Laboratory 3: Acid-Base Titrations

CHM 1311-

November 7th 2017

Introduction:

The experiment performed is known as titration, which in other words is “the test that measures the pH of an answer“ (Adele). A titration is done by adding a substance of known concentration, the titrant, to a solution of unknown concentration (Olmsted 784). The specific titration done in the experiment is an acid-base titration.

Acids and bases have different characteristics that depict them. There are two main theories that explain acid-base relations. First, the Bronsted-Lowry Theory describes an acid as a species that donates a proton, which means an H+, and a base is a species that accepts a proton (Olmsted 726). Then, there is the more expanded theory, Lewis Theory, which states that a Lewis acid accepts an electron pair, and the Lewis base donates an electron pair. More specifically, there are further classifications of acids and bases, which are weak acids and bases, and strong acids and bases. Weak acids and bases do not completely dissociate in water, while strong acids and bases completely dissociate in water. In this lab, strong acids and bases were used. In order to determine how acidic or basic a solution is, the pH of that substance can be measured using a pH probe in this lab specifically. There is a pH scale which is measured by the concentration of protons (H+ ions) in a solution. If the pH of a substance is between 8-14, then it is basic, and if the pH is from 0-6 it is acidic. There is also the pH of 7 which means a neutral pH that is usually a solution produced by a neutralization reaction of an acid reacting with a base to form water and a salt.

Titration of acids and bases occurs by slowly adding an acid or base with a known concentration to a solution of an acid or base with an unknown concentration. There is also an indicator added in this experiment, and the experiment stops when the equivalence point is reached. Equivalence point shows that the titration is over as the amount of moles of that acid is the same as the moles of the base. When doing the experiment, the visual endpoint will be noted, which is the point where the indicator used (phenolphthalein) changes colour from clear to pink in the solution because of the pH change. Noting the endpoint helps to determine the equivalence point. Then, once the titration experiment is over, the unknown concentration of the solution needs to be solved using the equation,

$$C_{acid}V_{acid} = C_{base}V_{base}$$

Where C is the concentration in mol/L of the acid or base, and V is the volume in L of the acid or base.

Next, the data recorded can be plotted on a pH curve where the equivalence point can be seen. A first derivative of the equivalence point can be plotted on the graph as well.

Procedure:

As described in the lab manual: Dr. R Venkateswaran, "Oh How Bitter a Thing It Is…", General Chemistry Laboratory Manual, 2017, Experiment 4, p73-84.

Data Tables / Observations:

Table 1: Formation of a stock solution of NaOH

Volume of concentrated NaOH solution (mL)	4.200
Concentration of concentrated NaOH solution (M)	6.000
Volume of stock solution after dilution (mL)	254.2
Approximate concentration of stock solution (M) (mol/L)	0.1

Table 2: Standardization of the stock solution of NaOH

Data	Trial 1	Trial 2

Concentration of standard acid solution (M)	0.1000	0.1000
Initial Volume of standard acid solution in burette (mL)	6.950	3.190
Final Volume of standard acid solution in burette (mL)	16.94	13.25
Change in Volume of standard acid solution in burette (mL)	9.990	10.06
Volume at colour change - endpoint (mL)	12.00	11.20
Concentration of stock solution of NaOH (M)	0.1000	

Table 3: Determining the concentration of an unknown acid HCl

Data	Trial 1	Trial 2
Sample number of unknown acid	1	1
Initial Volume of unknown acid solution in burette (mL)	4.720	11.55
Final Volume of unknown acid solution in burette(mL)	14.78	21.50
Change in Volume of unknown acid solution in burette (mL)	10.03	9.950
Volume at colour change - endpoint (mL)	8.000	9.000

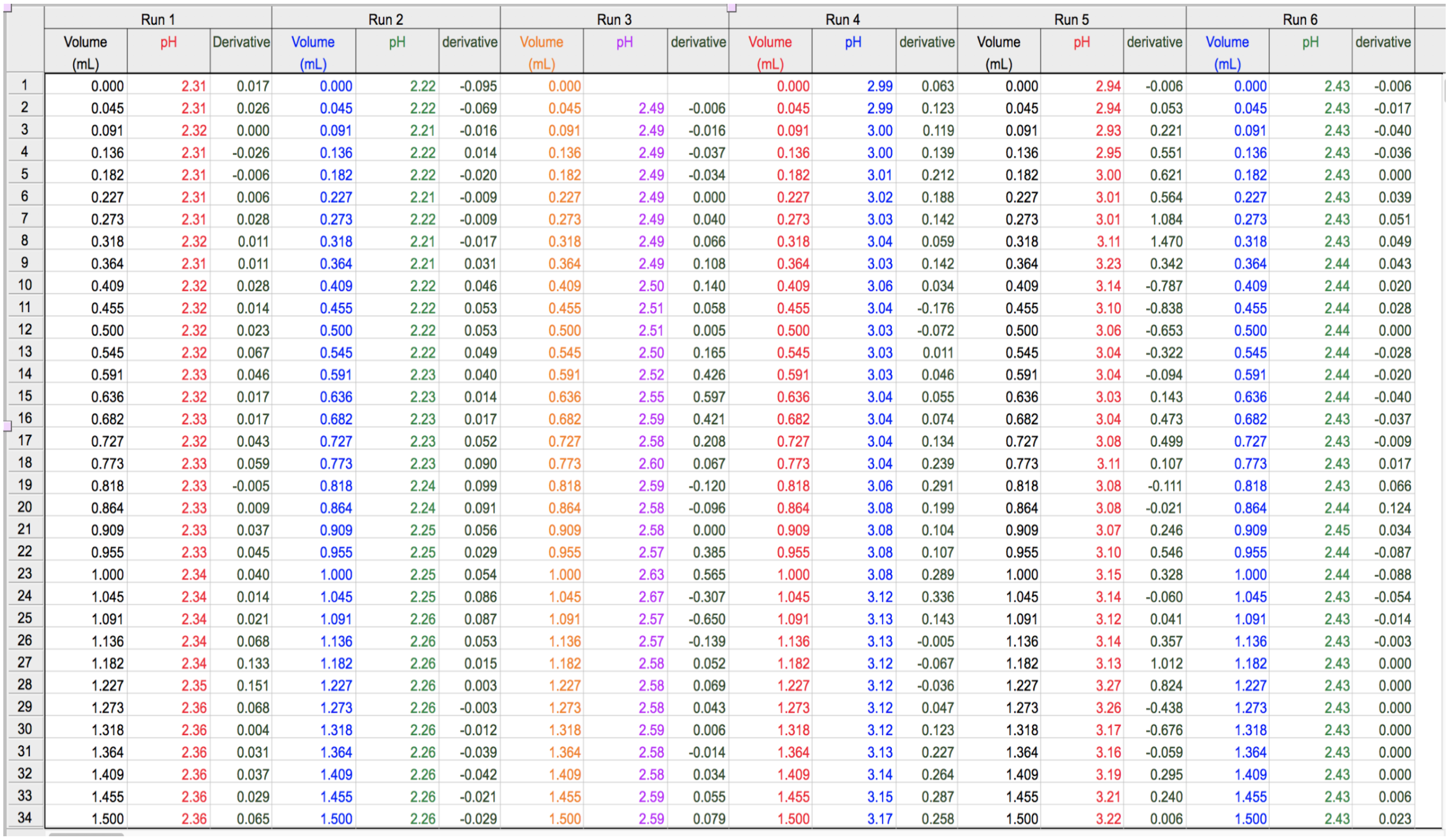
Table 4: determining the mass percentage of acid in a juice

Data	Trial 1	Trial 2
Sample number of juice	2	2

Initial Volume of juice in burette (mL)	2.890	5.400
Final volume of juice in burette (mL)	12.99	15.29
Change in volume of juice in burette (mL)	10.10	9.890
Volume at colour change - endpoint (mL)	9.000	9.600
Density of juice (g/mL)	1.0002	1.0002

Observations of all above trials: As the base was added to the acid, there was no initial change. Afterwards, as more base was added, the solution became more neutralized and the drops into the beaker would drop as pink and then disappear into a clear solution. After some time, the solution turned entirely pink, due to the phenolphthalein indicator.

Graphs:



	Run 1			Run 2			Run 3			Run 4			Run 5			Run 6		
	Volume (mL)	pH	Derivative	Volume (mL)	pH	derivative	Volume (mL)	pH	derivative	Volume (mL)	pH	derivative	Volume (mL)	pH	derivative	Volume (mL)	pH	derivative
1	0.000	2.31	0.017	0.000	2.22	-0.095	0.000			0.000	2.99	0.063	0.000	2.94	-0.006	0.000	2.43	-0.006
2	0.045	2.31	0.026	0.045	2.22	-0.069	0.045	2.49	-0.006	0.045	2.99	0.123	0.045	2.94	0.053	0.045	2.43	-0.017
3	0.091	2.32	0.000	0.091	2.21	-0.016	0.091	2.49	-0.016	0.091	3.00	0.119	0.091	2.93	0.221	0.091	2.43	-0.040
4	0.136	2.31	-0.026	0.136	2.22	0.014	0.136	2.49	-0.037	0.136	3.00	0.139	0.136	2.95	0.551	0.136	2.43	-0.036
5	0.182	2.31	-0.006	0.182	2.22	-0.020	0.182	2.49	-0.034	0.182	3.01	0.212	0.182	3.00	0.621	0.182	2.43	0.000
6	0.227	2.31	0.006	0.227	2.21	-0.009	0.227	2.49	0.000	0.227	3.02	0.188	0.227	3.01	0.564	0.227	2.43	0.039
7	0.273	2.31	0.028	0.273	2.22	-0.009	0.273	2.49	0.040	0.273	3.03	0.142	0.273	3.01	1.084	0.273	2.43	0.051
8	0.318	2.32	0.011	0.318	2.21	-0.017	0.318	2.49	0.066	0.318	3.04	0.059	0.318	3.11	1.470	0.318	2.43	0.049
9	0.364	2.31	0.011	0.364	2.21	0.031	0.364	2.49	0.108	0.364	3.03	0.142	0.364	3.23	0.342	0.364	2.44	0.043
10	0.409	2.32	0.028	0.409	2.22	0.046	0.409	2.50	0.140	0.409	3.06	0.034	0.409	3.14	-0.787	0.409	2.44	0.020
11	0.455	2.32	0.014	0.455	2.22	0.053	0.455	2.51	0.058	0.455	3.04	-0.176	0.455	3.10	-0.838	0.455	2.44	0.028
12	0.500	2.32	0.023	0.500	2.22	0.053	0.500	2.51	0.005	0.500	3.03	-0.072	0.500	3.06	-0.653	0.500	2.44	0.000
13	0.545	2.32	0.067	0.545	2.22	0.049	0.545	2.50	0.165	0.545	3.03	0.011	0.545	3.04	-0.322	0.545	2.44	-0.028
14	0.591	2.33	0.046	0.591	2.23	0.040	0.591	2.52	0.426	0.591	3.03	0.046	0.591	3.04	-0.094	0.591	2.44	-0.020
15	0.636	2.32	0.017	0.636	2.23	0.014	0.636	2.55	0.597	0.636	3.04	0.055	0.636	3.03	0.143	0.636	2.44	-0.040
16	0.682	2.33	0.017	0.682	2.23	0.017	0.682	2.59	0.421	0.682	3.04	0.074	0.682	3.04	0.473	0.682	2.43	-0.037
17	0.727	2.32	0.043	0.727	2.23	0.052	0.727	2.58	0.208	0.727	3.04	0.134	0.727	3.08	0.499	0.727	2.43	-0.009
18	0.773	2.33	0.059	0.773	2.23	0.090	0.773	2.60	0.067	0.773	3.04	0.239	0.773	3.11	0.107	0.773	2.43	0.017
19	0.818	2.33	-0.005	0.818	2.24	0.099	0.818	2.59	-0.120	0.818	3.06	0.291	0.818	3.08	-0.111	0.818	2.43	0.066
20	0.864	2.33	0.009	0.864	2.24	0.091	0.864	2.58	-0.096	0.864	3.08	0.199	0.864	3.08	-0.021	0.864	2.44	0.124
21	0.909	2.33	0.037	0.909	2.25	0.056	0.909	2.58	0.000	0.909	3.08	0.104	0.909	3.07	0.246	0.909	2.45	0.034
22	0.955	2.33	0.045	0.955	2.25	0.029	0.955	2.57	0.385	0.955	3.08	0.107	0.955	3.10	0.546	0.955	2.44	-0.087
23	1.000	2.34	0.040	1.000	2.25	0.054	1.000	2.63	0.565	1.000	3.08	0.289	1.000	3.15	0.328	1.000	2.44	-0.088
24	1.045	2.34	0.014	1.045	2.25	0.086	1.045	2.67	-0.307	1.045	3.12	0.336	1.045	3.14	-0.060	1.045	2.43	-0.054
25	1.091	2.34	0.021	1.091	2.26	0.087	1.091	2.57	-0.650	1.091	3.13	0.143	1.091	3.12	0.041	1.091	2.43	-0.014
26	1.136	2.34	0.068	1.136	2.26	0.053	1.136	2.57	-0.139	1.136	3.13	-0.005	1.136	3.14	0.357	1.136	2.43	-0.003
27	1.182	2.34	0.133	1.182	2.26	0.015	1.182	2.58	0.052	1.182	3.12	-0.067	1.182	3.13	1.012	1.182	2.43	0.000
28	1.227	2.35	0.151	1.227	2.26	0.003	1.227	2.58	0.069	1.227	3.12	-0.036	1.227	3.27	0.824	1.227	2.43	0.000
29	1.273	2.36	0.068	1.273	2.26	-0.003	1.273	2.58	0.043	1.273	3.12	0.047	1.273	3.26	-0.438	1.273	2.43	0.000
30	1.318	2.36	0.004	1.318	2.26	-0.012	1.318	2.59	0.006	1.318	3.12	0.123	1.318	3.17	-0.676	1.318	2.43	0.000
31	1.364	2.36	0.031	1.364	2.26	-0.039	1.364	2.58	-0.014	1.364	3.13	0.227	1.364	3.16	-0.059	1.364	2.43	0.000
32	1.409	2.36	0.037	1.409	2.26	-0.042	1.409	2.58	0.034	1.409	3.14	0.264	1.409	3.19	0.295	1.409	2.43	0.000
33	1.455	2.36	0.029	1.455	2.26	-0.021	1.455	2.59	0.055	1.455	3.15	0.287	1.455	3.21	0.240	1.455	2.43	0.006
34	1.500	2.36	0.065	1.500	2.26	-0.029	1.500	2.59	0.079	1.500	3.17	0.258	1.500	3.22	0.006	1.500	2.43	0.023

Table 5: Logger Pro Data Table

Figure 1: Graph for Standardization of Stock Solution of NaOH (Trial 1 in Table 2) (Run 1 in Table 5)

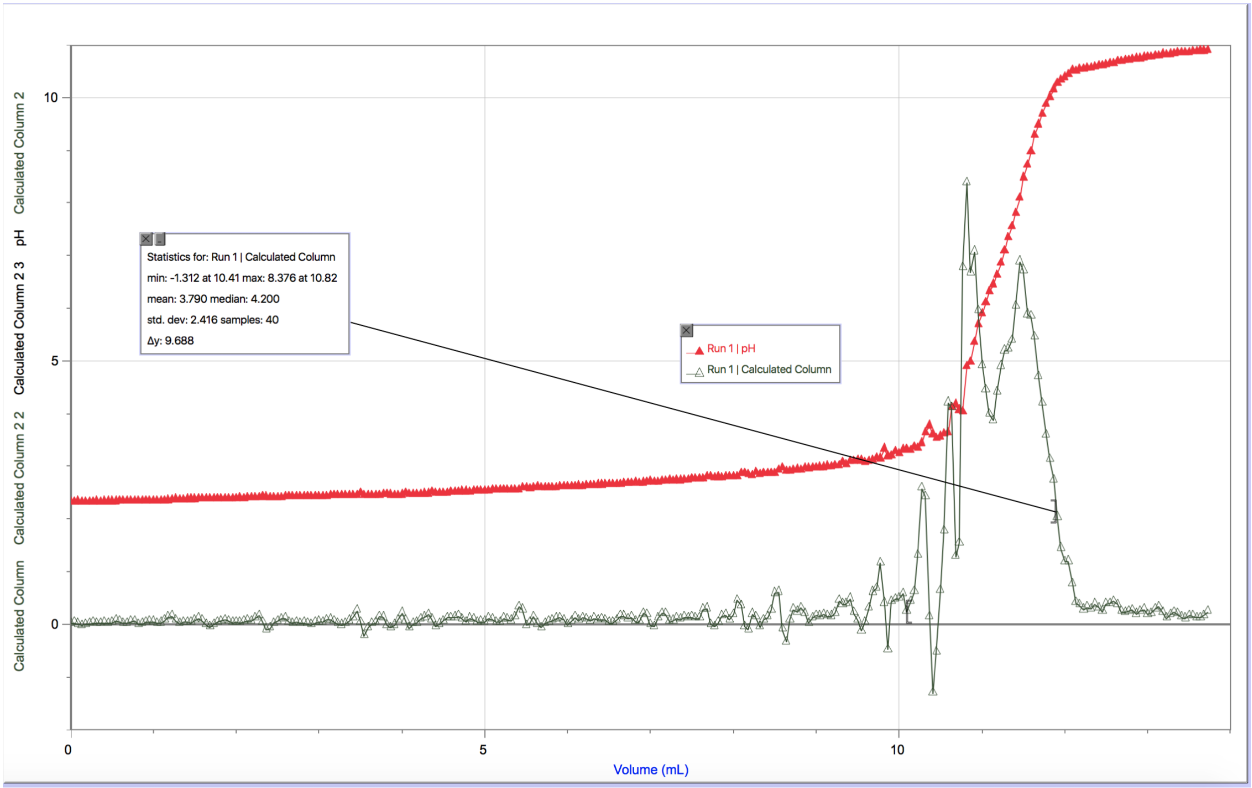


Figure 2: Graph for Standardization of Stock Solution of NaOH (Trial 2 in Table 2) (Run 2 inTable 5)

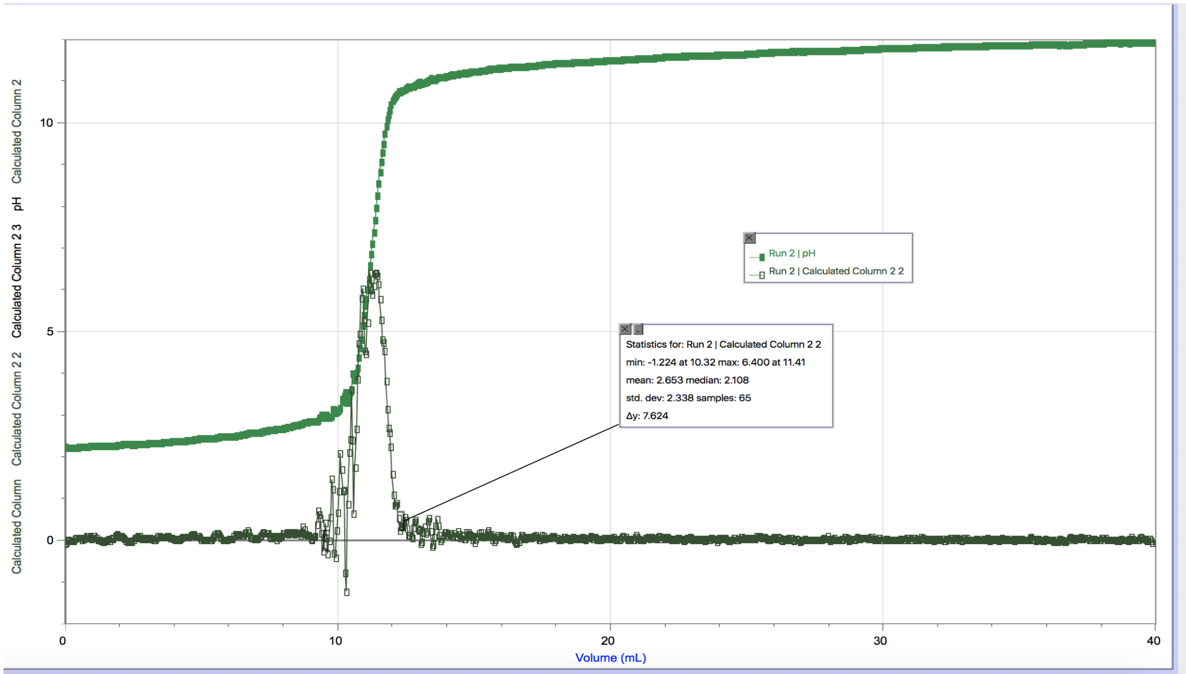


Figure 3: The Concentration of an Unknown Acid (Trial 1 in Table 3) (Run 3 in Table 5)

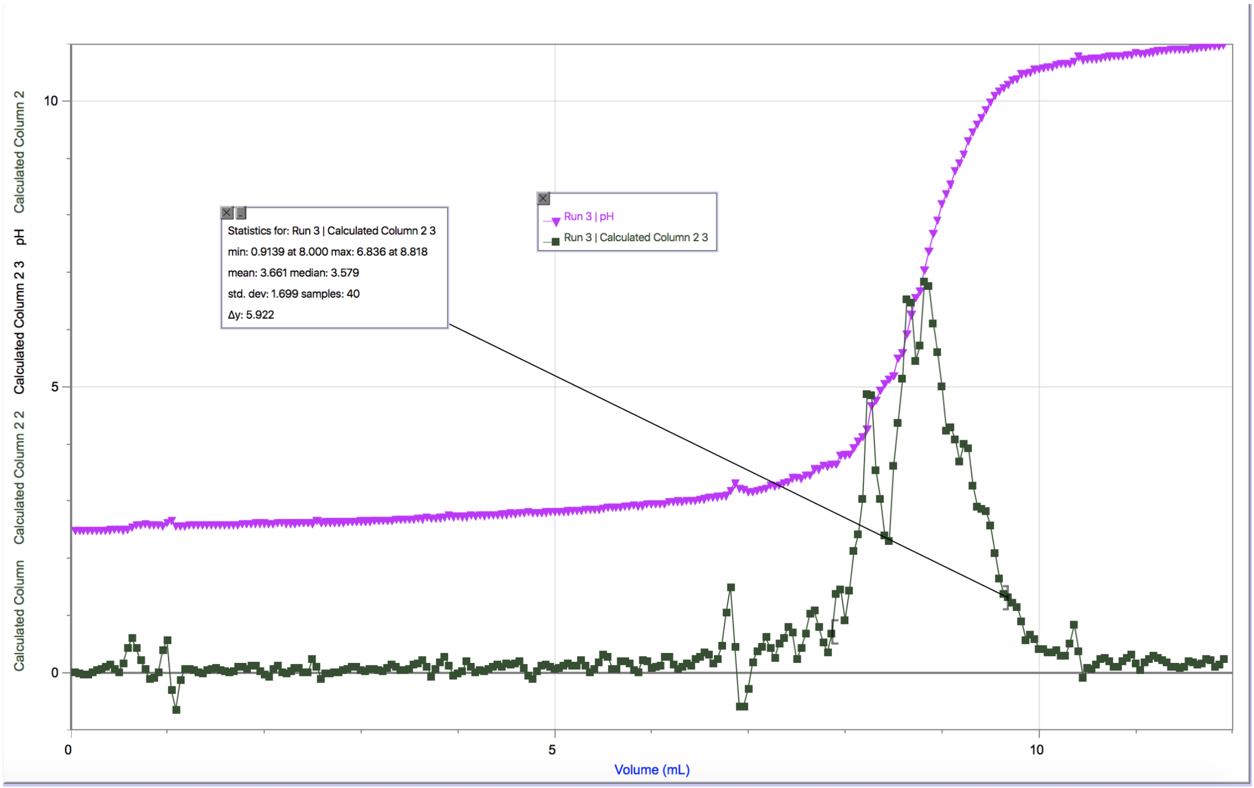


Figure 4: The Concentration of an Unknown Acid (Trial 2 in Table 3) (Run 6 in Table 5)

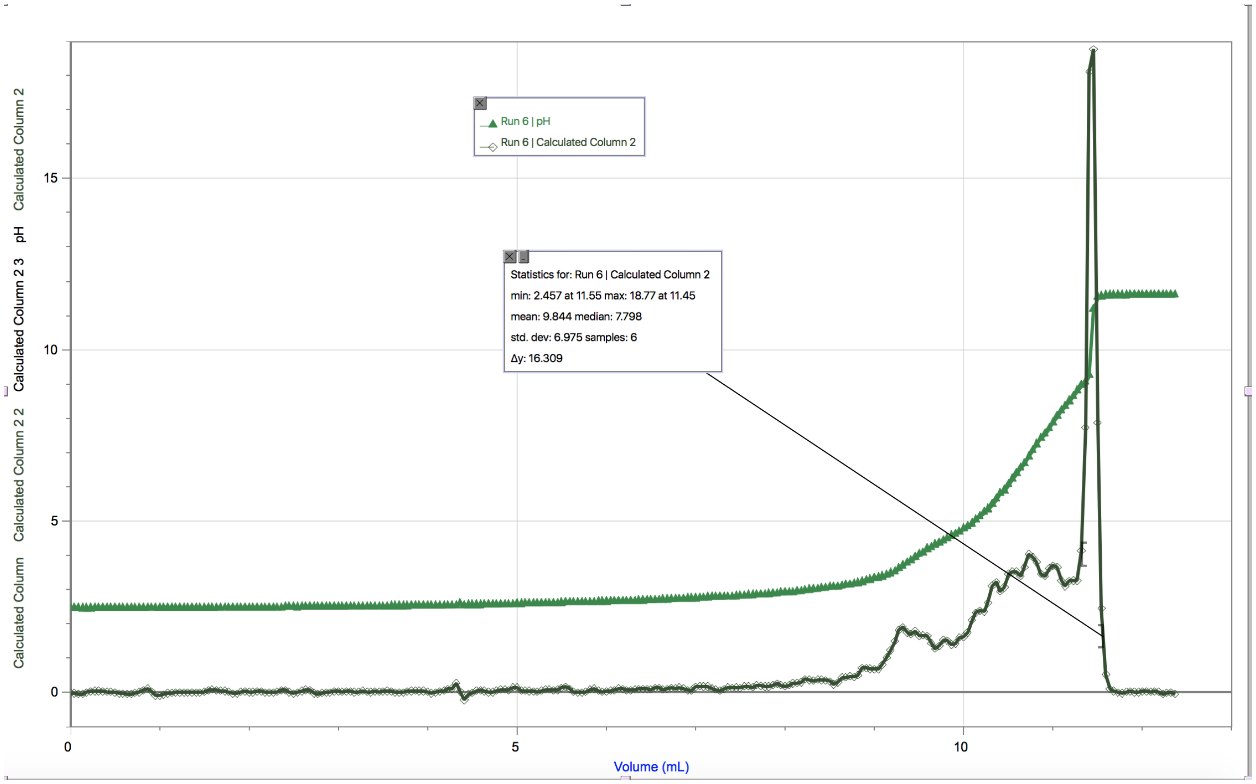
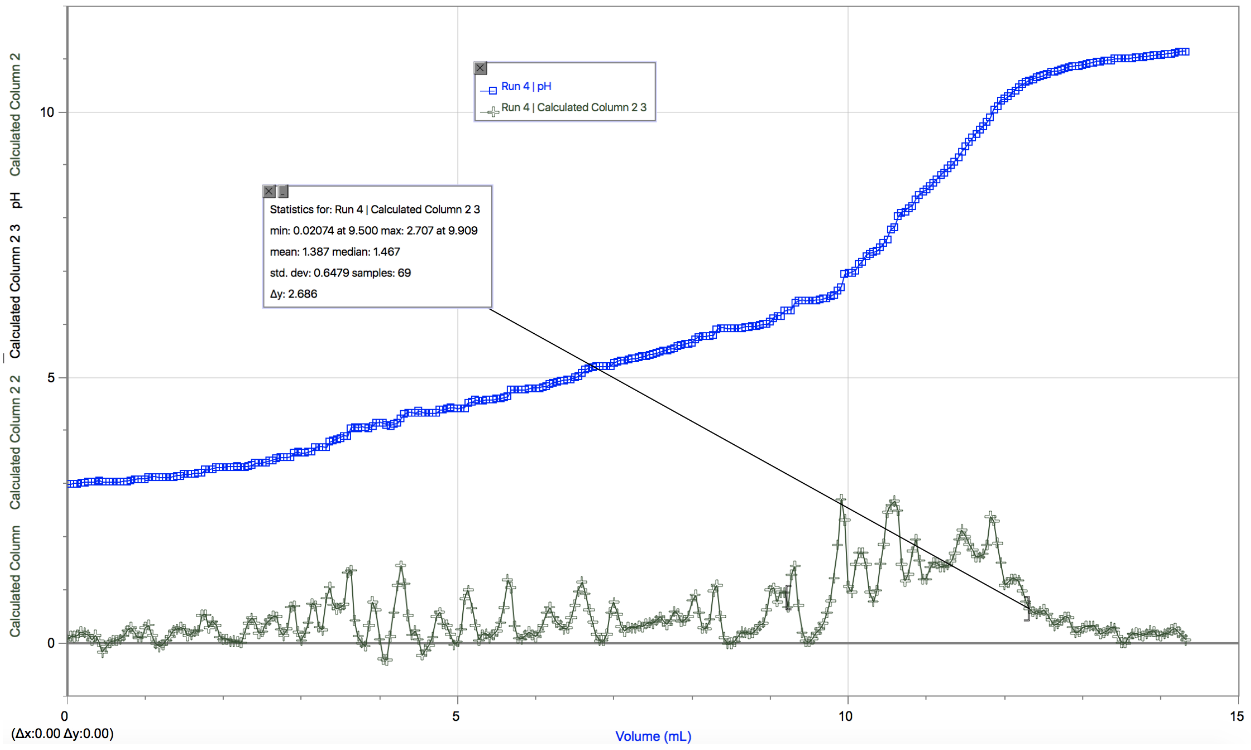
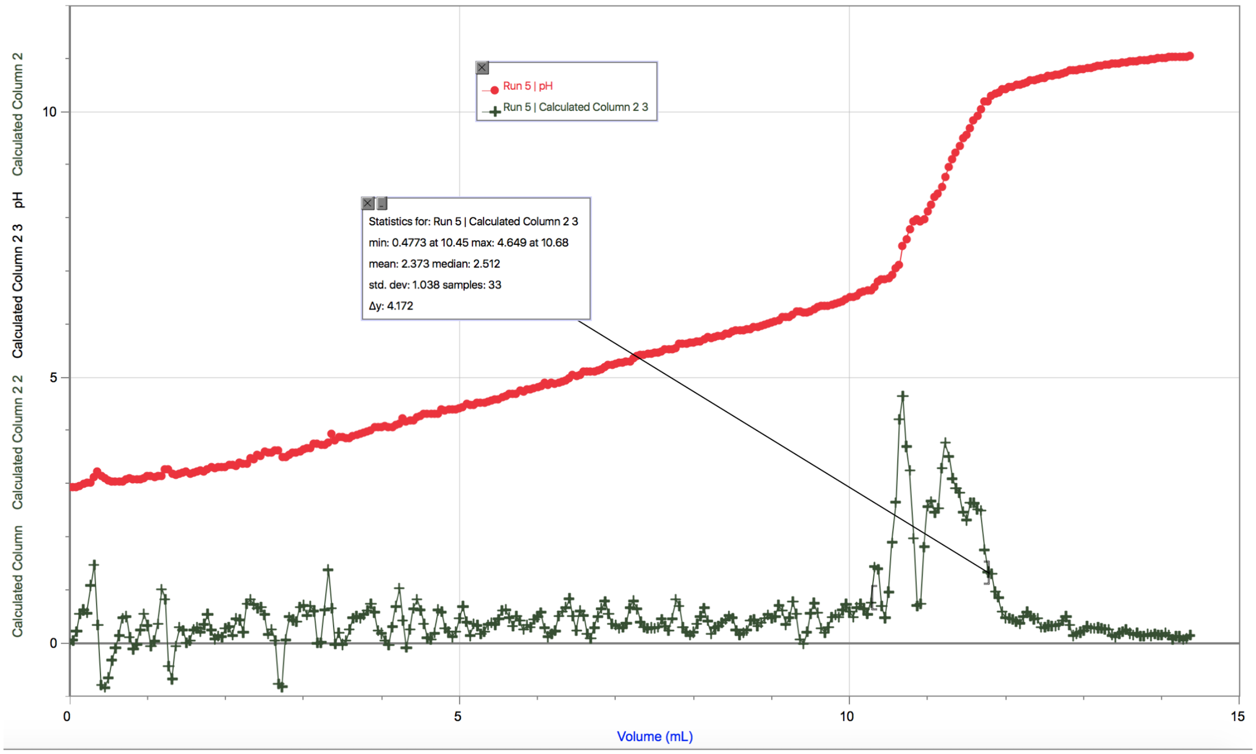


Figure 5: The Acid Concentration in a Juice Sample (Trial 1 in Table 4) (Run 4 in Table 5)



Statistics for: Run 4 | Calculated Column 2 3
min: 0.02074 at 9.500 max: 2.707 at 9.909
mean: 1.387 median: 1.467
std. dev: 0.6479 samples: 69
Δy: 2.686

Figure 6: The Acid Concentration in a Juice Sample (Trial 2 in Table 4) (Run 5 in Table 5)



Statistics for: Run 5 | Calculated Column 2 3
min: 0.4773 at 10.45 max: 4.649 at 10.68
mean: 2.373 median: 2.512
std. dev: 1.038 samples: 33
Δy: 4.172

Calculations:

Sample calculation 1:

1. Approximate concentration of stock solution NaOH

$C_1V_1 = C_2V_2$

$C_1 = 6.000$ M

$V_1 = 4.200$ mL (0.0042 L)

$C_2 = ?$

$V_2 = 254.2$ mL → (0.2542 L)

$C_2 = (6.000 \text{ M}) (0.0042 \text{ L}) / (0.2542 \text{ L})$

$C_2 = 0.099134539$ M

$C_2 = 0.1$ M

Sample calculation 2:

2. the exact concentration of your NaOH (from CV calculations and by first derivative from titration curve using Lab Quest 2 data)

Trial 1 (Run 1) Logger Pro

Equivalence point = volume of base

Volume of base NaOH from logger pro= 10.82 mL (0.01082 L)

Volume of standard acid HCl= 9.99 mL (0.00999 L)

Concentration of standard acid HCl = 0.1000 M

$C_{NaOH}V_{NaOH} = C_{HCl}V_{HCl}$

$C_{NaOH} = C_{HCl}V_{HCl} / V_{NaOH}$

C_{NaOH} = (0.1000 M)(0.00999 L) / (0.01082 L)

C_{NaOH} = 0.09232902 M

C_{NaOH} = 0.0923 M

Sample Calculation 3:

3. Concentration of unknown acid (from CV calculations and by first derivative from titration curve using Lab Quest 2 data)

Trial 1 (Run 3) Logger Pro

For a diprotic acid,

$H_2A_{(aq)} + 2NaOH_{(aq)} \rightarrow Na_2A_{(aq)} + 2H_2O_{(l)}$

Equivalence point logger pro = volume of base

Volume of base NaOH = 8.818 mL (0.008818 L)

Concentration of NaOH = 0.09232902 M (unrounded number for calculation sake)

Volume of unknown acid = 10.03 mL (0.01003 L)

Using equation 7 from lab manual,

$2n_{acid} = n_{NaOH}$

$2C_{acid}V_{acid} = C_{NaOH}V_{NaOH}$

$C_{acid} = C_{NaOH}V_{NaOH} / [2(V_{acid})]$

C_{acid} = (0.09232902 M) (0.008818 L) / [2(0.01003 L)]

C_{acid} = 0.040586106 M

C_{acid} = 0.04059 M

Sample calculation 4:

4. Concentration of acid in juice (from CV calculations and by first derivative from titration curve using Lab Quest 2 data)

Trial 1 (Run 4) logger pro

For a triprotic acid,

$H_3A_{(aq)} + 3NaOH_{(aq)} \rightarrow Na_3A_{(aq)} + 3H_2O_{(l)}$

Equivalence point logger pro = volume of base

Volume of base NaOH = 9.909 mL (0.009909 L)

Concentration of NaOH = 0.09232902 M (unrounded number for calculation sake)

Volume of juice = 10.10 mL (0.01010 L)

Using equation 7 from lab manual,

$3n_{acid} = n_{NaOH}$

$3C_{acid}V_{acid} = C_{NaOH}V_{NaOH}$

$C_{acid} = C_{NaOH}V_{NaOH} / [3(V_{acid})]$

$C_{juice} = (0.09232902 \text{ M}) (0.009909 \text{ L}) / [3(0.01010 \text{ L})]$

$C_{juice} = 0.030194331 \text{ M}$

$C_{juice} = 0.03019 \text{ M}$

Sample calculation 5:

______5. Mass percent of acid in juice

C_{acid} in juice = 0.030194331 M

Density of juice = 1.0002 g/mL

Molar mass of citric acid (H3C6H5O7),

MM = 8(1.01g/mol) + 6(12.01g/mol) + 7(16.00g/mol)

MM = 192.14 g/mol

Mass % Acid in Juice=[(C_{acid} mol/L)(MMacid,g/mol) / (density juice ,g/mL) x 1000] x 100 %

= [(0.030194331 M)(192.14 g/mol) / (1.0002 g/mL)(1000)] x 100 %

= 0.580037887

= 0.5800%

Discussion:

In the beginning of the lab, a certain volume of concentrated NaOH got diluted in water to produce the stock solution of NaOH that was used throughout the rest of the experiment. The initial volume of concentrated NaOH taken does not matter as it becomes diluted to produce a stock solution. However, even if the volume used did not matter, writing down the measurement for initial volume is important in order to be able to use the equation, $C_1V_1 = C_2V_2$, to find concentration of the stock solution later.

Determining the concentration of the NaOH is needed in order to be able to calculate all the other concentrations such as the unknown acid's concentration. Thus, the beginning of the lab preparing the NaOH solution is very important in order for the rest of the lab to go smoothly.

In each titration done, the equivalence point were determined by Logger Pro as well as through observations. To reiterate, in order to note down the equivalence point during the experiment, a colour change had to be observed. Both of the equivalence points noted, through Logger Pro and visually, were quite similar. Except, the equivalence points measured visually were mostly lower values than those of Logger Pro. The disparity can be due to the fact that softwares have very accurate results that humans cannot measure up to. Also, visually noting the equivalence point when the colour changes to pink is not completely accurate as there is a possibility that the solution did not reach its equivalence point yet. Thus, using the Logger Pro software to determine equivalence point according to LabQuest 2 data is much more accurate. Even though there is human error in visually determining the equivalence point, this did not affect the lab results.

In the calculations, part 5 (sample calculation 5) used an equation in order to calculate the mass percent of acid in juice. This equation has a factor of 1000 in the denominator,

Mass % Acid in Juice = [(C_{acid} mol/L)(MMacid,g/mol) / (density juice ,g/mL) x **1000**] x 100 %

The factor of 1000 in the denominator is there in order to allow all the different units of each variable in the equation to be consistent. There is the variable of concentration with is in the unit mol/L, but there is also the variable of density with the unit of g/mL. So, the factor of 1000 is used, specifically in the denominator, to convert the mL of density into L in order to have consistent units throughout the equation.

There were several sources of error in this experiment that affected the results of this lab. To begin, there are inaccuracies in reading measurements on the glass buret to note down volume. When the acid flows from the buret into the beaker, that action of decreasing the level of acid causes some liquid to stick to the sides of the buret, which means the volume taken was a greater value than in reality. This affected the results by causing the calculation for concentration of the NaOH (sample calculation 2) to be greater than it should have, as well as causing the calculated concentration of the acids (sample calculation 3 and 4) to be lower values. Another source of error is with the equipment accuracies for the pH probe and the magnetic stirrer specifically. Since the equipment and glassware were cleaned between each trial with just water, it is likely that a remainder of the previous acids used are still present on the equipment and glassware. Thus, this affected the results of the experiment itself for each trial, causing some unknown inaccuracies.

In the titration of the juice sample, the species can be found in different ratios at different amounts of added base.

a) At 0 mL of base, nothing changes, the original species is in solution.

b) At midway to the first equivalence point, the acid only donates one proton. Thus the equation shown below is a system where the $[H_3A] = [H_2A]$

   $H_3A + H_2O \rightleftharpoons H_2A^- + H_3O^+$

c) At the first equivalence point, all the H_3A has reacted to make H_2A^-, and the reaction occurring when the base is added is,

   $H_3A + NaOH \rightarrow H_2A^- + H_2O$

d) At midway to the second equivalence point,

   $H_2A + OH^- \rightleftharpoons HA^- + H_2O$

e) At the second equivalence point,

   $H_2A^- + NaOH \rightarrow HA^{2-} + H_2O$

f) At midway to the third equivalence point

   $H2A^- + H2O$ <-> $HA^{2-} + H_2O$

g) At third equivalence point

   $HA^{2-} + NaOH \rightarrow A^{3-} + H_2O$

Conclusion:

In conclusion, the concentration of the standardized solution of NaOH was 0.0923 mol/L. In using this value in the next calculations, the concentration of Acid #1 is found to be 0.04059 mol/L. Finally, the concentration of the acid in Juice #2 was 0.03019 mol/L, and had a mass percent of acid in the juice of 0.5800%.