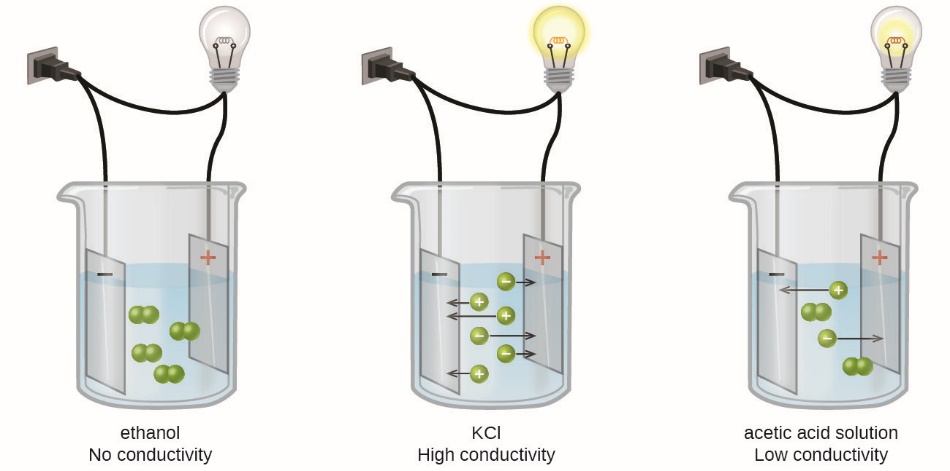
How does Concentration of and Temperature affect the Conductivity of an Aqueous Solution?

# Introduction

## Background

Temperature and concentration of basic solutions and its relationship to conductivity has huge implications upon the modern technological world. Technologies such as underwater cabling and insulators and conductors are greatly affected by its oceanic environment (Zhang, et al., 2020), and climate change alongside acid deposition in the modern technological world can have huge implications on our oceans (The Climate Reality Project, 2016). Furthermore, Hydrogen is one of the most prevalent elements in the universe. Understanding of its conductivity could bring about greater knowledge into the atomic world wherein electricity operates, and perhaps, a peak into the subatomic and beyond. Calcium Hydroxide too is especially ubiquitous in our society. Between its use as a lime in sewage treatment (British Lime Association, 2021), its use in the creation of lime mortar (Eden Hot Lime Mortar, 2021), in medicine in endodontics (Ba-Hattab, Al-Jamie, Aldreib, Alessa, & Alonazi, 2016), or in food preparation (Vandergriendt, 2018), Calcium Hydroxide’s basic properties are profoundly powerful.

******The theory of electrical conductivity stipulates that the conductivity of an aqueous solution is proportionate to the total activity of free ions in a solution (Siyavula, 2021). The total activity of free ions in an aquatic solution can be increased in three ways: increasing the temperature, as an increase in temperature would increase the movement of the particles in the system, therein increasing total activity. Too can one increase the concentration of ions in the solution, as there are more ions for ion activity. Lastly can one use stronger electrolytes wherein a larger portion of the dissolved solute exists as an ion, thereby increasing ion content.

**Figure 1:** Image describing ion movement in a circuit and effectiveness based on strength of electrolyte (Iowa State University, 2021)

Therein, between ’s basic properties and the theory of electrical conductivity, one wonders,

How does the concentration of and temperature affect the conductivity of an aqueous solution?

For this experiment, a series circuit with a multimeter and battery with two iron nails electrodes in the solution will be used. This standard circuit minimizes the resistance across the circuit, allowing for precise measurements of the current flowing through the circuit. To conserve resources, a small 9V battery will be used as the experiment will be conducted in a small solution size of 50mL of distilled water. Distilled water will be used herein to minimize the amount of random error in the foreign ions possible in tap-water. Too will a multimeter be utilized. The water will always be added in first, and Diagram

Description automatically generatedthen the for safety. A hot plate will furthermore be used to heat up the solution after each trial to minimize hot plate use and time.

**Figure 2**: A circuit diagram of the experimental set-up with a multimeter and a battery connected in series with a resistor that is the solution

Calcium Hydroxide is highly insoluble in water at room temperature, possessing a solubility rating of 0.16g per 100g or 1.73g per liter at a temperature of . For this experiment utilizing 50mL , is dissolved. Furthermore, Calcium Hydroxide possesses retrograde solubility, decreasing its solubility to 1.15g/L at a temperature of . This translates to in 50mL of at . (Saipullaev, Koichuev, Batyrova, Gadzhimuradova, & Mirzoeva, 2020) Its dissociation reaction is as follows:

Calcium Hydroxide is moreover a strong base, possessing a pH of 12.8 completely dissociating in a solution. Its solution too is a strong base, possessing a pH of 12.4. Lastly, due to Calcium Hydroxide’s low solubility, the effects of electrolysis will be scarcely observed.

For economical and safety purposes, the concentration of will be limited to a range of to and the temperature will be in the range of to . Since one is measuring the trend in conductivity as concentration increases, a large amount of need not be used, especially for 50mL of water. Thus, economically, concentrations of to or 5g of solid powder is suitable. For safety purposes, a temperature range of to is necessary as when the solution is increased to higher temperatures, may be hazardous when breathed in. (New Jersey Department of Health and Senior Services, 2005)

## Equations

Ohm’s Law will be used to relate voltage of the battery, amperes detected in the multimeter, and the resistance of the solution,

The electrical resistivity equation will be used to relate resistance of the solution to resistivity,

Combining these two equations and rearranging for resistivity, one gets,

Inputting for conductivity as the reciprocal of resistivity, one arrives at,

|  |  |  |
| --- | --- | --- |
|  |  |  |

But as the electrode is an iron nail, its conducts electricity in its cylindrical portion,

|  |  |  |
| --- | --- | --- |
|  |  |  |

Where,

# Research Question, Overview, Variables

## Research Question

How does the concentration of from to and temperature from to affect the conductivity of an aqueous solution?

## Hypothesis

One would hypothesize that the concentration of and temperature of an aqueous solution would positively linearly correlate to conductivity because under the theory of electrical conductivity, conductivity is proportionate to the total activity of ions in a solution, which is proportionate to the concentration of and temperature.

## Variables

|  |  |  |
| --- | --- | --- |
| Independent Variable | Range | How |
| Concentration of |  | will be inserted into the solution in increments of or 2 grams. Measured on an electronic scale |
| Temperature |  | Temperature will be maintained till measurement point using a handheld-thermometer and a hot plate. |

|  |  |
| --- | --- |
| Dependent Variable | How |
| Conductivity | A multimeter will be attached to the beaker, where a charge will be generated. The amperes measured in the circuit will then be used to determine the conductivity. |

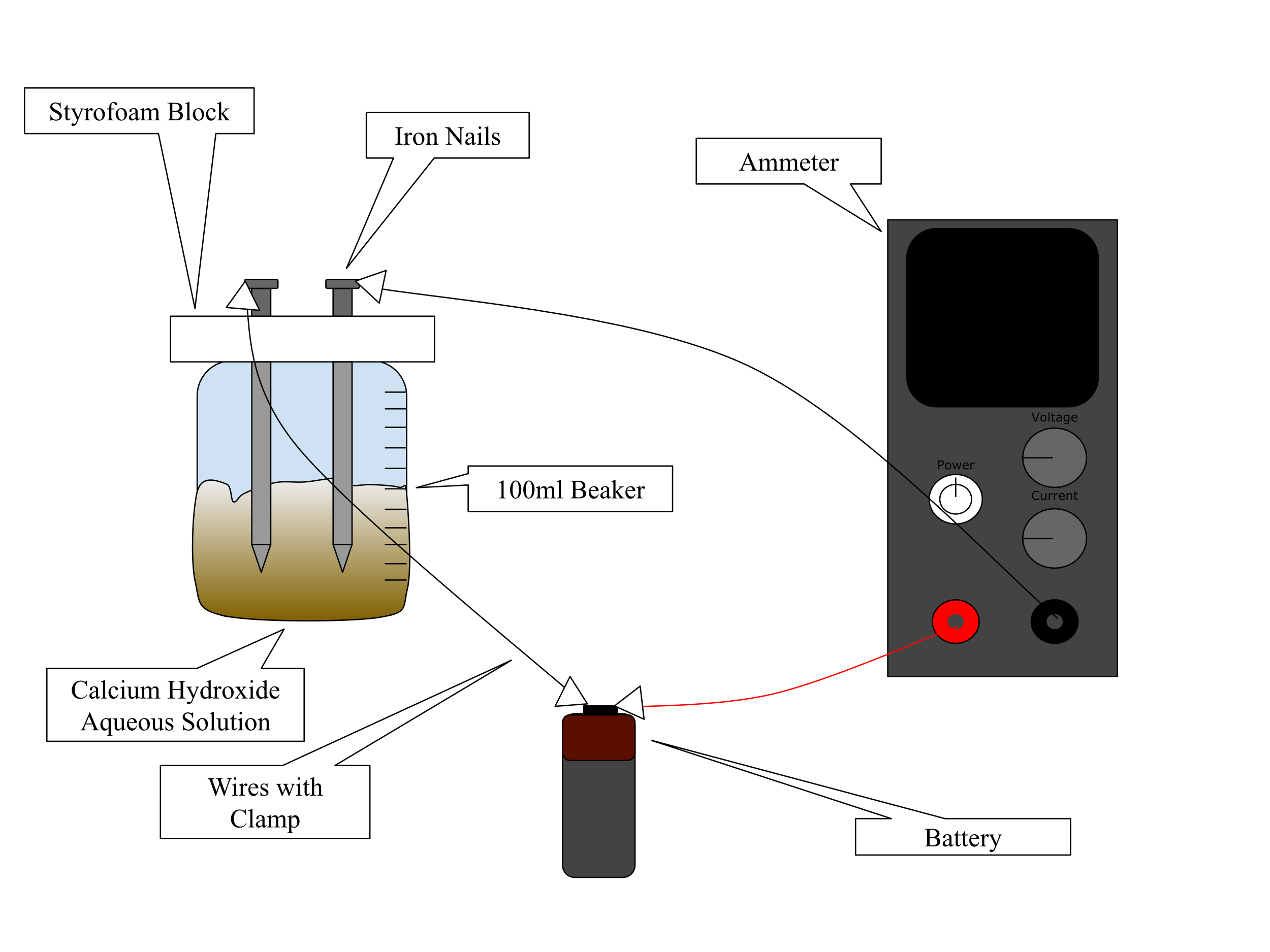
|  |  |  |
| --- | --- | --- |
| Control Variable | Why and How | Measure |
| Area of Beaker | Will affect concentration and heating rate, will be maintained by using same beaker. | Measuring the size of the beaker before use. |
| Purity of Water | Will affect ion concentration in water, will be maintained by extracting water from same source. | Perform conductivity check before experiment to determine its purity. |
| Length and Cross-Sectional Area of the Electrode | Will affect the amount of electricity able to be carried into the solution. Will be kept constant by using the same size of electrode. | Measuring and maintaining the dimensions of the electrodes before use. |
| Material of Electrode | Certain materials can conduct electricity better than others. A constant electrode material must be used for consistent ampere readings. | Determining and maintain the material of the electrode before use. |

# Methodology

## Equipment

|  |  |
| --- | --- |
| **Materials** | **Specifications** |
| 100g of Solid Powder | — |
| 3cm Tall Styrofoam Block | Must be able to be poked through by an iron nail and be placed upon the beaker. |
| 2x 9cm Long, 0.6cm Diameter Iron Nail | Must be made of the same materials and of the same dimensions. Uncertainty in measurement is 0.2cm for diameter and length. |
| 3x 20cm Long Alligator Cables | — |
| 1L Distilled Water | — |
| 100mL Beaker | Must be in diameter and tall. |
| Multimeter | Reading uncertainty of 0.01mA |
| 9V Battery | Reading uncertainty of 0.01V |
| Hot Plate | — |
| Electronic Scale | Reading uncertainty of 0.01g |
| Thermometer | Reading uncertainty of |
| Stirring Rod | — |
| Ruler | Able to measure up to 20cm. Reading uncertainty of 2mm. |

## Procedure

1. Fill a 100mL beaker with 50mL of distilled water.
2. Poke two holes 3.7cm apart in a Styrofoam block with the iron nails and fit them inside. Place it on the beaker. 8.5cm of the electrode should be in contact with the water. It should be a tight fit; the iron nails should not be able to move.
3. With the alligator cables, attach the multimeter to the battery, and then the battery to one of the electrodes. Attach the other electrode back to the multimeter. The circuit is now complete.
4. Place the Styrofoam block on top of the beaker. The iron nails should not be touching the floor of the beaker.
5. Switch the multimeter to measuring current onto the 200mA settings. Record the measurement. Turn the multimeter off.
6. With a hot plate, heat up the water to .
7. At , turn on the multimeter to obtain a measurement.
8. Repeat **Steps 6-7** heating up the water in increments of until the water is .
9. Dispose of the water down the sink.
10. Refill the 100mL beaker with 50mL of distilled water.
11. Obtain 1.00g of solid powder measured on top of an electronic scale
12. Insert the 1.00g of solid powder into the distilled water. Stir until the solution is a homogenous, consistent milky white colour.
13. Quickly place the Styrofoam block on top of the beaker and turn on the multimeter to acquire a reading.
14. With a hot plate, heat up the solution to . Continuously stir as it heats up.
15. When it reaches , quickly place the Styrofoam block on top of the beaker and turn on the multimeter to acquire a reading.
16. Repeat **Steps 14-15** heating up the solution in increments of until the solution is .
17. Dispose of the solution down the sink whilst flushing it with copious amounts of water. Thoroughly clean the beaker with distilled water.
18. Repeat **Steps 10-17** with increments of increasing by 1.00g until 5.00g.

***Figure 3:*** *Illustration of Experimental Set-up*

## Safety, Disposal, Ethical Concerns and Danger

* Heated and/or electrified water can be disposed of into the sink.
* can be disposed of down the drain when flushed with copious amounts of tap-water.
  + Cleaning up small stains can also be done with copious amounts of tap-water and scrubbing. If the stain is large or too difficult to scrub, refer to bottom.
  + A aqueous solution can be drained down the sink in the same way. (ScholAR Chemistry, 2009)
* Styrofoam cannot be recycled in conventional facilities. Place it in the trash or deliver it to specialized facilities for recycling.
* Distilled water can be disposed of down the sink.
* will stain the beakers. Large stains and cleaning the beakers will require distilled white vinegar. Ask the authorities on how to proceed. (The Plumbing Joint Inc., 2019)
* High temperatures near boiling for water could be a hazard in terms of spilling. Safety goggles are mandatory.
* Water once exposed to electrical current, either in temperature, or in is a hazard. Dispose of beaker using specified tools and wear gloves.
* is dangerous if breathed in, which may be a possibility in the solution on higher temperatures and concentrations. Take care not to heat solution over .
  + The solution can also be an irritant if absorbed through the skin, harmful when swallowed, and can irritate the eye. Wear full body clothing and be careful when operating it.
* If breathing in, ingestion, absorption through the skin, or contact with eyes and resulting in notable irritation or difficulty breathing, contact authorities immediately.
* Cobalt mining of lithium-ion batteries come at a high human cost. Use batteries from ecologically and humane-friendly sources like sodium-ion batteries if possible. (Amnesty International, 2016)

# Data Analysis

## Quantitative Analysis

### Raw Data

***Current Raw Data***

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Molarity (mol/mL)** |  |  |  |  |  |  |
| **0.00E+00** | 4.00E-02 | 9.00E-02 | 1.40E-01 | 2.00E-01 | 2.80E-01 | 3.80E-01 |
| **2.70E-02** | 7.00E+01 | 8.00E+01 | 8.33E+01 | 8.33E+01 | 8.50E+01 | 8.60E+01 |
| **5.40E-02** | 8.33E+01 | 8.33E+01 | 9.00E+01 | 9.00E+01 | 9.00E+01 | 9.33E+01 |
| **8.10E-02** | 8.33E+01 | 8.67E+01 | 9.00E+01 | 8.33E+01 | 9.33E+01 | 8.67E+01 |
| **1.08E-01** | 7.39E+01 | 7.20E+01 | 7.80E+01 | 7.90E+01 | 8.90E+01 | 1.12E+02 |
| **1.35E-01** | 8.20E+01 | 1.37E+02 | 1.38E+02 | 1.70E+02 | 1.60E+02 | 1.60E+02 |

***Table 1:*** *Table showing the raw data of the current measured on the multimeter ordered by molarities and temperatures [Current to 3 s.f.]*

### Experimental Conductivity

Conductivity is calculated using .

For example, using a current of from and solution from **Table 1,**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Experimental Conductivity ()**   |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | **Molarity (mol/mL)** |  |  |  |  |  |  | | **0.00E+00** | 1.0E-01 | 2.3E-01 | 3.6E-01 | 5.1E-01 | 7.2E-01 | 9.8E-01 | | **2.70E-02** | 1.8E+02 | 2.1E+02 | 2.1E+02 | 2.1E+02 | 2.2E+02 | 2.2E+02 | | **5.40E-02** | 2.1E+02 | 2.1E+02 | 2.3E+02 | 2.3E+02 | 2.3E+02 | 2.4E+02 | | **8.10E-02** | 2.1E+02 | 2.2E+02 | 2.3E+02 | 2.1E+02 | 2.4E+02 | 2.2E+02 | | **1.08E-01** | 1.9E+02 | 1.9E+02 | 2.0E+02 | 2.0E+02 | 2.3E+02 | 2.9E+02 | | **1.35E-01** | 2.1E+02 | 3.5E+02 | 3.5E+02 | 4.4E+02 | 4.1E+02 | 4.1E+02 | |

***Table 2:*** *Table showing the average conductivity obtained using* ***Table 1*** *and* ***Eq. 1*** *ordered by molarity and temperature. [Conductivity to 2 s.f.]*

### Experimental Conductivity Error

Using the rule for multiplying and dividing uncertainties:

Thus, modifying :

Once again using the current of from the and solution from **Table 1** with instrumental error from **§3.1**,

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Experimental Conductivity Error ()** | | | | | | |
| **Molarity ()** |  |  |  |  |  |  |
| **0.00E+00** | 4.2E-02 | 2.8E-02 | 5.4E-02 | 7.6E-02 | 1.0E-01 | 1.4E-01 |
| **2.70E-02** | 7.4E+01 | 4.9E+01 | 4.8E+01 | 4.5E+01 | 4.2E+01 | 4.1E+01 |
| **5.40E-02** | 8.8E+01 | 5.8E+01 | 5.0E+01 | 4.9E+01 | 4.6E+01 | 4.4E+01 |
| **8.10E-02** | 8.8E+01 | 5.8E+01 | 5.2E+01 | 4.9E+01 | 4.2E+01 | 4.5E+01 |
| **1.08E-01** | 7.8E+01 | 5.2E+01 | 4.3E+01 | 4.2E+01 | 4.0E+01 | 4.3E+01 |
| **1.35E-01** | 8.7E+01 | 5.8E+01 | 8.2E+01 | 7.5E+01 | 8.6E+01 | 7.7E+01 |

***Table 3:*** *Table showing the error of* ***Table 3*** *ordered by molarity and temperature [Error in 2 s.f.]*

## Relevant Qualitative Data

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Molarity ()** |  |  |  |  |  |  |
| **0.00E+00** |  |  |  |  | Multimeter readings for distilled water noticeably do not deteriorate. Instead settles of a number quickly. | Appears to be some bubbling as current is propagated through the circuit. Very minimal, however. |
| **2.70E-02** | The solution is quite murky and dominated by this white-yellow colour. |  | Rapid multimeter readings deterioration of 0.2mA every second. After waiting still drop, though slower. | After multimeter use, the cathode becomes somewhat white and paler. Meanwhile the anode has become noticeably darker. | Multimeter readings deteriorating even faster at increments of 0.3mA per second at beginning. | After disposal of solution, a white-yellow line is noticeable on beaker. |
| **5.40E-02** | There is a large congregation of undissolved on the bottom of the beaker that the nails do not touch. | Due to large clumping of *C* on floor, must stir rigorously to maintain homogenous temperature. |  |  | There are noticeable amounts of bubbling throughout the solution when the solution is heated to this temperature. |  |
| **8.10E-02** | After not stirring, solution clears up quickly for dissolved and undissolved *C* |  | Temperature becoming hard to measure as undissolved *C* at higher temperature. |  |  | Distinction between dissolved and undissolved more visible at this temperature. |
| **1.08E-01** | clumping on floor increases to a dough like shape on the bottom. Must mix. | Deterioration of multimeter readings at incredible rates peaking at 0.8mA/s. |  |  | Multimeter reading deterioration immense at higher temperatures, starting at 1mA/s. | Bubbling is more vigorous in this solution than previous. |
| **1.35E-01** | mixture is now somewhat greyish brown. | Bottom *C* residue stuck on bottom. Must use stirring rod to mix. |  |  |  | Bubbling of solution has resulted in less murkiness. |

## Graphical Analysis using Excel 2021

***Graph 1:*** *Scatterplot graph of the conductivity of a aqueous solution in increasing temperatures. Refer to appendix for other molarities in* ***Graphs 2-6****. [Conductivity in 2 s.f.]*

***Graph 7:*** *Scatterplot graph of the LOBF Gradient of the correlation equations between temperature and conductivity ordered by molarity. Error bars determined by the LOWF(Max) and LOWF(Min) of the related graphs. [Temperature-Conductivity in 2 s.f.]*

|  |  |  |  |
| --- | --- | --- | --- |
| **Molarity** | **LOBF Gradient** | **LOWF(Max)** | **LOWF(Min)** |
| **0.00E+00** | 1.7E-01 | 1.9E-01 | 1.2E-01 |
| **2.70E-02** | 7.0E+00 | 2.6E+01 | -1.5E+01 |
| **5.40E-02** | 5.1E+00 | 3.1E+01 | -2.0E+01 |
| **8.10E-02** | 2.2E+00 | 2.6E+01 | -2.5E+01 |
| **1.08E-01** | 1.8E+01 | 3.9E+01 | 1.8E+00 |
| **1.35E-01** | 3.7E+01 | 7.3E+01 | -1.9E+01 |

**Table 4:** Table accompanying **Graph 2** showing the LOBF Gradients of each molarities correlation equation between temperature and conductivity, as well as the LOWF(Max) and LOWF(Min)*. [Temperature-Conductivity in 2 s.f.]*

# Conclusion

In replying, the data in the experiment proposes a modest positive monotonic correlation between the concentration of and temperature to the conductivity of an aqueous solution.

Therefore, the hypothesis determined in **§2.2** has been cautiously accepted. The accuracy of the experimental results has been found to be uncertain, as shown in the low value of **Graph 7** of , as well as the wide variety of values in **Graphs 1-6**. The gradients of **Graphs 1-6** are compliant with the scientific basis, but the increasing y-Intercepts of **Graphs 1-6** propose a differing conclusion. Lastly, the large error bars present in **Graph 7** can be attributed to the large standard deviations and values in **Graphs 1-6**, which could be attributed to the low and decreasing solubility of , the large variance in multimeter readings, and inaccurate temperature distributions. These have resulted in a low precision in the experimental conclusions.

Still yet, the conclusions do correlate with the scientific basis of **§1.1**. **Graphs 1-6** all posit that an increase in the temperature of a solution correlates to an increase in the conductivity of a solution. This is in accordance with the theory of electrical conductivity: temperature is proportionate to the activity of ions in a solution. Notably however, the y-Intercept of **Graphs 1-6** are much more varied. As **Graphs 1-6** work on the kelvin scale, theoretically the y-Intercept, absolute zero, should be 0, as absolute zero is zero ion activity: zero conductivity. Moreover, the increasing quantities of y-Intercepts for **Graphs 1-6** correlate to the proportionately increasing gradients, which suggests two conclusions as to why the y-Intercepts are not zero. One, variational error in the experimental data resulting in an incorrect gradient, such to fail to extrapolate the trendline to zero, or systematically the experimental data being too large/small, such to offset the trendline away from zero. Two, the correlation between the data is not monotonic, such that there may be a plateau around absolute zero, due to special atomic properties around that temperature, or that the range measured in this experiment is itself an abnormal zone due to it being the confluence of three states of matter for .

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Molarity | **0.00E+00** | **2.70E-02** | **5.40E-02** | **8.10E-02** | **1.08E-01** | **1.35E-01** |
| y-Intercept ( |  |  |  |  |  |  |

***Table 5:*** *Table listing the y-Intercepts of* ***Graphs 1-6*** *[y-Intercept to 2 s.f.]*

On the other hand, the y-Intercept of **Graph 7** is exceedingly close to the origin at , which is consistent with the theory of electrical conductivity. Solutions that possess fewer free ions, that is solutions of lower concentration naturally possess lower conductivity, and therein are proportionately unaffected by temperature, such that distilled water, the solution, is relatively conductively inert. Furthermore, the gradient proposed in **Graph 7** also aligns, as the trend is a positive monotonic correlation. An increase in the concentration of in a solution increases the ability of temperature to increase the conductivity, as evident in the gradient of . What is finally of note is that concentration affects conductivity much more than temperature, at gradients of in **Graph 7** vs a max of in **Graph 6**. This may be a testament to the comparatively low range of temperatures measured of , or of the retrograde solubility of , decreasing free ion content across increasing temperatures and thus reducing temperature’s effect on conductivity.

# Evaluation

## Strengths

A strength of this experiment was that due to the insolubility of , the effects of electrolysis was scarcely observed within the experiment. Though some phenomena were observed, such as the changed colouring of the cathode and electrode as in **§4.2**, overall, the use of resulted in no gases being produced and the electrodes were unaltered during experimentation. This allowed for safe experimentation of higher temperature ranges, and the consistent and unaltered use of common materials like the iron nail.

## Weaknesses

Regarding instrumental error, though the LOBF (Line of Best Fit) does go through the LOWF (Line of Worst Fit), the large gradient difference of from LOWF(Max) to LOWF(Min) suggests low precision in the experimental results. The close y-Intercept values of LOWFs and LOBF however of to and suggests that there is experimental precision in the data. However, there are still yet large relative errors in **Graph 7** raising doubts as to the precision of the experiment. The largest component of relative error within the experiment came from measuring the surface area of the electrodes at error, then distance between electrodes at , and then length of electrodes at . Multimeter instrumental reading error was especially prevalent in lower conductivities, such as in the example calculation in **§4.1.3** at , but for larger conductivities was negligent at .The thermometer used also possessed an absolute error of , but this too is minor. Measurement of the concentration of was performed on an electronic scale, which possessed an absolute error of , again negligent in a range of . These instrumental errors have resulted in the large variance of LOWF(Min) and LOWF(Max) across **Graphs 1-6**, and the low precision in experimental results thus to the large error bars of **Graph 7**. To resolve these issues, finer measurement tools may be used, such as electronic rulers or infrared thermometers, or simply can one increase the size of the experiment, using larger electrodes or greater sized beakers and solutions to reduce the relative error and thus decreasing the error bar sizes.

Regarding systematic error, the clumping of undissolved observed in **§4.2** resulted in a greater density of free ions around the bottom of the beaker, meaning the solution was not homogenous, therein decreasing the ability of free ions to conduct around the electrode and thus decreasing the experimental values and shifting **Graphs 1-7** down. This effect is to be compounded in greater concentrations and thus masses of as evidenced in the darker solutions in **§4.2**, thereby increasing the downwards shift least affecting **Graph 1** and most affecting **Graph 6**. This downward shift would also incrementally increase in **Graph 7**. In higher temperatures, the bubbling of the solution as seen in **§4.2** would help the homogeneity of the solution by displacing the free ions upwards, but thus by changing the homogeneity of the solution again would this phenomenon be a systematic error, increasing the positive vertical displacement in **Graph 1**-**6** as temperature increases. The temperature would also be concentrated around the sunken as seen in the distinction of undissolved and dissolved in **§4.2**, affecting the temperature distribution of the solution and thus acting as another systematic error, decreasing conductivity and thus experimental values across the board, shifting **Graphs 1-7** down, with the effect increasing with temperature. This effect would also be compounded by the retrograde solubility of . What is commonplace in all these issues is the heterogeneity of the solution, and thus to resolve this one proposes using an electric mixer to keep separate and displace the , keeping the solution homogenous and too resolving the temperature distribution problem. This resolution will shift the graphs up, as there are greater free ions in contact and by electrodes.

Regarding random error, the values present within **Graphs 1-6** are greatly varied, in **Graph 4** to in **Graph 1**, as well as **Graph 7**’s value of 0.68 all demonstrate a high level of random error within the experiment. A significant proponent of this has been the multimeter and the clamps. The orientation of clamping the iron nail affected the experimental values in that clamping was often not tight, resulting in variabilities of current read on the multimeter. As the clamps would move every trial, this resulted in a significant source of random error. Furthermore, the timing necessary to ascertain a value on the multimeter before the solution became too heterogenous and cooled significantly was another difficulty. While it was cooling and becoming more heterogenous, its conductivity was decreasing, as observed in **§4.2**, and moreover this effect has also been observed to increase as temperature and concentration increased, further adding to the error. Lastly, transferring the using paper towels meant that not all measured may have been completely transferred over, introducing another element of random error. All these three sources of random error have resulted in the great variances of values in **Graphs 1-6**, and the low value of **Graph 7**. Additionally, the gradients of **Graphs 1-7** have likewise been affected, which may have resulted in the y-Intercept phenomena of **Graph 7** observed in **§5**. Potential solutions to what have been outlined could be to directly measure the conductivity of the solution using an electrode-head multimeter such that clamping is no longer a factor. Too can one continuously measure the current of the solution, such that when it is time to measure one can immediately take the value. This solution could be expanded upon using recording software such to take the instantaneous conductivity to remove the human factor altogether. Moreover, measuring the solution inside the beaker would remove the error of transferring the from the paper towel. Lastly, random error can be remedied by the conducting of more trials.

## Extensions

Here are some ideas of extensions for future experiments.

* Conductivity of higher concentrations of acids (e.g. or ) to see what the effect an acidic composition would have on conductivity and how affected it would be by error.
* Lower temperatures, ions are instead slowed down, how would dissolve?
* Instead of using a strong base like , use a weak base like and see how conductivity would respond in a base equilibrium reaction.

# Bibliography

Amnesty International. (2016, January 19). *Exposed: Child labour behind smart phone and electric car batteries*. Retrieved from Amnesty International: https://www.amnesty.org/en/latest/news/2016/01/child-labour-behind-smart-phone-and-electric-car-batteries/

Ba-Hattab, R., Al-Jamie, M., Aldreib, H., Alessa, L., & Alonazi, M. (2016). Calcium Hydroxide in Endodontics: An Overview. *Scientific Researcher*, Volume 6, No. 12.

British Lime Association. (2021). *Sewage sludge treatment*. Retrieved from BritishLime: https://britishlime.org/technical/sewage\_sludge\_treatment.php

Eden Hot Lime Mortar. (2021). *What is Lime & The Lime Cycle*. Retrieved from Eden Hot Lime and Mortar: https://edenhotlimemortar.co.uk/what-is-lime-mortar.php

Iowa State University. (2021). *Conductivity Meter*. Retrieved from Iowa State University: https://group.chem.iastate.edu/Holme/augmented-reality-in-educational-laboratories/conductivity/

New Jersey Department of Health and Senior Services. (2005, June). Calcium Hydroxide. *Hazardous Substances Fact Sheet*. Trenton, New Jersey, United States of America: New Jersey Department of Health and Senior Services.

Saipullaev, M., Koichuev, A., Batyrova, A., Gadzhimuradova, Z., & Mirzoeva, T. (2020). The disinfecting properties of Penox-1 solutions for sanitation of objects of veterinary supervision. *E3S Web of Conferences*, 175.

ScholAR Chemistry. (2009, January 23). *Limewater.* Retrieved from Material Safety Data Sheet: https://www.mccsd.net/cms/lib/NY02208580/Centricity/Shared/Material%20Safety%20Data%20Sheets%20\_MSDS\_/MSDS%20Sheets\_Lime\_Water\_407\_00.pdf

Siyavula. (2021). *18.3 Electrolytes, ionisation and conductivity*. Retrieved from Siyavula: https://intl.siyavula.com/read/science/grade-10/reactions-in-aqueous-solution/18-reactions-in-aqueous-solution-03

The Climate Reality Project. (2016, June 21). *GLOBAL WARMING’S EVIL TWIN: OCEAN ACIDIFICATION*. Retrieved from The Climate Reality Project: https://www.climaterealityproject.org/blog/global-warming-ocean-acidification

The Plumbing Joint Inc. (2019, April 8). *https://www.plumbingjoint.com/blog/2019/april/tips-to-remove-or-prevent-limescale-from-hard-wa/*. Retrieved from PlumbingJoint: https://www.plumbingjoint.com/blog/2019/april/tips-to-remove-or-prevent-limescale-from-hard-wa/

Vandergriendt, C. (2018, April 12). *How Is Calcium Hydroxide Used in Food, and Is It Safe?* Retrieved from healthline: https://www.healthline.com/health/calcium-hydroxide

Zhang, Y., Chen, X., Zhang, H., Liu, J., Zhang, C., & Jiao, J. (2020, April 20). Analysis on the Temperature Field and the Amplicity of XLPE Submarine HV Cable Based on Electro-Thermal-Flow Multiphysics Coupling Simulations. *polymers*.

# Appendices

***Graphs 2:*** *Scatterplot graph of the conductivity of a aqueous solution in increasing temperatures. [Conductivity in 2 s.f.]*

***Graphs 3:*** *Scatterplot graph of the conductivity of a aqueous solution in increasing temperatures. [Conductivity in 2 s.f.]*

***Graphs 4:*** *Scatterplot graph of the conductivity of a aqueous solution in increasing temperatures. [Conductivity in 2 s.f.]*

***Graphs 5:*** *Scatterplot graph of the conductivity of a aqueous solution in increasing temperatures. [Conductivity in 2 s.f.]*

***Graphs 6:*** *Scatterplot graph of the conductivity of a aqueous solution in increasing temperatures. [Conductivity in 2 s.f.]*