Abstract

A titration of acetic acid and HCl was done to determine the concentration of both acids and to determine the statistical difference from the use of volumetric and coulometric titration. Another titration, involving back titration, was done on the I_2 analyte. The titration of acetic acid gave a concentration of 0.1976 M with a standard deviation of 0.001840 for volumetric titration while a concentration of 0.2031 M for HCl with a standard deviation of 0.03172 for coulometric titration. The case 3 t-test gave a value of 0.05434. The results for the HCl titration gave a concentration of 0.1905 M and a standard deviation of 0.01112 for volumetric titration and 0.1901 M and a standard deviation of 0.007963 for coulometric result, with a case 2 t-test value of 0.05434. Both t-test values allow for the conclusion that no statistical difference resulted from the use of either titrimetric method. For the back titration, an average concentration of 0.002895 M and a standard deviation of 0.0001436. Comparing to the given value of 0.003 M for the I_2 analyte, a t-test value of 1.032. This allows for the conclusion that there was no statistical difference between the two values and that the back titration was done with accuracy and precision.

Introduction

Titration involves the quantitative analysis of the analyte through the addition of a titrant to determine the concentration of the analyte [1]. Common titrimetric methods include volumetric titration, where a titrant is added to an analyte to accurately determine the volume of titrant used, coulometric titration, where a passing charge is used to quantify the analyte [2], and back titration, where two titrations are done to determine the concentration of an analyte [3]. The coulometric titration is done in a single electrolytic cell, which involves non-spontaneous reactions and therefore the cell needs to consume energy from external power sources. The reactions in the electrolytic cell for coulometric titration for this experiment are:

$$2Ag \rightarrow 2Ag^{+} + 2e^{-}$$

for the anodic compartment and

$$2H_2O + 2e^{-} \rightarrow H_2 + 2OH^{-}$$

for the cathodic compartment. All of these reactions occur in a single cell without a salt bridge, and a need for inert electrodes are needed to prevent reduction and oxidation reactions from occurring outside the cathode and anode respectively, giving rise to the use of silver foil as electrode for the cathode and graphite for the anode.

The procedure of the iodine back titration mostly parallels that of coulometric titration, with the main difference in that the concentration of the analyte is determined indirectly for back titration [4]. A reagent in excess will first be reacted to the analyte. The excess titrant from the first titration will be titrated with another compound so that the amount of excess reagent used

for the first titration can be determined [3]. From this value, the concentration of the analyte can be determined. The reactions that occurred in the anode are:

$$2I^- \rightarrow I_2 + 2e^-,$$

$$I_2 + {S_2O_3}^{2-} \rightarrow 2I^- + {S_4O_6}^{2-}.$$

The reaction that occurred in the cathode compartment is:

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^-.$$

The experiment was divided into two portions. For the first portion of the experiment, a volumetric and controlled-current coulometric titration was done to determine the concentration of the analyte, HCl, and compare the two methods to see if the procedures are statistically different in terms of accuracy and precision. In addition, another objective is to compare the two titrimetric methods and determine which of the two methods are preferred.

For the iodine back titration, the second portion of the experiment, the goal is to determine the total charge transferred in the titration and the amount of excess reagent used. Through this, the concentration of the I_2 analyte can be determined.

Experimental Procedure

Preparation of Solutions for Acid-Base Coulometry

The HCl solution was prepared by adding 6 mL of 0.5 M HCl stock solution and 50 mL of deionized water into a 150 mL beaker. To standardize the NaOH, a burette was filled

with the NaOH solution, and about 0.3 g of KHP was weighed into an Erlenmeyer flask and 50 mL of deionized water was added to this flask. A few drops of phenolphthalein were added to the flask and 10 to 15 mL of NaOH were titrated into this solution.

For the preparation of 140 mL of 0.4 M KNO_3, 5.0833 g of KNO_3 were dissolved in deionized water in a 150 mL beaker. To prepare 125 mL of 0.1 M NaCl, 0.7198 g of NaCl was dissolved in deionized water in a 150 mL beaker. The acetic acid solution that was to be used for the acid-base coulometry was prepared beforehand.

Acid-Base Coulometry

12.5 mL of 0.4 M KNO_3 and 12.5 mL of 0.1 M NaCl were added into a 25 mL graduated cylinder. This solution was then transferred to a 100 mL beaker, where a few drops of phenolphthalein were added. Using a micropipette, 100 µL of acetic acid solution was added into the same 100 mL beaker. A stir bar was then added to the beaker and the pH probe placed through the lid into the beaker. The stir plate and the current were turned on, with the current adjusted to between 8 to 10 mA. The initial mode number was recorded.

For the electrodes, the silver foil was sanded and the electrodes rinsed with deionized water. The silver foil was then clamped to the red lead and the graphite rod was clamped to the black lead. The electrodes were placed into the 100 mL beaker and simultaneously the LabQuest program was started. After a colour change was noticed, the LabQuest program was stopped and the electrodes were removed to be rinsed with

deionized water, and for the silver foil sanded again. The titrant was disposed down the sink.

The entire procedure in acid-base coulometry was repeated two more times for the acetic acid, to give three trials involving acetic acid. Afterwards, the entire procedure was repeated three more times, with HCl replacing acetic acid, to give three trials involving HCl.

Preparation of Solutions for Iodine Back Titration

125 mL of 0.2 M KI was prepared through the dissolution of 4.1 g of KI with deionized water in a 150 mL beaker. For the preparation of 0.05 M thiosulfate, 0.2987 g of Na_2SO_3 x 5 H_2O was dissolved into a 25 mL volumetric flask with deionized water.

Iodine Back Titration

A photometer was placed around a 100 mL beaker. 25 mL of 0.2 M KI and 25 mL of the acetate buffer was placed into the same 100 mL beaker. Afterwards, about 5 mL of the I_2 analyte was added into a 50 mL beaker and 1000 µL of the I_2 analyte was pipetted into the same 100 mL beaker. A stir bar was then added. Stirring was turned on and a few drops of starch were added to the beaker. 3 mL of thiosulfate were added to a 50 mL beaker and 500 µL of the thiosulfate was pipetted into the beaker.

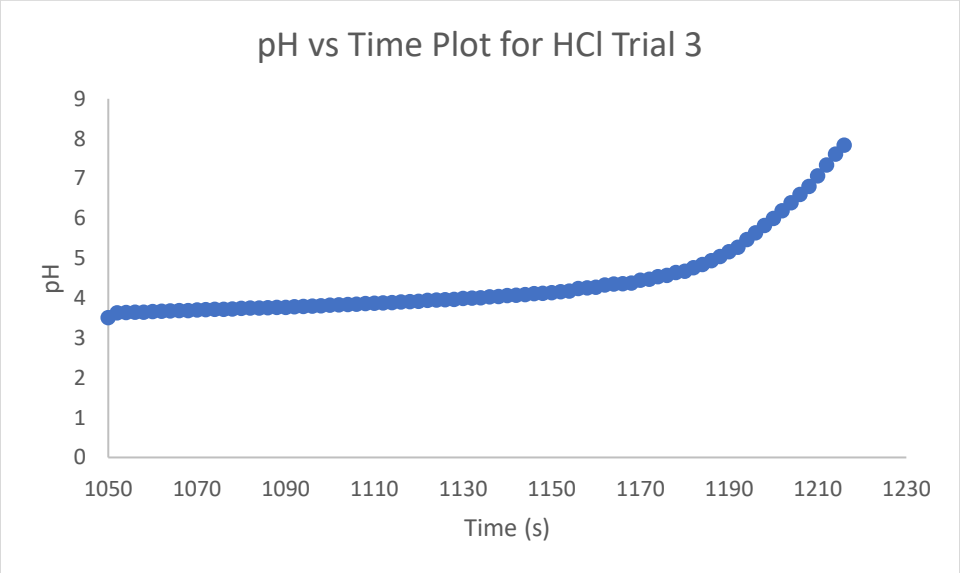
2 mL of KNO_3 and a few drops of phenolphthalein were added into the falcon tube and the lid was placed on the 100 mL beaker. The falcon tube was placed through the lid so that the cap is in the solution. The photometer was adjusted such that the path of the light emitted by the photometer was not blocked by either the falcon tube or the stir bar. Two graphite rods were used as the electrodes. They were both rinsed with deionized water and clamped to the black and red leads. The graphite rod clamped to the black lead was placed into the falcon tube while the other electrode was placed in the analyte solution. The current was turned on to 8 – 10 mA. At the same time the electrodes were placed in the solutions, the LabQuest and LabView programs were started. After a colour change was noticed, the LabQuest and LabView programs were stopped simultaneously. The electrodes were rinsed with deionized water and the solution was drained down the sink.

The entire procedure for iodine back titration was repeated two more times to give three trials in total.

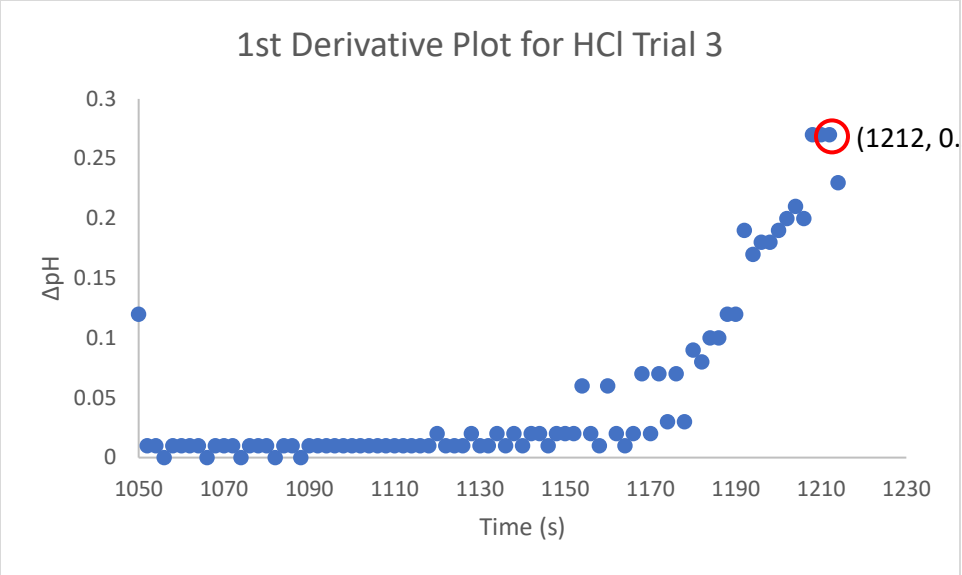
Results and Discussion

	Mass of KHP (g)	Volume of NaOH used (mL)	Moles of KHP	[NaOH] (M)
F01 F02 Trial 1	0.3024	16.12	0.001480	0.09185
F03 F04 Trial 1	0.296	15.78	0.00145	0.0918
F03 F04 Trial 2	0.3153	16.78	0.001544	0.09201
Average Concentration of NaOH:				0.0919
Standard Deviation:				8.94E-05

Table 1. Calculations for Question 1



Graph 1. pH vs time plot of HCl titration for trial 3



Graph 2. 1st Derivative plot for pH vs time for HCl titration trial 3

For calculating the total charge transferred, the trapezoidal rule was used, where trapezoidal areas in the integral are simplified into rectangles. The total charge is given by:

$$\int_{t=0}^{t=endpoint} Idt$$

Where I represents the current and t represents the time in seconds. The average of the current for two consecutive data points were taken to give the mean height of the two data points or the y-value of the rectangle. This acts as a simplification to find the area of a rectangle instead of a trapezoid. The average value was then multiplied to the difference in time between two consecutive data points, the x-value, to give the area of a rectangle. This area was then summed over the interval *t = 0* to *t = endpoint* to give the total area under the curve, which is equivalent to the total charge transferred.

Time (s)	Current (mA)
0	10.99
1	10.99
2	10.99
3	10.99

Table 2. A data table of current vs. time used for the calculations

The sample calculation that follows uses data from Table 2. Assuming that the endpoint of the reaction is at *t = 1*, the data points after *t = 1* can be ignored. The total charge transferred is given by:

$$\int_{t=1}^{t=0} Idt$$

The average of the current, or the height of the rectangle, is given by:

$$Height = \frac{I_{t=0} + I_{t=1}}{2} = \frac{10.99 + 10.99}{2} = 10.99.$$

The area of the rectangle, or the charge for a particular time interval, is given by:

$$Area = Height \times Width = Height \times \Delta t$$

$$Area = 10.99 \times (1 - 0) = 10.99 \times 1 = 10.99\, mA.$$

The total charge transferred is the total areas of the rectangles under the curve. As there is only one rectangle under this curve, the total charge transferred will be

$$10.99\, mA \times \frac{1\, C}{1000\, mA} = 0.01099\, C.$$

Trial #	Coulometric/Volumetric	Charge (C)	[HCl] (M)
1	Volumetric	N/A	0.2059
2	Volumetric	N/A	0.1815
3	Volumetric	N/A	0.1832
4	Volumetric	N/A	0.1915
1	Coulometric	1.921	0.1991
2	Coulometric	1.776	0.1841
3	Coulometric	1.805	0.1871

Table 3. Data table for the charge transferred and the concentration of HCl (Q3).

	Average Concentration	Standard Deviation	Confidence Interval
Volumetric	0.1905	0.01112	0.02042
Coulometric	0.1901	0.007963	0.02421

Table 4. Data table for the average concentration of HCl, with standard deviation and 95% confidence levels (Q4).

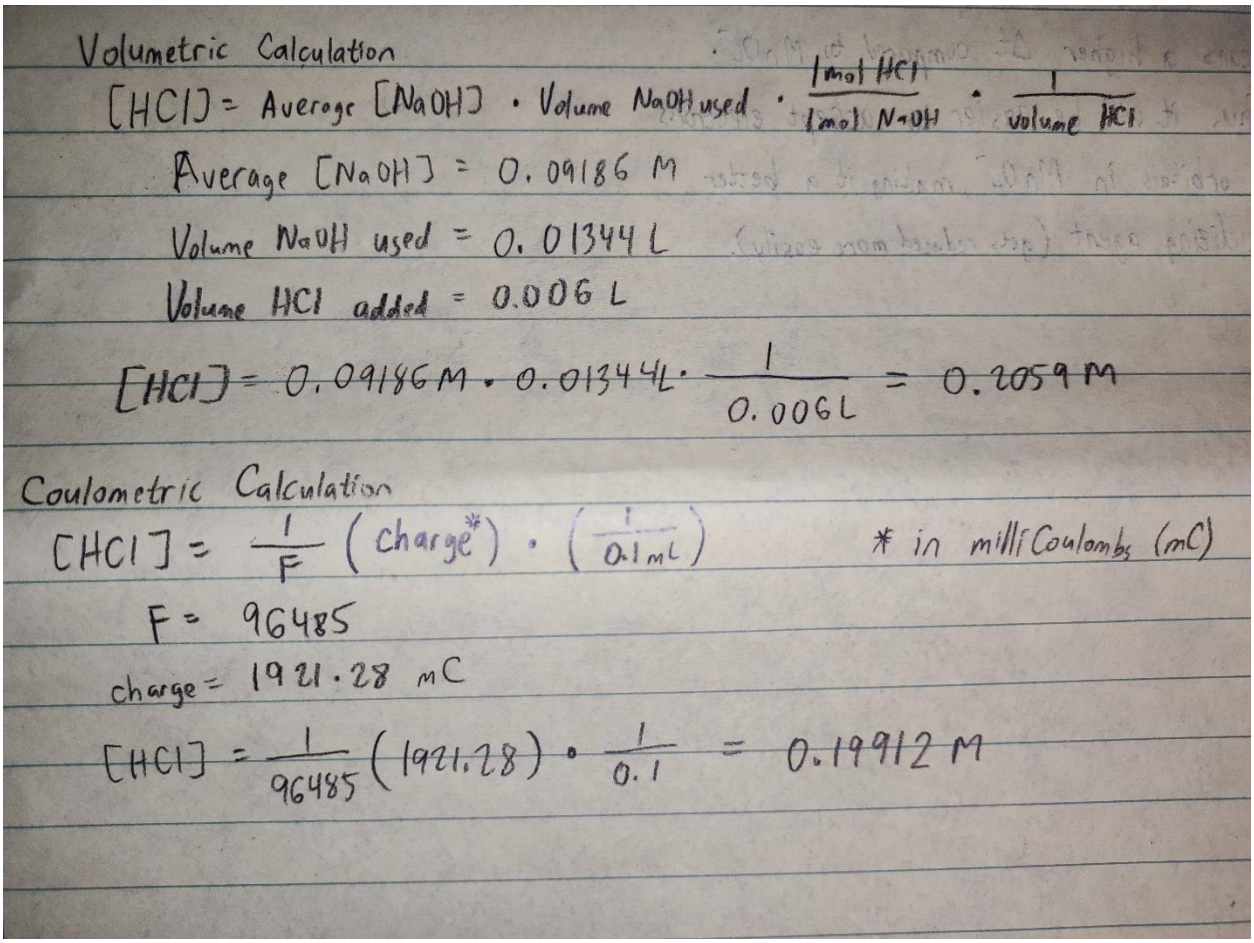


Image 1. Sample Calculations for Questions 3 to 6

F-test value	0.5124
Conclusion from F-test	Not statistically different
Case 2 t-test value	0.05434
Conclusion from Case 2 t-test	Not statistically different

Table 5. Results from statistical tests performed on data from Table 4 (Q5).

Trial #	Coulometric/Volumetric	Charge (C)	[Acetic Acid] (M)
1	Volumetric	N/A	0.1997
2	Volumetric	N/A	0.1970
3	Volumetric	N/A	0.1984
4	Volumetric	N/A	0.1955
1	Coulometric	1787.70	0.1853
2	Coulometric	2313.59	0.2398
3	Coulometric	1779.365	0.1844

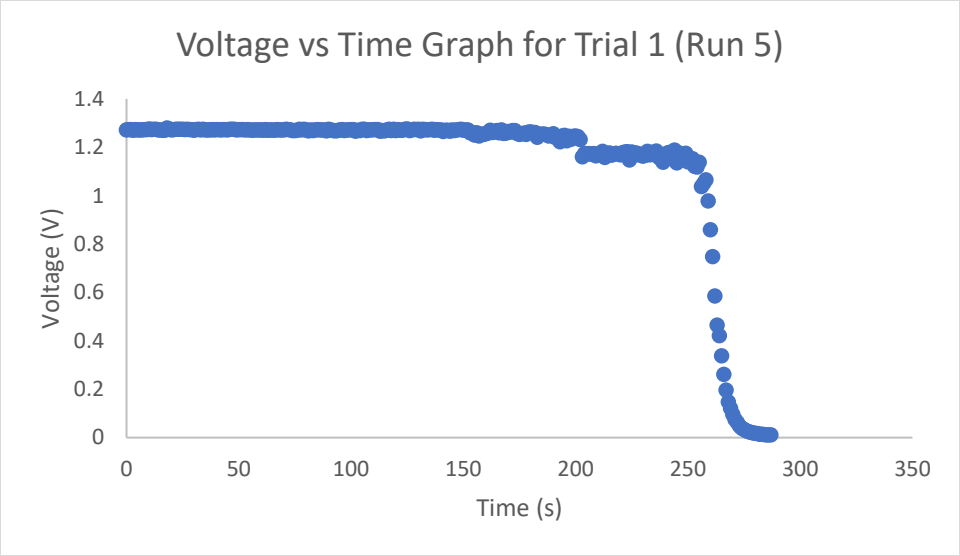
Table 6. Data table for the charge transferred and the concentration of acetic acid (Q6).

	Average Concentration	Standard Deviation	Confidence Interval
Volumetric	0.1976	0.0011840	$\pm$0.003378
Coulometric	0.2034	0.03172	$\pm$0.09645

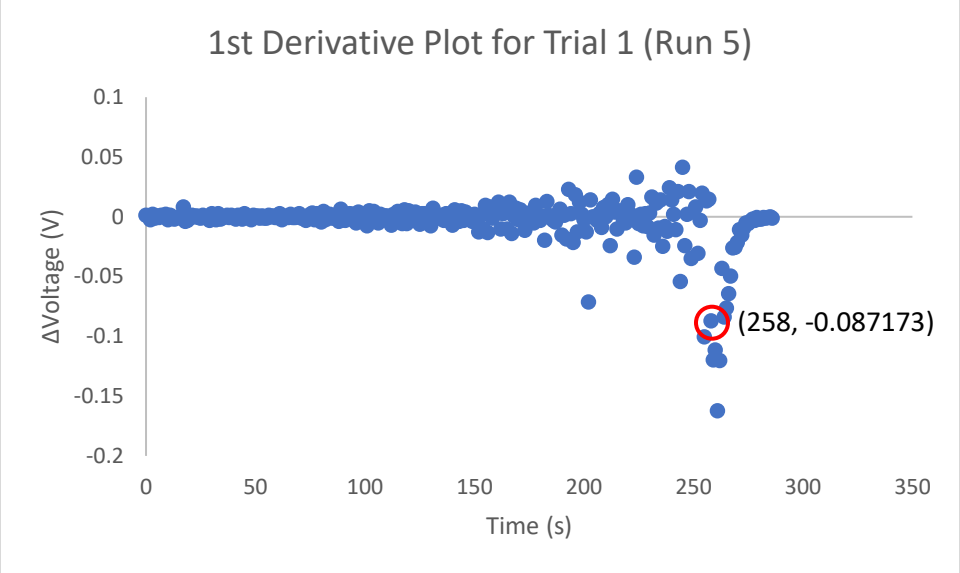
Table 7. Data table for the average concentration of acetic acid, with standard deviation and 95% confidence levels (Q6).

F-test value	297.3
Conclusion from F-test	Significantly different
Case 3 t-test	0.3013
Conclusion from Case 3 t-test	Not significantly different

Table 8. Results from statistical tests performed on data from Table 7 (Q6).



Graph 3. Voltage vs time graph for trial 1 or run 5 of the iodine back titration



Graph 4. 1st Derivative Plot for trial 1 or run 5 of the iodine back titration

Trial	Charge (C)	moles excess $(S_2O_3)^{2-}$	$[I_2]$ (M)
1	1.99746	2.07023E-05	0.003368953
2	1.99786	2.07064E-05	0.003364808

Table 9. Data table for the charge transferred, moles of thiosulfate in excess, and concentration of I_2 (Q7).

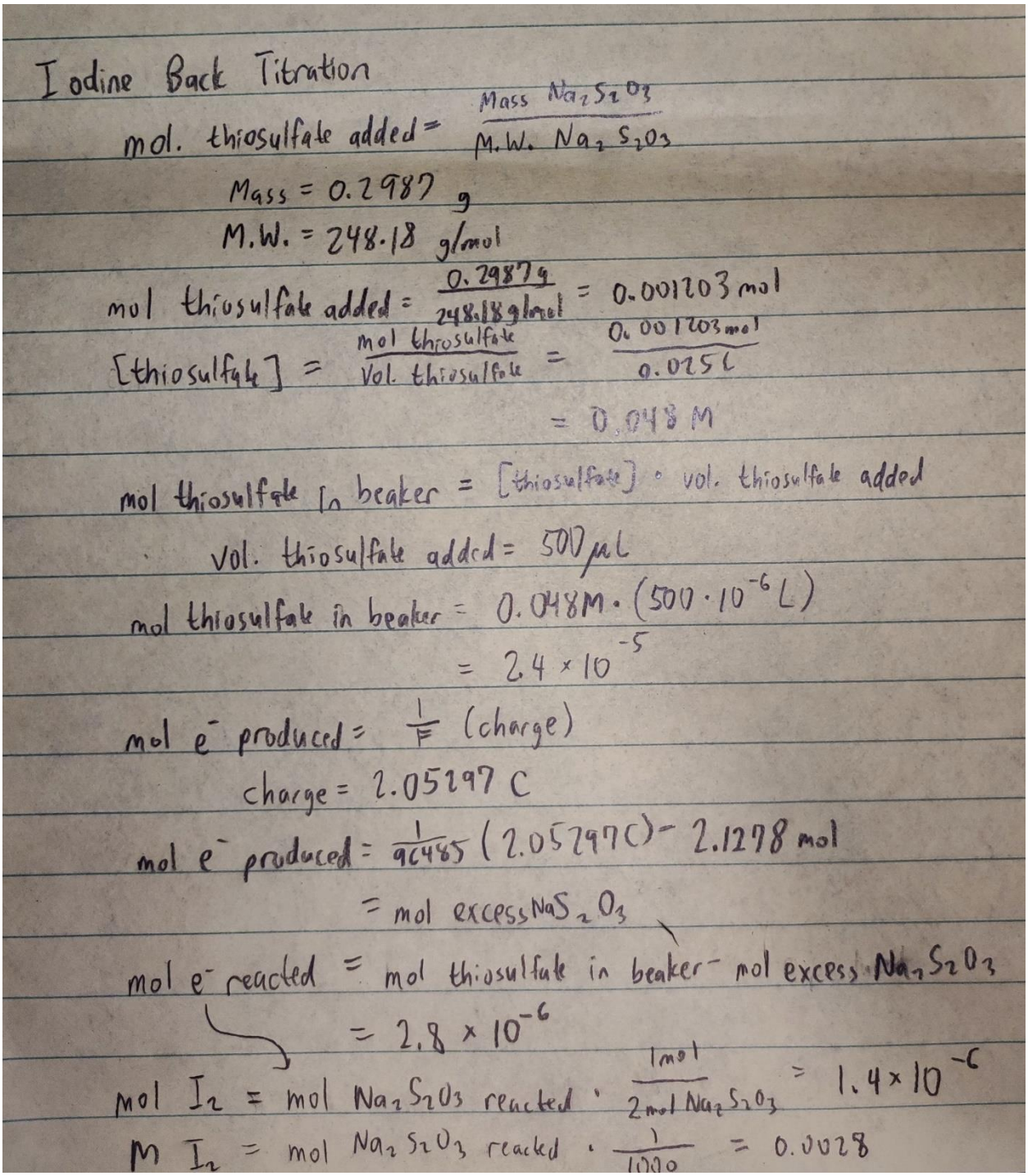


Image 2. Sample Calculation for Question 8.

Average Concentration	Standard Deviation	95% Confidence Limit
0.002895	0.0001436	$\pm$0.001291

Table 10. Data table for the average concentration of the I_2 analyte, with the standard deviation and the 95% confidence level.

Concentration for Comparison (M)	0.003
t-test Value	1.032
Conclusion from t-test	Not statistically different

Table 11. Results from statistical tests performed on data from Table 10.

In the acid titration portion of the experiment, a salt with a lower solubility constant (K_{sp}) was preferred. However, silver chloride instead of other silver halides (for this case silver bromide and iodide) was used for the precipitation of silver despite having the highest solubility constant among silver halides. When Ag reacts with chloride ions and other halide ions, slightly soluble solids are formed. As AgCl has a higher Ksp, this means that the chloride ions are more soluble than other halide ions and thus the precipitate is formed at a slower rate. This can be seen when sodium bromide or sodium iodide is used to precipitate silver. A thick layer of precipitate is formed quickly, and this will stop the flow of current from the electrode to the solution. The silver is prevented from oxidizing here. In addition, as bromide and iodide ions are weaker oxidizing agents compared to chloride ions, the bromide and iodide ions will oxidize to Br_2 and I_2, so although AgCl has the highest K_{sp}, it still is the best salt to use for this experiment (Q7) [5].

At the end of the coulometric titration, the pH probe was tested with deionized water. While it was determined that the pH meter used for this experiment was calibrated properly, a hypothetical scenario showed itself where the pH meter was not calibrated properly and was reading a pH different from one that is traditionally associated with deionized water. Even without proper calibration, the pH meter can still be used to accurately determine the endpoint. The pH data points would not be of much use for the calculations. The most important point of the pH readings is the graph which will be used to determine the equivalence point. Having an uncalibrated pH meter will only mean instrumental error that will be consistent throughout the measurements. The shape of the graph would not be affected, so this can still be associated with finding the equivalence point and associating this with the current plot where the total charge was to be calculated (Question 3).

After plotting all the graphs of the pH versus time data for the coulometric acid titration, sudden changes in pH were noted in the plots. This can be explained by the procedure, where the electrodes were placed in the solution at the same time the LabQuest program was started. The flow of current will suddenly start in the solution, and with this the redox reaction will also start, resulting in a sudden, if minor, change in pH of the solution at the beginning of the titration. At the end of the titration, the equivalence point is reached. At this point, the base has all reacted and the solution is turning acidic quickly, so there will be a steep jump in pH at the end of titration. In addition, the flow of the current is stopped here, so the reaction will also stop, which can also result in sudden jumps in pH (Q2).

Volumetric and coulometric titrations can both be used to determine the concentration of the analyte through the addition of a reagent with a known concentration until the endpoint

is reached. They differ in that volumetric titration involves the manual titration of titrant into the analyte while coulometric titration involves the use of electrical currents to drive reactions for titration. Based on the data collected from the experiment and the data resulting from calculations, no statistical difference was reported for both methods for this experiment. However, coulometric titration is prone to multiple errors such as human error and instrumental errors while volumetric titration is prone to just human error. Thus, volumetric titration is preferred. Although volumetric titration is made difficult by titration through addition of small amounts of the titrant at a time to ensure that the titration would not be overshot, coulometric analysis has multiple sources of error that may be harder to adjust or remove, and thus can affect the accuracy and precision of the results (Q6).

In addition, for the volumetric analysis, a proper pH indicator needs to be chosen, as the solution needs to absorb orange. Phenolphthalein absorbs green light and thus shows a pink hue. Because of this, the intensity will be constant and the colour change would not be seen (Q5) [4].

For the second portion of the experiment, a coulometric titration of iodine was done through back titration instead of a direct titration as the concentration of the iodine was expected to be very low. This meant that if a direct coulometric titration was done, a large amount of analyte is needed (Q9). As a large amount of analyte was hard to make given limitations in resources, a back titration was done instead of a direct titration.

If a back titration with the acid coulometric titration setup was to be done, the analyte will be slightly insoluble basic salts. This salt will get reacted with the acid which is in excess so to neutralize the solution (Q8).

For the experiment, acetate buffer was added to maintain acidic pH in the solution. Hydroxide will react with iodine in basic conditions and create iodate ions that would interfere with the reaction in the titration, so a slightly acidic solution would be needed for the entire experiment (Q4).

While plotting the graphs for current versus time for the iodine back titration, it was noted that the maximum possible current for the acid titration was higher than that for the iodine back titration. This phenomenon is due to lesser resistance in the salt bridge for the acid coulometric titration compared to the iodine back titration. Lesser resistance means that more current can flow, leading to a higher maximum current for the acid titration. Having a higher current means that the reaction will occur quicker, such as the case for the first trial for the iodine back titration, where the current is high (12.68 mA) and the equivalence point was reached within five seconds. Compared to trial 5 where a current of 7.93 mA led to the reaching of the equivalence point at 251 seconds, the reaction in the first trial occurred quickly (Q1).

Conclusion

The average concentrations from volumetric and coulometric titrations are 0.1905 M and 0.1901 M for HCl respectively, and 0.1976 M and 0.2032 M for acetic acid respectively. The statistical tests for these results show that the concentrations from volumetric and coulometric methods are not statistically different, and that both methods can be used for precisely determining the concentration of an analyte.

For the back titration, the average concentration for the I_2 analyte is 0.002895 M. Using statistical tests to compare this value to a given value showed no statistical difference. This showed that a back titration can accurately and precisely determine the concentration of an analyte.

The three types of titrations that were used for this experiment showed that accuracy and precision can be gained for any of the three titrimetric methods. They can all be used for determining the concentration of analytes. The choice of which type of titration to use will mostly depend on the physical properties of the analyte and the quantities of the analyte, as well as the possible errors that each method can incur and the preparations required to do titrations.

References

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Appendix

Data for Coulometric Titration: pH probe data

Time	pH
Acetic Acid Trial 1	
0	4.18
2	4.18
4	4.18
6	4.19
8	4.53
10	4.32
12	4.31
14	4.31
16	4.32
18	4.32
20	4.33
22	4.35
24	4.36
26	4.37
28	4.38
30	4.39
32	4.41
34	4.42
36	4.44
38	4.45
40	4.46
42	4.47
44	4.48
46	4.5
48	4.51
50	4.52
52	4.53
54	4.55
56	4.56
58	4.58
60	4.59
62	4.6
64	4.62
66	4.63
68	4.64
70	4.66
72	4.67
74	4.69
76	4.7
78	4.71
80	4.73
82	4.74
84	4.76
86	4.77
88	4.79
90	4.81
92	4.82
94	4.84
96	4.85
98	4.87
100	4.88
102	4.9
104	4.92
106	4.94
108	4.96
110	4.97
112	4.99
114	5.01
116	5.02
118	5.08
120	5.09
122	5.11
124	5.12
126	5.13
128	5.19
130	5.21
132	5.22
134	5.23
136	5.29
138	5.31
140	5.32
142	5.33
144	5.4
146	5.42
148	5.43
150	5.5
152	5.52
154	5.59
156	5.61
158	5.63
160	5.7
162	5.72
164	5.8
166	5.88
168	5.92
170	6
172	6.09
174	6.18
176	6.28
178	6.39
180	6.51
182	6.68
184	6.86
186	7.06
188	7.27
190	7.48
192	7.76
194	8.01
196	8.22
198	8.47
200	8.66
202	8.79
204	8.97
206	9.08
208	9.18
210	9.27
212	9.29
214	9.37
216	9.4
218	9.42
220	9.49
222	9.51
224	9.58
226	9.6
Acetic Acid Trial 2	
228	4.13

230	4.07
232	4.09
234	4.09
236	4.1
238	4.11
240	4.12
242	4.13
244	4.14
246	4.15
248	4.16
250	4.16
252	4.17
254	4.18
256	4.18
258	4.19
260	4.2
262	4.21
264	4.22
266	4.22
268	4.23
270	4.24
272	4.25
274	4.26
276	4.27
278	4.29
280	4.3
282	4.31
284	4.32
286	4.34
288	4.35
290	4.36
292	4.37
294	4.38
296	4.39
298	4.41
300	4.42
302	4.43
304	4.44
306	4.46
308	4.47
310	4.48
312	4.5

314	4.51
316	4.53
318	4.54
320	4.56
322	4.57
324	4.59
326	4.6
328	4.62
330	4.63
332	4.65
334	4.67
336	4.68
338	4.7
340	4.72
342	4.73
344	4.75
346	4.77
348	4.79
350	4.81
352	4.82
354	4.84
356	4.86
358	4.88
360	4.9
362	4.97
364	4.98
366	4.99
368	5
370	5.01
372	5.08
374	5.09
376	5.1
378	5.11
380	5.18
382	5.19
384	5.21
386	5.22
388	5.28
390	5.3
392	5.37
394	5.38
396	5.4

398	5.47
400	5.5
402	5.57
404	5.59
406	5.67
408	5.74
410	5.77
412	5.86
414	5.95
416	6.05
418	6.14
420	6.25
422	6.36
424	6.47
426	6.65
428	6.78
430	6.99
432	7.24
434	7.45
436	7.72
438	7.94
440	8.2
Acetic Acid Trial 3	
442	4.63
444	4.71
446	4.71
448	4.72
450	4.73
452	4.73
454	4.74
456	4.71
458	4.7
460	4.7
462	4.69
464	4.69
466	4.57
468	4.38
470	4.41
472	4.42
474	4.43
476	4.44

478	4.45
480	4.47
482	4.48
484	4.5
486	4.51
488	4.53
490	4.55
492	4.57
494	4.59
496	4.61
498	4.63
500	4.65
502	4.66
504	4.68
506	4.7
508	4.71
510	4.73
512	4.75
514	4.77
516	4.79
518	4.85
520	4.85
522	4.87
524	4.88
526	4.89
528	4.95
530	4.96
532	4.97
534	4.98
536	5.04
538	5.05
540	5.07
542	5.13
544	5.14
546	5.16
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558	5.42
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568	5.62
570	5.7
572	5.72
574	5.81
576	5.9
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580	6.09
582	6.19
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588	6.75
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592	7.14
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614	9.31
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624	9.58
626	9.6
628	9.62
630	9.68
632	9.7
634	9.71
636	9.72
638	9.73
640	9.79
642	9.8
644	9.82

646	9.83
648	9.84
650	9.86
652	9.88
654	9.9
656	9.91
658	9.93
660	9.95
662	9.96
664	9.98
666	9.99
668	10.01
670	10.02
672	10.04
674	10.05
676	10.06
678	10.07
680	10.09
682	10.1
684	10.11
686	10.12
688	10.13
690	10.14
692	10.15
694	10.16
696	10.17
698	10.18
700	10.19
702	10.2
704	10.21
706	10.22
708	10.23
HCl Trial 1	
710	3.6
712	3.6
714	3.61
716	3.61
718	3.62
720	3.63
722	3.64
724	3.64
726	3.65

728	3.66
730	3.66
732	3.67
734	3.68
736	3.68
738	3.69
740	3.7
742	3.71
744	3.71
746	3.72
748	3.73
750	3.74
752	3.75
754	3.75
756	3.76
758	3.77
760	3.78
762	3.79
764	3.8
766	3.81
768	3.82
770	3.83
772	3.84
774	3.85
776	3.86
778	3.87
780	3.88
782	3.89
784	3.9
786	3.91
788	3.92
790	3.94
792	3.95
794	3.96
796	3.98
798	3.99
800	4.01
802	4.02
804	4.03
806	4.05
808	4.06
810	4.08

812	4.1
814	4.12
816	4.14
818	4.16
820	4.22
822	4.24
824	4.25
826	4.26
828	4.32
830	4.34
832	4.36
834	4.42
836	4.44
838	4.51
840	4.54
842	4.61
844	4.64
846	4.72
848	4.81
850	4.85
852	4.94
854	5.09
856	5.21
858	5.37
860	5.49
862	5.61
864	5.78
866	5.9
868	6.08
870	6.21
872	6.39
874	6.58
876	6.79
878	7.05
880	7.27
882	7.53
884	7.8
HCl Trial 2	
886	3.66
888	3.7
890	3.51
892	3.57

894	3.55
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940	3.7
942	3.71
944	3.72
946	3.79
948	3.83
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952	3.86
954	3.85
956	3.85
958	3.84
960	3.83
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964	3.84
966	3.84
968	3.84
970	3.85
972	3.86
974	3.87
976	3.89

978	3.94
980	3.95
982	3.96
984	4.02
986	4.03
988	4.04
990	4.05
992	4.06
994	4.14
996	4.16
998	4.17
1000	4.26
1002	4.28
1004	4.34
1006	4.36
1008	4.45
1010	4.48
1012	4.61
1014	4.72
1016	4.82
1018	4.91
1020	5.11
1022	5.27
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1026	5.55
1028	5.67
1030	5.79
1032	5.97
1034	6.14
1036	6.32
1038	6.51
1040	6.78
1042	7.04
1044	7.32
1046	7.65
1048	7.93
HCl Trial 3	
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1052	3.63
1054	3.64
1056	3.65
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1096	3.8
1098	3.81
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1104	3.84
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1108	3.86
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1114	3.89
1116	3.9
1118	3.91
1120	3.92
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1124	3.95
1126	3.96
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1130	3.99
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1136	4.03
1138	4.04
1140	4.06
1142	4.07

1144	4.09
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1148	4.12
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1176	4.57
1178	4.64
1180	4.67
1182	4.76
1184	4.84
1186	4.94
1188	5.04
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1192	5.28
1194	5.47
1196	5.64
1198	5.82
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1202	6.19
1204	6.39
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1214	7.61
1216	7.84

Data for Coulometric Titration: Current Data

Vernier Format 2	
labquest data.txt 1/1/116 12:9:47	
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s	A
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4	1
5	1
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7	49.91
8	48.08
9	17.5
10	1
11	3.23
12	3.85
13	4.26
14	5.88
15	5.68
16	5.88
17	5.88
18	5.88
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23	6.5
24	7.1
25	7.1
26	7.1
27	7.31
28	7.72
29	9.14
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Vernier Format 2	
labquest data.txt 1/1/116 12:9:47	
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12	11.18
13	11.18
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15	11.18
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18	11.18
19	11.18
20	10.99
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29	11.18
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213	11.18
Vernier Format 2	

labquest data.txt 1/1/116 12:9:47	
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Time	Current
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269	11.18
Vernier Format 2	
labquest data.txt 1/1/116 12:9:47	
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10	10.99
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12	10.99
13	11.18
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70	11.18
71	11.18
72	10.99
73	11.18
74	11.18
75	11.18
76	11.18
77	10.99
78	11.18
79	11.18
80	11.18
81	11.18
82	11.18
83	11.18
84	10.99
85	11.18
86	11.18
87	10.99
88	10.99
89	11.18
90	11.18
91	11.18
92	11.18

93	10.99
94	11.18
95	11.38
96	11.18
97	11.18
98	11.18
99	10.99
100	11.18
101	11.18
102	11.18
103	11.18
104	10.99
105	10.99
106	11.18
107	11.18
108	11.18
109	11.18
110	10.99
111	10.99
112	10.99
113	11.18
114	11.18
115	11.18
116	11.18
117	11.18
118	11.18
119	11.18
120	11.18
121	11.18
122	11.18
123	10.99
124	10.99
125	11.18
126	11.18
127	11.18
128	11.18
129	11.18
130	11.18
131	11.18
132	11.18
133	11.18
134	10.99

135	11.18
136	11.18
137	10.99
138	10.99
139	10.99
140	11.18
141	11.18
142	11.18
143	11.18
144	11.18
145	10.99
146	11.18
147	10.99
148	11.18
149	11.18
150	11.18
151	11.18
152	11.18
153	11.18
154	11.18
155	10.99
156	10.99
157	10.99
158	11.18
159	11.18
160	11.18
161	10.99
162	11.18
163	11.18
164	11.18
165	11.18
166	11.18
167	11.18
168	11.18
169	11.18
170	11.18
171	11.18
172	11.18
173	11.18
174	10.99
Vernier Format 2	

labquest data.txt 1/1/116 12:9:47	
Run 5	
Time	Current
T	C
s	A
0	10.78
1	10.99
2	10.99
3	10.99
4	10.99
5	10.99
6	10.99
7	10.99
8	10.99
9	10.99
10	10.99
11	10.99
12	10.99
13	10.99
14	10.99
15	10.99
16	10.99
17	10.99
18	10.99
19	10.99
20	10.99
21	10.99
22	10.99
23	10.99
24	10.99
25	10.99
26	10.99
27	10.99
28	10.99
29	10.99
30	10.99
31	10.99
32	10.99
33	10.99
34	10.99

35	10.99
36	10.99
37	10.99
38	10.99
39	10.99
40	10.99
41	10.99
42	10.99
43	10.99
44	10.99
45	10.99
46	10.99
47	10.99
48	10.99
49	11.18
50	10.99
51	10.99
52	10.99
53	10.99
54	10.99
55	10.99
56	10.99
57	10.99
58	10.99
59	10.99
60	10.99
61	10.99
62	11.18
63	11.18
64	10.99
65	11.18
66	10.99
67	10.99
68	10.99
69	10.99
70	10.99
71	11.18
72	10.99
73	11.18
74	11.18
75	10.99
76	10.99

77	10.99
78	10.99
79	10.99
80	11.18
81	10.99
82	10.99
83	10.99
84	10.99
85	10.99
86	10.99
87	10.99
88	10.99
89	10.99
90	10.99
91	10.99
92	11.18
93	10.99
94	10.99
95	10.99
96	11.18
97	10.99
98	10.99
99	11.18
100	10.99
101	11.18
102	11.18
103	11.18
104	11.18
105	10.99
106	11.18
107	10.99
108	10.99
109	11.18
110	10.99
111	10.99
112	10.99
113	10.99
114	10.99
115	10.99
116	10.99
117	10.99
118	10.99

119	10.99
120	10.99
121	10.99
122	10.99
123	11.18
124	10.99
125	11.18
126	11.18
127	10.99
128	10.99
129	11.18
130	10.99
131	11.18
132	10.99
133	11.18
134	10.99
135	10.99
136	10.99
137	10.99
138	10.99
139	11.18
140	10.99
141	10.99
142	11.18
143	10.99
144	10.99
145	11.18
146	10.99
147	10.99
148	10.99
149	10.99
150	11.18
151	10.99
152	10.99
153	11.18
154	11.18
155	11.18
156	11.18
157	11.18
158	11.18
159	11.18
160	11.18

161	11.18
162	11.18
163	10.99
164	11.18
Vernier Format 2	
labquest data.txt 1/1/116 12:9:48	
Run 6	
Time	Current
T	C
s	A
0	10.99
1	10.99
2	10.99
3	10.99
4	10.99
5	10.99
6	10.99
7	10.99
8	10.99
9	10.99
10	10.99
11	10.99
12	10.99
13	10.99
14	10.99
15	10.99
16	10.99
17	10.99
18	10.99
19	10.99
20	11.18
21	10.99
22	10.99
23	10.99
24	10.99
25	10.99
26	10.99
27	10.99
28	10.99
29	10.99

30	10.99
31	11.18
32	10.99
33	11.18
34	10.99
35	10.99
36	11.18
37	10.99
38	10.99
39	10.99
40	10.99
41	10.99
42	10.99
43	11.18
44	10.99
45	10.99
46	10.99
47	10.99
48	11.18
49	11.18
50	11.18
51	11.18
52	10.99
53	10.99
54	11.18
55	11.18
56	11.18
57	11.18
58	10.99
59	11.18
60	10.99
61	11.18
62	10.99
63	10.99
64	10.99
65	10.99
66	10.99
67	11.18
68	10.99
69	11.18
70	10.99
71	11.18

72	10.99
73	10.99
74	11.18
75	11.18
76	10.99
77	10.99
78	11.18
79	11.18
80	10.99
81	10.99
82	10.99
83	10.99
84	10.99
85	11.18
86	11.18
87	11.18
88	10.99
89	11.18
90	10.99
91	11.18
92	10.99
93	10.99
94	10.99
95	11.18
96	10.99
97	10.99
98	11.18
99	11.18
100	10.99
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103	11.18
104	11.18
105	11.18
106	11.18
107	11.18
108	10.99
109	11.18
110	11.18
111	10.99
112	10.99
113	11.18

114	11.18
115	10.99
116	11.18
117	11.18
118	11.18
119	11.18
120	11.18
121	11.18
122	11.18
123	10.99
124	10.99
125	11.18
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128	11.18
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130	11.18
131	11.18
132	10.99
133	11.18
134	11.18
135	10.99
136	11.18
137	10.99
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140	10.99
141	11.18
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144	11.18
145	11.18
146	10.99
147	11.18
148	10.99
149	11.18
150	11.18
151	10.99
152	11.18
153	11.18
154	11.18
155	11.18

156	10.99
157	10.99
158	11.18
159	11.18
160	11.18
161	11.18
162	10.99
163	10.99
164	11.18
165	11.18
166	11.18
167	11.18
168	11.18

Data for Iodine Back Titration Trial 1: Absorbance Data

Time	Current (mA)
-1	1.274909
0	1.271727
1	1.273
2	1.273636
3	1.271091
4	1.273
5	1.271727
6	1.272363
7	1.271727
8	1.273
9	1.273636
10	1.275545
11	1.273
12	1.274272
13	1.274272
14	1.272363
15	1.271727
16	1.271091
17	1.271091
18	1.279363
19	1.275545
20	1.272363
21	1.273
22	1.274272
23	1.274272
24	1.274909
25	1.274272
26	1.273
27	1.274272
28	1.273636
29	1.273636
30	1.270454
31	1.273
32	1.274272
33	1.271727
34	1.274272
35	1.272363
36	1.271727
37	1.271727
38	1.273
39	1.272363
40	1.273636
41	1.273636
42	1.271727
43	1.273
44	1.273636
45	1.271727
46	1.274272
47	1.274272
48	1.274272
49	1.271727
50	1.273
51	1.273
52	1.273636
53	1.272363
54	1.273
55	1.271727
56	1.270454
57	1.271727
58	1.271727
59	1.272363
60	1.271727
61	1.271091
62	1.273636
63	1.271091
64	1.271727
65	1.271727
66	1.271091
67	1.273
68	1.272363
69	1.271727
70	1.271727
71	1.274272
72	1.273
73	1.271727
74	1.268546
75	1.269182
76	1.271091
77	1.274272

78	1.271727
79	1.274272
80	1.272363
81	1.267909
82	1.272363
83	1.269818
84	1.271727
85	1.273636
86	1.272363
87	1.271727
88	1.271727
89	1.267909
90	1.274272
91	1.271727
92	1.268546
93	1.267273
94	1.269818
95	1.271727
96	1.273636
97	1.268546
98	1.272363
99	1.272363
100	1.273636
101	1.273636
102	1.266
103	1.271091
104	1.269818
105	1.274272
106	1.274909
107	1.269818
108	1.271727
109	1.272363
110	1.273
111	1.273636
112	1.273636
113	1.266637
114	1.268546
115	1.267909
116	1.272363
117	1.274272
118	1.268546
119	1.274272

120	1.268546
121	1.273636
122	1.270454
123	1.270454
124	1.274272
125	1.275545
126	1.269182
127	1.271727
128	1.274272
129	1.273636
130	1.274909
131	1.267273
132	1.274272
133	1.273636
134	1.272363
135	1.273
136	1.274272
137	1.271091
138	1.273636
139	1.271727
140	1.272363
141	1.265364
142	1.271091
143	1.270454
144	1.266637
145	1.271727
146	1.268546
147	1.272363
148	1.273
149	1.274272
150	1.270454
151	1.272363
152	1.272363
153	1.259637
154	1.26091
155	1.250729
156	1.260274
157	1.246912
158	1.255183
159	1.253911
160	1.256456
161	1.259001

162	1.271091
163	1.26091
164	1.263455
165	1.269818
166	1.259637
167	1.271727
168	1.257729
169	1.258365
170	1.265364
171	1.262819
172	1.268546
173	1.268546
174	1.257092
175	1.253274
176	1.256456
177	1.258365
178	1.253274
179	1.262819
180	1.263455
181	1.260274
182	1.26091
183	1.241185
184	1.253911
185	1.255183
186	1.254547
187	1.251366
188	1.246912
189	1.249457
190	1.25582
191	1.240549
192	1.241821
193	1.223369
194	1.246275
195	1.24882
196	1.227186
197	1.245639
198	1.232913
199	1.245003
200	1.246912
201	1.244366
202	1.23164
203	1.160375

204	1.174374
205	1.174374
206	1.174374
207	1.171192
208	1.173737
209	1.164829
210	1.172465
211	1.172465
212	1.182646
213	1.158466
214	1.173101
215	1.176919
216	1.166738
217	1.171829
218	1.175646
219	1.173101
220	1.168011
221	1.178191
222	1.1801
223	1.181373
224	1.147649
225	1.180737
226	1.17501
227	1.176919
228	1.169283
229	1.171829
230	1.163557
231	1.166738
232	1.183282
233	1.168011
234	1.179464
235	1.16992
236	1.183918
237	1.159103
238	1.150831
239	1.138741
240	1.16292
241	1.176919
242	1.178828
243	1.168011
244	1.189009
245	1.134923

246	1.176283
247	1.152103
248	1.154012
249	1.17501
250	1.140014
251	1.143831
252	1.152103
253	1.121561
254	1.11838
255	1.138105
256	1.03757
257	1.050932
258	1.065567
259	0.978394
260	0.858771
261	0.747419
262	0.585163
263	0.464903
264	0.421635
265	0.337644
266	0.261288
267	0.197022
268	0.147391
269	0.121303
270	0.095851
271	0.074217
272	0.0634
273	0.048129
274	0.038584
275	0.033494
276	0.027767
277	0.02395
278	0.022041
279	0.018859
280	0.018223
281	0.016314
282	0.014405
283	0.013769
284	0.012496
285	0.01186
286	0.01186
287	0.010587

Data for Iodine Back Titration Trial 2: Absorbance Data

Time	Current
-1	1.208097
0	1.195371
1	1.195371
2	1.19728
3	1.196644
4	1.194735
5	1.196644
6	1.197917
7	1.197917
8	1.19728
9	1.194735
10	1.19728
11	1.197917
12	1.198553
13	1.197917
14	1.19728
15	1.198553
16	1.19728
17	1.198553
18	1.19219
19	1.195371
20	1.199189
21	1.195371
22	1.198553
23	1.197917
24	1.190281
25	1.19728
26	1.198553
27	1.199826
28	1.197917
29	1.196008
30	1.196008
31	1.19728
32	1.199189
33	1.197917
34	1.196008
35	1.197917
36	1.197917

37	1.198553
38	1.197917
39	1.197917
40	1.199189
41	1.198553
42	1.197917
43	1.198553
44	1.198553
45	1.196644
46	1.199826
47	1.197917
48	1.19728
49	1.198553
50	1.197917
51	1.195371
52	1.195371
53	1.19728
54	1.19728
55	1.19728
56	1.196644
57	1.199189
58	1.19728
59	1.196008
60	1.197917
61	1.16992
62	1.199189
63	1.194099
64	1.196644
65	1.195371
66	1.193463
67	1.194735
68	1.194099
69	1.195371
70	1.195371
71	1.19728
72	1.19728
73	1.194735
74	1.194735
75	1.194099
76	1.196008
77	1.195371
78	1.197917
79	1.196644
80	1.198553
81	1.19728
82	1.197917
83	1.199189
84	1.196644
85	1.196008
86	1.198553
87	1.194099
88	1.195371
89	1.193463
90	1.199189
91	1.198553
92	1.195371
93	1.197917
94	1.199189
95	1.199189
96	1.195371
97	1.194099
98	1.199826
99	1.195371
100	1.199189
101	1.199826
102	1.199189
103	1.193463
104	1.198553
105	1.190281
106	1.197917
107	1.196644
108	1.19728
109	1.196008
110	1.196008
111	1.19728
112	1.199189
113	1.19728
114	1.199826
115	1.196008
116	1.19728
117	1.19728
118	1.194099
119	1.197917
120	1.196644
121	1.194735
122	1.19728
123	1.190917
124	1.194735
125	1.19219
126	1.196644
127	1.194735
128	1.19728
129	1.189009
130	1.197917
131	1.199189
132	1.194735
133	1.195371
134	1.197917
135	1.19728
136	1.196008
137	1.198553
138	1.191554
139	1.195371
140	1.194099
141	1.19728
142	1.196008
143	1.199189
144	1.196008
145	1.195371
146	1.198553
147	1.190281
148	1.195371
149	1.191554
150	1.199826
151	1.197917
152	1.190281
153	1.19728
154	1.192826
155	1.194099
156	1.192826
157	1.194099
158	1.19728
159	1.195371
160	1.194099
161	1.196008
162	1.197917

163	1.194735
164	1.194099
165	1.195371
166	1.196644
167	1.193463
168	1.197917
169	1.189009
170	1.194735
171	1.195371
172	1.183918
173	1.196644
174	1.192826
175	1.19728
176	1.196644
177	1.196644
178	1.194735
179	1.195371
180	1.190281
181	1.194735
182	1.194099
183	1.19728
184	1.185191
185	1.191554
186	1.191554
187	1.192826
188	1.19728
189	1.190917
190	1.19219
191	1.196644
192	1.185191
193	1.192826
194	1.192826
195	1.190917
196	1.198553
197	1.192826
198	1.192826
199	1.195371
200	1.193463
201	1.196008
202	1.195371
203	1.19219
204	1.19728

205	1.189009
206	1.195371
207	1.185191
208	1.185191
209	1.195371
210	1.192826
211	1.1871
212	1.176283
213	1.195371
214	1.187736
215	1.187736
216	1.184554
217	1.189009
218	1.17501
219	1.191554
220	1.1871
221	1.195371
222	1.193463
223	1.189009
224	1.183918
225	1.190281
226	1.175646
227	1.188372
228	1.178828
229	1.178191
230	1.175646
231	1.186463
232	1.19219
233	1.185191
234	1.184554
235	1.194735
236	1.159103
237	1.1871
238	1.1801
239	1.167374
240	1.176919
241	1.184554
242	1.185827
243	1.167374
244	1.155285
245	1.182009
246	1.166738

247	1.152103
248	1.183282
249	1.177555
250	1.164829
251	1.171829
252	1.157194
253	1.14065
254	1.140014
255	1.173737
256	1.141286
257	1.164829
258	1.140014
259	1.105017
260	1.11838
261	1.104381
262	0.970123
263	0.854317
264	0.760145
265	0.644339
266	0.550803
267	0.440724
268	0.351642
269	0.267651
270	0.204022
271	0.16139
272	0.128302
273	0.106032
274	0.08567
275	0.072944
276	0.062764
277	0.057037
278	0.051947
279	0.046856
280	0.043039
281	0.039857
282	0.037312
283	0.03413
284	0.032221
285	0.030949
286	0.028404
287	0.026495
288	0.025222

289	0.02395
290	0.022041
291	0.021404

Data for Iodine Back Titration: Current Data*

*Only Runs 5 and 6 were used for this experiment

Vernier	**Format**
Labquest	iodine.txt
Run	1
Time	Current
T	C
s	A
0	12.48
1	12.48
2	12.68
3	12.68
4	12.68
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Vernier	Format
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Run	5
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Vernier	Format
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