How does the length of a wire affect the resistance it presents?

Plan:

This investigation will be on how changing the length a wire in a circuit affects the resistance it offers to the circuit and will try to answer the following question: does only increasing the length of the wire in a circuit can cause an increase in resistance across that circuit? In this investigation, the **independent variable** will be the length of the wire through which the current will flow, the **controlled variables** will be current, voltage, wire material, its cross section and temperature while the **dependant variable** is the resistance of the wire.

Research Question:

How does the length of a wire in a circuit affect the resistance it presents?

Dependant variable:

- Resistance of a wire: this will be calculated through the use of the formula R=V/I, where R is resistance, measured in ohms (Ω), V is voltage, measured in volts (V) and I is current, measured in amps (A). Voltage and current will be measured by using two different multimeters set to measure voltage and current separately. This will increase the reliability of the results obtained since it eliminated human error.

Independent variable:

- Length: Through connecting a long piece of wire into a circuit. This will have been previously attached to a ruler so that the length of wire being tested can be measured accurately (range and number of results I am going to take). The fact that the wire is longer enables us to slide crocodile clips along the length of the wire so that the length becomes variable. When connecting to the ruler, it is important to try and straighten the wire as well as possible.

Controlled variables:

- Type of Wire (in terms of its physical properties): The same wire will be used throughout the experiment (same material: nichrome).
- Same thickness: We cannot overlook the fact that the wire is not necessarily the same thickness all the way through/ the cross sectional area is not necessarily constant. A change in cross sectional area could present a difference in readings. In theory, a larger cross sectional area would offer a larger current going through the circuit. This would affect the final readings and cause the data collected to be wrong or at least less accurate. In order to avoid that, we will use a micrometer to measure the cross section of the wire in ten centimetre intervals. Also, this measure will be taken from more that one angle each time since we also cannot assume that the wire is a perfect, constant shape. This will make sure that the cross section of the wire is constant. If there is a significant change in cross section in the length of wire to be used, this piece would have to be discarded and another one measured and tested.
- Current: a variable resistor will be added to the circuit (as shown in the circuit diagram below) in order to keep the current the same (at 0.91 amps) for all measurements taken.

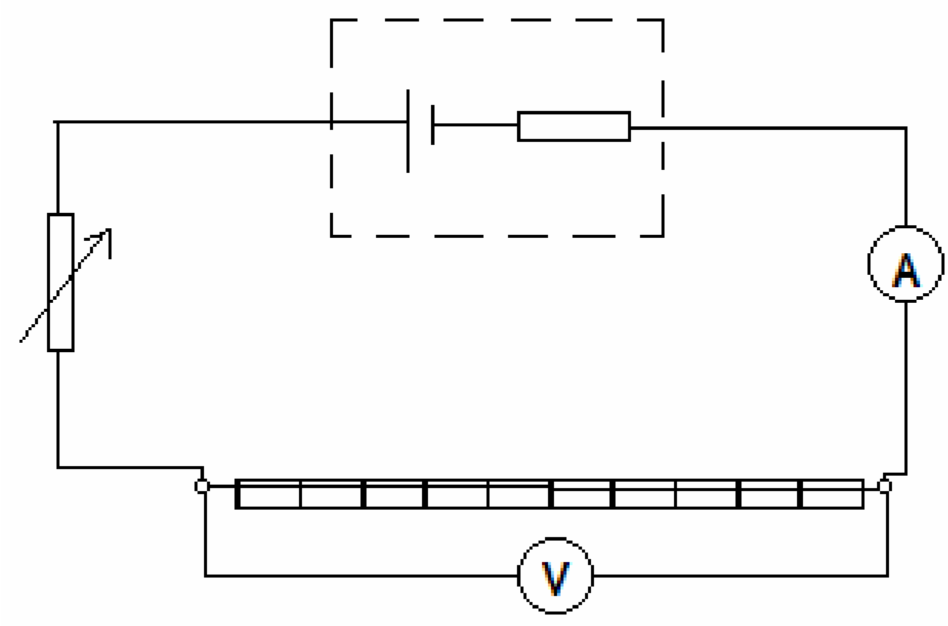
The multimeter set to the ammeter settings will be used to measure the current and further reinforce it being constant. The current should be kept constant since power is actually energy being dissipated. An alteration in current would mean a different power dissipation in each measurement therefore a different temperature change in each reading.

- Emf: To keep this constant, we will use the same power pack as a supply all the way through the data collection, set with the same settings all the way through the experiment, as well as the same micrometers when reading voltage and current. If any of these present a dysfunction half way through and can no longer be used, all of the readings have to be taken again with the new apparatus. Still, in order to find the power being supplied accurately, the voltage and current will be measured, using digital readers, before the wire is connected and calculated through the formula power = current * voltage. This will be equal to the heat energy being transferred per second to the circuit, therefore it is relevant.
- Temperature of wire: We will keep the power pack in the lowest settings in order to avoid a high current. If we used a high current, the temperature of the wire would increase and would also cause variations in the results. An increase in temperature causes an increase in resistance. The circuit will be left connected through small periods of time to avoid temperature increase and the wire used in the investigation should not be used in very short lengths since that would mean a high current. This control could be further emphasised through the addition of a variable resistor, which would cause the current to be even smaller using the same value of power. Also, between each repeat, the circuit should be turned off by a longer period of time so that the wire would cool down to its initial temperature.
- External Conditions: taking all measurements in a same room and in a same day would make external conditions (humidity, temperature and air pressure) relatively constant.

Amount of Data:

Three repeats will be recorded. The measurements will be taken at 10cm intervals from 10cm to 80cm.

Method:



Apparatus:

- A power pack or another controlled energy source
- Wires (about six)
- A wire to be tested (in this case, a nichrome wire with constant diameter)
- Two crocodile clips
- Volt meter (precision of 0.1 V) and ammeter (precision 0.01A), (preferably digital)
- A ruler (preferably a meter ruler since small wire lengths can be dangerous, also, preferably in wood so that it does not conduct electricity and disrupts the results)
- A variable resistor – this is optional but encouraged in order to control the current through the circuit
- A micrometer

1. Set up circuit like shown in diagram above
2. Starting at a wire length of ten centimetres, measure the voltage and current being recorded. Through these we will calculate power supplied and resistance using the formulas presented previously.
3. Repeat step two varying the length of wire connected in the circuit by sliding the crocodile clips. Take readings every ten centimetres until the eighth reading. Measure the length as in increases and then as it decreases (the repeat in order to improve reliability of results).

ılts:

Diameter measurements

length (cm) ± 0.1	10.0	20.0	30.0	40.0	50.0	60.0	70.0
diameter (horizontal) mm ± 0.01	0.36	0.36	0.36	0.36	0.36	0.36	0.36
diameter (vertical) mm ± 0.01	0.36	0.36	0.36	0.36	0.36	0.36	0.36

length cm (±0.1)	Potential Difference (V) ± 0.1			Average PD (V) ± (max deviation from mean V + 0.1)
	1	2	3	
10	1.0	1.0	0.9	1.0
20	1.9	2.0	1.9	1.9
30	2.9	2.8	2.8	2.8
40	3.7	3.7	3.7	3.7
50	4.7	4.6	4.6	4.6
60	5.5	5.7	5.5	5.6
70	6.8	6.6	6.4	6.6
80	7.6	7.5	7.3	7.5

Uncertainties and other calculations:

For the uncertainty of PD (shown above) the value of ± 0.1 was used because it was the smallest unit of the multimeter, but for the uncertainty of the average PD, I have decided to use 0.01 + the deviation from the mean value in order to minimize the chances of random error. For example, if the reading were not taken with regular time intervals from adjusting the resistance, there would probably have been a difference in temperature which was not constant throughout the experiment, creating an uncertainty.

Most of the calculations here were done through the use of software, an example of each type is shown below.

For the average PD, we calculated the sum of the valued for the three repeats and then divided this by three. An example of this using the data at 30cm is:

(2.9+2.8+2.8)/3 = 2.83 (correct to 2 decimal places)

For the absolute uncertainty of the average PD, the calculation was the addition of ± 0.1 to the value of maximum deviation from the average (/mean) value. In other words, it is the value difference from the average to the highest value (+) and to the lowers value (-),± 0.01. Therefore, using the data at 60cm, we found that: the average =5.6, maximum value = 5.7, minimum value = 5.5 so that the value of deviation from the mean value is of ± 0.01.

± 0.1 + ± 0.1 = ± 0.2

For the % uncertainty of the average PD, the value found as absolute reference is divided by the average value for PD and the result is multiplies by 100. Therefore using the data at 60cm:

(0.2/5.6)*100= ± 3.57 %

The absolute uncertainty for current has also to be taken into account even though it was planned that that would have a constant value. The adjustment of the current was done manually and therefore, there could have been some human error. This way, the absolute value for current error will be ± 0.01.

The % uncertainty for current can therefore be calculated through the same method as in voltage, but this time, the denominator will be 0.91 rather than an average. Therefore, the constant value for the uncertainty for current will be:

(0.01/0.91)*100 = ± 1.10% (correct to 2 decimal places)

Resistance will be calculated by using the formula R=V/I. In this case, the V would be used as the average value obtained for PD and I will be the constant value set for current (0.91 A). Therefore, at 30cm:

(2.8/0.91)= 3.08 Ω (correct to 2 decimal places)

The % uncertainty for resistance will be calculated through the addition of the % uncertainty values for current and PD. For example, at 60cm:

± 3.57% + ± 1.10% = ± 4.67%

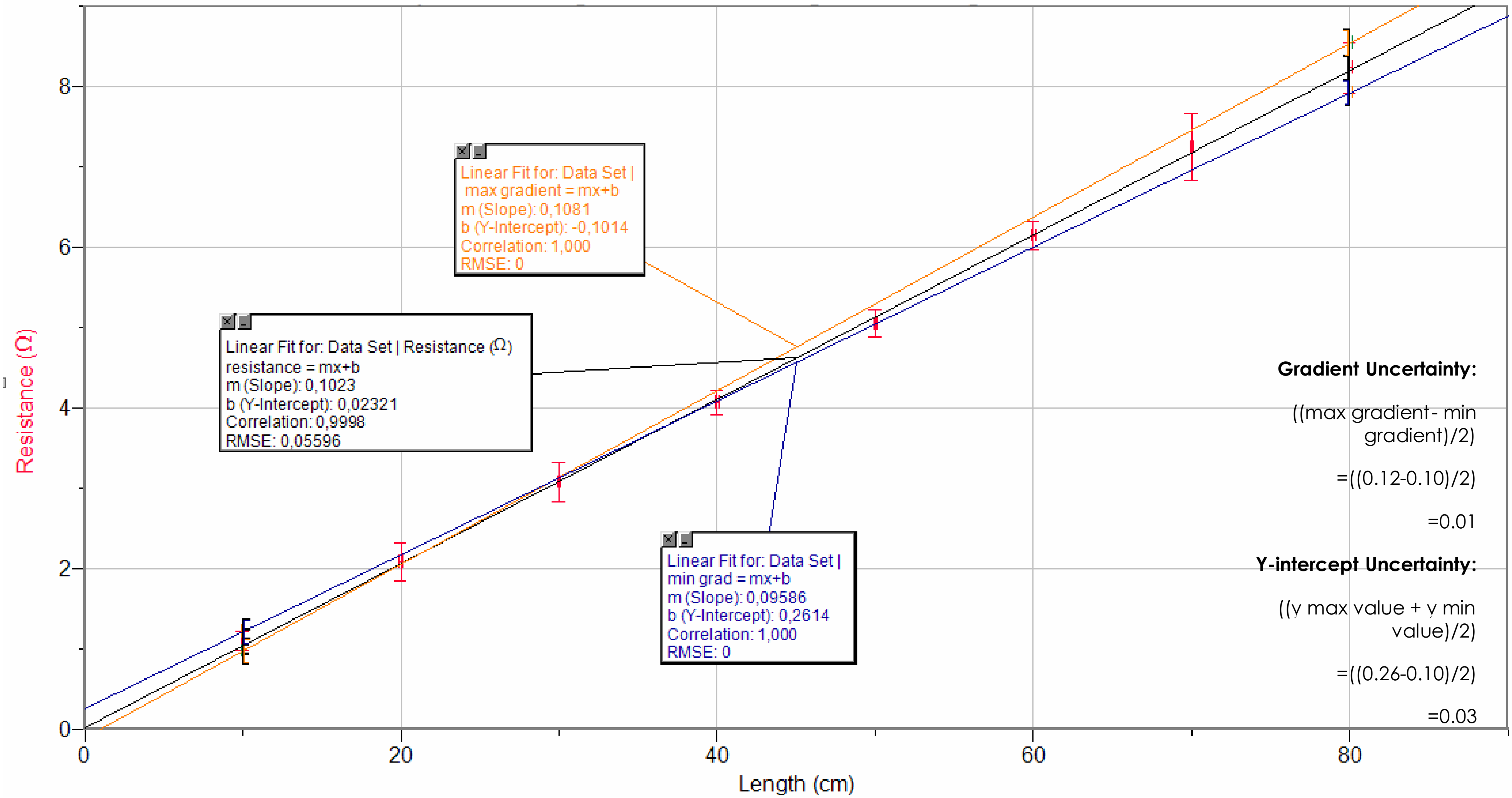
The absolute value of uncertainty for resistance should be calculated through the division of the total % uncertainty found over 100 and that multiplied y the value obtained for resistance. Therefore at 60 cm:

(4.67/100) * 6.15 = ±0.29 (correct to two decimal places)

	Potential difference (V)			Current (A)			Resistance (Ω)		
length cm (±0.1)	Average	Absolute uncertanity ±	% uncertainty ±	Current	Absolute uncertainty ±	% uncertainty ±	Calculated Resistance	Absolute uncertainty ±	% uncertainty ±
10	1.0	0.1	10.0	0.91	0.01	1.10	1.10	0.12	11.10
20	1.9	0.2	10.5	0.91	0.01	1.10	2.09	0.24	11.63
30	2.8	0.2	7.1	0.91	0.01	1.10	3.08	0.25	8.24
40	3.7	0.1	2.7	0.91	0.01	1.10	4.07	0.15	3.80
50	4.6	0.1	2.2	0.91	0.01	1.10	5.05	0.17	3.27
60	5.6	0.1	1.8	0.91	0.01	1.10	6.15	0.18	2.89
70	6.6	0.3	4.5	0.91	0.01	1.10	7.25	0.41	5.65
80	7.5	0.2	2.7	0.91	0.01	1.10	8.24	0.31	3.77

This table shows the results with the processed data.

Graph showing Resistance Against Lenght of a Wire



Gradient Uncertainty:

((max gradient - min gradient)/2)

=((0.12-0.10)/2)

=0.01

Y-intercept Uncertainty:

((y max value + y min value)/2)

=((0.26-0.10)/2)

=0.03

Conclusion:

From the results collected and displayed above, it could be stated that within experimental error, resistance is proportional to the length of a wire in a circuit taken that cross section, temperature and other variables remain constant meaning a positive answer to the question being investigated. This is obvious when observed in the graph above. The data points are all within the allowed error from the best fit line which, allowing for experimental error goes through the origin (reference to calculation below). All of which indicate a strong positive correlation between the two variables (length and resistance) being investigated.

y-intercept calculations:

Maximum value: 0.26 – 0.03= -0.122 (goes through origin)

Minimum value: -0.10 + 0.03= -0.07(could be considered close enough to origin)

In order to further test these results, we could use the theory of resistivity. This could be defined as the resistance of a material to the flow of electrical current through it. Each material has a value for resistivity and that of nichrome (the metal out of witch the wire being tested was produced) is accepted to be 1.1 × 10-6 Ωm which means is not a very low value for resistivity neither a very high one. In each extreme we have Silver with a low value (1.59e−8 Ωm) and Teflon with a high one (10e22 to 10e24 Ωm). Resistivity can be calculated through (Resistance/length)*cross sectional area. The latter can be found through $((\pi*\text{radius})^2$. The resistance/length part of the equation is actually the gradient of the graph above and the cross sectional area will be calculated from the diameter measurements taken previously. Below is the table of results obtained.

Diameter measurements

length (cm)	10	20	30	40	50	60	70
diameter ($m * 10^{-3}$)	0.36	0.36	0.36	0.36	0.36	0.36	0.36
Cross sectional area (m^2*10^{-7})*	1.02	1.02	1.02	1.02	1.02	1.02	1.02
Gradient of graph (Ω/m):	10.81	10.81	10.81	10.81	10.81	10.81	10.81
Calculated Resistivity (Ωm) 10^{-6}**	1.10	1.10	1.10	1.10	1.10	1.10	1.10

* % uncertainty of cross sectional area = 2 * % uncertainty of diameter = 2(0.01/0.36)*100 =5.6%

** %uncertainty for ρ = %uncertainty for gradient + %uncertainty for cross sectional area

= [(0.01/0.108)*100] +5.6 = 14.9% (= ± 0.16 * 10^{-6})

From this table we can see that allowing for experimental error; the value for the resistivity of nichrome corresponds to the text book value since 1.1 × 10-6 Ωm is within the range of 1.10 × 10 -6 Ωm ± 0.16 * 10-6. This result is further evidence to the positive correlation between resistance of a wire and the resistance it presents taken that cross section, temperature and other variables remain constant, showing that not only there is a positive answer to the question posed previously but also, that the measurements were taken accurately.

The textbook support this by relating resistance, length and area through the formula $R \propto L/A$, but is A remains constant (like done in this experiment), than $R \propto L/1$ so that $R \propto L$ which states that resistance is proportional to length, like proven above.

Limitations and Improvements

Limitations to this experiment include the fact that the wire tested was not completely straight due to the way it was stored as well as other occasions in which it suffered small deformations. Even though these would be very small differences in the readings, they could become significant taking into consideration that the errors also have small values. This is significant because is could have meant a different error for length readings. This could have been dealt with by using instrument to straighten the wire on the ruler. Another way to try and overcome this problem would be by using a more malleable metal to be tested. This could have been straightened with more ease and could have improved the results.

Another factor which could have presented a limitation to the experiment was the heat which gathered on the wire after some time doing the experiment. As discussed before, even though the circuit would not be left connected for a long period of time in order to avoid great temperature changes, is would be very hard to make sure that the wire was at exactly the same temperature every time it was tested. This could affect the results since, as discussed before, a temperature change does affect resistance. A way of overcoming this issue or making its results more subtle would be to have taken time between each reading for the wire to cool down to its original temperature. This was hard to do during the actual practical due to time constraints but it would had been ideal.

Furthermore, we have the fact that an ideal ammeter would have zero resistance and the ideal voltmeter would have infinite resistance which was not the case during the collection of data. In this case, neither would present a change in the data but since the instruments used are probably not ideal, we have to take their resistance into consideration. In this case, we would not only me measuring the resistance of the wire but also of the other components of the circuit.

Also, when taking the readings for voltage, it is important to remember that those readings are not specific only for the wire being tested but that we do have to take into consideration the fact that the connecting wires would also show some resistance and could therefore alter the results obtained. In this experiment, it was assumed that the resistance that they presented was zero but to make very accurate results, these resistances would also have to have been previously tested. In order to do so, before connecting the wire to be tested into the circuit, we would have to put a circuit with only the connecting wires, ammeter, voltmeter and resistor. The values obtained from the ammeter and voltmeter would be used to calculate the resistance of the connecting wires by using the formula for resistance stated previously. Since these all of the circuit is connected in series, the wire resistance could be subtracted from the total resistance so that only the resistance of the actual nichrome wire was measured. A simpler way to reduce the resistance of the connecting circuits would also be to use shorter wires. This solution would be less precise than the first suggested, but it would be an option.

Moreover, this experiment could have been repeated a larger number of times so that the results would be even more reliable and another wire of the same parameters could have been tested. If the results obtained were different, what would justify that?