

This activity has been used in an introductory chemistry course (prep chemistry or GOB course)

Learning Goals:

- Name phase changes
- Identify phase changes at molecular (particulate) level
- Name intermolecular forces
- Relate phases to strength of intermolecular forces of a molecule
- Relate energy of phase changes to intermolecular forces of a molecule
- Interpret a heating curve

Prerequisite knowledge –

- States of matter
- Convert to temperature °C to K
- Specific heat of water
- Draw simple Lewis dot structures,
- Determine polarity of simple molecules

ChemActivity: Phase Changes and Intermolecular Forces

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Open phet.colorado.edu, choose play with simulations, choose Chemistry Tab

Open: States of Matter Basics

Please record all answers on a separate piece of paper,

1. Draw a particulate diagram of a solid, liquid and gas,
 - a. Indicate which phase should have the molecules moving at the greatest speed.
 - b. Indicate the phase where the molecules are farthest apart.
 - c. Check your particulate drawings with the first option in the simulation: States (box on left in HTML version)
2. Choose the Phase Changes option, spend 2 minutes playing with the simulation.
3. Choose oxygen from the molecules on the left, record initial temperature of the model _____
4. Add heat until you notice a phase change (example: solid to liquid), Record the temperature _____
5. Add heat until you notice another phase change, Record the temperature _____
6. Reset the model, the melting point of oxygen is $-219\text{ }^{\circ}\text{C}$ and the boiling point is $-183\text{ }^{\circ}\text{C}$.
 - a. Convert both temperatures to K
 - b. Now increase the heat until the temperature reaches that melting point. How does this compare to your results in 4?

Most students will have overestimated the temperature of the phase change in their answers. Most don't realize that a phase change has both states in it (solid and liquid).

- c. Add heat until the temperature is at the boiling point. How does this compare to your results in 5?
7. According to the simulation, which phase has the fastest moving molecules? Does this match your prediction in 1?

Gas

8. Reset the model, change the molecule to water, record the initial temperature _____
9. Add heat until you notice a phase change (example: solid to liquid), Record the temperature _____
10. Add heat until you notice another phase change, Record the temperature _____
11. Reset the model, the melting point of water is 0.0 °C and the boiling point is 100.0 °C.
- Convert both temperatures to K
 - Increase the heat until the temperature reaches that melting point. How does this compare to your results in 9?

Students might be closer this time to their estimate around based on their initial experience with oxygen above.

- c. Add heat until the temperature is at the boiling point. How does this compare to your results in 10?
12. Which molecule, oxygen or water, melt at a lower temperature? Evaporate at a lower temperature?

Oxygen, just by looking at the temperatures, but they can also see this through the simulation, the molecules moving around more at a lower temperature.

13. Considering your answers to question 12, describe what you think is happening between the molecules of water compared to oxygen.
They are sticking together longer. There is something holding them together.
(not expected to know intermolecular forces yet)

STOP for mini-lecture on intermolecular forces

Talk about definition of intermolecular force (or attractive force), the three types, the strength of each, and what kinds of molecules they are found between (polar, nonpolar)

14. What is an intermolecular force?

Force	Description	Found in polar and/or nonpolar molecules	Example
Dispersion		Nonpolar/Polar	N ₂
Dipole-Dipole		Polar	CCl ₃ F
Hydrogen Bonding		Polar	H-F, H ₂ O, NH ₃

15. Using your answers from question 1, draw where the intermolecular forces would exist.

16. Using the three types of intermolecular forces, how does this explain your comparison of water to oxygen?

Students should recognize that oxygen has van der Waals interactions which are not as strong as hydrogen bonds in water, thus will change phase at lower temperatures (require less energy).

Energy and Phase Changes

17. What are the phase changes between solid, liquid and gas? Record as many as you can here. (There are six)

Freeze, melt, evaporation, condensation, sublimation, deposition (last two are not discussed because they don't fit on the heating curve.)

Using the information from questions 1-16, answer the following questions:

18. Does it take more heat (energy) to change from solid to liquid or liquid to gas? How do you know based on the data you took? Explain.

Liquid to a gas, it takes longer (and more heat) to get to the temperature to change from liquid to gas.

19. Draw a heating curve similar to the one show on the powerpoint slide. On a heating curve, diagonal lines indicate changes in temperature for a physical state, and horizontal lines (plateaus) indicate changes of state.

a. Identify the phase(s) and phase changes present in each segment (A→B, B→C, etc.).

Any heating curve will work (x-axis is heat added) and y-axis is temperature
The first segment A→ B is solid

Can be changed to accommodate the heating curved used.

20. What is the specific heat (J/°C g) of liquid water? Remember that specific heat is the amount of heat that a substance is able to absorb to change the temperature of 1 gram of by 1 °C. Where can you find these values?

Can find this in any textbook or online. $4.18\text{J/g }^\circ\text{C}$

21. The amount of heat added to melt (freeze) or evaporate (condense) a substance can be determined by knowing the heat of fusion or vaporization and the amount of substance you have. See slide.

A slide can be provided with the values for heat of vaporization and fusion (2260 J/C and 334 J/C)

- a. How much energy takes to convert 1g solid water to 1g liquid water? This is known as the heat of fusion.
- b. How much energy takes to convert 1g liquid water to 1g water vapor? This is known as the heat of vaporization.
- c. Using the simulation, how can you show that it takes more energy to convert a liquid to a gas than a solid to a liquid?

They may have already answered this in 18, but if not, they can try again here.

22. On your heating curve, write in the heat of fusion, heat of vaporization and specific heat of liquid water on the correct segments.

23. Looking at the heating curve for water:

- a. When going through a phase change, does the temperature change? How do you know?

No, the line is straight for temperature, it doesn't change as more heat is added

- b. Why is the horizontal line for boiling so much longer than melting?

It takes more energy to boil something than melt it (see heats of vaporization and fusion.)

- c. What state (phase) is the molecule in during a phase change? Give a real life example.

In boiling, there is both liquid and gas,
Ice cube is melting (both liquid and solid)

- d. The temperature is constant during segment D→E even though energy is being added, if more energy is being added, where is it going?

D→E is the boiling segment (phase change)
It is going into the phase change, causing the molecules to separate, breaking the intermolecular forces.

24. Based on what you know about heating curve, what do you think a cooling curve looks like? An example might be a gas that condenses to liquid and is then frozen to a solid. Draw your prediction. See slide to check.

It should like the opposite of a heating curve (x-axis heat removed)

25. Using the table and information provided, answer the following questions

Information can be updated in the table as necessary depending on how many organic molecules are discussed.

Molecule	Polarity of Molecule	Type of bond	Heat of Vaporization (J/g)	Heat of fusion (J/g)	At room temp
Oxygen	Nonpolar	Covalent	214	14	Gas
Propane	Nonpolar	Covalent	336	18	Gas
Benzene	Nonpolar	Covalent	395	128	Liquid
Acetic acid	Polar	Covalent	390	192	Liquid
Ethanol	Polar	Covalent	841	109	Liquid
Ammonia	Polar	Covalent	1380	351	Liquid
Water	Polar	Covalent	2260	334	Liquid
Sodium Chloride	Polar	Ionic	13000	518	Solid

- At room temperature, what phase do you think each of these compounds might in? How do you know? Consider your experiences with any of these molecules.
- Identify the type of attractive force in each compound (consider lewis structure and polarity of each structure)

Some texts refer to intermolecular forces as attractive forces. Change as necessary for your class.

They would need to draw out the lewis structure to determine the polarity of the molecules,

Nonpolar covalent – propane, butane – van der Waals (dispersion)

Polar covalent – acetic acid, ethanol – dipole-dipole

ammonia, water – hydrogen bonding

NaCl is ionic (between atoms/ions)

- Which intermolecular force is the strongest for the covalently bonded molecules? (note ionic bond is not an intermolecular force)
Ionic is the strongest force, but hydrogen bonds are the strongest intermolecular force.
- Write a claim on how phase changes are affected by intermolecular forces. Support with evidence (data) from your simulation and the table above.
The greater the heat of vaporization and fusion means stronger attractive forces.