Chemistry 130 Pre-lab
Titrations: Part II

Background
We are going to treat the titration that you performed last week as a job interview for the chemistry division of a pharmaceutical company. The calculations that you do in this pre-lab exercise will provide you with an analysis of how well you did in the interview and help the company decide if it should hire you.

In the experiment/job interview last week your goal was to determine the concentration of a sodium hydroxide solution. To do this, you titrated a 0.06375\(\text{M}\) H\(_2\)SO\(_4\) solution with NaOH. You knew both the molarity and volume of the H\(_2\)SO\(_4\) solution that you started with and you used that information to find the concentration/molarity of the NaOH solution. Like any good scientist, you knew one measurement was not enough, so you performed at least three titrations. Ideally, the molarity of NaOH you obtained for each trial should be the same. This would make sense as all of the NaOH came from the same container.

The method the company is going to use to evaluate your skills during the job interview is to compare the closeness of your three values to each other and also by comparing your average NaOH concentration to the true NaOH concentration. You are going to have a second job interview with the same company this week. This job interview will also involve a titration. Whether or not you get hired depends on the titrations you did last week and to a larger extent on the titrations that you do this week. In the sections that follow, you are going to analyze your titrations the same way the company will. Based on your analysis of the titrations from last week, you will know if you need to change things or if you just need to keep up the same good work.

Analyzing Your Results
When experimental values are obtained in the laboratory it is important that we know how meaningful or good our measurements are. If possible, we want to determine how close our experimental value or the average of our experimental values is to what the value should be, i.e. the true value. If the true value is known, we can determine how accurate our experimentally obtained value is by calculating the absolute and percent relative errors. As we have already done these types of calculations multiple times this semester we won’t elaborate any more here.

If the true value is not known, we need some other way of determining how good our measurements are. In this case, one method for deciding the merit of our experimentally obtained values is by determining the precision of our measurements. Precision is a measure of the closeness of a set of experimentally obtained values to each other. The closer the values are the better the precision of the experiment. While good precision does not ensure that your results are accurate, in the absence of knowing a true value it provides an acceptable method for gauging the worth of your experimentally obtained values. It is assumed that if your precision is poor,
your results are probably not accurate. On the other hand, if your precision is good, it is assumed that your results are probably accurate.

In the text that follows, the calculations used to determine precision will be discussed. Additionally example problems will be given so that you get practice calculating precision. At the end of this pre-lab exercise, you will calculate the precision associated with your titrations last week.

**Calculating Precision**

When trying to determine the precision associated with a set of experimentally obtained values, you must perform a series of calculations. These calculations are outlined below and an example problem is given.

**Absolute Deviation, |d|**: is the absolute value of the difference between either two values, e.g. A and B, or a value and some average (or mean).

\[
|d| = |A - B| \quad \text{or} \quad |d| = |\overline{X} - B|
\]

**Percent Relative Average Deviation from the Mean, % rad**: This is the calculation/tool that the chemical company will use to best assess your precision. Although the length of this term is long and may seem overwhelming, it you take it a word at a time, you’ll see you already know how to calculate it. You will calculate the absolute deviation of each measurement from the mean, average them, making the average deviation relative (dividing by the average) and convert to a percent (multiplying by 100). The average deviation and %rad equations are shown below. The average deviation equation is shown for an example where there are four measurements. If there are more or less measurements, your average deviation equation will have more or less terms in the numerator.

\[
\text{average deviation (}|d|\text{)} = \frac{|\overline{X} - \text{Measurement 1}| + |\overline{X} - \text{Measurement 2}| + |\overline{X} - \text{Measurement 3}| + |\overline{X} - \text{Measurement 4}|}{4}
\]

\[
% \text{rad} = \frac{\text{average deviation}}{\overline{X}} \times 100\% \quad \% \text{rad} = \frac{|d|}{\overline{X}} \times 100\%
\]

In the example below, you will calculate the average, average deviation, and the percent relative average deviation for an sample experiment.
**Example**
The mass % of oxygen in calcium oxide was measured five times during an experiment. The five experimentally obtained values are shown in the table below.

<table>
<thead>
<tr>
<th>Trial #</th>
<th>Mass %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>56.08%</td>
</tr>
<tr>
<td>2</td>
<td>56.04%</td>
</tr>
<tr>
<td>3</td>
<td>55.95%</td>
</tr>
<tr>
<td>4</td>
<td>56.23%</td>
</tr>
</tbody>
</table>

The precision of the experiment is calculated below. First the average \( \bar{X} \) is calculated, then the average absolute deviation \( |\bar{d}| \) is calculated and finally the percent relative average deviation \( \% \text{rad} \) is calculated.

**a) Calculation of the average**

\[
\bar{X} = \frac{56.08\% + 56.04\% + 55.95\% + 56.23\%}{4} = \frac{224.30\%}{4} = 56.07\% \approx 56.08\%
\]

**b) Calculation of the average deviation (\( |\bar{d}| \)).**

\[
|\bar{d}| = \frac{|56.07\% - 56.08\%| + |56.07\% - 56.04\%| + |56.07\% - 55.95\%| + |56.07\% - 56.23\%|}{4} = \frac{0.00\% + 0.03\% + 0.12\% + 0.15\%}{4} = 0.08\% = 0.08\%
\]

**c) Calculation of the percent relative average deviation (\( \% \text{rad} \)).**

\[
\% \text{rad} = \frac{|\bar{d}|}{\bar{X}} \times 100\% \\
\% \text{rad} = \frac{0.08\%}{56.05\%} \times 100\% = 0.142\% = 0.1\%
\]
Analysis of Results

You may be asking yourself, “What does the magnitude of the %rad tell the pharmaceutical company about my results?” In all experiments, the lower the percent relative average deviation the better. You can use the table below to analyze the percent relative average deviations calculated in the example problems and for your titrations.

<table>
<thead>
<tr>
<th>% rad</th>
<th>Quality of Precision</th>
<th>Will you be hired?</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤0.5%</td>
<td>Excellent</td>
<td>If your % relative error is also low, you will be hired with a very large signing bonus.</td>
</tr>
<tr>
<td>≤1.0%</td>
<td>Very Good</td>
<td>If your % relative error is also low, you will be hired with a moderate signing bonus.</td>
</tr>
<tr>
<td>≤1.5%</td>
<td>Good</td>
<td>If your % relative error is also low, you will be hired.</td>
</tr>
<tr>
<td>≤2.0%</td>
<td>Acceptable</td>
<td>If your % relative error is low, you may be hired but without a signing bonus and only if no-one is available who got a lower %rad.</td>
</tr>
<tr>
<td>≤3.0%</td>
<td>Not Great</td>
<td>Even if your % relative error is also low, you probably won’t be hired.</td>
</tr>
<tr>
<td>≥3.0%</td>
<td>Not Acceptable</td>
<td>You probably won’t be hired.</td>
</tr>
</tbody>
</table>

As you can see from the table above, having good precision is not the only important factor. In addition to having good precision, you must also be accurate. Precision is only half the story. If you are precise but not accurate, that means you are doing something wrong in your titrations and you are doing the same thing each time. On the other hand it is possible to be accurate but not precise. If that is the case, your potential employer might attribute your accuracy to luck rather than to skill in the laboratory. The percent relative error calculation is shown below. A good percent relative error is generally less than 2.5%. Any % r.e. higher than 4.5% would be below average. The tolerance for the percent error is a little higher than the %rad because it is easier to be consistent than it is to be accurate.

\[
\% \text{ r.e.} = \left| \frac{\text{true value} - \text{your measurement}}{\text{true value}} \right| \times 100\%
\]
A student prepared and standardized a solution of sodium hydroxide in CHEM 180. The 3 values she obtained were: 0.01965 M NaOH, 0.01976 M NaOH, and 0.01960 M NaOH.

1. Calculate the average concentration in the space below.

2. Calculate the average deviation of the measurements in the space below.

3. Calculate the percent relative average deviation in the space below.

4. Assuming the true concentration of the sodium hydroxide solution is 0.01970 M, what is the %r.e. of her average NaOH concentration?

5. Based on the answers to questions 3 and 4, if you were in the position to hire a chemist, would you hire this student?
**Solutions to the practice problem**

A student prepared and standardized a solution of sodium hydroxide in CHEM 180. The 3 values she obtained were: 0.01965 M NaOH, 0.01976 M NaOH, and 0.01960 M NaOH.

1. Calculate the average concentration in the space below.

\[
\bar{X} = \frac{0.01965 M + 0.01976 M + 0.01960 M}{3} = \frac{0.05903 M}{3} = 0.01967 M = 0.01968 M
\]

2. Calculate the average deviation of the measurements in the space below.

\[
|\bar{d}| = \frac{|0.01967 M - 0.01965 M| + |0.01967 M - 0.01976 M| + |0.01967 M - 0.01960 M|}{3}
\]
\[
= \frac{0.00002 M + 0.00009 M + 0.00006 M}{3} = \frac{0.00018 M}{3} = 0.00006 M
\]

3. Calculate the percent relative average deviation in the space below.

\[
\% \text{ rad} = \frac{0.00006 M}{0.01967 M} \times 100\% = 0.3\% \text{ rad} = 0.3\%
\]

4. Assuming the true concentration of the sodium hydroxide solution is 0.01970 M, what is the %r.e. of their average NaOH concentration?

\[
\% \text{ r.e.} = \frac{|0.01970 M - 0.01967 M|}{0.01970 M} \times 100\% = \frac{0.00002 M}{0.01970 M} \times 100\% = 0.1\% \text{ r.e.} = 0.1\%
\]

5. Based on the answers to questions 3 and 4, if you were in the position to hire a chemist, would you hire this student?

Yes, I would hire her in a second. I would probably throw all sorts of money her way to ensure that she would join my company. She not only had an excellent % rad, but her % r.e. was also awesome!
Pre-Lab: Acid-Base Titrations Part II

1. In the space below, list the three calculated NaOH concentrations you obtained from your work last week.

   | Successful Trial #1 | Successful Trial #2 | Successful Trial #3 |

2. Calculate the average NaOH concentration for your three good titrations in the space below.

3. Calculate the average deviation of the three concentrations in the space below.

4. Calculate the percent relative average deviation in the space below.

5. The true concentration of the sodium hydroxide solution you used was 0.1047±29 M, what is the %r.e. of your average NaOH concentration?

6. Based on the answers to questions 3 and 4, if you were in the position to hire a chemist, would you hire yourself?

If your % rad is high, but you had a good faint pink color as your end point, it probably means you were not reading the volumes accurately. Have me or your neighbor double check your first few measurements this week. If your % rad is low, but your % r.e. is high, it probably means you were reading the volumes incorrectly but you were consistent in your errors.