Resistance of a Wire

Task

To investigate how the resistance of a wire is affected by the length of the wire.

Theory

What is resistance?

Electricity is conducted through a conductor, in this case wire, by means of free electrons. The number of free electrons depends on the material and more free electrons means a better conductor, i.e. it has less resistance. For example, gold has more free electrons than iron and, as a result, it is a better conductor. The free electrons are given energy and as a result move and collide with neighbouring free electrons. This happens across the length of the wire and thus electricity is conducted. Resistance is the result of energy loss as heat. It involves collisions between the free electrons and the fixed particles of the metal, other free electrons and impurities. These collisions convert some of the energy that the free electrons are carrying into heat.

How is it measured?

The resistance of a length of wire is calculated by measuring the current present in the circuit (in series) and the voltage across the wire (in parallel). These measurements are then applied to this formula:

V = I ´ R where V = Voltage, I = Current and R = Resistance

This can be rearranged to:

R = V

I

Ohm’s Law

It is also relevant to know of Ohm’s Law, which states that the current through a metallic conductor (e.g. wire) at a constant temperature is proportional to the potential difference (voltage). Therefore V ¸ I is constant. This means that the resistance of a metallic conductor is constant *providing that* the temperature also remains constant. Furthermore, the resistance of a metal increases as its temperature increases. This is because at higher temperatures, the particles of the conductor are moving around more quickly, thus increasing the likelihood of collisions with the free electrons.

Variables

Input:

- Length of wire. *
- Material of wire.
- Width of wire.
- Starting temperature of wire.

Output:

-

  and thus the resistance of the wire. †

- Voltage across wire.
- Current in circuit.

- Temperature of wire.

The variable marked with a * will be varied, the other input variables will be kept constant. The output variable marked with a † will be measured.

Predictions

The longer the wire, the higher the resistance. This is because the longer the wire, the more times the free electrons will collide with other free electrons, the particles making up the metal, and any impurities in the metal. Therefore, more energy is going to be lost in these collisions (as heat).

- Furthermore, doubling the length of the wire will result in double the resistance. This is because by doubling the length of the wire one is also doubling the collisions that will occur, thus doubling the amount of energy lost in these collisions.

Method

The following circuit was constructed to perform the investigation:

wire

The two dots ( ) represent the crocodile clips that were placed at the ends of the required length of wire.

1. One metre length of 0.4mm diameter “constantan” (a metal alloy) wire is fixed to a metre rule.
2. The first crocodile clip is clipped to the wire at the 0cm position on the metre rule.
3. The second crocodile clip is clipped to the relevant position depending on the required length of wire.
4. The power supply is turned on. The voltage and current are then read off the ammeter and voltmeter, and recorded.

5. The power supply is then turned off and the second crocodile clip is moved to the next position.

The above steps are completed for each length and then the entire investigation is repeated for accuracy.

Rough Trials

In order to decide upon the voltage and lengths of wire to use in the final experiment, the following rough trials were carried out:

At 3V:

Length (cm)	**Voltage (V)**	**Current (A)**	**Resistance (W) (to 2 d.p.)**
10	0.41	0.90	0.46
20	0.51	0.57	0.89
30	0.56	0.42	1.33
40	0.60	0.32	1.88
50	0.63	0.26	2.42
60	0.64	0.23	2.78
70	0.65	0.20	3.25
80	0.66	0.18	3.67
90	0.67	0.16	4.19
100	0.68	0.15	4.53

At 5V:

Length (cm)	**Voltage (V)**	**Current (A)**	**Resistance (W) (to 2 d.p.)**
10	Could not be carried out as the wire simply melted.		
20	2.12	2.07	1.02

30	2.25	1.56	1.44
40	2.34	1.24	1.88
50	2.41	1.02	2.36
60	2.45	0.88	2.78
70	2.49	0.77	3.23
80	2.52	0.68	3.71
90	2.54	0.62	4.10
100	2.56	0.55	4.65

After performing these rough trials, it was decided that 3V would be used in the proper experiment, as it provided results from 10cm up to 100cm and the higher voltage provided no additional ease of measurement.

Furthermore, it was also decided to allow the wire to cool between experiments as considerable heat was noticed at lower lengths and, as mentioned above, an increase in temperature results in an increase in resistance. By allowing the wire to cool between experiments a fair test could be assured.

Safety

In order to perform a safe experiment, a low voltage of 3V was chosen so that overheating was minimilised. Furthermore, lengths lower than 10cm were not tried, which also helped to avoid overheating.

Results

Wire 1, Set 1:

Length (cm)	**Voltage (V)**	**Current (A)**	**Resistance (W) (to 2 d.p.)**
10	0.66	1.22	0.54

20	0.84	0.89	0.94
30	0.97	0.70	1.39
40	1.06	0.57	1.86
50	1.16	0.50	2.32
60	1.22	0.44	2.77
70	1.25	0.38	3.29
80	1.27	0.35	3.63
90	1.31	0.29	4.52
100	1.33	0.29	4.59

Wire 1, Set 2:

Length (cm)	**Voltage (V)**	**Current (A)**	**Resistance (W) (to 2 d.p.)**
10	0.51	1.02	0.50
20	0.79	0.79	0.97
30	0.91	0.65	1.40
40	1.02	0.55	1.85
50	1.08	0.48	2.25
60	1.15	0.42	2.74
70	1.19	0.37	3.22
80	1.22	0.33	3.70
90	1.26	0.30	4.20
100	1.27	0.28	4.54

Having completed two sets of results for one wire, it was noticed that these was a large black mark towards one end of the wire, where it appeared that it had been melted to some degree at some point. It was therefore decided to conduct experiments on an additional piece of wire that was checked for integrity prior to investigation:

Wire 2, Set 1:

Length (cm)	Voltage (V)	Current (A)	Resistance (W) (to 2 d.p.)
10	0.95	1.06	0.90
20	1.19	0.67	1.78
30	1.28	0.48	2.67
40	1.35	0.37	3.65
50	1.38	0.32	4.31
60	1.42	0.27	5.26
70	1.45	0.24	6.04
80	1.46	0.21	6.95
90	1.48	0.19	7.79
100	1.50	0.17	8.82

Wire 2, Set 2:

Length (cm)	Voltage (V)	Current (A)	Resistance (W) (to 2 d.p.)
10	0.92	1.05	0.88
20	1.16	0.66	1.76
30	1.28	0.47	2.72
40	1.34	0.39	3.44
50	1.38	0.32	4.31
60	1.42	0.27	5.26
70	1.45	0.23	6.30

80	1.47	0.21	7.00
90	1.47	0.17	8.65
100	1.48	0.16	9.25

Averages for each wire were then calculated to give these results, which were then graphed:

Length (cm)	**Resistance (W) (to 2 d.p.)**	
	Wire 1	**Wire 2**
10	0.52	0.89
20	0.96	1.77
30	1.40	2.70
40	1.86	3.55
50	2.29	4.31
60	2.76	5.26
70	3.26	6.17
80	3.67	6.98
90	4.36	8.22
100	4.57	9.04

<u>Conclusions</u>

Having performed the investigation, the following conclusions were drawn:

- As predicted, an increase in length resulted in an increased resistance. This can be clearly said for both wires tested.

- Both wires show a strong trend of a straight line, i.e. the length of the wire is shown to be directly proportional to the resistance – double the length and the resistance doubles.
- The overall resistance of the two wires seems to differ considerably. Due to the strong correlation of the results, the explanation of this is unlikely to be the method used to obtain the results. The more likely explanation would be that the first wire was actually of a larger diameter than the second one. Obviously this is a rather important oversight and this will be discussed more in the *Evaluation* section. The reason why this is the likely explanation is because resistance is known to be inversely proportional to the cross-sectional area, i.e. if you *increase* the cross-sectional area (by increasing the diameter) then you *decrease* the resistance. This is because a wider wire means less likelihood of the free electrons having collisions and losing energy.

It is important to realise, however, that despite the fact that it would appear that the resistance of wire 2 is double that of wire 1, that does not mean that the diameter is half that of the wire 1. That is because if you halve the diameter then you decrease the area by a factor of about 3 ($A = \pi r^2$)

<u>Evaluation</u>

- As mentioned previously, the biggest downfall of the investigation was the apparent mistakes when choosing the wire, in that they would appear to be of differing diameters. This did not, in this case, cause a big problem as the same wire was used for each set of results so it is known that the results for each wire are correct.
- Generally speaking, wire 1 would appear to contain the most accurate results due to the fact that all of its points bar one sit on the line of best fit for that wire. The only one that does not is the point at 90cm, which was exactly at the point that the black mark (mentioned previously) was found to be.
- Wire 2, on the other hand, had three main anomalous results: at 50, 80 and 90cm. They are by no means that far off but in an experiment such as this, which is generally a very

accurate one anyway, such anomalous results should not be quite so common. Possible explanations for these anomalies are as follows:

- The length of wire for that particular measurement was not correct. At 50 and 80cm it is possible that the length was shorter, causing a lower resistance, and at 90cm it is possible that it was longer, causing a higher resistance. The solution to this is to measure the lengths more carefully and ensure that the wire is pulled tight against the metre rule.
- For a particular result, one or more of the connections could have been faulty, causing extra resistance at the connections. A solution to this would be to, before each experiment, connect the connections together without the wire in place and measure the resistance then. If it is higher than it should be then the connections could be cleaned.
- Whilst extremely unlikely, it is conceivable that the power supply was providing a different voltage for some of the results. This is unlikely to be a problem in this investigation but it might have been an issue had we used batteries instead.

NB: If one were to assume that Ohm's Law applies, then another possible explanation could be that at some points (more likely in the lower lengths), the wire was not allowed to cool completely so that the temperature was higher for that measurement. Whilst unlikely (due to the two sets of results), this would cause a higher resistance as explained previously. However, it is now known, after researching the metal alloy "constantan," that the resistivity (the electrical resistance of a conductor of particular area and length) of this alloy is *not* affected by temperature. Therefore, in these experiments Ohm's Law does not apply.