Exemplar
IRP Research Report
Physics 2

The Electrical Conductivity of Chlorinated Water

Exploration

Introduction:

An electrical conductor is a material that can carry electrical charge, electrons transferring through its atoms. Purified water is not a good electrical conductor, however – once impurities (non-water substances) are introduced to water, the conductivity of water will change according to the nature of the impurities added. In this experiment, the concentration of pool chlorine in an aqueous solution will be varied to determine the change in electrical conductivity.

Physical exercise is an important factor in staying healthy, one exercise I enjoy performing above others is swimming, I understand that lightning is a dangerous hazard to swimmers – hence the need for lightning detectors and rods. I became curious to explore why lightning is such a hazard in swimming pools leading me to investigate this topic as an independent project for Physics 2. This investigation serves to answer the research question:

How does the concentration of pool chlorine in an aqueous solution affect the solution's electrical conductivity?

The electrical conductivity of water can be changed by many variables, in this specific scenario where chlorine is added to water, the water becomes electrically conductive due to water reacting with chlorine to form hypochlorous and hydrochloric acid.

$$Cl_2 + H_2O \rightarrow HClO + HCl \qquad \text{(Equation 1)}$$

Hypochlorous acid then breaks down into hypochlorite ions, and the hydrochloric acid breaks down into chlorine ions, which are the prominent conductive impurities in chlorinated water.

$$HClO \rightarrow ClO^- + H^+\ (aq)$$
$$HCl \rightarrow Cl^- + H^+\ (aq) \qquad \text{(Equation 2)}$$

In a metal conductor, the current consists of valence electrons moving through the conductor. In a solution, the current is caused by the movement of aqueous ions in the solution. Therefore, an increase in chlorine concentration is predicted to result in a higher number of reactants allowing for an increased amount of conductive hypochlorite ions hence increasing the conductivity of the solution. This prediction shows similarity to an investigation on "Chlorination of Water" (Race) where calcium

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Commented [JE2]: **Introduction:** Meaningful discussion of research question demonstrates clear personal interest and creativity or initiative

Commented [JE3]: **Introduction:** Identifies a focused and appropriate problem or research question hypochlorite is used to vary the conductivity of distilled water, the graph shown in Fig. 1 displays a linear trend in which as the calcium hypochlorite ppm (concentration) increases, the conductivity increases as well. This equation can be modeled with the equation

$$\kappa = C * K \qquad \text{(Equation 3)}$$

where "κ" is the electrical conductivity of water, "C" is the concentration of chlorine (therefore – concentration of hypochlorite), and "K" is a constant.

The measurement of conductivity used in this investigation is siemens that is the reciprocal of resistance,

$$S = \frac{1}{R} \qquad \text{(Equation 4)}$$

however, alternatively, the conductivity of the solution can be measured using current which is then converted into siemens for ease of measurement.

$$V = IR \qquad \text{(Equation 5)}$$

$$V = \frac{I}{S} \qquad \text{(Equation 6)}$$

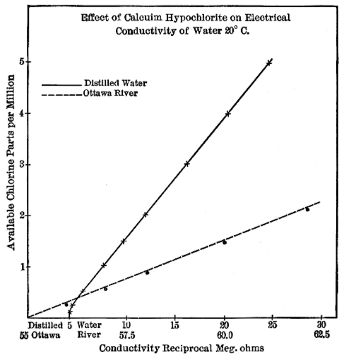

Figure 1. Similar Scientific Model

As this lab involves changing the concentration of chlorine to observe the change in electrical conductivity, the amount of chlorine that is added into the solution will be varied with a range from 0 to approximately 2.5 grams of chlorine (independent variable). By varying the mass of the chlorine, there will be a change in the concentration of chlorine to water in the solution hence changing the electrical conductivity measured in siemens (S) of the aqueous solution by a change in dissolved impurities (dependent variable). In order to reduce the possibility of error in this experiment, it is important to keep certain values constant. The ambient and water temperatures must be kept at a constant 26°C (± 0.5°C) so that that the kinetic energy of the electrons and water remain the same and the total voltage in the electric circuit must also remain constant in order to not cause a change in the equation (refer to Eq. 3-5) as a change in voltage would mean that the current would also increase giving an unstable measurement for current to be converted into siemens. Additionally, the mass of water must also be maintained at 200.00 g (±0.01 g) to not cause a second factor to affect the concentration of the chloride solution.

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Introduction: Subject specific terminology and conventions are appropriate and correct

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Introduction: Identification and discussion of all relevant controlled variables

Method:

A **drinking glass** that could contain more than 200 ml of liquid was selected; the drinking glass was placed on a **digital balance** that was zeroed making the balance disregard the mass of the drinking glass while measuring any additional mass. **Distilled water** was poured into the drinking glass using a 500 ml beaker until the mass measurement on the digital balance read 200.00 g. This measurement of water mass was recorded into a **computer** spreadsheet program. A device supporting **copper electrodes** (shown in Fig. 2) was placed on top of the drinking glass. A **220V power supply** was plugged into a wall socket; an electrical circuit was formed using electrical wiring and the power supply with the copper electrodes (running through water) and a **multimeter** connected as a parallel circuit. (Shown in Fig. 3) The power supply was switched on with the voltage adjusted to 1.00V. The multimeter was switched on, adjusted to measure microamps, the current measured was recorded into a computer spreadsheet program. The drinking glass (containing ~200 g distilled water) was placed on the digital balance. The digital balance was zeroed again to disregard the added mass of water, 0.51 g of pool chlorine solution was added to the distilled water using a **pipette** (for precision) and stirred using a **glass stirring rod** to dissolve. The process of measuring current was repeated for three trials for this amount of chlorine and for 1.03, 1.50, 2.00, 2.48 grams of chlorine with all data recorded in a spreadsheet. The values for electrical current were then converted to electrical conductivity. (Eq. 5)

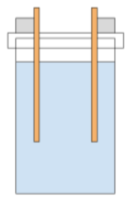

Fig. 2 Copper Electrodes

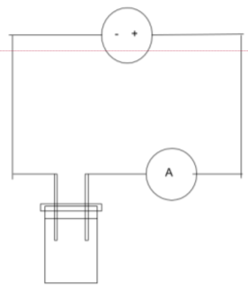

Fig. 3 Experimental Circuit

Safety, Ethical, or Environmental Concerns:

Reasonable safety precautions were taken during the setup and conduct of this experiment. Chlorine is an acidic chemical therefore was handled with **latex gloves** throughout the experiment. All fragile items, including all glassware used were handled with care to prevent breaking. All materials were disposed safely into a sink or a trash can or recycling. There were no ethical or environmental concerns.

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Methods: Materials selected are suitable for the experiment

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Methods: Procedure outlines a fair test giving details regarding control of all variable

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Methods: Method allows for the collection of sufficient relevant data

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Methods: Sensible order of steps for the procedure, giving details of apparatus set-up, methodology, and when and how to make observations

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Introduction: Complete consideration of safety, environmental, and ethical concerns is shown

Analysis

Data Collection:

Qualitative Observations

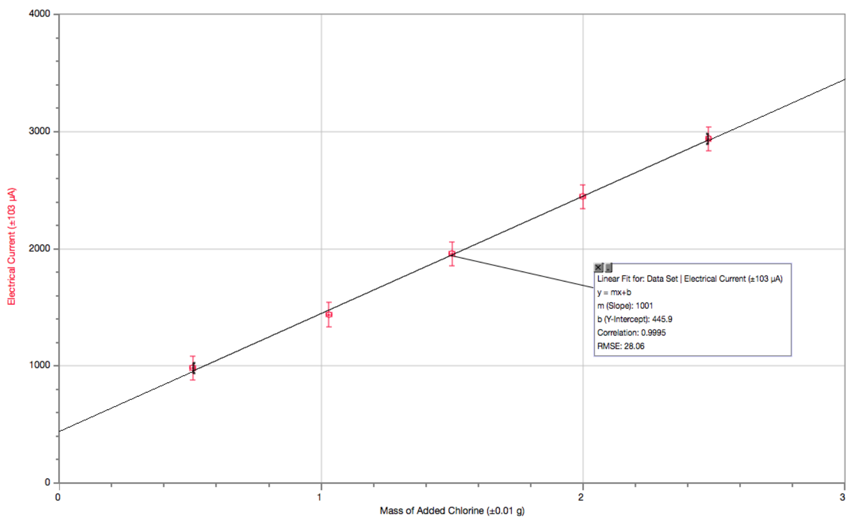
- When choosing what voltage to use, it was noticed that above about 2 V, bubbles formed on the electrodes, thus 1.0 V was chosen as the constant voltage to be used.
- The current readings were never constant, jumping around in a range of about 2 μA.
- Any bumping or moving of the electrodes made the current change, so I was careful to not touch or move the setup once I started taking data.

Quantitative Data

Table 1: Mass of Added Chlorine in Solution vs. Electrical Current

Chlorine Mass (±0.01 g)*	Current			
	Trial 1 (±1 μA)*	Trial 2 (±1 μA)*	Trial 3 (±1 μA)*	Average (±100 μA)
0.00	0.10	0.10	0.10	0.10
0.51	982	906	1057	1000
1.03	1495	1445	1375	1400
1.50	2051	1897	1923	2000
2.00	2425	2490	2419	2400
2.48	2966	2821	3026	2900

Figure 2: Graph of Average Electrical Current As a Function of Mass of Added Chlorine



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Data are carefully organized

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Table 2: Measurements of Controlled Variables

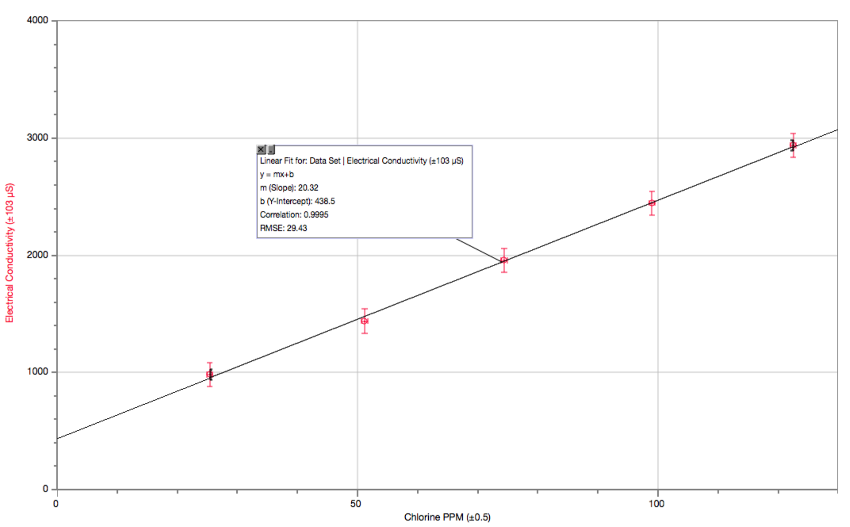
Ambient Temperature (±0.5°C)*	Voltage (±0.1 V)*	Mass of Water (±0.01 g)*
26.0	1.0	200.00

Data Processing

Table 3: Chlorine PPM vs. Electrical Conductivity

Chlorine PPM (±0.5 PPM)	Conductivity (±100 μS)			
	Trial 1 (±1 μS)	Trial 2 (±1 μS)	Trial 3 (±1 μS)	Average (±100 μS)
0.00	0.10	0.10	0.10	0
25.4	982	906	1057	1000
51.2	1495	1445	1375	1400
74.4	2051	1897	1923	2000
99.0	2425	2490	2419	2400
122.5	2966	2821	3026	2900

Figure 3: Graph of Average Electrical Conductivity As a Function of Chlorine PPM



*Instrumental Uncertainties

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Data Collection: Tables and graphs of processed data have a clear and appropriate format

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Processed Data: Tables and graphs of processed data provide a clear and accurate summary of important results

Sample Calculations:

Commented [JE22]: **Processed Data:** Data is processed in clear and appropriate steps

Clearly labeled and accurate sample calculations are included for each step of data processing

Conversion from amperes into siemens

$V = IR, \quad S = \frac{1}{R}, \quad V = \frac{I}{S}, \quad 1.0\,V = \frac{I}{S}$

$\therefore I = S, \quad 982\ \mu\text{A} = 982\ \mu\text{S}$

Conversion from chlorine mass to PPM:

$$PPM_{Cl} = \frac{M_{Cl}}{M_{Cl} + M_{H_2O}} * 10000$$

$$PPM_{Cl} = \frac{1.5}{1.5 + 200} * 10000$$

$$PPM_{Cl} = 74.442 \rightarrow 74.4$$

Calculation for uncertainty of chlorine PPM:

Actual value for PPM

$$PPM_{Cl} = \frac{M_{Cl}}{M_{Cl} + M_{H_2O}} * 10000$$

$$PPM_{Cl} = \frac{2.48}{2.48 + 200} * 10000$$

$$PPM_{Cl} = 122.481$$

Highest and lowest possible values for PPM

$$PPM_{Cl}\,(hi) = \frac{M_{Cl} + 0.01\,(hi)}{M_{Cl} - 0.01\,(lo) + M_{H_2O} - 0.01\,(lo)} * 10000$$

$$PPM_{Cl}\,(lo) = \frac{M_{Cl} - 0.01\,(lo)}{M_{Cl} + 0.01\,(hi) + M_{H_2O} + 0.01\,(hi)} * 10000$$

$$PPM_{Cl}\,(hi) = \frac{2.48 + 0.01}{2.48 - 0.01 + 200 - 0.01} * 10000 = 122.987\ldots$$

$$PPM_{Cl}\,(lo) = \frac{2.48 - 0.01}{2.48 + 0.01 + 200 + 0.01} * 10000 = 121.975\ldots$$

Calculating uncertainty

$$Uncertainty = 0.5 * Range$$

$$Uncertainty = \frac{PPM_{Cl}\,(hi) - PPM_{Cl}\,(lo)}{2}$$

$$Uncertainty = \frac{PPM_{Cl}\,(hi) - PPM_{Cl}\,(lo)}{2}$$

$$Uncertainty = \pm 0.506 \rightarrow \pm 0.5 PPM$$

Evaluation

Conclusion:

From the results of the experiment and the data analyzed, it supports that as the concentration of chlorine increased the electrical conductivity of the aqueous solution increased. This can be seen in Fig. 3 that suggests a linear trend for the increase of electrical conductivity as chlorine concentration increases. I have a moderate level of confidence in the precision of my data and my conclusion. Firstly, my data comes to the same conclusion as the scientific context provided by a similar investigation on the "Chlorination of Water" (Race), but there is no accepted value to calculate percent error reducing my confidence in the accuracy of the conclusions. The graph in Fig. 1 suggests a linear correlation and trend line while Fig. 2 and 3 also suggests the same. Also, while the error bars in Fig. 3 defining the procedural uncertainty of electrical conductivity are large, relative to the range of the data, the error bars on the conductivity measurement is approximately 5% of the range of average data values for conductivity (103 / (2937.7-981.7)), however the error bars still intersect with the linear trend line in the graph. In addition, the equation of the graph given in Fig. 3 correlates with the modeled Eq. 3

$$\kappa = C * K$$
$$\kappa = (C * 20.32) + 438.5 \qquad \text{(Equation 3)}$$

where the slope of Fig. 3 can be defined as the cell constant of chlorine, however the y-intercept of 438.5 is an anomaly.
Lastly (in relation to the previous mention of Eq. 3), while the y-intercept of Fig. 3 is given to be 438.5 suggesting that the conductivity of non-chlorinated water is 438.5 µS this conflicts with the measurement given by the multimeter of the conductivity of non-chlorinated water being 0.1 µS, this reduces my confidence in defining conductivity as a function of concentration as a linear relation but rather an exponential correlation.

Evaluation:

This experiment had both strengths that added consistency and confidence to the data and weakness that led to uncertainties in the data. A strength of this experiment is that a multimeter is used to measure the current rather than used to measure resistance. Due to the current and voltage readings on the power supply being only accurate to the nearest hundredths of their respective units, the measurements on the power supply were not accurate enough to give an output value of resistance (to convert into siemens) due to a high range of unknown values. (Eq. 4) However, due to using the

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Conclusion: Conclusion is discussed and explained in a scientific context

Key results and processed data are used to support the conclusion

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Conclusion: Conclusion is complete and valid

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Evaluation: Identifies and evaluates key strengths of the investigation

multimeter, which could measure units very accurately (hence the microamps and siemens), the multimeter produced very accurate measurements of the current which could be converted easily into siemens due to the voltage being at a constant 1.00 V.

However, one prominent source of error in this experiment is the use of liquid pool chlorine as the source for chlorine. Due to being a liquid, this chlorine is already in an aqueous solution thus effectively adding more water to the solution changing all measurements for chlorine concentration. Also, the chlorine could have several other unaccounted impurities such as other cleaning chemicals effective in water treatment which would mean that this sample of chlorine is possibly more or less effective at causing water to conduct electricity than pure chlorine. To address this issue, the chlorine used in this experiment should be changed to pure chlorine from a chemistry supply or a non-aqueous form of chlorine such as tablets reducing the likelihood of changing the chlorine concentration to an unknown.

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Evaluation: Identifies and evaluates key limitations and weaknesses

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Evaluation: States realistic improvements and extensions

The last source of error present in this experiment was that the device holding the copper electrodes was not structurally stable (Fig 2), due to them swaying, the distance between the two rods were not constant for each trial this had a high chance of leading to the high percent errors in the data due to the electric current having to travel either longer or shorter distances from one end of a copper electrode to another, losing some potential energy as the water is not an ideal conductor. A solution to this would be to secure the copper electrodes very tightly to the device, via an adhesive or some other form of bond in order to stop them from loosening.

References

Race, Joseph. “Chlorination of Water.” *The Project Gutenberg*. 15 Aug. 1917.

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Communcation: MLA citations are used to appropriately acknowledge sources