

CHAPTER 24 OF 29 · STATES OF MATTER

Chapter 24: Heat, Temperature, and State Changes

Lesson 24: How does adding or removing energy change a substance's particles, temperature and state?

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



PHENOMENON

The sweating glass and the stubborn thermometer

A can of cold juice and a tall glass of ice water sit on a towel in a 27 °C room. Within a minute both turn misty; soon drops run down their sides, though neither leaks. A thermometer in the stirred ice water reads 0 °C for most of an hour while the ice shrinks. Only when the last ice is gone does the reading start to climb.

- Notice: what changes on the glass and in the glass, and what stays the same?
- Wonder: where could water on the outside of a sealed can come from?
- Predict: what will the thermometer do after the last ice is gone?





LEARNING TARGETS

What you will be able to do

- Tell temperature, thermal energy and heat apart, and compare samples by temperature and amount of matter.
- Predict which way energy flows as heat between two objects, and when it stops.
- Use a particle model to predict all six changes of state when energy is added or removed.
- Read heating and cooling curves and explain why the temperature holds steady during a change of state.
- Explain why substances melt and boil at different temperatures using attractions between particles.
- Design and improve a container that slows the energy flowing into an ice cube.

Temperature: a reading of the average

- Particles are always moving: vibrating in solids, sliding past each other in liquids, flying freely in gases.
- Kinetic energy is energy of motion. In one substance, faster particles carry more of it.
- Temperature tracks how much kinetic energy a sample's particles have on average.
- Warmer water: its molecules move faster on average. Colder water: slower on average.
- A thermometer reports that average. It cannot tell you how much matter, or how much total energy, is there.



MODEL

Hotter is not the same as more thermal energy

Thermal energy adds up the energy of every particle in a sample, so it depends on how much matter there is as well as on its temperature.

Model: A mug of tea and a bathtub

Mug of tea: 250 g at 80 °C	Bathtub: 150 kg at 40 °C
Higher temperature	Lower temperature
Molecules more energetic on average	Molecules less energetic on average
About 1/600 as many molecules	About 600 times as many molecules
Much less thermal energy in total	Far more thermal energy in total
Cooling to 0 °C, melts about 0.25 kg of snow	Cooling to 0 °C, melts about 75 kg of snow

Snow amounts are rounded estimates for snow already at 0 °C, with no energy lost to the air.



VOCABULARY IN CONTEXT

Three words to keep apart (part 1)

- **temperature:** Tracks how much kinetic energy a sample's particles have on average; it is what a thermometer reports. *A drop and a pot of boiling water at sea level have the same temperature, 100 °C.*
- **thermal energy:** The energy of every particle in a sample added together. It depends on amount of matter, temperature and state. *A lake at 15 °C holds far more thermal energy than a 90 °C kettle.*
- **kinetic energy:** The energy an object or particle has because it is moving. *As soup warms, its water molecules gain kinetic energy and move faster on average.*





Heat: energy on the move from warm to cool

- Heat is energy that moves from warmer matter to cooler matter because their temperatures differ.
- Where two objects touch, their particles collide billions of times every second.
- On average, more energetic particles pass energy to less energetic ones in those collisions.
- The warmer object cools and the cooler one warms until both reach the same temperature.
- After that, energy still passes both ways, but in equal amounts, so no net heat flows.
- Objects store thermal energy, not heat. And cold never flows; only energy does.

MODEL

Following energy across a boundary

Model: How heat flows between two touching objects

1. Warm object: more energetic particles
2. Collisions where the objects touch
3. Energy passes to less energetic particles
4. Warm object cools; cool one warms
5. Same temperature: no net heat

Heat always flows from higher to lower temperature. The flow stops when the temperatures are equal, though the particles never stop moving.



CHECK FOR UNDERSTANDING

Quick check: which way does the energy go?

- An ice pack on a sore knee.
- A $70\text{ }^{\circ}\text{C}$ spoon dropped into a cup of $20\text{ }^{\circ}\text{C}$ water.
- A glass of milk and the refrigerator air it has sat in all night.
- Your hand wrapped around a can of cold juice.
- A swimmer's skin (about $34\text{ }^{\circ}\text{C}$) in a $40\text{ }^{\circ}\text{C}$ hot tub.

For each pair, say which way energy flows as heat, or whether no net heat flows. Name the warmer object each time.





THINK, PAIR, SHARE

Discuss: which water melts more ice?

- Think about: each option's temperature, and how many water particles each one has.
- Think about: how far each can cool before it stops giving energy to the ice.
- Then: would a full tank of water at exactly 0 °C melt any ice at all?

A camper must melt a big block of ice for drinking water. Option A: one mug of nearly boiling water. Option B: a large pot of lukewarm water from a sun-warmed tank. Which melts more ice, and why?

Three states, six changes

Solid: particles held in fixed positions by their attractions, vibrating in place.

Liquid: particles still close together, but able to slide past one another.

Gas: particles far apart, moving freely and colliding.

- Add energy: melting (solid $\rightarrow$ liquid), evaporating or boiling (liquid $\rightarrow$ gas), subliming (solid $\rightarrow$ gas).
- Remove energy: freezing (liquid $\rightarrow$ solid), condensing (gas $\rightarrow$ liquid), depositing (gas $\rightarrow$ solid).
- The particles themselves never change; only their motion, spacing and arrangement do.



MODEL

Same molecules, three arrangements

Model: Water as a solid, a liquid and a gas



Ice (solid): particles tightly spaced;
Vibrate in fixed positions



Liquid water: particles mediumly spaced;
Close, sliding past each other



Water vapor (gas): particles loosely spaced;
Far apart, moving freely

A model: real molecules are far too small to see, and real water vapor is far more spread out.

The six-change map

Every change has a partner that runs the opposite way. Partners differ only in whether energy goes into the substance or comes out of it.

Model: Changes of state and the direction of energy

Center: Energy in (+) or out (–)

Melting: solid → liquid:
energy in

**Evaporating or
boiling:** liquid → gas:
energy in

Subliming: solid → gas:
energy in

Freezing: liquid →
solid: energy out

Condensing: gas →
liquid: energy out

Depositing: gas →
solid: energy out

Each change is undone by the change directly across from it: the same two states, with energy moving the other way.



VOCABULARY IN CONTEXT

Names for the changes (part 2)

- **condensation:** The change from gas to liquid, as gas particles lose energy and their attractions hold them together. Releases energy. *Condensation of water vapor from the air formed drops on the cold can.*
- **sublimation:** The change from solid straight to gas, without becoming a liquid first. Takes in energy. *A block of dry ice shrank by sublimation and left no puddle.*
- **deposition:** The change from gas straight to solid, without becoming a liquid first. Releases energy. *Deposition coated the windshield with feathery frost overnight.*

CHECK FOR UNDERSTANDING

Quick check: name that change

- Feathery frost grows on a car windshield on a clear winter night.
- A puddle on the playground is gone by lunchtime.
- Melted candle wax drips onto the table and hardens.
- A block of dry ice in a cooler shrinks but leaves no puddle.
- Cold glasses fog up when you walk into a warm, steamy kitchen.
- A snowman slumps on a sunny afternoon.

Name the change of state in each case, and say whether energy goes into or out of the substance that changes.



Why the thermometer gets stuck at 0 °C

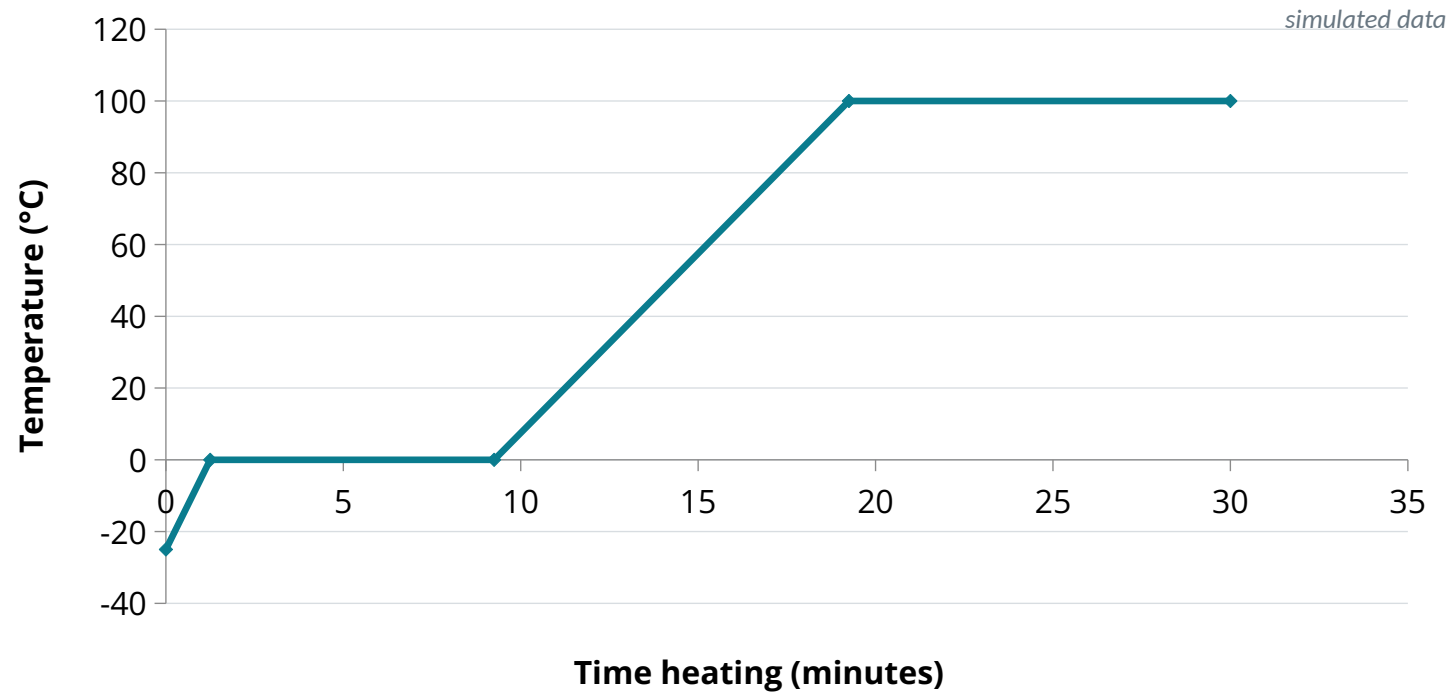
While ice melts, energy keeps flowing in, yet the temperature stays at 0 °C (at normal air pressure).

- That energy pulls particles free of the attractions holding them in place.
- It does not make the particles move faster on average, so the thermometer reading does not rise.
- Only after all the ice has melted does the added energy raise the temperature again.
- The same holds while water boils at 100 °C at sea level, and while it freezes or condenses.
- This works for pure substances. Mixtures such as salt water or wax change state over a range.

Reading a heating curve

A steady heater warms a sample of ice at sea-level air pressure. Where is the energy speeding particles up, and where is it changing the state?

Model: Idealized heating curve for water



Idealized teaching curve: a steady heater, normal sea-level air pressure, perfect stirring. Boiling all the water away would take far longer than shown.



CHECK FOR UNDERSTANDING

Quick check: read the curve

On the heating curve, during which minutes is the water (a) all solid, (b) melting, (c) all liquid and warming, (d) boiling? During which stretches is the molecules' average kinetic energy rising?



Evaporation and boiling are not the same

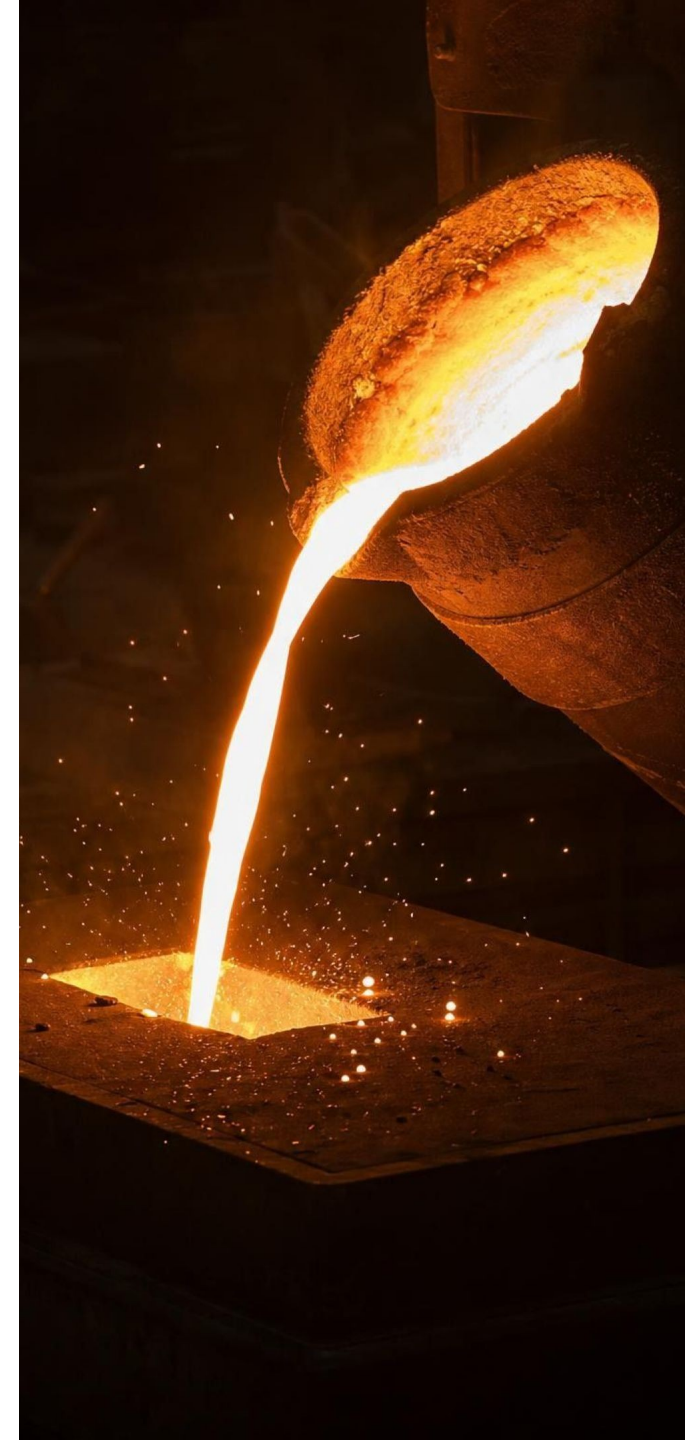
- Evaporation: the most energetic particles escape from the liquid's surface, at many temperatures.
- That is why puddles dry and laundry dries on a cool, breezy day.
- Evaporation carries energy away, so the liquid left behind cools. Sweating works this way.
- Boiling: at the boiling point, bubbles of vapor form throughout the liquid, not just at the top.
- The big bubbles in boiling water are water vapor, not air.
- Boiling point depends on air pressure: water boils near 90 °C at 3,000 m, as at Yosemite's Tioga Pass.



Why substances change state at different temperatures

- The particles of every substance attract one another, but how strongly depends on the substance.
- Stronger attractions take more energy to overcome, so melting and boiling happen at higher temperatures.
- Helium atoms barely attract: helium boils at $-269\text{ }^{\circ}\text{C}$ and will not freeze at normal air pressure.
- Melting and boiling points are properties that help identify a pure substance.

Substance	Melts at ($^{\circ}\text{C}$)	Boils at ($^{\circ}\text{C}$)
Helium	does not freeze	-269
Nitrogen	-210	-196
Ethanol (alcohol)	-114	78
Water	0	100
Table salt	801	1465
Iron	1538	2861





REAL-WORLD CONNECTION

California connection: sprinklers on a frosty night

On clear spring nights a frost can kill grape buds and strawberry blossoms. Some California growers switch on sprinklers. As the water freezes on the plants it releases energy, and as long as liquid keeps freezing, the coat of ice and water stays near 0 °C, warmer than the frosty air, so the tissue inside is protected.

- Freezing releases energy: it is melting run backward.
- The ice-water coat holds at the melting point, just like the cup in Lab 1.
- The sprinklers must keep running until the ice melts in the morning, or evaporation can chill the plants.
- The cost: in 2008, frost-night pumping stranded young salmon and steelhead in Russian River streams.

THINK, PAIR, SHARE

Discuss: back to the sweating glass

- Where is the water before it shows up on the glass?
- What happens to a water vapor particle that collides with the cold surface?
- The vapor releases energy as it condenses. Where does that energy go next?
- Would the glass sweat as much in dry desert air? Would a glass of warm water sweat at all?

Use particles and energy to explain both puzzles: where the drops on the outside of the glass came from, and why the ice water stayed at 0 °C for most of an hour.



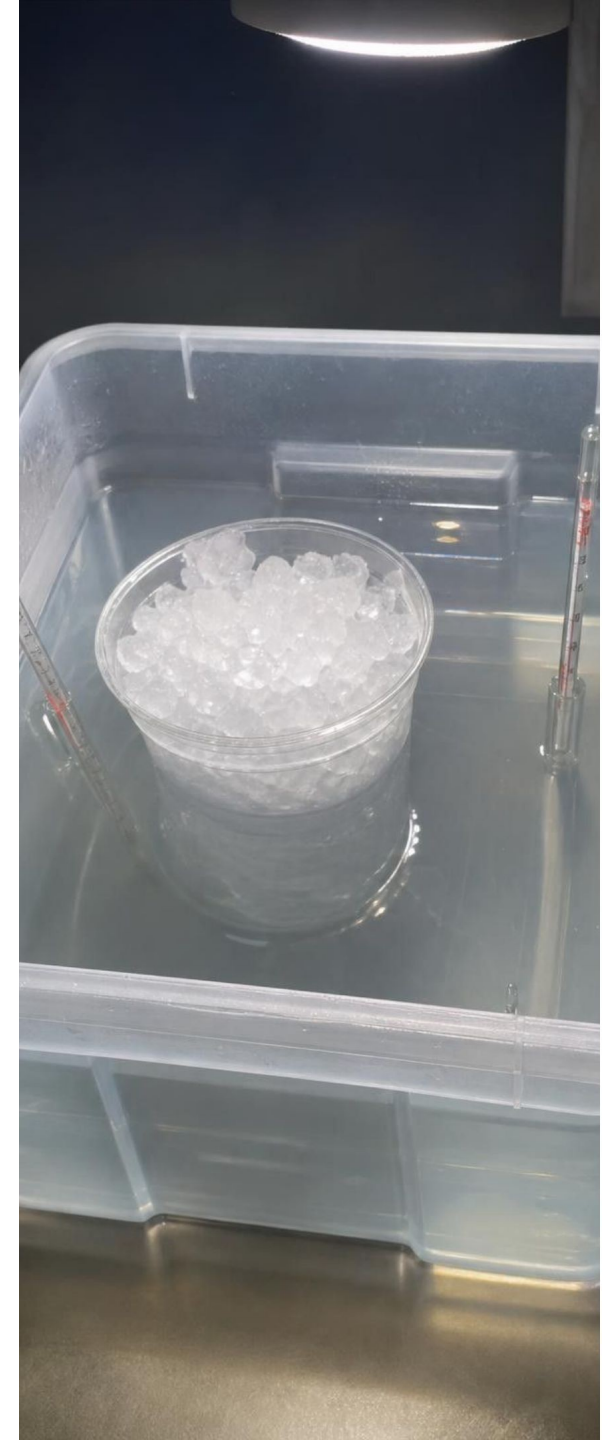
Task: the bath and the cup

A group set a cup holding 150 g of crushed freezer ice in a tub of 2 liters of warm water, stirred both, and read two thermometers. Teaching data:

Time (min)	Ice cup (°C)	Warm bath (°C)	What is in the cup
0	-6	44	Ice, no liquid yet
2	0	42	Ice and a little water
5	0	40	Slush
8	0	38	A few small chunks
11	3	35	All liquid (last ice gone at about 10.5 min)
15	21	33	Liquid
20	28	32	Liquid

- During which minutes was the ice melting? Give two pieces of evidence.
- Was energy flowing into the cup between minutes 2 and 8? How do you know?
- Where did that energy go, if not into raising the temperature?
- Why did the cup's temperature finally rise, and what final temperature do you predict?

Simulated data for practice.





MISCONCEPTION CHECK

True or false? More heat always means hotter

"If you keep adding heat to something, its temperature has to keep going up. Turn the stove higher under a pot of boiling water and the water will get hotter than 100 °C."

True or false? Explain your reasoning.

PUTTING IT TOGETHER

Putting it together

- Temperature is an average; thermal energy is a total; heat is energy moving from warmer to cooler.
- Heat flows until temperatures are equal. The amount a sample can give depends on its mass and temperature.
- Adding energy melts, evaporates or sublimates a substance; removing energy freezes, condenses or deposits it.
- During a change of state, a pure substance stays at one temperature while energy separates or joins particles.
- Stronger attractions between particles mean higher melting and boiling points.
- Insulators slow energy transfer by trapping still air; they do not make cold or heat.





EXIT TICKET

Exit ticket

01

A 35 °C bathtub or an 80 °C cup of cocoa: which has the higher temperature? Which has more thermal energy?

02

You hold an ice cube. Which way does energy flow, and what happens to the cube's temperature while it melts?

03

Name the change, and whether energy goes in or out: frost forms on grass overnight.

04

Sketch a cooling curve for water vapor cooled from 110 °C to -10 °C and label where it condenses and freezes.