

Heat or Dye? Building a Convection Cell in a Tank

Investigation question: When colored water is released at the bottom of a tank, what makes it rise, the dye or the temperature difference, and what does the cold side of the loop look like?

Physical model

Groups of 4

1 session

Setup 8 · Activity 35 · Cleanup 7 min

MS-ESS2-1 · practice

Scientific purpose

Students use a clear tank of room-temperature water as a physical model of a convection cell. They release the same dyed water at three temperatures (room temperature, warm and hot), time how fast the plume reaches the surface, add a dyed ice cube to see the sinking leg, and decide from the control run whether the dye or the heat is doing the moving. The lab turns the sentence 'warm material is pushed up as cooler, denser material sinks' into something they watched, timed and sketched.

Why this helps students with this chapter

Students arrive believing that heat rises on its own and that dye or steam simply drifts upward. A control run with room-temperature dye shows that dye by itself stays near the bottom, and the dyed ice cube makes the hidden half of the loop, the sinking of cooler denser water, visible. Timing two temperatures turns a vague 'hotter goes faster' into a measured relationship, and the sketches become the convection-cell diagram students will draw for the mantle, the ocean and the air.

Standards connections

MS-ESS2-1 (practice, the energy-flow half: a physical model of energy from below driving the circulation of material): Students build and interpret a physical model of a convection cell, the mechanism that cycles mantle rock, ocean water and air. The lab builds the model-based reasoning the PE asks for; the geologic processes in the clarification statement come in Lesson 17.

Roles (rotate each session)

- **Tank manager:** Fills and refills the tank, checks the water is still and at room temperature, and holds the ruler against the side during each run.
- **Releaser:** Lowers the covered vial to the bottom with tongs, slides the cover off on the timer's signal, and places the ice cube on the timer's signal. Never fills the warm or hot vials.
- **Timer:** Starts the stopwatch at release, calls out 30, 60 and 120 seconds, and records the time the dye first touches the surface.
- **Observer and sketcher:** Narrates what the dye does, sketches the plume at 60 seconds for each run, and records the written description.

Materials

Item	Quantity	Per	Note
Clear plastic container, about 2 to 4 liters, at least 10 cm deep (shoebox-size food storage box or small plastic tank)	1	group	Plastic, not glass. A white sheet of paper taped behind it makes the dye easy to see.
Small clear vials or 30 mL medicine cups	3	group	All the same size so the amount of dyed water is a controlled variable.
Squares of thin plastic card or index card, about 5 cm, to cover the vials	3	group	
Kitchen tongs or a bent wire loop on a stick	1	group	
Red food coloring	1 bottle	class	Same color and same number of drops for every run.
Blue-dyed ice cubes	2	group	Made the day before: 4 drops of blue food coloring per cube compartment.
Thermometer (digital or alcohol, 0 to 100 °C)	1	group	
Stopwatch or phone timer	1	group	
Ruler, 30 cm, marked in mm	1	group	
Bucket for used water and a second bucket of room-temperature refill water	1 each	class	
Electric kettle or hot-water urn with a thermometer, plus an insulated jug of water held at about 40 °C	1 set	class	Teacher station only. Hot water is kept at or below 60 °C.
Paper towels and the recording sheet	1 set	group	

Estimated cost: 10 to 18 per class (an estimate; Food coloring (about \$3 for two bottles), a bag of 30 mL medicine cups (about \$4 for 100), and clear food-storage boxes if the classroom has none (about \$1.50 each for 8). Tongs, rulers, thermometers and a kettle are usually already in stock.)

Safety

- Hot water is dispensed only by the teacher, from a kettle or urn kept at or below 60 °C, into a vial that the teacher sets on the group's tray. Students never pour hot water and never touch the kettle.
- The 'warm' vial is about 40 °C, which is bath temperature and safe to handle briefly; the 'hot' vial at about 55 °C is carried on the tray and lowered with tongs, not fingers.
- Use plastic containers, not glass. Wipe spills immediately; wet floors near a kettle are a slip and electrical hazard. Keep the kettle cord away from walkways and water.
- Food coloring stains skin and clothing; wear aprons or old shirts and keep the dye bottle at the teacher station.
- Nothing in this lab is to be tasted, and vials are not reused for drinking.

Teacher preparation and setup

1. The day before, freeze two trays of blue-dyed ice cubes (about 4 drops of blue food coloring per compartment) and keep them frozen until the lab.
2. Fill the refill bucket and let it sit overnight so the water is at room temperature; cold tap water will give false results in the control run.
3. Set up a teacher station away from the sinks and the tanks: kettle or urn, a thermometer, an insulated jug of water at about 40 °C, and a tray to carry filled vials. Decide the signal groups use to request a vial.
4. Run the hot vial once yourself in a tank to see how fast the plume rises in your container depth; adjust the 30, 60 and 120 second checkpoints if the plume reaches the surface in under 10 seconds.
5. Print one recording sheet per student and tape a sheet of white paper to the back of each tank.

Investigation design

Independent variable	Temperature of the dyed water in the vial (room temperature, about 40 °C, about 55 °C)
Dependent variable	Time for the dye to first reach the surface, and the height of the dye front at 30, 60 and 120 seconds
Controlled	Tank water at room temperature and 10 cm deep, settled before each run; Same vial size, 3 drops of the same red dye, same cover and release method; Vial placed at the same end of the tank each run; Same observer reading the ruler
Trials	One run at each temperature per group; the class pools times on the board so each temperature has 6 to 8 trials.
Comparison	The room-temperature control run against the warm and hot runs; the red rising leg against the blue sinking leg in the final run.

Student procedure

1. Fill the tank with room-temperature water from the refill bucket to a depth of 10 cm. Let it stand for 3 minutes with no one touching the table. Measure and record the tank temperature.
2. Control run: the tank manager fills one vial with room-temperature water from the bucket and adds exactly 3 drops of red dye. Record the vial temperature. Cover the vial with a card, hold the card in place, and use the tongs to lower it upright to the bottom of the tank at one end.
3. When the timer says 'go', slide the card off the vial without lifting the vial. Start the stopwatch. Record the height the dye has reached at 30, 60 and 120 seconds, and the time the dye first touches the surface if it does. Sketch the dye at 60 seconds.
4. Empty the tank into the used-water bucket, wipe it, and refill to 10 cm from the refill bucket. Let it settle for 2 minutes.
5. Warm run: ask the teacher for a vial of water at about 40 °C with 3 drops of red dye. Record its temperature. Cover, lower, release and record exactly as in steps 2 and 3.
6. Empty, wipe and refill the tank as in step 4.

7. Hot run: ask the teacher for a vial of water at about 55 °C with 3 drops of red dye. Record its temperature. Cover, lower with tongs, release and record exactly as before.
8. As soon as the red dye reaches the surface in the hot run, the releaser sets one blue ice cube on the water surface at the opposite end of the tank. Watch for 2 minutes. Record and sketch where the blue goes and where the red goes; draw arrows showing the direction of flow along the bottom and along the top.
9. Compare the three sketches and the three times. Decide as a group: what moved the water, the dye or the temperature difference? Write the decision and the single strongest piece of evidence on the recording sheet.
10. Answer the analysis questions individually, then compare within the group. Empty the tank, return vials to the teacher tray, and wipe the table.

Expected observations

- Control: the red dye leaks out of the vial and spreads slowly along the bottom; after 2 minutes it has risen only a centimeter or two and the top of the tank is still clear.
- Warm run: a visible plume rises above the vial and reaches the surface in roughly 10 to 40 seconds, then spreads along the surface as a thin red layer.
- Hot run: a faster, narrower plume reaches the surface in a few seconds to about 15 seconds and spreads along the top; the red layer thickens from the top down over the next minutes.
- Ice-cube run: a blue column sinks from under the cube, spreads along the bottom toward the hot vial, and is drawn in under the rising red plume, completing a loop that is often visible as a tilted ring of color.

Likely difficulties

- Students bump the table or pour the refill water too fast, so the tank is still swirling at release; insist on the settling time and have the tank manager check for motion with a floating speck of dye.
- Sliding the card off lifts the vial and dumps the dye; practice the move once with an empty vial.
- The plume is faint against a dark background; the white paper behind the tank fixes it, and a phone video lets students re-watch for the 30 second reading.
- Some groups report the hot plume as slower because they started the timer late; have the releaser and timer agree on a countdown.
- Students treat the control as 'the boring one' and skip the readings; the control is the whole argument, so check that its row is filled in before the warm run.

Structured debrief

1. Pool every group's three times on the board. Ask why the control column is mostly 'no' or very slow while the hot column is seconds. Lead students to the sentence: the dye only marks the water; the temperature difference moves it.
2. Ask what the blue ice cube added that the first three runs could not show. The sinking leg. A convection cell has two legs, and most students only ever notice the rising one.

3. Walk the mechanism with gravity in every sentence: the hot water's particles spread out, so the same mass fills more space and its density drops; gravity pulls harder on the denser surrounding water, which sinks under the hot water and shoves it up; at the surface the water cools, gets denser and sinks, especially under the ice cube.
4. Connect to Earth: the hot vial is the core-mantle boundary or the sun-warmed tropical surface; the ice cube is the cold polar air or the cool crust. Then draw the limits: the tank mixes in minutes and the mantle takes a hundred million years; the tank is liquid and the mantle is solid; the tank has one heat source at one spot while Earth is heated across whole regions.

Recording sheet: what students fill in

Lab 1 recording sheet: Heat or dye?

Fill in every box for each run. If the dye never reaches the surface within 3 minutes, write 'no' in the time column and record how high it got. Use the ruler taped to the tank; heights are measured from the bottom.

Plume data

Run	Vial water temperature (°C)	Tank water temperature (°C)	Dye height at 30 s (cm)	Dye height at 60 s (cm)	Dye height at 120 s (cm)	Time dye first touched the surface (s)
Control (room temperature)						
Warm (about 40 °C)						
Hot (about 55 °C)						

-  Four panels. Panels 1 to 3: the tank at 60 seconds for the control, warm and hot runs, with the red dye drawn and arrows for its direction; label the vial, the water surface and the dye front. Panel 4: the hot run 2 minutes after the blue ice cube was added, with red and blue arrows along the top, the bottom and both ends, and labels for where water is warming and where it is cooling.

Answer: Panels 1 to 3: control shows red dye pooled at the bottom with short sideways arrows; warm shows a plume part way up or just at the surface with upward arrows; hot shows a narrow plume reaching the surface and a red layer spreading across the top. Panel 4: red rising above the vial and spreading along the top toward the ice end; blue sinking under the cube and creeping along the bottom toward the vial; the two meet near the vial, forming a loop. 'Warming' labeled at the vial, 'cooling' labeled at the surface and under the ice.

Why: The sketches are the student's convection-cell model; the fourth panel must show both legs of the loop, which is the main thing the ice cube adds.

- Panels 1 to 3 show the difference in plume height between runs
- Panel 4 shows a rising leg and a sinking leg with arrows
- Warming and cooling locations labeled correctly

1. Group decision: what moved the water, the dye or the temperature difference? Give the single strongest piece of evidence from your runs.

Answer: The temperature difference. Strongest evidence: the control vial contained the same dye and the same amount of water but stayed near the bottom, while the hot vial's dye reached the surface in seconds.

Why: The control isolates the dye as a variable; only temperature changed between runs.

- Names the temperature difference, not the dye
- Cites the control run or the time difference between runs as evidence

2. In the ice-cube run, describe the path of the blue water in one or two sentences. Where did it meet the red water, and what happened there?

Answer: The blue water sank straight down from under the ice cube, spread along the bottom toward the hot vial, and was pulled in under the rising red plume, where it mixed and was carried up. Together the red and blue made a loop.

Why: Cold melt water is denser than the tank water (it is only slightly fresher), so it sinks; the rising plume draws in water along the bottom to replace what it lifts.

- Describes sinking and movement along the bottom
- Notes the meeting with the red plume or the loop

Analysis questions: answer key

3. Compare the control run to the hot run. What did the dye do in each, and why does the control run matter for your conclusion?

Answer: In the control the dye crept out of the vial and stayed within a centimeter or two of the bottom, spreading sideways. In the hot run the dye shot upward in a plume, reached the surface in seconds and spread across the top. The control matters because it shows that dye by itself, with no temperature difference, does not rise. So the rising in the hot run must be caused by the temperature difference, not by the dye.

Why: This is the fair-test logic of the lab: same dye, same water, same release, different temperature.

- Accurate description of both runs
- Explains the control as ruling out the dye as the cause

4. Use the class data. On average, how many times faster did the hot plume reach the surface than the warm plume? Show the calculation. What does a larger temperature difference do to the speed of convection?

Answer: Class-dependent. Example: if the warm plumes averaged 24 s and the hot plumes averaged 8 s, then $24 \div 8 = 3$, so the hot plume was about 3 times faster. A larger temperature difference makes a larger density difference, so gravity sorts the water faster and convection speeds up.

Why: Students divide the mean warm time by the mean hot time. Any ratio with the calculation shown and the correct direction (hotter is faster) earns credit.

Also acceptable: Accept a comparison of heights at 30 s if the warm plume never reached the surface in 3 minutes, as long as the ratio is computed from the data.

5. Explain why the warm red water went up and the cold blue water went down. Your answer must use the words density and gravity and must say what pushed the red water upward.

Answer: Heating the red water spread its particles apart, so the same mass took up more volume and its density dropped below that of the tank water. Gravity pulls harder on each cubic centimeter of the denser tank water, so that water sank under the red water and pushed it upward; the red water did not rise on its own. The blue water was cold and denser than the tank water, so gravity pulled it down faster than the water around it and it sank along the bottom.

Why: Full credit requires the push: convection is gravity sorting dense from less dense, not heat rising.

- Links heating to lower density and cooling to higher density
- Uses gravity as the force acting on the denser water
- States that the warm water was pushed up by sinking denser water

6. Suppose you had released the hot vial at the surface instead of the bottom. Predict what the dye would have done and explain using density.

Answer: The hot dyed water would spread out across the surface in a thin red layer and stay there; it would not sink and no loop would form. It is already the least dense water and it is already on top, so gravity has nothing to sort. It would slowly cool and mix downward over many minutes.

Why: Stable stratification: warm over cool is the resting state of a fluid under gravity.

- Predicts a surface layer with no plume or loop
- Explains with density and position

7. Match each part of the tank model to the real mantle: the hot vial, the room-temperature water, the water surface, the red plume and the blue sinking water. Then name two important ways the tank is not like the mantle.

Answer: Hot vial: the core-mantle boundary where heat enters the mantle. Room-temperature water: the bulk of the mantle. Water surface: the cool crust and Earth's surface. Red plume: hot, less dense mantle rock rising (for example under an ocean ridge). Blue sinking water: cooled, denser rock sinking back toward the core. Differences: the mantle is solid rock that creeps, not a liquid; the mantle takes a hundred million years or more for one loop while the tank takes seconds; the mantle is heated across its whole bottom and from radioactive decay inside it, not from one small vial; the mantle has no free surface like the water's top.

Why: Any two valid differences earn full credit; the solid-versus-liquid and time-scale differences are the most important.

- Maps all five parts sensibly
- Names at least two real differences, one of them solid versus liquid or time scale

8. Your hot plume crossed the 10 cm of water in the tank in seconds. Mantle rock rises at about 3 cm per year. How many years would mantle rock take to rise the same 10 cm? Then, using your hot-run time and 1 year $\approx$ 31,500,000 seconds, calculate about how many times slower the mantle is than your plume. Show both calculations.

Answer: 10 cm $\div$ 3 cm per year $\approx$ 3.3 years for mantle rock to rise 10 cm. In seconds: $3.3 \times 31,500,000 \approx 105,000,000$ s. If the hot plume took 8 s, then $105,000,000 \div 8 \approx 13,000,000$, so the mantle rises about ten million times more slowly than the plume (the exact figure depends on the group's time).

Why: Same distance, two speeds: the first step is a simple division, the second converts years to seconds and divides by the measured time. Any answer in the millions with the working shown earns credit; the point is the size of the gap, not the last digit.

Also acceptable: Accept 3.3 years and a ratio anywhere from about 5 million to 30 million depending on the measured plume time; accept 'about 10^7 times slower.'

Individual evidence of learning

Each student submits their own completed data table, the two sketch panels and written answers to q1 through q8. The group decision in q1 is copied by each student with their own evidence sentence; q5 and q7 are the primary evidence for the convection-cell target and for understanding the model's limits.

Assessment criteria

Criterion	Proficient looks like
Data and sketches	All three runs recorded with temperatures and heights; sketches show the plume at 60 seconds with direction arrows and, in the ice-cube panel, both the rising and the sinking leg.
Use of the control	States that the room-temperature dye barely rose, so the dye itself does not move the water, and uses that to argue that the temperature difference causes the motion.
Mechanism	Explains the rising and sinking legs with density changes and gravity, and says the warm water was pushed up by denser water sinking rather than rising on its own.
Model and its limits	Maps tank parts to the mantle (or ocean) correctly and names at least two real differences, including speed and liquid versus solid.

Accessibility adaptations

- Project one group's tank with a document camera so students with low vision can watch the plume enlarged; use extra dye drops in that tank only and note it as a changed variable.
- Allow the observer role to record a spoken description on a device instead of writing, and accept photographs of the sketch panels drawn large on a whiteboard.
- Provide a pre-labeled sketch template with the tank outline, the vial and the surface already drawn for students who need more support.
- Give multilingual learners a word strip with rise, sink, spread, plume, dense and gravity with a small arrow icon for each, and pair them with a partner who narrates the run aloud.

Low-cost alternative

Use one large clear tank at the front with a document camera as a class demonstration, with student groups timing and sketching from their seats; use a clear 2 liter soda bottle with the top cut off if no boxes are available; replace the dyed ice cube with a plain ice cube and a drop of blue dye placed beside it on the surface.

Model limitations

The tank is liquid water that turns over in seconds; the mantle is solid rock that creeps a few centimeters per year, so the model shows the mechanism but not the material or the time scale. The tank is heated at one small spot by a vial that cools quickly, while Earth's core and the sun-warmed tropics supply energy continuously over huge areas. The dye also spreads a little by diffusion and by the disturbance of releasing the vial, which is why the control run exists. The ice cube's melt water is fresh, like the tank water, so it sinks for temperature alone (fresh water is densest near 4 °C, well below the tank's 21 °C); the real polar ocean sinks for two reasons, cold and salt, which the tank cannot show. This activity has not been physically tested by the authors; the plume times given are estimates for a 10 cm deep tank and should be checked in a trial run.

Teacher notes

If your trial run shows the hot plume reaching the surface in under 10 seconds, shorten the checkpoints to 10, 20 and 60 seconds. Keep the control row visible on the board during the debrief; it is the argument that the dye is only a marker. If a group's control plume rose quickly, their refill water was warmer or cooler than the vial; ask them to compare the two temperature columns and let them discover it. The blue melt water is fresh, like the tank water, and at 0 to 4 °C it is denser than the 21 °C tank water, so it sinks on temperature alone; the polar ocean sinks for both reasons, cold and salty, which is a difference worth naming in the debrief.