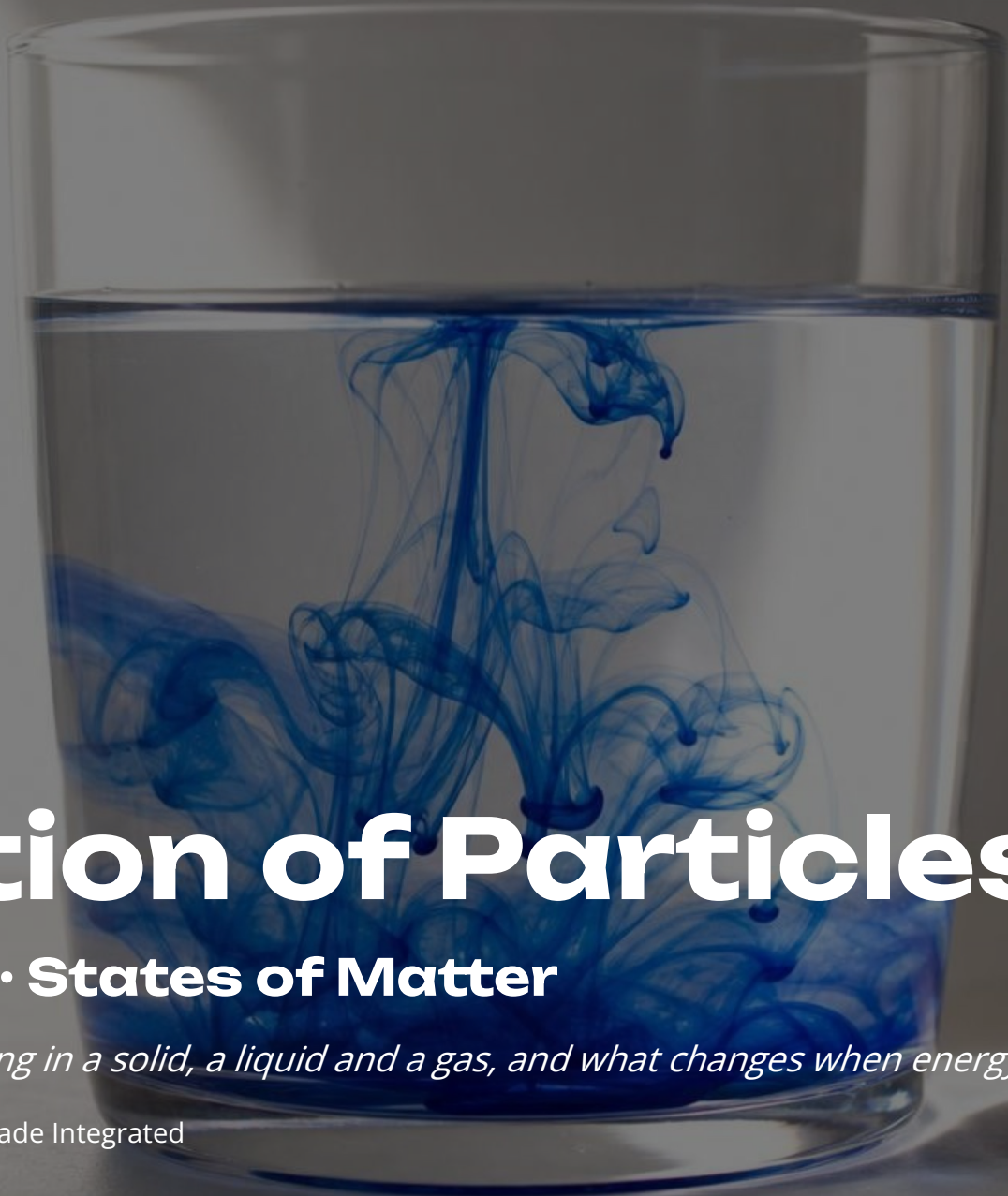




The Motion of Particles

Chapter 23 of 29 • States of Matter

Lesson 23: What are particles doing in a solid, a liquid and a gas, and what changes when energy goes in or out?

Angela's Wand • Bring Science Alive! 7th Grade Integrated

PHENOMENON

Two drops, two speeds, and nobody stirred

Two clear cups of still water sit side by side. One came from the refrigerator; the other is about as warm as a hot bath. One drop of blue food coloring falls into each cup at the same moment, and nobody stirs or bumps either one. In two minutes the warm cup is evenly blue. Ten minutes later the cold cup is still streaky, with a dark patch near the bottom.

- Notice: what is the same about the two cups, and what is different?
- Wonder: if nobody stirred, what moved the color through the water?
- Predict: would the cold cup ever turn evenly blue? What would a drop do in ice?





LEARNING TARGETS

What you will be able to do

- 1 I can describe how particles are arranged and how they move in a solid, a liquid and a gas.
- 2 I can explain that temperature measures the average motion of a sample's particles.
- 3 I can model how particle motion, temperature and state change as energy is added or removed.
- 4 I can explain how colliding gas particles make pressure, and how pressure helps set the state.
- 5 I can use melting points, boiling points and a state diagram to predict a substance's state.

One substance, three states

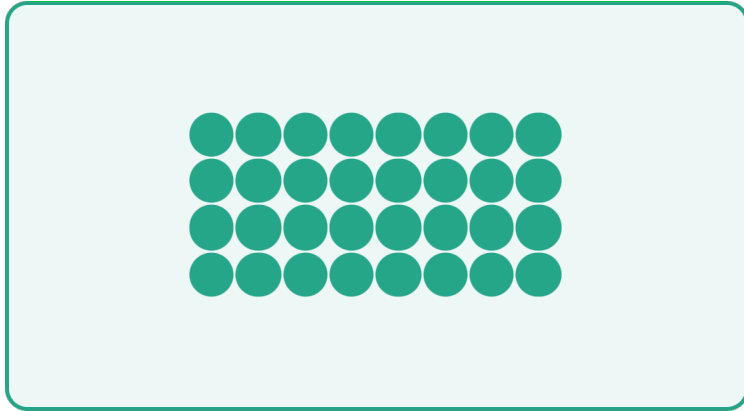
- Ice, liquid water and water vapor are all made of the same water molecules.
- A state of matter is set by how close the particles are and how freely they move.
- The particles never change size, shape or mass when the state changes.
- In every state, the particles are always moving.
- Scientists say 'particles' for the atoms or molecules a substance is made of.



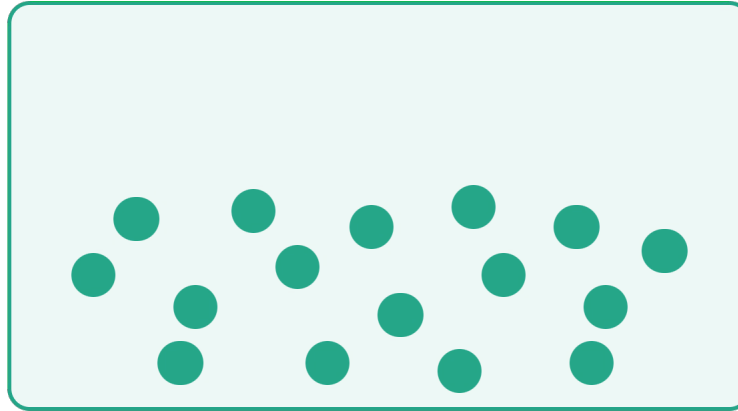
MODEL

Water's particles in three states

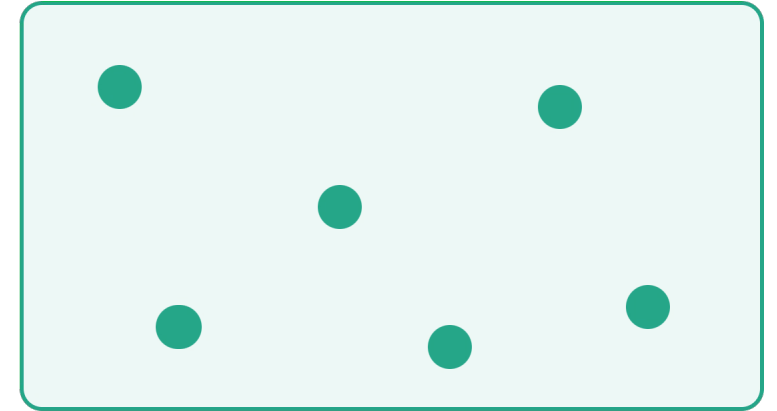
Model: The same water molecules as ice, liquid and vapor



Ice (solid): particles tightly spaced; Packed;



Liquid water: particles mediumly spaced;



Water vapor (gas): particles loosely spaced;

Every particle is the same size in all three panels. Real gas particles are far more spread out than any drawing can show.





Solids: packed in place, but never still

- Particles are packed tightly and touch their neighbors, often in a repeating pattern.
- Each particle vibrates around one spot. It cannot trade places with its neighbors.
- So a solid keeps its own shape and nearly its own volume, whatever container it is in.
- Warm a solid and the vibrations grow, so it expands very slightly. The particles do not grow.
- Gesture: fists pressed together, trembling.

Liquids: close together, sliding past each other

- Particles stay close together and touching, but they are not locked in place.
- They slide and tumble past one another, so a liquid can flow and be poured.
- Gravity pulls the particles down until they fill the bottom of the container.
- A liquid's shape changes with its container; its volume stays nearly the same.
- Gesture: palms sliding over each other.





Gases: far apart, flying free

- Particles are far apart, with empty space between them.
- Each moves in a straight line until it hits another particle or a wall, then changes direction.
- So a gas spreads out to fill its container, taking its shape and its whole volume.
- Squeeze a gas and the same particles simply move closer together.
- Water vapor and carbon dioxide gas are invisible. A white cloud is tiny droplets of liquid water.
- Gesture: hands flying apart.

CHECK FOR UNDERSTANDING

Quick check: which state is it?

A sample keeps the same volume when it is poured into a new container, but its shape changes. What state is it in, and what are its particles doing?



A. Solid: its particles vibrate in fixed spots

B. Liquid: its particles stay close but slide past each other

C. Gas: its particles are far apart and fly freely

D. You cannot tell without knowing its temperature

Vocabulary in context

Words for the three states



solid

A state in which particles are packed close in fixed spots and can only vibrate, so the sample keeps its own shape and nearly its own volume. *An ice cube, a coin and a block of dry ice are all solids.*

liquid

A state in which particles stay close but slide past one another, so the sample flows and takes its container's shape while keeping its volume. *Juice poured from a carton into a glass changes shape but not volume.*

gas

A state in which particles are far apart and move freely until they collide, so the sample fills any container it is in. *The helium in a balloon presses on every part of the inside of the rubber.*

Temperature measures average particle motion

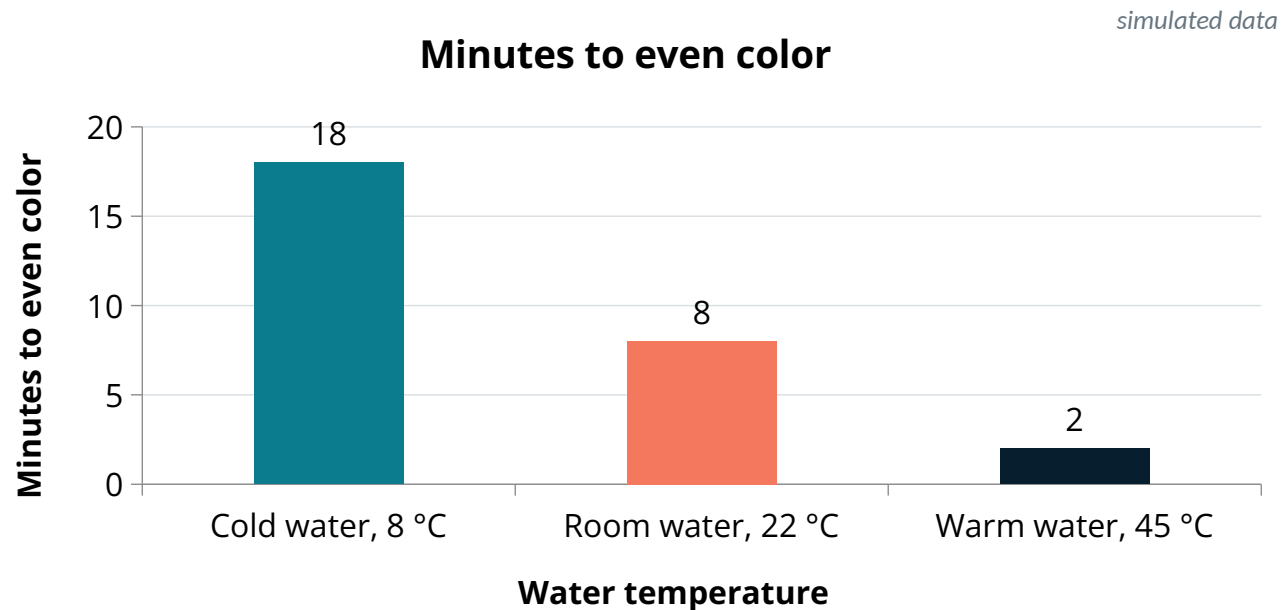
- The particles in any sample move at many different speeds, changing every time they collide.
- Temperature is a measure of their average motion energy, which scientists call kinetic energy.
- Higher temperature means faster particles on average; lower temperature means slower on average.
- Thermal energy is the total motion energy of all the particles in the sample.
- A bathtub of warm water has a lower temperature than a cup of hot tea, but far more thermal energy.



MODEL

Warmer water, faster spreading

Model: Minutes until one dye drop looked evenly mixed



Teaching dataset (simulated): class averages for 200 mL of still water and one drop of food coloring. Your own times will differ.





Think, pair, share

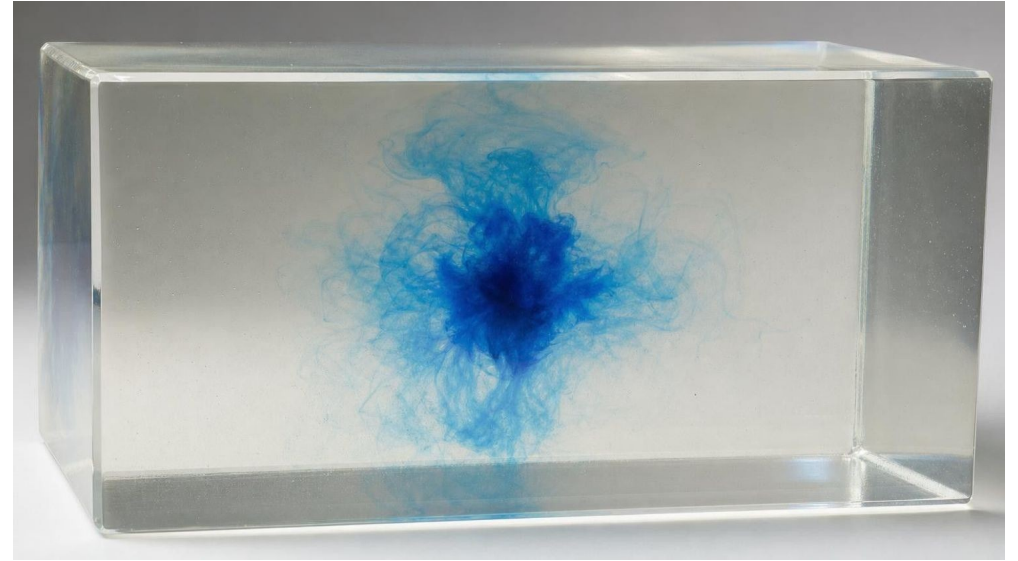
Discuss: would the cold cup ever turn evenly blue?

- Use the words particle, motion and temperature.
- Then: if dye were frozen into the middle of an ice cube, would it spread? Why or why not?

If you left the cold cup alone for a whole day, would it ever become evenly blue? What does your answer tell you about the particles in cold water?

VOCABULARY IN CONTEXT

Words for motion and energy



temperature

A measure of the average motion energy (kinetic energy) of a sample's particles. Higher temperature means faster particles on average. *The molecules in water at 45 °C move faster, on average, than those in water at 8 °C.*

thermal energy

The total motion energy of all the particles in a sample. It depends on both the temperature and how many particles there are. *A swimming pool at 26 °C holds far more thermal energy than a mug of cocoa at 70 °C.*

diffusion

The spreading of particles from where they are crowded to where they are fewer, caused only by their own random motion. *In set gelatin, where nothing can flow, dye particles slowly diffuse outward from a drop.*



CHECK FOR UNDERSTANDING

Quick check: adding energy to cold ice

A sealed bag of ice at $-10\text{ }^{\circ}\text{C}$ sits in a warm room and slowly gains thermal energy. What happens first?

A. The ice melts right away, while it is still at $-10\text{ }^{\circ}\text{C}$

B. The ice warms toward $0\text{ }^{\circ}\text{C}$: its particles vibrate faster, but it stays solid

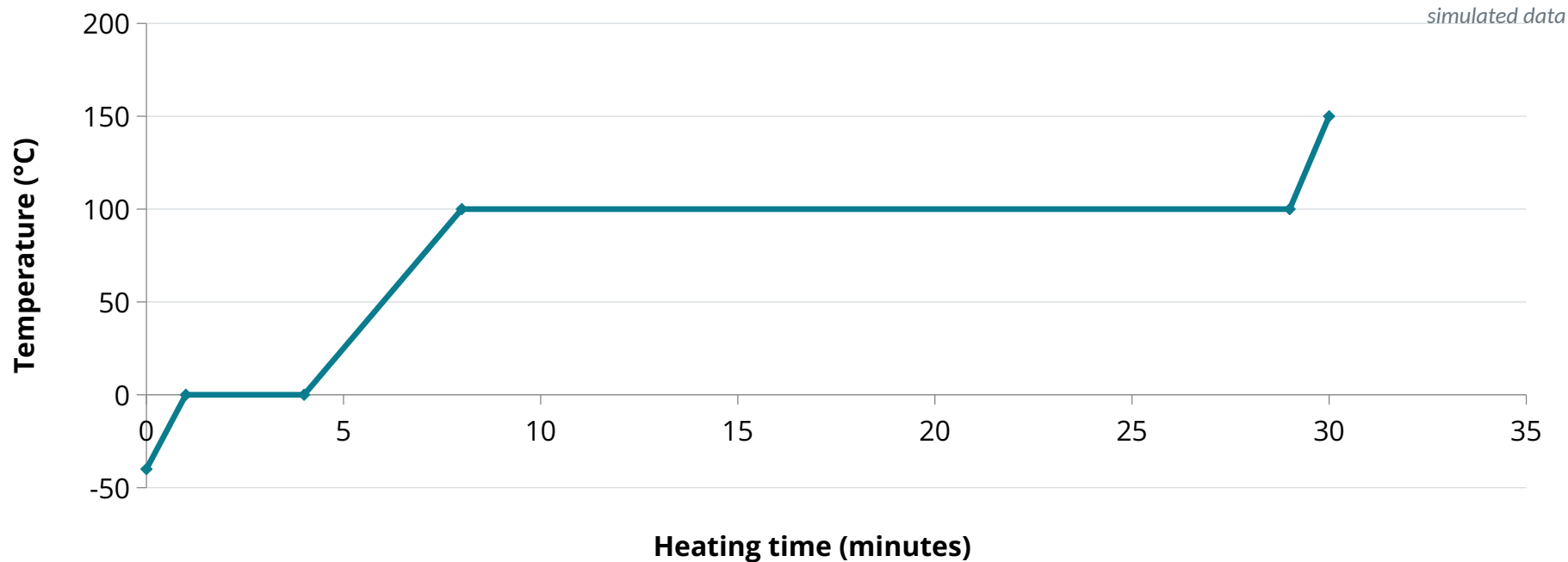
C. The particles grow until they no longer fit in a pattern

D. Nothing happens until the ice reaches $100\text{ }^{\circ}\text{C}$

The heating curve: two flat steps

Energy goes in at a steady rate the whole time. Watch what the temperature does.

Model: Water heated at a steady rate at sea-level pressure (idealized)



Idealized curve: the flat steps are melting at 0 °C and boiling at 100 °C. Times are illustrative, not measured.



Words for changes of state



melting point

The temperature at which a pure solid turns into a liquid as energy is added, at a stated pressure. The liquid freezes at the same temperature. *At sea-level pressure gallium melts at about 30 °C, so it melts slowly in a warm hand.*

boiling point

The temperature at which a pure liquid turns into a gas all through the liquid, at a stated pressure. Lower pressure means a lower boiling point. *Water boils at 100 °C at sea level but at about 85 °C on top of Mount Whitney.*

sublimation

A change straight from solid to gas, with no liquid in between. *At sea-level pressure, dry ice (solid carbon dioxide) sublimates at -78.5 °C.*



REAL-WORLD CONNECTION

California connection: cooking on Mount Whitney

Mount Whitney in the Sierra Nevada rises 4,421 m, the highest summit in the lower 48 states. Air pressure at the top is only about 58 kPa, not much more than half of sea-level pressure. Water there boils at about 85 °C, so backpackers' noodles cook slowly. About 135 km away, at Badwater Basin in Death Valley, 86 m below sea level, water boils just above 100 °C.

- Boiling starts when vapor bubbles inside the water can push back against the pressure above it.
- Less air pressure above the water means bubbles can form at a lower temperature.
- A pressure cooker does the opposite: about 200 kPa inside, so water boils near 120 °C.

Pressure: particles hitting the walls

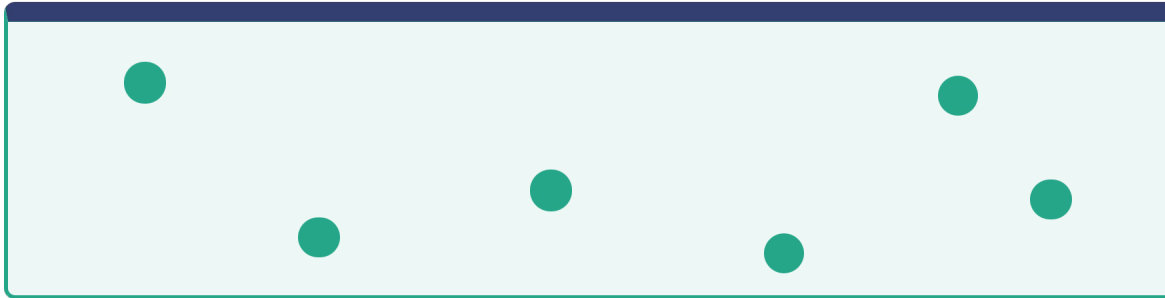
- Pressure is force spread over an area. The same push on a smaller area makes more pressure.
- A gas pushes on its container because huge numbers of particles hit every bit of wall each second.
- More particles hitting the same area, or particles hitting faster, means more pressure.
- Scientists measure pressure in kilopascals (kPa). Air at sea level presses with about 101 kPa.
- Air high on a mountain is less crowded, so it hits surfaces less often and its pressure is lower.



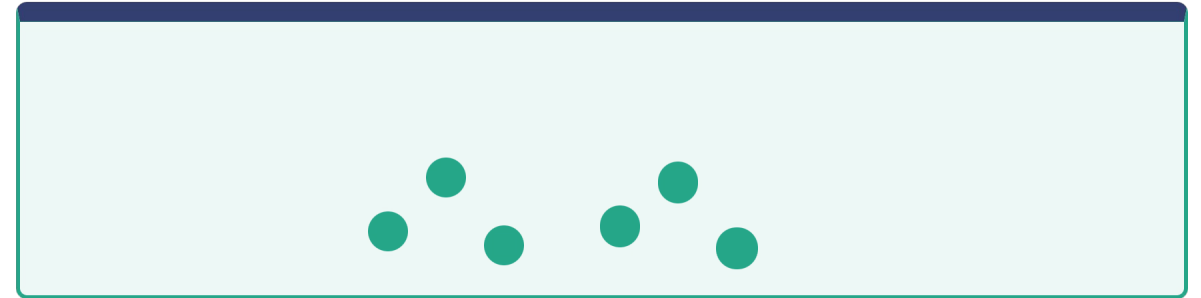
MODEL

Same temperature, more pressure: gas to liquid

Model: Water at 100 °C in a sealed cylinder with a piston



At 50 kPa: a gas: particles loosely spaced; Particles far apart, flying



Pushed to 200 kPa: a liquid: particles mediumly spaced; Same

Pushing the piston in crowds the particles. At 100 °C, water above about 101 kPa is a liquid.

CHECK FOR UNDERSTANDING

Quick check: the sealed syringe

You seal air in a syringe, cap the tip, and push the plunger halfway in while the temperature stays the same. What happens inside?



A. The air particles shrink, so the pressure stays the same

B. The same particles crowd closer and hit the walls more often, so the pressure rises

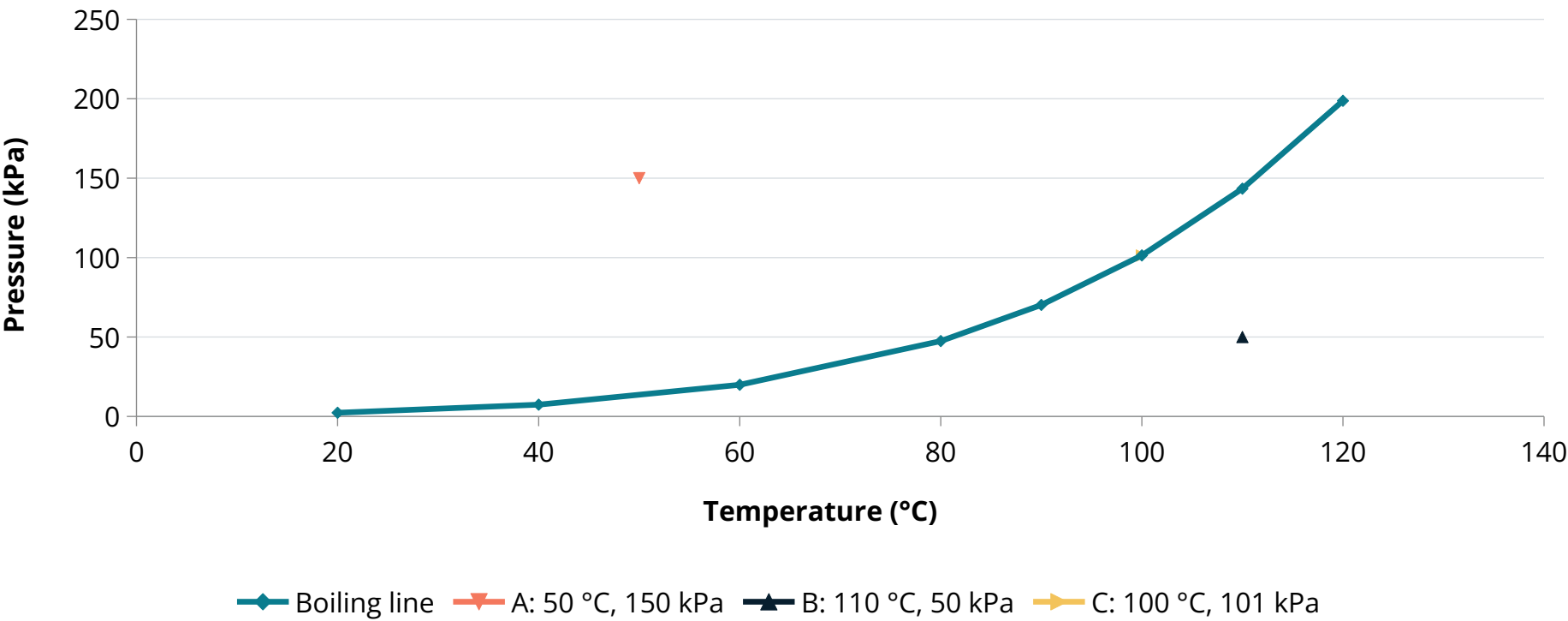
C. Some air particles are destroyed, so the pressure drops

D. The particles stop moving, so the pressure drops to zero

Reading water's state diagram: liquid or gas?

Find the temperature on the bottom axis, go up to the pressure, and see which side of the boiling line the point lands on.

Model: The liquid-gas part of water's state diagram (20 to 120 °C)



Above and left of the line: liquid. Below and right: gas. On the line, both exist together. At these pressures water is solid below 0 °C, off the left edge. Values from NIST.



Task: predict the state of three pure substances

Use the melting and boiling points at 101 kPa to predict each substance's state in each place. Then explain one prediction in terms of particle motion.



Pure substance at 101 kPa	Melts at	Boils at	Freezer, $-18\text{ }^{\circ}\text{C}$	Cool room, $18\text{ }^{\circ}\text{C}$	Hot car, $50\text{ }^{\circ}\text{C}$
Water	$0\text{ }^{\circ}\text{C}$	$100\text{ }^{\circ}\text{C}$			
Gallium	about $30\text{ }^{\circ}\text{C}$	above $2,000\text{ }^{\circ}\text{C}$			
Carbon dioxide	no liquid at 101 kPa	sublimates at $-78.5\text{ }^{\circ}\text{C}$			

- Compare each place's temperature with the substance's melting and boiling points.
- Below the melting point: solid. Between the two: liquid. Above the boiling point: gas.
- Pick one cell and describe what the particles are doing there.
- Bonus: which of your nine answers would change if the pressure were 50 kPa?

THINK, PAIR, SHARE

Discuss: what is the white fog over dry ice?

- Clue 1: the bubbles are very cold carbon dioxide gas.
- Clue 2: the warm water gives off invisible water vapor, and the room air already holds some.

Dry ice dropped in warm water bubbles and spills a white fog over the rim. Carbon dioxide gas is invisible. So what is the fog made of, and why does it sink?





Why scientists always state the conditions

- A state, a melting point or a boiling point is incomplete without the temperature and pressure.
- So scientists report results at agreed conditions, or say exactly which conditions they used.
- STP, short for standard temperature and pressure, means 0 °C and 100 kPa (older sources: 101.325 kPa).
- At STP gallium is a solid and carbon dioxide is a gas. Water sits exactly at its melting point.
- That is why recipes say 'adjust for high altitude' and lab reports list the pressure.

MISCONCEPTION CHECK

True or false? Melting particles get softer and bigger

"When ice melts, its water molecules soften and get bigger, and when the water boils the molecules swell up, which is why the gas takes up so much more room."

True or false? Explain your reasoning.



Putting it together

1 Solid, liquid, gas: the same particles, with different spacing and different motion.

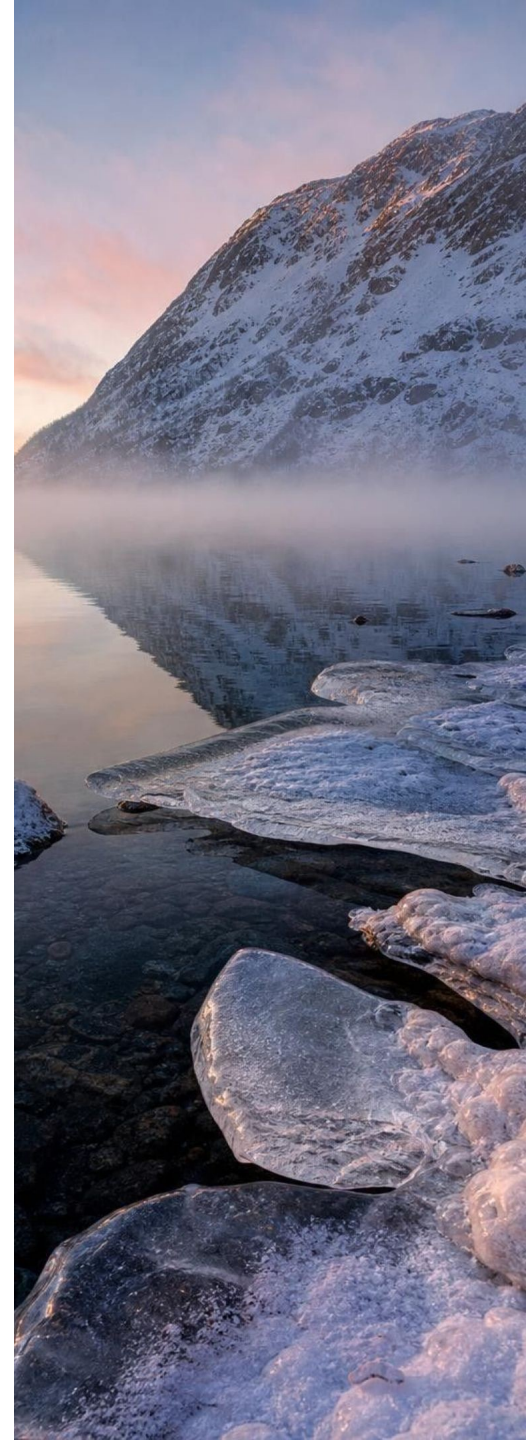
2 Particles in every state are always moving. Temperature measures their average motion.

3 Add energy: particles speed up until a change of state, when the energy loosens or separates them.

4 Remove energy: particles slow down until the substance condenses or freezes.

5 Gas pressure comes from particles hitting walls; pressure and temperature together set the state.

6 A state diagram maps those conditions, so always state the temperature and pressure.





EXIT TICKET

Exit ticket

- Draw one pure substance as a solid, a liquid and a gas. Keep every particle the same size.
- A cup of water cools from 20 °C to -15 °C at 101 kPa. Describe its particles, temperature and state.
- Why does food coloring spread faster in warm water than in cold?
- Liquid or gas: water at 70 °C and 101 kPa? Water at 95 °C and 50 kPa? (It boils near 81 °C at 50 kPa.)