**Determining the Relative Strength of Intermolecular Forces**

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**Introduction**

**Theoretical background**

Intermolecular Forces (IMF) are the forces between molecules that attract them to each other. There are mainly three types of intermolecular forces: dipole-dipole forces, hydrogen bonding, and London (dispersion) forces.

Dipole-dipole forces are attractions between positive and negative poles of polar molecules; Hydrogen bonding is a particular type of dipole-dipole interactions between molecules containing O-H, N-H, or F-H bonds;

London force is the weakest intermolecular force yet is present in all molecules in solid and liquid state. It is produced because, electrons in an atom are in random motion. Thus, at every instantaneous moment, the electrons will not be evenly distributed and thus results in temporary dipole on a certain side, and thus produce attracting force with the neighboring molecules. Thus, the larger the molar mass, the larger the dispersion, and thus resulting in lager London force. However, London forces are still relatively small comparing to stronger bonds of dipole-dipole forces.

Because of the difference in these intermolecular forces of different molecules, the physical properties of different substances vary.

First is the boiling point. To boil a substance requires enough heat energy to break the bonds. The boiling point, i.e. the energy, is different for different substances, because their intermolecular forces are different. Higher boiling points usually implies a strong intermolecular force.

Also, surface tension can be influenced by intermolecular forces: the larger the force, the more cohesive the molecules are and thus the larger surface tension.

Similarly, viscosity, which describes a substance’s resistance to flow, can also increase when the intermolecular forces increase, because stronger intermolecular forces can make it harder for a substance to flow.

The strength of intermolecular forces, therefore, affects many physical properties like surface tension, viscosity and boiling point.

**Aim**

The aim of this experiment is to determine the relative strength of intermolecular forces of different molecules—distilled water, ethanol, acetone and heptane—by the methods of boiling point, surface tension and viscosity.

Table 1. substances for the experiment (PubChem)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Substance | Formula | Structural Formula | Molar mass (g/mol) | Types of IMF |
| Distilled water | H2O | Image result for water structure | 18.015 | Dipole-dipole,  H-bond, LDF |
| Ethanol | C2H5OH | Image result for ethanol | 46.07 | Dipole-dipole,  H-bond, LDF |
| Acetone | (CH₃)₂CO | Related image | 58.08 | Dipole-dipole, LDF |
| Heptane | H₃C(CH₂)₅CH₃ | Image result for heptane | 100.21 | LDF |

The table above is a summary of some basic information about each of the substances.

**Hypothesis**

We hypothesize that among the four chemicals, due to the strong hydrogen bonding of water and ethanol, acetone and heptane should have weaker IMFs, and thus lower boiling points, smaller viscosity and smaller surface tension. Also, even though acetone is partially polar (only with C=O) while heptane is non-polar, the molar mass of heptane is almost twice that of acetone, so we hypothesize that heptane should have stronger IMFs. Moreover, water should be more polar than ethanol, as water molecule is polar with two hydrogen bonding yet ethanol is partially polar (only O-H).

Therefore, we hypothesize that the molecule with largest to least intermolecular force should be: water > ethanol > heptane > acetone.

**Methodology**

In this experiment, three methods will be used to determine the relative strength of the intermolecular forces between the substances.

The three methods are boiling point, surface tension, and viscosity.

**Method 1: boiling point**

The first method to determine the relative strength of each intermolecular forces is through boiling.

1. **Apparatus**

Four clean and dry beakers (25mL), a thermometer, a hot plate

1. **Procedure**
2. Measure out 10mL of each liquid in every beaker.
3. Put the beakers on the hot plate one at a time and heat them.
4. Wait until the liquid begins boiling and the water temperature becomes constant. Measure the boiling point of each.
5. Record all the data in a table.
6. **Variables**

Independent variable:

Different liquids and thus different intermolecular forces.

Control variable:

The volume of liquids, the initial temperature of the liquid, the room temperature, the shape of beakers, the atmospheric pressure.

**Method 2: surface tension**

The surface tension of each substance can be measured by the cohesion, i.e. the diameter of each drop. In consideration of sustainability, only one drop of each substance will be placed in a glass disk. The more spread out the liquid gets, the less surface tension it has.

1. **Apparatus**

A glass disk, a ruler (with precision of 0.1cm), a dropper

1. **Procedure**
2. Put the disk on a ruler.
3. Use a dropper to add a drop of the liquid under test on the glass dish above the ruler.
4. Adjust the disk slightly to obtain the rough estimate of the diameter of the drop.
5. Change to another liquid and repeat the procedure.
6. Compare the diameter of a drop of different liquids.
7. **Variables**

Independent variable:

Different liquids and thus different intermolecular forces.

Control variable:

The volume of each drop, the temperature of each liquid, the room temperature, the atmospheric pressure.

**Method 3: viscosity**

The viscosity of a substance can be measured by the speed of flowing. i.e. the time it takes to flow over a same distance. In consideration of sustainability, each time, one drop of each liquid will be added to the wall of a test tube and the time for it to reach the bottom will be recorded.

**Apparatus**

A test tube, a marker, a dropper, a timer, a clamp stand.

1. **Procedure**
2. Use the marker to mark the starting position of the liquid at the top of the test tube.
3. Clamp the test tube with a certain inclination.
4. Use the dropper to put one drop of a liquid onto the mouth of the test tube.
5. Start timing as soon as the drop reaches the mark.
6. Stop the timer as soon as the drop reaches the bottom of the test tube.
7. Rotate the test tube but keep the inclination same, so that we can make sure the wall is dry for the next trial.
8. Change to different liquids and repeat the process.
9. **Variables**

Independent variable:

Different liquids and thus different intermolecular forces.

Control variable:

The volume of each drop, the temperature, the dryness of the wall of test tube, the distance each drop travels, the inclination of the test tube.

**Data and Calculation**

**Raw data**

Table 2. boiling points for different substances

|  |  |  |
| --- | --- | --- |
|  | Boiling point (℃) | Uncertainty (℃) |
| DI water | 98 | 0.5 |
| Ethanol | 80 | 0.5 |
| Acetone | 55 | 0.5 |
| Heptane | 92 | 0.5 |

Table 3. the diameter for a drop of different substances

|  |  |  |
| --- | --- | --- |
|  | Diameter (cm) | Uncertainty (cm) |
| DI water | 0.8 | 0.1 |
| Ethanol | 1.7 | 0.1 |
| Acetone | 1.9 | 0.1 |
| Heptane | 1.4 | 0.1 |

Table 4. the time for travelling a certain distance

|  |  |  |  |
| --- | --- | --- | --- |
|  | Trial 1 (s) | Trial 2 (s) | Trial 3 (s) |
| DI water | 2.3 | 2.7 | 2.4 |
| Ethanol | 1.7 | 1.2 | 0.9 |
| Acetone | 0.6 | 0.7 | 0.7 |
| Heptane | 1.0 | 0.9 | 1.3 |

**Processed data**

Table 5. a summary for processed data

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Boiling point | | Surface tension | | Viscosity | |
| Boiling point (℃) | Uncertainty (℃) | Diameter (cm) | Uncertainty (cm) | Mean time travels (s) | Uncertainty (s) |
| DI water | 98 | 0.5 | 0.8 | 0.1 | 2.5 | 0.2 |
| Ethanol | 80 | 0.5 | 1.7 | 0.1 | 1.3 | 0.4 |
| Acetone | 55 | 0.5 | 1.9 | 0.1 | 0.7 | 0.05 |
| Heptane | 92 | 0.5 | 1.4 | 0.1 | 1.1 | 0.2 |

From the table above, we can obtain the sequence from highest to lowest for the boiling points: Water > heptane > ethanol > acetone, which is also the first estimation of IMFs from largest to least, as the stronger the forces, the harder it is to break the bond.

Also, since the larger the IMFs, the more curve the drop and the less the diameter, we can also get the IMF from largest to least according to the data from surface tension: Water > heptane > ethanol > acetone;

Lastly, the smaller the time, the faster a substance flows, which means that the viscosity is larger and the IMF is stronger. Thus, we can get the third sequence from largest to least according to viscosity that: Water > ethanol > heptane > acetone.

**Sample calculation**

The sample calculation of the uncertainty for the third method:

Therefore, the uncertainty for the time water takes to travel along the tube is 0.2s.

**Conclusion and Evaluation**

In conclusion, by putting the results of the three methods together to determine the relative strength between them, we can get:

Water > heptane > ethanol > acetone.

It can be affirmed that water indeed has the strongest intermolecular forces, and acetone has the weakest. However, there is some controversy between heptane and ethanol, as the experiment shows that ethanol has higher viscosity, while heptane has higher boiling point and stronger surface tension. Hypothesis also states that ethanol has stronger IMF.

The reason could be because of the relatively large molar mass of heptane that it outweighs the strength of the H-bonding in ethanol. Because ethanol is only partially polar and there is one Hydrogen bonding present in one molecule.

Still, the reason should contribute more to the errors present in this experiment:

In the first method of boiling point, some of the data may not be very accurate. First, because of the small amount of liquid we used on behalf of sustainability, as well as some liquids evaporate at a high rate, the bulbs of thermometer may not be completely immersed in the liquids when the liquid starts boiling. To solve this problem and still use a small amount of chemicals, we can use a Bunsen burner to heat an appropriate amount of liquids in a test tube, which has longer length and smaller diameter. Also, because of the limitation of time, some of the data are took in a hurry and may not be that accurate.

In the second method of surface tension, there exist a lot of random errors. First, we could not guarantee that every drop we put on the glass disk was of the same volume, so that the diameter may be affected. Also, the measurement is only done by eyes and the diameter is estimated by ourselves, there can be errors existing. Moreover, some of the drops are not perfect circles, which makes it even harder to determine the diameter of the drop. We should do more trials if we could have more time. Alternatively, we can use a better method by adding a layer of liquid into the glass disk, and resting a piece of glass on the surface of the liquid that is connected to forcemeter. Then we can compare the strength of different surface tensions by comparing the forces needed to lift the glass off the surface of the liquid. That can effectively address all the problems exist in our method, but may not be as environmentally friendly as this one.

In the third method of viscosity, there are also many errors. The first one is human reaction time, as all the time that we collected was by ourselves using a timer on phone. A better approach may be taking videos and analyzing afterwards. Also, it is hard to control the amount of chemicals we added, which results in different flowing speed and leads to errors. Also, even though we tried to dry the tube or use another side of it, some of the chemicals were added before the tube completely dries because of time limitation. So that the later liquids actually mixed with some of the former ones, which will influence the final result. To deal with this, we can use ethanol to wash the tube and since ethanol is easy to evaporate, the tube will dry much faster.

In conclusion, by the methods of boiling points, surface tension and viscosity, we can affirm that among the four chemicals of distilled water, ethanol, acetone and heptane, water has the strongest intermolecular forces while acetone has the weakest, with ethanol and heptane in between. However, no clear conclusion can be drawn for the relative strength between heptane and ethanol because of the different results from different method. We still need more accurate experiments and more thorough analysis before asserting a final convincing result.

**Works cited**

“PubChem Structure Search.” *National Center for Biotechnology Information. PubChem Compound Database*, U.S. National Library of Medicine, pubchem.ncbi.nlm.nih.gov/search/search.cgi.