

Substance Experts: Why Each Substance Changes State at Its Own Temperature

Learning target: I can work with my group to compare the melting and boiling points of twelve pure substances, predict each one's state at a given temperature, and explain the pattern with how strongly their particles attract one another.

Collaborative investigation

About 50 min

Jigsaw

MS-PS1-4 · practice

collaboration

discussion

data analysis

Name _____

Date _____

Period _____

Directions

Work in home groups of four. Each member joins an expert group (A, B, C or D) and studies that group's three cards. Experts meet for about 10 minutes to agree on their notes, then return home and teach the others. As a home group, complete Part B together. Part C is done alone, without notes from your group. All values on the cards are real and are given at normal air pressure.

You will need: One set of twelve cards per home group (cut apart), A paper strip about 30 cm long per group, This worksheet, Pencil

Twelve substance cards (cut apart; all values at normal air pressure)

1 Card 1: Helium

Boils at about -269°C at normal air pressure. It cannot be frozen at all at normal air pressure, no matter how cold it gets; it becomes solid only when it is also squeezed under high pressure. Liquid helium keeps the magnets inside hospital MRI scanners extremely cold. Expert group A.

2 Card 2: Nitrogen

Melts at about -210°C and boils at about -196°C at normal air pressure. About 78 percent of the air you breathe is nitrogen gas. Liquid nitrogen is used to freeze foods quickly and to store cell samples. Expert group A.

3 Card 3: Oxygen

Melts at about -219°C and boils at about -183°C at normal air pressure. About 21 percent of the air is oxygen. Hospitals often store oxygen as a liquid in insulated tanks, because the liquid takes up far less space than the same amount of gas. Expert group A.

4 Card 4: Methane

Melts at about -182°C and boils at about -162°C at normal air pressure. Methane is the main part of natural gas. Its molecules have about the same mass as water molecules, yet it is a gas at room temperature. Ships carry it across oceans as a liquid chilled below -162°C . Expert group B.

5 Card 5: Carbon dioxide

At normal air pressure it has no liquid state at all. Solid carbon dioxide, called dry ice, sublimates straight into gas at about -78°C . Liquid carbon dioxide can exist only when it is squeezed to more than about five times normal air pressure, as inside a fire extinguisher. Expert group B.

6 Card 6: Ethanol

Melts at about -114°C and boils at about 78°C at normal air pressure. Ethanol is the alcohol in many hand sanitizers. It evaporates from your skin within seconds, which is why sanitizer feels cool. Expert group B.

7 Card 7: Water

Melts at 0°C and boils at 100°C at normal (sea-level) air pressure. Water molecules are small and light, but they attract one another unusually strongly for their size. That is why water is a liquid at room temperature while methane, made of molecules of about the same mass, is a gas. Expert group C.

8 Card 8: Mercury

Melts at about -39°C and boils at about 357°C at normal air pressure. It is the only common metal that is a liquid at room temperature. Its vapor is poisonous, so schools have replaced mercury thermometers with digital or alcohol ones. Expert group C.

9 Card 9: Table salt (sodium chloride)

Melts at about 801°C and boils at about $1,465^{\circ}\text{C}$ at normal air pressure. Salt is made of particles with opposite electric charges that pull on one another very strongly. Expert group C.

10 Card 10: Aluminum

Melts at about 660°C and boils at about $2,470^{\circ}\text{C}$ at normal air pressure. Recycled cans are melted in furnaces; the liquid metal is poured into molds and freezes into solid blocks at about 660°C , long before it cools to room temperature. Expert group D.

11 Card 11: Copper

Melts at about $1,085^{\circ}\text{C}$ and boils at about $2,560^{\circ}\text{C}$ at normal air pressure. Copper is used for electrical wires, water pipes and the bottoms of some cooking pots. Expert group D.

12 Card 12: Iron

Melts at about $1,538^{\circ}\text{C}$ and boils at about $2,860^{\circ}\text{C}$ at normal air pressure. Steel, which is mostly iron, is melted in huge furnaces and poured into molds. Of the twelve substances on these cards, iron has the highest boiling point. Expert group D.

Part A: Expert round

1. Record your expert group's three substances. If a substance has no liquid state or no melting point at normal pressure, write that and explain it to your group.

Melting point ($^{\circ}\text{C}$)	Boiling point ($^{\circ}\text{C}$)	State at room temperature (25 $^{\circ}\text{C}$)	One fact to teach your group
My first substance:			
My second substance:			
My third substance:			

Part B: Home group task

1. Each expert reads their three cards aloud and teaches the group the most surprising fact.
 2. Lay all twelve cards in a column from the lowest boiling point at the bottom to the highest at the top. Place carbon dioxide by the temperature at which it sublimates, and mark it with a star.
 3. Lay a paper strip beside the column and mark three lines on it: $-100\text{ }^{\circ}\text{C}$, $25\text{ }^{\circ}\text{C}$ (room temperature) and $200\text{ }^{\circ}\text{C}$.
 4. For each line, decide which substances would be solid, liquid or gas at that temperature, and complete the group record.
 5. Agree on an answer to each question in Part B before anyone writes it down.
2. Group record: write S (solid), L (liquid) or G (gas) for each substance at each temperature, at normal air pressure.

At $-100\text{ }^{\circ}\text{C}$	At $25\text{ }^{\circ}\text{C}$	At $200\text{ }^{\circ}\text{C}$
Helium		
Nitrogen		
Oxygen		
Methane		
Carbon dioxide		
Ethanol		
Water		
Mercury		
Table salt		
Aluminum		
Copper		
Iron		

3. Write your boiling-point ladder from lowest to highest. Then use it to rank the substances from the weakest to the strongest attractions between particles, and explain why a boiling point can be used this way.

4. Now order the substances by melting point instead. Find at least one pair of substances whose order swaps between the two ladders. What might explain the swap?

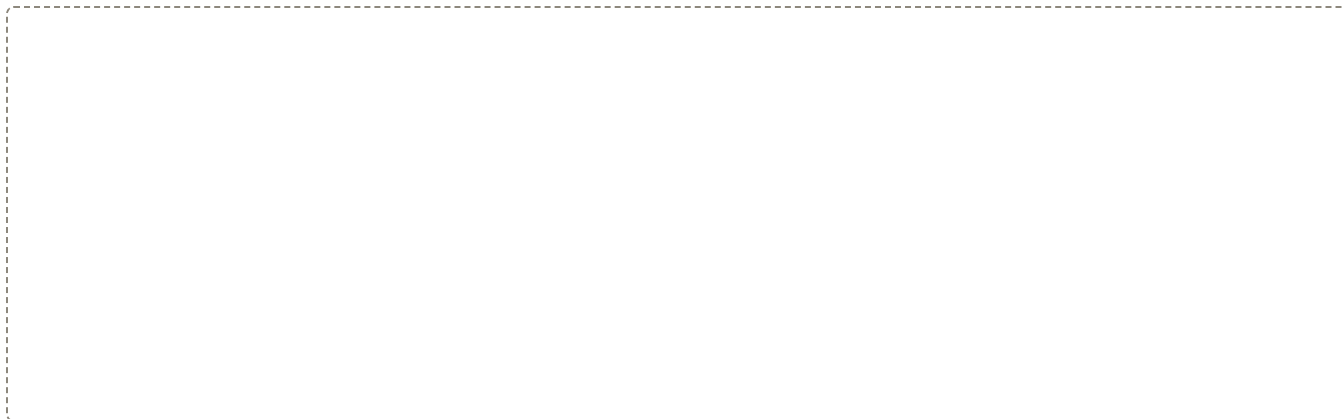
5. Imagine a furnace at 1,000 °C. Which of these four substances would be liquid in it: table salt, aluminum, copper and iron, and which would still be solid? Show how you decided.

Part C: Individual accountability (complete alone)

6. Substance X, an ingredient in some nail-polish removers, melts at about -95°C and boils at about 56°C . What state is it in at 25°C ? Where would it go on your ladder? Are its particles more or less strongly attracted to one another than water's? Explain.

7. Two tanks, one of pure nitrogen gas and one of pure oxygen gas, are slowly cooled to -190°C while each is kept at normal air pressure. Will either tank now contain liquid? If so, which gas condensed, and which one is still a gas? Use the cards to explain.

8. Draw two particle boxes side by side: helium at 25 °C and iron at 25 °C. Show spacing and motion, and add a one-line label under each box that says how strongly its particles attract.



9. Methane and water are made of molecules of about the same mass, but at 25 °C one is a gas and the other is a liquid. Explain why, using what happens to particles when a substance takes in thermal energy, and the idea of attractions between particles.

Reading a melting point and a boiling point

A substance is solid below its melting point, liquid between its melting point and its boiling point, and gas above its boiling point (at normal air pressure). Draw a short number line for any substance you are unsure of: mark its melting point and boiling point, then mark the temperature you are testing and see which zone it lands in. Remember that $-150\text{ }^{\circ}\text{C}$ is colder than $-100\text{ }^{\circ}\text{C}$.

Getting oxygen out of the air

Factories make liquid oxygen and liquid nitrogen by cooling air until it turns liquid and then letting it warm up slowly. Use the boiling points on Cards 2 and 3 to explain which gas boils off first as the liquid air warms, and how this could be used to separate the two. Then predict where argon (boiling point about $-186\text{ }^{\circ}\text{C}$) would come off, and explain why separating argon from oxygen is harder than separating nitrogen from oxygen.