Lab 5. Temperature Changes Due to Evaporation: Which of the Available Substances Has the Strongest Intermolecular Forces?

Introduction

Matter exists in three basic states: solid, liquid, and gas. Whether a substance is a solid, liquid, or gas at room temperature (20°C–25°C) depends on the properties of that specific substance. Oxygen, for instance, is a gas at room temperature, but water is a liquid. Substances also maintain their state over a broad range of conditions; for example, water is a liquid from 0°C all the way to 100°C. For a substance to transition from one phase to another, the conditions again must be just right. Transitioning from a solid to a liquid (i.e., melting) or transitioning from a liquid to a gas (i.e., boiling) requires a transfer of energy.

Boiling or vaporization is the process by which a substance changes from a liquid to a gas. Evaporation is vaporization that occurs at the surface of a liquid. Chemists explain the process of evaporation using the *molecular-kinetic theory of matter*. According to this theory, the molecules that make up a liquid are in constant motion but are attracted to other molecules by different types of *intermolecular forces*. The temperature of the liquid is proportional to the average *kinetic energy* of the molecules found within that liquid. Kinetic energy is the energy of motion. The kinetic energy of a molecule depends on its velocity and its mass. From this perspective, some of the molecules at the surface of a liquid will have greater or lower kinetic energy than the average. Some of the molecules will have enough kinetic energy to disrupt the intermolecular forces that hold it near the other molecules in the liquid. These molecules, as a result, will break away from the surface of the liquid. When this happens, the average kinetic energy of the remaining molecules in the liquid decreases. The temperature of a liquid therefore goes down as it evaporates.

There are several important factors that will influence the evaporation rate of a liquid. One of these factors is temperature. A liquid will evaporate faster at a higher temperature because more molecules at the surface will have enough kinetic energy to break free from the other molecules in that liquid. Another important factor is the type of intermolecular forces that exist between the molecules in that liquid. Intermolecular forces, as noted earlier, are attractive in nature. A liquid with weak intermolecular forces will evaporate quickly because it takes less kinetic energy for a molecule at the surface of the liquid to break away from the other molecules in the liquid. A liquid with strong intermolecular forces, in contrast, will evaporate slowly because the molecules that make up this type of liquid require more kinetic energy to break away from the other molecules at the surface of the liquid.

In this investigation, you will use what you have learned about evaporation, the molecular-kinetic theory of matter, and this brief introduction to intermolecular forces to determine the relative strength of the intermolecular forces that exist between the molecules in six different types of liquids. This is important for you to be able to do because chemists often need to rely on their understanding of intermolecular interactions to explain the bulk properties of matter. It is also important because it will help you understand the underlying reasons for several important natural phenomena, such as the water cycle or evaporative cooling, that have many practical applications for everyday life.

Your Task

Determine how temperature changes when six different liquids evaporate from a material and then rank the substances in terms of the relative strength of their intermolecular forces.

The guiding question of this investigation is, **Which of the available substances has the strongest intermolecular forces?**

Materials

You may use any of the following materials during your investigation:

Consumables	Equipment
• Filter paper • Rubber bands • Acetone, $(CH_3)_2CO$ • Ethyl alcohol, CH_3CH_2OH • Heptane, C_7H_{16} • Hexane, C_6H_{14} • Isopropyl alcohol, $(CH3)_2CHOH$ • Methyl alcohol, CH_3OH	• Temperature sensor kit • Test tubes w/ stoppers • Test tube rack • Pipettes

Safety Precautions

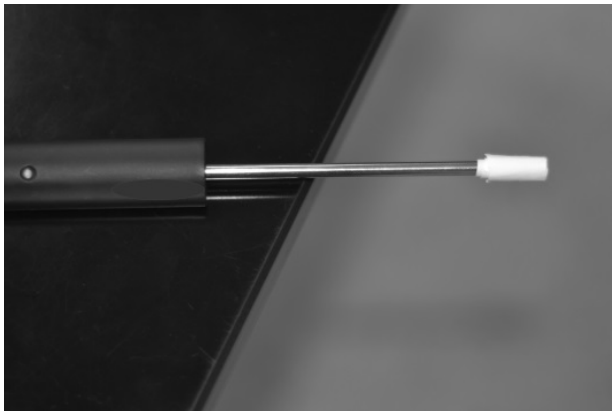
Follow all normal lab safety rules. Acetone, ethyl alcohol, heptane, hexane, isopropyl alcohol, and methyl alcohol are flammable liquids. Acetone, ethyl alcohol, and heptane are each moderately toxic by ingestion and inhalation. Given the fire and health hazards associated with these chemicals, all lab work must be done under a fume hood. In addition, take the following safety precautions:

- Wear indirectly vented chemical-splash goggles and chemical-resistant gloves and apron while in the laboratory.
- Handle all glassware with care.
- Wash your hands with soap and water before leaving the laboratory.

Investigation Proposal Required? ☐ Yes ☐ No

FIGURE L5.1

Temperature probe with filter paper



Getting Started

The first step in this investigation is to carry out a series of tests to determine how the temperature of each substance changes as it evaporates. One way to generate these data is by attaching a small piece of filter paper to a temperature probe using a rubber band (see Figure L5.1). Then briefly soak the filter paper in one of the substances, remove the apparatus from the liquid, and observe as the liquid evaporates from the filter paper.

Before you begin your tests, however, you will need to determine what type of data you need to collect during each test, how you will collect the data, and how you will analyze the data.

To determine *what type of data you need to collect*, think about the following questions:

- What type of measurements or observations will you need to record during each test?
- How often will you need to make these measurements or observations?

To determine *how you will collect the data*, think about the following questions:

- How long will you need to conduct each test?
- What types of comparisons will you need to make?
- What will you do to reduce measurement error?
- How will you keep track of the data you collect and how will you organize it?

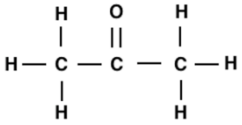
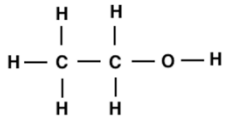
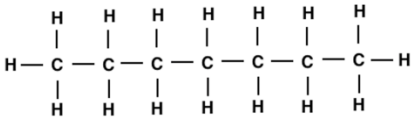
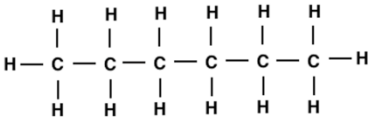
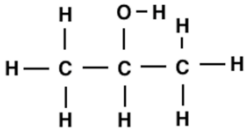
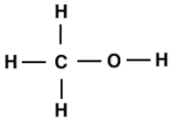
To determine *how you will analyze the data*, think about the following questions:

- What type of calculations will you need to make?
- What type of graph could you create to help make sense of your data?

The second step in your investigation will be to develop a way to rank order the substances in terms of the relative strength of their intermolecular forces. At this point in the investigation, it may also be useful to consider the molecular characteristics of each substance, such as the molecular structure or shape, molar mass, whether the molecule is polar, and so on. Table L5.1 provides the structural formula for each substance for comparison purposes.

TABLE L5.1

Molar mass and the structural formulas of the substances used in this investigation

Substance	Molar mass	Structural formula
Acetone	58.08 g/mol	
Ethyl alcohol	46.07 g/mol	
Heptane	100.21 g/mol	
Hexane	86.18 g/mol	
Isopropyl alcohol	60.10 g/mol	
Methyl alcohol	32.04 g/mol	

Connections to Crosscutting Concepts, the Nature of Science, and the Nature of Scientific Inquiry

As you work through your investigation, be sure to think about

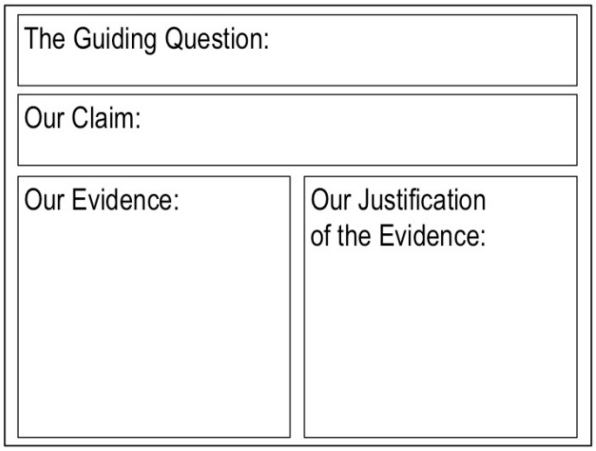
- how energy and matter flow within systems,
- the importance of the structure of molecules in relation to the ways they function,
- the nature and role of experiments in science, and
- the difference between observations and inferences.

Initial Argument

Once your group has finished collecting and analyzing your data, you will need to develop an initial argument. Your argument must include a *claim*, which is your answer to the guiding question. Your argument must also include *evidence* in support of your claim. The evidence is your analysis of the data and your interpretation of what the analysis means. Finally, you must include a *justification* of the evidence in your argument. You will therefore need to use a scientific concept or principle to explain why the evidence that you decided to use is relevant and important. You will create your initial argument on a whiteboard. Your whiteboard must include all the information shown in Figure L5.2.

FIGURE L5.2

Argument presentation on a whiteboard



Argumentation Session

The argumentation session allows all of the groups to share their arguments. One member of each group stays at the lab station to share that group's argument, while the other members of the group go to the other lab stations one at a time to listen to and critique the arguments developed by their classmates. The goal of the argumentation session is not to convince others that your argument is the best one; rather, the goal is to identify errors or instances of faulty reasoning in the initial arguments so these mistakes can be fixed. You will therefore need to evaluate the content of the claim, the quality of the evidence used to support the claim, and the strength of the justification of the evidence included in each argument that you see. To critique an argument, you might need more information than what is included on the whiteboard. You might therefore need to ask the presenter one or more follow-up questions, such as:

- What did your group do to analyze the data, and why did you decide to do it that way?
- Is that the only way to interpret the results of your group's analysis? How do you know that your interpretation of the analysis is appropriate?
- Why did your group decide to present your evidence in that manner?
- What other claims did your group discuss before deciding on that one? Why did you abandon those alternative ideas?
- How confident are you that your group's claim is valid? What could you do to increase your confidence?

Once the argumentation session is complete, you will have a chance to meet with your group and revise your original argument. Your group might need to gather more data or design a way to test one or more alternative claims as part of this process. Remember, your goal at this stage of the investigation is to develop the most valid or acceptable answer to the research question!

Report

Once you have completed your research, you will need to prepare an *investigation report* that consists of three sections that provide answers to the following questions:

1. What question were you trying to answer and why?
2. What did you do during your investigation and why did you conduct your investigation in this way?
3. What is your argument?

Your report should answer these questions in two pages or less. The report must be typed and any diagrams, figures, or tables should be embedded into the document. Be sure to write in a persuasive style; you are trying to convince others that your claim is acceptable or valid!