Identification of a Substance by Physical Properties

Every substance has a unique set of properties that allow us to differentiate between them. These properties are classified as **physical properties** and **chemical properties**. Physical properties are those that can be determined or measured without changing the composition or identity of the substance. These properties include color, odor, taste, density, melting point, boiling point, conductivity, and hardness. Chemical properties tell us how the substance interacts with other substances and may include reaction with oxygen (oxidation), chlorine, metals, etc.. Determination of chemical properties results in the change of the identity of the substance.

Some properties, such as solubility, melting point, boiling point, and density are independent of the amount of substance being examined. These properties are known as **intensive properties** and are used to identify a substance. **Extensive properties,** such as mass and volume depend on the amount of substance present and are not useful in the identification of a substance.

In this experiment, we will use three properties to identify a liquid substance: solubility, density and boiling point..

The **solubility** of a substance is usually expressed as the mass of a substance, in g, that will dissolve in a fixed amount of solvent (liquid), usually 100 g, at a given temperature. Depending on the molecular structure of the substance, it will have different solubility in different solvents depending on the nature of the solvent. For example, sodium chloride (table salt) is an ionic compound and is soluble in a polar solvent such as water, but it is insoluble in a non-polar solvent such as cyclohexane or toluene. If a solvent has properties somewhere between the polar solvent and the non-polar solvent (then it is weakly polar), the sodium chloride may only be slightly soluble. In this experiment, we will use three solvents to compare solubilities: water (polar), cyclohexane (non-polar), and ethanol (weakly polar). The solubilities will be recorded as soluble (completely dissolved), slightly soluble (partially dissolved), or insoluble.

The **density** of a substance is defined as the mass per unit volume. Mass is usually measured in g and volume in mL or cm^3. Substances such as lead or gold have high densities and we recognize these substances as being “heavy”. Other substances such as aluminum or titanium have low densities and we recognize these elements as being “light in weight”. Density does vary with the temperature of the substance, so it is usually expressed at 20°C, which is considered to be room temperature. For most substances, the variation in density with temperature is small. The density of water from 0° to 30°C, is tabulated in Table 1.

The **boiling point** of a liquid is that temperature at which it is converted from a liquid to a gas. This process occurs at a constant temperature which we call the boiling point. At the boiling point, the temperature of the liquid is the same as the escaping vapor (or gas). Although the boiling point does vary slightly with the prevailing atmospheric pressure, we will use the normal boiling points at one atmosphere pressure.

Materials Needed

Solubility

Test tubes, 12 x 75 mm
Test tube rack
Dropper
10 mL graduated cylinder
Cyclohexane
Distilled or deionized water
Ethanol (absolute)

Density

5-mL or 10-mL volumetric flask
Dropper
Distilled or deionized water
Acetone (95%)
Test tube holder
Thermometer, 110 or 120°C
Drying oven

Boiling Point

Test tube, 6 x 50 mm
Glass capillary tube, closed one end
150-mL beaker
Dropper
Rubber tubing or small rubber band
Scissors
Triangular file
Test tube holder
Thermometer clamp
2 support rings
Wire gauze
Bunsen burner

Safety Precautions

The unknown liquids used in this experiment are flammable. Although the danger of fire is greatly reduced by the use of small samples, it is not eliminated. Keep all liquid samples away from open flames.

Avoid inhaling vapors from volatile liquids. The vapors from the liquids used in this experiment may be irritating and can be toxic if exposed to the vapors for long periods of time. These problems are minimized by using small amounts of the liquids. If you are bothered by the odors of any liquids, work in the fume hood.

Avoid skin contact with the volatile liquids.

Disposal

Dispose of all liquids, other than water, in the proper waste container.

Procedure

You will use the same unknown liquid for all three parts of this experiment. You will receive a sufficient amount of the unknown liquid (between 15 and 20 mL) to complete the experimental procedure and to recheck your results if necessary. Additional samples of the unknown liquids will not be provided.

1. Solubility

A. Solubility in cyclohexane (a non-polar liquid)

Place 1 mL of cyclohexane to a 10 x 75 mm test tube. Add three drops of the unknown liquid to the test tube. Agitate the mixture in the test tube. Does the liquid dissolve in the cyclohexane? If you are not sure about the solubility, add one or two more drops of the liquid to the test tube and observe the results.

B. Solubility in water (a polar liquid)

Repeat the solubility test from part A using 1 mL of water in place of the cyclohexane.

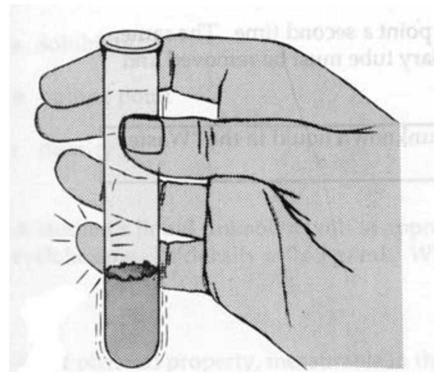

Figure 1. Agitate by tapping test tube with little finger

C. Solubility in ethanol (an organic polar liquid)

Repeat the solubility test from part A using 1 mL of absolute ethanol in place of the cyclohexane.

2. Density

A. Calibration of a Volumetric Flask

Obtain a 5-mL or 10-mL volumetric flask from the stockroom.

Determine the mass of the clean, dry 5 or 10-mL volumetric flask. Fill the volumetric flask with room temperature distilled or deionized water to the fill line. Determine the mass of the flask plus water. Determine the temperature of the water in the flask to the nearest 0.3°C. Using the mass of the water, and its density, calculate the volume of the volumetric flask.

Rinse the volumetric flask with two separate 1.0 mL portions of acetone. Pour the waste acetone into the proper waste bottle. Dry the flask by placing it in the drying oven for approximately 5 minutes. Use a test tube holder when removing the flask from the drying oven. Allow the flask to cool to room temperature. (About 5 minutes.)

B. Determination of Density

Fill the volumetric flask with your unknown liquid to the fill line. Determine the mass of the flask plus liquid. Determine the density of the liquid.

The liquid, if not contaminated, can be used for the boiling point determination. Dispose of any excess liquid in the proper waste container.

Clean and dry the volumetric flask before returning it to the stockroom.

3. Boiling point by microscale boiling point determination

Safety note: The boiling point, like the melting point, is used to characterize a liquid substance and is particularly useful for identifying organic liquids. Many organic liquids, however, are flammable and this determination must be done with care. This procedure provides a safe and simple method for determining the boiling point of a flammable, volatile liquid.

Procedure

Obtain a 6 x 50 mm test tube. Holding it with a test tube holder, slowly heat the test tube from the bottom to the open top to remove any water condensed on the interior of the tube. Place the tube on a ceramic hot pad to cool before use.

Obtain a 120°C thermometer and assemble the boiling point apparatus (See Figure 2)

Obtain a glass capillary tube. Using the file, carefully cut a piece 3 to 4 cm long, measuring from the closed end of the tube. Place this tube, open end down, into the micro boiling point tube prepared above.

Using a clean, dry dropper, add 10 drops of the unknown liquid to the test tube attached to the thermometer. The depth of the liquid in the tube should be about 1.5 to 2.0 cm high.

Using a Bunsen burner, gently heat the beaker of water to produce a temperature increase of between 5 to 10 degrees a minute. While the system is being heated, bubbles will come out of the open end of the capillary tube.

When a rapid and continuous stream of bubbles comes out of the small capillary tube and passes through the liquid, discontinue heating and allow the apparatus to cool.

The stream of bubbles will slow as the apparatus cools. When the bubbles stop coming out of the capillary tube and just before the liquid enters it, read and record the temperature on the thermometer. This temperature is the boiling point of the liquid.

If all the liquid evaporates, remove the burner, allow the apparatus to cool, and add additional liquid to the test tube. Repeat the heating process.

Repeat the boiling point determination a second time to confirm your results. If the two determinations do not agree, repeat the boiling point determination a third time.

Clean-up and Disposal:

Dispose of any remaining liquid in the proper waste container.

The 6 x 50 mm test tube can be cleaned and dried in the burner flame (CAUTION: Flammable liquid residue may be present), and reused. Be sure to hold the test tube with a test tube holder.

Dispose of the capillary tubes in the glass disposal box.

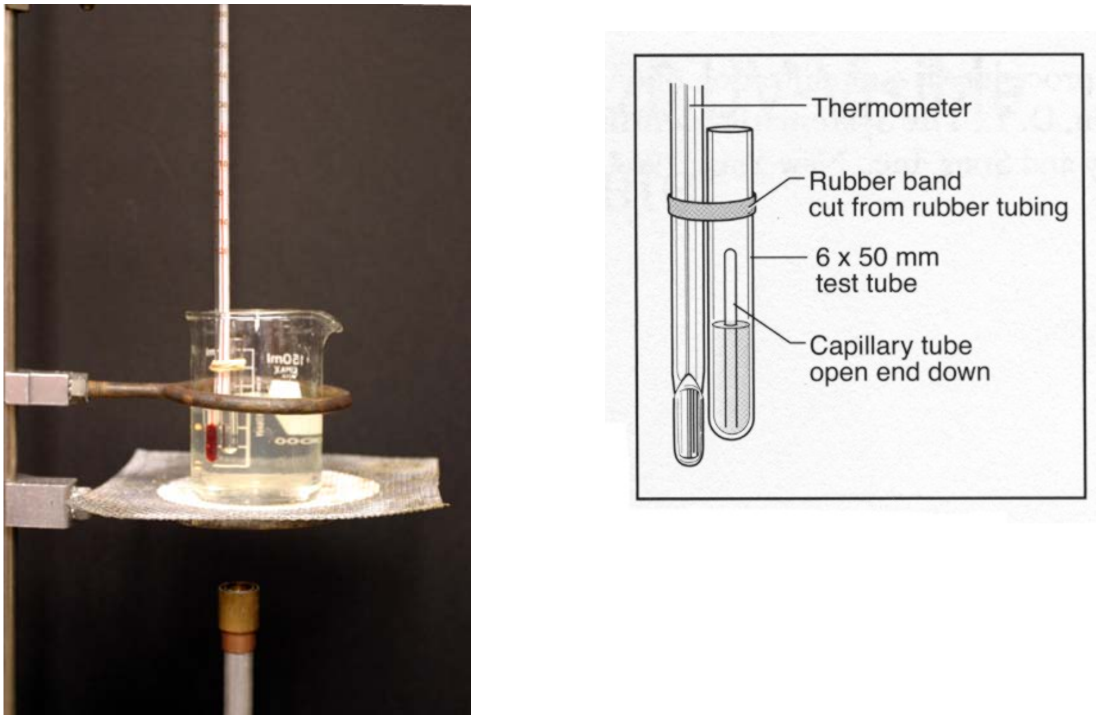

Figure 2. Micro boiling point apparatus with detail shown on the right.
(The thermometer is supported by a thermometer clamp.)

Data Analysis

Tabulate your data and compare your results with the values in Table 2.

Determine the identity of the unknown liquid and calculate the percent error in your values for density and boiling point.

Table 1. Density of Water (g/mL) at Various Temperatures (°C)

	0.0	0.3	0.5	0.7
0	0.999841	0.999860	0.999872	0.999884
1	0.999900	0.999914	0.999923	0.999930
2	0.999941	0.999950	0.999955	0.999960
3	0.999965	0.999969	0.999971	0.999972
4	0.999973	0.999972	0.999972	0.999969
5	0.999965	0.999959	0.999955	0.999950
6	0.999941	0.999931	0.999924	0.999916
7	0.999902	0.999888	0.999877	0.999866
8	0.999849	0.999830	0.999817	0.999803
9	0.999781	0.999758	0.999742	0.999726
10	0.999700	0.999673	0.999654	0.999635
11	0.999605	0.999574	0.999553	0.999531
12	0.999498	0.999463	0.999439	0.999415
13	0.999377	0.999339	0.999312	0.999285
14	0.999244	0.999202	0.999173	0.999144
15	0.999099	0.999054	0.999023	0.998991
16	0.998943	0.998893	0.998860	0.998826
17	0.998774	0.998722	0.998686	0.998650
18	0.998595	0.998539	0.998501	0.998463
19	0.998405	0.998345	0.998305	0.998265
20	0.998203	0.998141	0.998099	0.998056
21	0.997992	0.997926	0.997882	0.997837
22	0.997770	0.997701	0.997655	0.997608
23	0.997538	0.997466	0.997418	0.997369
24	0.997296	0.997221	0.997171	0.997120
25	0.997044	0.996967	0.996914	0.996862
26	0.996783	0.996703	0.996649	0.996594
27	0.996512	0.996429	0.996373	0.996317
28	0.996232	0.996147	0.996089	0.996031
29	0.995944	0.995855	0.995796	0.995736
30	0.995646	0.995555	0.995494	0.995433

Reference: Handbook of Chemistry and Physics, 62nd ed.

Table 2. Physical properties of some common liquids.

Compound	Density g/mL	Boiling point °C	Solubility		
			H_2O	C_6H_{12}	C_2H_5OH
acetone	0.79	56	s	s	s
2-butanone	0.805	80	s	s	s
cyclohexane	0.79	80.7	i	-	s
cyclohexene	0.81	83	i	s	s
ethanol	0.79	79	s	s	-
ethylacetate	0.90	77	sls	s	s
heptane	0.684	98	i	s	s
n-hexane	0.66	68	i	s	s
1-hexene	0.67	63	i	s	s
2-propanol	0.79	83	s	s	s
methanol	0.79	65	s	s	s
n-propanol	0.805	97	s	s	s
water	1.00	100	-	i	s

Symbols used: s = soluble, sls = slightly soluble, and i = insoluble