Acid-Base Titrations

Introduction:

In this laboratory, the objective was to perform a titration using HCl and an unknown acid, with a solution of NaOH to obtain the exact concentration of the NaOH solution. The understanding of the definition an acid and base is essential for the completion of this experiment. The most simple explanation of acids and bases is known as the Arrhenius definition. This definition states that acids, when dissolved in water, are proton donors and that bases are hydroxide ion donors when placed in water. The Arrhenius definition considers protons to be H+ ions and hydroxide ions to be OH-. The Brønsted-Lowry definition is slightly more detailed than the Arrhenius definition. This description expands on bases and states that they are also capable to accept hydrogen ions when placed in water. Finally, the most detailed explanation to this date is known as the Lewis definition. It describes acids as electron pair acceptors and bases as electron pair donors. However, for the theory involved in this laboratory, the Arrhenius definition is adequate.

Acids and bases can also be defined in terms of their strength as well as their concentration. A strong acid or base will dissociate completely in water, whereas a weak acid or base will not. The molarity of the acid or base is dependant on the ratio of acid/base to water. When there is a larger amount of acid or base, then the solution will have a greater concentration. When the amount of acid or base is less than the amount of water, then the solution will be less concentrated. This relationship is seen in the following equation:

$$\text{Concentration (mol / L)} = \text{Amount of solute (mol)} \div \text{Volume of solution (L)}$$

An acid-base titration makes is possible to determine the concentration of either the acid or base. When an acid and a base react, water and a salt are formed. This process is referred to as neutralization. A full neutralization is when there is an equal amount of the acid and base, also known as the point of equivalence. The point at which the titrand changes colour due to the indicator is called the end point. The indicator used in this laboratory is called phenolphthalein, the solution is clear when acidic and pink when basic. The equivalence point and end point of a successful titration will be very close in value.

In order to obtain the concentration of the base and the unknown acid, the following equation must be used. Where C is the concentration, V is the volume, and b/a is the coefficient of the base over the acid:

$$Cbase * Vbase = (b/a) * Cacid * Vacid$$

This experiment consists of calculating the exact concentration of the prepared NaOH solution through standardizing it with a solution of HCl. Next, the same NaOH solution will be used to titrate the unknown acid solution. The exact concentration of NaOH that was calculated will then be used to find the concentration of the unknown acid.

Procedure:

As described in the lab manual (Acid Base Titrations, Dr. Rashmi Venkateswaran, Experiment 4, pages 78-83).

Observations:

- The HCl in the first portion of the experiment turned pink more quickly than the unknown acid in the second portion when they were titrated with the NaOH solution.
- In each parts of the laboratory, the pH of the titrands stabilized at around 11-12
- The graphs for the unknown acid has two equivalence points as it is diprotic.

Table 1: Data Obtained From HCl and NaOH Titration

	Trial 1	Trial 2	Trial 3
Volume of NaOH Used to Reach Endpoint (mL)	*Initial: 40.0* *Final: 30.5* **9.5**	*Initial: 30.5* *Final: 20.3* **10.2**	*Initial: 20.3* *Final: 10.0* **10.3**
Volume of 0.1M HCl (mL)	Initial: 4.00 Final: 14.00 **10.00**	Initial: 14.00 Final: 24.00 **10.00**	Initial: 14.40 Final: 24.00 **9.60**
Point of Equivalence Obtained from LabQuest2 (mL)	9.374	8.943	9.565
Final pH	11.06	11.11	11.02

Sample Calculations: Finding the Change of Volume in the Burette

Part 1, Trial 1 (Change in Volume of NaOH)

Change in Volume = Initial Volume - Final Volume

= 40.0mL - 30.5mL

= 9.5mL

Table 2: Data Obtained From Unknown Acid and NaOH Titration

	Trial 1	Trial 2	Trial 3
Volume of NaOH Used to Reach Endpoint (mL)	*Initial: 40.0* *Final: 27.2* **12.8**	*Initial: 27.2* *Final: 14.9* **12.3**	*Initial: 25.0* *Final: 12.1* **12.9**
Volume of Unknown Acid #2 (mL)	*Initial: 7.00* *Final: 17.00* **10.00**	*Initial: 2.81* *Final: 12.85* **10.04**	*Initial: 12.85* *Final: 22.80* **9.95**
Point of Equivalence Obtained from LabQuest2 (mL)	5.165	5.261	9.995
Final pH	11.13	11.03	11.05

Calculations:

1. Concentration of Prepared NaOH solution:

Concentration of NaOH concentrate	6M
Volume of NaOH concentrate	5.0 mL
Volume of Distilled Water	250 mL
Concentration of NaOH solution	C1*V1 = C2*V2 (6)(5.0) = C2 (25.0 + 5.0) C2 = 0.117646 **C2 ≈ 0.1M**

2. Exact Concentration of NaOH Solution

	Formula: *Cbase * Vbase = Cacid * Vacid*
Trial 1	Cbase (9.374) = (0.1)(10.00) Cbase = 0.1067
Trial 2	Cbase(8.943) = (0.1)(10.00) Cbase = 0.1118
Trial 3	Cbase(9.565) = (0.1)(9.60) Cbase = 0.1004
Average	(0.1067+0.1118+0.1004) / 3 = 0.1063 M **$C_{NaOH} \approx 0.1M$**

3. Exact concentration of Unknown Acid #2

	Formula: *Cbase * Vbase = (b/a) * Cacid * Vacid*
Trial 1	(0.1063)(5.165) = (½)*Cacid*(10.00) Cacid = 0.1098
Trial 2	(0.1063)(5.261) = (½)*Cacid*(10.04) Cacid = 0.1114
Trial 3	(0.1063)(9.995) = (½)*Cacid*(9.95) Cacid = 0.2136
Average	(0.1098 + 0.1114 + 0.2136) / 3 = 0.1449 M **$C_{Unknown\ Acid} \approx 0.15M$**

Graphs:

Figure 1: Part 1, Trial 1

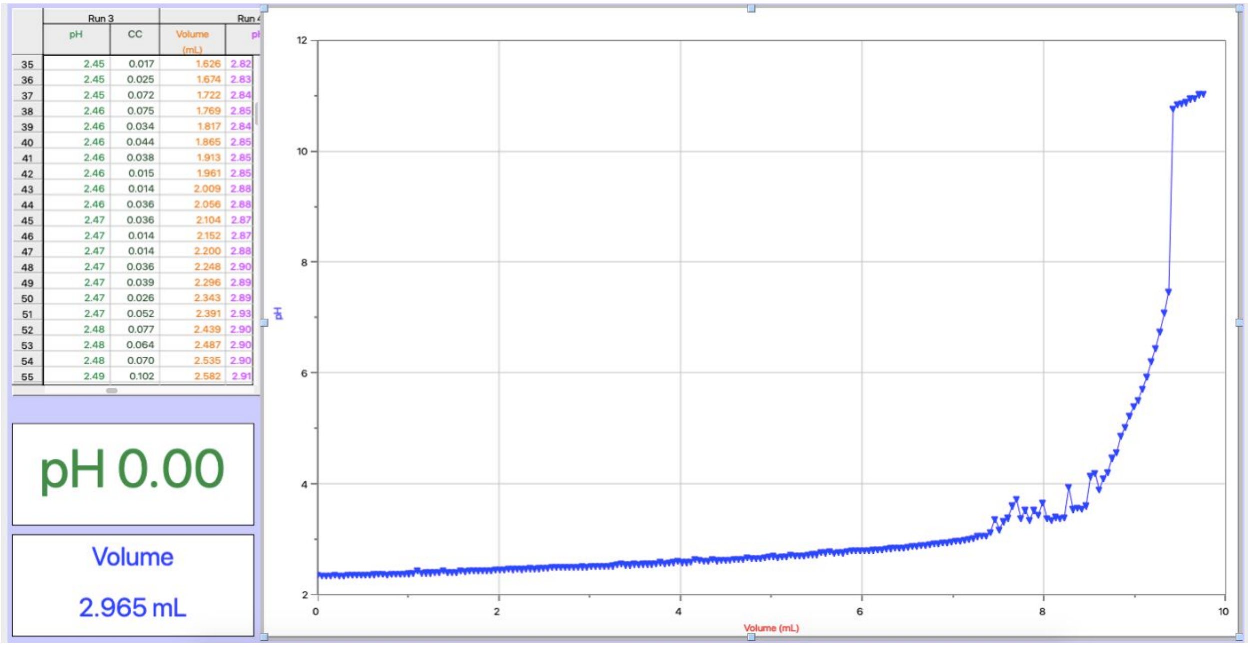


Figure 2: Part 1, Trial 2

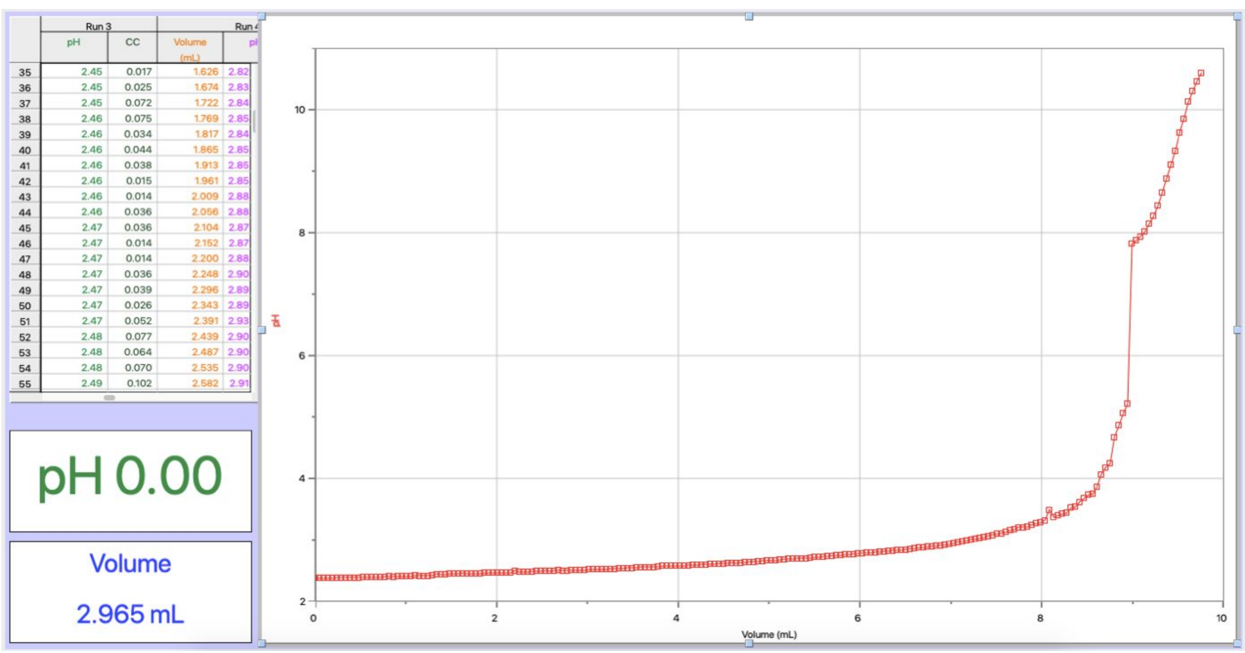
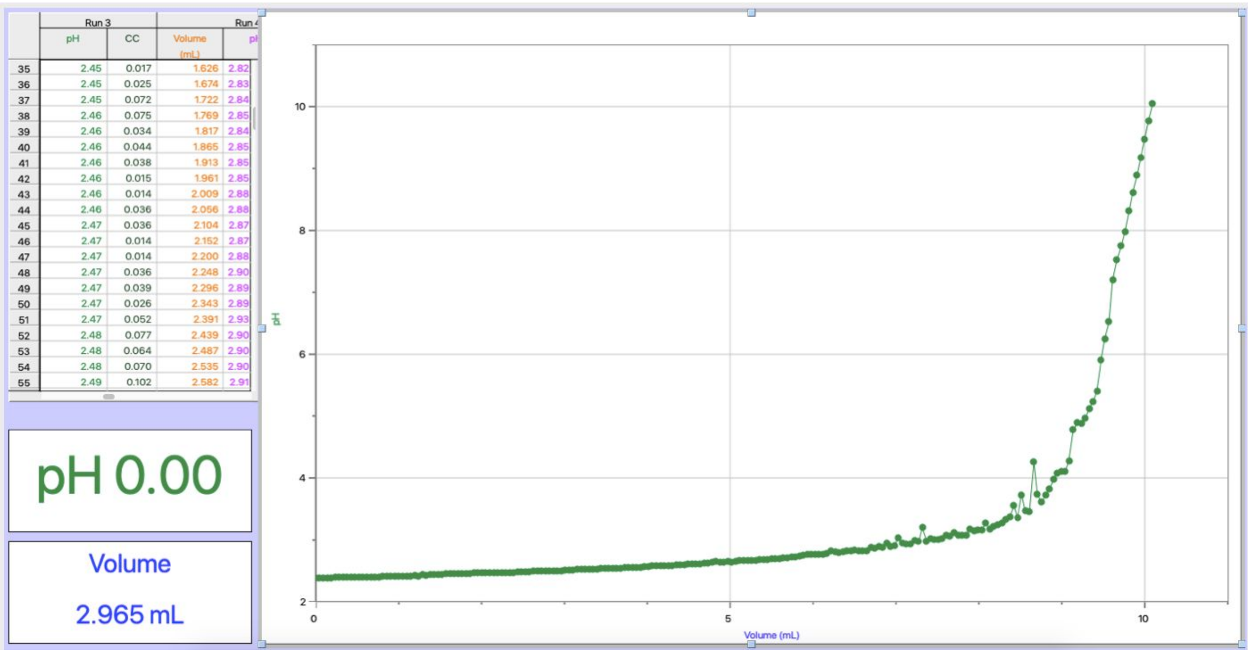
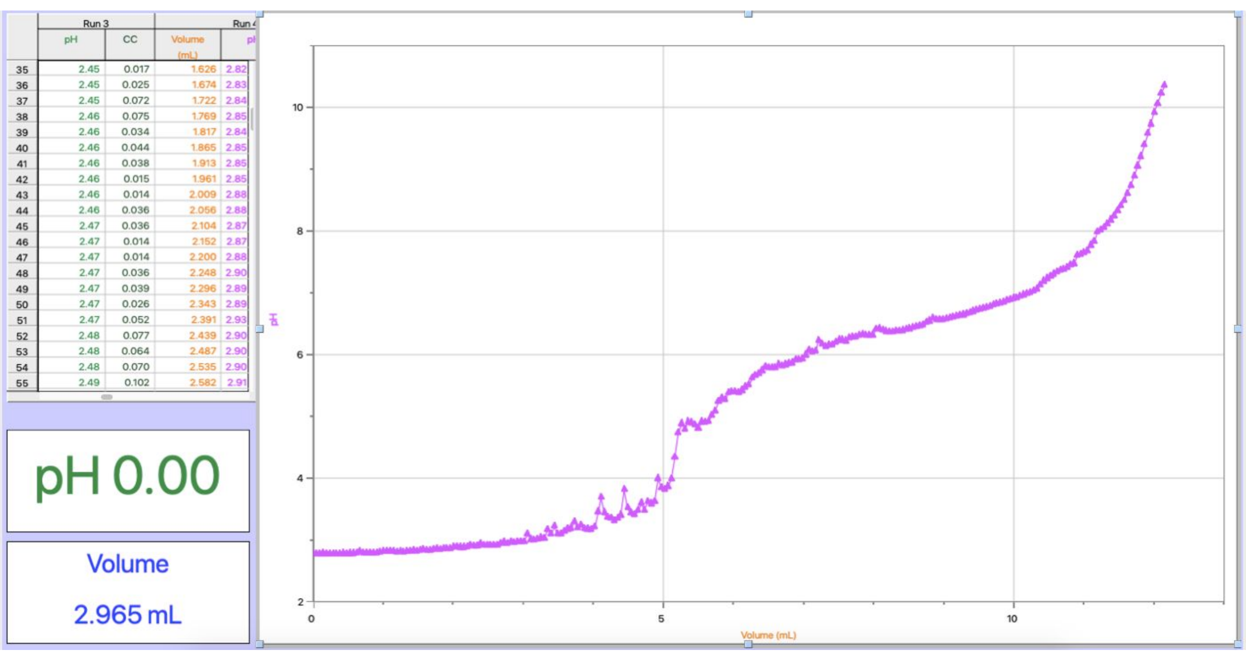


Figure 3: Part 1, Trial 3



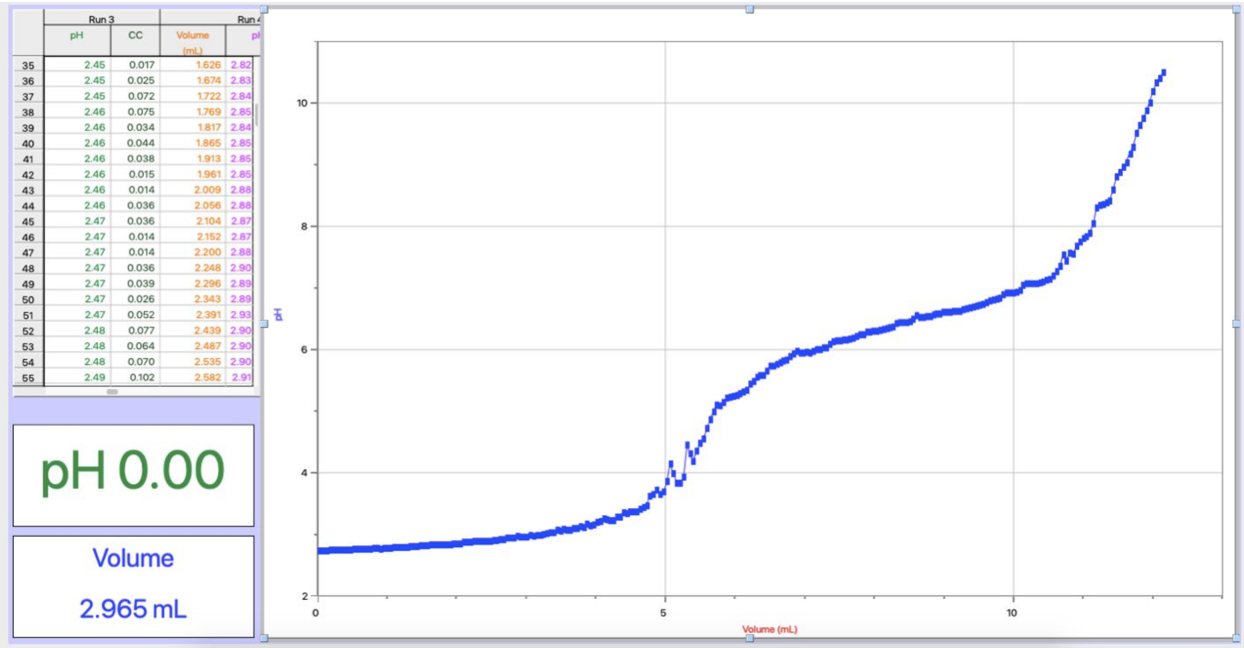
	Run 3			Run 4
	pH	CC	Volume (mL)	pH
35	2.45	0.017	1.626	2.82
36	2.45	0.025	1.674	2.83
37	2.45	0.072	1.722	2.84
38	2.46	0.075	1.769	2.85
39	2.46	0.034	1.817	2.84
40	2.46	0.044	1.865	2.85
41	2.46	0.038	1.913	2.85
42	2.46	0.015	1.961	2.85
43	2.46	0.014	2.009	2.88
44	2.46	0.036	2.056	2.88
45	2.47	0.036	2.104	2.87
46	2.47	0.014	2.152	2.87
47	2.47	0.014	2.200	2.88
48	2.47	0.036	2.248	2.90
49	2.47	0.039	2.296	2.89
50	2.47	0.026	2.343	2.89
51	2.47	0.052	2.391	2.93
52	2.48	0.077	2.439	2.90
53	2.48	0.064	2.487	2.90
54	2.48	0.070	2.535	2.90
55	2.49	0.102	2.582	2.91

Figure 4: Part 2, Trial 1



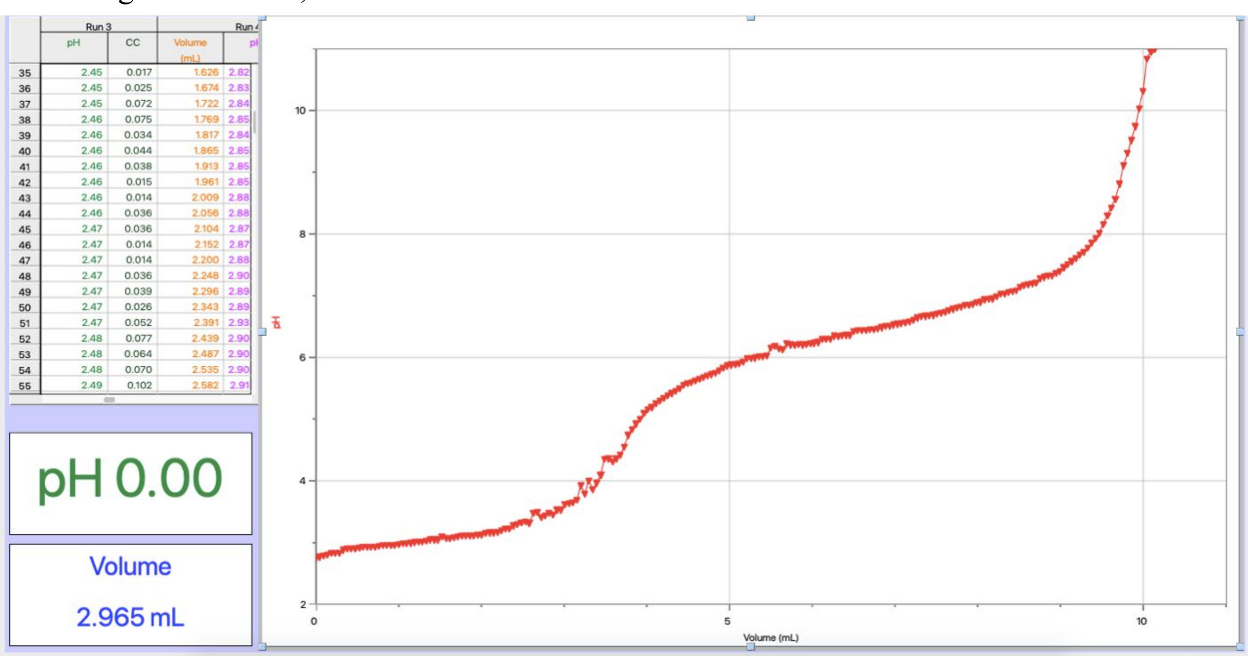
	Run 3			Run 4
	pH	CC	Volume (mL)	pH
35	2.45	0.017	1.626	2.82
36	2.45	0.025	1.674	2.83
37	2.45	0.072	1.722	2.84
38	2.46	0.075	1.769	2.85
39	2.46	0.034	1.817	2.84
40	2.46	0.044	1.865	2.85
41	2.46	0.038	1.913	2.85
42	2.46	0.015	1.961	2.85
43	2.46	0.014	2.009	2.88
44	2.46	0.036	2.056	2.88
45	2.47	0.036	2.104	2.87
46	2.47	0.014	2.152	2.87
47	2.47	0.014	2.200	2.88
48	2.47	0.036	2.248	2.90
49	2.47	0.039	2.296	2.89
50	2.47	0.026	2.343	2.89
51	2.47	0.052	2.391	2.93
52	2.48	0.077	2.439	2.90
53	2.48	0.064	2.487	2.90
54	2.48	0.070	2.535	2.90
55	2.49	0.102	2.582	2.91

Figure 5: Part 2, Trial 2



	Run 3			Run 4
	pH	CC	Volume (mL)	pH
35	2.45	0.017	1.626	2.82
36	2.45	0.025	1.674	2.83
37	2.45	0.072	1.722	2.84
38	2.46	0.075	1.769	2.85
39	2.46	0.034	1.817	2.84
40	2.46	0.044	1.865	2.85
41	2.46	0.038	1.913	2.85
42	2.46	0.015	1.961	2.85
43	2.46	0.014	2.009	2.88
44	2.46	0.036	2.056	2.88
45	2.47	0.036	2.104	2.87
46	2.47	0.014	2.152	2.87
47	2.47	0.014	2.200	2.88
48	2.47	0.036	2.248	2.90
49	2.47	0.039	2.296	2.89
50	2.47	0.026	2.343	2.89
51	2.47	0.052	2.391	2.93
52	2.48	0.077	2.439	2.90
53	2.48	0.064	2.487	2.90
54	2.48	0.070	2.535	2.90
55	2.49	0.102	2.582	2.91

Figure 6: Part 2, Trial 3



	Run 3			Run 4
	pH	CC	Volume (mL)	pH
35	2.45	0.017	1.626	2.82
36	2.45	0.025	1.674	2.83
37	2.45	0.072	1.722	2.84
38	2.46	0.075	1.769	2.85
39	2.46	0.034	1.817	2.84
40	2.46	0.044	1.865	2.85
41	2.46	0.038	1.913	2.85
42	2.46	0.015	1.961	2.85
43	2.46	0.014	2.009	2.88
44	2.46	0.036	2.056	2.88
45	2.47	0.036	2.104	2.87
46	2.47	0.014	2.152	2.87
47	2.47	0.014	2.200	2.88
48	2.47	0.036	2.248	2.90
49	2.47	0.039	2.296	2.89
50	2.47	0.026	2.343	2.89
51	2.47	0.052	2.391	2.93
52	2.48	0.077	2.439	2.90
53	2.48	0.064	2.487	2.90
54	2.48	0.070	2.535	2.90
55	2.49	0.102	2.582	2.91

Derivative Graphs:

Figure 7: Trial 1

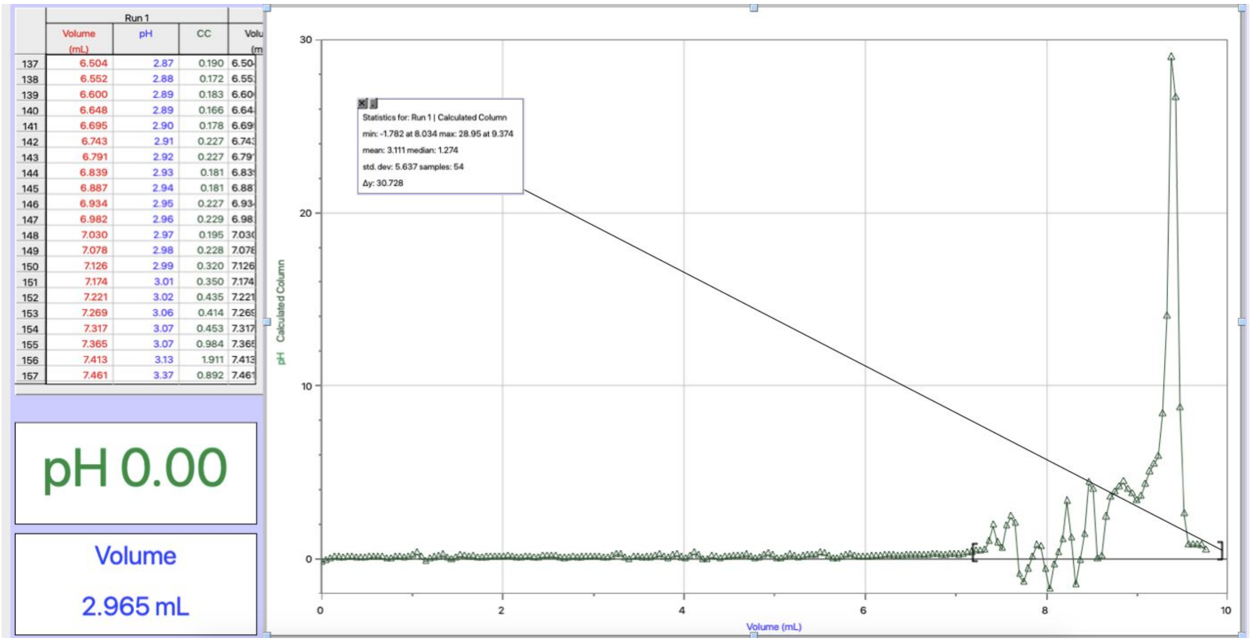


Figure 8: Trial 2

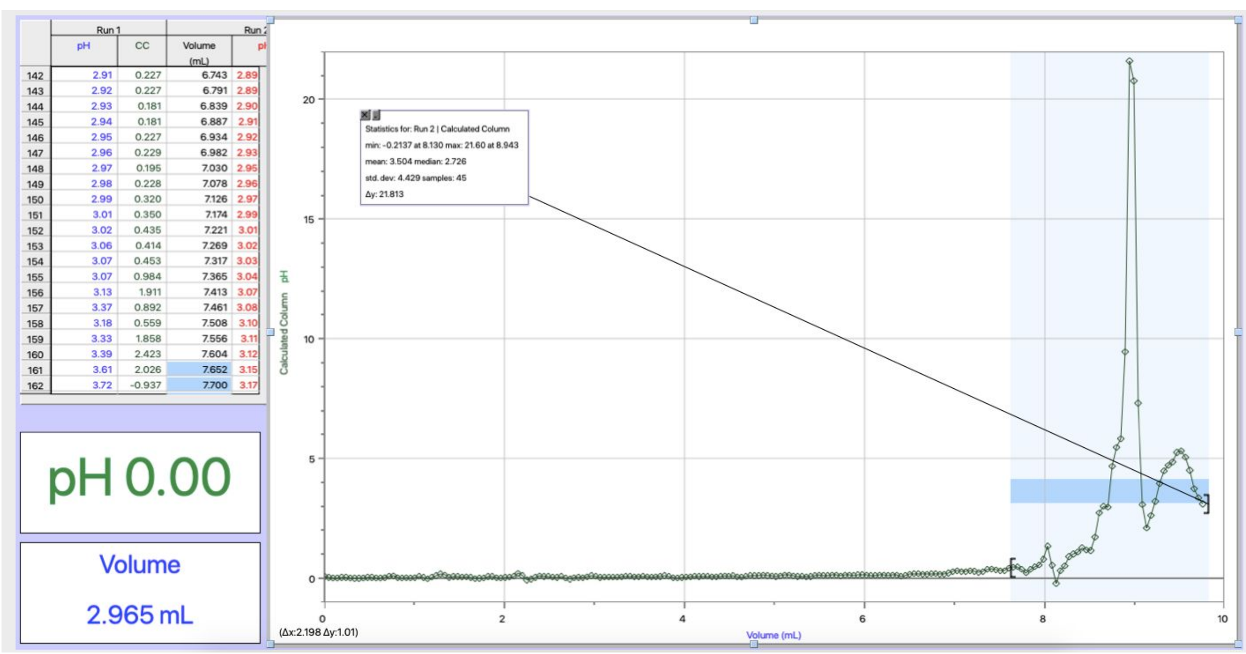
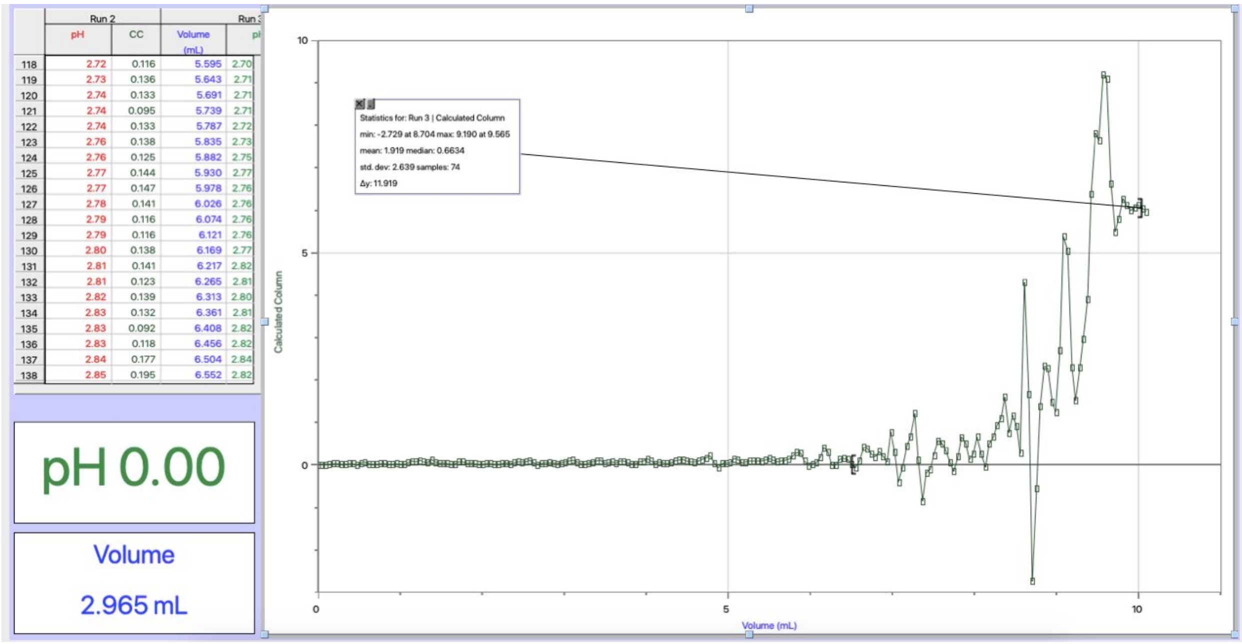
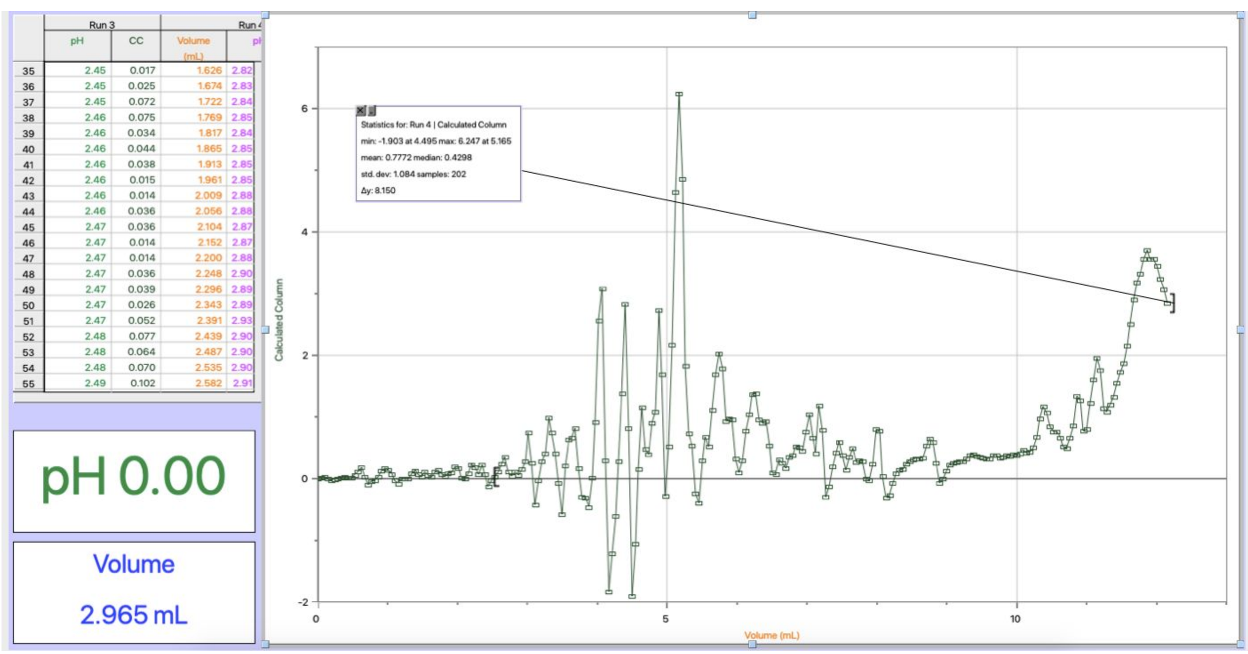


Figure 9: Trial 3



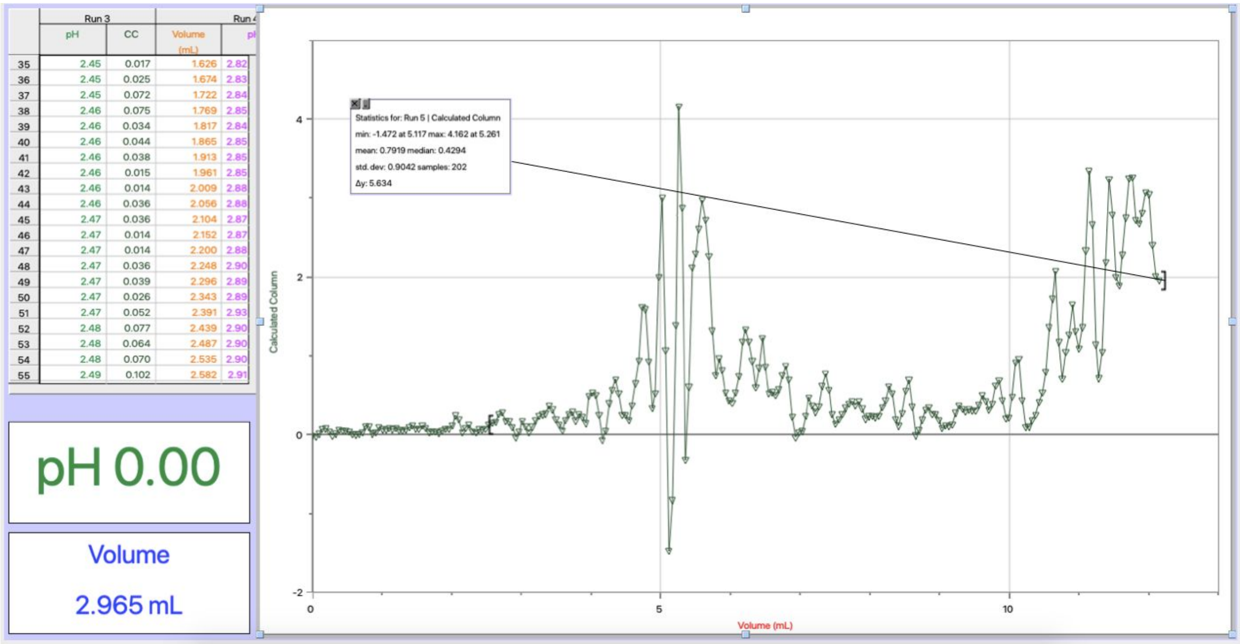
	Run 2			Run 3
	pH	CC	Volume (mL)	pH
118	2.72	0.116	5.595	2.70
119	2.73	0.136	5.643	2.71
120	2.74	0.133	5.691	2.71
121	2.74	0.095	5.739	2.71
122	2.74	0.133	5.787	2.72
123	2.76	0.138	5.835	2.73
124	2.76	0.125	5.882	2.75
125	2.77	0.144	5.930	2.77
126	2.77	0.147	5.978	2.76
127	2.78	0.141	6.026	2.76
128	2.79	0.116	6.074	2.76
129	2.79	0.116	6.121	2.76
130	2.80	0.138	6.169	2.77
131	2.81	0.141	6.217	2.82
132	2.81	0.123	6.265	2.81
133	2.82	0.139	6.313	2.80
134	2.83	0.132	6.361	2.81
135	2.83	0.092	6.408	2.82
136	2.83	0.118	6.456	2.82
137	2.84	0.177	6.504	2.84
138	2.85	0.195	6.552	2.82

Figure 10: Trial 4



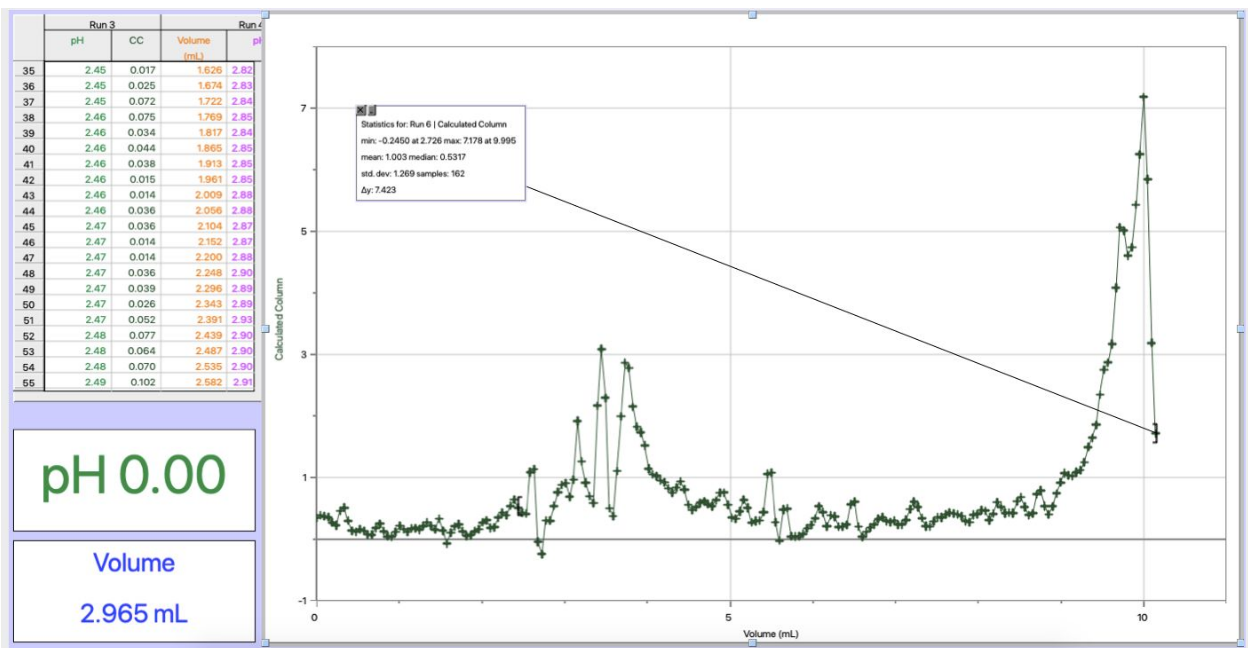
	Run 3			Run 4
	pH	CC	Volume (mL)	pH
35	2.45	0.017	1.626	2.82
36	2.45	0.025	1.674	2.83
37	2.45	0.072	1.722	2.84
38	2.46	0.075	1.769	2.85
39	2.46	0.034	1.817	2.84
40	2.46	0.044	1.865	2.85
41	2.46	0.038	1.913	2.85
42	2.46	0.015	1.961	2.85
43	2.46	0.014	2.009	2.88
44	2.46	0.036	2.056	2.88
45	2.47	0.036	2.104	2.87
46	2.47	0.014	2.152	2.87
47	2.47	0.014	2.200	2.88
48	2.47	0.036	2.248	2.90
49	2.47	0.039	2.296	2.89
50	2.47	0.026	2.343	2.89
51	2.47	0.052	2.391	2.93
52	2.48	0.077	2.439	2.90
53	2.48	0.064	2.487	2.90
54	2.48	0.070	2.535	2.90
55	2.49	0.102	2.582	2.91

Figure 11: Trial 5



	Run 3			Run 4
	pH	CC	Volume (mL)	pH
35	2.45	0.017	1.626	2.82
36	2.45	0.025	1.674	2.83
37	2.45	0.072	1.722	2.84
38	2.46	0.075	1.769	2.85
39	2.46	0.034	1.817	2.84
40	2.46	0.044	1.865	2.85
41	2.46	0.038	1.913	2.85
42	2.46	0.015	1.961	2.85
43	2.46	0.014	2.009	2.88
44	2.46	0.036	2.056	2.88
45	2.47	0.036	2.104	2.87
46	2.47	0.014	2.152	2.87
47	2.47	0.014	2.200	2.88
48	2.47	0.036	2.248	2.90
49	2.47	0.039	2.296	2.89
50	2.47	0.026	2.343	2.89
51	2.47	0.052	2.391	2.93
52	2.48	0.077	2.439	2.90
53	2.48	0.064	2.487	2.90
54	2.48	0.070	2.535	2.90
55	2.49	0.102	2.582	2.91

Figure 12: Trial 6



	Run 3			Run 4
	pH	CC	Volume (mL)	pH
35	2.45	0.017	1.626	2.82
36	2.45	0.025	1.674	2.83
37	2.45	0.072	1.722	2.84
38	2.46	0.075	1.769	2.85
39	2.46	0.034	1.817	2.84
40	2.46	0.044	1.865	2.85
41	2.46	0.038	1.913	2.85
42	2.46	0.015	1.961	2.85
43	2.46	0.014	2.009	2.88
44	2.46	0.036	2.056	2.88
45	2.47	0.036	2.104	2.87
46	2.47	0.014	2.152	2.87
47	2.47	0.014	2.200	2.88
48	2.47	0.036	2.248	2.90
49	2.47	0.039	2.296	2.89
50	2.47	0.026	2.343	2.89
51	2.47	0.052	2.391	2.93
52	2.48	0.077	2.439	2.90
53	2.48	0.064	2.487	2.90
54	2.48	0.070	2.535	2.90
55	2.49	0.102	2.582	2.91

Discussion:

The objective of this laboratory was to perform titrations of HCl and an unknown acid using a solution of NaOH as well as to obtain the concentrations of the NaOH solution and the diprotic, unknown acid. In the first portion of the experiment, a basic of solution of NaOH was prepared by dilution. The solution was made by mixing 5.0 mL of 6M NaOH and 250.0 mL of distilled water. The amount of NaOH concentrate used was not significant as long as it is recorded and used to find the new concentration after the dilution. If a smaller amount of of the NaOH concentrate was used, then the final concentration of the solution would be smaller and would require a larger volume to reach the endpoint. Likewise, if a larger amount of NaOH concentrate was used, the solution would have a higher concentration and would require less solution to reach the endpoint. Throughout all the titrations, the solutions turned pink at the end points due to the indicator, phenolphthalein, that was present. This explains the reason way that the concentration of the NaOH solution was important. Seen in the calculations above, the average concentration of the NaOH solution was approximately 0.12M. This value was determined soon before it was used because bases are not stable for long periods of time. Using the data obtained from LabQuest2, the average concentration of NaOH was found to be 0.11M and the concentration of unknown acid 2 was 0.15M. These values were calculated using the equation see in in the introduction: *Cbase * Vbase = (b/a) * Cacid * Vacid*

There were some noticeable discrepancies between the point of equivalency, obtained from Logger Pro, and the observed endpoint. In the first section of the experiment when HCl was titrated with NaOH the equivalence points and the observed endpoints were close in value, as they were in 1-2 mL of each other. This can be seen in table 1. These values indicate that the first set of titrations were successful. However, this is not the case in the second portion of the laboratory. The result from the titration between the unknown acid and the NaOH solution indicate that the titrations were not very successful. The point of equivalence and the observed endpoint were different in value by approximately 5-7 mL, this can be seen in figure 2. The discrepancy in the second portion of the experiment are due to the sources of error listed below.

Firstly when the volumes at the endpoints were documented, the value was taken off of the plastic burette and not LabQuest2. This reduces the overall accuracy of the results and made it a possibility that the value obtained from the burette was not read properly. This source of error could explain why the the endpoints were larger than all the points of equivalence. This source of error did not affect the calculated concentration of NaOH or the unknown acid as the values from LabQuest2 were used for calculation. In theory, the equivalence point and the endpoint should have been very close in value. Secondly, another source of error seen in this experiment would be that the titration was stopped when the solution the titrand was a darker pink instead of a light pink. This would have over titrated the solution and given a value for the endpoints that was much larger than the actual value.

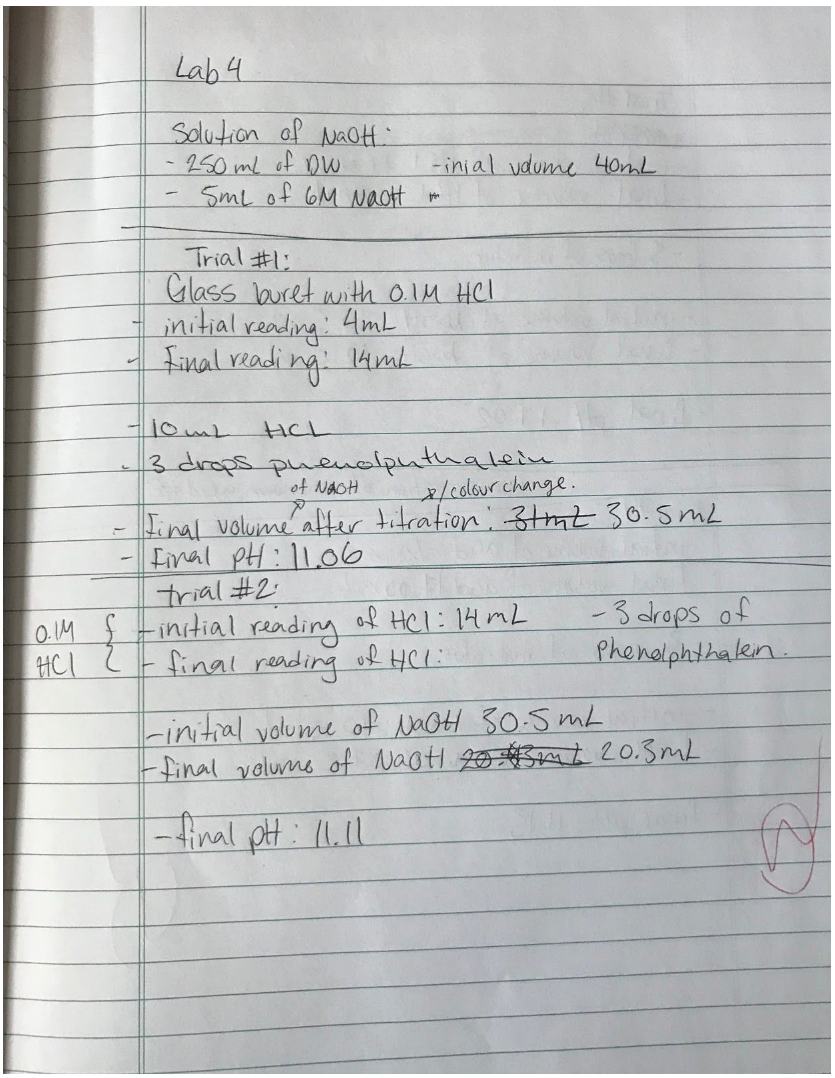
Conclusion:

In this laboratory, the exact concentration of an NaOH solution and an unknown acid were found by performing two sets of titrations. The calculated value of the NaOH solution was 0.11M and the concentration of the unknown acid was calculated to be 0.15M. These results were mildly impacted by some sources of error.

References:

- Clay, J.T., Walters, E.A., & Brabson, G.D. (1995). A dibasic acid titration for the physical chemistry laboratory. Journal of Chemical Education, 72(7), 665.

Raw Data:



Lab 4

Solution of NaOH:
- 250 mL of DW — -inial volume 40mL
- 5mL of 6M NaOH

Trial #1:
Glass buret with 0.1M HCl
- initial reading: 4mL
- Final reading: 14mL

- 10mL HCL
- 3 drops phenolphthalein
- Final volume of NaOH after titration w/ colour change: ~~31mL~~ 30.5mL
- Final pH: 11.06

Trial #2:
0.1M HCl { - initial reading of HCl: 14mL — - 3 drops of Phenolphthalein.
- final reading of HCl:

- initial volume of NaOH 30.5mL
- final volume of NaOH ~~20.43mL~~ 20.3mL

- final pH: 11.11

Trial #3:

~~NaOH of~~

- initial volume of HCl: 14.4mL
- final volume of HCl: 24mL

- 3 drops of indicator.

- initial volume of NaOH: 20.3mL
- final volume of NaOH: 10.0 mL

- final pH: 11.02

concentration of unknown acid #2.

trial #1:

intial volume of acid: 7.00mL
final volume of acid: 17.00mL

- 3 drops of indicator

- initial volume of NaOH: 40.0 mL
- final volume of NaOH: 27.2 mL

- final pH: 11.13

trial #2:

- initial volume of acid: ~~47.00mL~~ 2.81mL
- final ~~initial~~ volume of acid: 12.85 mL

- 3 drops of indicator

- initial volume of NaOH: 27.2 mL
- final volume of NaOH: 14.9 mL

- final pH: 11.03

---

trial #3:

- initial volume of acid: 12.85 mL
- final volume of acid: 22.80 mL

- 3 drops of indicator

- initial volume of NaOH ~~14.9mL~~ 25.0mL
- final volume of NaOH: 12.1 mL

- final pH: 11.05