Lab: Intermolecular Attractions in Organic Liquids

FOR THE TEACHER

Summary
In this lab, students will analyze the molecular structure of substances in order to predict how different types of intermolecular attractions will affect the boiling points of various organic liquids. Students will then complete laboratory testing in order to collect data and compare their results with their predictions.

Grade Level
High School

NGSS Alignment
This lab will help prepare your students to meet the performance expectations in the following standards:

- **HS-PS1-3**: Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.
- **Scientific and Engineering Practices**:
  - Developing and Using Models
  - Analyzing and Interpreting Data
  - Engaging in Argument from Evidence

Objectives
By the end of this lab, students should be able to

- Identify the types of intermolecular attractions present in a molecule by looking at its structure.
- Make a prediction for ranking the boiling points of various substances based on the intermolecular attractions present in the substances.

Chemistry Topics
This lab supports students’ understanding of

- Intermolecular Forces
- Molecular Structure
- Organic Chemistry

Time
**Teacher Preparation**: 20 Minutes  
**Lesson**: 1.5 - 2 hours

Materials
- Thermometers
- Filter Paper
- Small Rubber Bands (the size used for braces work well)
- 6 small beakers (~50mL)
- ~30 mL of the following liquids:
  - Ethyl acetate
  - 1-pentanol
  - Hexane
  - Ethanol
  - Methanol
  - Isopropyl Alcohol

Submitted by
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Thanks to:
Dow Chemistry Teacher Summit
Safety
- Always wear safety goggles when handling chemicals in the lab.
- Students should wash their hands thoroughly before leaving the lab.
- All of the substances used in this lab are flammable and hazardous if ingested or inhaled. Heat sources should not be used during this lab. See SDS for each substance (listed in Materials section) for additional information.
- All substances used in this lab are slightly hazardous if they contact skin and should be washed off quickly and completely. See SDS for each substance (listed in Materials section) for additional information.

Teacher Notes
- This lab is designed to be used in a high school Organic Chemistry classroom, but it can also be used in an AP or general Chemistry class.
- Students should have already learned about the different types of intermolecular attractions and how to identify them by analyzing the molecular structure.
- This lab is designed so that students practice identifying hydrogen bonding, dipole-dipole forces, and dispersion forces; and use their knowledge of these to predict boiling points.
- Optional: Before beginning this lab, teachers could walk around the classroom with a bottle of acetone (nail polish remover) and a pipette and squirt a drop on the backs of a student’s hand. The students will notice that it feels cold on their hands. If there is time, you can do the same with water and compare how different acetone feels from water. You can talk about how nail polish remover feels.
- Also, you could also start a discussion surrounding the idea that people used to think it was a good idea to use rubbing alcohol on babies to bring down fevers. (It DOES cause a temperature drop in the skin, but BAD to inhale!) This will set the stage for discussions about evaporative cooling and intermolecular attractions.
- In the pre-lab sections, students should work in pairs to complete the table. Alternatively, they could work alone and then pair up to compare answers.
- If students are not familiar with organic structures, you can have them do a search on the internet, or provide the structures for students to reference.
- The “prediction” sections are designed to make students think about the structure and intermolecular forces—they will not necessarily make correct predictions.
  - For example, I usually tell my students that I am surprised that the boiling point of octane is so much higher than 1-propanol and I “did not expect” the dispersion forces to be that much stronger than the hydrogen bond.
  - We talk about how much bigger the octane molecule is and how that affects the intermolecular attractions.
- Note that the pre-lab can take an entire class period to complete.
- An answer key has been provided for teacher reference.
FOR THE STUDENT

Lesson

Intermolecular Attractions in Organic Liquids

Background
In this lab, you will be using your knowledge of intermolecular attractions to predict the boiling points of various organic liquids.

Objective
Rank the organic liquids in order of boiling point from least to greatest.

Safety
• Always wear safety goggles when handling chemicals in the lab.
• Students should wash their hands thoroughly before leaving the lab.
• Always use caution around open flames. Keep flames away from flammable substances.
• All of the chemicals used in this lab are flammable and hazardous if ingested or inhaled. They are also slightly hazardous if they come in contact with skin and should be washed off quickly and completely.

Prelab Questions
1. For the substances listed in the table below, draw the structural formula for each substance and calculate its molecular weight. Then, determine the type(s) of intermolecular attraction(s) that exists between particles of each substance.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Structural Formula</th>
<th>Molecular Weight</th>
<th>Intermolecular Attraction(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-propanol</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>methyl acetate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pentane</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>octane</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2. Predict the boiling points, from lowest value to the highest value for the substances listed in the table. Record your predictions below, then look up the actual boiling point values for each substance online and record those in the table.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Predicted Boiling Point Rank (1 = lowest)</th>
<th>Actual Boiling Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-propanol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>methyl acetate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pentane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>octane</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. In this experiment, thermometers are placed in various liquids. Evaporation occurs when the thermometer is removed from the liquid’s container. This evaporation is an endothermic process that results in a temperature decrease. Explain why evaporation is an endothermic process:

4. The magnitude of a temperature decrease is, like volatility and boiling temperature, related to the strength of intermolecular forces of attraction. How are volatility and boiling point related?

5. You will study the temperature changes caused by the evaporation of several liquids and relate the temperature changes to the strength of intermolecular forces of attraction. Complete the following table.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Formula</th>
<th>Structural Formula</th>
<th>Molecular Weight</th>
<th>Intermolecular Attraction(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ethyl acetate</td>
<td>C₄H₈O₂</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-pentanol</td>
<td>C₅H₁₀O</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hexane</td>
<td>C₆H₁₂</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. Before you perform this experiment, predict the order for the substances from the smallest to greatest temperature change during evaporation. Record your prediction in the experiment data table below.
**Procedure**
Carefully wrap some filter paper tightly around the bottom of a thermometer.
1. Record the temperature on the thermometer.
2. Dip the thermometer-filter paper combination into one of the solvent samples.
3. Set the thermometer on a table or lab bench and allow the solvent to evaporate for exactly 60 seconds.
4. Again, record the temperature.
5. Calculate the temperature change.
6. Be sure to use the proper number of significant figures and to "read one decimal past the precision of your instrument".

<table>
<thead>
<tr>
<th>Substance</th>
<th>Predicted Rank (1 = smallest temp change)</th>
<th>DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Starting Temp</td>
</tr>
<tr>
<td>ethyl acetate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-pentanol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>hexane</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. Explain your reasoning for choosing the above predicted order for temperature changes of the substances:

8. Do the lab results match your predictions? (explain why or why not)

9. Complete the following table:

<table>
<thead>
<tr>
<th>Substance</th>
<th>Formula</th>
<th>Structural Formula</th>
<th>Molecular Weight</th>
<th>Intermolecular Attraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>ethanol</td>
<td>C₂H₆O</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>methanol</td>
<td>CH₄O</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>isopropyl alcohol</td>
<td>C₃H₈O</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
10. Follow the exact same lab procedure as previously described for the following four substances. *Note that you will again need to predict the order for the substances from the smallest to greatest temperature change during evaporation in the experiment data table.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Predicted Rank</th>
<th>DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1 = smallest temp change)</td>
<td>Starting Temp</td>
</tr>
<tr>
<td>ethanol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>methanol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>isopropyl alcohol</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

11. Explain your reasoning for choosing the above predicted order for temperature changes of the substances:

12. Do the lab results match your predictions? (explain why or why not)

**Conclusion**

Write a thorough conclusion that includes three sections:

- **Purpose of the Lab (Claim)**
  - If a question has been “asked” you write a “claim”, which is a statement that responds to the question asked or problem posed.
  - If you cannot come up with a question, you could just answer the question, “What was the purpose of doing this lab?”
  - This is usually only worth a couple points.

- **Results and Comparisons (Evidence)**
  - This is where you should include scientific data (qualitative or quantitative) used to support the claim or the purpose.
  - Avoid using words like “I” and “We”.
  - You should only include suitable and significant data, not every single thing you did. Make comparisons and analyze where appropriate.
  - This is the longest part of the conclusion and will be worth the most points.

- **Conclusions and Summary Statements (Reasoning)**
  - Use scientific principles to show why the data that you chose was important supports your initial claim.
  - For example, here is where you would make the jump from what you observed in the lab, to why it happened based on things we’ve learned in class.
  - This section is CONCISE and should only summarize the lab, but very important.
  - Sometimes this is the ONLY thing that you will be required to do for the lab.