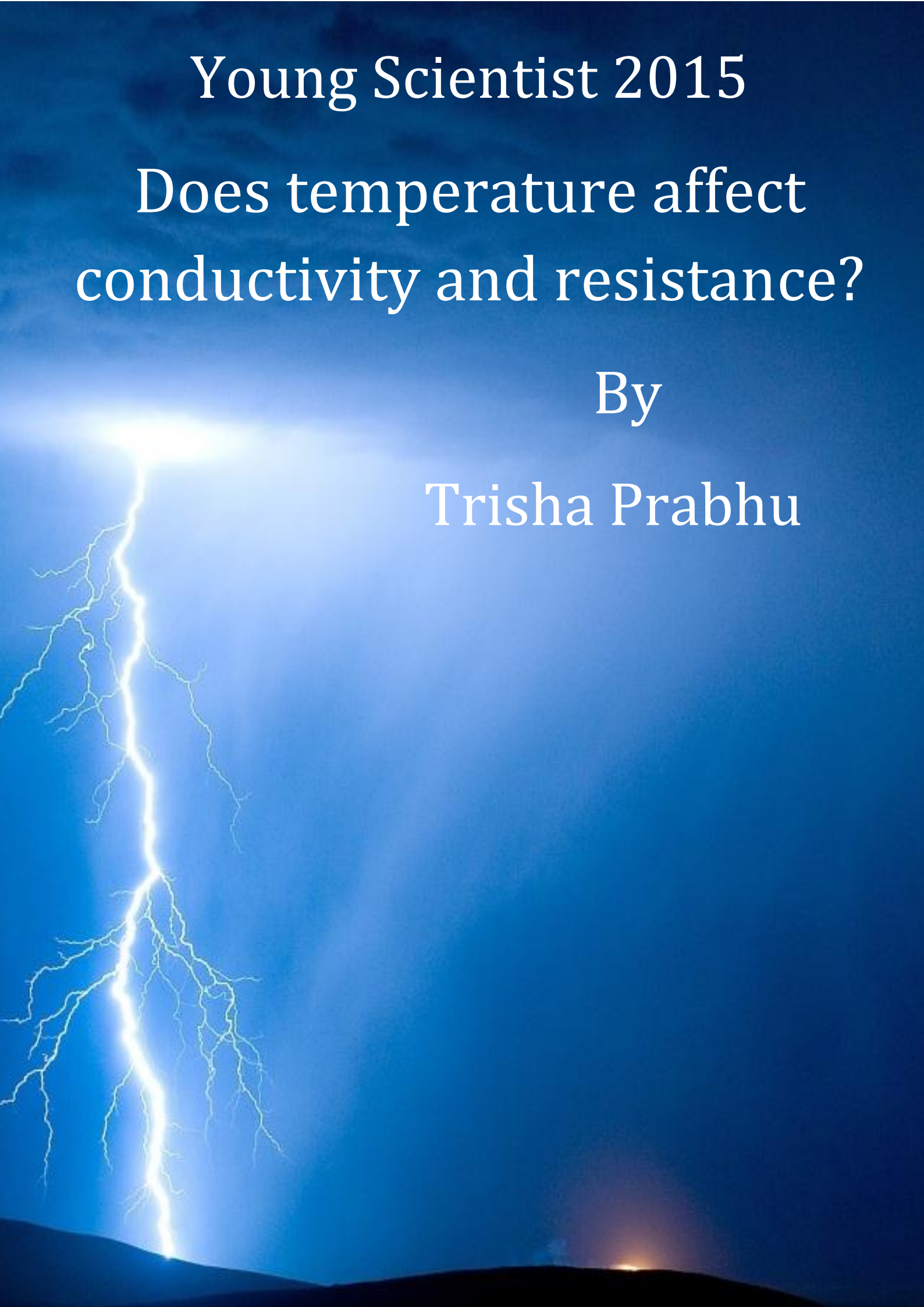

Young Scientist 2015

Does temperature affect conductivity and resistance?

By

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1. Introduction

The problem I am investigating is the effect of temperature on **conductivity** and **resistance**. Using a suitable **conductor** such as a copper wire, the following experiment will study whether the temperature of a wire will affect the flow of **electrical current** through a conductor. Many experiments have been carried out to study the various factors affecting electrical conduction through the use of **independent variables** such as the material of the conductor, the thickness of the conductor, the variation in temperature of a conductor and presence of impurities within a conductor. The impact on electrical conductivity through varying the temperature of the conductor is the **phenomenon** that I am curious about and greatly interested in and hence the motivation behind conducting this research project.

2. Aim of the Experiment

The aim of this experiment is to investigate how temperature impacts the conductivity and resistance of a conductor. Using a copper wire, this experiment will try to analyse if the flow of electric current through the wire is affected by varying the temperature of the wire. At the conclusion of the experiment we should be able to have a clear understanding of the relationship between temperature and the conductivity of the material. We should also able to prove the initial hypothesis (as stated in Section 4) as true or false.

3. Background

5.1 Current

Electric current is the flow of electrons in a wire. Some substances allow electricity to flow through easily and these substances are called as **conductors,** while **insulators** are those materials that do not freely allow the flow of electrical charge. The best electrical conductors are **metals** such as copper, aluminium and silver. Their increased conductivity (the ability to allow electric current to flow easily) is because of the makeup of their atoms. In a conductor, the outer electrons of the atom are loosely bound and can freely move through the material when an electric charge is applied. The current that flows through an electrical circuit is measured in **amperes (A)** and is measured using an *ammeter*.

5.2 Voltage

A voltage across an electrical component such as a lamp is needed to make a current flow through it. Cells or batteries can be used to produce a voltage. Voltage is measured in **volts (V)** using a **voltmeter**.

5.3 Resistance and Ohms Law

The electrical **resistance** of a material is the opposition to the passage of an electrical current through it. If resistance is low, the electrical charge is allowed to freely move through the substance. A high resistance indicates that it is more difficult for an electrical charge to pass through the substance. All materials on earth have some sort of resistance except for **super conductors**. Electrical resistance shares similar concepts to the notion of **friction**. Electrical resistance is measured in **ohms (Ω)** using an *ohmmeter*.

One of the most important and basic laws of electrical circuits is **Ohm's Law** that when a current **I** *amperes* flows inside a conductor of resistance **R** *ohms***,** the voltage **V** *volt* across the wire will be the product of the current and the resistance.

$$\mathbf{V = I\,R}$$

5.4 Why do we have resistance?

As stated before, an electrical current is the flow of electrons through a wire. The moving electrons collide with the atoms of the conductor, which makes it more difficult for the current to flow and causes resistance. The movement of electrons determine how resistance a substance is to the movement of electrons. Metals have very minimal resistance to an electrical charge as the electrons in a metal are free to move around. On the other hand, insulators such as Teflon contain electrons which are tightly bounded to a molecule, and these require great force to pull them apart.

The resistance of a given conductor, *R* depends on: (a) the material of the conductor (b) area of its cross-section (c) length of the conductor (d) the temperature of the conductor. For example, a long copper wire will have a higher resistance than an identical shorter wire, as electrons collide with atoms more often in a long wire than they do in a short wire. Resistance of a conductor is inversely proportional to its cross-sectional area, e.g., a thick copper wire would have a lower resistance than an identical thinner wire, because a thin wire has fewer electrons to carry than a thick wire. The resistance of a wire also increases with the temperature of the wire because as temperature increases, the electrons begin to move faster and collide with each other more, thereby causing resistance to increase. Therefore, resistance in a wire increases as:

- Length of the wire increases
- Thickness of the wire decreases
- Temperature of the wire increases

For the purposes of this experiment, I will investigate how an increase in temperature affects the increase in the resistance of the wire. I chose to use a 0.5mm diameter copper wire as the conductor. This material was chosen because copper is well-known for its high electrical conductivity and will help to provide conclusive and decisive results. I anticipate that I will have to carry out the experiment 3 - 4 times to ensure validity and accuracy.

5 Hypothesis

An increase in temperature of the copper wire will cause an increase in the resistance of the copper wire, and will thereby reduce **conductivity**, which is the flow of electric current through the wire.

6 Method

6.1 Materials

- 5m of Varnished Copper Wire with diameter of 0.5mm

- Two PVC pipes each about 300mm in length

- 6V high-capacity alkaline battery or power supply

- 5 jumper wires with crocodile clips at both ends

- Voltmeter

- Ohmmeter

- Ammeter

- A plastic knife

- An infra-red thermometer(can vary in cost from around $20 to $100's)

- 1 roll of insulation tape

6.2 Independent, Controlled and Dependent Variables

Independent Variables:

- The temperature of the conductor(copper wire)

Controlled Variables:

- Room Temperature and conditions
- Applied voltage
- Type of wire
- Diameter of wire
- Length of wire
- Cross Section shape of wire

Dependant Variable:

- Resistance of conductor(Copper Wire)

6.3 Health and Safety Risk Assessment

This experiment is a medium risk experiment. There are certain precautions that can be taken when conducting this experiment, to ensure that there are no injuries. Below is a table summarises some of the elements addressed in the overall risk assessment.

Identify the Risk	Level of Risk (Low, Med, High)	Precaution	Reason for precaution
Handling Electrical Cables	High	Wear rubber footwear and gloves	To avoid any change of getting electrocuted
Minor burns, when coming in contact with the exposed ends of the hot conductor	Medium	1. Wear glove, 2. Keep hands away from conductor while the current is flowing	To avoid getting burnt when the conductor is very hot
Cutting injuries from sharp equipment(scalpels, knives)	Medium	Keep sharp side of the blade away from hands and people around you	To avoid incurring cuts to your skin, as well as the people around you

Leakage in current	High	Only allow the current to flow once the circuit is closed	To avoid any chance of electrocution

6.4 Procedure

Setting up the circuit

1. Wind the 5m insulated copper wire around the PVC pipe as shown in the diagram on the right. This will act as the coil for the experiment.
2. Tape the ends of the copper wire to the pipe, using the insulation tape
3. Remove approximately 3cm of insulation wire from the tips of the wire, using the plastic knife.
4. Solder the ends of the jumper wires to the coil.
5. Connect the power supply to the coil, the ammeter, and the volt meter using the jumper wires. The ammeter is connected in ***series*** with the copper coil, while the voltmeter is connected in ***parallel*** across the coil. The circuit diagram of my setup is shown in figure 2 and the actual circuit built is shown in figure 4.

Figure 1- 300mm PVC wound with insulated copped wire

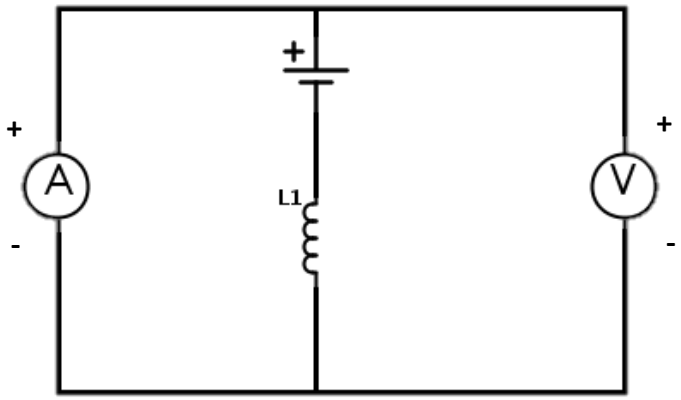

Figure 2: Circuit diagram of the setup used in the experiment

CIRCUIT SYMBOLS	
	Cell
	Voltmeter
	Ammeter
	Copper Coil
	Connecting wire

Figure 3: Key of circuit symbols

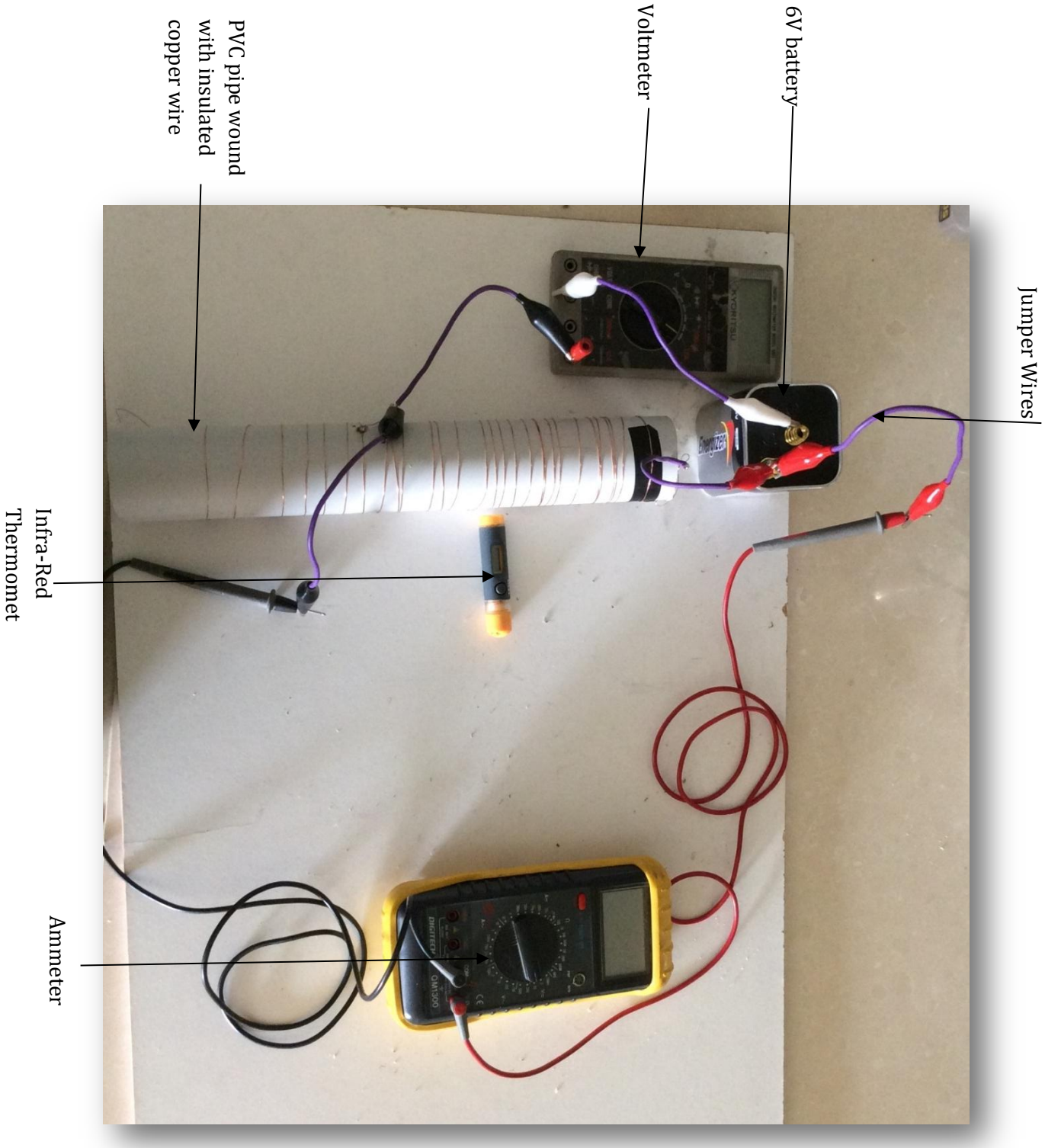

Figure 4: Setup of the experiment

Using an Infra-Red Thermometer to measure temperature of the copper wire

6. Turn the infra-red thermometer on. There are a number of steps that have to be taken to ensure that the readings on the thermometer
7. Change the units, it not already so, to Degrees Celsius
8. Place the thermometer the same distance away as the diameter of the wire. For the purpose of this experiment place the thermometer 0.5mm away from the coil because this is the diameter of the wire as shown in the figure on the right
9. When you are ready to take the recording, press the **On** button
10. Keep repeatedly pressing the button when you want to acquire a new reading. Make sure that your hand is steady when taking the measurement, and doesn't move

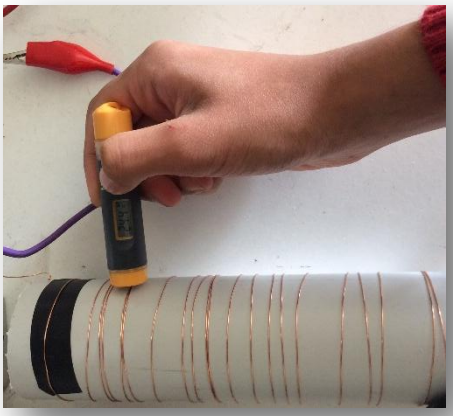

Figure 4- Figure showing how to measure temperature using Infra-Red Thermometer

Measuring the Resistance

11. Disconnect the wire from the circuit
12. Immediately measure the resistance of the wire using an ohm metre. Ensure that the recording is taken immediately, to ensure that the results are as accurate as possible

Recording the data

13. Disconnect the battery from the circuit
14. Then measure the resistance, and temperature of the wire
15. Re-connect the battery to the circuit
16. Keep constantly pressing the button on the thermometer to have a constant reading of the temperature
17. When the temperature rises in intervals of $5^{O}C$ quickly record the current, resistance and voltage
18. Continue the experiment, until the temperature reaches around $70^{o}C$
19. After completing the experiment, wait for the copper wire to reach room temperature again, before carrying out another trial
20. Repeat the experiment 3-4 times to ensure that the results are accurate and valid

7 Results and Observations

In this experiment, 3 trials were conducted. The results and the associated graphs are shown below. All readings recorded on the instruments were up to 2 decimal place

precision. More accurate resistance readings could have been obtained, if we had an ohmmeter with 3 decimal precision.

6.1 Trial 1

Trial 1			
Temperature (°C) (0 d.p.)	Voltage (Volts)	Current (Amperes)	Resistance (ohms) (2 d.p.)
24.6	5.11	5.35	0.96
31.6	5.11	5.33	0.96
33.6	5.13	5.3	0.97
38.2	5.12	5.27	0.97
41	5.1	5.2	0.98
44	5.14	5.22	0.98
47.8	5.12	5.2	0.98
50.8	5.14	5.18	0.99
53.2	5.13	5.15	1.00
56	5.13	5.13	1.00
59.6	5.12	5.11	1.00
60.8	5.1	5.08	1.00
61.8	5.11	5.08	1.01
63	5.12	5.06	1.01

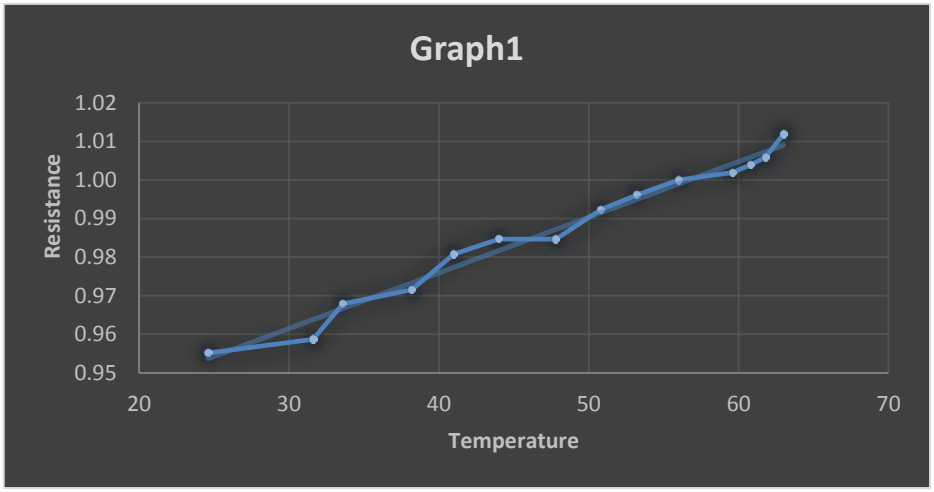

Figure 5: Graph and Results of Trial 1

6.2 Trial 2

Trial 2			
Temperature (°C) (0 d.p.)	Voltage (Volts)	Current (Amperes)	Resistance (ohms) (2 d.p.)
22.6	5.09	5.38	0.95
29.6	5.09	5.37	0.95
31.6	5.1	5.33	0.96
36.2	5.09	5.29	0.96
39	5.11	5.27	0.97
42	5.09	5.26	0.97
44.9	5.1	5.23	0.98
47.8	5.11	5.21	0.98
52.9	5.12	5.19	0.99
55.1	5.11	5.17	0.99
58.6	5.11	5.15	0.99
61.3	5.12	5.11	1.00
64	5.1	5.09	1.00
65	5.09	5.07	1.00

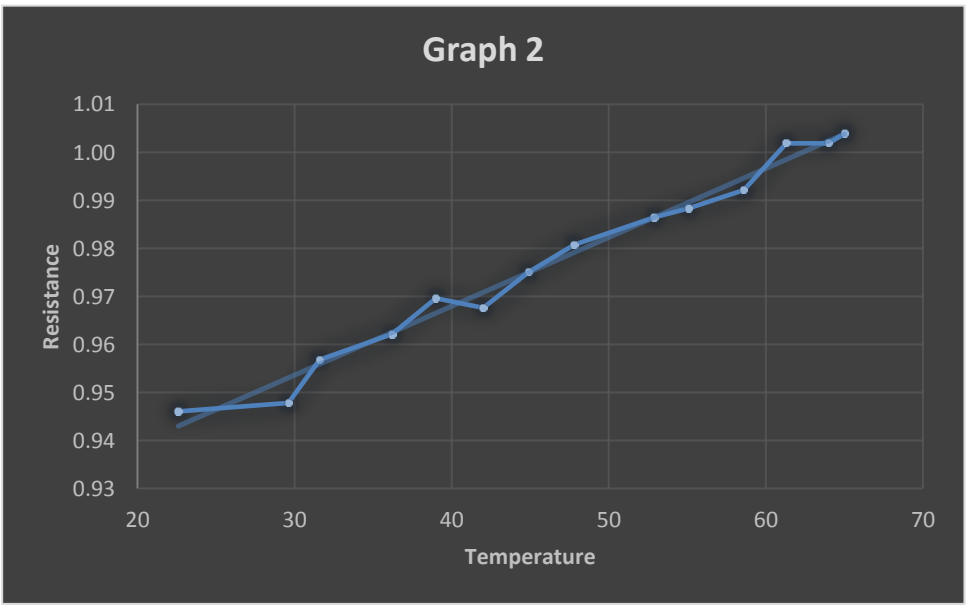

Figure 6: Graph and results of trial 2

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6.3 Trial 3

Trial 3			
Temperature (°C) (0 d.p.)	Voltage (Volts)	Current (Amperes)	Resistance (ohms) (2 d.p.)
23.4	5.1	5.36	0.95
30.4	5.1	5.35	0.95
32.4	5.09	5.32	0.96
37	5.09	5.29	0.96
39.8	5.1	5.28	0.97
42.8	5.11	5.26	0.97
45.7	5.1	5.24	0.97
48.6	5.1	5.21	0.98
53.7	5.12	5.18	0.99
55.9	5.13	5.17	0.99
59.4	5.12	5.13	1.00
62.1	5.11	5.11	1.00
64.8	5.1	5.08	1.00
65.8	5.09	5.05	1.01

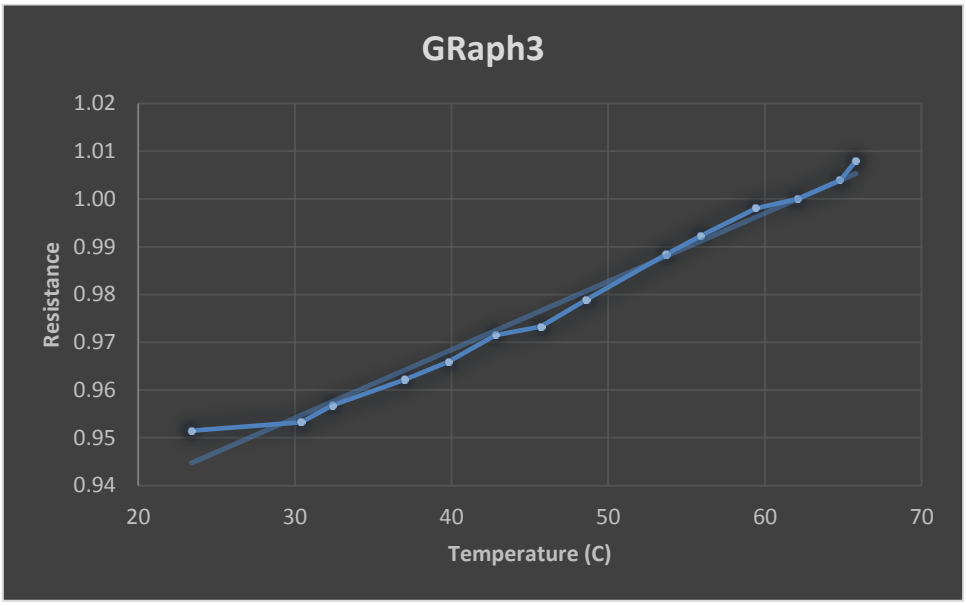


Figure 7: Graph and results of trial 3

8 Discussion

In this experiment, I investigated if temperature will affect the amount of current flowing through a conductor such as a copper wire. My hypothesis that the electrical resistance of the copper wire will increase with temperature and the conductivity of the wire will

reduce has been proven to be true as in the results of the three trials and the corresponding graphs.

Overall the experiment that was carried was successful. After conducting the above experiment it is evident that the hypothesis was proved to be true. An increase in temperature of the conductor will cause an increase in the resistance of the copper wire, and will thereby reduce the flow of current through the wire. The results acquired from this experiment are very reliable due to the fact that there were three trials conducted.

The results in the experiment were decisive and accurate. The voltage applied to the copper wire was maintained around 5.1 Volts. On average the current began at 5.35 amperes. In all the three trials the initial temperature of the copper wire was quite constant. There was only very minor variation between 22^0C and 24^0C. As the temperature gradually increased, the resistance also increased. The resistance was quite similar throughout each of the trials. In all the three trials the resistance, began at 0.95 ohms (2.d.p). In each of the trials the resistance changed from 0.95 ohms to 1.01 ohms. When the trials were graphed it was evident that the results were fairly linear. The graph displaying resistance, presented a line which increased at a relatively steady rate. From the research performed it is evident that this was due to the fact that the conductivity is simply the inverse of the resistance.

8.1 Why does resistance increase with temperature?

Energy exists in various forms such as mechanical energy, heat energy, chemical energy, electrical energy, light energy and nuclear energy. According to the law of conservation of energy, energy can be transformed from one form to another. When an electric current flows through it, the wire is heated up. The thin copper wire is made up of atoms. The movement of electrons through the wire will cause them to collide with the atoms of the conductor. In the collision, some of the kinetic energy from the electrons are transferred to the atoms of the conductor and the atoms begin to vibrate violently. Within the atoms, the kinetic energy is converted to heat energy or thermal energy causing the temperature of the copper wire to rise. This process is referred to as “joule heating” or the “heating effect of current” and is the basic principle that is utilized in a number of electrical heating appliances used in our daily life such as electric iron, room heaters. When an electric current is passed through a metallic wire like filament of an electric heater, oven or geyser, the filament gets heated up and here electrical energy is converted into heat energy. *Greater the number of electrons flowing per second, greater will be the rate of collision and hence more heat is produced. And more the atoms jostle around in the material, more collisions are caused and hence greater the resistance to flow.*

9 Limitations

This experiment was quite a challenging task. Many difficulties were experienced along the way. Some of the equipment required for this experiment was quite difficult to find, such as locating a sensitive, and still reasonably economical infra-red thermometer. It took several days to source all the equipment required for this experiment.

One of the main challenges encountered in this experiment was the generation of a steady current of around 5 amperes. Initially the experiment was conducted using 3 1.5V "D" batteries connected in series that was expected to produce a net voltage of 4.5V. I had initially thought that this would be sufficient to produce a constant voltage of about 4.5V and produce a steady current of about 10 A. However, once the circuit was completed, we were only able to generate about 3A of current (as recorded on the ammeter). A number of factors were responsible for the low current output as described below:

- The net voltage supply had dropped to 2.8V (instead of the expected 4.5V), due to internal resistance of the voltage source itself.
- Further, the use of jumper wires to connect the different components of the circuit such as the battery cell to the copper coil and to the ammeter and the voltmeter itself introduced significant resistance in the circuit, causing the resistance of the overall circuit to be quite high and consequently the low current.

As a result, I was only able to generate around 2.8A of current despite having a net voltage of 4.5V and the temperature of the wire only increased to about 29 C. The resistance of the circuit was as high as 1.29 ohms, which was not what I had expected. In order for the results to be accurate, *a higher constant voltage supply was needed* and *the resistance needed to be reduced*. In the first attempt, the initial voltage of the batteries had dropped from 4.9V, to 2.8V. In order to increase the voltage of the batteries, I tried to connect another 1.5V battery in series in order to increase the net voltage to about 6 volts. Following this, a high current was generated, and the wire was able to heat up to a maximum of 38^{o}C. Still, I was only able to generate a maximum of 4 A of current. The current also started dropping to about 3A within 5 minutes. To ensure a steady voltage supply of at least 5V and reduce the overall resistance of the circuit, the following changes were made to the circuit.

1. The jumper wires between the crocodile clips were replaced with thicker wires. Initially the wires were very thin. The thin wires generated an increased resistance. (Refer to section 2.3 on how resistance decreases with increase in thickness of wire)
2. The four 1.5 V "D" batteries were discarded and replaced by a power-supply that were able to produce a constant voltage of about 5 volts.

With these changes in place, we were successful in attaining a stable, constant voltage of 5.0 V throughout the experiment. The overall resistance of the circuit was also significantly reduced as was seen in our tabulated results.

I believe that conducting 3 trials of the experiment were sufficient and we were able to receive accurate and reliable information. The use of 3 trials allowed us to reach a decisive conclusion. The results would have been easier to analyze and more accurate if the equipment used was more precise and accurate. For example it would have been better to use an ohm metre that was more sensitive and could measure the resistance to three decimal places rather than two.

10 Suggestions for future research

In the future, if this experiment was to be repeated I would vary the material and length of the conductor. For example it would be an interesting phenomenon to study, the use of different conductor materials such as aluminum and iron. Copper has high thermal conductivity. It was slightly hard to get it hot. The wire also cools down quite quickly. This experiment would have probably worked better if I had used an iron wire instead of copper, as its electrical resistivity is more sensitive to temperature than copper. Varying the length, and diameter of the wire, would also produce interesting results.

11 Acknowledgement

I would first of all like to thank my teacher Ms Miller for guiding me and providing me feedback throughout the experiment. I would like to thank my mum and grandfather for providing all the required equipment needed for my experiment and also supervising me during the experiment. They ensured that I had addressed all the safety aspects of the experiment. I would also like to thank my school, MLC for giving me the opportunity to participate in this science challenge. Finally, I would like to thank my brother for teaching me how to build graphs for the results from the trials.

12 References

Moving Electrons and Charges - http://www.physics4kids.com/files/elec_intro.html

Resisting Current - http://www.physics4kids.com/files/elec_resistance.html

Electricity - http://www.explainthatstuff.com/electricity.html

Factors affecting electrical conductivity - http://www.ehow.com/info_8650976_factors-affecting-electrical-conductivity.html

APPENDIX A: 2015 LOG ENTRY

Week - 27th July to 2nd August, 2015 – After brainstorming several ideas with my teacher Ms Miller, I finally decide on the topic of my scientific investigation which was to investigate the effect of temperature on the flow of electricity through a copper wire. I also researched on the internet different websites to understand the various factors that affect the flow of electricity through a conductor, about relationship between voltage, current and resistance.

02 Aug 2015: 10:00 am

I discussed with my mother and grandfather what I wanted to investigate and with their help, listed out all the necessary equipment for the experiment.

03 Aug 2015: 10:00 am

My mother has helped to purchase the following from JayCar Electronics and Bunnings:

1. 3 "D" cell batteries 1.5 V, a battery-case to hold the batteries
2. Crocodile clips and jumper wires
3. A spool of 5m 0.5mm thin copper wire, insulated with enamel
4. 2 PVC pipes (diameter 25mm)
5. Infra-red thermometer (range: -30C to 150)
6. A multimeter

I borrowed a second multimeter from my grandfather.

03 Aug 2014: 6:00 pm

Start of the experiment. Using the above equipment and with the help of my mother, I start building a circuit that will have a net voltage supply of 4.5V. With a simple circuit, the resistance should be around 0.5 ohms. And hopefully, I will be able to generate about 8A of current.

7:00 pm (after first trial – not successful)

The experiment has not been successful. I have hit with several problems. I am only able to generate around 3A of current and the temperature of the wire only increased to about 29 C. I investigated the reason behind the low current, despite having a net voltage of 4.5 V. My mother suggests that I should check the resistance of the circuit I have assembled. I quickly checked the resistance of the circuit I have assembled. The resistance of the circuit is around 1.49 ohms, which was not what I had expected. It appears that the overall resistance of the circuit has increased to 1.5 ohms. The battery is also draining pretty fast. I started with initial voltage of 4.9V, in just about 45 minutes, the battery has drained and this has dropped to 2.9V.

I have to investigate ways to increase the current flowing through the circuit. I ring my grandfather and after brain-storming with him, I find several ways to do this:

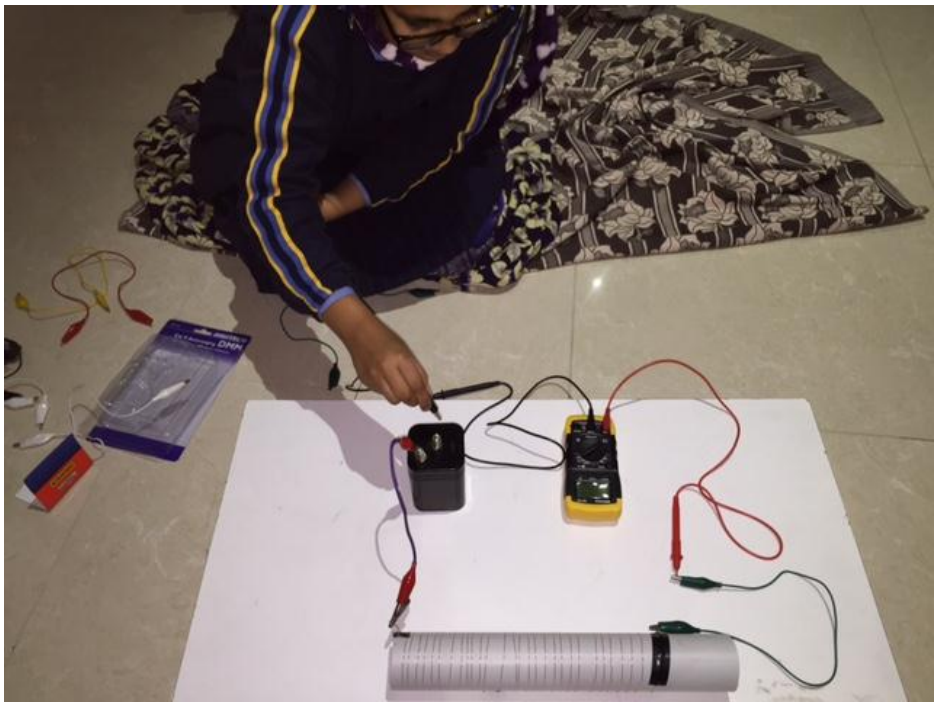
(a) I could add more batteries in series
(b) I could investigate, if using a thicker copper wire increases the conductivity
(c) Investigate ways to decrease the resistance of the overall circuit.

04 Aug 2014

I have asked my mother to purchase an additional 1.5V "battery" which I plan to connect in series to the circuit, to increase the voltage and potentially the current.

05 Aug 2014 – 6:00 pm (second trial – not successful)

My mother buys a heavy duty 6V battery from Jaycar electronics, instead of buying an additional 1.5V battery. My mum thinks that the net voltage generated should at least be about 6.2 V. I conduct another trial replacing all of the 'D' batteries with the single 6V battery. I am now able to generate about 4.5 A of current. The copper wire is heating and the temperature rises to about 38 C. But again, I am not able to generate more current beyond this. The reason is the resistance of the circuit is still high and I also find that the jumper wires are heating up, with the danger of the insulation around them melting. The current also started dropping to about 3 A within 30 minutes. I am going to discuss with my grandfather, who is the expert in this field on how to proceed. The circuit that was built is shown in the picture below.



06 Aug 2014

My grandfather has come over. He has a look at my circuit. He makes the following suggestions. He says that he will replace all of the thin jumper wires, with thicker jumper wires and ask the school for a power-supply

07 Aug 2014

I discuss the problem with my teacher and she lends me a power supply that can produce a steady voltage.

07 Aug 2014 – 7:00 pm – first successful trial

I rebuild the circuit after I return from school. My grandfather has come over and has supplied me thicker jumper wires, which he thinks will help reduce the resistance of the circuit. I use the

power supply from the school and start taking my readings. This trial is successful. The voltage from this power supply maintains a steady voltage around 5.09 – 5.11 V. Temperature of wire also gradually increases from around 25°c to nearly 63°c. The current initially was 5.35 A and it drops to 5.13A when the temperature of the wire is around 63°c.

08 Aug 2014 – 2nd successful trial

09 Aug 2014– 3rd successful trial

I have successfully performed three trials of this experiment using the power supply and the new jumper wires supplied by my grandfather.