Determining the Concentration of an Unknown acid Using a Known base by means of Titration

Written By:

Carine Niyonzima, 0300060796

TA: Jacky Deng

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Introduction:

Acids and bases are substances with certain distinct physical and chemical properties including but not limited to, texture, and pH (1). Bases taste bitter and have a slippery or slimy feel to them while acids taste sour but have no characteristic feel to them. While these physical properties can be useful in distinguishing between weak and non-toxic nor corrosive acids and bases, other chemical properties derived from experiments can be used to differentiate them without having to touch or taste them . Commonly known acids include citric acid, which is found in fruits such as lemons and oranges, vinegar and stomach acids (1). Commonly known bases include baking soda, soap, and other detergents.

The Bronsted-Lowry theory of acids and bases describes acids as matter that donates protons, or H^+ and bases as matter that attracts, or accepts protons. When in solution, acids will form hydronium H_3O^+ ions and bases will form hydroxyl OH^- ions.

Another property commonly associated with describing acids and bases is the pH. pH, or the Power of Hydrogen, is a scale ranging from 1-14 which describes the ability of aqueous matter to attract, or repel protons. Acids have a pH that ranges between one and 6 while bases have a pH that falls between the values of pH 8-14. Substances whose pH are 7 are considered to be neutral substances and one such substance is water.

Strong acids and bases ionize completely in solution meaning that all of their molecules are going to release or attract protons. Because of this strong ionization, they are corrosive. Strong acids include HCl, HBr, HI, H_2SO_4, HNO_3, and $HClO_3$ while strong bases consist of all hydroxides of group 1 and group 2 metals. While their concentrations may vary, which can affect their pH, strong acids will have a

lower pH compared to the same concentration of a weak acid and strong bases will have a higher pH than the same concentration of a weak base, as weak acids and bases do not ionize completely in solution.

Titration is a technique used to identify the concentration of an unknown solution as will be done throughout this experiment through neutralization. This is rather an accurate technique as a burette is thin enough on the inside to give more accurate readings than a beaker or measuring cylinder would. Inside the burette is the titrant, which is a solution of known concentration that is used to determine the concentration of the unknown solution by adding it to it until there is a visual change or considerable change in pH. (4) A visual change can be observed if an indicator has been added at the beginning (2). This is a weak acid or a base that will respond to changes in pH, and its colour will change when the solution is neutralized (2). A commonly used indicator is phenolphthalein which is a weak acid that is colourless when in acidic solutions and responds. to the change in the pH as it rises (2). The pH range for the colour change of phenolphthalein is 8.0-10.0. There are several stages in a titration in relation to pH. The equivalence point in a titration is the point at which the number of moles of the acids is equivalent to that of a base and this is when the titration is approaching an end point (2). The equivalence point can be calculated through the equation:

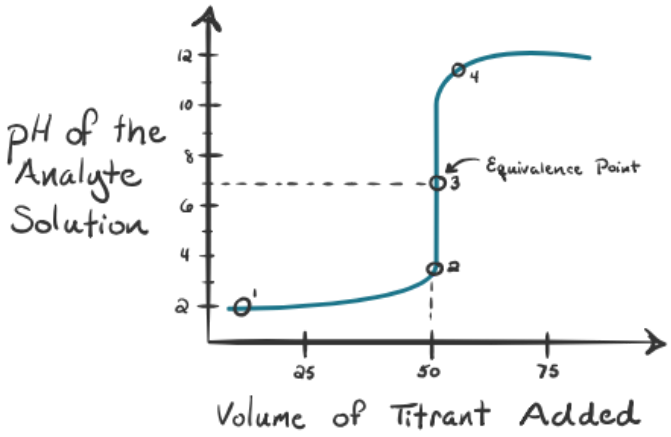
$$C_1V_1=C_2V_2$$

Where the concentration and corresponding volume of each substance is put on the same side of the equation and subscripts “1” refer to the base and subscripts “2” refer to the acid. The reason as to why it can be calculated like this is because it is known that at the equivalence point, the moles of acid is the same as the wolves of the base and one way to calculate moles is:

$$n = CV$$

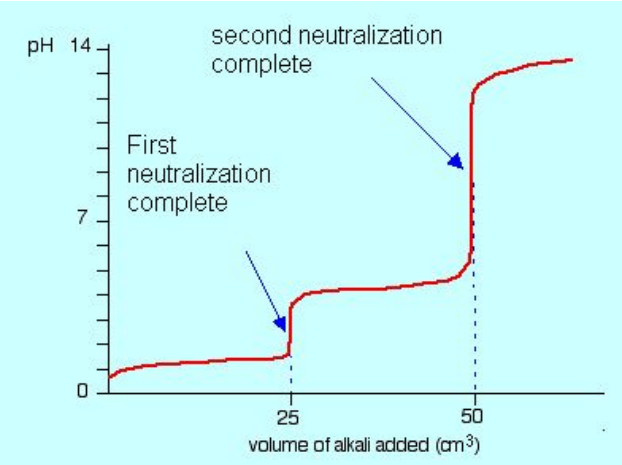
The end point of the titration is when a sharp colour change is observed and the solution is neutralized. Titration curves are used to visually represent the change in pH as the volume of titrant is added inside the beaker of the unknown solution. This is the graph of the pH as a function of the volume

of the titrant. The equivalence point in a titration curve can be indicated on the titration curve. A typical titration curve looks like this where the equivalence point is the point on the graph with the steepest slope:



(3)

Acids can be further categorized into monoprotic and polyprotic acids. Monoprotic acids are those that will release one H^+ ion per molecule while polyprotic acids release more than one H^+ ion per molecule. An example of a monoprotic acid is HCl while an example of a polyprotic acid is H_2SO_4 (4). More specifically, H_2SO_4 is a diprotic acid as it releases two protons per molecule. The above titration curve was shown for a typical titration involving a monoprotic acid. There is only one equivalence point for monoprotic acids as they are going to release one proton per molecule while diprotic acids will have two equivalence points (4). A typical titration curve for a diprotic acid looks like this:



(3)

Procedure:

As described in the lab manual (Venkateswaran, R. Acid-Base Titrations (2018))

Observations:

Table 1: Formation of the dilute NaOH solution with distilled water:

Concentration of NaOH (M)	Volume of NaOH (mL)	Volume of distilled water (mL)
6.0	4.25	250

Table 2: Standardization of NaOH with various volumes of 0.1M HCl and distilled water added to it

Trial Number	**Volume of HCl (mL)**	**Volume NaOH added (mL)**	**Drops of phenolphthalein added**	**Distilled water added (mL)**
1	9.50	17.5	3.00	75
2	10.5	23.1	3.00	77

Figure 1: Graph of Trial 1 standardization with one curve indicating the actual change and the other curve indicating the derivative of the curve.

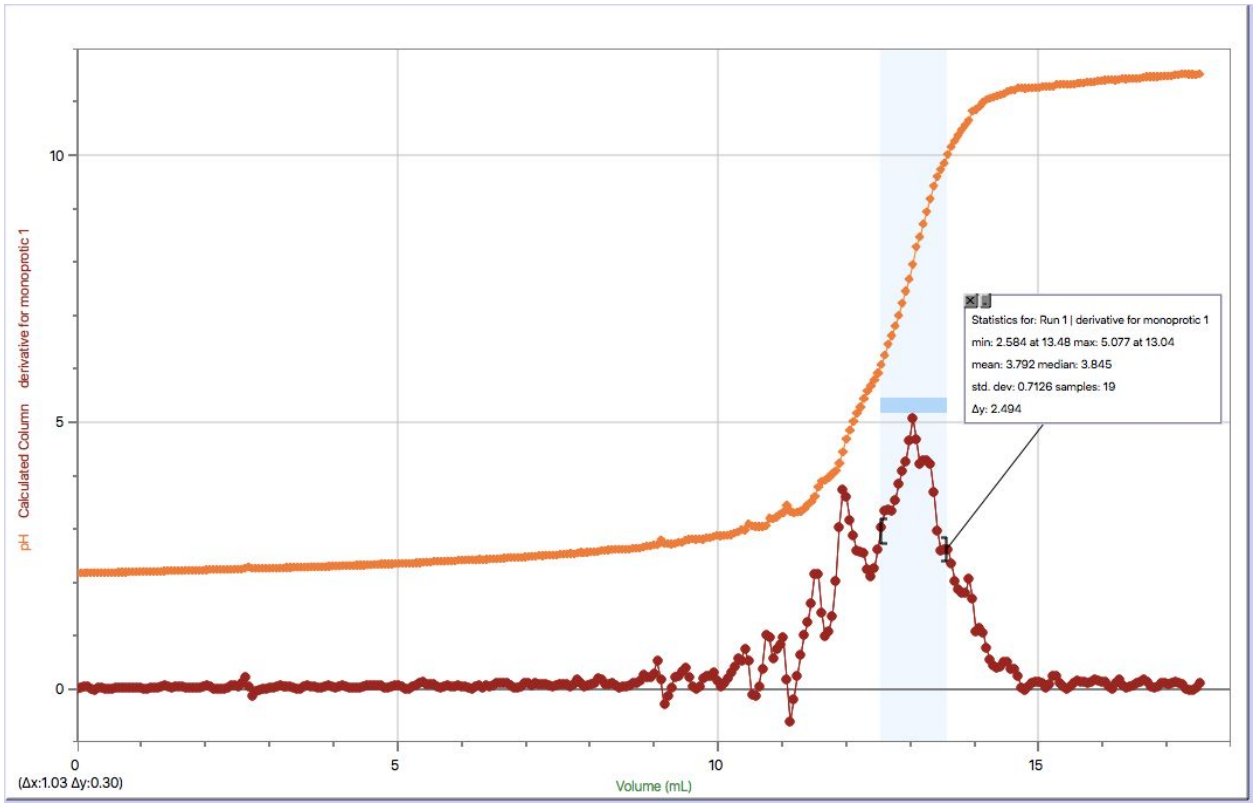


Figure 2: Graph of Trial 2 standardization with one curve indicating the actual change and the other curve indicating the derivative of the curve.

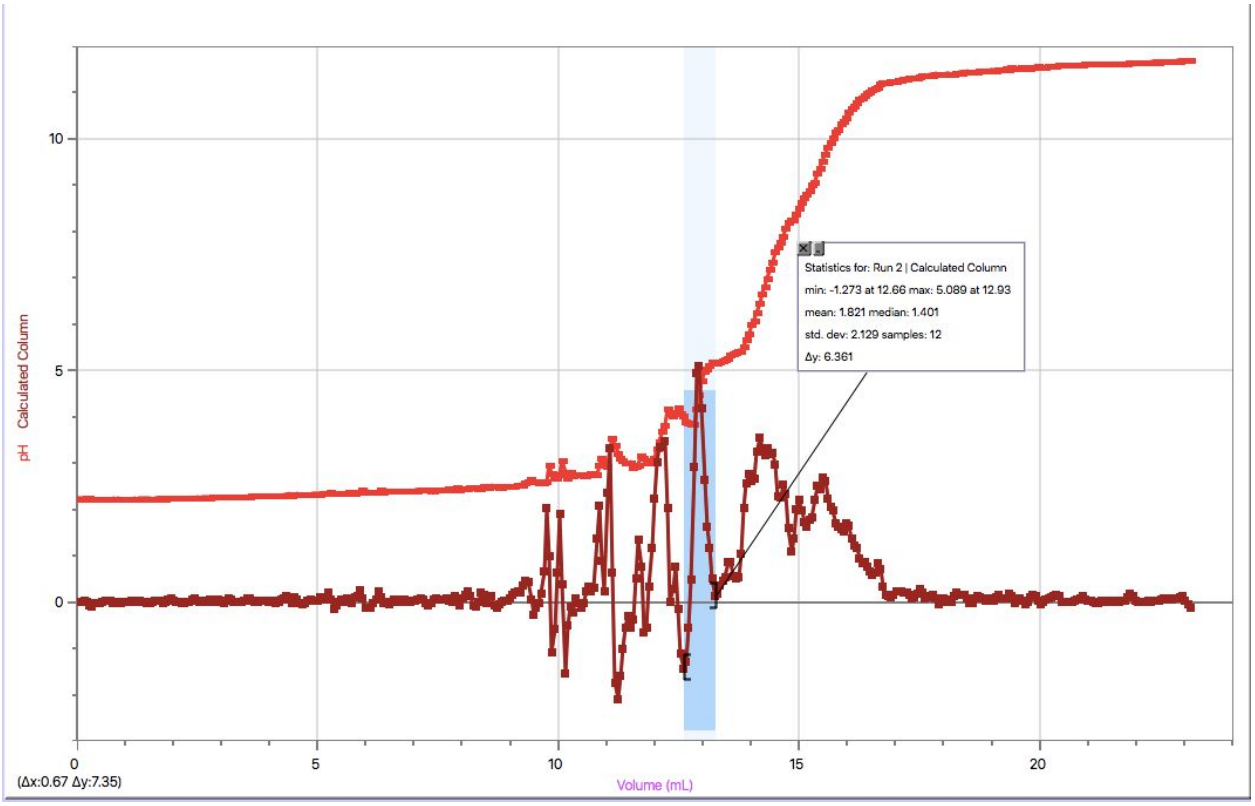


Table 3: Titration of diprotic acid using 0.0771 mol/L NaOH

Trial Number	**Volume HCl in beaker (mL)**	**Drops of phenolphthalein**	**Volume of distilled water added to beaker (mL)**	**Final volume of NaOH added to HCl (mL)**	**Volume of NaOH added when colour changes from clear to pink (mL)**
1	9.30	2.00	75.0	23.1	12.5
pH				11.71	6.87
2	9.40	3.00	75.0	24.0	13.5
pH				11.74	6.89
3	9.70	3.0	76.0	25.0	13.0
pH				11.73	6.54

Table 4: Equivalence point obtained through visual observation vs equivalence point obtained by Logger Pro for titration of diprotic acid:

Volume of NaOH added when colour changes from clear to pink (mL)	**Equivalence point obtained by logger pro (mL)**
12.5	14.29
13.5	15.17
13.0	16.09

Figure 3: Graph of Trial 1 titration with one curve indicating the change and the other curve indicating the derivative of the first curve.

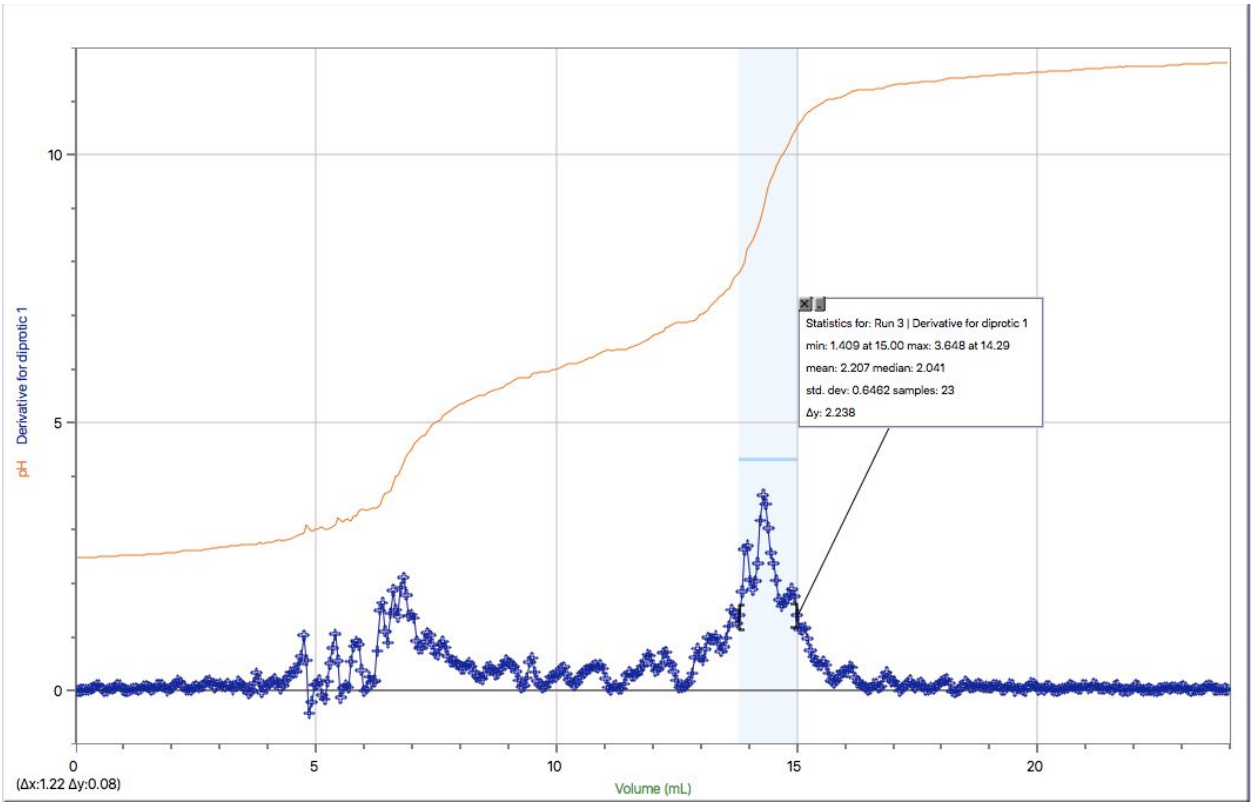


Figure 4: Graph of Trial 2 titration with one curve indicating the change and the other curve indicating the derivative of the first curve

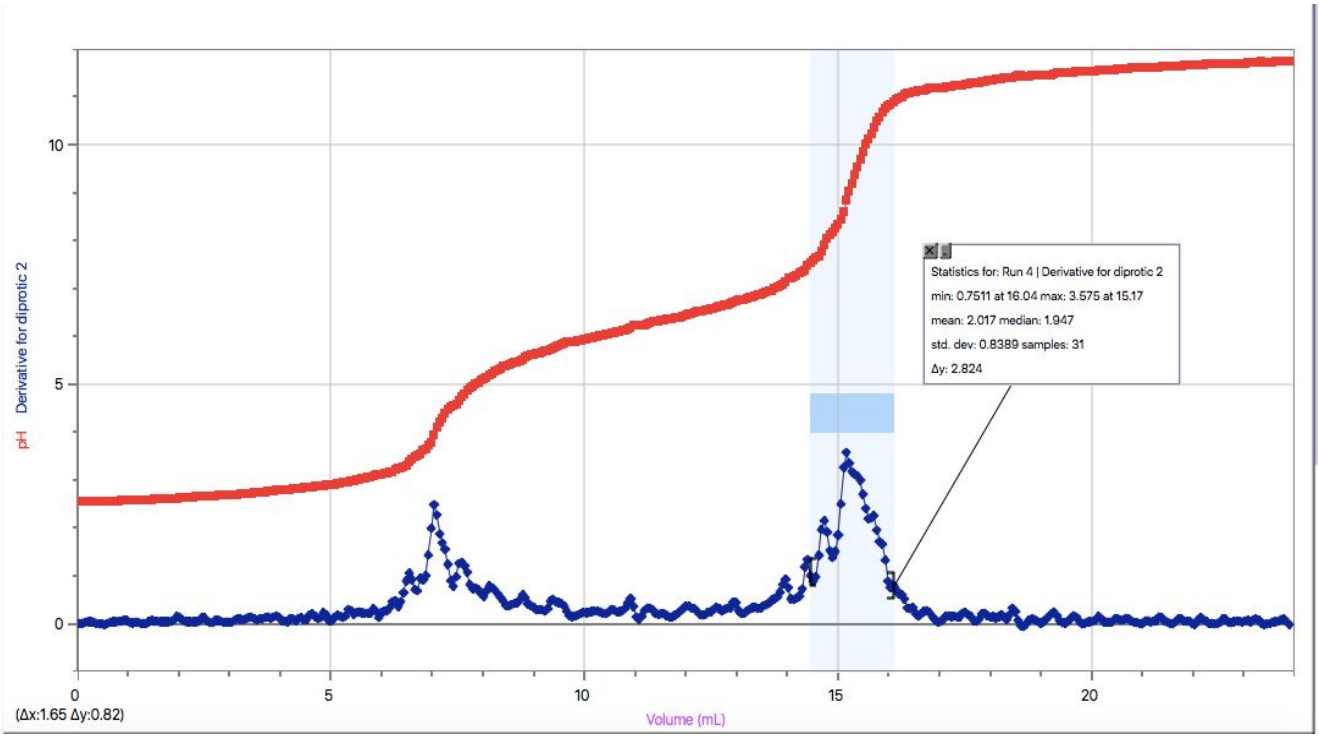
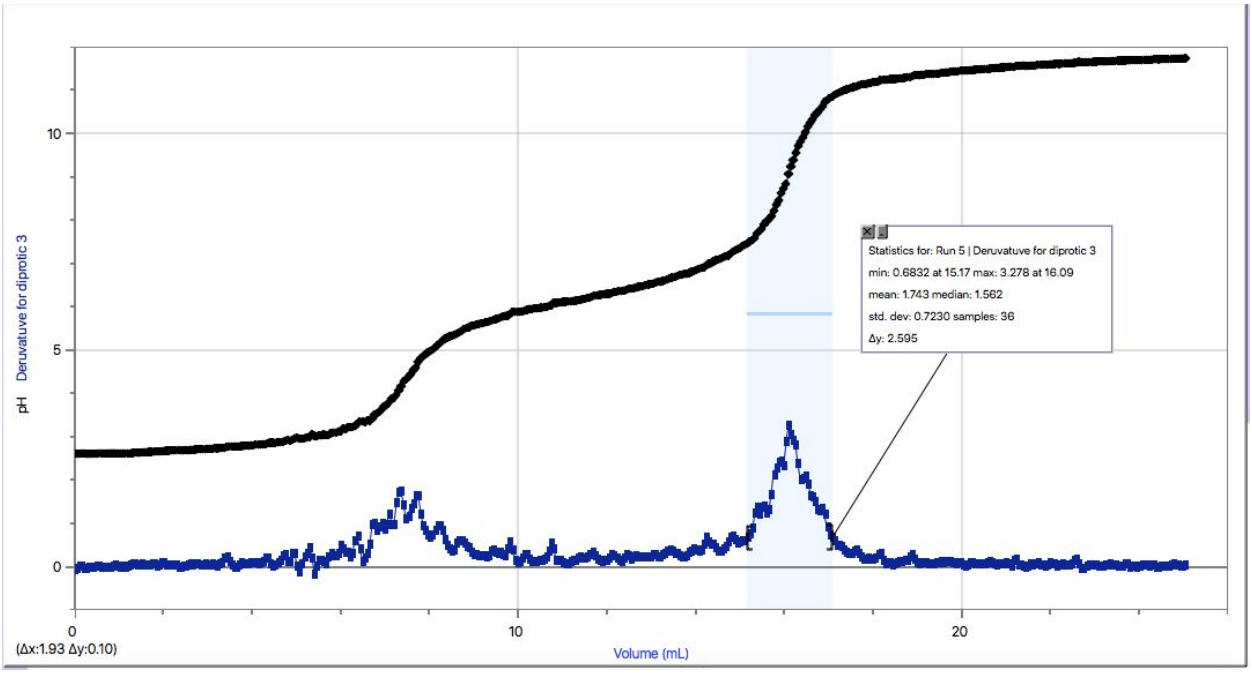


Figure 5: Graph of Trial 3 titration with one curve indicating the change and the other curve indicating the derivative of the first curve



Calculations:

1. Obtaining the concentration of the NaOH

Trial 1:

$$C_1V_1 = C_2V_1$$
$$C_1 = \frac{C_2V_2}{V_1}$$
$$C_1 = \frac{(0.100mol/L)(9.5mL)}{(13.004mL)}$$
$$C_1 = 0.0729mol/L$$

Average of trial one and two:

$$Avg = \frac{0.0729 + 0.0812}{2}$$
$$Avg = 0.07705$$
$$= 0.0771\ mol/L$$

2. Calculating the concentration of an unknown diprotic acid

Trial 1: $C_1V_1 = C_2V_2$ $\quad C_1 = 0.0771$

$C_2 = \frac{C_1V_1}{V_2}$ $\quad C_2 = ?$

$V_1 = 14.29$

$C_2 = \frac{(0.0771mol/l)(14.29ml)}{(9.30ml)}$ $\quad V_2 = 9.30$

$C_2 = 0.118mol/L$

Average of trial one, two, and three:

$$Avg = 0.118 + 0.114 + 0.127 = 0.369$$
$$Avg = \frac{0.369}{3} = 0.113$$

Discussion:

This lab has been successful in determining the concentration of an unknown diprotic acid through a titration. During the first part of the experiment, a dilute solution of NaOH was standardized with a 0.100 M of HCl. It was then determined through the two trials of titration, the average concentration of the NaOH was 0.0771 M. This was done through the calculations of moles at the equivalence point. The equivalence point on the graphs was the point at which the slope was the steepest and this was determined by using Logger Pro. The derivative was determined through the application and the maximum value of that derivative was used to determine the volume at which the equivalence point had been reached. On the graphs for the standardization part of the experiment, the peak points can clearly be distinguished from other points. A specific volume of NaOH, which was initially 4.25 was diluted in 250mL was important in the outcome of the experiment. This is due to the fact that NaOH is a strong base and its dissociation in water has rather a significant impact in the solutions that it is combined with as all of its molecules dissociate (4). It was important to take that volume into consideration because otherwise, assuming its concentration would have had an impact on the errors of the experiment.

The second part of the experiment involved an unknown diprotic acid and the known concentration of 0.0771 M of NaOH. The same titration process was used in order to determine the concentration of the unknown acid, however, diprotic acid curves seem to have two equivalent points as their molecules release two protons during the titration. Only one of these equivalent points were used and in this case, it was the one at which the derivative was the highest. Determining the concentration of NaOH was important in that it would be useful in determining the concentration of the diprotic acid. With the use of the $C_1V_1 = C_2V_2$ equation, the concentration of the diprotic acid was successfully

determined. Three values were needed in order to determine the last unknown value which was the concentration of the acid. One of those values was was needed in order to determine the concentration of the unknown acid was the concentration of the base. Due to the different stages in a titration, different chemical reactions can be expected throughout the entire titration. For the titration of the unknown acid, these are the species that were expected at:

- 0 mL of added base:
  - $H_2A + H_2O \rightarrow H_3O^+ + HA^-$
  - This is because the diprotic acid should dissociate in an aqueous solution to form hydronium ions and a negatively charged ion. Since there is no base in the water, there should be no basic species yet.

- At midway to the first equivalence point
  - $H_2A + NaOH \rightarrow NaH + HA^-$
  - At this point, half of the base should be added because it is known that at the equivalence point, the moles of acid and base should be equal so over here, there should be half of the base present.
  - Ratio of acid:base is 2:1

- At the first equivalence point
  - $H_2A + NaOH \rightarrow NaHA + HA^-$
  - At this point, the moles of the base should be equal to the moles of the acid as the equivalence point has been reached.
  - The ration of the acid:base is 1:1

- At midway to the second equivalence point
  - $NaHA + NaOH \rightarrow NaA + H_2O$
  - This time, the ration has been shifted to 2:1 with respect to base: acid and this is now because the amount of base has surpassed the acid before it release another proton in solution

- At the second equivalence point
  - $NaHA + NaOH \rightarrow NaA + H_2O$
  - For the second time, the ratio is 1:1 because another proton has released so the moles of acid and base have become equivalent again

Despite the success in determining the concentration of the unknown acid, there were some errors that may have disturbed the outcome of the experiment. One of these errors was the reliance on logger pro

to determine the equivalence points. There were rather larger differences in the values of the equivalence point obtained by logger pro and the visual observations of the colour changes made. The value of logger pro obtained were, 14.29 mL, 15.17 mL, and 16.09 mL while the colour changes were observed when 12.5 mL, 15.5 mL, and 13.0 mL of base was added to the solution. Since the values obtained in logger pro were used for the calculations, this had an effect on the concentration of the diprotic acid obtained. It made the concentration higher than what it should have been because the volume of the base was part of the denominator in the equation. It is known that a higher denominator will result in a higher final answer. A way in which this error could have been reduced was making sure that the drop counter was calibrated carefully by counting the drops in comparison to the amount of times the red light blinked on the drop counter.

Conclusion:

This experiment was successful in determining the concentration of an unknown diprotic acid by titrating it with a known concentration of NaOH. The concentration of NaOH was determined by standardizing it with a known concentration of HCl. Mathematical equations were used in determining the concentration of the unknown species by deriving a titration curve and using the maximum point in the derivative as the volume obtained at the equivalence point. Although the experiment was a success, there were some errors that occurred including the misinterpretation of the volume at the equivalence point because of a drop counter that was not properly calibrated. This error could be avoided in future experiments by properly calibrating the drop counter.

Sources:

1.Acids and Bases (nd) retrieved from, http://www.mcwdn.org/chemist/acidbase.html

2.Indicators (nd) retrieved from, http://www.science.uwaterloo.ca/~cchieh/cact/c123/indicator.html

3.Khan. S. (2016). Acid-Base Titration Curves. Retrieved from, https://www.khanacademy.org/test-prep/mcat/chemical-processes/titrations-and-solubility-equilibria/a/acid-base-titration-curves

4.Olmsted, J Ⅲ. Williams, G. Burk, R.C. *Chemistry.* Wiley, Third Canadian Edition (2016)