

**TED ANKARA COLLEGE FOUNDATION HIGH
SCHOOL**

**INTERNATIONAL BACCALAUREATE CHEMISTRY
EXTENDED ESSAY**

**WHICH METHOD IS THE BEST FOR DETERMINING
THE END-POINT IN STRONG ACID – STRONG BASE
TITRATIONS: USING A PH INDICATOR,
MEASURING TEMPERATURE CHANGE, OR
MEASURING RESISTANCE?**

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Word Count: 4018

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ABSTRACT

In this essay, three of the methods for finding the end-point in acid-base titrations are examined and compared. The titration is done with 0.1 molar NaOH as the titrant and 0.1 molar HCl as the analyte. The methods are: Using phenolphthalein as an indicator, measuring the temperature change, measuring the resistance of the analyte. The goal is to determine which method among these three is the most accurate, in order to find out which method can be used in the absence of a pH meter.

In each method, a pH meter is also used to see the actual pH when the method comes to the end-point. The variables for each experiment are graphed, together with pH, and then at the end-point of the methods the pH is found using graphing software. The mean values for each method are calculated and compared with the literature value of the equivalence point for this titration, which is 7. The indicator method is proved to be the best among these three with a very low error percentage, the resistance method comes second, however it has a high error percentage and is not very appropriate for using in this titration. The temperature method did not give any sign of reaching the end-point; therefore its error percentage could not be calculated and proved that it is not suitable for this titration. For titrations with different conditions all the methods have to be tested again before deciding which is the best.

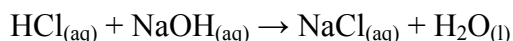
To sum up, amongst these methods, using phenolphthalein as an indicator of the end-point is the best method to use in the absence of a pH meter, for this acid-base titration.

(275 Words)

INTRODUCTION

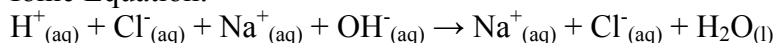
A titration is done in order to find the unknown concentration of a solution with a known volume, which is called the analyte. This is done with the help of another solution with a known concentration and volume, which is called the titrant. The titrant reacts with the analyte. A titration can simply be done like this: The solution with the unknown concentration is put in a beaker or a flask, and the other solution is put in a burette. The solution in the burette is dropped into the other solution so that they react. The point, at which the amount of titrant added is equal to the amount of analyte in the solution, is called the equivalence point. By using the value for the volume of the titrant added at this point, the concentration of the titrant, and the volume of the analyte, the concentration of the analyte can be calculated through the reaction that takes place between these two solutions. But how is it possible to know when the equivalence point is reached? There are several methods to find the equivalence point such as indicators, potentiometer, conductance, calorimeter, precipitation, light spectroscopy and so forth, but none of them shows the point exactly, these methods give a sign after the reaction between the two solutions has ended, this is called the end-point. So the end-point comes after the equivalence point. All methods show an end-point but none of them are equally away from the equivalence point. The closer the end-point is to the equivalence point, the better the method is.

In an acid-base titration, this process occurs either between an acidic solution with unknown concentration and a basic solution with a known concentration or vice versa. An example:

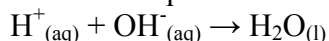


Hydrochloric acid is a strong acid and sodium hydroxide is a strong base, which means they both ionize fully in water. When equal amounts of hydrochloric acid and sodium hydroxide is mixed the result is aqueous sodium chloride.

Ionic Equation:



Net Ionic Equation:

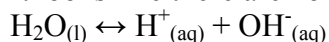


The end-point of an acid base titration is mostly determined by using a pH meter.

pH is the co-logarithm of the molarity of hydrogen ions in a solution. The pH is calculated using this formula:

$$\text{pH} = -\log[\text{H}^+]$$

It looks like there are no hydrogen ions in the resulting solution, but water self-ionizes:



Dissociation constant for water is K_w and it is the multiplication of the molarities of hydrogen and hydroxide ions that dissociate. ($K_w = 10^{-14} \text{ mol}^2 \cdot \text{dm}^{-6}$)

$$K_w = [\text{H}^+] \cdot [\text{OH}^-] = 10^{-14} \text{ mol}^2 \cdot \text{dm}^{-6}$$

The molarity of hydroxide and hydrogen ions, when water dissociates, are equal.

$$K_w = x \cdot x = x^2 = 10^{-14} \text{ mol}^2 \cdot \text{dm}^{-6}$$

$$(x^2)^{1/2} = (10^{-14} \text{ mol}^2 \cdot \text{dm}^{-6})^{1/2}$$

$$x = [\text{OH}^-] = [\text{H}^+] = 10^{-7} \text{ mol}\cdot\text{dm}^{-3}$$

The co-logarithm of 10^{-7}

$$\text{pH} = -\log 10^{-7} = 7$$

This means, when an acid-base pair fully neutralizes each other, which is also the equivalence point of this reaction in a titration, the pH is 7.

Using a pH meter is the best way of determining pH, and it is also the best for finding the end-point in acid base-titrations. But what other method can be used in the absence of a pH meter? There are many more methods to determine the end-point in acid-base titrations, but which method is better? While learning the Acid-Base topic in my chemistry lessons, I came up with this question: “pH meter is the best, but how accurate are the other methods compared to the pH meter?” So I narrowed my question and made it my extended essay research question.

“Which method is better for determining the end-point in acid-base titrations: Measuring temperature change, measuring the resistance of the solution or using a pH indicator?”

Then I narrowed the conditions for my experiments, I chose 0.1 molar HCl as the analyte and 0.1 molar NaOH as the titrant.

Assuming that the pH meter always show the exact pH value of the solution at any instant, I will also be using a pH meter with all the experiments so that when the method I am testing comes to the end-point I can see the actual pH of the solution. Then I will be able to compare that pH value with the literature value for this experiment, which is $\text{pH} = 7$ as I calculated above. The percentage error of each method will allow me to get to a conclusion.

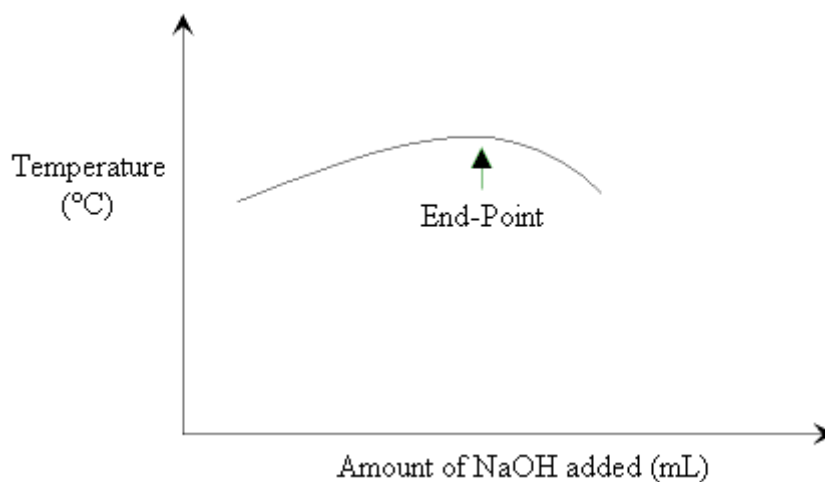
In the indicator method I will use phenolphthalein as an indicator, which is colorless in acidic but pink in basic solutions. It changes color around pH 7 so it is suitable as an indicator for this titration.



Figure – 1: Phenolphthalein in basic solution

I have done some acid-base titration experiments with indicators in class before and the results were very accurate, so I can presume that this method will have a small error percentage.

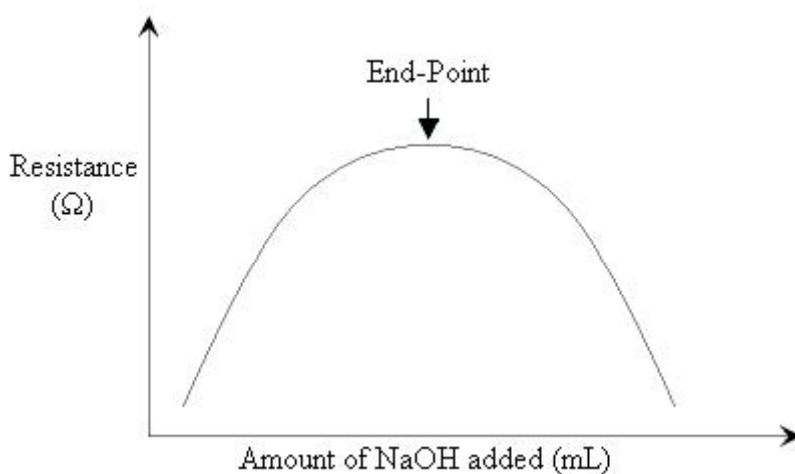
Most acid base reactions are exothermic, which means the reaction gives out heat. The reaction of HCl and NaOH is also exothermic. When titrating these solutions, until the equivalence point the temperature of the solution will increase, but after that it will start to decrease because there will be no more HCl left to react with the NaOH coming from the burette. So the temperature versus NaOH added graph will be like this:



Graph – 1: My hypothesis of how the temperature versus base added graph will be like.

However, from my previous experiences in chemistry classes I know that the experiments which need measuring the temperature had high errors. I can presume that this method will have moderate amount of percentage error.

For the resistance method, the HCl ionizes fully in water therefore it is a good conductor of electricity so at the start of the experiment the resistance will be low. When some NaOH is added the reaction will take place and start to produce water molecules which will decrease the molarity of the ions in the solution. This will increase the resistance because the lesser the concentration of ions gets, the lesser the current will pass through the solution. And this will increase the resistance. This can be proved by the formula $V=i \cdot R$ where V is volts, i is the current in amps, and R is the resistance in ohms. The voltage of the ohmmeter, which is measuring the resistance, is constant. Therefore if the current is decreasing because of the molarity of the solution is decreasing, the resistance should be increasing. After the equivalence point the resistance will start to decrease again because there is excess amount of base that is being added, and this base also fully ionizes in water, so it is also a good conductor.



Graph – 2: My hypothesis of how the resistance versus base added graph will be like.

I do not have any experience with this type of experiment therefore; I am not able to comment on how the results will be following this method.

To sum up, I presume that the indicator method will be the method with least percentage error.

METHOD DEVELOPMENT

In order to compare three different methods of finding the end point I had to make sure that all methods were equally improved and carefully applied. Also in all methods I will be using a pH meter in order to see the actual pH when the method comes to its end-point. So I will be able to compare that pH with the literature value and find the percentage error for each method.

I also needed to raise the level of the analyte in order to have the magnetic stirrer and the probe of the pH meter in the solution at the same time. To raise the level I added 15 mL of pure water to the initial 10 mL of 0.1 molar HCl solution.

Another issue with all the methods was that every 10 seconds (or sometimes every 5 seconds for the resistance method) I needed to record the data for volume of NaOH added. However, reading the burette in such a short time interval was too hard for me so instead I took data for time. Since the volume of base added is directly proportional with time, the volume of base used at any time can be calculated easily by only recording the initial and the final volume of the base. Then I realized that as the volume of the solution in the burette decreases the speed of the flow through the burette might also decrease. I have done an experiment in order to find out how this affects the calculation. I measured how many drops equals to 1 mL by counting 100 drops of the base solution from the burette and reading the volume on the burette. 100 drops were equal to 5 mL, so 1 mL equals to 20 drops. Then I filled the burette fully (50 mL) and measured the time for 20 drops to drop. Then with only 5 mL in the burette I measured the time for 20 drops again. There was a decrease in the speed of dropping. I graphed the speed of the base flowing from the burette versus time and by calculating the area under the graph I managed to draw the graph of volume of base added versus time. This graph was supposed to be curved because the speed was changing with time. It was actually curved but when I used the "linear fit" tool of the graphing software I saw that the curve of this graph is nearly negligible and it was more of a linear fit. So when the volume of base is needed at any time, it can be calculated through the final and initial volume of base and time values, if the decrease in the speed of the base coming from the burette is neglected. This process is only necessary when any of these methods are used for a titration. I know the concentration of both solutions, but instead of measuring the volume of base added at the need point and calculating the concentration of the acid and comparing it with the original value I chose to use a pH meter for comparing and calculating the error percentage.

The Indicator Method:

The only data I needed to record in this method, except the pH, was the time value when the indicator (phenolphthalein) gave the first stable pink color to the solution. I chose phenolphthalein, because it changes from colorless into pink color at around pH 7. There were other indicators with the same pH range but I chose this one because its color change is more noticeable than the others. In order not to miss the slightest color change I put a white paper under the beaker while titrating. This white background made the first color change more visible. I also dripped the solution in the burette very slowly because when the end point is near even 1 drop changes the pH vastly. The use of a magnetic stirrer was also necessary because each drop of base makes the point where it fell a bit pink but these color changes do not indicate the end point, when the solution is stirred the solution becomes colorless again, so the magnetic stirrer removed these unstable pink color immediately and avoided recording wrong data.

The Temperature Method:

The data that needs to be recorded in this method is the temperature, so it's important that the solution does not lose or gain heat from the environment. In order to minimize the heat transfer I used a coffee cup calorimeter instead of a beaker, and I put the pH probe, the temperature probe and the tip of the burette inside the calorimeter through the hole on the lid of the calorimeter. I used the magnetic stirrer in this method too because the base dripping from the burette needs to be distributed in the solution homogeneously. Another issue was that I needed to run the base from the burette rapidly because if I had done it slowly as in the indicator method, the change in the temperature of the solution could not be recorded. This is because the amount of heat that one drop of base gives out when it reacts with the acid is very small and the solution would lose that amount of heat until the other drop of base drops. So I just let the base flow from the burette and recorded the data every 10 seconds.

The Resistance Method:

Originally this method was supposed to be measuring conductivity, but I was not able to obtain a conduct meter, so I changed the method and measured the amperage through the solution. However I needed to change the method again because I realized that the current going through the solution would electrolyse it. Therefore, I used an ohmmeter to measure the resistance and in order to measure the resistance, the ohmmeter also runs a small amount of current through the solution. This seemed like a problem to me because the current going through the solution could still electrolyse the solution. So I tested the ohmmeter in 3 different conditions:

In 25 mL of 0.1 molar HCl solution,

In 25 mL of 0.1 molar HCl + 25 mL of 0.1 molar NaOH solution

In 25 mL of 0.1 Molar NaCl + 25 mL of pure water + 25 mL of 0.1 M NaOH

These 3 conditions are respectively: initial acid solution, the end point, and the addition of excess base after the end point. In all conditions the resistance increased over time, this shows that either some ions coat around the electrodes or the ion concentration of the solution decrease. However, I decided to ignore the effect the current has on the solution. I thought the graph of resistance vs. time when I am doing the titration would be the combination of these 3 graphs. (Add them end to end respectively).

Another issue was that each time I had to clean the electrodes I needed to remove the pincers of the ohmmeter from the electrodes and even a small position change of these pincers changed the resistance vastly, to avoid this I soldered the wires of the ohmmeter to the copper electrodes. I also bent the edges of the electrodes so that I can put them in the beaker in a fixed position. (Picture of the electrodes can be found in the appendix)

Then I decided to run the titration experiment and see what the resistance and pH versus time graph looks like. I did many trials and saw that the graphs are always similar to each other. The trend of the graph is simply like this: The resistance is nearly stable but has small ups and downs but when it nears the end point the resistance makes a small but noticeable increase and then decreases vastly and after the end point it increases in parallel with the pH graph.

This was not what I expected but after many trials I was sure that the graph will always follow this trend and the indication of the end point is the vast decrease of the resistance.

DATA COLLECTION

Indicator Method:

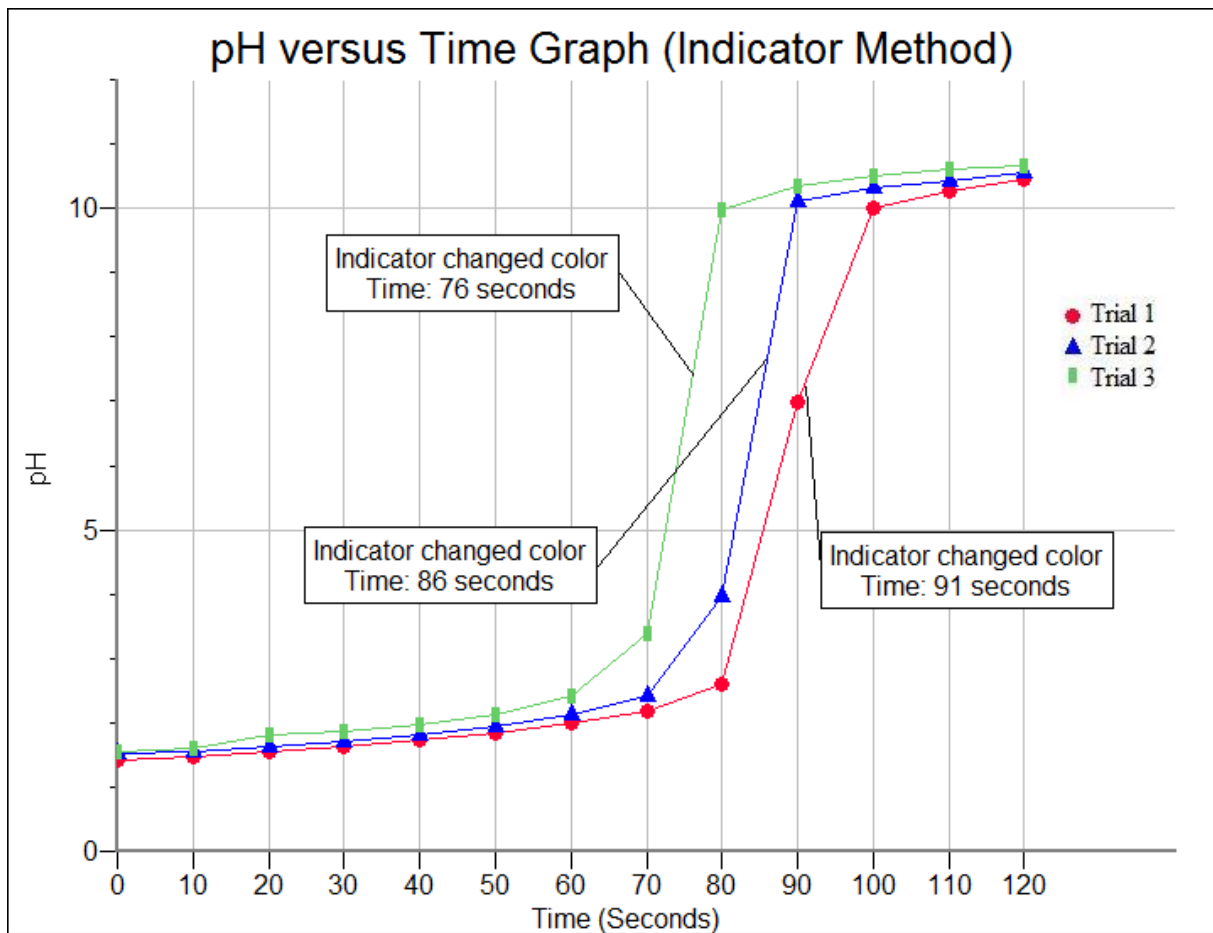
The apparatus is prepared and the data is collected according to the Indicator Method in the appendix.

Time (Seconds)	pH \pm 0.01		
	Trial 1	Trial 2	Trial 3
0	1.41	1.52	1.56
10	1.47	1.56	1.60
20	1.55	1.62	1.80
30	1.63	1.70	1.87
40	1.73	1.80	1.98
50	1.84	1.93	2.14
60	1.99	2.12	2.42
70	2.18	2.41	3.38
80	2.60	3.96	9.97
90	6.98	10.12	10.35
100	10.01	10.32	10.50
110	10.28	10.42	10.61
120	10.45	10.56	10.67

Table – 1: The readings on the pH meter at every 10 seconds for 3 trials, titrating with the indicator method.

Trial Numbers	Time (seconds) \pm 0.01
1	91.00
2	86.00
3	76.00

Table – 2: The time values at which the indicator gave the first stable pink color for 3 trials.



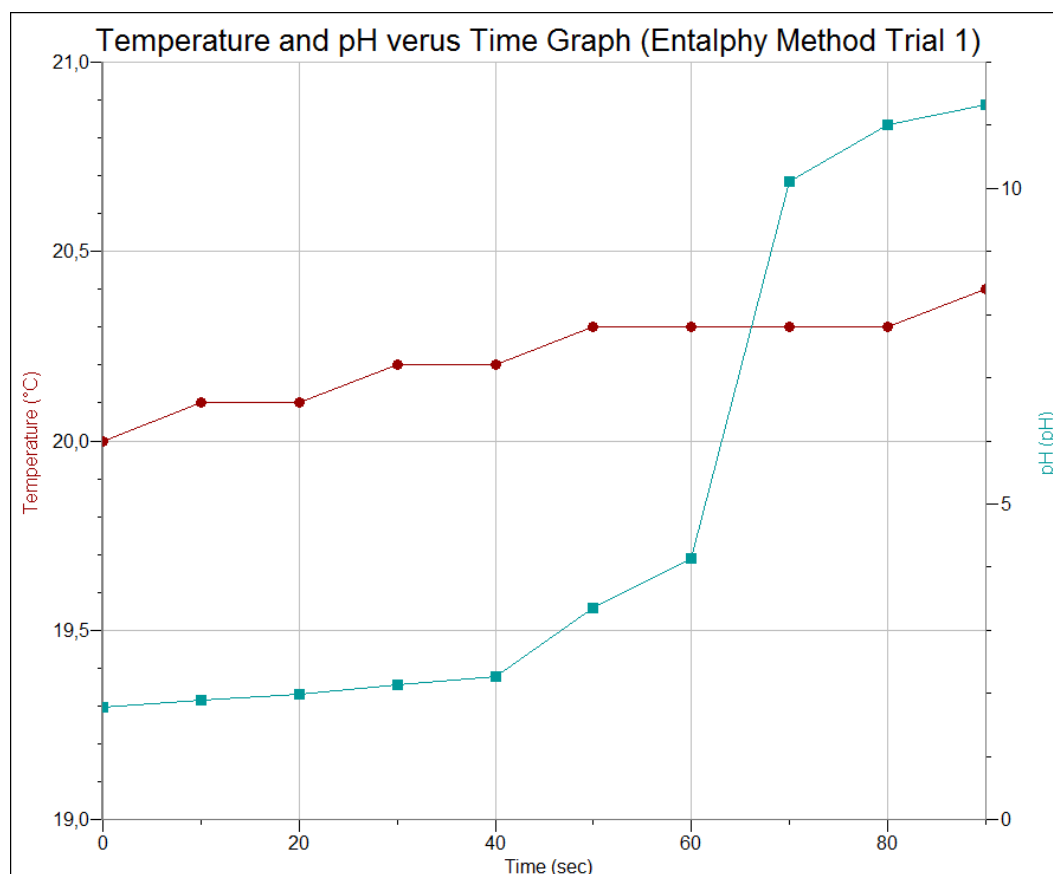
Graph – 3: The pH versus time graph for each 3 trials and the points where indicator changed color at every trial.

Temperature Method:

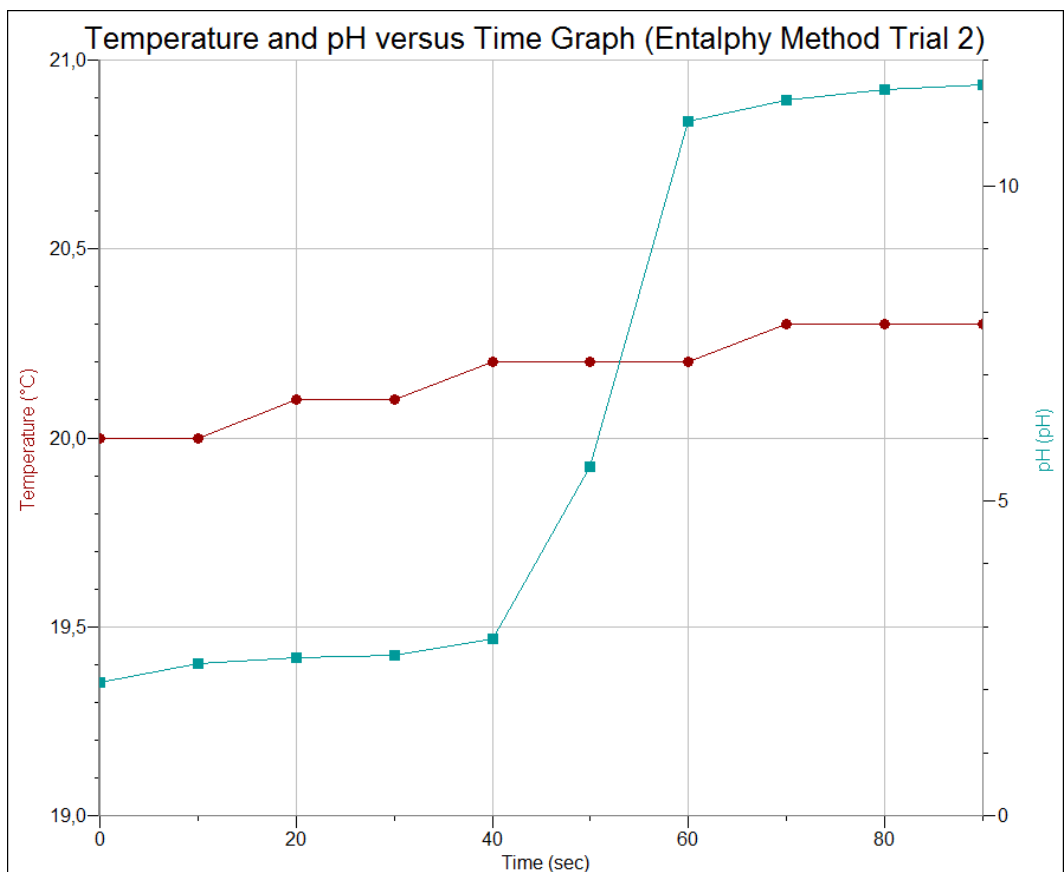
The apparatus is prepared and the data is collected according to the Temperature Method in the appendix.

Time (seconds)	Trial 1		Trial 2		Trial 3	
	pH ± 0.01	Temperature ($^{\circ}\text{C}$) ± 0.1	pH ± 0.01	Temperature ($^{\circ}\text{C}$) ± 0.1	pH ± 0.01	Temperature ($^{\circ}\text{C}$) ± 0.1
0	1.78	20.0	2.12	20.0	1.72	20.0
10	1.90	20.1	2.42	20.0	1.76	20.0
20	1.99	20.1	2.50	20.1	2.09	20.1
30	2.13	20.2	2.55	20.1	2.69	20.1
40	2.27	20.2	2.80	20.2	3.31	20.2
50	3.36	20.3	5.55	20.2	6.22	20.2
60	4.13	20.3	11.03	20.2	10.89	20.2
70	10.11	20.3	11.37	20.3	11.23	20.3
80	11.00	20.3	11.54	20.3	11.42	20.3
90	11.33	20.4	11.61	20.3	11.54	20.3

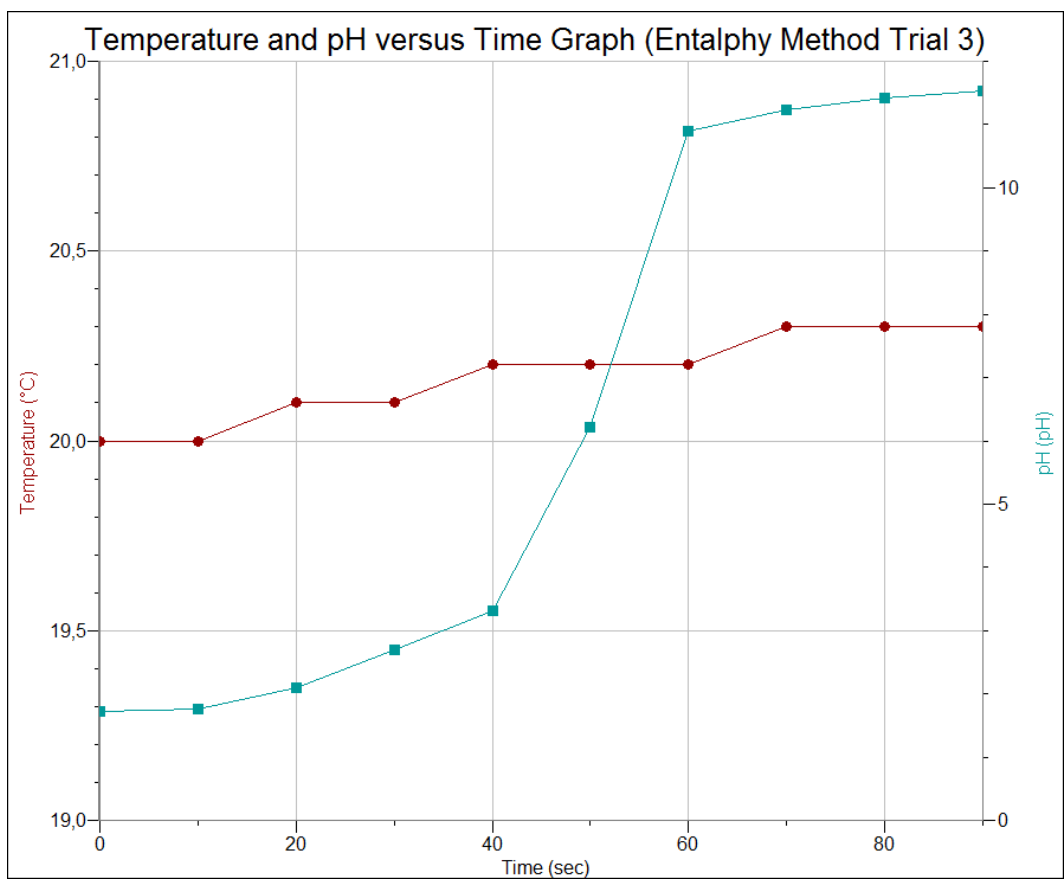
Table – 3: The pH and Temperature readings at every 10 seconds for 3 trials, titrating with the temperature method.



Graph – 4: The pH and Temperature readings at every 10 seconds, Trial 1.



Graph – 5: The pH and Temperature readings at every 10 seconds, Trial 2.



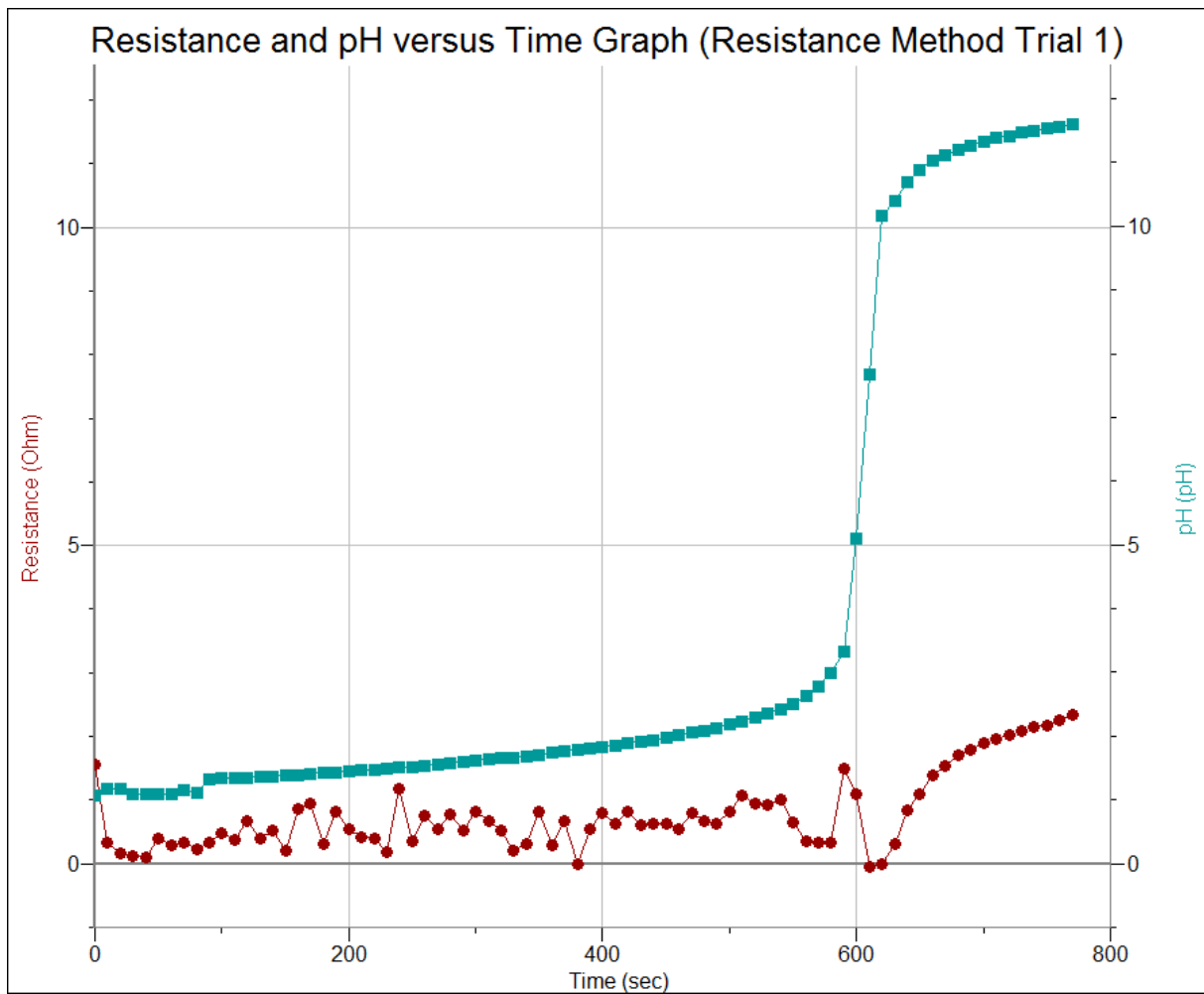
Graph – 6: The pH and Temperature readings at every 10 seconds, Trial 3.

Resistance Method:

The apparatus is prepared and the data is collected according to the Resistance Method in the appendix.

Time (seconds)	Resistance (Ohms) ± 0.01	pH ± 0.01	Time (seconds)	Resistance (Ohms) ± 0.01	pH ± 0.01
0	1.55	1.06	390	0.55	1.81
10	0.34	1.18	400	0.80	1.83
20	0.17	1.18	410	0.62	1.86
30	0.12	1.08	420	0.82	1.89
40	0.10	1.09	430	0.61	1.92
50	0.40	1.10	440	0.63	1.94
60	0.28	1.09	450	0.63	1.98
70	0.34	1.15	460	0.55	2.02
80	0.23	1.11	470	0.79	2.06
90	0.34	1.33	480	0.68	2.09
100	0.48	1.34	490	0.63	2.13
110	0.37	1.34	500	0.82	2.18
120	0.66	1.35	510	1.07	2.24
130	0.40	1.36	520	0.95	2.29
140	0.52	1.37	530	0.93	2.35
150	0.21	1.38	540	1.00	2.43
160	0.85	1.39	550	0.65	2.50
170	0.95	1.41	560	0.36	2.63
180	0.31	1.42	570	0.34	2.77
190	0.81	1.43	580	0.34	2.98
200	0.54	1.44	590	1.49	3.32
210	0.42	1.46	600	1.10	5.10
220	0.40	1.48	610	-0.05	7.68
230	0.18	1.49	620	0.00	10.17
240	1.17	1.51	630	0.30	10.40
250	0.35	1.52	640	0.83	10.69
260	0.76	1.54	650	1.09	10.89
270	0.55	1.56	660	1.38	11.03
280	0.77	1.57	670	1.54	11.12
290	0.52	1.59	680	1.70	11.20
300	0.82	1.61	690	1.80	11.27
310	0.68	1.63	700	1.89	11.33
320	0.52	1.65	710	1.96	11.38
330	0.20	1.67	720	2.03	11.42
340	0.31	1.69	730	2.09	11.47
350	0.81	1.71	740	2.14	11.50
360	0.29	1.74	750	2.18	11.53
370	0.67	1.76	760	2.25	11.56
380	0.00	1.78	770	2.33	11.61

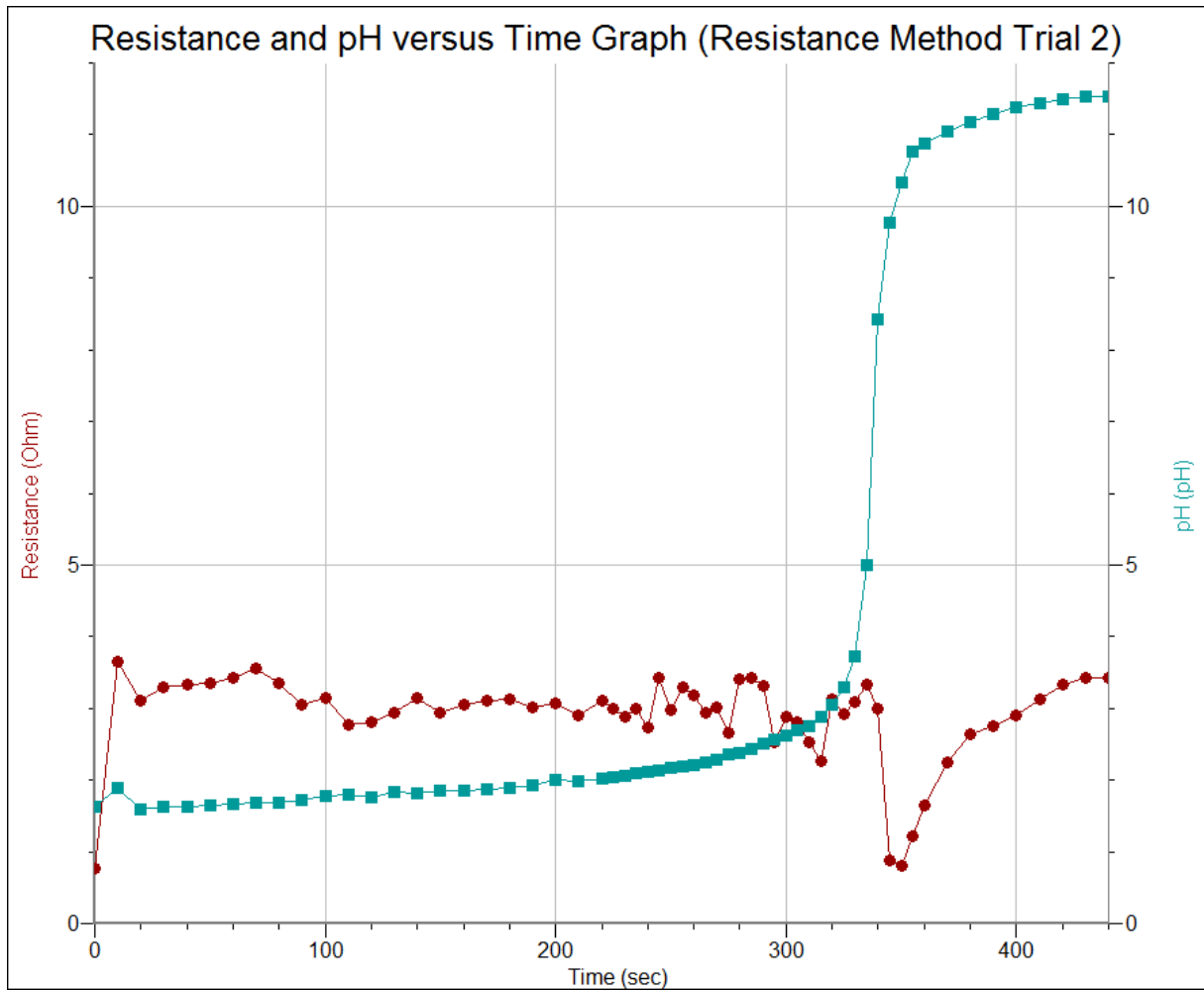
Table – 4: The pH and resistance readings taken according to the Resistance Method, Trial 1.



Graph – 7: The graph of the pH and resistance readings taken according to the Resistance Method, Trial 1.

Time (seconds)	Resistance (Ohms) ± 0.01	pH ± 0.01	Time (seconds)	Resistance (Ohms) ± 0.01	pH ± 0.01
0	0.76	1.62	260	3.19	2.21
10	3.65	1.89	265	2.94	2.25
20	3.11	1.59	270	3.01	2.28
30	3.29	1.62	275	2.66	2.35
40	3.33	1.63	280	3.41	2.38
50	3.36	1.65	285	3.43	2.44
60	3.42	1.67	290	3.31	2.50
70	3.55	1.68	295	2.53	2.57
80	3.35	1.69	300	2.89	2.62
90	3.05	1.72	305	2.80	2.69
100	3.15	1.78	310	2.53	2.76
110	2.78	1.79	315	2.26	2.89
120	2.80	1.76	320	3.12	3.06
130	2.93	1.84	325	2.92	3.30
140	3.14	1.82	330	3.09	3.72
150	2.94	1.85	335	3.34	5.00
160	3.05	1.86	340	3.00	8.43
170	3.11	1.87	345	0.88	9.77
180	3.13	1.89	350	0.80	10.33
190	3.01	1.93	355	1.21	10.76
200	3.07	2.00	360	1.64	10.87
210	2.91	1.99	370	2.25	11.05
220	3.10	2.02	380	2.64	11.18
225	3.00	2.04	390	2.75	11.29
230	2.88	2.06	400	2.91	11.38
235	3.00	2.09	410	3.13	11.44
240	2.73	2.11	420	3.34	11.50
245	3.42	2.13	430	3.42	11.54
250	2.98	2.18	440	3.42	11.54
255	3.30	2.19			

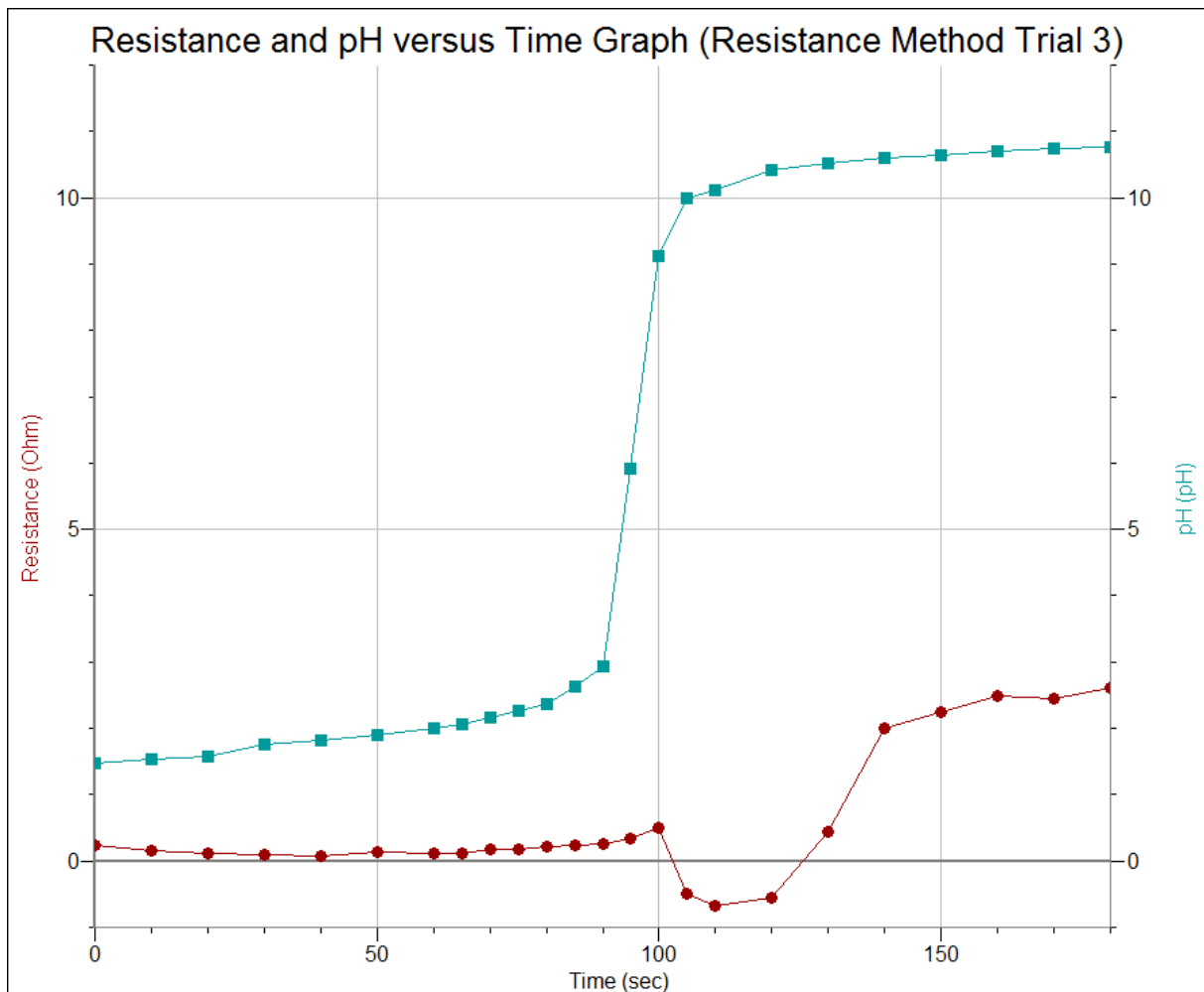
Table – 5: The pH and resistance readings taken according to the Resistance Method, Trial 2.



Graph – 8: The graph of the pH and resistance readings taken according to the Resistance Method, Trial 2.

Time (seconds)	Resistance (Ohms) ± 0.01	pH ± 0.01
0	0.24	1.48
10	0.15	1.53
20	0.11	1.58
30	0.09	1.75
40	0.08	1.81
50	0.13	1.90
60	0.11	2.00
65	0.12	2.07
70	0.17	2.17
75	0.17	2.27
80	0.22	2.37
85	0.23	2.63
90	0.25	2.93
95	0.34	5.91
100	0.50	9.11
105	-0.50	10.00
110	-0.68	10.11
120	-0.56	10.42
130	0.43	10.51
140	2.00	10.61
150	2.25	10.65
160	2.48	10.70
170	2.44	10.74
180	2.60	10.77

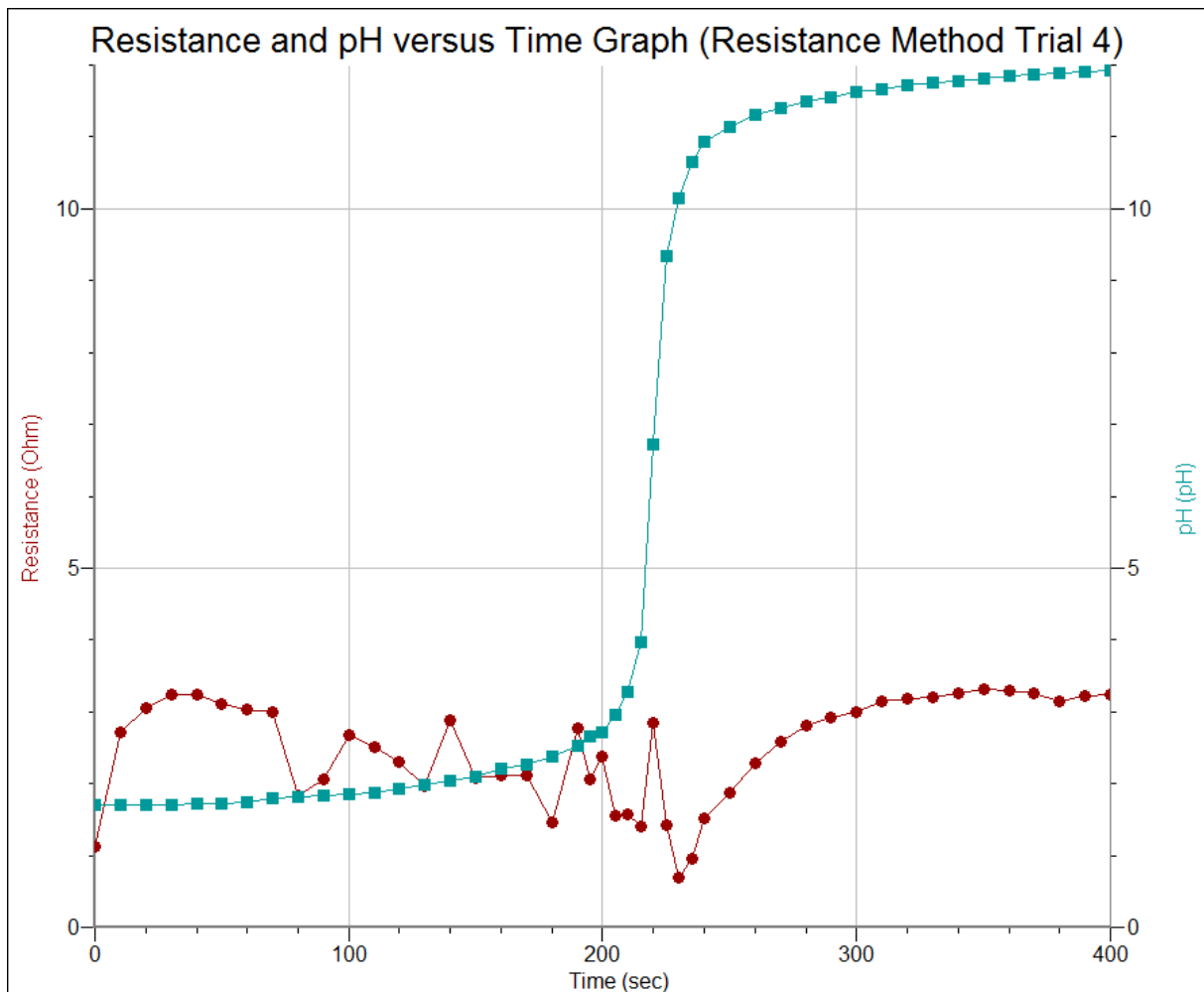
Table – 6: The pH and resistance readings taken according to the Resistance Method, Trial 3.



Graph – 9: The graph of the pH and resistance readings taken according to the Resistance Method, Trial 3.

Time (seconds)	Resistance (Ohms) ± 0.01	pH ± 0.01	Time (seconds)	Resistance (Ohms) ± 0.01	pH ± 0.01
0	1.13	1.70	210	1.57	3.28
10	2.72	1.70	215	1.40	3.96
20	3.06	1.70	220	2.85	6.73
30	3.23	1.71	225	1.43	9.35
40	3.24	1.72	230	0.70	10.14
50	3.11	1.73	235	0.96	10.66
60	3.04	1.75	240	1.52	10.94
70	3.00	1.80	250	1.88	11.14
80	1.84	1.81	260	2.28	11.30
90	2.06	1.83	270	2.58	11.41
100	2.68	1.85	280	2.80	11.50
110	2.51	1.88	290	2.92	11.56
120	2.30	1.93	300	3.00	11.63
130	1.97	1.98	310	3.14	11.67
140	2.88	2.04	320	3.19	11.71
150	2.07	2.10	330	3.20	11.75
160	2.11	2.20	340	3.26	11.78
170	2.12	2.26	350	3.32	11.82
180	1.46	2.38	360	3.30	11.85
190	2.78	2.53	370	3.25	11.87
195	2.05	2.65	380	3.14	11.89
200	2.38	2.72	390	3.22	11.91
205	1.56	2.95	400	3.24	11.93

Table – 7: The pH and resistance readings taken according to the Resistance Method, Trial 4.



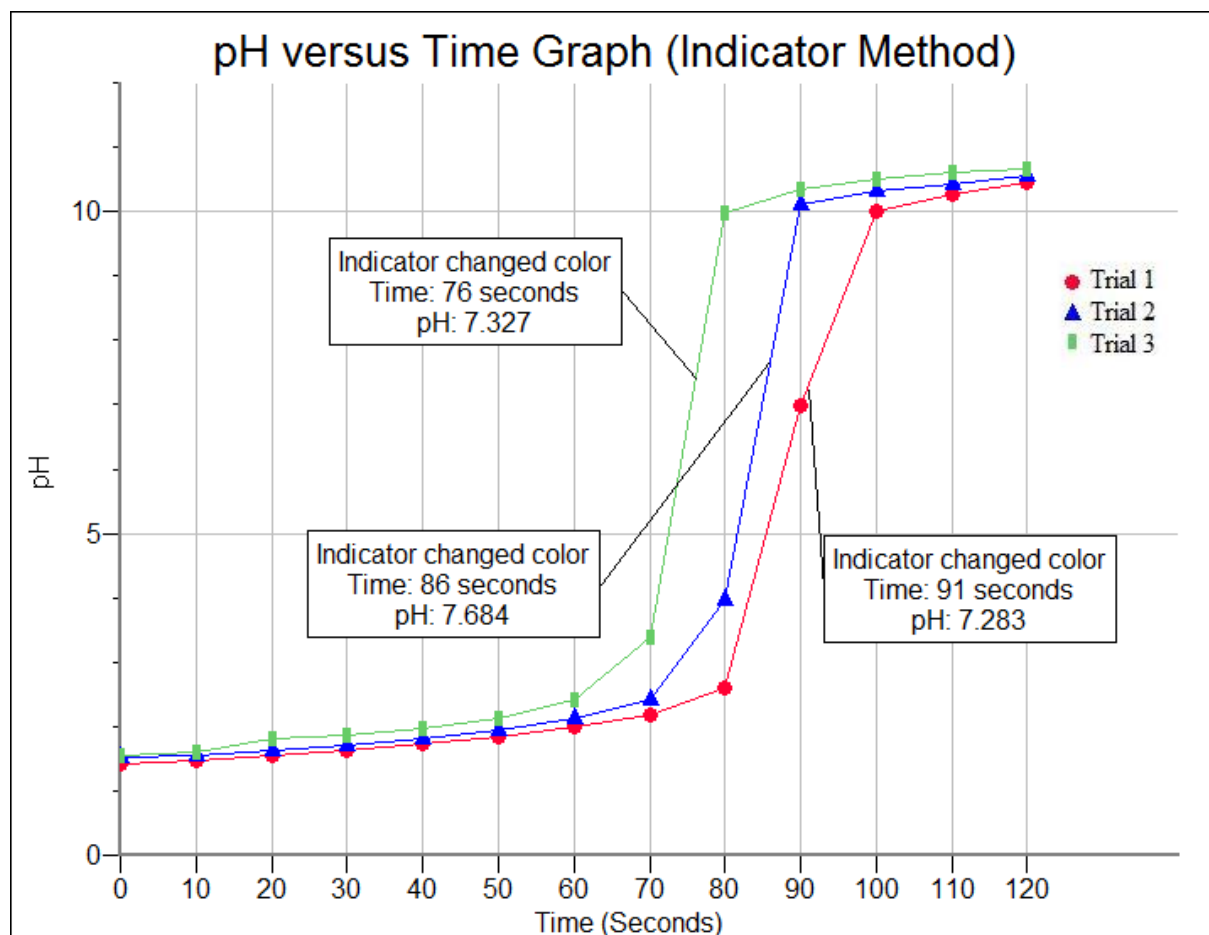
Graph – 10: The graph of the pH and resistance readings taken according to the Resistance Method, Trial 4.

DATA ANALYSIS

This is the part where mean values of the end points found by using different methods will be calculated and compared with the literature value of the equivalence point, which is pH 7.

Indicator Method:

Using the “interpolate” tool of the graphing software Logger Pro 3.4.5 (Vernier Software), I found the corresponding pH value for the time value at which the indicator changed color.



Graph – 11: The pH versus time graph for each 3 trials, the points where indicator changed color at every trial and the corresponding pH values.

$$\text{Mean Value} = [(\text{Trial 1}) + (\text{Trial 2}) + (\text{Trial 3})] / 3$$

$$(7.283 + 7.684 + 7.327) / 3 = 7.431$$

$$\text{Percentage Error} = [| \text{Observed Value} - \text{Literature Value} | / \text{Literature Value}] \times 100$$

$$[| 7.431 - 7 | / 7] \times 100 = \mathbf{6.157 \% \text{ Error}}$$

The results for this method were as predicted.

Temperature Method:

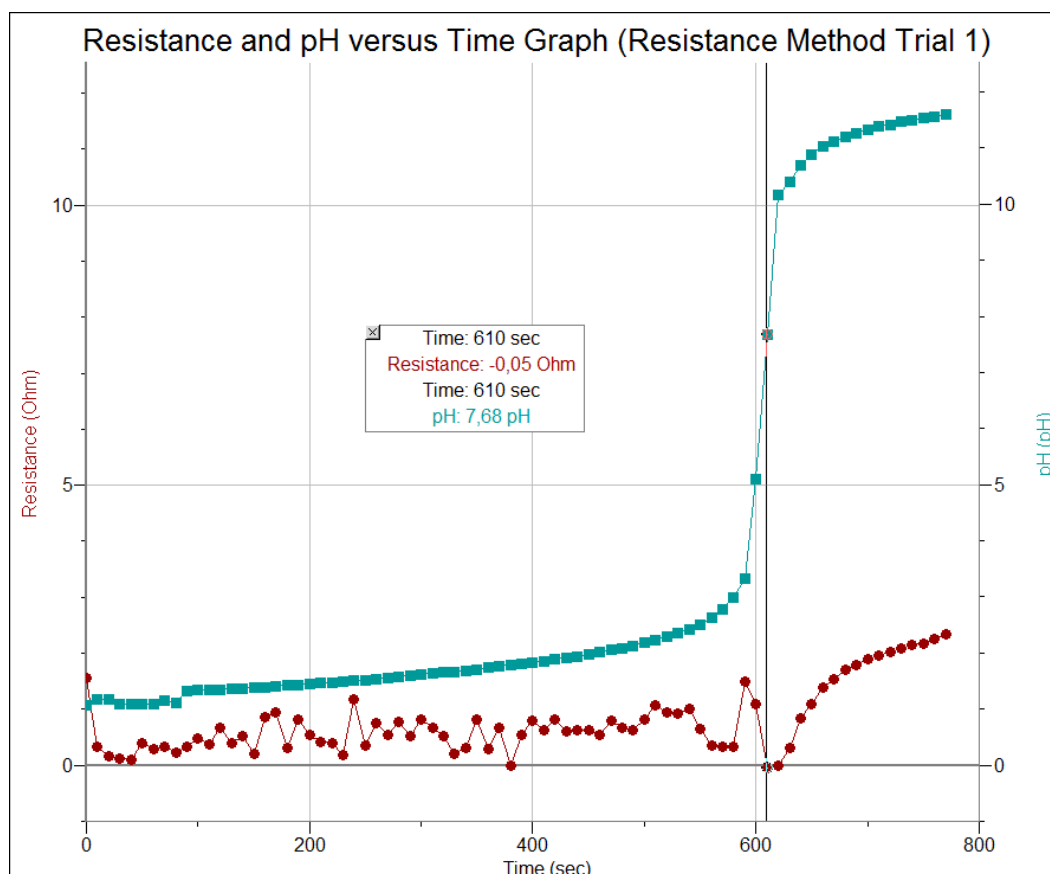
I presumed that the temperature would decrease after the equivalence point and the maximum point on the temperature graph would be the end-point. However the Temperature Method did not give any indication of reaching the end point. The temperature kept increasing even after the equivalence point, and there were no point on the graph that can be chosen as the end point, therefore the percentage error cannot be calculated.

Resistance Method:

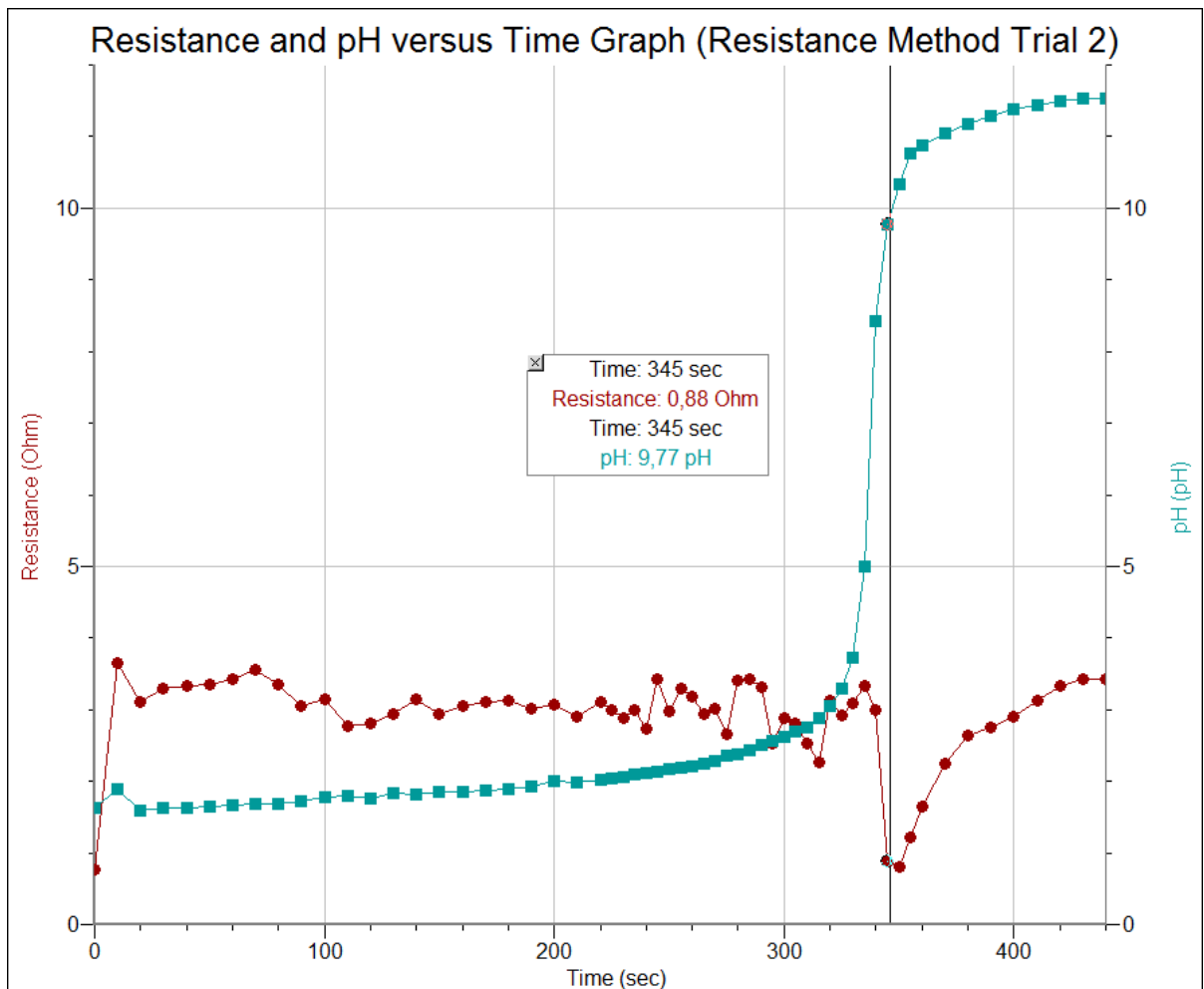
The resistance versus time graphs, were completely different than how I expected them to be. However they still showed a noticeable end-point on them.

The resistance method graphs show a sudden and vast decrease and then an orderly increase. This increase is just like the increase in pH after the equivalence point. The point between this large, sharp decrease and the steady increase is the end point.

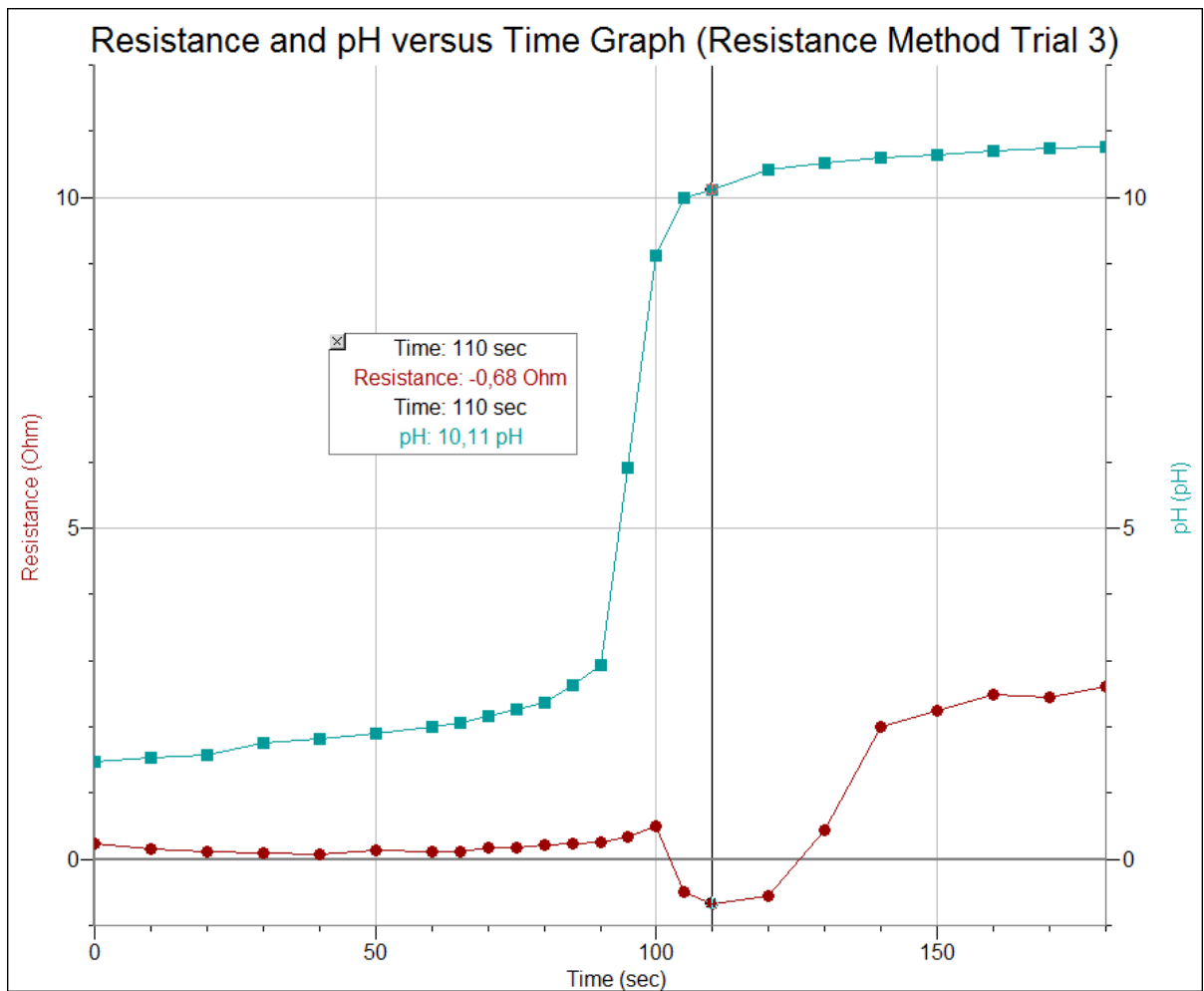
Using the “examine” tool of the graphing software Logger Pro 3.4.5 (Vernier Software), I managed to find the corresponding pH value for the end points on the resistance graphs.



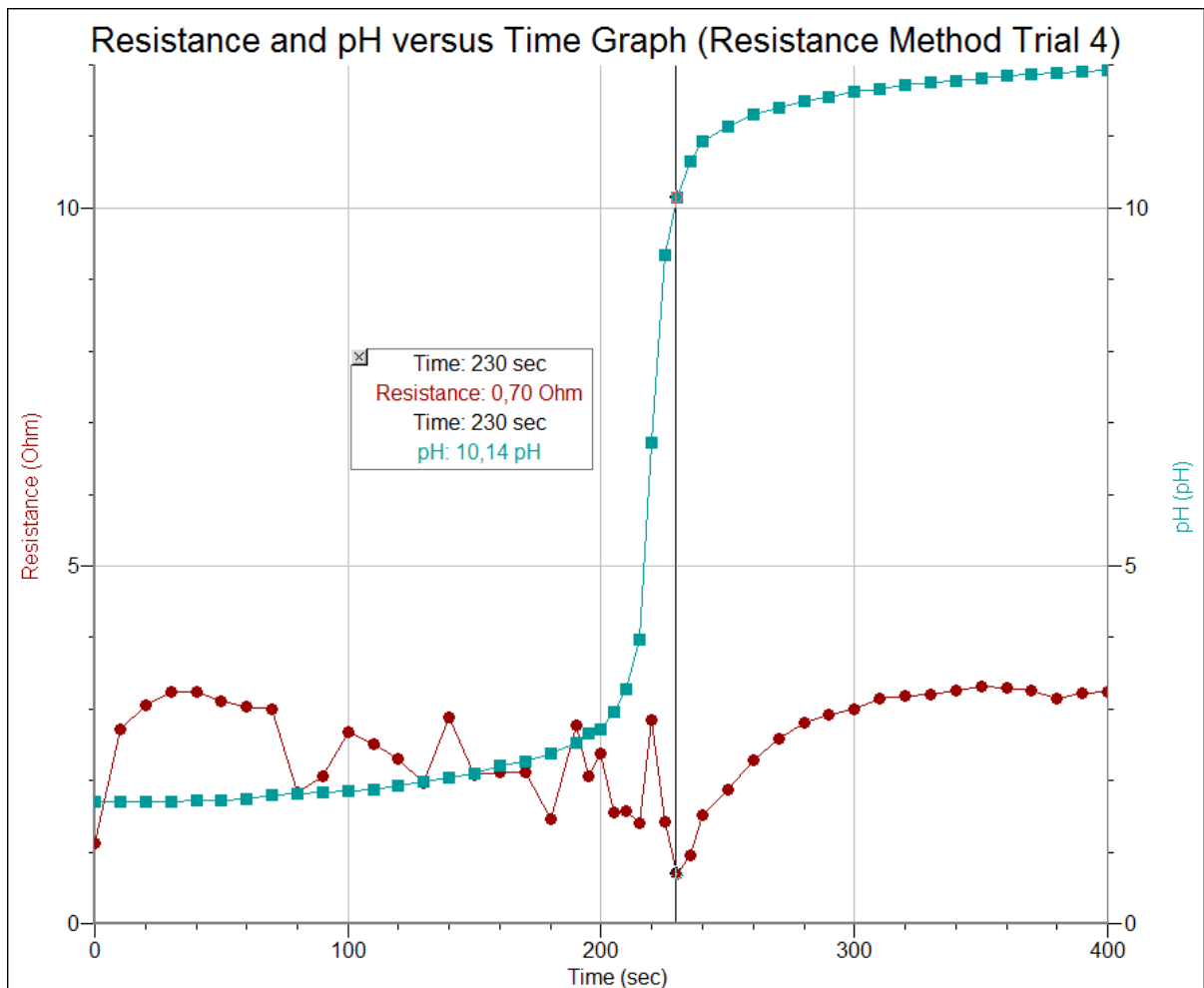
Graph – 12: The graph of the pH and resistance readings taken according to the Resistance Method, and the corresponding pH and resistance values at the end point, Trial 1.



Graph – 13: The graph of the pH and resistance readings taken according to the Resistance Method, and the corresponding pH and resistance values at the end point, Trial 2.



Graph – 14: The graph of the pH and resistance readings taken according to the Resistance Method, and the corresponding pH and resistance values at the end point, Trial 3.



Graph – 15: The graph of the pH and resistance readings taken according to the Resistance Method, and the corresponding pH and resistance values at the end point, Trial 4.

The first trial for this method did not give results similar to the other three trials so it will not be taken into account in the calculations.

$$\text{Mean Value} = [(\text{Trial 2}) + (\text{Trial 3}) + (\text{Trial 4})] / 3$$

$$(9.77 + 10.11 + 10.14) / 3 = 10.01$$

$$\text{Percentage Error} = [| \text{Observed Value} - \text{Literature Value} | / \text{Literature Value}] \times 100$$

$$[| 10.01 - 7 | / 7] \times 100 = \mathbf{43.00\% \text{ Error}}$$

CONCLUSION

Three methods of finding the end-point in an acid-base titration were compared. The titrant used for the experiments was 0.1 molar NaOH and the analyte was 10 mL of 0.1 molar HCl but 15 mL of pure water was added to the analyte in order to raise the level in the container. The methods that were compared are, using phenolphthalein as an indicator, measuring temperature change and measuring the resistance of the solution.

The end-points of the indicator method for three trials are given in Graph – 11. As you can see from the graph, the end-points for the indicator method are between pH 7 and 7.5. The error calculations give that the indicator method has an error of 6.157%.

The temperature method did not give any indication of reaching the end point, as you can see in Graph – 4, Graph – 5, Graph – 6 the temperature keeps increasing even way after the equivalence point. So the error calculation for this method could not be done. However, solutions of 0.1 molar concentrations are not enough to produce a noticeable temperature change. If 1 molar or more of both solutions were used this method would have been more successful because the temperature increase would be more and the heat would be lost easily therefore the decrease could be viewed on the graph. But this essay compares all methods at same conditions so this proves that the temperature method is not suitable for solutions with low concentrations.

The end-points of the resistance method for each four trial are given separately in Graph – 12, Graph – 13, Graph – 14, Graph – 15. The end point on a resistance graph is the point between a sudden, sudden steep decrease and a smooth increase, which looks like the graph of pH after the equivalence point. The end-points for the resistance method vary between pH 9.5 and 10.5 also the first trial for this method was not taken into account because it was not coherent with the other data. The resistance method has an error of 43.00%. The trend of the resistance graphs were not as I expected, after a bit of research I also found out that my hypothesis about the resistance method was incorrect. As the titration nears the equivalence point the conductivity does not decrease because of the forming water molecules. It decreases because the hydronium ions are better conductors than sodium ions and when base is added to the solution the hydronium ions merge with the hydroxide ions to form water, and sodium ions replace them as conductors. Therefore the conductivity decreases until the equivalence point because the hydronium ion concentration decreases and sodium ions do their job as positive charges. Also the conductivity increases after the equivalence point because the excess hydroxide ions are increasing the conductivity because hydroxide ions are better conductors than chlorine ions. However this still does not explain the trend on my resistance graphs. The graphs still should have been as the one shown in my hypothesis. Conductivity and resistance are inversely proportional (Siemens is the unit for conductivity and $1 \text{ Ohm} = 1/\text{Siemens}$) and therefore if the conductivity decreases at the equivalence point, the resistance should increase. However, my graphs show that the resistance also decreases at the end-point. I was not able to explain this. Even if the graphs are in contradiction with scientific facts, it still shows the end-point of the titration.

Among these three methods, the indicator method is the best for acid-base titrations with the lowest error percentage. The resistance method is the second but it has a very high error percentage, if this method is used, the calculations would result in high errors so I do not recommend this method. Lastly, the temperature method failed when applied with these solutions, but it can still be a good method for other titrations, though it still needs to be tested.

(3999 Words)

APPENDIX

Experimental Setups and Methods:

The Indicator Method:

Materials:

40 ml 0.1 molar HCl
70 ml 0.1 molar NaOH
2 burettes
A 100 ml beaker
Phenolphthalein
500 mL pure water
pH meter
Chronometer
Graduated cylinder
2 stands
A burette holder for a stand
A utility clamp
Magnetic stirrer

Method:

- 1- Rinse both burettes with 15 ml of pure water. Then rinse one of the burettes with 10 ml of 0.1 molar HCl solution name this burette as Burette 1. Rinse the other burette with 10 ml of 0.1 molar NaOH solution and name this burette as Burette 2.
- 2- Put the 2 burettes on the burette holder and fix it to a stand
- 3- Fill burette 1 with 30 ml 0.1 molar HCl and burette 2 with 50 ml 0.1 molar NaOH
- 4- Measure 15 ml of pure water in the graduated cylinder and pour it into the 100ml beaker.
- 5- Pour 10 ml of the HCl in burette 1 into the 100ml beaker.
- 6- Add 5 drops of phenolphthalein into the 100 ml beaker.
- 7- Put the utility clamp on the other stand and put the pH meter probe on the clamp.
- 8- Place the magnetic stirrer under burette 2, the stirring piece inside the beaker and put the beaker on the stirrer
- 9- Place the stand with the pH probe near the beaker so that the pH probe is right above the beaker. Then lower the utility clamp so that the tip of the pH probe is in the solution. But do not lower it too much because the stirring piece should not touch the pH probe while stirring.
- 10- Turn on the magnetic stirrer, turn on the pH meter and wait until the value on the pH meter is stable.
- 11- Note the initial reading on the pH meter, start dripping the NaOH from the burette and start the chronometer. Record the pH value every 10 seconds and record the time value when you see the first stable pink color in the beaker.
- 12- When you have dripped around 15-20 ml of NaOH, stop the burette, the chronometer, the magnetic stirrer and the pH meter.
- 13- Clean the beaker and the stirring piece and the pH probe using pure water.
- 14- Repeat steps 4,5,6,7,8,9,10,11,12,13 2 more times.

The Temperature Method:

Materials:

40 ml 0.1 molar HCl
70 ml 0.1 molar NaOH
2 burettes
A coffee cup calorimeter
500 mL pure water
pH meter
Chronometer
Digital thermometer
Graduated cylinder
2 stands
a burette holder for a stand
a utility clamp
Magnetic stirrer

Method:

- 1-** Rinse both burettes with 15 ml of pure water. Then rinse one of the burettes with 10 ml of 0.1 molar HCl solution name this burette as Burette 1. Rinse the other burette with 10 ml of 0.1 molar NaOH solution and name this burette as Burette 2.
- 2-** Put the 2 burettes on the burette holder and fix it to a stand
- 3-** Fill burette 1 with 30 ml 0.1 molar HCl and burette 2 with 50 ml 0.1 molar NaOH
- 4-** Measure 15 ml of pure water in the graduated cylinder and pour it into the calorimeter.
- 5-** Pour 10 ml of the HCl in burette 1 into the calorimeter.
- 6-** Put the utility clamp on the other stand and put the pH meter probe and the probe of the digital thermometer on the clamp.
- 7-** Place the magnetic stirrer under burette 2, the stirring piece inside calorimeter and put the calorimeter on the stirrer
- 8-** Place the stand with the pH and temperature probe near the calorimeter so that the probes are right above the calorimeter. Then lower the utility clamp so that the tips of the probes are in the solution through the hole on the calorimeter. But do not lower it too much because the stirring piece should not touch the probes while stirring.
- 9-** Make sure the tip of the burette is also going through the hole on the lid of the calorimeter.
- 10-** Turn on the magnetic stirrer, turn on the pH meter and the thermometer and wait until the values on the pH meter and the thermometer are stable.
- 11-** Note the initial reading on the thermometer and the pH meter, start dripping the NaOH from the burette and start the chronometer. Record the pH and the temperature values every 10 seconds.
- 12-** When you have dripped around 15-20 ml of NaOH, stop the burette, the chronometer, the magnetic stirrer, the thermometer and the pH meter
- 13-** Clean the calorimeter, the stirring piece, probe of the thermometer and the pH probe using pure water.
- 14-** Repeat steps 4,5,6,7,8,9,10,11,12,13 2 more times.

The Resistance Method:

Materials:

40 ml 0.1 molar HCl
70 ml 0.1 molar NaOH
2 burettes
A 100 ml beaker
500 mL pure water
Sand paper
An Ohmmeter
My special copper electrodes
pH meter
Chronometer
Graduated cylinder
2 stands
A burette holder for a stand
A utility clamp
Magnetic stirrer

Method:

- 1-** Rinse both burettes with 15 ml of pure water. Then rinse one of the burettes with 10 ml of 0.1 molar HCl solution name this burette as Burette 1. Rinse the other burette with 10 ml of 0.1 molar NaOH solution and name this burette as Burette 2.
- 2-** Put the 2 burettes on the burette holder and fix it to a stand
- 3-** Fill burette 1 with 30 ml 0.1 molar HCl and burette 2 with 50 ml 0.1 molar NaOH
- 4-** Clean the copper electrodes using sand paper and pure water.
- 5-** Measure 15 ml of pure water in the graduated cylinder and pour it into the 100ml beaker.
- 6-** Pour 10 ml of the HCl in burette 1 into the 100ml beaker.
- 7-** Place the copper electrodes in the beaker on opposite sides.
- 8-** Put the utility clamp on the other stand and put the pH meter probe on the clamp.
- 9-** Place the magnetic stirrer under burette 2, the stirring piece inside the beaker and put the beaker on the stirrer. Make sure the stirring piece does not touch the electrodes while stirring.
- 10-** Place the stand with the pH probe near the beaker so that the pH probe is right above the beaker. Then lower the utility clamp so that the tip of the pH probe is in the solution. But do not lower it too much because the stirring piece should not touch the pH probe while stirring. And make sure it does not touch the electrodes too.
- 11-** Turn on the magnetic stirrer, turn on the pH meter and wait until the value on the pH meter is stable. Note the initial reading on the pH meter
- 12-** Connect the electrodes to the ohmmeter.
- 13-** Turn on the ohmmeter, keep the initial resistance value in your mind, start dripping the NaOH from the burette and start the chronometer. Then note the initial resistance value. Record the resistance and the pH value every 10 seconds but when the pH gets above 2 record data every 5 seconds and when the pH gets above 10 again record data every 10 seconds.
- 14-** When you have dripped around 15-20 ml of NaOH, stop the burette, the ohmmeter, the chronometer, the magnetic stirrer and the pH meter.
- 15-** Clean the beaker and the stirring piece, the copper electrodes and the pH probe using pure water.
- 16-** repeat steps 4,5,6,7,8,9,10,11,12,13.14.15 2 more times.



Figure – 2: An image showing the experimental setup for the temperature method.

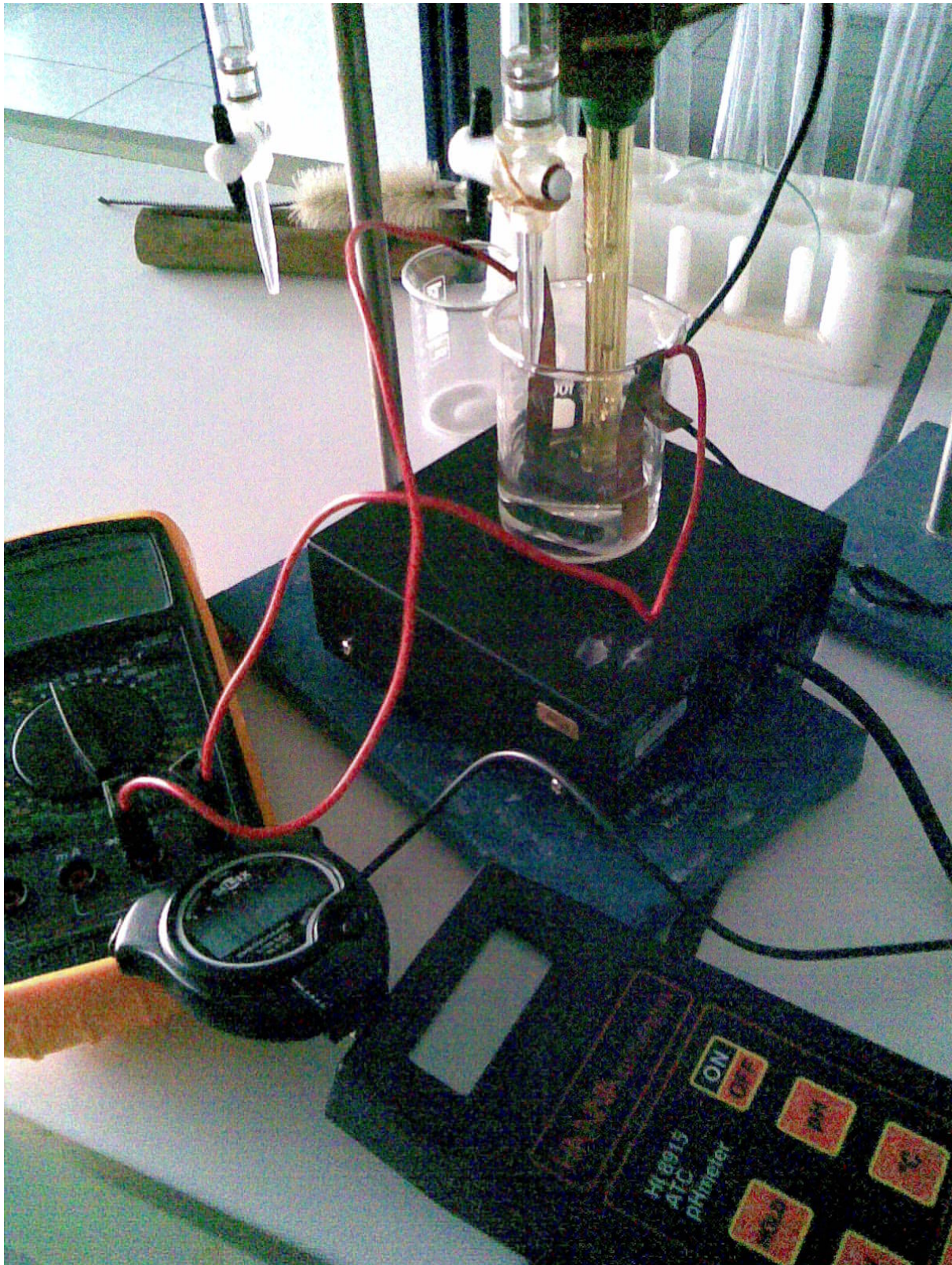


Figure – 3: An image showing the experimental setup for the resistance method.

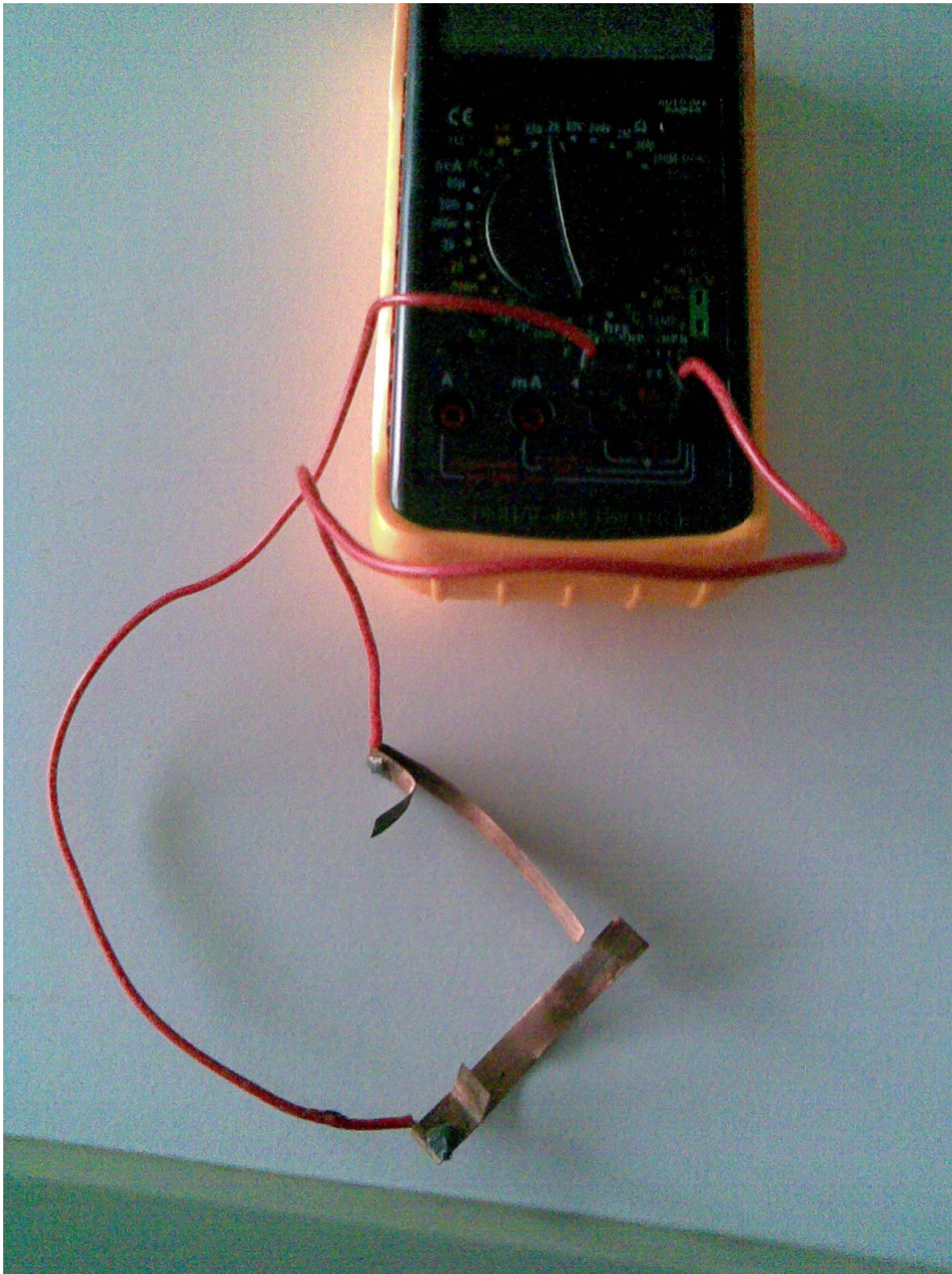


Figure – 4: An image showing the electrodes that are used in the resistance method.

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