Name _____

Group _____

Date _____

Your role today

- ☐ **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.

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.

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.

Record your observations

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.

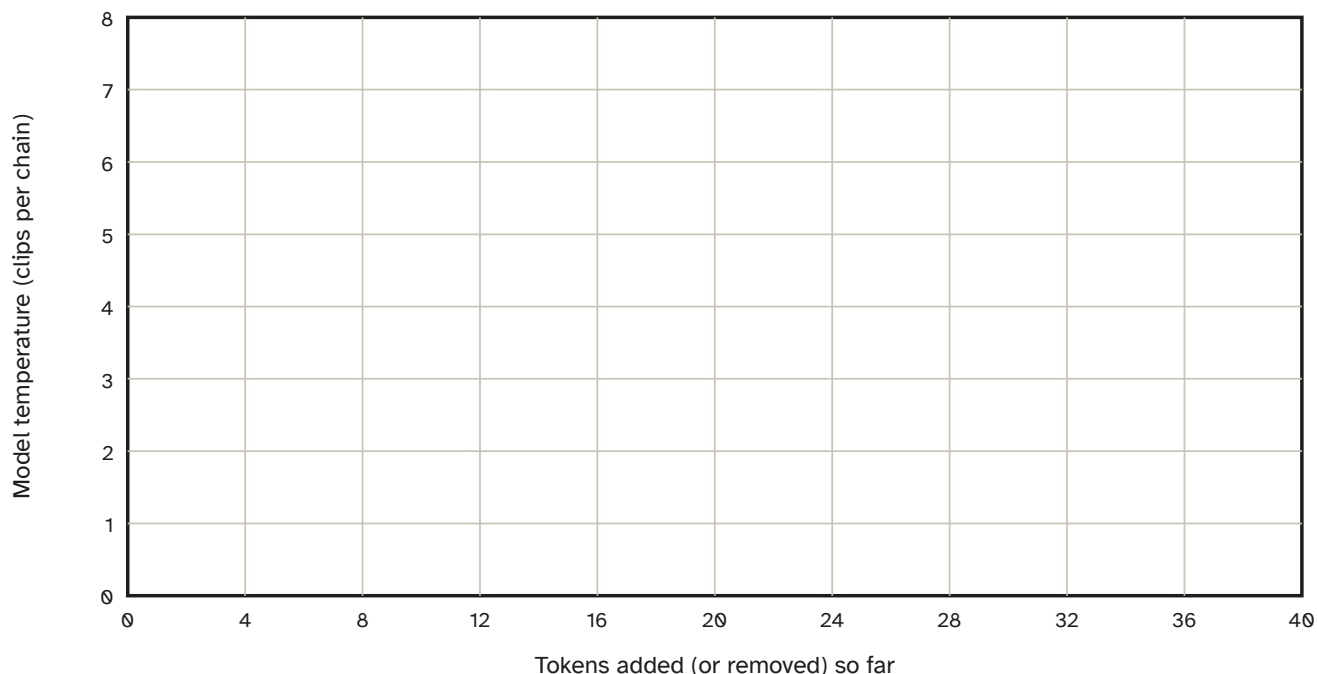
Heating rule card

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?

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?

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?

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						

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

Analysis questions

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.

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.

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.

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.

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.

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.



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.
