The Densities of Solutions and Solids

Objectives

The objectives of this laboratory are as follows:

- To compare the precision of various types of volumetric glassware.
- To determine, and then compare, the densities of regular and diet de-gassed sodas.
- To determine the density of an unknown metal and use this value to identify the metal.
- To use a common spreadsheet program, Microsoft Excel®, to perform graphical analysis of experimental data.

Background

Density is a fundamental physical property of matter. Physical properties are those characteristics of a substance that can be determined without changing the chemical identity of the substance. Other physical properties include melting point and solubility. In general, since different substances have unique densities, determining the density of an unknown substance can help identify it. Density is specifically defined as the ratio of a substance’s mass to its volume:

\[
\text{Density} = \frac{\text{Mass}}{\text{Volume}}
\]

The S.I. unit of density is kg/m³, but in chemistry it is more often expressed in units of g/cm³ for solids, and g/mL for liquids and solutions.

In Part A of this lab, a study of density values will be conducted in order to introduce the concept of precision and the statistical nature of experimental data. Specifically, the density of water will be determined using measurements obtained from three different types of volumetric glassware: a buret, a 100-mL graduated cylinder and a volumetric pipet. Multiple measurements will be performed so that a large ensemble of density values is acquired for each type of glassware used. Simple statistical analyses of the three data sets will then be carried out, including calculations of the average density and standard deviation. Note that an average value (\(x\)) is defined as the sum (\(\Sigma\)) of each of the measurements (\(x_i\)) divided by the number of measurements (\(N\)):

\[
\bar{x} = \frac{\sum x_i}{N}
\]

Standard deviation (\(s\)) is defined as:

\[
s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{N - 1}}
\]

Standard deviation essentially indicates the degree to which a set of measured values deviate from the average value. Data sets with a wide range of values (for example, see VG 2 data in the following figure) will have a larger standard deviation and are associated with less precise
measurements than data sets with a narrow range of values. With this information, the precision of the measurements obtained using the three types of volumetric glassware can be compared.

The three density data sets will also be displayed in a Scatter Plot, as shown below:

![Scatter Plot](image)

Occasionally one or more measurements in a data set will appear not to “fit in” with the others. This will often be evident upon close examination of a scatter plot. These points are called outliers – values that occur far outside the range defined by the rest of the measurements. One rough criterion for identifying an outlier is that it lies beyond two standard deviations from the average value. Such values may be legitimately excluded from a data set, as they can skew results to a great extent.

In **Part B**, the densities of two de-gassed sodas (regular and diet) will be determined and compared. Here, a buret will be used to dispense precise soda volumes. The masses of several different volumes of each soda will be measured, and this data will be used to determine the density of each soda.

This section of the lab will also clearly illustrate the intensive nature of density. An intensive property is one that is independent of the amount of matter present. This means that a pure substance will have the same density whether it is a larger sample or a small sample of that substance. In contrast, an extensive property is one that is dependent on the amount of matter present. Note that both mass and volume are extensive, however, since density is a ratio of these properties, density is an intensive property.

In **Part C**, the density of an unknown metal will be determined, and the metal identified using this value. Since mass can be more precisely measured than volume (due to the limitations of the instrumentation available), the technique employed here will involve mass measurements only. Using a capped glass vial, the following four mass measurements will be obtained:
The difference in masses A and B is the mass of the metal sample. The volume of the metal is obtained by taking the difference between the water volumes in C and D. These water volumes will be calculated using the water masses and the known density of water (see table below). Although simple, this method can yield density results accurate to 0.1%.

Once the density is determined, this experimental value will be compared to the true densities of several known metals (obtained from suggested reference sources) in order to identify the assigned unknown metal. The percent error between this experimental value ($EV$) and the true density value ($TV$) of the metal will also be calculated.

$$
Percent \ Error = \frac{|EV - TV|}{TV} \times 100
$$

Note that a more accurate experimental value will yield a lower percent error (< 5% is desirable) than a less accurate value.

<table>
<thead>
<tr>
<th>Temperature ($^\circ$C)</th>
<th>Density (g/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>0.9989</td>
</tr>
<tr>
<td>17</td>
<td>0.9988</td>
</tr>
<tr>
<td>18</td>
<td>0.9986</td>
</tr>
<tr>
<td>19</td>
<td>0.9984</td>
</tr>
<tr>
<td>20</td>
<td>0.9982</td>
</tr>
<tr>
<td>21</td>
<td>0.9980</td>
</tr>
<tr>
<td>22</td>
<td>0.9978</td>
</tr>
<tr>
<td>23</td>
<td>0.9975</td>
</tr>
<tr>
<td>24</td>
<td>0.9973</td>
</tr>
<tr>
<td>25</td>
<td>0.9970</td>
</tr>
<tr>
<td>26</td>
<td>0.9968</td>
</tr>
<tr>
<td>27</td>
<td>0.9965</td>
</tr>
<tr>
<td>28</td>
<td>0.9962</td>
</tr>
<tr>
<td>29</td>
<td>0.9959</td>
</tr>
</tbody>
</table>

*obtained from the CRC Handbook of Chemistry and Physics, 53rd Edition
Procedure

Safety

There are no major safety considerations in this lab.

Materials and Equipment

Materials: De-gassed sodas (regular and diet), unknown metal sample.
Equipment: 10-mL volumetric pipet and pipet bulb*, 50-mL buret*, two 50-mL Erlenmeyer flasks*, 100-mL graduated cylinder, two 100-mL beakers, 50-mL beaker, electronic balance, capped glass vial, thermometer, wash bottle filled with distilled water.

*Items with an asterisk must be checked out from the stockroom.

Part A: The Precision of Volumetric Glassware

All glassware should be cleaned and rinsed with distilled water before use. Pay special attention to significant figures in your recorded measurements.

1. Using a medium 100-mL beaker, obtain approximately 50 mL of distilled water from the supply in the lab.

2. Weigh a small **dry** 50-mL beaker on an electronic balance, and record this mass.

3. **Graduated Cylinder**: Fill the 100-mL graduated cylinder with approximately 10 mL of distilled water, and record the actual volume used. To how many significant figures should the volume be recorded? Transfer this distilled water into the small pre-weighed beaker, and measure the combined mass. When finished, empty the distilled water out of the small beaker, then carefully dry it.

4. **Volumetric Pipet**: Your instructor will demonstrate the correct use of the volumetric pipet at the beginning of the lab session. Use the pipet to transfer the exactly 10 mL of distilled water from the medium beaker into the small pre-weighed beaker. Record the volume used and the combined mass of the beaker and water. To how many significant figures should the volume be recorded? Again, empty the water out of the small beaker when finished, then carefully dry it.

5. **Buret**: Your instructor will demonstrate the correct use of the buret at the beginning of the lab session. Fill the buret with the remaining distilled water in your medium beaker and note the initial buret reading. Then drain approximately 10 mL of this water into the small pre-weighed beaker. Record the actual volume used (= final – initial buret reading) and the combined mass of the beaker and water. To how many significant figures should the volume be recorded?

6. For each of the three sets of data collected (using the graduated cylinder, volumetric pipet and buret), calculate the density of distilled water to the correct number of significant figures. Then share your three density values with all the students in your lab section, and record the results of the entire class on your report form. You should have at least ten density values for each type of volumetric glassware used in this part of the lab.
Part B: The Densities of Degassed Sodas

The following procedure should be performed for both a regular soda and a diet soda.

1. A buret will be used to dispense precise volumes of each of the two sodas used. The buret should first be rinsed with distilled water, and then rinsed with a small quantity of the relevant soda before filling it with that soda.

2. Using a medium 100-mL beaker, obtain approximately 40 mL of the regular soda from the stock bottle. Fill the buret with this soda, and record the initial buret reading.

3. Weigh a small dry 50-mL Erlenmeyer flask using an electronic balance, and record this mass. Then drain approximately 5 mL of the soda from the buret into this flask, and record the new buret reading. Finally, measure and record the combined mass of the flask and soda.

4. Next, add an additional 5 mL of soda from the buret to the flask. Again, note the new buret reading and the new combined mass of the flask and soda. Then repeat this step four more times. You will have obtained a total of six measurements and used approximately 30 mL of the soda when you are finished.

5. Now perform the same series of steps 1-4 using the diet soda. Use your second small (dry) Erlenmeyer flask for this soda.

Part C: The Density of an Unknown Metal

1. Obtain a capped glass vial and an unknown metal sample from your instructor. The cap on the vial should have a small hole pierced through it. This hole will allow air and excess water to be expelled from the vial. Record the ID Code of the metal on your report form.

2. All mass measurements are to be performed on an electronic balance, and should be recorded on your report form. First, weigh the empty, dry capped vial. Then add the entire sample of your unknown metal to the vial, and weigh it again (with cap).

3. Now fill the vial (with the metal still in it) to the brim with distilled water. Gently tap the vial to ensure that no air remains between the metal pieces. Place the cap on firmly, pressing out any air or excess water. Wipe off any drops of water on the outside of the vial, and then weigh it.

4. Next, remove the metal from the vial and then fill it to the brim with distilled water only. Place the cap on firmly, wipe off excess water, and weigh.

5. Finally, using your thermometer, measure and record the temperature of the water in the vial. When finished, dry the metal sample and vial, and return them to your instructor.