

# The Jiggle That Would Not Stop: Reading the Evidence for Moving Particles

**Learning target:** I can use evidence from a reading to explain how scientists learned that particles are always moving, and how temperature is linked to their average motion.

Reading with evidence

About 40 min

Individual

MS-PS1-4 · practice

MS-PS3-4 · supports

reading

writing

## Standards connections

**MS-PS1-4 (practice):** The passage builds the motion half of the particle model: particles in every state are always moving, and a higher temperature means faster average motion. Students cite evidence and use it to predict what cooling or warming does to particle motion, but they do not yet build the full heating-and-cooling model the PE asks for.

**MS-PS3-4 (supports):** This is a Grade 6 PE in the California integrated sequence. The reading relies on its core idea, that temperature reports the average kinetic energy of a sample's particles, without asking students to plan the energy investigation the PE describes.

**Purpose:** build · **Time:** about 40 minutes · **Format:** individual

## Answers with reasoning

### The Jiggle That Would Not Stop

[1] In the summer of 1827, the Scottish botanist Robert Brown was studying pollen from a wildflower under his microscope. He had placed the pollen grains in a drop of water, and he noticed something strange. Tiny specks that had come out of the grains were trembling and darting about. They never settled down. Each speck zigzagged a little one way, then a little another way, and it kept going for as long as Brown watched.

[2] Brown's first thought was that the specks might be alive. Pollen comes from living plants, and living things move. So he tested the idea. He ground up bits of glass and rock, materials that had never been alive, and put those specks in water too. They jiggled in exactly the same restless way. Whatever was causing the motion, it was not life. Brown described what he saw with great care, but he could not explain it. For almost eighty years the jiggling, now called **Brownian motion**, stayed a puzzle.

[3] In 1905 a young physicist named Albert Einstein proposed an explanation. Suppose, he reasoned, that water is made of particles far too small to see, and that those particles are always moving in every direction. A speck like the ones Brown saw is enormous compared with a water molecule, thousands of times wider, but it is still small enough to feel the hits. Every instant, a huge number of water molecules crash into it from all sides. At any moment, slightly more of them happen to strike one side than the other, so the speck gets nudged. A moment later the uneven push comes from a different side, and the speck lurches a new way. The speck is not moving by itself. It is being bumped by the invisible particles around it.

[4] Einstein's idea did more than explain. It made predictions that could be checked, including how far a speck should wander in a given time. Around 1908 the French physicist Jean Perrin tracked tiny particles under a microscope, recorded their paths and measured how far they drifted. His results matched Einstein's predictions. Perrin's measurements persuaded most of the remaining doubters that atoms and molecules are real, and in 1926 he received the Nobel Prize in Physics.

[5] Brownian motion also shows how temperature and particle motion are linked. When the same kind of specks are watched in warm water, they jiggle more vigorously than in cold water. A thermometer cannot see molecules, but what it reports depends on them: the higher the temperature of a sample, the faster its particles are moving **on average**. Those two words matter. In any glass of water, some molecules are moving quickly and others slowly at each moment, and they keep trading speed as they collide. Warming the water raises the average speed; cooling it lowers the average.

[6] The same restless motion explains how a drop of food coloring can spread through water that no one stirs. Moving water molecules keep knocking the dye particles about, and the dye particles are moving too, so over time they wander away from the crowded spot where the drop landed and toward places where there are fewer of them. Spreading caused only by this random motion is called **diffusion**. In warmer water the particles move faster on average, so diffusion is faster. In a real cup, gentle currents in the water also help carry the color, but the random motion of the particles never stops.

[7] Every state of matter has this motion, although it looks different in each one. In a gas such as air, the particles are far apart and fly freely; specks of smoke drifting in still air jiggle just as Brown's specks do in water. In a liquid, the particles stay close together but slide past one another. In a solid, particles are held in place, yet they still vibrate back and forth around their positions. Cooling a sample slows its particles, and warming it speeds them up. Not one particle changes its size along the way. What changes is how fast the particles move and how freely they can move past one another.

An original passage written for this worksheet. The dates and names are historical; Brown, Einstein and Perrin are real scientists.

## Part A: Find the evidence

1. According to paragraph 2, what was Brown's first explanation for the jiggling? Describe the test he ran and explain why its result ruled that explanation out.

**Answer:** Brown first thought the specks might be alive, because pollen comes from living plants [2]. He tested this by grinding up glass and rock, which had never been alive, and putting those specks in water. They jiggled in the same way, so life could not be the cause [2].

**Why:** The test kept everything the same (tiny specks in water) except whether the specks came from a living thing. Identical motion from non-living specks rules out life as the cause.

*Also acceptable: Accept 'he used things that were never alive' with the conclusion.*

- Names the 'alive' explanation
- Describes the glass and rock test
- Explains that the same motion from non-living specks rules out life
- Cites paragraph 2

2. Paragraph 3 says the speck 'is not moving by itself.' What is actually making it move, and why does the speck change direction again and again? Cite the paragraph.

**Answer:** Invisible water molecules moving in every direction crash into the speck from all sides. At any moment slightly more molecules hit one side than the other, so the speck is nudged that way; a moment later the uneven push comes from another side, so it changes direction [3].

**Why:** The direction keeps changing because the imbalance in hits is random from moment to moment.

*Also acceptable: Accept 'it gets pushed around by the water particles unevenly'.*

- Says water molecules hit the speck
- Explains the uneven number of hits on different sides
- Explains why the direction changes
- Cites paragraph 3

3. Paragraph 3 says the speck is thousands of times wider than a water molecule but 'still small enough to feel the hits.' Why would a much larger object, such as a grain of sand, sit still in the same water even though it is being hit too?

**Answer:** A sand grain is hit by vastly more molecules at once, from every side, so the pushes on opposite sides almost exactly cancel, and it is far heavier, so a tiny leftover push barely moves it. Only a very small speck is light enough, and hit by few enough molecules at a time, for the uneven pushes to show.

**Why:** This is a scale question: the same molecular hits that move a micrometer-sized speck have no visible effect on an object thousands of times larger. Students only need the idea that the hits balance out or are too small for a big object.

*Also acceptable: Accept 'it is too heavy for the little hits to move it' as a partial answer; full credit needs the cancelling idea or a clear comparison of size.*

- Says the large object is still hit by molecules
- Explains that the hits balance out or are too small to move a heavy object

4. Brown described the motion very carefully, yet the passage says Perrin's work is what persuaded most doubters. Using paragraph 4, explain what Perrin did that Brown did not do.

**Answer:** Perrin made measurements: he tracked particles, recorded their paths and measured how far they drifted, then compared the results with Einstein's predictions and found that they matched [4]. Brown only described the motion.

**Why:** A testable prediction that matches careful measurements is stronger evidence than a description, because the prediction could have failed.

*Also acceptable: Accept 'Perrin tested Einstein's idea with numbers'.*

- Says Perrin measured how far particles moved
- Says he compared the measurements with Einstein's predictions
- Contrasts measuring with describing

5. Which statement about a glass of water at 20 °C is best supported by paragraph 5?

**Answer:** B. The molecules are moving at many different speeds, and 20 °C reflects their average.

**Why:** Paragraph 5 says some molecules move quickly and others slowly at each moment and that temperature reflects the average. A contradicts this, C contradicts the never-ending motion, and D confuses an average with a maximum.

*Also acceptable: None.*

6. True or false: according to the passage, the particles of a solid do not move at all. Give the paragraph number that supports your answer.

**Answer:** False. Paragraph 7 says the particles of a solid are held in place 'yet they still vibrate back and forth around their positions' [7].

**Why:** This is the chapter's first misconception. Solid particles cannot trade places, but they are never still.

*Also acceptable: None.*

## Part B: Use the evidence

7. Predict what you would see if you watched Brown's specks in a drop of water that is slowly cooled from 30 °C to 5 °C (still a liquid). Explain your prediction using paragraph 5.

**Answer:** The specks would keep jiggling the whole time but less and less vigorously as the water cools, because a lower temperature means the water molecules are moving more slowly on average, so their hits are gentler [5].

**Why:** Paragraph 5 links warm water to more vigorous jiggling and says cooling lowers the average speed. The specks do not stop, because the water is still a liquid with moving particles.

*Also acceptable: Accept 'they would jiggle less' with the temperature-motion link.*

- Predicts slower or gentler jiggling
- Says the jiggling does not stop
- Connects lower temperature to slower average motion of the water molecules

8. Paragraph 6 says that in a real cup, 'gentle currents in the water also help carry the color.' Why is it still fair to say that diffusion happens faster in warmer water? Describe a way to spread dye in water where currents could not help.

**Answer:** Currents can add to the spreading, but the random motion of particles is always there and is faster when the water is warmer, so diffusion itself is faster in warm water [5, 6]. To remove currents, put the dye in a gel such as gelatin or agar, which is mostly water but cannot flow, and compare how far the color spreads at two temperatures.

**Why:** This separates diffusion (random particle motion) from bulk flow. In a gel the water cannot flow, so any spreading is diffusion; W5 uses exactly this kind of data.

*Also acceptable: Accept 'use a very narrow tube' or 'keep the cup perfectly still at one temperature' if the student explains it reduces currents; the gel answer is the strongest.*

- Says random particle motion is faster in warm water whether or not currents help
- Proposes a setup that prevents flow (gel, very thin layer, or similar)

9. Paragraph 7 says that as a sample is cooled or warmed, 'not one particle changes its size.' Then what does change when ice melts into liquid water? Use two ideas from paragraph 7.

**Answer:** How the particles move and how freely they can move past one another change [7]. In ice they are held in place and only vibrate; in liquid water they stay close together but slide past one another [7].

**Why:** Melting changes the arrangement and freedom of motion, not the particles themselves.

*Also acceptable: Accept 'the particles can trade places once it melts'.*

- Says particle size does not change
- Describes vibrating in place in the solid
- Describes sliding past one another in the liquid

10. Does the passage give evidence that particles move in **every** state of matter? Write a short argument. Use evidence from at least two different paragraphs, and point out one part of the claim that the passage states without showing any evidence for it.

**Answer:** Partly. The passage gives direct evidence for liquids: Brown's specks jiggled in water [1, 2], and the jiggling was explained by moving water molecules [3] and confirmed by Perrin's measurements [4]. It also gives evidence for gases: smoke specks in still air jiggle the same way [7]. For solids, paragraph 7 only states that the particles vibrate around their positions; it gives no observation or measurement showing this, because specks stuck inside a solid cannot be seen jiggling.

**Why:** A strong answer separates claims backed by evidence from claims that are only stated. Students do not need to supply outside evidence for solids, but a student who mentions that solids expand slightly when warmed, or that a tight metal lid loosens in hot water, is reaching for real evidence.

*Also acceptable: Accept 'yes' if the student still identifies the solid claim as resting only on a statement.*

- Takes a position (yes, no or partly)
- Uses evidence from at least two different paragraphs with numbers
- Identifies the solid state (or another part) as stated without evidence
- Explains why the evidence shown does or does not cover that part

## Teacher notes

The history is accurate: Robert Brown reported the motion in 1827 after watching tiny particles released from pollen grains (often wrongly retold as the pollen grains themselves) and found the same motion in powdered glass and rock; Einstein's explanation appeared in 1905; Jean Perrin's measurements around 1908-1909 confirmed it, and he received the 1926 Nobel Prize in Physics for work on the discontinuous structure of matter. Specks jiggle harder in warm water for two reasons, faster molecules and water that flows more easily when warm; the passage keeps the first, which is the chapter's focus. Keep the discussion qualitative; no energy calculations belong here. Pair this sheet with a short video of Brownian motion or a smoke-cell demonstration if one is available, and use q10 as a quick discussion of the difference between a stated claim and evidence.

### Scaffold offered to students: A map of the passage

Before answering, fill in this map in the margin. Paragraphs 1-2: what Brown saw and how he tested it. Paragraphs 3-4: who explained it and who checked the explanation. Paragraph 5: the link to temperature. Paragraph 6: the link to dye spreading. Paragraph 7: the three states. When a question names a paragraph, start your answer by rereading only that paragraph.

### Extension: Why Perrin's measurements counted

Einstein predicted that a speck's typical distance from where it started does not grow in step with time: if you watch four times as long, the speck has typically wandered only about twice as far. Explain why a zigzag path made of random steps would wander away from its start more slowly than a speck moving in a straight line. Then describe how Perrin could have used a microscope, a grid and a clock to check this prediction, and say what result would have shown Einstein was wrong.