

The Marble Tray: Shake In Energy, Watch the State Change

Investigation question: When a tray of marbles is shaken harder or more gently, how do the marbles' motion and arrangement change, and what happens to the number of hits on a wall when the same marbles are given less room or more energy?

Physical model

Groups of 4

1 session

Setup 5 · Activity 40 · Cleanup 5 min

MS-PS1-4 · assesses

Scientific purpose

A gently tilted tray of 36 marbles is a model of one pure substance. Shaking the tray adds energy, and three shake levels set by a metronome stand for three temperatures. At each level groups photograph or count how many marbles reach each zone of the tray, describe how the marbles move, and match the level to a state; then they ease off the shaking to model cooling and draw the three arrangements with marbles of one size. In Part B the tray is laid flat with 10 marbles as a gas, and groups count hits on one end wall at two shake levels and with a divider that halves the space, building a particle explanation of pressure.

Why this helps students with this chapter

Students can recite 'solid particles vibrate, gas particles fly' without ever seeing that one set of particles can do all three. Here the same 36 marbles become solid-like, liquid-like and gas-like only because of how much energy the shaking gives them, and they gather back together when the shaking eases. The tilt plays the part of the attraction that holds real particles together, which gives students a physical reason why a liquid stays low in its container and why a gas needs more energy. Counting wall hits turns pressure into something students can see and tally rather than a definition to memorize.

Standards connections

MS-PS1-4 (assesses, the motion-and-state part of the model: describing and predicting how particle motion and arrangement change as energy is added or removed): Students run a physical model in which adding energy (harder shaking) changes the particles' motion and arrangement from solid-like to liquid-like to gas-like and removing it reverses the change; the three-panel drawing and q4 to q7 produce qualitative evidence toward the PE. Part B adds the PS1.A idea that pressure comes from particle collisions. The model has no thermometer, so the temperature part of the PE is completed in Lab 3; no energy is calculated.

Roles (rotate each session)

- **Shaker:** Moves the tray side to side, across its width, in time with the metronome, keeping each stroke between the tape marks for the level being tested.
- **Timekeeper and metronome operator:** Sets the tempo, times each 10-second trial, and calls 'look' at 8 seconds and 'stop' at 10.
- **Photographer and counter:** Takes a photo from directly above at the 8-second call (or, without a camera, counts the marbles in Zones 2 and 3 at that moment), then counts the marbles in each zone.

- **Recorder and hit counter:** Fills the tables and, in Part B, watches only the pressure wall and makes a tally mark for every marble that hits it.

Materials

Item	Quantity	Per	Note
Rimmed baking tray or plastic cafeteria tray, inner floor about 30 cm by 20 cm, rim at least 2 cm high	1	group	
Glass marbles, all the same size (about 16 mm)	36	group	See the low-cost alternative for beans or beads.
Closed paperback book or wooden block about 2 cm thick, to tilt the tray	1	group	
Masking tape and a marker	about 1 m of tape	group	
Ruler, 30 cm	1	group	
Corrugated cardboard divider cut to the tray's inner width, about 4 cm tall	1	group	
Metronome: a free metronome app or website on one device per group, or one the teacher runs for the class	1	group	
Phone or tablet camera (optional)	1	group	Without one, the counter counts by eye at the 8-second call.
Recording sheet and pencil	1 each	student	

Estimated cost: 15 to 30 per class (marbles and trays last for years) (an estimate; About 300 matching glass marbles in bulk cost about \$15 to \$20; dollar-store baking trays are about \$1.25 each if the classroom has none; a roll of masking tape is about \$3; cardboard, books and rulers are free or classroom stock. Estimated retail prices, not quotes.)

Safety

- Marbles on the floor are a serious slip hazard. Keep the tray over the table, count the marbles out and back in, and pick up any dropped marble at once.
- Shake the tray, not the table, and keep the strokes within the tape marks. If marbles jump the rim, slow down; keep faces above and back from the tray.
- Marbles are a choking hazard for young children. Never put them in your mouth, and store them out of reach of younger visitors.
- Arms tire at level 3; switch shakers between levels rather than pushing on.

Teacher preparation and setup

1. Test the tilt before class. With the high end of the tray on a 2 cm book, the 36 marbles should stay packed at the low end at level 1 and reach the top zone at level 3. Use a thinner or thicker book until they do, and note the thickness for every group.

2. Mark each tray: stick two strips of tape across the tray floor to divide it into three equal zones from the low end, and label them Zone 1 (bottom), Zone 2 (middle) and Zone 3 (top).
3. On the table beside each tray, stick pairs of tape marks 1 cm, 3 cm and 5 cm apart so the shaker can see how far to move the tray at each level.
4. Cut one cardboard divider per group to fit snugly across the tray, and have tape ready to hold it upright at the halfway point for Part B.
5. Set the metronome tempos and test them: level 1 at 60 beats per minute with 1 cm strokes, level 2 at 120 with 3 cm strokes, level 3 at 180 with 5 cm strokes (one stroke per beat).
6. Count the marbles into each group's tray (36) and plan to count them back in at the end.

Investigation design

Independent variable	Part A: the shake level, which stands for the energy added and so the temperature (set by metronome tempo and stroke length). Part B: the shake level and the space available to the marbles (full tray or half tray).
Dependent variable	Part A: the number of marbles in each zone during shaking, and the type of motion. Part B: the number of hits on the pressure wall in 10 seconds.
Controlled	The same marbles, all one size (36 in Part A, 10 in Part B); The same tilt in Part A and a flat tray in Part B; 10-second trials, with the Part A count taken at 8 seconds; The same pressure wall and the same hit counter throughout Part B
Trials	Two trials at every condition; record both and use the average.
Comparison	Zone counts across the three shake levels; wall hits at level 2 versus level 3 in the full tray, and in the full versus the half tray at level 3.

Student procedure

1. Part A. Count 36 marbles into the tray, rest the high end of the tray on the book so the marbles roll to the low end, and place the tray between the tape marks.
2. Before shaking, write your prediction in q1: at each level, which zones will the marbles reach, and how will they move?
3. Level 1 (cold): set the metronome to 60 beats per minute. On each beat the shaker moves the tray 1 cm side to side, across its width, keeping the low end low. Shake for 10 seconds. At the 8-second 'look' call the photographer takes a photo from directly above, or counts the marbles in Zones 2 and 3 by eye. Watch how the marbles move.
4. Count the marbles in each zone from the photo, record the counts, and write a few words about the motion (for example: jiggling in place, sliding past one another, flying and bouncing). Run a second trial.
5. Level 2 (warm): 120 beats per minute, 3 cm strokes. Run two trials with the same measurements.
6. Level 3 (hot): 180 beats per minute, 5 cm strokes. Run two trials, switching shakers if arms are tired.
7. Cooling: shake at level 3 for 5 seconds, then switch straight to level 1 for 5 seconds without stopping. Watch what the marbles do as the energy drops and answer q2.
8. Make the three-panel drawing of levels 1, 2 and 3, with every marble the same size and arrows showing how the marbles move.

9. Part B. Remove the book so the tray lies flat, and take out all but 10 marbles. These 10 are a gas. Choose one short end wall as the 'pressure wall'.
10. Full tray, level 2: shake for 10 seconds while the hit counter watches only the pressure wall and makes one tally mark for every marble that hits it. Run two trials, then repeat at level 3.
11. Half tray: tape the divider upright across the halfway line so the 10 marbles have only the half that includes the pressure wall. Run two trials at level 3, then average every pair of trials and answer q3.
12. Count the 36 marbles back into their container, then answer the analysis questions individually.

Expected observations

- Level 1: nearly all 36 marbles stay packed in Zone 1, jiggling against their neighbors without trading places (solid-like). Typical counts: 36, 0, 0.
- Level 2: the pack loosens; marbles slide and roll past one another and the surface sloshes, but most stay low (liquid-like). Typical counts: 25 to 32 in Zone 1, 4 to 10 in Zone 2, 0 to 2 in Zone 3.
- Level 3: marbles fly apart, bounce off the walls and one another, and reach all three zones (gas-like). Typical counts: 10 to 18 in Zone 1, 8 to 14 in Zone 2, 6 to 12 in Zone 3.
- Cooling: when the shaking drops to level 1, the marbles roll back to the low end within a second or two and pack together again.
- Part B (typical tallies, estimated): full tray at level 2 about 3 to 8 hits; full tray at level 3 about 8 to 15; half tray at level 3 about 15 to 30. Counts are estimates for an untested setup; the order matters more than the numbers.

Likely difficulties

- The tilt is wrong: too steep and the marbles never leave Zone 1, too shallow and they spread even at level 1. Test it in prep and adjust the book.
- Shakers speed up or lengthen their strokes as they get excited. The timekeeper watches the tape marks and calls 'steady'; switch shakers between levels.
- Photos blur at level 3. Count the clearly visible marbles and estimate the blurred ones; the pattern across levels matters more than exact counts.
- Hit counters lose count in the half tray at level 3. Let two students tally the same wall and average, or film the trial and count in slow motion.
- Students say the marbles 'got hot'. In the model, the marbles' speed stands for temperature; the marbles themselves barely warm up.

Structured debrief

1. Collect each group's level 3 zone counts on the board. Ask what the three levels have in common (the same 36 marbles) and what changed (only their motion and spacing). That is the whole idea of a state of matter.
2. Ask what the tilt stood for, and what happened when the shaking eased: the marbles rolled back and packed together. Real particles attract one another, so when they slow down the attraction pulls them back into a liquid and then a solid. Ask what a flat tray would have shown (q7).

3. Post the Part B averages from every group. Look for the pattern rather than the numbers: half tray at level 3 above full tray at level 3, which is above full tray at level 2. Connect to the syringe check and the mountain bottle: crowding particles or speeding them up raises pressure.
4. Name the model's limits together: the marbles stop when the shaking stops, but real particles never stop; marbles lose energy at every bounce, but particles in a sealed gas at a steady temperature keep their average speed. Preview Lab 3, which adds a thermometer to the model.

Recording sheet: what students fill in

Lab 2 recording sheet: The marble tray

In this model each marble stands for one particle of a pure substance, **shaking the tray adds energy**, and **the tilt plays the part of the attraction** that pulls real particles together. Level 1 = cold (60 beats per minute, 1 cm strokes). Level 2 = warm (120, 3 cm). Level 3 = hot (180, 5 cm).

1. Prediction: at levels 1, 2 and 3, which zones will the marbles reach, and how will they move?

Answer: Accept any reasoned prediction. The expected pattern: at level 1 the marbles stay packed at the bottom and jiggle; at level 2 they loosen and slide but mostly stay low; at level 3 they spread into every zone and bounce around.

Why: Predictions are not graded for correctness; they should name where the marbles will be and how they will move at each level.

- A prediction for each level
- Mentions both position and motion

Part A: where the 36 marbles are at the 8-second look

Shake level	Trial	Zone 1 (bottom)	Zone 2 (middle)	Zone 3 (top)	How the marbles moved	Which state does this look like?
1 (cold)	1					
1 (cold)	2					
2 (warm)	1					
2 (warm)	2					
3 (hot)	1					
3 (hot)	2					

2. Cooling: what did the marbles do when the shaking switched from level 3 straight to level 1? Which real change or changes of state does this model?

Answer: When the shaking dropped from level 3 to level 1, the marbles rolled back to the low end and packed together again, first sliding as a crowd and then only jiggling in place. This models a gas condensing into a liquid and the liquid freezing into a solid as energy is removed.

Why: Removing energy reverses the sequence; the tilt, standing for attraction, pulls the slowed particles back together.

- Describes the marbles returning to the bottom and packing together
- Names condensing and freezing (gas to liquid to solid)

-  Draw the tray at level 1, level 2 and level 3 in three side-by-side boxes. Make every marble the same size, show which end is low, and add arrows for how the marbles move. Label each box with a state.

Answer: Three boxes. Level 1: all the marbles packed in rows at the low end, touching, with tiny back-and-forth arrows. Level 2: marbles still close together and mostly at the low end, but out of rows, with short curved arrows showing them sliding past one another. Level 3: marbles scattered through the whole tray with long straight arrows, some bouncing off walls. Every marble the same size; boxes labeled solid, liquid and gas.

Why: This is the chapter's three-panel evidence of learning; the key checks are equal marble size and correct motion arrows.

- The same marble size in all three boxes
- Packed and vibrating, close and sliding, spread out with straight-line motion
- Each box labeled with a state

Part B: hits on the pressure wall in 10 seconds (10 marbles, flat tray)

Condition	Trial 1	Trial 2	Average
Full tray, level 2			
Full tray, level 3			
Half tray, level 3			

3. Which condition gave the most hits on the pressure wall? What does that tell you about pressure?

Answer: Usually the half tray at level 3. More hits on the wall in the same time means more pressure: the same number of particles in less space, or particles moving faster, hit the wall more often.

Why: Numbers are group-specific; the expected order is half tray at level 3, then full tray at level 3, then full tray at level 2.

- Names the condition with the most hits
- Links more hits to more pressure

Analysis questions: answer key

4. Use your zone counts to describe how the marbles' arrangement and motion changed from level 1 to level 3. Match each level to solid, liquid or gas, and give the evidence for each match.

Answer: Group-specific counts. Expected: at level 1 nearly all the marbles stayed in Zone 1, packed together and jiggling in place, which matches a solid. At level 2 most stayed in Zones 1 and 2 but slid and rolled past one another and the surface sloshed, which matches a liquid: close together but not fixed in place. At level 3 the marbles were spread through all three zones, moving in straight lines and bouncing off the walls and one another, which matches a gas.

Why: Students must use the counts as evidence and connect each level to both arrangement and motion.

- Uses zone counts from the table
- Describes arrangement and motion at each level
- Matches levels 1, 2 and 3 to solid, liquid and gas

5. In this model, what does shaking harder stand for? Use your answer to explain why heating a real solid can turn it into a liquid and then a gas.

Answer: Shaking harder stands for adding thermal energy, which makes the particles move faster, that is, a higher temperature. When a real solid is heated, its particles vibrate harder until they have enough energy to break out of their fixed spots and slide past one another (melting). With still more energy they move fast enough to escape their neighbors completely and fly apart (boiling).

Why: This is the PE's causal chain: energy in, faster particles, change of state.

- Shaking harder = adding energy or raising temperature
- Describes melting as particles breaking out of fixed positions
- Describes boiling as particles separating completely

6. Did any marble change size, shape or mass between level 1 and level 3? What does that tell you about real particles when a substance melts or boils?

Answer: No. The same 36 marbles, each with the same size, shape and mass, were used at every level; only their spacing and motion changed. In the same way, when a real substance melts or boils its particles stay exactly the same, and only how far apart they are and how they move changes.

Why: This targets the misconception that particles grow, soften or melt during a change of state.

- States that no marble changed
- Applies the idea to real particles during melting or boiling

7. The tilt pulled the slowed marbles back together. Predict what would happen in the cooling step if the tray were flat, and explain what this shows about why real gases condense and real liquids freeze when energy is removed.

Answer: On a flat tray the slowed marbles would stop wherever they happened to be, scattered across the tray; they would not gather back together, so the model would not 'condense'. Real gases condense and real liquids freeze when energy is removed because their particles attract one another: once the particles are slow enough, the attraction holds them together. In the model, the tilt plays the part of that attraction.

Why: Students identify what the tilt represents and why attraction matters for condensing and freezing.

- Predicts that marbles on a flat tray would stay scattered
- Explains that real particles attract one another
- Identifies the tilt as the model's stand-in for attraction

8. Use Part B to explain gas pressure in particle terms. Why did the half tray give more hits than the full tray at the same level, and why did level 3 give more hits than level 2?

Answer: Pressure comes from particles hitting the walls. In the half tray the same 10 marbles had half the space, so they were more crowded and reached the pressure wall more often, giving more hits in 10 seconds: more pressure. At level 3 the marbles moved faster than at level 2, so they reached the wall more often (and hit it harder): also more pressure. So the pressure of a gas rises when it is squeezed into less space or when its particles move faster at a higher temperature.

Why: Both comparisons connect the count of collisions per wall to pressure without any gas-law formula.

- Pressure = particles hitting the walls
- Explains the half-tray result by crowding
- Explains the level 3 result by faster motion

9. A sealed, empty plastic bottle crumples as a car drives down from a mountain to the coast. Use your Part B results to explain why.

Answer: The bottle was sealed high on the mountain, where the air is less crowded, so the air inside hits the bottle's walls less often than the more crowded air outside does near the coast. Like the half tray compared with the full tray, the more crowded outside air makes more hits on each bit of the wall, so the outside pressure is greater and pushes the walls in until the air inside is crowded enough to match.

Why: Students transfer the crowding-and-hits idea from the tray to the textbook's bottle example.

- Compares how crowded the air is inside and outside
- Links more hits to more pressure
- Explains why the bottle crumples inward

10. Name two ways the marble model is not like real particles. For each, say whether it makes the model's predictions wrong or only less detailed.

Answer: Any two, each with a judgment. (1) Marbles stop and roll downhill when the shaking stops, but real particles never stop moving: this makes the model wrong about a solid at rest. (2) Attraction is shown by a one-directional tilt, so the 'liquid' always sits at one end: less detailed, but the basic idea is right. (3) A gas in the tray is not nearly as spread out as a real gas: less detailed. (4) Marbles lose energy at every bounce, while real gas particles at a steady temperature keep their average speed: this makes the model wrong about a gas left alone, whose pressure would not fade. (5) Marbles are large enough to see and handle, while real particles are far too small to see: a scale difference that makes the model less detailed.

Why: Credit any two genuine differences with a sensible judgment of their effect.

- Names two specific differences
- Judges the effect of each on the model's predictions

Individual evidence of learning

Each student submits their own zone table, three-panel drawing, Part B table and answers to q1 through q10. The drawing and q4 to q7 are the evidence for modeling how adding or removing energy changes particle motion and state; q8 and q9 are the evidence for the particle explanation of pressure; q10 shows that the student can evaluate the model.

Assessment criteria

Criterion	Proficient looks like
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Three-panel model	Marbles the same size in every panel; packed and jiggling at level 1, close but sliding at level 2, spread out with straight-line arrows at level 3; each panel labeled with a state.
Energy and state	Explains that shaking harder adds energy, which speeds the particles up until they break out of their arrangement, and that removing energy lets attraction pull them back together (q5, q7).
Particles are unchanged	States that no marble changed size or mass, so a change of state rearranges particles rather than changing them (q6).
Pressure reasoning	Uses averaged hit counts to explain that more crowded or faster particles hit a wall more often, so the pressure rises (q8, q9).
Model evaluation	Names two specific differences from real particles and judges the effect of each (q10).

Accessibility adaptations

- Accept a labeled photo of the tray at each level in place of the three-panel drawing for students who need an alternative to drawing.
- Use large marbles or wooden beads and a tray with a high rim for students with low vision or limited fine-motor control; a student who cannot shake can run the metronome and count from the photos.
- Give the 'which state' column a word bank (solid, liquid, gas) for students who need support.
- In Part B, a student who finds tallying hard can use a click counter or count from a slow-motion recording.
- Offer a sentence frame for q5: 'Shaking harder stands for _____. When a real solid is heated, its particles _____ until _____.'

Low-cost alternative

Use 36 dried lima beans or large flat buttons in a shoebox lid tilted on a book, and swirl the lid rather than shaking it. Beans slide instead of rolling, so the levels need bigger strokes, but the solid, liquid and gas patterns still appear. For Part B, count hits by ear against the cardboard end of the lid, or skip the half-tray test and compare the two levels only.

Model limitations

The model gets the big pattern right but differs from real particles in several ways. Real particles never stop moving, while the marbles stop and roll downhill the moment the shaking stops. Real particles attract one another in every direction, while the marbles are pulled together only by the one-directional tilt (gravity). Real gas particles are far more spread out than marbles in a 30 cm tray can show, and they do not lose energy when they bounce, while marbles slow down at every collision. Wall hits are only a stand-in for pressure, which also depends on how hard each particle hits. This lab has not been physically tested by the authors; the tilt, stroke lengths and typical counts are estimates to check during prep.

Teacher notes

Check the drawings for the most important feature: equal marble size in all three panels. In Part B the order of the three averages matters more than the numbers; if a group's level 2 count beats its level 3 count, ask

whether the strokes stayed steady. Collect the class's Part B averages on the board to show the pattern across groups. A photo of a tray at each level makes a good figure for the W4 diagram worksheet or a class display.