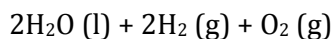


Effect of the molarity of an alkaline electrolyte in electrolysis on the rust removal rate of steel

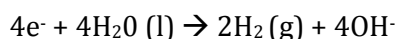
Introduction

Electrochemistry is the branch of chemistry which deals with chemical reactions, especially with electric currents and potentials. Electrochemistry was founded by some of the greatest scientists of all time, John F. Daniell and Michael Faraday. This is the branch of science which specifically deals with the current investigation, does the molarity of an alkaline electrolyte affect the rust removal rate of steel through the process of electrolysis.

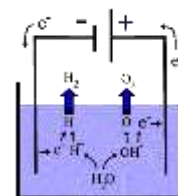
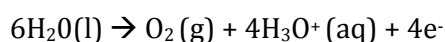
Electrolysis is the decomposition reaction of water whereby the water molecule is split into its constituent elements, Hydrogen and Oxygen due to the presence of an electric current through the water.



Electrolysis was first used by William Nicholson and Anthony Carlisle as they passed an electric current through water in 1800, a few weeks after Alessandro Volta created the first electric battery. In 1834, English scientist, Michael Faraday published his laws of electrolysis, and was thus, the first time electrolysis was formulated. The first law was in regards to the fact that the mass of a substance is in proportion to the amount of electricity used, whilst his second law looked on the fact that for the given number of electric charge, the mass of the material modified by the electrode is proportional to its equivalent weight. The main principle of electrolysis involves two electrodes that are placed in the water. The water and hydrogen are connected due to the intramolecular force of the covalent bond. The electrical potential provides the energy by which the covalent bond is broken. At the cathode, reduction takes place, providing electrons to the hydrogen cations which form the hydrogen gas. For pure water:



At the anode, oxidation takes place, producing oxygen gas and giving electrons to the anode. For pure water:

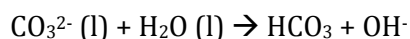


Due to the fact that water is a polar molecule, the H^+ is produced at the cathode, whilst the O^- is produced at the anode. Due to this, for every mole of oxygen gas produced, two moles of hydrogen gas are produced. Electrolysis upholds a plethora of practical applications such as hydrogen power, a renewable resource, which utilises the production of hydrogen through the process of electrolysis. This brings about the production of the hydrogen fuel cell which can be used to power electricity and is already being used in automobiles.

Rust is the formation of iron oxide, a brittle ionic compound, on iron or steel due to oxidation. Rust is usually a product of iron being exposed to oxygen and water or air moisture. The outer layer, also known as 'red rust' is a compound known as ferric oxide. Underneath this layer is a layer is iron (II) iron (III) oxide, commonly referred to as 'black' rust or ferrous ferric oxide. Rust weakens the iron or steel and is commonly economically detrimental to individuals. Especially near coastal areas, rusted equipment is repeatedly replaced and has negative ramifications of the pockets of individuals. Methods of rust prevention such as cathodic protection and the galvanisation of steel is used frequently by

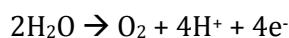
industries to reduce possibilities of rust, yet, soil and sand can wear away the layer of zinc or other chemical, thus, leading to the formation of rust. In the experiment, steel, an alloy of iron will be used which has 99.8% Iron and 0.2% carbon in it. As well, hydrochloric acid is going to be placed on the commercially available galvanised steel to remove the zinc coating. This reaction is called an acid on a metal reaction. The products of this type of reaction are hydrogen and a salt. In particular to iron and hydrochloric acid, the following reaction occurs, $2\text{Fe (s)} + 6\text{HCl (aq)} \rightarrow 2\text{FeCl}_3 \text{ (aq)} + 3\text{H}_2 \text{ (g)}$. Hydrogen peroxide will be added to the steel to make it rust. This is evident in the formula, $\text{Fe(s)} + 2(\text{HO}) \rightarrow \text{FeO} + \text{H}_2\text{O}$.

The process by which rust occurs is an electrochemical one, thus, it is possible to reverse the process with the utilisation of electricity. Rust removal through the use of electrolysis is not a well-known method of rust removal and has only recently been exposed to the public and internet approximately in the early 2000's. Water is a poor conductor of electricity due to its high resistance. The sodium carbonate electrolyte works exceptionally well in allowing the movement in current due to its alkaline environment at a high pH level of 11.6. The intramolecular forces within the sodium carbonate compound are both ionic (sodium-carbon) and covalent (carbon-oxygen). As well, sodium carbonate is a polar compound. Due to this, and the fact that water is polar, the constituent of water, Hydrogen in the water is attracted to the carbonate anions and the constituent of water, oxygen is attracted to the sodium cations. These attractions lead to a pull of the ions out of the lattice, thus, the dissolution of sodium carbonate in water occurs. Thus, when including sodium carbonate into the solution, the sodium and carbonate dissociate, hence, sodium becomes the cation (Na_2^+) and carbonate becoming the anion (CO_3^{2-}). The resistance is lowered due to the introduction of the movement of ions which allow the current to flow easily. This is due to the fact that ions are charge carriers in the solution. Sodium carbonate has a solubility of 215g/L (293.15 Kelvin) in water. If the amount of grams per Litre exceed this, the sodium carbonate would be too concentrated to dissolve in the water, thus, remaining solid. The sodium and carbonate ions are not electrochemically involved, yet, carbonate reacts with water to release hydroxide. This is evident in the chemical formula:

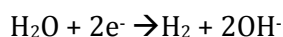


The Bronsted-Lowry theory states that the acid is the water, due to the fact that it donates a proton (H^+) to the carbonate ion. This additionally shows that water is amphoteric in nature. The Bronsted-Lowry base is the carbonate due to the fact that it accepts the proton (H^+) from the water.

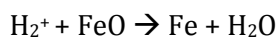
The oxidation-reduction reaction which occurs as a result of the electrolysis is a pivotal aspect of the experiment. At the anode, the water is oxidised and the half-cell is:



At the cathode, the water is being reduced and the half-cell is:



The process by which the iron oxide is removed involves the heavily oxidised iron to be reduced to a less oxidised form. This occurs as H^+ reacts with FeO , so that it is removed as water:



As evident in the above equation, the amount of hydrogen produced has a direct effect on the amount of liberated oxygen, essentially, the amount of rust removed. The amount of hydrogen produced is highly dependent on the reduction of water and the reaction in which carbonate reacts with water to produce OH^- , affecting the H^+ concentration. Due to this, the current has an effect on the rust removal rate, thus, the more ions (charge carriers) and less resistance, the current would move at a faster rate. As a result, the molarity of sodium carbonate in the solution has an effect on the rust removal rate of steel through

the process of electrolysis. As well as this, the production of hydrogen also results in the removal of loose rust and grease, known as cathodic cleaning.

Molarity is a unit of concentration which is involved in determining the number of moles of solute divided by the number of litres in a solution. Sodium carbonate has a molar mass of 83g. This is defined as 6.022×10^{23} (Avogadro's constant) of Sodium Carbonate atoms.

The purpose of the experiment that will be carried out is to investigate whether the molarity of sodium carbonate has an impact on the rust removal rate of steel. Rust removal through the process of electrolysis is commonly used as a DIY as it is convenient, effective and produced great results. In particular, this method is used by Antique collectors and individuals who want to remove rust off tools in comparison to alternative rust removal methods such as power grinding. Antique collectors use this method to other methods of rust removal to increase the value of their antique by removing the rust. This is due to the fact that the metal is not being abraded or removed. Essentially, it is one of the least destructive ways of removing oxidation. By understanding whether the concentration of the alkaline electrolyte affects the rust removal rate of steel, knowledge is given to these antique collectors on how to increase the rate at which the rust is removed. Additionally, this method is economically feasible as it uses relatively cheap materials.

Aim

To investigate if the molarity of Sodium Carbonate (Na_2CO_3) affect the rust removal rate of steel through the process of electrolysis?

Hypothesis

If the molarity of sodium carbonate is increased, then the rust removal rate will increase

Equipment

- 2 250mL beaker
- 25% Hydrochloric Acid solution
- Container
- 6% Hydrogen Peroxide solution
- 4 x 7 cm steel rod (1 cm diameter)
- 1L distilled water
- 3 Alligator Clips; 2 red and 1 black
- 1 zinc electrode
- 1 Stopwatch
- 1 Cotton bud
- 1 6 Volt Batteries
- Switch
- Lectric Washing Soda (Sodium Carbonate)
- Plastic spoon (1 tbsp.)
- Thermometer
- Electronic Scale
- Tongs

Variables

Independent Variable: The molarity of sodium carbonate. Four molarities will be changed and tested; 0.12, 0.6, 1.2 and 1.6.

Dependent Variable: The amount of rust removed will be measured by the amount of mass lost by the process of rust removal. This will be measured through the use of an electronic balance, every 5 minutes.

Controlled Variables:

Variable	How could it affect your experiment?	How will it be controlled?
Volume of Water	It creates a differentiation in the concentration of sodium carbonate to water ratio, thus, the independent variable cannot be performed accurately.	By applying the same volume of water for each concentration of sodium carbonate made.
Material of Electrodes	If the electrodes are different materials each time, certain ions could potentially be dissolved and reduced, hence, can affect the result of the amount of iron oxide removed. As well, the reactivity series must be the same or the results will be invalid.	By using the same material for the electrodes. In this case, the anode is going to be zinc and the cathode is the piece of rusted steel.
Voltage	The greater the amount of voltage, the greater the current, thus, the rate at which the iron is removed will be affected.	By keeping the voltage the same for each concentration. In this case, 6 Volts will be used.
Temperature of water	The higher the temperature of water, the greater the speed at which the oxygen and hydrogen gas is produced and additionally, affects the amount of potential evaporation which occurs, thus, impacting the volume of water.	By using the same temperature water for all the concentrations to receive an accurate reading of the effect that the concentration has on the rust removal rate of iron. The temperature of all the water is 293.15K.
Interval at which the rust removal is measured	If the intervals are not measured the same for every concentration, the results will be inaccurate as the rust removal rate will not be measured fairly. As well, the times in which the piece of steel interacts with the air will affect the results, thus, intervals have to be the same.	By measuring the amount of rust removed every 5 minutes for every repetition.
Surface area of steel	If the rusted steel has a greater surface area, the greater amount of current needed to remove the rust, thus, the results will not be accurate.	By keeping the size of the rusted steel the same. The surface area is 23.6cm ²
Mass of steel	If the mass of steel is different, it will alter time rates and amount of rust produced	By having the same mass for each and measuring the mass of each steel piece before used in the experiment. The mass is 58grams
Material of metal	Different metals corrode in different manners, thus, if the same material (steel) is not used, an inaccurate result will be obtained.	By using steel for all my experiments
Environmental Conditions	By placing the setup of the apparatus in different environments with different	By measuring the temperature of the water with a thermometer and

	amount of ventilation can have an impact on the temperature of the solution which create an unfair experiment.	making sure that they are all the same.
Amount of iron oxide formed onto the iron	If a greater amount of iron oxide forms on one of the steel pieces, the rust removal rate will be affected, leading to an inaccurate description	By placing four layers of hydrogen peroxide on all the steel pieces so the same amount of iron oxide will form.
Length of alligator clips	If the alligator clips are of different lengths for each repetition, the amount of energy lost as the current travels through the wire will differ, leading to a disruption in the rust removal rate.	By using the same length alligator clips for each experiment
Positioning of electrodes	If the electrodes aren't positioned in the same place every time, the distribution of current will differ, leading to a disruption in the results of the rust removal rate.	By positioning the electrodes in the same areas for every experiment.
Material of the Beaker	If the material of the bucket is not plastic, the bucket, is not an insulator, will begin to conduct electricity, hence, the current will follow different parts, not just the electrolytic solution and can also be a safety hazard, possibly causing short circuit and create damage to skin.	By making sure the bucket/beaker is plastic for every experiment.
Same size of the Beaker	If the beaker is not the same size, the positioning of the anodes to the rusted piece of steel will differ, thus, the current would have to take longer to react with the rusted piece of steel and can affect results	By using the same sized beaker, 250mL.
Type of Water	Water can uphold impurities which can deviate the results.	By using distilled water
Movement of Current	If the current used alternates from DC to AC and vice versa, the poles will change, thus, electrolysis will not be consistent amongst all trials, hence, the amount of rust removal will differ	By using DC current for all trials
Brand of Washing Soda	Some brands of washing soda have added ingredients to the sodium carbonate. These added ingredients affects the experiment as the electrolyte is no longer purely sodium carbonate.	By ensuring that Lectric branded washing soda is used, composed of purely sodium carbonate.

Rusting the Steel

- Ensure you are wearing protective gear, a face mask, gloves and safety goggles for this section
1. Prepare the steel pieces, 25% hydrochloric acid solution in the container and 6% hydrogen peroxide solution on a bench
 2. Record the mass of the piece of steel before any rusting has begun
 3. Dip the steel piece into the hydrochloric acid and leave it in the solution for 1 minute
 4. Remove the steel piece out of the hydrochloric acid solution with tongs
 5. Dip the brush into the hydrogen peroxide and place 1 layer onto the piece of steel
 6. Leave it to dry for 3 minutes
 7. Repeat 5-6 until four layers of hydrogen peroxide has been placed onto the piece of steel
 8. Record the mass of the piece of steel after the iron oxide has formed onto the steel
 9. Repeat steps 2-7 for four pieces of steel

Removing the Rust

10. Prepare a beaker with 250mL, an empty beaker, 1 6V battery, 1 switch, 3 alligator clips, 1 graphite electrode, a piece of rusted steel and 250mL of distilled water in a well-ventilated area
11. Fill the beaker with the 250mL of distilled water
12. Measure 0.6mol of sodium carbonate with another beaker, measuring its mass, then place it in the distilled water
13. Place the red alligator clip into the negative terminal of the battery
14. Connect the same alligator clip to the switch
15. Connect the switch to another red alligator clip
16. Connect the rusted steel piece to the red alligator clip
17. Place the black alligator clip into the positive terminal of the battery
18. Connect the anode, the zinc electrode to the black alligator clip
19. Ensure the switch is off
20. Place the anode and the rusted steel piece into the sodium carbonate solution
21. Open the switch
22. Start the time of the stopwatch
23. Close the switch after 5 minutes
24. Detach the red alligator clip from the rusted steel piece
25. Measure using the electronic balance, the mass of the piece of steel
26. Record the mass of the piece of steel after 5 minutes of rust removal
27. Repeat steps 21-24 for six 5 minute intervals. For example, at 5minutes, 10minutes, 15 minutes... Up to 30 minutes
28. Repeat steps 1-25 using different molarities of sodium carbonate solution, 0.12, 0.6, 1.2 and 1.68
29. Repeat steps 1-26 6 times

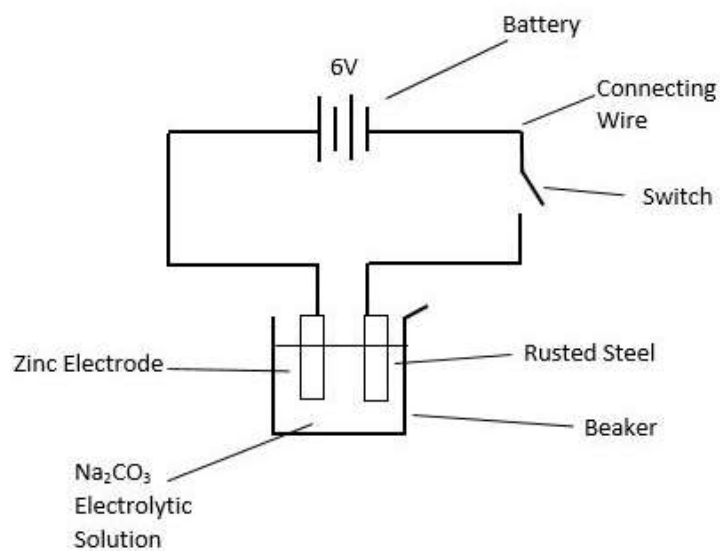
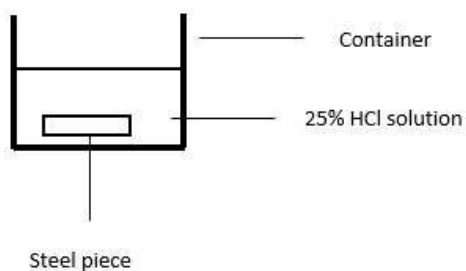
Risk Assessment

Risk	How the risk will be reduced or avoided	Assess
Contact with Hydrochloric Acid is corrosive to eyes, skin and mucous membrane and can thus result in chest pain, inflammation and coughing Consuming hydrochloric acid can lead to nausea, diarrhoea , vomiting and severe burns	<ul style="list-style-type: none"> Wear rubber gloves and safety goggles whilst placing the hydrochloric acid on By making no contact between the oral area and the hydrochloric acid 	Low Risk having applied suggested controls
Contact with hydrogen peroxide with skin, eyes and body tissue leads to burns. Eye contact with Hydrogen peroxide can lead to permanent loss of vision	<ul style="list-style-type: none"> Wear gloves and safety goggles whilst in contact with the hydrogen peroxide Ensure that protective safety goggles are being worn 	Low risk having applied suggested controls
Contact with the sodium carbonate solution whilst it is conducting electricity can electrocute an individual, thus, leaving burns and damage to the skin and internal organs.	<ul style="list-style-type: none"> Keep all contact away from the solution whilst the motor is running. If a modification is needed, the motor must be closed. 	Low risk having applied suggested controls
Contact with an individual's eyes and the sodium carbonate solution can lead to irritation	<ul style="list-style-type: none"> Wear safety goggles throughout the whole process 	Low risk having applies suggested controls
Contact with electrodes whilst current is flowing can lead to dangerous flow of electricity near the chest area	<ul style="list-style-type: none"> Don't make any contact with the electrodes whilst the motor is on. If a modification to the electrodes are needed, the motor must be turned off. 	Low risk if suggested controls are applied
The interaction between the motor and the liquid can cause the production of sparks and heat which can potentially cause a fire and burns to the skin	<ul style="list-style-type: none"> Don't bring about any flammable material near the area within which the experiment is taking place. Stay in a well-ventilated area 	Medium Risk if suggested controls have been applied
Elemental Hydrogen and Oxygen gas are produced and if any flammable material is placed near it, can cause an explosion, causing burns and a potential hazard for fires.	<ul style="list-style-type: none"> Must stay in a well-ventilated area 	Medium Risk is suggested controls have been applied
If electrodes connect or disconnect throughout the running of electricity, sparks and an explosion could be produced, causing burns and skin irritation.	<ul style="list-style-type: none"> Don't make contact with the electrodes throughout the process. If a modification is needed, the motor and running of electricity must be off. 	Low risk is suggested controls are applied

Diagrams

2. Electrolytic Rust Removal

1. Rusting of the Steel



Results

Mass of all pieces before rusting: 58 grams

Molarity 0.12

Time (min)	Mass (g)						
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Average
0	58.8	58.8	58.8	58.9	58.8	59.0	58.9
5	58.8	58.8	58.8	58.9	58.8	59.0	58.9
10	58.7	58.7	58.7	58.8	58.7	58.9	58.8
15	58.5	58.6	58.6	58.7	58.6	58.8	58.6
20	58.4	58.4	58.4	58.5	58.4	58.6	58.4
25	58.4	58.4	58.4	58.5	58.4	58.6	58.4
30	58.3	58.3	58.3	58.4	58.3	58.5	58.4

Observations:

- Immediate fizzing
- Production of gases
- bubbles

Molarity 0.6

Time (min)	Mass (g)						
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Average
0	58.9	58.9	58.7	58.8	58.8	58.9	58.8
5	58.8	58.7	58.6	58.6	58.6	58.8	58.6
10	58.7	58.6	58.5	58.6	58.5	58.7	58.6
15	58.6	58.5	58.4	58.5	58.4	58.6	58.5
20	58.5	58.4	58.3	58.4	58.3	58.5	58.4
25	58.5	58.4	58.3	58.3	58.3	58.5	58.4
30	58.4	58.3	58.2	58.2	58.2	58.4	58.3

Observations:

- Immediate fizzing
- Production of gases
- Bubbles

Molarity 1.2

Time (min)	Mass (g)						
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Average
0	58.8	58.8	58.7	58.8	58.8	58.9	58.8
5	58.6	58.7	58.6	58.7	58.7	58.8	58.7
10	58.5	58.5	58.5	58.5	58.5	58.7	58.5
15	58.4	58.4	58.4	58.4	58.4	58.6	58.4
20	58.2	58.3	58.3	58.3	58.3	58.4	58.3
25	58.2	58.3	58.2	58.3	58.3	58.3	58.3
30	58.2	58.2	58.1	58.2	58.2	58.2	58.2

Observations

- Immediate fizzing
- Production of gases
- Bubbles
- Rusted steel piece is a higher temperature than previous molarities

Molarity 1.68

Time (min)	Mass (g)						
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Average
0	58.7	58.8	58.8	58.7	58.9	58.8	58.8
5	58.5	58.6	58.6	58.5	58.7	58.6	58.6
10	58.4	58.5	58.5	58.4	58.6	58.5	58.5
15	58.2	58.4	58.4	58.2	58.4	58.4	58.3
20	58.2	58.2	58.2	58.2	58.3	58.2	58.2
25	58.1	58.2	58.2	58.1	58.2	58.2	58.2
30	58	58.1	58.1	58	58.1	58.1	58.1

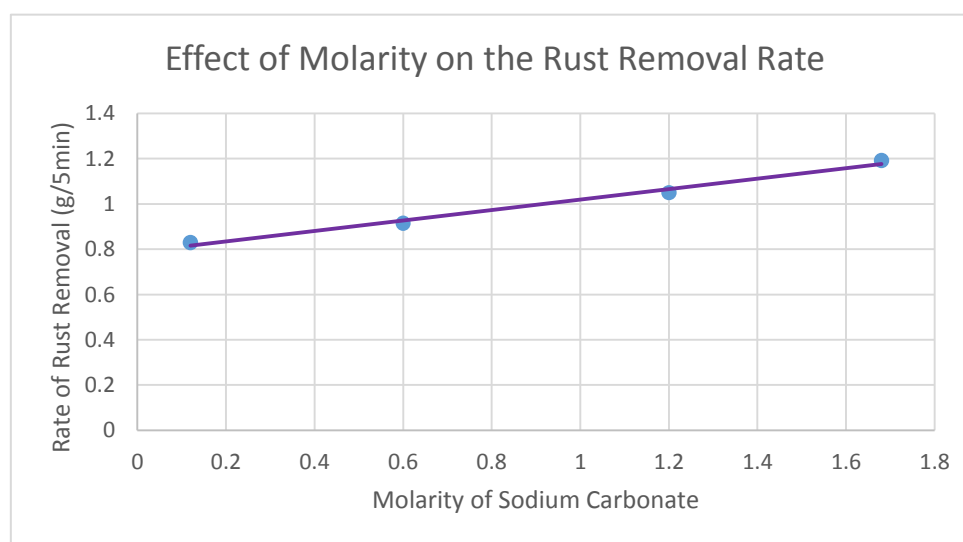
Observations

- Immediate fizzing
- Production of gases
- Greater amounts of Bubbles being produced at the cathode and anode than less molarities
- Cathode hotter than other pieces of rusted steel from other tests with less molarity

Rust Removal Rates

Molarity of Sodium Carbonate	Rust Removal Rates (g/5min)						Average
	1	2	3	4	5	6	
0.12	0.83	0.83	0.83	0.83	0.83	0.83	0.83
0.6	0.83	1	0.83	1	1	0.83	0.915
1.2	1	1	1	1	1.17	1.17	1.05
1.68	1.17	1.17	1.17	1.17	1.3	1.17	1.192

Discussion /Analysis



Graph showing Average quantities

The results of the experiment have brought about significant trends and patterns. To begin, the main observations that were extracted from my observations of my results included the immediate fizzing, the production of gases on both the anode and cathode and the variations of the amounts produced depending on the molarity of the sodium carbonate. At the anode, oxidation takes place, producing oxygen gas. At the cathode, reduction takes place, producing hydrogen gas.

As depicted in the tables and the graph above, as the molarity of sodium carbonate in the solution increased, the rust removal rate increased. It is for this reason that my hypothesis has been confirmed. This is due to the fact that a greater molarity, results in a greater number of ions (charge carriers) in the solution. With a greater number of ions, the resistance of the electrolyte is lowered, thus, more energy can travel to the electrodes for the rust to be removed. Another trend which is evident throughout my experiment was the fact that as the molarity increased, a greater number of bubbles of gas were being produced at both the anode and cathode. This is due to the fact that the electrolyte had a greater number of ions, thus, the current was travelling at a faster rate and the water molecules were being oxidised and reduced at a faster rate. It is for this reason that greater amounts of elemental hydrogen gas and oxygen gas were being produced. Thus, it is evident that the greater the molarity of an alkaline electrolyte in electrolysis, the faster the rate for the splitting of the water molecule to occur. Another trend evident in my experiment is the fact that the greater the molarity, the higher the temperature of the rusted steel piece after the 30 minutes of testing. This is due to the fact that an exothermic reaction

is taking place as the current is reaching the cathode. A greater molarity of sodium carbonate, results in a greater amount of ions in the solution. These ions create less resistance in the solution, allowing the electrons to flow to the cathode at a faster rate. As the electrons reach the cathode as a faster rate, the amount of heat produced is increased within the vicinity of time (30min) in which the experiment is being tested.

Validity in my experiment was ensured through several avenues. To start, the experiment answered the aim as the experiment, does the molarity of an alkaline electrolyte affect the rust removal rate of steel through the process of electrolysis? Used sodium carbonate (an alkaline electrolyte) to test if it affected the rust removal rate of steel. As well, all factors were controlled such as volume of water, material of the anode and the temperature to ensure that the only possible variable which can impact the results is the molarity of sodium carbonate. Additionally, my experiment was repeated six times to improve the validity of the experiment. Validity could have been improved with a greater amount of time for repetition. Furthermore, reliability was ensured through the experiment as it was repeated six times and consistent results were extracted from the experiment. Accuracy was ensured as my observations and measurements utilised methods which limited greatly the amount of human error which could occur. Although, in saying this, certain measurements could have been measured to a greater accuracy. For example, I used an electronic balance to measure the mass of the steel pieces which gave me the mass to 1 decimal place. The measuring of the mass could have been to greater detail if accessibility to a microbalance was enabled.

The experiment I chose to pursue possessed several limitations and factors by which needed to differ. Initially, I had conducted a trial experiment as I had never previously set up electrolysis and/or used it to remove rust. A handful of YouTube videos portrayed the use of this with industrial tools in which I did not possess. To start off, I was not able to use a 12 volt power pack due to safety reasons, thus, I alternatively used 2 6Volt batteries, connecting a positive terminal of one battery to the negative terminal of the other. This is not as accurate of a power supply as a power pack would have been as the battery can run out, whereas the power pack cannot. Additionally, a well-ventilated area is essential in my experiment as elemental hydrogen is being produced which can possibly be very destructive. The traditional way to control this through the utilisation of a fume hood. As I did not complete my experiment at school, I was not in a position to use this equipment, thus, I had to rely on the opening of windows. Initially, the experiment I was prepared to undertake used iron for the rusting. As 98% of iron mined goes towards the production of steel for commercial purposes, steel was the only accessible metal. I also believed that using steel would be more relevant to today's society as the alloy of iron, steel, is used more commonly than pure iron. Furthermore, traditional rust formation can take months to years to occur through the exposure of oxygen and moisture in the air. As I did not possess the time frame for my steel pieces to undergo rusting, I had to use a quick and controlled method. I was notified by this method of rust removal on a YouTube video and when I completed the chemical equation for the rusting ($\text{Fe} + 2(\text{HO}) \rightarrow \text{FeO} + \text{H}_2\text{O}$), I realised it was possible to utilise this method. In addition, prior to my trial experiment, I obtained the notion that measuring the amount of steel removed based on the amount of iron oxide formed on the top of the solution would be accurate. As I did research, rust removal using electrolysis does not abrade or take away the iron, hence, it is not possible for iron oxide to form on the surface of the solution. It is for this reason, and the fact that human error is inevitable in this method that I chose to use the mass as a means for measuring the amount of rust removed. This was done by measuring the mass before it was removed and at 10 minute intervals throughout the process of electrolysis to determine the rate. In saying this, I had access to a digital balance and a spring balance. The spring balance was not providing an accurate reading of the mass in grams, as well, human error is inevitable with the use of a spring balance, henceforth, I resorted to the digital balance. The measures of mass would be more accurate if I had access to a microbalance, yet, it isn't commercially available in stores locally. After my trial, I also realised that the time frame set for my results and the amount of voltage I was prepared to use was making the rust remove too fast to record any results. Due to this, I decided to only use one 6V battery. Finally, a limitation in which reduced the amount of time I had to perform my experiment was the material of my electrodes. In my trial experiment, I was using a

graphite anode. Due to the anodic cleaning that was occurring, the graphite electrode was depositing carbon onto the rusted steel piece which interrupted the rust removal process. Graphite electrodes were unfavourable, therefore, I was informed to utilise a zinc electrodes. The graphite was undergoing electrodeposition, thus, was depositing carbon onto the rusted piece of steel and disrupting the rust removal process in my trial. When using the zinc electrode, this did not occur. Zinc was also a better electrode than graphite as the standard electrode potential is -0.76 in comparison to graphite's -0.10 . Steel has a standard reduction potential of $E^\circ = 0.77$. The greater the number of a standard reduction potential, the easier it is to gain electrons. As well, the electromotive force that zinc possesses is more reactive than iron on the reactivity series, thus, the transfer of electrons can occur more readily. This is mainly due to the fact that zinc has two valence electrons ($1s^22s^22p^63s^23d^{10}4s^2$) and wants to remove them to become stable (octet rule), whereas, graphite has 4 valence electrons ($1s^22s^22p^2$).

The results presented in this experiment are very useful to a wide range of individuals in an everyday situation. To begin, the method of rust removal through the utilisation of electrolysis is ubiquitous amongst antique collectors as it does not abrade the metal. Moreover, the rust in nooks and crannies can be removed easily through the use of electrolysis and don't need to deconstruct if utilising traditional methods such as chemical removers or sanding the surface. The artefact restoration business also uses this method of rust removal. By understanding the fact that the greater the molarity of the alkaline solution, the faster the rate at which the rust is removed, the less time consuming the process of removing the rust will be for these individuals. Electrolytic rust removal can additionally eventually become a portable and effective method of removing rust if a portable device was to be invented.

Conclusion

Ultimately, the experiment, does the molarity of an alkaline electrolyte affect the rust removal rate of steel through the process of electrolysis had come to the conclusion that it does. The affect stated in the hypothesis and proven by the experiment is that the greater the molarity of sodium carbonate, the increased the rate of rust removal of the rusted steel piece. This is evident as the molarity 0.6 of sodium carbonate in the solution had an average rust removal rate of $0.83\text{g}/5\text{min}$, whilst the molarity 1.68 of sodium carbonate in the solution had an average rust removal rate of $1.192\text{g}/5\text{min}$.

- "Acids + Metals." *Launceston College - Home*. Web. 16 Aug. 2013.
<<http://www.launc.tased.edu.au/online/sciences/PhysSci/pschem/acidbase/acidRxns.htm>>

- "Anthony Carlisle - Wikipedia, the free encyclopedia." *Wikipedia, the free encyclopedia*. 26 Feb. 2013. Web. 20 July 2013. <http://en.wikipedia.org/wiki/Anthony_Carlisle>
- Atom, distorting the distribution of electrons around the argon, and the polar. "Intermolecular Forces." *Purdue University College of Science Welcome*. 5 July 2007. Web. 9 Aug. 2013. <<http://chemed.chem.purdue.edu/genchem/topicreview/bp/intermol/intermol.html>>
- Aylward, Gordon, and Tristan Findlay. *SI Chemical Data*. 6 ed. Queensland: Wiley, 2008. Print.
- "Baking Soda vs. Washing Soda as an Electrolytic Derusting Electrolyte." *French Creek Valley Activities*. 5 June 2010. Web. 17 Aug. 2013. <<http://www.spaco.org/Blacksmithing/Rust/BakingVsWashingSoda.htm>>
- "Balance Chemical Equations." *WebQC.org*. Web. 3 Aug. 2013. <[www.webqc.org/balance.php?reaction=Fe\(s\)%2BHCl\(aq\)%3DFeCl3\(aq\)%2BH2\(g\)](http://www.webqc.org/balance.php?reaction=Fe(s)%2BHCl(aq)%3DFeCl3(aq)%2BH2(g))>
- "Bases - pH Values." *Engineering ToolBox*, 9 July 2006. Web. 5 Aug. 2013. <http://www.engineeringtoolbox.com/bases-ph-d_402.html>
- Blackman, Allan, Steven Bottle, Gregory Williams, Siegbert Schmid, Mauro Mocerino, Uta Wille, James Brady, Fred Senese, William Brown, Thomas Poon, and John Olmsted. "Oxidation and reduction." *Chemistry*. 2 ed. Queensland: Wiley, 2012. 489. Print.
- "Brønsted-Lowry acid-base theory - Wikipedia, the free encyclopedia." *Wikipedia, the free encyclopedia*. 5 July 2013. Web. 9 Aug. 2013. <http://en.wikipedia.org/wiki/Brønsted-Lowry_acid-base_theory>
- "Cathodic cleaning (Meaning of)." *Online Encyclopedia*. Web. 1 Aug. 2013. <<http://www.encyclo.co.uk/define/cathodic%20cleaning>>
- Chaplin, Martin. "Magnetic and electric effects on water." *London South Bank University*. 24 Mar. 2013. Web. 6 Aug. 2013. <<http://www.lsbu.ac.uk/water/electrolysis.htm>>
- "Chemistry Tutorial: Faraday Laws of Electrolysis." *AUS-e-TUTE for astute science students*. 10 Aug. 2007. Web. 4 Aug. 2013. <<http://www.ausetute.com.au/faraday1.html>>
- Clark, Jim. "Iron and steel." *chemguide: helping you to understand Chemistry - Main Menu*. Web. 17 Aug. 2013. <<http://www.chemguide.co.uk/inorganic/extraction/iron.html>>
- Dickerson, Bill. "Rust removal by electrolysis." *Bill's Antique Gas Engines - collecting, restoring, repairing old gasoline engines with vintage engine trading post, show dates and chat forums*. 8 Mar. 2007. Web. 17 Aug. 2013. <[Http://antique-engines.com/electrol.asp](http://antique-engines.com/electrol.asp)>
- "Electrochemistry Encyclopedia -- What is electrochemistry?" *YCES - Case Western Reserve University*. Web. 18 Aug. 2013. <<http://electrochem.cwru.edu/encycl/art-i02-introduction.htm>>
- "Electrolysis of water - Wikipedia, the free encyclopedia." *Wikipedia, the free encyclopedia*. 7 Aug. 2013. Web. 17 July 2013. <http://en.wikipedia.org/wiki/Electrolysis_of_water#History>
- "Electrolysis." *Curriculum 7-12*. 27 May 2004. Web. 4 July 2013. <http://www.nmsea.org/Curriculum/7_12/electrolysis/electrolysis.htm>
- "Electrolysis." *MLR EDU*. Web. 13 Aug. 2013. <www.mrl.ucsb.edu/sites/default/files/mrl.../jt_student_electrolysis.doc>
- "Electron affinity - Wikipedia, the free encyclopedia." *Wikipedia, the free encyclopedia*. 7 Aug. 2013. Web. 10 Aug. 2013. <http://en.wikipedia.org/wiki/Electron_affinity>
- "Faraday's laws of electrolysis - Wikipedia, the free encyclopedia." *Wikipedia, the free encyclopedia*. 9 Aug. 2013. Web. 21 July 2013. <http://en.wikipedia.org/wiki/Faraday's_laws_of_electrolysis>
- Francis, Eden. "Bronsted-Lowry Concept." *Clackamas Community College Distance Learning*. Web. 3 Aug. 2013. <<http://dl.clackamas.cc.or.us/ch105-04/bronsted.htm>>
- Geriepy, Geoff. "Geoff's Science Garage - Electrolytic Rust Removal - YouTube." *YouTube*. 1 Nov. 2005. Web. 17 Aug. 2013. <<http://www.youtube.com/watch?v=R5I5WBG5HPw>>
- Haines, S. 2013, 04 August. <R.Haines@unsw.edu.au>
- "HCO₃⁽⁻⁾ + OH⁽⁻⁾ -- CO₃⁽²⁻⁾ + H₂O which is stronger acid hco₃⁽⁻⁾ Or h₂o? - Science Engineering Technology and Mathematics." *Science Engineering Technology and Mathematics / Authpad*. Web. 2 Aug. 2013. <<http://stem.authpad.com/hco3-oh-co3-2-h2o-whish-is-stronger-acid-hco3-0r-h2o>>
- Helmenstine, Anne Marie. "Ionization Energy Definition - Chemistry Glossary Definition of Ionization Energy." *About.com Chemistry - Chemistry Projects, Homework Help, Periodic Table*. Web. 15 Aug. 2013. <<http://chemistry.about.com/od/chemistryglossary/a/ionizationenerg.htm>>
- Helmenstine, Anne Marie. "Electrolysis Definition - Chemistry Glossary Definition of Electrolysis." *About.com Chemistry - Chemistry Projects, Homework Help, Periodic Table*. Web. 15 Aug. 2013. <<http://chemistry.about.com/od/chemistryglossary/a/electrolysisdef.htm>>

- "Rust." *Merriam Webster*. Web. 8 July 2013. <<http://www.merriam-webster.com/dictionary/rust>>.
- Helmenstine, Anne Marie. "Dissociation Reaction Definition - Definition of Dissociation Reaction." *About.com Chemistry - Chemistry Projects, Homework Help, Periodic Table*. Web. 16 Aug. 2013. <<http://chemistry.about.com/od/chemistryglossary/g/Dissociation-Reaction-Definition.htm>>.
- Helmenstine, Anne Marie. "Electronegativity Definition - Chemistry Glossary Definition of Electronegativity." *About.com Chemistry - Chemistry Projects, Homework Help, Periodic Table*. Web. 17 Aug. 2013. <<http://chemistry.about.com/od/chemistryglossary/a/Electronegdef.htm>>
- hoolooovoo33. "Separate Hydrogen and Oxygen from Water Through Electrolysis." *DIY Instructables - Share What You Make*. 13 Feb. 2013. Web. 8 July 2013. <<http://www.instructables.com/id/Separate-Hydrogen-and-Oxygen-from-Water-Through-El/>>.
- "How to use electrolysis for rust removal - YouTube." *YouTube*. 1 Feb. 2009. Web. 2 July 2013. <<http://www.youtube.com/watch?v=-8vT2mdXBs8>>.
- "Hydrochloric Acid (Hydrogen Chloride) | Technology Transfer Network Air Toxics Web site | US EPA." *US Environmental Protection Agency*. 11 June 2011. Web. 10 July 2013. <<http://www.epa.gov/ttnatw01/hlthef/hydrochl.html>>
- "Hydrogen Peroxide." *Hazard Communication Sheet*. 12 Apr. 2005. Web. 13 July 2013. <www.riskassessmentservices.co.uk/HazCom/Hydrogen%20Peroxide.pdf>
- "Hydrogen Power and Fuel Cells." *Renewable Energy World - World's #1 Network for Renewable Energy News & Information*. 6 Jan. 2013. Web. 5 July 2013. <<http://www.renewableenergyworld.com/rea/tech/hydrogen>>
- "Intramolecular forces of attraction." *Department of Chemistry at Texas A&M University*. 23 Mar. 2009. Web. 2 Aug. 2013. <<http://www.chem.tamu.edu/class/majors/tutorialnotefiles/intra.htm>>
- "Ionic bond - Wikipedia, the free encyclopedia." *Wikipedia, the free encyclopedia*. 13 June 2013. Web. 13 Aug. 2013. <http://en.wikipedia.org/wiki/Ionic_bond>.
- "Iron (II, III) oxide - Wikipedia, the free encyclopedia." *Wikipedia, the free encyclopedia*. 22 May 2013. Web. 17 Aug. 2013. <[http://en.wikipedia.org/wiki/Iron\(II,III\)_oxide](http://en.wikipedia.org/wiki/Iron(II,III)_oxide)>
- Khan, Salman. "Reactions in Equilibrium." *Khan Academy*. Web. 6 Aug. 2013. <<https://www.khanacademy.org/science/chemistry/reaction-rates/v/reactions-in-equilibrium>>.
- Kinsey, Ted. "Stovebolt Tech Tip -- Antique Chevy / GMC Truck Restoration Help." *Stovebolt -- Old GM - GMC - Chevy Trucks!* Web. 18 Aug. 2013. <http://www.stovebolt.com/techtips/rust/electrolytic_derusting.htm>
- "Michael Faraday." *Wikipedia*. 7 Aug. 2013. Web. 3 Aug. 2013. <https://en.wikipedia.org/wiki/Michael_Faraday>
- Nagy, Zoltan. "Electrochemistry Encyclopedia -- What is electrochemistry?" *YCES - Case Western Reserve University*. 12 May 2005. Web. 17 Aug. 2013. <<http://electrochem.cwru.edu/encycl/art-i02-introduction.htm>>.
- Oxlade, C.O, 2003, Material Changes and Reactions, Heinemann Library, London
- "Q & A: Iron, Steel, and Rust | Department of Physics | University of Illinois at Urbana-Champaign." *Physics Van | Department of Physics | University of Illinois at Urbana-Champaign*. 14 Jan. 2013. Web. 17 Aug. 2013. <<http://van.physics.illinois.edu/qa/listing.php?id=876>>.
- "Reactivity series - Wikipedia, the free encyclopedia." *Wikipedia, the free encyclopedia*. 13 Aug. 2013. Web. 17 Aug. 2013. <http://en.wikipedia.org/wiki/Reactivity_series>.
- "Rust in History." *Corrosion Doctors*. 21 June 2001. Web. 25 July 2013. <<http://corrosion-doctors.org/Corrosion-History/Rust-history.htm>>.
- "Rust - Wikipedia, the free encyclopedia." *Wikipedia, the free encyclopedia*. 22 July 2013. Web. 3 July 2013. <<http://en.wikipedia.org/wiki/Rust>>.
- "Rust removal by Electrolysis - Removing rust from a Briggs and Stratton engine shroud - YouTube." *YouTube*. 7 Feb. 2012. Web. 1 Aug. 2013. <<http://www.youtube.com/watch?v=y4yYF8gSHdA>>.
- "Rust removal by electrolysis." *PembletonsAreGo*. 7 Feb. 2013. Web. 7 Aug. 2013. <<http://www.thepembleton.org.uk/techpages/derusting.htm>>
- Schaffler, Lawrence. "EBSCOhost: fighting GALVANIC CORROSION AND ELECTROLYSIS." *EBSCO Publishing Service Selection Page*. 1 Feb. 2012. Web. 7 Aug. 2013. <<http://web.ebscohost.com/ehost/detail?vid=3&sid=f372c18c-822c-4f9a-a956->

e5fece2c1e60%40sessionmgr113&hid=108&bdata=JnNpdGU9ZWWhvc3QtbGl2ZQ%3d%3d#db=anh&AN=73206869>

- Sharwood, Jenny, Judy Gordon, 2008, *Nelson Chemistry*, Thomson Nelson, South Melbourne, Victoria
- "The History of Electrochemistry." *BASi - Your Scientific Connection* Web. 12 Aug. 2013. <<http://www.basinc.com/library/history/97/>>
- "The Reactivity Series." *Zephyrus Interactive Education Website*. Web. 17 Aug. 2013. <<http://www.zephyrus.co.uk/thereactivityseries.html>>
- ToolNut. "Electrolytic Rust Removal aka Magic." *DIY Instructables - Share What You Make*. 4 Feb. 2013. Web. 3 Aug. 2013. <<http://www.instructables.com/id/Electrolytic-Rust-Removal-aka-Magic/>>
- U. "Co32- + H2O - Wolfram Alpha." *Wolfram Alpha: Computational Knowledge Engine*. Web. 4 Aug. 2013. <<http://www.wolframalpha.com/input/?i=Co32-+%2B+H2O>>
- Vondriska, George. "Remove Rust with Electrolysis." *Woodworking videos, projects, classes, tips and techniques | WWGOA*. 2 May 2011. Web. 17 Aug. 2013. <<http://www.wwgoa.com/removing-rust-with-electrolysis/>>
- Westcott, Andrew. "ELECTROLYTIC RUST REMOVAL (ELECTROLYSIS)." *Unlimited TV, Broadband and Phone Packages: Now with FREE You View Box | Talk Talk*. Web. 9 July 2013. <<http://myweb.tiscali.co.uk/andyspatch/rust.htm>>
- "What is cathodic protection? Definition and meaning." *BusinessDictionary.com - Online Business Dictionary*. 9 June 2013. Web. 13 Aug. 2013. <<http://www.businessdictionary.com/definition/cathodic-protection.html>>
- "Wikipedia." *Culvert*. 1 Aug. 2013. Web. 12 Aug. 2013. <<http://en.wikipedia.org/wiki/Culvert>>
- Woodshop, Rick's. "Rust Removal Using Electrolysis." *Rick's Woodshop Creations*. 16 May 2006. Web. 17 Aug. 2013. <http://www.rickswoodshopcreations.com/miscellaneous/rust_removal.htm>