PHYSICS INVESTIGATION

INVESTIGATING THE RESISTANCE OF A WIRE

AIM:

The aim of this experiment is to investigate how a change in the length of wire made from nichrome will affect the potential difference (voltage) and the current across that length, hence affecting the resistance.

Introduction:

Resistance is the opposing force to the current in a circuit. The unit of resistance is the ohm (**Ω**). The electrical resistance of a conductor is defined by:

$$R\ (\text{Ohms}) = \frac{V\ (\text{volts})}{I\ (\text{amperes})}$$

Where I is the current flowing through the conductor when the Potential Difference across it is V.

The ohm is defined as being:

" The resitance of a conductor through which a c urrent of one ampere is flowing when the PD across it is one volt, i.e. $1\,\Omega = 1VA^{-1}$"

Some conductors have resistances which depend on the current flowing through them, but the majority of conductors, notably metals, depends entirely on their physical condition. There are four factors which affect resistance in a metal wire:

- Type of Material - The resistivity of various types of materials are different (see resistivity table further on). For instance, gold is a better conductor of electricity than copper, and therefore has less resistance.
- Length – The longer a wire the more resitance it has as there is more matter for the electrons to collide with, so as to be able to pass.
- Cross Sectional Area - The resistance of a material is inversely proportional to the cross sectional area. This means that the thicker the diameter of the wire, the lower the resistance. This is because the larger the cross sectional area is, the less friction there is over a given length.
- Temperature - In various types of materials, resistance can vary inversely or directly with the temperature. This is because of the chemical properties of the material. In Carbon, for instance, the resistance decreases as the temperature rises. So we say it varies inversely. In copper, however, the opposite is true, with the rise in temperature, we have a rise in the resistance.

Such conductors are called ohmic conductors and are said to obey Ohm's law. By rearranging the resistance equation and when R is constant we obtain the following expression:

$$\frac{V}{I} = \text{a constant} \qquad (\text{i.e. } I \propto V)$$

Therefore Ohm's law may be stated as:

"The current through an ohmic conductor is directly proportional to the potential difference across it, provided there is no change in the physical conditions (e.g. temperature) of the conductor"

The current-voltage reationship of various non-ohmic conductors, together with that of an ohmic conductor is shown in the resistance equation.

The experimental determination of the resistivity of a material involves measuring the resistance of a specimen of the material. The specimen must be regularly shaped in order that its dimensions L and A can be measured and used in the resistivity equation. If the speciemn is in the form of a wire, its diameter should be measured at about six different points.

Preliminary Work:

Aim:

To investigate the ideal input voltage for the experiment, and to learn more about the apparatus provided.

Hypothesis:

I believe that no matter the input voltage the resistance will remain constant. I also expect an input voltage of 1.5V to be an ideal voltage.

Prediction:

A higher input voltage will mean there is a greater potential difference between the ends of the wire. Therefore that will mean there will be a greater current, as their relationship is directly proportional. As both of these variables are increased in fixed amounts the resistance will remain constant.

Apparatus:

The apparatus I shall use in this experiment are:

- 1.03m of Nichrome wire – I shall use nichrome wire instead of the other option, which is copper, because its resistance is much larger. Therefore a small length of constantan will have the same resistance compared to a wire made of copper which is much longer. Therefore this option is much more convenient to use as well as enabling me to collect a wide range of readings.
- A 1m ruler mounted onto a wooden board with 2 nails on either side.
- A voltmeter – accurate to 0.2V
- Micrometer – accurate to 0.01mm
- An ammeter – accurate to 0.05A
- 6 wires
- 3x 1.5V batteries – for 3readings (1.5, 3.0 and 4.5V)
- Circuit board

Method:

I first placed the batteries in their slots in the circuit board, and connected one wire from the positive terminal to the ammeter. I then wrapped the nichrome wire around the two nails in the mounted ruler as tightly as possible. Next, I attached another wire from the positive terminal in the ammeter to the first nail on the mounted ruler. I then attached another wire from the same nail to the voltmeter, and connected the voltmeter to the second nail. After that I connected a fifth wire from the variable resistor to the nichrome wire at the 100cm mark:

Lastly I connected the sixth wire from the variable resistor to the negative terminal of the battery, 'tuned' the variable resistor to the required voltage, and jotted down the reading on the ammeter in a table.

Results:

The following table lists the results obtained:

Voltage (volts)	Current (Amps)				Resistance (ohms)
	First reading	Second reading	Third reading	Average reading	
0.0	0.00	0.00	0.00	0.00	0.00
1.5	0.15	0.15	0.15	0.15	0.33
3.0	0.30	0.30	0.30	0.30	0.33
4.5	0.45	0.45	0.45	0.45	0.33

Conclusion:

Graph 1 shows that the material constantan, is in fact an ohmic conductor and so is suitable for the investigation. Graph 2 on the other hand proves that the resistance is constant, no matter the current, and that supports my earlier prediction. However from these results I cannot deduce which is the best input voltage as all have extremely accurate results. I will however determine the ideal voltage through the practicality of the values. In the experiment, I believe that an input voltage of 2V is the best, due to a number of reasons:

- Firstly, it wasn't too high so as to produce a lot of heat and so increase the resistance, as well as needing a long length of wire, which is inappropriate to use.
- With 2V, the resistance of a small length of constantan could be measured, as it would remain in the scales in the ammeter, and so would enable me to obtain a wide range of results.
- Lastly, as I had to balance all the factors affecting resistance, i.e. the cross-sectional area, the shortest length possible to be measurable, as well as the scales of the apparatus available.

Evaluation:

In this investigation there were no anomalous results, and so I can be confident I have the best method. The results were extremely accurate, and I repeated the experiment for increased reliability. Also, for the main investigation I have decided to use 2V as the input voltage.

Some things I can improve on in the main investigation, is to get a more accurate rheostat, so as to be even more precise with the voltages. I did have a lot of trouble tuning the variable resistor, as the band was so minute it was an intricate process to get a specific voltage. This never showed up in the results because the equipment I have is not that accurate.

Final Investigation

The variables in this investigation are:

Independent variable:

- The resistance of the different lengths of wire – this is because with increased length, the resistance increases due an increased number of obstacles for the electrons to avoid and flow.

Dependant variable:

- The current and potential difference of the measured wire – by measuring these two I will be able to determine the resistance (R = V / I).

Control variables (these are external factors that must be controlled in order to conduct a fair investigation):

- The cross-sectional area of the wire – a thicker wire will mean there is less resistance, because there are a greater number of paths for the same quantity of electrons to flow, decreasing the likelihood of a collision, and so decreasing resistance. I will keep this constant by measuring the thickness at six different points, using the micrometer so as to get the average cross-sectional area. Also, I will avoid applying pressure to a certain point so as to decrease the diameter of the wire and so increase the resistance in that particular point.
- The temperature – a higher temperature will mean there is a higher resistance. That is, according to the kinetic theory, because the constantan atoms vibrate even more around their fixed positions, and so will reach further out than previously. This will mean electrons flowing will be obstructed further:

  As you can see from the diagram above, if the vibrations of the constantan atom were greater, than there would be a greater obstruction to the flow of electrons. To avoid this problem I will turn the circuit off after a reading is taken to allow the wire to cool down.
- The wire will be made of constantan throughout the experiment because different materials have different resistivities. For example if copper has a much lower resistivity. Therefore a small length of constantan will have the same resistance to a copper wire around 30 times longer. Consequently a change in the material of the conductor will dramatically affect the validity of the results.
- The wire will remain constantly wrapped tightly around the nails, because a loose wire will mean there is extra material in the length being measured, and as already explained length increases resistance.

- The input voltage will remain constant, because it is directly proportional to the current, and therefore an increase in current will lead to higher temperatures, therefore increasing the resistance.

These control variables must be controlled and kept constant, to enable the investigation to be a fair study. That is because they are all contributing factors to the either increasing or decreasing the resistance, so even if one factor were to fluctuate, the reliability of the results would be placed in jeopardy. That is because it wouldn't be the change in length causing the difference in resistance solely.

Hypothesis:

I believe that if the length of the wire is increased the resistance will increase, and I believe this relationship to be directly proportional. I expect this to show a strong positive gradient as a straight line:

Prediction:

The resistance increases with the length of a wire due to the increasing number of particles in the path of the flowing electrons. The resistance of the wire is directly proportional to it's length, therefore the longer the material is, the more resistance it has. This is because the electrons must flow through more matter, and therefore the electrons collide with more constantan atoms, i.e. it meets more friction over the entire distance.

For example, if the wire was 10 cm then the electrons that flow, would have to avoid only those constantan atoms in that length. A wire doesn't have any holes in it, therefore electrons must dodge other particles to be able to flow and continue. And so with a length of 20cm there is double the matter present, and so electrons must avoid twice as many atoms as before, i.e. the resistance doubles.

Consequently I predict that the resistance will double with twice the length of wire, and that there will be a straight line originating from (0,0) in a graph with V on the x-axis, and I on the y-axis, as constantan is an ohmic conductor. This means it obeys Ohm's law that says 'the current through an ohmic conductor is directly proportional to the potential difference across it, provided there is no change in the physical conditions of the conductor'.

Apparatus:

- Micrometer – *with this device, I shall measure the diameter of the wire. It is extremely accurate (0.01mm), and therefore I can take precise readings. The reason why I shall use this device is because the wire must have a constant cross - sectional area throughout, as a higher area will decrease the resistance, by providing electrons with more paths to take. Therefore to ascertain the experiment is fair, this will be controlled.*
- Mounted 1 meter ruler – *accurate to 1mm therefore enabling precise measurements. It is the same instrument used in the preliminary work. I found it to be extremely useful, as I will not have to worry about holding the wire and the ruler. This therefore facilitates the process of obtaining results.*

- One voltmeter – *this device is accurate to 0.2V, with a maximum reading of 5V. I will place it in parallel in the circuit to give me a reading of the potential difference between the two ends of the measured wire.*
- One ammeter – *with this device I will be able to take a reading of the current (coulombs travelling per second) in the circuit. It is accurate to 0.05A and the maximum reading is 2A.*
- 1.03m of wire made from nichrome – *The reason why I shall use constantan wire is because it is an ohmic conductor. I shall also use it, instead of for example copper, because its resistance is much larger. Therefore a small length of constantan will have the same resistance to a copper wire around 30 times longer. This option is therefore much more convenient to use as well as being enabling me to use a wide range of readings. The reason why I shall use 1.03m, although I only need 1m, is because the extra 30 cm will be wrapped around the nails in the mounted ruler stick so as to be as tight and straight as possible. The range I will chose is 10 readings, which are 10, 20, 30, 40, 50, 60, 70, 80, 90, 100cm.*
- Circuit board – *with this piece of apparatus I will be able to organise and hold the batteries in a fixed position throughout, therefore saving me the hassle of taping them together.*
- Six wires – *I will use these wires to connect the equipment together. Some will be 'plug-in' wires, and others will be crocodile clips. I will use them according to the instrument I shall attach them to.*
- 2 x 1.5V batteries – *this will be the voltage source. By having three (a maximum possible in the circuit board) I will be able to obtain a wide range of results, so therefore my final graph will be very accurate.*

Safety:

In the experiment as part of my safety requirements I shall take the following precautions and procedures to enable the investigation to go through without harm to any of my classmates or I:

- Before starting the experiment I shall clear my desk from any unnecessary materials
- I will tuck my stool inside my table and remove bags away from the floor to avoid people or myself tripping when moving around the working area.
- I will work away from a water supply to avoid contact with electricity and therefore ruling out electrocution.
- I will check the wires for any tears in the insulation, because again I can be electrocuted
- I will not touch the constantan wire with the current flowing through, nor any other metallic piece in the circuit.
- I will take care with the crocodile clips to avoid them being clipped onto my fingers and so preventing myself from being cut.

Proposed Methods:

First I shall place the batteries in their slots in the circuit board, and connect one of the wires from the positive terminal to the ammeter. I will then take readings of the thickness of the nichrome wire at six different points, and then tie the nichrome wire around the two nails in the mounted ruler as tightly as possible. That is so that I have exactly the length I wish measure. If the wire were to bent and uneven, then I would be actually measuring more wire. Next, I will clip another wire from the positive terminal in the ammeter to the first nail on the mounted ruler. I will then attach a third wire from the same nail to the voltmeter, and connect the voltmeter to a different wire, but keep its other end free. Then I will connect a wire from the variable resistor to the negative terminal of the battery.

After that I will then take the free end of the wire from the variable resistor and place it inside the socket of the wire from the negative terminal of the voltmeter (next page). The circuit will be complete. I will then 'tune' the rheostat to 2V. The next stage will involve, placing the same junction of wires and clipping them at one of the required lengths. One consideration here is to place the crocodile clip after the required length, so as to be measuring that length.

I will then jot down the potential difference across the wire as well as the current in a table is shall make. The following illustration shows the mounted ruler and its connections:

I shall repeat the experiment three times in order to increase the reliability of my results. Before taking repeat readings, I will disassemble the whole circuit, and connect it up again, so as to avoid repeating the same error if any are to occur. I will also take and average of the values from the results that I obtain, and if any errors, gather the three results that bare closest resemblance to each other.

RESULTS:

Firstly the diameter of the wire at six different points is listed below. Please note anomalous results are highlighted.

1. 0.36mm
2. 0.36mm
3. 0.37mm
4. 0.36mm
5. 0.36mm
6. 0.36mm

The average diameter is therefore 0.36mm

The results from the investigation are:

	Potential difference (Volts)			Current (Amps)		
Length (metres)	1st reading	2nd reading	3rd reading	1st reading	2nd reading	3rd reading
0.000*	2.00	2.00	2.00	0.00	0.00	0.00
0.100	0.60	0.60	1.00	1.80	1.80	1.30
0.200	0.80	0.80	0.80	1.45	1.45	1.45
0.300	1.20	1.20	1.20	1.05	1.10	1.10
0.400	1.40	1.40	1.40	1.00	0.95	1.00
0.500	1.60	1.60	1.60	0.90	0.90	0.90
0.600	1.80	1.80	1.70	0.80	0.80	0.85
0.700	2.00	2.00	1.80	0.75	0.75	0.80
0.800	2.40	2.20	2.20	0.65	0.70	0.70

0.900	2.40	2.40	2.40	0.60	0.60	0.60
1.000	2.40	2.40	2.40	0.60	0.60	0.60

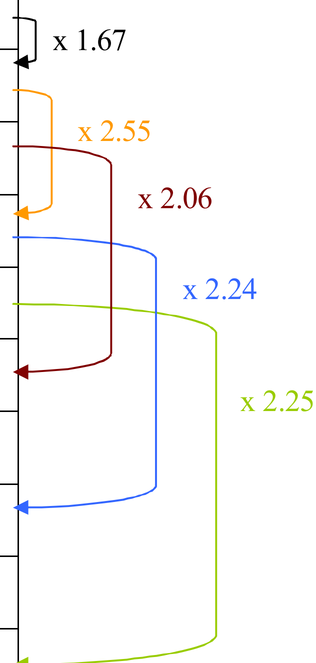
*Control test – this was to actually determine the input voltage once more, and prove it was the length of wire affecting the resistance.

Length (metres)	Average potential difference (Volts)	Average current (Amps)	Resistance (Ohms)
0.100	0.60	1.80	0.33
0.200	0.80	1.45	0.55
0.300	1.20	1.10	1.09
0.400	1.40	1.00	1.40
0.500	1.60	0.90	1.78
0.600	1.80	0.80	2.25
0.700	2.00	0.75	2.67
0.800	2.20	0.70	3.14
0.900	2.40	0.60	4.00
1.000	2.40	0.60	4.00

Graph 1 shows the relationship between the length and the resistance. The final result on the line, which is for the 1m length of wire, is exactly the same in value to that of the 0.9m length. An explanation for this probable anomaly is the fact that the resistance was so great the current was hindered, and could not increase above 0.6A. A more probable explanation however is that because of the accuracy of the equipment provided (see evaluation for further analysis).

The graph shows exactly what I expected, a straight line with a strong positive gradient, as well as the fact that these two variables of resistance and length of wire are directly proportional. If you take the resistances of the different lengths we see that the value is twice as much as that before it, as long as the length is double also:

Length (m)	Resistance (Ohms)
0.100	0.33
0.200	0.55
0.300	1.09
0.400	1.40
0.500	1.78
0.600	2.25
0.700	2.67
0.800	3.14
0.900	4.00
1.000	4.00



The average of these factors is 2.15, which has a percentage error of 6.98%. That is extremely close to the expected scale factor of '2' (representing double the amount), and so the results seem accurate and reliable.

Graph 2 on the other hand shows the relationship of current and resistance to be inversely proportional which is what I predicted. As the resistance increases the current decreases, and so I can be confident the results are reliable and accurate.

CONCLUSION:

In this investigation I have concluded that the longer a wire is the greater the resistance. That is, according to my sources of information, my investigation and my calculations, because of the increased amount of matter obstructing the flow of electrons. I have found this relationship to be directly proportional, i.e. if the length of wire is doubled, then the resistance will double also. This conclusion was deduced by using graph 1. Moreover I have concluded that the current and resistance are inversely proportional to each other by using graph 3 as well as my background reading.

The conclusions I have drawn are exactly what I predicted. The results are accurate and extremely reliable and so I was able to draw a firm conclusion in that respect. I had predicted that 'the resistance increases with the length of a wire due to the increasing number of particles in the path of the flowing electrons. The resistance of the wire is directly proportional to it's length, therefore the longer the material is, the more resistance it has. This is because the electrons must flow through more matter, and therefore the electrons collide with more constantan atoms, i.e. it meets more friction over the entire distance'. I also predicted that 'resistance will double with twice the length of wire, and that there will be a straight line originating from (0,0) in a graph with V on the x-axis, and I on the y-axis'. This is exactly true as seen in graph 1.

EVALUATION:

I believe the investigation worked well for a number of reasons. Firstly the results I obtained in both the main investigation, as well as the preliminary work, were extremely accurate and so I was able to plot accurate graphs, and perform necessary calculations. I took three readings and averaged the two closest to each other, which meant they were very reliable as well. The results matched those I predicted and so were very dependable.

I also feel the investigation worked well because the patterns and trends in the results I obtained were extremely similar to the predictions I had made and so were correct and precise. Moreover the method I deployed is justified through these points, as well as the fact that nothing harmful befell my classmates or I.

The results I obtained were accurate enough for the investigation because the graphs, and my range and number of readings had proved my prediction to be true, and supported the information in my background reading. The results proved:

- Resistance is directly proportional to the length of wire, i.e. if the length was doubled then so will the resistance.
- Resistance is inversely proportional to current, therefore when the resistance increases the current decreases in the same amount.

- Voltage is directly proportional to current, and so will cause the current to increase in the same ratio when it does.
- Constantan is an ohmic conductor; therefore it has a constant resistance when the current and voltage fluctuate.

In fact this investigation supports the following rule:

$$R = \frac{V}{I}$$

There were a number of anomalous results I can identify, although all graphs followed the same pattern and trend and seemed very accurate. Firstly the resistance for the 1m lengths is exactly similar to that of 0.9m. The reason I can think of for this occurrence is the fact that at 0.9m the maximum resistance was achieved, and so the current could not be hindered further. However the theoretical results indicate the resistance does increase. Consequently a more sound explanation for this result would be due the ammeters and voltmeters I used being analogue devices. Although they were set to 0A and 0V, they weren't extremely accurate. They had reasonable precision, but the marker didn't point to the exact positions seen in the results. They were often wayward of the marks, and I cannot make an estimate of their exact position, as that would be inaccurate. Therefore the actual resistance for 0.9m was probably less than that for 1m, but as the devices were not that accurate I wasn't able to show that.

To enhance the accuracy and reliability of this investigation I could undertake a number of improvements:

- Measuring the lengths of the wire is a place where there could have been slight inaccuracy. The meter stick was accurate to 1mm, however it is difficult to get an extremely accurate reading of length by eye. Therefore to increase the accuracy of measurement a more precise ruler could be used.
- In the investigation I had the problem of keeping the wire extremely tight. It was always slightly loose, meaning there was a little extra length in that being measured, however I felt that was inevitable. I could have avoided this problem if I was permitted to nail either side of the wire to the plank of wood the ruler was mounted on, under strict safety guidelines, or I could have tied a knot with some string to keep the wire tightly fastened to the nails.
- As mentioned previously the ammeter and voltmeter were only accurate to 0.05A, and 0.2V, with a range of 0-2A, and 0-5V. Therefore to increase the accuracy of the results most, I could use digital devices with a greater range, and greater accuracy, to enable me to obtain a greater number, and greater range of results with increased preciseness.
- To increase the reliability of my results I could have asked my teacher for the manufacturers graph showing the resistance with different lengths of the constantan wire I used, and so use it as my line of best fit to draw an even more detailed conclusion.

The method I used I feel was the best possible considering the equipment I had. Firstly the method enabled me to obtain very accurate and reliable results that were enough for me to draw my conclusion. That is because I used the apparatus well, and took 3 readings of 10 lengths, which is in total 30 results. I average the two closest one for each length and so I was able to plot accurate graphs. Furthermore the actual results I obtained were very similar to the theoretical results I predicted, suggesting my results were accurate and were reliable. The method I used ensured I was not going to injure myself, or cause an injury through negligence or carelessness. Moreover due to the method I adopted I was able to draw a firm conclusion that supported the predictions I made.

To extend this work I could investigate the other factors I kept constant in my investigation. For example I could investigate the effect of cross-sectional area of wire, temperature of wire and different metal wires on resistance. Below is a rough plan of an investigation I could follow:

AIM:

The aim of this experiment is to investigate the effect of the cross-sectional area of a wire on its resistance.

PREDICTION:

The relationship of these two variables is inversely proportional, i.e. an increase in the diameter of a wire causes the resistance to decrease. That is because the larger the cross sectional area is, the less friction there is over a given length. Furthermore, the electrons circulating have more routes than one to flow, an so they are not concentrated into an area as much as a wire with small cross-sectional area. That means the liklihood of a collision between particles and other electrons is decreased.

APPARATUS:

The apparatus I shall use for this experiment are:

- 1.03m of Constantan wire 0.09mm thick
- 1.03m of Constantan wire 0.18mm thick
- 1.03m of Constantan wire 0.36mm thick
- 1.03m of Constantan wire 0.54 mm thick
- 1.03m of Constantan wire 0.72mm thick
- A 1m ruler mounted onto a wooden board with 2 nails on either side.
- A voltmeter – accurate to 0.2V
- Micrometer – accurate to 0.01mm
- An ammeter – accurate to 0.05A
- 6 wires
- Variable resistor
- 3x 1.5V batteries – for 5 readings (0.5, 1.0, 1.5, 2.0, and 2.5V)
- Circuit board

METHOD:

I will first place the batteries in their compartment in the circuit board, and connect one wire from the positive terminal to the ammeter. I will then take measurements of the thickness of the 0.09mm thick constantan wire at six different points, to be sure of the average thickness. I will then wrap the constantan wire around the two nails as tightly as possible. Next, I will attach another wire from the positive terminal in the ammeter to the first nail on the mounted ruler, and a third wire from the same nail to the voltmeter. I will then connect the voltmeter to the other nail. After that I will connect another wire from the variable resistor to the constantan wire at the 50cm mark.

Lastly, to complete the circuit I will connect the last wire from the variable resistor to the negative terminal of the battery, ‘tune’ the variable resistor to 2V, and then jot down the reading on the ammeter in a table. I will then repeat this process for each wire thrice, for increased reliability.