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Module 7; Strengths of Intermolecular Forces

Procedures and Data

In this activity, you will watch an animation of intermolecular forces for comparison and then use a simulation to investigate them and determine how they relate to change in state.

Part One: Comparing Strengths of Intermolecular Forces

1. Click on the following link to open a short (1 minute 19 seconds) YouTube Video. Put it on a split screen so you can answer the following questions while you watch the video. You can use "k" to pause and restart.

https://youtu.be/zDVDoWpdrxg

Molecule in image	Name of Force	Describe (or draw) the intermolecular force shown
The yellow molecule represents two atoms bonded together to make a nonpolar molecule with no partial charges (until induced). You can imagine O_2 as an example.	London Forces	Weak, temporary, and extremely temporary bonds due momentary electron distribution imbalances.
The red/blue molecule represents a polar molecule. You can imagine HCl with the hydrogen carrying the partial positive charge and the chlorine carrying the partial negative charge.	Dipole-Dipole Forces	Attractions between oppositely charged ends of polar molecules.
The red/white molecules represent a polar molecule as well. You can imagine this as water with the oxygen carrying the partial negative charge and the hydrogens with the partial positive.	Hydrogen Bonding	Especially strong forms of Dipole-Dipole bonding due to Hydrogen bonding to Fluorine, Oxygen, or Nitrogen.

2. Why is the London Dispersion Force so weak?

They only exist due to temporary imbalances in the electron distribution of a molecule.

3. What causes the permanent dipoles found in molecules that can form dipole-dipole forces and hydrogen bonds?

The polarization of a molecule inherent in its structure due to a lack of symmetry

4. Why is the Hydrogen bond so strong?

N, O, and F are incredibly electronegative, so they are naturally very polarizing, and Hydrogen is the smallest atom, so Hydrogen's positive poles are incredibly close to negative poles.

5. Which atoms are required for molecules to form Hydrogen bonds?

Nitrogen, Oxygen, or Fluorine

6. What do STRONG intermolecular forces mean in terms of melting and boiling points. Why?

Strong IMFs result in a higher resistance within the molecules of a substance to changing its state of matter, which in turn causes higher melting/boiling points.

Part Two: Comparing Dipole-Dipole and London Forces

1) Open the following simulation and put it on a split screen. (You may need to cut and paste into the browser if the link isn't working.)

   https://learn.concord.org/eresources/745.run_resource_html

2) You should see the simulation.

3) From the drop down "select a pair of molecules" menu, Select "pull apart two polar molecules" and make a note of the arrangement – opposites attract. (You can imagine that the molecule is H-Cl with the blue positive representing hydrogen and the red negative representing chlorine).

4) Play with the simulation: click-and-drag the star to "feel" how hard it is to pull apart the molecules; move the molecule back and watch it stick together; notice that when it sticks together it always has opposite poles attract; you can even move the star and then let go – watch as the molecules are pulled together by the dipole-dipole forces.

5) Now select "pull apart two nonpolar molecules" and make a note that there are no +/- signs, because these molecules are nonpolar.

6) Play with the simulation and watch how much easier it is to pull part these molecules. They ONLY have London-dispersion forces of attraction; no dipole-dipole forces.

7) After you separate them, try to get them to stick back together by dragging the molecule in.

8) Select "pull apart a nonpolar and polar molecule" and play with the simulation.

9) Rank the strength of the force (1 = strongest) based on the simulation:

	Rank 1 = strongest
Between two non-polar molecules	3
Between two polar molecules	1
Between a polar and non-polar molecule	2

1) Compare the specificity of the polar molecule when interacting with another polar molecule or with a non-polar molecule. Does the red atom on the moving molecule always interact with the same atom on the stationary molecule?

No.

Part Three: Hydrogen-Bonding forces

ALL covalent molecules which have N-bonded-to-H, or O-bonded-to-H, or F-bonded-to-H exhibit hydrogen bonding forces. Because H is such a low electronegativity nonmetal and N, or O, or F are such high electronegativity nonmetals, H-bonding is a VERY strong type of dipole-dipole force. Hydrogen-bonding forces are so strong they given their own name (not dipole-dipole). Molecules with H-bonding also have L-D forces in addition to the H-bonding forces. Common molecules with H-bonding are: H_2O, NH_3, HF, C_2H_5OH (alcohol), CH_3NH_2, etc.

1. Open the following simulation in a split screen:

   https://learn.concord.org/eresources/769.run_resource_html

2. Deselect "show hydrogen bonds" and "show partial charges". You will see water molecules.

What does the white color represent?	Hydrogen
What does the red color represent?	Oxygen

3. Then check "show hydrogen bonds" and "show partial charges." The "+" and "-" signs actually represent δ+ (partial positive) and δ- (partial negative). These partial charges are based on low and high electronegativity and create a very polar molecule.

4. Click the play button (way at the bottom after a lot of blue empty space) to observe these water molecules as they move around, and the dotted lines represent the hydrogen-bonding that occurs.

5. Play with the simulation by clicking "cool" and watch the particles slow down and begin to get closer together – this would eventually lead to freezing. Answer the questions in the table below.

Cool it all the way down to watch water freeze. Wait – it takes a while. Describe frozen water at the molecular level:	Tightly packed together with little to no movement
Click "heat" and watch the particles move faster and further apart – this would eventually lead to melting and boiling. Stop at the point when you would consider water to be liquid. Compare liquid water at the molecular level to frozen water.	More movement, with molecule bonding groups more spread out
Then heat it up some more. Stop at the point when you would consider water to be a gas (steam). Compare gaseous water at the	Fastest movement with the smallest molecule bonding groups

molecular level to the other states.	

6. Continue to play with the simulation by checking and un-checking any of the boxes and heating/cooling and noting the formation of hydrogen-bonding forces when particles get close together. Be sure to check the slow-motion and watch that for a while; it's easiest to see the hydrogen bonds in slow motion.

Part Four: Freezing, Melting and Boiling

The physical processes of freezing, melting and boiling involve the making and breaking of intermolecular forces.

1. Open the following link in a split screen and click on preview:

https://learn.concord.org/eresources/749.run_resource_html

1) There are two images. One is an image of a bunch of polar molecules and one is an image of a bunch of nonpolar molecules. Answer the questions in the table below:

Which image (left or right) is for polar molecules?	Right
How do you know?	The atoms have partial charges
Which image (left or right) has stronger intermolecular forces?	Right
Make a prediction: Which image (left or right) will boil faster?	Left
Which button (cool or heat) would you select for boiling?	Heat
Run your experiment. To do this, press "play" at the very bottom of the screen (after all the blue space). And immediately select the correct button (cool or heat) for boiling. Record your observations	The nonpolar compound separated quickly whereas the polar compound still did not separate/melt at high temperature.
Now freeze the two different molecules. Record your observations:	The polar compound has even less movement at lowest temp. whereas
Expand your screen so that you can see the gray dashed lines between molecules. You will see them best at about 400K. These gray dashed lines are intermolecular forces.	

What is the name of the force between molecules in the left image?	London Forces
What is the name of the force between molecules in the right image?	Dipole – Dipole Forces

POST LAB QUESTIONS

Complete the tables below

Molecules	Polar or Nonpolar Molecules	Kind of Force between molecules	Rank strength of force from 1 to 3 (1= strongest)	Rank boiling point from 1-3. (1 = highest)
H_2 and H_2	Nonpolar	London	3	3
HBr and HBr	Polar	Dipole	2	2
HF and HF	Polar	Hydrogen	1	1

Molecules	Polar or Nonpolar Molecules	Kind of Force between molecules	Rank strength of force from 1 to 2 (1= strongest)	Rank boiling point from 1 to 2. (1 = highest)
H_2 and H_2	Nonpolar	London	2	2
Br_2 and Br_2	Nonpolar	London	1	1

Look up the boiling points of H_2 and Br_2 in °C. Record them. Are they consistent with your predictions?

$H_2 \rightarrow -252.9°C$

$Br_2 \rightarrow 58°C$

Yes, this is consistent.

Module 7: Intermolecular Forces and Properties

Pre-Laboratory Questions

Read about intermolecular forces in your textbook, pages 186- 192. Construct a table comparing the following intermolecular forces: dipole-dipole interactions, Hydrogen bonds and London Forces.

Force	For polar or nonpolar molecules?	Examples of Molecules (indicate two or more)	Relative strength (strongest-weakest)	Boiling point effect (highest to lowest)
Hydrogen Bonds	Polar	H_2O HF	Strongest	Highest
Dipole-Dipole Bonds	Polar	HCl HBr	somewhat strong	middle
London Forces	Nonpolar	O_2 Br_2	weakest	Lowest

Answer the following questions. Make sure you also understand the reasoning for each one (although you do not need to write the reasoning here). Check your answers in your textbook in section 7.1.2:

a. Order the following compounds of group 14 elements and hydrogen from lowest to highest boiling point: SiH_4, CH4, GeH_4, and SnH_4.

$CH_4 < SiH_4 < GeH_4 < SnH_4$

b. Order the following hydrocarbons from lowest to highest boiling point: C_3H_8, C_4H_{10} and C_2H_6

$C_2H_6 < C_3H_8 < C_4H_{10}$

c. Predict which will have the higher boiling point: N_2 or CO

CO

d. Predict which will have the higher boiling point: ICl or Br_2

ICl

e. Consider the compounds dimethyl ether (CH_3OCH_3), ethanol (CH_2CH_2OH) and propane ($CH_3CH_2CH_3$). Their boiling points, not necessarily in order are -42.1°C, -24.8°C, and 78.4°C. Match each compound with its boiling point.

Dimethyl Ether → -24.8°C, Ethanol → 78.5°C, Propane → -42.1°C

f. Ethane (CH_3CH_3) has a melting point of -183°C and a boiling point of -89°C. Would the melting and boiling points for methylamine (CH_3NH_2) be higher or lower? Why?

Methylamine would be significantly higher as the NH pairing could cause hydrogen bonds to form.

Procedure and Data

Watch the following video and answer the following questions. I suggest you use a split screen so that you can watch the experiment as you collect the data. I caught one mistake in this video regarding the kind of intermolecular force in nail polish remover. When you get to that part of the video, I will correct it in the data table I provide.
https://www.youtube.com/watch?v=jrY4jlec7-Q

Part 1: Evaporation

When molecules evaporate, the forces are broken which keep the molecules attached to other molecules in the beaker – when those forces are broken, the molecules escape the beaker. In this evaporation experiment, the experimenter placed 50 mL of three chemicals in beakers and allowed them to evaporate for four days. Then he rechecked their volume. Record the data in the table below:

Chemical	Volume before	Volume after (Zoom in and read the beakers)	Change in Volume (subtract)	Rank of evaporation 1 = most	Rank of IMF strength 1 = strongest
Fingernail polish remover (acetone*)	50mL	5mL	45mL	1	3
Water	50mL	36mL	14mL	3	1
Methylated Spirits (ethanol)	50mL	20mL	30mL	2	2

*The speaker says that acetone has London Forces. TRUE – ALL molecules have London forces. What he did not mention is that it also has dipole-dipole forces.

In subsequent experiments, the experimenter will also test oil and glycerin. After you see those experiments, come back and answer this question: Why do you think the experimenter did NOT check the evaporation of oil and glycerin? Write your answer in the box below:

The IMFs of oil and Glycerin are probably so strong that neither of the substances would have evaporated naturally by the sun's temperature.

Part 2: Surface Tension

Surface tension is the attractive force exerted upon the surface molecules of a liquid by the molecules underneath. In this surface tension experiment, the experimenter drops the chemicals on pennies to see how many "stick" will together:

Chemical	Number of Drop on the penny before it bursts	Ranking of drops 1 = most	Ranking of surface tension 1 = greatest	Rank of IMF strength 1 = strongest
Oil	38	1	1	1
Water	31	3	3	3
Glycerin	37	2	2	2
Fingernail polish remover (acetone*)	19	5	5	5
Methylated Spirits (ethanol)	24	4	4	4

*The speaker says that acetone has London Forces. TRUE – ALL molecules have London forces. What he did not mention is that it also has dipole-dipole forces.

Part 3: Solubility

This is an interesting experiment in which you see that "like dissolves like" (polar molecules dissolve in polar compounds and nonpolar molecules dissolve in nonpolar compounds). We will explore these topics in our last module, the module on solutions. You can skip this part of the experiment and jump to 8:13 in the video. (If you do watch the solubility tests, know that his data table is confusing; he puts a √ in the data box which seems to mean "tested", not "soluble" or "insoluble".

Part 4: Boiling Point

When molecules boil, the forces are broken which keep the molecules attached to other molecules in the beaker – when those forces are broken, the molecules escape the beaker. In this simulated boiling point experiment, the experimenter placed 50 mL of three chemicals in beakers and allowed them to evaporate for four days. Then he rechecked their volume. Record the data in the table below:

Chemical	Boiling Point	Rank of boiling point 1 = highest	Rank of IMF strength 1 = strongest
Water	94°C	3	3
Oil	280°C	2	2
Glycerin	284°C	1	1
Nail Polish Remover	50°C	5	5
Methylated Spirits (ethanol)	62°C	4	4

Post-Laboratory Questions

1. Rank these chemicals (water, oil, glycerin, nail polish remover and methylated spirits) from strongest molecular force (1) to weakest (5):
1) oil
2) Glycerin
3) Water
4) Methylated spirits
5) Nail Polish Remover

2. In which experiments did oil exhibit stronger intermolecular forces than water?

All of them. (Surface Tension and Boiling Point)

3. Would you be surprised to learn that oil can only make London Forces the weakest of all intermolecular forces. What conclusion can you draw about oil given that it behaves as if its intermolecular forces are stronger than water even though it can only form London forces and water can form hydrogen bonds?

Yes, I would be surprised.

I can conclude that London Forces can be stronger than Hydrogen bonds in certain circumstances, such as more complex molecules (H_2O vs. $C_{18}H_{34}O_2$ + $C_{16}H_{30}O_2$ + ...)

4. Why do you think glycerin has stronger forces than either water or oil?

Glycerin will only form hydrogen bonds and is a long molecule.