Physical Properties of Organic Solvents

Purposes of this lab:

- To become familiar with the names and properties of the organic liquids that we will use as solvents in the organic chemistry lab.
- To learn how to measure density, solubility, and boiling points.
- To learn how to properly record a laboratory experiment
- To learn the process of organizing experiments, deciding on necessary tasks, dividing up the work load, collecting data, and drawing conclusions from the data.

Introduction:

In general chemistry, as well as in everyday life, the most common liquid is water. Water can dissolve many different compounds, and is found in all kinds of solutions, including beverages like milk, orange juice, and root beer; bodily fluids like blood, urine, and tears; commercial products like window cleaner, aftershave lotion, and battery fluid; and laboratory solutions like 1.0 M NaOH, saturated $NaHCO_3$, or 25% NH_4OH. If the solvent isn't given, it is assumed to be water. It may also be specified by using the word "aqueous," as in "aqueous sodium bicarbonate," which means a solution of sodium bicarbonate in water.

In organic chemistry, however, we several other clear, colorless liquids that look like water but do not behave like water. They boil at different temperatures, evaporate more (or less) easily, have different viscosities, different densities, different surface tension, and even smell different. They also dissolve different kinds of compounds. They are important tools for working with organic compounds, so it is important that you become familiar with them.

The behavior of the organic solvents is determined by their molecular structures. With experience, you will be able to predict how a solvent will behave by knowing its structure; this lab will help you to begin getting that experience. As you investigate the properties of the solvents, you will look for relationships between the structure of the molecule and how soluble it is in water, what its density is, what its boiling point is, and what kinds of other molecules it will dissolve.

Some organic solvents will dissolve in water; if you pour them together they will mix. Others don't mix; instead they form a separate layer with a visible boundary between them. This is called their solubility in water. It depends on whether the molecular forces in the solvent are similar to or different from the molecular forces in water. The more similar the intermolecular forces are, the more likely it is that the solvent will dissolve in water. For practical reasons, it will be very important for you to know which solvents dissolve in water, and which won't.

Most organic solvents have a lower density than water, while a few are more dense than water. The density of an organic solvent is determined by how strong the intermolecular forces are and how heavy the atoms in the molecules are. Molecules with light atoms and weak intermolecular forces have low densities, while molecules with heavier atoms or stronger intermolecular forces have higher densities. It will be important for you to know which solvents are more dense than water and which are less dense – this is particularly important for solvents which are not soluble in water so that you can tell if a solvent will float on top of water or sink beneath it.

Some organic solvents evaporate easily and boil at low temperatures, while others evaporate more slowly and boil at higher temperatures. The boiling point of a solvent is determined by the size of its molecules as well as by the strength of its intermolecular forces. Solvents with low boiling points evaporate easily, and can easily be removed by mild heating. It will be important for you to know which solvents are low boiling, which are intermediate, and which are high boiling. Boiling points are also affected by the atmospheric pressure at which the measurement is taken – if the pressure is lower, then the measured boiling point will be lower as well. St. George is at an altitude of approximately 2860 feet, so boiling points will typically be between 2-5 degrees lower than at sea level.

The ability of a solvent to dissolve other compounds (which could be solids, liquids, or gases) depends on how similar its polarity is to the compound. Nonpolar solvents are best for nonpolar compounds, while more polar solvents are best for polar compounds, but organic compounds often show a wide range of solubility in organic solvents. Ionic compounds will only dissolve in highly polar solvents, with water usually being the best solvent. The dielectric constant, a physical measurement of how a substance interacts with an electric field, can be used to compare the polarity of different solvents. It will be important for you know which solvents have which range of polarity, so that you can judge the solubility of organic compounds in them.

Rather than talking about intermolecular forces molecules, we often use the word "polarity." Organic liquids with weak intermolecular forces are said to be nonpolar; organic liquids which have very strong intermolecular forces are said to be highly polar. Organic solvents are spread across the range from nonpolar to low polarity to moderately polar to highly polar. Since water is a very polar solvent, only moderately or highly polar organic solvents will dissolve in it.

In this lab, you will investigate the following:

Part 1 – the solubility of organic solvents in water
Part 2 – the density of organic solvents compared to water
Part 3 – the boiling points of organic solvents
Part 4 – the solubility of organic solids in different solvents

As you do so, you will look for relationships between the molecular structure of the solvents and how they behave.

Instructions:

Before you come to lab:

- Print out a copy of this lab and read through the introduction and procedures. Put it in your binder and bring it to lab.

- Print out a copy of "Keeping a Notebook" (found on the course website), and put it in your binder as well. Read it carefully.

- Write an introduction in your lab notebook explaining the purpose of the lab in your own words.

- Copy the solvent table below into your lab manual and fill in the last two columns. Do your best without consulting classmates first, then compare your answers either before you come to lab or as soon as you come to lab before it starts.

- Complete the pre-lab questions on-line before the deadline.

- On a piece of notebook paper (not in your lab notebook), legibly jot down the following for parts 1-4 of the lab:
  - what data you should obtain,
  - a table that would make sense to gather this data,
  - a plan for gathering this data,
  - what kinds of conclusions you hope to be able to make from the data you will collect.

Solvent table:

solvent	alternate names	formula	structure	functional group
acetone		CH_3COCH_3		
dichloromethane	methylene chloride	CH_2Cl_2		
diethyl ether	ethyl ether or ether	$CH_3CH_2OCH_2CH_3$		
ethanol	ethyl alcohol	CH_3CH_2OH		
ethyl acetate		$CH_3CO_2CH_2CH_3$		
hexane		$CH_3(CH_2)_4CH_3$		
methanol	methyl alcohol	CH_3OH		
toluene		$C_6H_5CH_3$		
water		H_2O		

During lab:

- In each part of the lab, first participate in the discussion and planning, then do your part in the data collection and recording, and then participate in a brief discussion of the results.

- After all of the parts are complete, participate in a final discussion of possible conclusions that can be gathered from the data collected.

After lab:

- Write your own conclusions in your lab notebook, using data collected during lab to support your claims.

- Answer the post lab questions in your lab notebook.

<u>Procedures</u>:

Part 1 – Procedure for determining the water solubility of an organic solvent:

Add some water to a test tube. Then add about the same amount of the solvent to it and observe what happens. Does it dissolve, sink, or float? Make sure to shake or vigorously stir the two liquids before deciding for sure. Solvents can be obtained from the bottles by either pouring or using a plastic pipet. Each solvent should be tested by more than one team, and the observations compared. When you are finished, dispose of the waste appropriately.

Part 2 – Procedure for determining the density of an organic solvent:

Measure a known volume of solvent as carefully as you can, then measure the mass of that volume and divide so that you know how much one ml of the solvent weighs. The smaller the amount that you measure, the greater any error will be. Possible devices for measuring volume include a graduated cylinder, graduated pipet, or a syringe. Be careful not to allow evaporation of the solvent to occur between the time you measure the volume and the mass. You may need to obtain a careful mass of the measuring device before and after adding the solvent. At least two groups should measure each solvent. Compare your measurements with the density given in the Aldrich catalog. See if your observations from the density experiment match your results. Dispose of the waste appropriately.

Part 3 – Procedure for determining the boiling point of a solvent:

Measure the temperature of the vapors of each boiling solvent using the instructions below. Because of time considerations, each boiling point will be measured by only one group, but the measurements should be checked against the value in the Aldrich catalog.

1. Add about 3 ml of a solvent to a conical vial. Put in a spin vane, point down.

2. Add a reflux condenser, and secure it with a clamp. Hook up the tubing so that the water goes from the spigot to the bottom of the condenser, then out the top of the condenser and into the drain.

3. Insert a thermometer so that the bottom is just above the level of the liquid. Secure the thermometer with a thermometer clamp (you will have to use a separate support stand, as our thermometer clamps are not the same length as the regular clamps).

4. Wrap a piece of aluminum foil around the glassware where the thermometer end is to keep the heat from escaping and allow a more accurate measurement.

5. Turn on the water, then the heating and stirring. Observe the thermometer until the temperature stabilizes. Record this temperature.

6. Remove the insulation and allow the apparatus to cool. Do not remover the thermometer while it is still hot – sliding it past the cold reflux condenser can crack the glass.

Part 4 – Procedure for determining the solubility of organic compounds in the solvents:

Five solid organic compounds have been provided: naphthalene, benzophenone, vanillin, benzoic acid, and citric acid. These are in order from least polar to most polar. Determine the solubility of each compound in each of the solvents by adding around 100 mg of the solid to approximately 2 ml of each solvent. Shake or stir and allow it to sit for a few minutes, then observe whether the solid dissolves.

At least two different teams should perform each set of experiments. Use this data to put the solvents in order of polarity. Compare your conclusions with the dielectric constant for each solvent in the table that will be provided. Dispose of the waste appropriately.

Questions:

1) Petroleum ether is another organic solvent – it is a mixture of hydrocarbons obtained by the distillation of petroleum. Would it be classified as polar or nonpolar? Would you expect it to be miscible or immiscible with water? (2 pts)

2) Only one of the common solvents is more dense than water. Which is it? Explain why it makes sense that this solvent should be unusually dense. (2 pts)

3) Organic liquids A, B, and C have densities of 0.69 0 , 0.955 g/ml, and 1.126 g/ml. A and C are low polarity solvents, while B is a high polarity solvent. When each is added to water, how would you expect them to behave? (3 pts)

4) Why are the boiling points we measured in the lab lower than the ones in the catalogue? Are melting points affected by this issue? Why or why not? (3 pts)

5) Why does ethyl acetate have a higher boiling point than hexanes, even though they are approximately the same molecular weight? (1 pt)

6) Why does methanol have a lower boiling point that ethanol even though it is more polar? (1 pt)

7) Why does ethanol have a higher boiling point than ethyl ether even though ethyl ether is heavier? (1 pt)

8) 2-Methylbenzamide and 3-nitrobenzoic acid both have a melting point of 140.1 - 140.4 ^{o}C. However, if you mixed them together and took the melting point, it would not be140.1 - 140.4 ^{o}C. Why not? (Hint - this is not the result of a chemical reaction!) (1 pt)