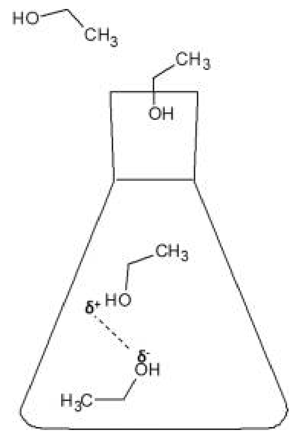
Why is O_2 a gas at room temperature and H_2O a liquid?[1]



Objective:
Relate structural characteristics to relative boiling point for a variety of molecules.

Process:
You will be given a **sample of several different chemicals** and will need to **find the boiling point** for each one. You will also be provided with a list of accepted boiling points for an additional set of molecules. **You will need to draw out structures for all of the molecules. You will then group your molecules into categories based on structural characteristics and relative boiling points, drawing conclusions regarding the relationships between the two.**

Pre-lab:
- ❖ **Read the entire procedure**, including Part I, Part II, and Part III.
- ❖ Look up the **SDS for the liquids** you will be using in **part I**.
- ❖ **Set up** an **appropriate table** to record your data for **part I**.
- ❖ **Formulate a hypothesis** to answer the question posed in the title; "Why is O_2 a gas at room temperature and H_2O a liquid?"

Part I: Boiling Points
1. Using a hot plate ***Never a flame!),*** heat approximately 50 mL of distilled water in an Erlenmeyer flask until it boils.
2. Measure the boiling point with a thermometer, ensuring the thermometer does not touch the bottom of the flask. Record your measurement in an **appropriate table** to the **proper number of digits**.
3. Repeat steps 1 and 2 for samples of **CH_3OH, CH_3CH_2OH and $CH_3CHOHCH_3$**.
4. **DO NOT DISCARD ANY OF THE LIQUIDS!! LEAVE THE FLASKS TO COOL FOR THE NEXT CLASS TO USE.**

Table 1: Literature Values (Merck Index 14th Ed.)

Molecule	Boiling Point (°C)
CH_3OH – methanol	64.7
CH_3CH_2OH – ethanol	78.5
H_2O	100
$CH_3CHOHCH_3$ – isopropanol/ isopropyl alcohol	86.2

Once you have measured all four boiling points, respond to the following questions.

1. Explain how your measured boiling points would have changed if a different amount of liquid were used.
2. How did your measured boiling points compare to the literature values found in Table 1? Explain. Calculate the percent error for each liquid.
3. Choose one of the molecules and draw a series of three pictures at a particulate level: the liquid before heating, the liquid while boiling, and the gas that has escaped while the liquid is boiling. (*Hint: think of the pHet simulation lab you completed previously*)

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[1] *An Inquiry Experience with High School Students to Develop an Understanding of Intermolecular Forces by Relating Boiling Point Trends and Molecular Structure*. Melinda Ogden. Journal of Chemical Education. April 30, 2017. Edited and adapted by Ema Gluckmann 3/18.

Part II: Structural Categorization

You will now combine your data with the data provided in Table 2, totaling 16 molecules. Draw each molecule on a card and include its boiling point. Then, work to create categories of molecules which show relationships between the molecule's structure and boiling point. Every molecule should be included in a category.

Table 2: Literature Boiling Points for Additional Molecules (Merck Index 14th Ed.)

Molecule	**Condensed structural formula**	**BP (°C)**
Methane	CH_4	-161.4
Diethyl ether	$CH_3CH_2OCH_2CH_3$	34.6
Dimethyl ether	CH_3OCH_3	-24.82
ethane	C_2H_6	-88
Propane	C_3H_8	-42.1
butane	C_4H_{10}	-0.50
Diethyl sulfide	$CH_3CH_2SCH_2CH_3$	92
Methyl ethyl ether	$CH_3OCH_2CH_3$	10.8
1-butanthiol	C_4H_9SH	98.4
1-butanol	C_4H_9OH	118
acetone	CH_3COCH_3	56.5
glycerol	$HOCH_2CHOHCH_2OH$	290.0

Once you have categorized all of your molecules, write out a thorough explanation. In your explanation, **make sure you have identified all of the relationships and thoroughly explained why and how** you were able to determine those relationships. Your logical thinking and reasoning should be clear. **You should also include an explanation for the variation in boiling points within each category**. Your conclusions should allow another person to estimate the relative boiling point of a compound that is not one present in the lab. Your instructor may give you a **BONUS** molecule for which you will draw the structure, estimate its boiling point and place it into one of the categories you have already made with an explanation for its placement

Part III: Intermolecular Forces

1. What is a **London Dispersion Force**? How does it arise? What types of molecules are involved?
2. What is a **dipole-dipole force**? How does it arise? What types of molecules are involved?
3. What is **hydrogen bonding**? How does it arise? What types of molecules are involved?
4. Based on your responses to questions 1-3, explain the relative strengths of the IMFs. (**Why is one type generally stronger or weaker than another?**)
5. Draw at the particulate level the interaction between two molecules of C_4H_9SH and name the type(s) of interaction(s) involved.
6. Draw at the particulate level the interaction between two molecules of C_2Cl_6 and name the type(s) of interaction(s) involved.
7. Draw at the particulate level the interaction between two molecules of $C_2H_5NH_2$ and name the type(s) of interaction(s) involved.
8. Draw at the particulate level the interaction between one molecule of CH_3Br and one molecule of water. Name the type(s) of interaction(s) involved.
9. Explain, using drawings **with** descriptions, why O_2 is a gas at room temperature and H_2O is a liquid.
10. Draw ammonia and I_2 and explain how ammonia can be a gas at room temperature while iodine is a solid.