

LAB 4: ACID BASE TITRATIONS

Date: 30/10/2018
Course: CHM1311
Section:
TA:
By:

Introduction:

Acids and bases are not only found in the chemistry lab, they are found in households and have many uses in our daily lives. There are many theories to define the acids and bases. One such theory is the Arrhenius definitions. The Arrhenius definition of an acid simply states that they are substances that when dissolved in water act as proton donors; they donate H^+ ions. Acids have a pH below 7. The lower the pH value of an acid, the higher the concentration of H^+ ions in it. The more acidic a solution is the more corrosive it is. For example, when HNO_3 dissolves in water the following equation is used to describe the dissociation that occurs:



Given that the dissociation results in the production of H^+ , HNO_3 is classified as an acid.

The Arrhenius definition of a base states that they are substances that when dissolved in water act as hydroxide ion donors; they donate OH^- ions. Bases have a pH above 7. The higher the pH value of a base, the higher the concentration of OH^- ions in it. The more basic a solution is the more corrosive it is. For example, when $NaOH$ dissolves in water the following equation is used to describe the dissociation that occurs:



Given that the dissociation results in the production of OH^- , $NaOH$ is classified as a base.

The Arrhenius definition of a base does not apply to all bases. There are several substances that act like bases but do not donate hydroxide ions when dissolved in water. These solutions are defined by the require the slightly wider scoped Brønsted-Lowry definition of a base. The definition states that bases are substances that accept hydrogen ions when dissolved in water; this concept explains the basic properties of bases such as $HCO_3^-(aq)$ and $CO_3^{2-}(aq)$. Overall, the Brønsted-Lowry definition of an acid is fairly similar to its Arrhenius counterpart.

In addition, there are substances that have been found to have acid and base qualities and yet contain no hydrogen ions. Thus an even more comprehensive definition than both the above given definitions was required; thus the Lewis definition was formed. According to the Lewis definition, an acid is a substance that is an electron pair acceptor and a base is a substance that is an electron pair donator. For the purpose of this lab experiment, the Arrhenius definition will be sufficient given that all acids and bases used contain either hydrogen or hydroxide ions.

Acids and bases can be described according to their strength or according to their concentration. If an acid or base is being described according to its strength, it is said to be strong or weak. When placed in water a strong acid or base will dissociate almost completely. Therefore, as in the cases of [1] and [2] there will be very little of the reactants, (HNO_3 or $NaOH$), remaining following the reaction given that a majority of the reactants will have been dissociated to form H^+ , NO_3^- , Na^+ and OH^- . Given this feature, HNO_3 can be identified as a strong acid and $NaOH$ as a strong base. When placed in water a weak acid or base will not dissociate completely. A majority of the solution will be comprised of the reactants following the dissociation reaction. Acetic acid is an example of a weak acid and ammonia is an example of a weak base. For the purpose of this lab experiment, mainly strong acids and bases will be used.

If an acid or base is being described according to its concentration, it is described as more or less concentrated and will depend on the ratio of acid or base added to a specified volume of water. The added acid or base in this case is considered the solute and the water is considered the solvent. If the volume of the solute is greater than the volume of the solvent, it is considered to be more concentrated. If the volume of the solute is less than the volume of the solvent, it is considered to be less concentrated. The amount (n) of the solute (acid or base) is measured in moles and the volume of the solution, comprised of both the solute and the solvent, is measured in litres. The concentration of the solute can be calculated with the following equation describes the relation:

$$\text{concentration (mol/L)} = \frac{\text{amount of solute (mol)}}{\text{amount of solution (L)}} \quad [3]$$

The moles of solute can be calculated by dividing its mass (grams) by its molar mass (grams per mole). The following equation describes the relation:

$$\text{moles of solute (mol)} = \frac{\text{mass of solute (g)}}{\text{molar mass of solute (g/mol)}} \quad [4]$$

When an acid and base are combined they undergo a neutralization reaction that produces a salt and water. The stoichiometry of the reaction determines the ratio of acid to base that is required for a complete neutralization to occur. Every neutralization reaction has an equivalence point, which is defined as the point when the base has been completely titrated out by the acid. The equivalence point is where there is an equal amount of acid and base in solution. The volume of acid required to fully titrate a base can be calculated by using the simple methodology shown below.

Step 1: identify the moles of base

$$n_{\text{base}} = \text{concentration}_{\text{base}} * \text{volume}_{\text{base}} \quad [5]$$

Step 2: identify the molar relationship between the acid and the base

$$x * n_{\text{base}} = y * n_{\text{acid}} \quad [6]$$

(x and y will be stoichiometric coefficients determined by the balanced chemical equation)

Step 3: calculate the amount of moles of acid required

$$\begin{aligned} n_{\text{acid}} &= x/y * n_{\text{base}} \\ n_{\text{acid}} &= x/y * n_{\text{base}} \quad (\text{rearrangement of [6]}) \end{aligned}$$

Step 4: calculate the volume of acid

$$\begin{aligned} \text{volume}_{\text{acid}} &= n_{\text{acid}} / \text{concentration}_{\text{acid}} \\ \text{volume}_{\text{acid}} &= n_{\text{acid}} / \text{concentration}_{\text{acid}} \quad (\text{rearrangement of [5]}) \end{aligned}$$

This process can be simplified by recognizing that the stoichiometric ratio of acid to base in the balanced equation of the neutralization. This information combined with [5] and [6] is used to develop the following simplified equation:

$$\text{concentration}_{\text{base}} * V_{\text{base}} = (b/a) * \text{concentration}_{\text{acid}} * V_{\text{acid}} \quad [7]$$

(in this equation the stoichiometric coefficient of the base is represented by b and the stoichiometric coefficient of the acid is represented by the a; both values are derived from the balanced chemical equation for the neutralization reaction)

When an acid or base with a known concentration is added to water to form a diluted acid or base, the concentration of the dilute solution can be calculated using equation [7], without the stoichiometric coefficients.

However, given that for the most part acids and bases are both colourless it can be hard to identify the point at which equivalence is achieved. Therefore, we make use of an indicator; an indicator is a weak acid that will dissociate in solution to different extents depending on the solutions' acidity. The most important quality of an indicator is that it is coloured. Making sure that the indicator chosen will change colour at a pH that is very close to the pH at which the equivalence point will occur is crucial in ensuring that the equivalence point and the endpoint have approximately the same value. The endpoint can be detected by a colour change in the acid base titration caused by the indicator.

The purpose of this lab is to better understand the use of indicators to identify equivalence points in titration as well we the stages of a titration between different kinds of acids and bases.

Procedure:

As described in the lab manual (Acid Base Titrations, Dr. Rashmi Venkateswaran, 2018, Exp. 4, p. 78-82).

Data & Results:

Table 1: Volume and Concentration of Various Substances in Part 1

Substance	Volume (L)	Concentration (mol/L)
NaOH	0.005	6.00
Dilute NaOH	0.255	unknown
H ₂ O	0.250	-
HCl	0.010	0.100
Dilute HCl	0.110	0.009091

Table 2: Calibration of Drop Counter in Part 1

	Total volume (mL)	# of drops
Trial 1	2	42
	4	42
Trial 2	2	42
	4	41

Table 3: Burette Volume for Trial 1 and 2 in Part 1

	Burette _{initial}	Burette _{final}
Trial 1	25.00	15.00
Trial 2	25.00	15.00

Table 4: Observed Equivalence and End Points in Part 1

	Colour	pH	Volume
Trial 1	Pink	-	17.416
	Stable	-	-
Trial 2	Pink	8.23	17.596
	Stable	10.86	-

Table 5: Burette Volume for Trial 1 and 2 in Part 2

	Burette initial	Burette final
Trial 1	25.00	15.00
Trial 2	25.00	15.00

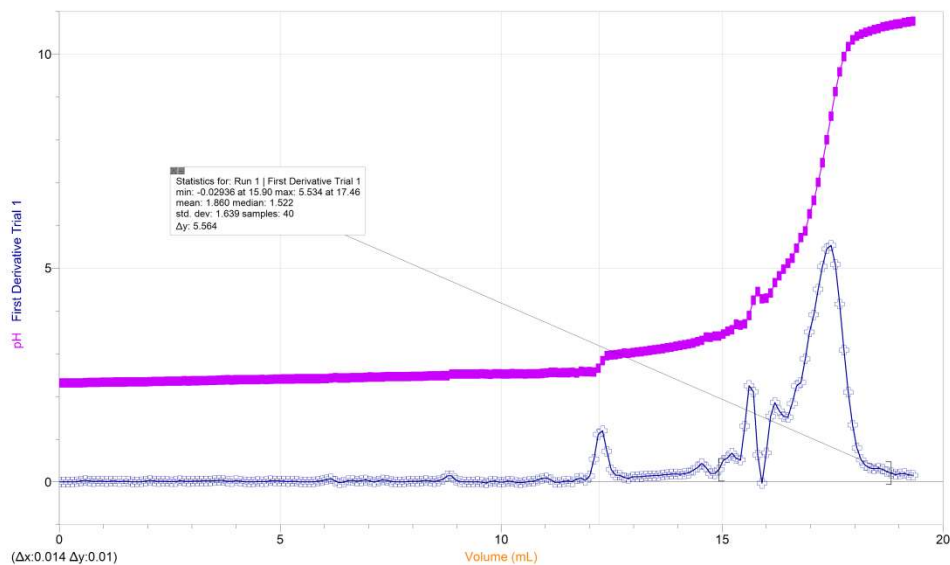
Table 6: Volume and Concentration of Various Substances in Part 1

Substance	Volume (L)	Concentration (mol/L)
Dilute unknown acid	0.120	unknown
Dilute NaOH	0.255	0.117647

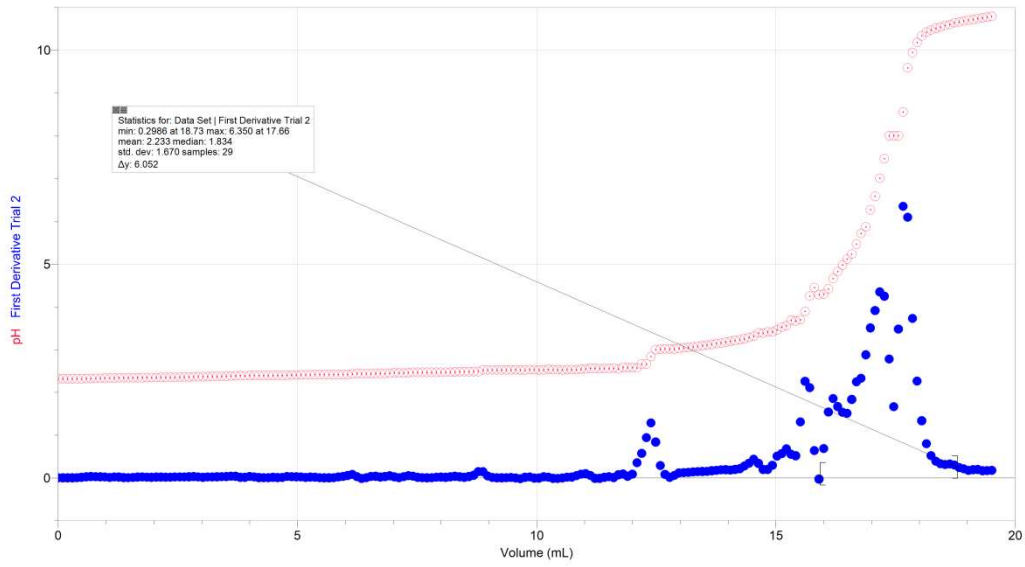
Table 7: Observed Equivalence and End Points in Part 1

	Colour	pH	Volume
Trial 1	Pink	8.2	30.439
	Stable	10.91	33.268
Trial 2	Pink	8.22	29.464
	Stable	-	-

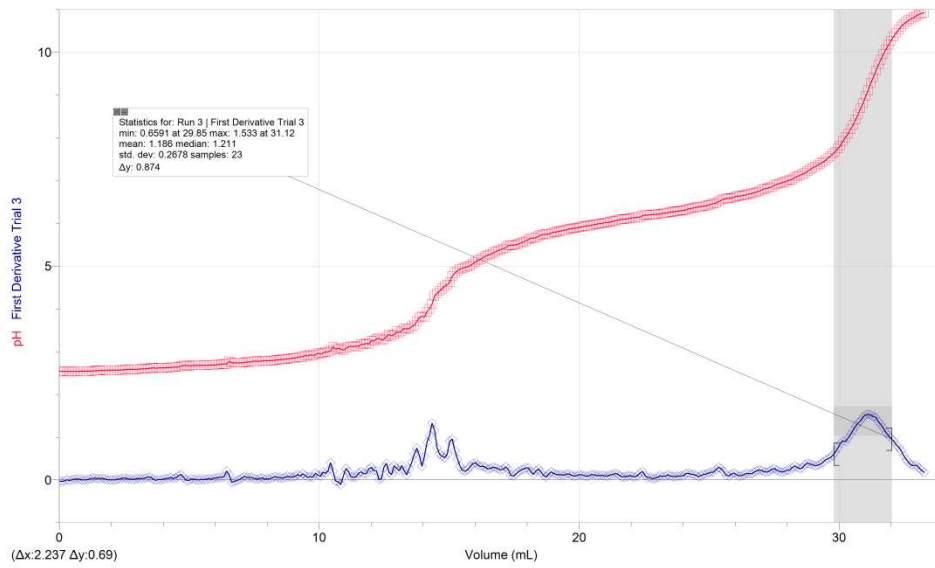
Graph 1: pH and First Derivative vs. Volume (Trial 1) – Experiment 4



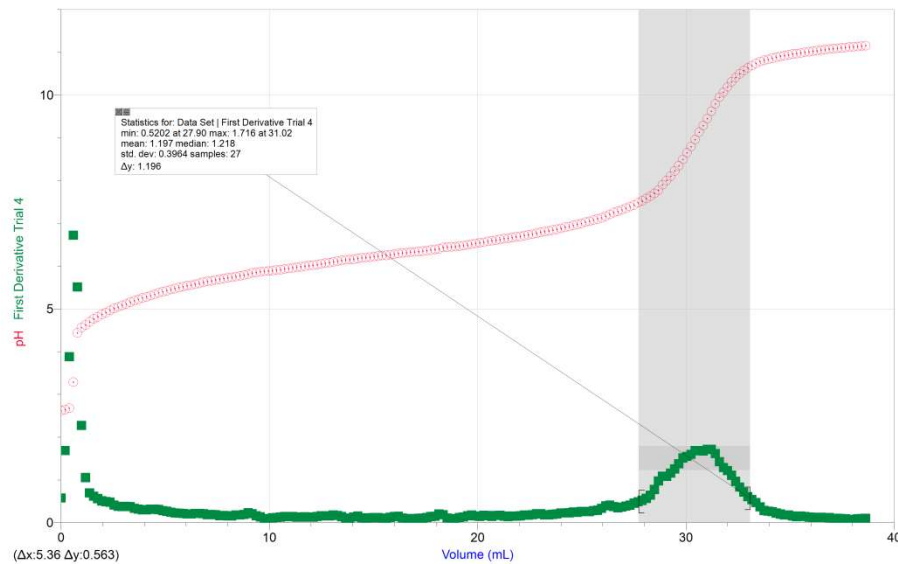
Graph 2: pH and First Derivative vs. Volume (Trial 2) – Experiment 4



Graph 3: pH and First Derivative vs. Volume (Trial 1) – Experiment 4



Graph 4: pH and First Derivative vs. Volume (Trial 2) – Experiment 4



Calculations

Conversions to Litres

Conversion factor: 1000 mL/L

- Volume NaOH = 5 mL * (1L/1000mL)
= 0.005 L
- Volume H₂O = 0.250 L
- Volume of HCl (Trial 1) = 0.010 L
- Volume of HCl (Trial 2) = 0.010 L
- Volume of dilute HCl = 0.110 L
- Volume of dilute unknown acid = 0.120 L
- Volume of dilute NaOH = 0.255 L
- Volume at Equivalence (Part 1 Trial 1) = 0.01746 L
- Volume at Equivalence (Part 1 Trial 2) = 0.01766 L
- Volume at Equivalence (Part 2 Trial 1) = 0.03112 L
- Volume at Equivalence (Part 2 Trial 2) = 0.03102 L

Concentration of dilute HCl:

$$C_1V_1 = C_2V_2$$

$$(0.100M) * (0.010L) = (x M) * (0.110 L)$$

$$0.009091 M \approx x$$

1. Concentration of NaOH based on initial concentration

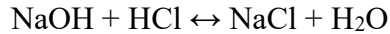
$$C_{\text{initial}} * V_{\text{initial}} = C_{\text{final}} * V_{\text{final}}$$

$$6.00 \text{ mol/L} * 0.005L = C_{\text{final}} * 0.255 L$$

$$C_{\text{final}} = 1.2 * 10^{-1} \text{ mol/L}$$

The approximate concentration of the NaOH based on the initial concentration is $1.2 * 10^{-1} \text{ mol/L}$.

2. Concentration of dilute NaOH – based on individual trials:



Trial 1:

$$C_{\text{NaOH}} * V_{\text{NaOH}} = (b/a) * C_{\text{HCl}} * V_{\text{HCl}}$$

$$C_{\text{NaOH}} * V_{\text{NaOH}} = (1/1) * C_{\text{HCl}} * V_{\text{HCl}}$$

$$C_{\text{NaOH}} * 0.01746 \text{ L} = 0.100 \text{ mol/L} * 0.010 \text{ L}$$

$$C_{\text{NaOH}} = 5.73 * 10^{-2} \text{ mol/L}$$

Trial 2:

$$C_{\text{NaOH}} = 5.66 * 10^{-2} \text{ mol/L}$$

Average C_{NaOH} :

$$\begin{aligned} \text{Average } C_{\text{NaOH}} &= (C_{\text{NaOH1}} + C_{\text{NaOH2}})/2 \\ &= (5.73 * 10^{-2} \text{ mol/L} + 5.66 * 10^{-2} \text{ mol/L})/2 \\ &= 5.7 * 10^{-2} \text{ mol/L} \end{aligned}$$

The approximate concentration of the NaOH is $5.7 * 10^{-2} \text{ mol/L}$.
(Based on individual trials)

3. Concentration of Unknown Acid (H_2A):



Trial 1:

$$C_{\text{NaOH}} * V_{\text{NaOH}} = (b/a) * C_{\text{H}_2\text{A}} * V_{\text{H}_2\text{A}}$$

$$C_{\text{NaOH}} * V_{\text{NaOH}} = (2/1) * C_{\text{H}_2\text{A}} * V_{\text{H}_2\text{A}}$$

$$5.7 * 10^{-2} \text{ mol/L} * 0.03112 \text{ L} = (2/1) * C_{\text{H}_2\text{A}} * 0.120 \text{ L}$$

$$7.39 * 10^{-3} \text{ mol/L} = C_{\text{H}_2\text{A}}$$

Trial 2:

$$C_{\text{H}_2\text{A}} = 7.38 * 10^{-3} \text{ mol/L}$$

Average $C_{\text{H}_2\text{A}}$:

$$\begin{aligned} \text{Average } C_{\text{H}_2\text{A}} &= (C_{\text{H}_2\text{A1}} + C_{\text{H}_2\text{A2}})/2 \\ &= (7.39 * 10^{-3} \text{ mol/L} + 7.38 * 10^{-3} \text{ mol/L})/2 \\ &= 7.38 * 10^{-3} \text{ mol/L} \end{aligned}$$

The approximate concentration of the unknown acid (H_2A) is $7.38 * 10^{-3} \text{ mol/L}$.
(Based on individual trials)

Discussion:

Not knowing the initial volume of the diluted NaOH used has no impact on this lab. This is because regardless of the volume of the NaOH the concentration of the dilute solution could be calculated using the values collected in the first part of the lab. However, calculating the concentration of NaOH before it is used is vital because this is the value used to calculate the concentration of the unknown acid.

The volume of base at which equivalence was determined by the Logger Pro was higher than the volumes at which equivalence was determined visually.

There were a few instance in which errors could have occurred; the two primary ones being when liquids were being transferred between containers and the calibration of the drop counter. Since the liquids were transferred across a number of different containers, there was

may have been some solution remaining in the container the liquid was previously in. This would have resulted in a slightly lower value for the volumes which in turn would have resulted in higher concentration values. This error could have been decreased by transferring the liquid between fewer containers. The second source of error likely occurred when calibrating. When calibrating the drop counter the first time, the counted value for 2 mL was equivalent to the drops counted by the machine. The second time the calibration was done the counted value for 2 mL was slightly higher than the value counted by the machine. This would have caused the tracked value for the volume according to the LoggerPro to be higher. As a result, when the concentration calculations are done, the concentration of NaOH and the unknown acid would be lower. This error likely occurred due to the collection of droplets on the sensors' surface, this error can be decreased by slightly increasing the distance between the drop counter and the burette.

At 0 mL of added base

At the beginning of the titration of the unknown acid there was 0 mL of base present in the solution. At this point the primary species present would have been the diprotic acid (H_2A) and water (H_2O). Given that the diprotic acid is weak, as demonstrated by the two step titration curve, H^+ and HA^- would have also been present.

At midway to the first equivalence point

Midway to the first equivalence point there was some base present in the dilute acid solution. The species present would have been H_2A , NaOH, NaHA, H_2O , H^+ , Na^+ , OH^- and HA^- . This is the result of adding NaOH to the unknown diprotic acid. NaOH dissociated into sodium ions (Na^+) and hydroxide ions (OH^-). At the same time, the unknown acid continued to dissociate into hydrogen protons (H^+) and HA^- . The ions present in solution recombine to form water and a salt.

At the first equivalence point

At the first equivalence point, the unknown acid had released the majority of its first protons. The species present at this point would have been NaHA, HA^- and H_2O . At the first equivalence point there were no more ions or extra NaOH present in the solution. Hence, the only species present were the unknown acid sans one hydrogen ion, water and the salt which was the byproduct of the first step of this neutralization reaction.

At midway to the second equivalence point

Midway to the second equivalence point there is once again more base added to the 'new' acid solution. The species present in solution at this point would have been NaHX, NaOH, Na_2X , H_2O , H^+ , Na^+ , OH^- and A^{2-} . This was due to the dissociation of NaOH into sodium ions (Na^+) and hydroxide ions (OH^-) as well as the dissociation of HA^- into hydrogen ions (H^+) and the other constituent of the acid (A^{2-}). As the dissociation continued the free ions recombine to form water and a salt.

At the second equivalence point

At the second equivalence point there was no excess NaOH or H_2A present in the solution. The amount of base in solution is equivalent to the amount of acid in solution, this was because the equivalence point had been reached as indicated by the colour change. The only two species present would have been Na_2A and H_2O as the acid and base had been completely neutralized.

Conclusion:

In conclusion, the calculated concentration of NaOH was 5.7×10^{-2} mol/L and the calculated concentration of the unknown acid was 7.38×10^{-3} mol/L. This calculation was made possible by the process of titration and the values that were easily identified during the initial part of this lab.

Reference:

- <https://www.chemguide.co.uk/physical/acidbaseeqia/phcurves.html>, Jim Clark, Chem Guide

Raw Data:**Electronic Data:**

Table 8: Partial Representation of the Titration of NaOH with HCl (Trial 1)

	Run 1		
	Volume (mL)	pH	FD1
1	0.000	2.32	0.000
2	0.098	2.32	0.000
3	0.195	2.32	0.000
4	0.293	2.32	0.001
5	0.390	2.32	0.007
6	0.488	2.32	0.024
7	0.585	2.32	0.036
8	0.683	2.33	0.024
9	0.780	2.33	0.012
10	0.878	2.33	0.019
11	0.976	2.33	0.019
12	1.073	2.33	0.011
13	1.171	2.33	0.020
14	1.268	2.34	0.020
15	1.366	2.34	0.011
16	1.463	2.34	0.019
17	1.561	2.34	0.017
18	1.659	2.34	0.005
19	1.756	2.34	0.003
20	1.854	2.34	0.007
21	1.951	2.34	0.023
22	2.049	2.35	0.036
23	2.146	2.35	0.025
24	2.244	2.35	0.012
25	2.341	2.35	0.019
26	2.439	2.36	0.017
27	2.537	2.36	0.008
28	2.634	2.36	0.011
29	2.732	2.36	0.031
30	2.829	2.37	0.023
31	2.927	2.36	0.012
32	3.024	2.37	0.021
33	3.122	2.37	0.023
34	3.220	2.37	0.024

Table 9: Partial Representation of the Titration of NaOH with HCl (Trial 2)

Data Set			
	Volume (mL)	pH	FD2
1	0	2.319323245	0.000
2	0.097560976	2.319326544	0.000
3	0.195121951	2.319329634	0.000
4	0.292682927	2.319333383	0.001
5	0.390243902	2.319329634	0.003
6	0.487804878	2.319329634	0.013
7	0.585365854	2.321507027	0.024
8	0.682926829	2.324452221	0.031
9	0.780487805	2.328642221	0.026
10	0.87804878	2.328969812	0.024
11	0.975609756	2.333641774	0.020
12	1.073170732	2.333641891	0.011
13	1.170731707	2.333641912	0.020
14	1.268292683	2.338664211	0.019
15	1.365853659	2.338670159	0.006
16	1.463414634	2.33867323	0.005
17	1.56097561	2.339156253	0.008
18	1.658536585	2.339556253	0.018
19	1.756097561	2.343280563	0.021
20	1.853658537	2.344986253	0.014
21	1.951219512	2.345280578	0.012
22	2.048780488	2.346391447	0.018
23	2.146341463	2.349193509	0.019
24	2.243902439	2.350919351	0.016
25	2.341463415	2.351919351	0.014
26	2.43902439	2.352592703	0.021
27	2.536585366	2.356592703	0.023
28	2.634146341	2.357592703	0.020
29	2.731707317	2.359592703	0.025
30	2.829268293	2.362231491	0.031
31	2.926829268	2.367266055	0.023
32	3.024390244	2.367231491	0.012
33	3.12195122	2.367231491	0.020
34	3.219512195	2.371604843	0.023

Table 10: Partial Representation of the Titration of NaOH with Unknown Acid (Trial 1)

Run 3			
	Volume (mL)	pH	FD3
1	0.000	2.54	-0.019
2	0.098	2.54	-0.032
3	0.195	2.53	-0.019
4	0.293	2.54	0.003
5	0.390	2.54	-0.010
6	0.488	2.53	0.003
7	0.585	2.54	0.018
8	0.683	2.54	0.022
9	0.780	2.54	0.019
10	0.878	2.54	0.005
11	0.976	2.54	0.003
12	1.073	2.54	0.007
13	1.171	2.54	0.024
14	1.268	2.55	0.041
15	1.366	2.55	0.042
16	1.463	2.56	0.031
17	1.561	2.56	0.030
18	1.659	2.56	0.037
19	1.756	2.57	0.024
20	1.854	2.57	0.007
21	1.951	2.57	0.001
22	2.049	2.57	0.001
23	2.146	2.57	0.005
24	2.244	2.57	0.020
25	2.341	2.57	0.028
26	2.439	2.57	0.042
27	2.537	2.58	0.042
28	2.634	2.58	0.028
29	2.732	2.59	0.021
30	2.829	2.59	0.012
31	2.927	2.59	0.024
32	3.024	2.59	0.037
33	3.122	2.60	0.030
34	3.220	2.60	0.032

Table 11: Partial Representation of the Titration of NaOH with Unknown Acid (Trial 2)

	Data Set		
	Volume (mL)	pH	FD4
1	0.000	2.619884581	0.577
2	0.195	2.639162157	1.684
3	0.390	2.677133142	3.878
4	0.585	3.287881824	6.723
5	0.780	4.437234317	5.511
6	0.976	4.561370228	2.272
7	1.171	4.623292141	1.054
8	1.366	4.694852842	0.694
9	1.561	4.761740192	0.617
10	1.756	4.814315401	0.563
11	1.951	4.871563963	0.509
12	2.146	4.909534947	0.491
13	2.341	4.966783508	0.479
14	2.537	5.009719929	0.411
15	2.732	5.043017562	0.380
16	2.927	5.081280631	0.373
17	3.122	5.114578264	0.382
18	3.317	5.157514685	0.374
19	3.512	5.191104402	0.333
20	3.707	5.219728682	0.316
21	3.902	5.253026315	0.300
22	4.098	5.276977244	0.300
23	4.293	5.310274876	0.312
24	4.488	5.338899157	0.313
25	4.683	5.372196789	0.307
26	4.878	5.400821107	0.279
27	5.073	5.424771999	0.265
28	5.268	5.453396279	0.244
29	5.463	5.472381772	0.227
30	5.659	5.4963327	0.220
31	5.854	5.515318193	0.215
32	6.049	5.539269121	0.203
33	6.244	5.553581262	0.203
34	6.439	5.57753219	0.214