

Which Cup Holds More Thermal Energy? The Four-Cup Ice Mystery

Investigation question: Four covered cups of water look identical from the outside. Which one can melt the most ice, which one holds the most thermal energy, and are those the same question?

Evidence-based mystery

Groups of 4

1 session

Setup 7 · Activity 38 · Cleanup 7 min

MS-PS3-4 · supports

MS-PS1-4 · practice

Scientific purpose

Students receive four lidded foam cups that hide different amounts of water at different temperatures. Using only a scale and a thermometer they gather evidence, predict which cup will melt the most ice, and then test all four with equal masses of ice for the same time. The measured grams of ice melted reveal that the hottest cup does not win, that the amount of water matters as much as its temperature, and that an ice-cold cup with plenty of thermal energy melts almost nothing because there is no temperature difference to drive heat.

Why this helps students with this chapter

Students say 'thermal energy depends on mass and temperature' long before they believe it; when they must bet on a cup, almost everyone bets on the hottest one. Gathering the evidence themselves, committing to a ranking, and then weighing the meltwater makes the result their own. The ice-cold cup is the twist that separates thermal energy from heat: it has five times the water of the hottest cup, yet it can give the ice almost nothing because the two are at nearly the same temperature.

Standards connections

MS-PS3-4 (supports, the relationship among energy transferred, mass and temperature, used as background): This is a California Grade 6 PE, and the lab resembles its clarification example (ice melted by water samples). Here it supports the Grade 7 work: the investigation is designed for students rather than planned by them, and no one calculates the energy transferred, which the assessment boundary excludes.

MS-PS1-4 (practice, using a particle model to explain temperature, thermal energy and melting when energy is added): Students explain with particles why a larger, cooler cup can melt more ice than a smaller, hotter one, and why melting stops at 0 °C. This practices the particle reasoning of the PE; the full model of temperature and state over time is assessed in Lab 1.

Roles (rotate each session)

- **Weigher:** Tares the scale, weighs every cup and collection cup, and calls each mass aloud for the recorder.
- **Thermometer reader:** Reads each cup's temperature through the lid hole after the reading settles, wipes the thermometer between cups, and reads the final liquid temperatures.

- **Recorder:** Fills the evidence and results tables, subtracts to find each mass, and posts the group's results on the class chart.
- **Timekeeper and skeptic:** Runs the six-minute timer, checks that all four cups are treated the same way, and asks 'how do we know?' before the group commits to its prediction.

Materials

Item	Quantity	Per	Note
16-oz (about 470 mL) foam cups with lids that have a sip hole, labeled W, X, Y and Z, empty mass written on the bottom	4	group	Prepared by the teacher; see prep for what goes in each.
Clear plastic collection cups, labeled W to Z, empty mass written on each	4	group	
Ice cubes or crushed ice held at 0 °C in an ice-water cooler, drained before use	600 g (150 g per cup) plus a little spare	group	
Kitchen scale reading to 1 g (0.1 g is better)	1	group	Two groups can share if needed.
Thermometer, alcohol-filled glass or digital probe	1 or 2	group	
Plastic spoons	4	group	
Small kitchen strainer	1	group	For draining ice before weighing; a slotted spoon also works.
Four small bowls or cups for weighed ice portions	4	group	
Timer, tray and paper towels	1 each	group	

Estimated cost: About 15 to 25 per class with scales on hand; about 50 to 80 if scales must be bought (an estimate; Estimate: foam cups with lids about \$8 per 50, clear cups about \$3 per sleeve, two bags of ice about \$6, small strainers about \$2 each; kitchen scales about \$10 to \$15 each if the school has none.)

Safety

- Water above about 50 °C can scald. The teacher prepares all warm water, and no cup is warmer than 45 °C. Report a cup that feels hot.
- Spilled water and ice make floors slippery. Keep all pouring over the tray and wipe up at once.
- Keep the scale dry; water can damage it and cause a shock hazard with plug-in models. Use battery scales and set cups on a paper towel on the pan.
- Glass thermometers can break and cut. Do not stir with them; report any break to the teacher.
- Lab water and ice are not for drinking or eating; collection cups and spoons stay in the lab.

Teacher preparation and setup

1. Thirty minutes before class, fill a cooler with ice and water so the ice settles at 0 °C. Ice straight from a freezer is colder than 0 °C and can freeze some water onto itself, which spoils the ice-cold cup.
2. Weigh each empty foam cup with its lid and write the mass on the bottom; do the same for the clear collection cups.
3. Fill each group's cups shortly before class, weighing the water in: W gets 40 g of water at about 45 °C; X gets 200 g of water left out overnight at room temperature (about 22 °C); Y gets 200 g at about 35 °C; Z gets 200 g of ice-cold water strained from the cooler (about 0 to 2 °C), with no ice pieces. Mix warm water from hot and cold tap water and check it with a thermometer; students never receive water above 45 °C. Snap on the lids.
4. Keep a key card of what is in each cup out of sight until the reveal. Students' measured masses should match within a couple of grams; their temperatures will have drifted a little toward room temperature, especially the small cup W.
5. Run the test once yourself if you can, to check that six minutes of stirring brings every cup with leftover ice close to 0 °C with your cups and ice.

Investigation design

Independent variable	The water in each cup, which differs in mass and in starting temperature from cup to cup.
Dependent variable	The grams of ice melted in six minutes (liquid collected minus starting water).
Controlled	150 g of ice per cup, all held at 0 °C and drained the same way; Six minutes of steady stirring for every cup, started together; The same foam cups, lids, pouring method and scale; All cups tested at the same time and place
Trials	One test of each cup per group; the class chart gives one result per cup from every group, so the class has several trials of each cup.
Comparison	W against Y (hotter but much less water), X against Y (same water mass, different temperature), X against Z (same mass, one ice-cold), and W against X (the trade-off between temperature and amount).

Student procedure

1. Read the case card: four cups labeled W, X, Y and Z, lids on. Your job is to predict which cup can melt the most ice, using only the evidence you can gather without looking inside. Do not open any lid until step 5.
2. Gather evidence. The weigher weighs each cup with its lid and subtracts the empty mass written on the bottom to find the mass of water. The thermometer reader slides the thermometer through the lid hole, waits until the reading settles, and calls it out. The recorder fills the evidence table.
3. Predict. As a group, rank the cups from most ice melted to least (q1) and write the rule you used (q2). The skeptic checks that every member can explain the ranking. Show the teacher your prediction before you continue.

4. Prepare the ice. Drain ice from the class cooler in the strainer for about one minute, then weigh four portions of 150 g each into the small bowls. Work quickly so the portions do not sit and melt.
5. Test. Each member takes one cup and one ice portion. On the timekeeper's 'go', everyone removes their lid, tips in the ice and starts stirring gently and steadily with a spoon. Keep stirring for six minutes.
6. At exactly 6:00, everyone pours their cup's liquid into its matching collection cup at the same time, holding the ice back with the spoon. Tip the cup until no more liquid comes out, but do not squeeze or shake the ice.
7. The reader measures the temperature of each collected liquid. The weigher weighs each collection cup and subtracts its empty mass. The recorder finds the ice melted: liquid collected minus starting water.
8. Post your four 'ice melted' values on the class chart, then copy the class results into your table. The teacher reveals what was put in each cup.
9. Empty all ice and water into the sink, dry the cups and spoons, and answer the analysis questions individually.

Expected observations

- Measured masses close to the prepared values (W about 40 g; X, Y and Z about 200 g). Measured temperatures drift a little toward room temperature: W may read 40 to 44 °C by the time it is measured; Z may read 1 to 4 °C.
- Grams of ice melted, roughly: Y most (about 75 to 95 g), X next (about 45 to 65 g), W much less (about 15 to 30 g), Z least (about 0 to 8 g). The ranking Y, X, W, Z should hold in nearly every group even though the exact values vary.
- Final liquid temperatures of about 0 to 3 °C in every cup that still had ice; colder in cups that melted less.
- Cup Z's small positive 'melt' is mostly water that clung to the drained ice, not real melting.

Likely difficulties

- Students forget to subtract the empty-cup mass, so the 'water' column is 5 to 10 g too high. The recorder should check that cups X, Y and Z come out near the same water mass.
- Pouring is slow or uneven, and ice keeps melting in the cups that are poured last. Pour all four at once on the timekeeper's call.
- Ice taken straight from a freezer instead of the 0 °C cooler can make cup Z's result negative, as some water freezes onto the very cold ice. Use the cooler, or treat a negative Z as a discussion point.
- Groups argue that W 'should have won' and suspect an error. Have them compare with the class medians: when the same surprising result repeats across groups, it is evidence, not a mistake.
- The small cup W cools quickly while waiting. Measure its temperature last before the test, or have the teacher fill W cups a few minutes later than the others.

Structured debrief

1. Reveal the cups: W held 40 g at about 45 °C, X 200 g at room temperature, Y 200 g at about 35 °C, Z 200 g of ice-cold water. Put the class medians on the board next to the predictions. Most groups will

have ranked W first; ask what they now think the rule should be.

2. Ask where each gram of melted ice got its energy: from the water cooling down. Water can give energy to the ice only while it is warmer than the ice, so what matters is how much water there is and how far it can cool before it reaches 0 °C. W cooled a long way but had little water; Y cooled less far but had five times as much.
3. Spend the most time on Z. It has five times the water of W, its molecules are moving almost as energetically, so it holds more thermal energy than W, yet it melted almost nothing. Heat needs a temperature difference. This is the cleanest evidence in the unit that thermal energy and heat are different ideas.
4. Connect back to the slide 10 camper and the slide 5 bathtub: the big pot of lukewarm water, like cup Y, beats the small mug of nearly boiling water, and a tank at 0 °C, like cup Z, does nothing for the ice.

Recording sheet: what students fill in

Lab 2 recording sheet: The four-cup ice mystery

The cups hide different water. You may weigh them and take their temperature, but you may not look inside until the test. Every gram of ice that melts needs energy, and in this lab all of that energy comes from the water in the cup.

Evidence before testing

Cup	Cup + lid + water (g)	Empty cup + lid (g)	Water (g)	Temperature (°C)
W				
X				
Y				
Z				

1. Prediction: rank the cups from the one that will melt the most ice to the one that will melt the least.

Answer: Any ranking with a reason earns credit; it is a prediction. Most groups predict W first because it is hottest. The ranking the data will support is Y, X, W, Z.

Why: Do not grade predictions for correctness. Keep them visible: the gap between the prediction and the result is the point of the mystery.

2. What rule did you use to make your ranking? If two pieces of evidence pointed in different directions for a pair of cups, say how you decided.

Answer: Group-specific. Strong rules use both evidence columns, for example 'more water and warmer both help; when they disagree, the cup with five times the water probably wins'. A rule using temperature alone is common.

Why: Credit a clear statement of the rule and how conflicts were settled.

- States a rule
- Mentions how a conflict between mass and temperature was handled

Test results (150 g of ice per cup, 6 minutes)

Cup	Starting water (g)	Liquid collected (g)	Ice melted (g)	Final temperature (°C)
W				
X				
Y				
Z				

Class results: grams of ice melted

Group	W	X	Y	Z
1				
2				
3				
4				
5				
6				
7				
8				
Class middle value (median)				

3. Was your prediction right? Which result surprised your group most, and why?

Answer: Group-specific. Expected surprise: W, the hottest cup, melted much less than Y and less than X; or Z melted almost nothing.

Why: Credit any honest comparison of prediction with result that names the surprising cup and gives a reason.

- Says whether the prediction matched
- Names the most surprising result with a reason

Analysis questions: answer key

4. Make a claim: rank the cups by how much ice they melted, using your results and the class medians as evidence. Did the hottest cup melt the most? Explain why or why not.

Answer: Claim: Y melted the most ice, then X, then W, then Z (for example, class medians of about 85 g, 55 g, 22 g and 4 g). The hottest cup, W, did not win: it melted less than half as much as X and about a quarter as much as Y. W's water was warmest, but it held only 40 g, one fifth as much water as the others, so it had far less energy to give before it cooled to the ice's temperature.

Why: The claim must rest on the measured values. Teacher estimate for ideal conditions (ice at 0 °C, everything cooled to 0 °C, no losses): W about 22 g, X about 55 g, Y about 88 g, Z about 2 g; measured values will be somewhat lower, plus a few grams of clinging water.

- Correct ranking Y, X, W, Z
- Cites numbers from the group or class data
- Explains that W lost because it had much less water

5. Cup W's water molecules were more energetic on average than cup Y's. Use particles and energy transfer to explain why cup Y still melted more ice.

Answer: Melting each gram of ice takes energy, and that energy comes from the cup's water molecules colliding with the ice and passing energy to it as the water cools. W's molecules started out more energetic on average, but there were only a fifth as many of them, and they could give energy only until they cooled to 0 °C. Y had five times as many molecules, each able to give up energy as the water cooled from about 35 °C to 0 °C, so Y's water had much more energy to transfer in total and melted more ice.

Why: The key is total energy available to transfer (many particles each giving some) versus average energy per particle. Students should not compute energy.

- Melting needs energy transferred from the water
- W more energetic per molecule but far fewer molecules
- Y has more molecules giving energy while cooling to 0 °C
- Mentions collisions or transfer from warmer to cooler

6. Cup Z melted almost no ice. Does that mean the water in cup Z had no thermal energy? Explain.

Answer: No. Z's 200 g of water had plenty of thermal energy: its molecules were still moving and sliding as a liquid. It melted almost no ice because it was at nearly the same temperature as the ice, so there was almost no temperature difference to make energy flow as heat into the ice.

Why: Separates 'has thermal energy' from 'can transfer heat'. Any answer saying Z had no or zero energy is incorrect.

- States Z has thermal energy
- Explains heat needs a temperature difference
- Notes Z and the ice were at nearly the same temperature

7. Which statement is best supported by the class data?

Answer: C. Both the amount of water and how much warmer it is than the ice matter, and water melts ice only while it is warmer than the ice.

Why: A is contradicted by W (hottest, melted little). B is contradicted by Z (as much water as X and Y, melted almost none). D is contradicted by X (room temperature, melted plenty). Only C fits all four cups.

8. Every cup that still had ice in it ended close to 0 °C. Explain why the temperature stopped there instead of continuing to fall.

Answer: Once the water cooled to 0 °C it was at the same temperature as the melting ice, so no more energy flowed from the water into the ice. The ice-water mixture stays at the melting point, 0 °C, as long as both ice and liquid are present; it can only get colder if energy leaves it, and nothing colder than 0 °C was touching it.

Why: Applies the equal-temperature stopping point and the melting-point plateau from Lab 1.

- No temperature difference, so no net heat
- Ice-water mixture sits at the melting point

9. Now rank the cups by total thermal energy, not by ice melted. Hint: water at 1 °C is not 'empty' of energy; its molecules still move almost as energetically, on average, as at 45 °C, because the coldest possible temperature is –273 °C. Which two cups trade places between the two rankings, and what does that tell you about the difference between thermal energy and heat?

Answer: By total thermal energy: Y (most water, warmest of the big cups), then X, then Z, then W. W and Z trade places: Z has five times as much water as W, and its molecules are only a little less energetic on average, so Z holds more thermal energy than W, yet W melted far more ice. Thermal energy is how much energy the water holds; heat is energy that actually moves, and it moves only from warmer to cooler. A cup can hold a lot of thermal energy and still give the ice almost none if it is not warmer than the ice.

Why: X, Y and Z have equal mass, so warmer means more thermal energy among them. Comparing Z with W needs the hint: measured from –273 °C, 1 °C and 45 °C are about 274 and 318 degrees above the bottom of the scale, so W's molecules carry only about 16 percent more energy of motion on average, while Z has five times as many molecules. Students need not use these numbers; credit reasoning that combines five times the molecules with only slightly lower average energy. Accept 'Y, X, then Z and W close, with Z ahead' with sound reasoning.

Also acceptable: A student who ranks W above Z but explains clearly why Z's large mass might outweigh its low temperature, and recognizes that this question cannot be settled with a thermometer alone, earns partial credit.

- Ranking Y, X, Z, W (or Z above W with reasoning)
- Names W and Z as the pair that switches
- Distinguishes thermal energy (held) from heat (transferred because of a temperature difference)

10. Name two sources of error in measuring 'ice melted', and explain how cup Z's result can help you judge the size of one of them.

Answer: Possible sources: water clinging to the drained ice adds a few grams to every cup's 'melt'; liquid left clinging to the ice and cup after pouring makes 'melt' too low; cups poured last keep melting longer; some energy goes into warming the cup and spoon, or comes in from the room air; temperatures drift before the test; scale rounding. Cup Z is almost a blank: it should melt nearly nothing, so the few grams it appears to gain estimate the clinging-water error, and that amount could be subtracted from the other cups.

Why: The blank is the key idea; any two real error sources plus a sensible use of Z earns full credit.

- Two real sources of error
- Explains Z as a blank or control that measures the clinging-water effect

11. A team must melt as much ice as possible to fill a cooler with cold water. They can pour on either 1 liter of 25 °C tap water or 100 mL of 60 °C water from a coffee maker. Which should they choose? Explain without calculating energy.

Answer: The 1 liter of 25 °C tap water. It has ten times as much water as the coffee-maker water. The hot water is warmer, but 60 °C is less than three times as far above the ice's 0 °C as 25 °C is, so it cannot make up for having one tenth of the water. Like cup Y against cup W, the larger amount wins.

Why: Without any energy calculation, the student compares the amount ratio (10 times) with the temperature-above-0 ratio (about 2.4 times). For the teacher: the liter can melt roughly four times as much ice as the 100 mL.

- Chooses the liter of tap water
- Uses the much larger amount of water as the main reason
- Recognizes the hotter water is not hot enough to make up the difference, or links to cups W and Y

Individual evidence of learning

Each student submits the evidence and results tables, their own copy of the class medians and individual answers to q4 through q11. The claim in q4 with its evidence, the particle explanation in q5, and the thermal-energy ranking in q9 are the main evidence that the student can separate temperature, thermal energy and heat.

Assessment criteria

Criterion	Proficient looks like
Claim from evidence	Ranks the cups Y, X, W, Z by ice melted using group and class data, and states that the hottest cup did not melt the most (q4).
Particle explanation	Explains that each gram melted needs energy from the water cooling, that Y has many more molecules to give energy while cooling to 0 °C, and that the transfer happens through collisions while the water is warmer than the ice (q5, q8).
Thermal energy versus heat	Ranks total thermal energy Y, X, Z, W, notes that W and Z trade places, and explains that heat flows only with a temperature difference, so a cup can hold much thermal energy and still give the ice almost none (q6, q9).
Quality of evidence	Names real error sources such as clinging water, uneven pouring or temperature drift, and uses cup Z as a blank to estimate the clinging-water error (q10).
Transfer	Chooses the liter of tap water and justifies it with ten times the water against a temperature less than three times as far above 0 °C, without an energy calculation (q11).

Accessibility adaptations

- Provide a calculator and a subtraction frame (liquid collected – starting water = ice melted) for students who need support with the arithmetic.
- Students with limited fine-motor control can take the recorder or skeptic role; the pouring can be done by a partner while the student calls the timing.

- Use a talking or large-display scale and digital thermometer for students with low vision; the weigher and reader call every value aloud.
- Offer sentence frames for the claim: 'Cup ___ melted the most ice because _____. Cup ___ was the hottest, but _____.'

Low-cost alternative

Without scales, use identical ice cubes instead of weighed ice: add one cube at a time to each cup, stirring until it melts, and count how many cubes each cup melts completely before a cube survives for three minutes. Measure the water with a measuring cup (1 mL of water has a mass of about 1 g). The ranking is the same, though the counts are coarser.

Model limitations

This activity has not been physically tested by the authors; the expected grams melted are estimates from the masses and temperatures used, and real values will be lower because six minutes may not bring every cup all the way to 0 °C and some energy goes into warming the cup and spoon. Drained ice carries a film of water that adds a few grams to every cup's 'melt', and the room air adds a little energy through the foam. The lab measures the energy each cup can give to 0 °C ice, not its total thermal energy: total thermal energy cannot be measured with a thermometer and scale, which is exactly why q9 is answered by reasoning rather than measurement. The 'Which cup holds more thermal energy?' title is a question to investigate, and the answer turns out to differ from the ice-melting ranking.

Teacher notes

The prepared contents are W 40 g at about 45 °C, X 200 g at room temperature, Y 200 g at about 35 °C and Z 200 g at about 1 °C. The ideal-melt estimates in the q4 reasoning use 'grams melted is about grams of water times degrees above 0 °C, divided by 80', which is for teacher checking only; do not teach it as a formula, because the PEs' assessment boundaries exclude calculating energy. If a group's ranking differs from Y, X, W, Z, look first for a missed subtraction or a late pour. Post the class medians; slide 10's camper discussion, W5 (Twice the Ice) and W10 item 2 can refer back to them.