PHYSICS

AIM

The aim of the experiment I am conducting is to find the resistivity of a 24 watt light bulb. This will be conducted through a series of experiments which will be followed by some calculations using formulas such as:

$$resistance = \frac{resistivity\ x\ length}{cross\ sectional\ area}$$

Or

$$R = \frac{\rho l}{A}$$

ρ is the resistivity (measured in ohm metres, Ω-m)

R is the electrical resistance of the material (measured in ohms,Ω)

l is the length of the piece of material (measured in metres, m)

A is the cross-sectional area of the material (measured in square metres, m²).

There are other equations that could be used to work out electrical resistivity, such as:

$$\rho = \frac{E}{J}$$

E is the magnitude of the electric field (measured in volts per metre, V/m);

J is the magnitude of the current density (measured in amperes per square metre, A/m²).

Finally, electrical resistivity is also defined as the inverse of the conductivity σ (sigma), of the material, or:

$$\rho = \frac{1}{\sigma}.$$

Electrical conductivity or is a measure of a material's ability to conduct an electric current. This is because resistivity and conductivity are reciprocals.

I aim to use the first equation to work out resistivity by re-arranging it, like so:

$$\rho = \frac{RA}{l}$$

So if I can measure ‘R’, being resistance, ‘A’ being cross sectional area and ‘l’ being length of a light bulb, I can use the latter equation to work out the resistivity of the light bulb.

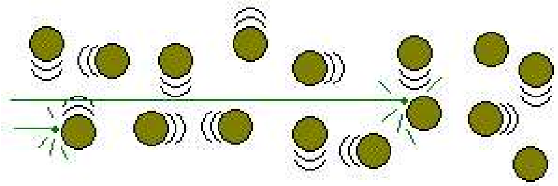
RESISTIVITY

The resistance of a wire depends on quite a few factors; these will affect the wires in many different ways, such as temperature increasing resistance. The length of the wire will make a difference. This is because when you have a long wire, the electrons have to ‘squeeze’ together for longer to be able to pass through the wire than they do in order to be able to pass through a short wire, the electrons have to squeeze together in order for them to avoid ‘bumping’ into the other particles in the lattice of the wire. The thickness of the wire would also affect the resistance of wire, a thick wire of the same material, length and temperature would have less of a resistance of a thinner wire, this is because there is more room for more electrons to be able squeeze together, creating more ‘lanes’ for the electrons to be able to pass through, this increases the current, which for if the voltage was the same, would lower the resistance, we can see this using the simple formula:

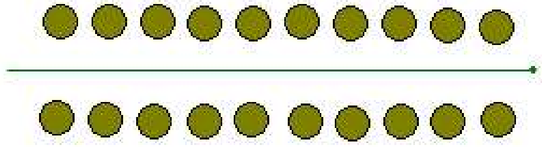
$$R = V/I$$

Where V is voltage and I is current.

In a thin wire, there are fewer ‘lanes’ for the electrons to be able to pass through, causing a lower current and therefore a higher resistance. Another cause of an increased or decreased resistance in a wire is temperature. In general, electrical resistance of metals increases with temperature; this is caused by electron-phonon interactions. Phonons being the mode of vibration which occurs in a rigid lattice, such as the lattice of the wire. Also collision theory comes to play, where at higher temperatures the particles in the wire move around more, causing more collisions between the particles and the electrons, this will generally slow down the electrons and forcing them to squeeze together. At high temperatures, the resistance of a metal increases proportionately with temperature. This can



ELECTRONS PASSING THROUGH A HEATED UP MATERIAL



ELECTRONS PASSING THROUGH A SUPERCONDUCTOR be shown in this diagram

As the temperature of a metal is reduced, the temperature dependence of resistivity follows a complex temperature rule. Mathematically the temperature dependence of the resistivity ‘ρ’ of a metal is given by a formula called the Bloch-Gruneissen formula. The Bloch-Gruneissen equation is quite complicated and is as follows.

$$\rho(T) = \rho(0) + A\left(\frac{T}{\Theta_R}\right)^n \int_0^{\frac{\Theta_R}{T}} \frac{x^n}{(e^x - 1)(1 - e^{-x})} dx$$

Different materials also affect the resistance of the wire, for example copper is a better conductor than steel, steel is a better conductor than silicon, and so on.

As we can see if I was to work out the resistance of a particular wire I would need to take into account the length, temperature, area and material of the wire. The relevant property of the material is its resistivity.

VOLTAGE AND CURRENT

VOLTAGE

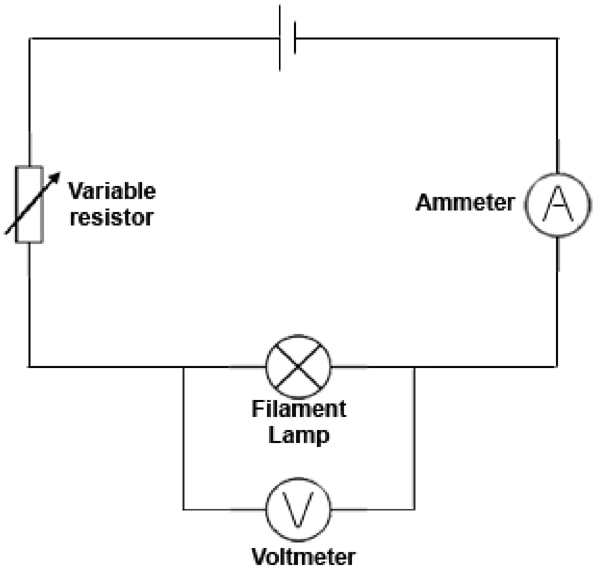
Voltage is the ‘push’ which makes a current flow through a wire. We can distinguish between two types of voltage, one being a voltage where the charge is losing energy, such as through a resistor on the wire like a light bulb, this is called a potential difference. Voltage can also be where a charge is gaining energy, such as in transformers and generators, this is called an electromotive force. Thus the voltage across the power supply is an electromotive force or e.m.f., while the voltage across a resistor in a circuit (such as a wire or a light bulb) is a potential difference or p.d. You can add two voltages in a circuit together, using Kirchhoff’s circuit laws.

CURRENT

Electric current is a net flow of charged particles, usually around a circuit. The direction of flow in circuits can change depending on whether you are using ‘conventional current’ or the actual current flow. Conventional current is a scientific convention that is false; in conventional current the current flows from the positive terminal of the cell to the negative terminal. As I have said before conventional current as proved false, what actually happens is called electron flow. In the material of the wire there are free electrons (there needs to be free electrons for current to flow). The atoms of the wire would usually bind tightly together in a lattice such as in copper or steel, one electron from each atom will break away from this and become a conduction electron. The atom remains as a positively charge ion. Since there are equal numbers of free electrons –ve and ions +ve, the metal has no overall charge and it is neutral. When a power source is connected to the wire and switched on, voltage is produced which provides a push to make the conduction electrons flow around the circuit. Since electrons are negatively charged, they flow towards the positive terminal in the cell (opposites attract). As we can see from this the actual electrons and their charge are flowing from the negative terminal in the cell to the positive. Current is always flowing at all points in the circuit as soon as the circuit is complete, we don't have to wait for charge to travel from the cell. This is because the electrons are already present in the wire and all around the circuit before a power source is connected. It is also good to note that having an electric current passing around a circuit produces a magnetic field. This is called Ampere's law.

EQUIPMENT

This is the equipment I am going to use in the experiments a re:



Variable resistor: So I can change the voltage, and thus the resistance in the bulb, so I can draw a table, find the averages, and draw a graph; this would ensure I get as much of an accurate result a possible and minimise any affects that errors wou ld have on my result.

Ammeter: This is to measure the amps in the circuit, so I can measure the resistance. I will measure the resistance using the voltage divided by the amps. As per Ohms law and the equation V=IR.

Voltmeter: This would be used alongside the variable resistor to ensure I know the voltage across the bulb.

PRELIMINARY

Before I begin my main experiment I will perform some preliminary tests. These are to obtain a general trend of results and so will give me a reference to check back to if I think I make any large errors in my main experiment. I am going to conduct six repeats, using the power supply's built in electromotive force variables, from 3 to 12 in steps of 1.5.

I am going to record, the electromotive force, and the voltage across the bulb, the current around the circuit and the resistance in the bulb.

On my first repeat I achieved the following results:

EMF	Voltage across bulb (V)	Current across bulb (I)	Resistance of bulb (V/I) (Ω)
12	11.6	1.31	8.86
9	9	1.08	8.33
7.5	7.4	0.93	7.96
6	5.9	0.77	7.66
4.5	4.4	0.59	7.46
3	3.1	0.41	7.56

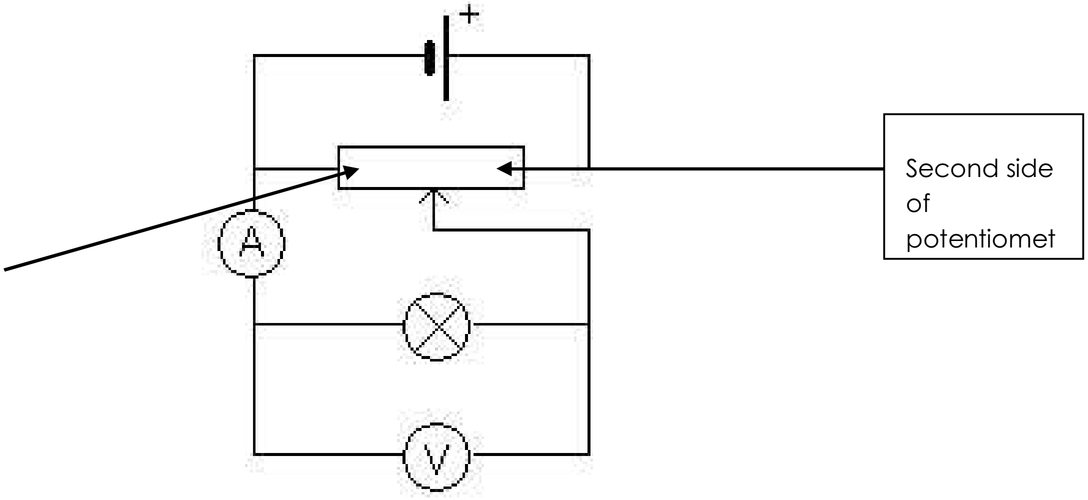
In this first preliminary experiment, you can see that there may be some inaccuracies; an example of this is that the trend of the resistance of my bulb should decrease as I decrease my EMF in my power pack, but as you can see when my EMF is at its lowest, the resistance increases slightly. There is also another error here, the voltage across the bulb is slightly increased in correspondence to my E MF from the power pack, and this means that voltage has been added to my system, which is false. I will repeat these readings to see if this error was random or a systematic error.

On my repeat, I used different wires, to see if this helped remove my erro r and I also used a more accurate voltmeter, and a more accurate ammeter, I also changed power packs.

On this preliminary repeat, I setup the circuit differently, as a potential divider, this is so I can keep the EMF the same, and lower the voltage. The v oltage across the bulb would depend on where the potentiometer splits, this can be described in the following equation:

$$Vout = Vin \frac{Rb}{Ra + Rb}$$

Where Vout is the voltage across the bulb, Vin is the voltage that's input into the circuit, Rb is the resistance on the first side of the potentiometer, and Ra is the resistance on the second side of the potentiometer.



I took the readings on intervals according to the value of voltage I was given, and kept the electromotive force the same, on 12. As it is on 12, the power pack would heat up rapidly, and because I don't want it to overheat, I have to keep on turning the power pack off between readings.

First side of potentiometer

second repeat the following results were achieved:

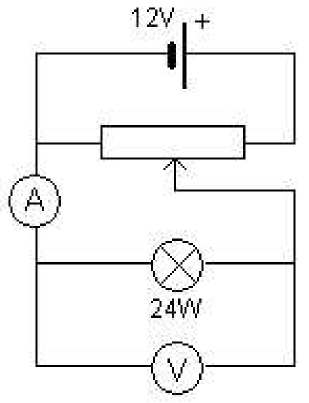
EMF	**Voltage across bulb (V)**	**Current across bulb (I)**	**Resistance of bulb (V/I) (Ω)**
12	**10**	**1.65**	**6.06**
12	**9**	**1.56**	**5.77**
12	**8**	**1.47**	**5.44**
12	**7**	**1.37**	**5.11**
12	**6**	**1.26**	**4.76**
12	**5**	**1.14**	**4.39**
12	**4**	**1.02**	**3.92**
12	**3**	**0.88**	**3.41**
12	**2**	**0.72**	**2.78**
12	**1**	**0.52**	**1.92**
12	**0**	**0**	∞

After looking at my second preliminary results I can see that they're far more accurate, and so I am going to use this circuit as my final setup. For a good average I would need to use repetitions, and so I am going to conduct my experiment four times, this will ensure that my standard deviation and line of best fit would be more accurate, as any errors or anomalies wouldn't have as much impact on the line on my graph, as they would get smoothed out.

As the resistance of the bulb changes with the effect of temperature, as I have discussed, I am going to ensure that on all repeats, the bulb is around the same temperature so that this effect of temperature would be minimalised. To do this I am going to leave the circuit flowing for 1 minute before I take my readings, I have chosen one minute as it gives sufficient time for the circuit and bulb to warm up, but it isn't too long a time that my power pack may overheat.

IMPLEMENTING

This is how my final circuit looked; I have included the EMF of the power supply and the power of the lamp in this diagram.



After conducting my first repeat, I got the following results :

EMF	Voltage across bulb (V)	Current across bulb(I)	Resistance of bulb (V/I)
12	10	1.96	5.10
12	9	1.85	4.86
12	8	1.73	4.62
12	7	1.62	4.32
12	6	1.5	4.00
12	5	1.36	3.68
12	4	1.23	3.52
12	3	1.07	2.80
12	2	0.9	2.22
12	1	0.69	1.45
12	0	0	∞

On the second repeat I got the following results:

EMF	**Voltage across bulb (V)**	**Current across bulb (I)**	**Resistance of bulb (V/I)**
12	**10**	**1.55**	**6.45**
12	**9**	**1.46**	**6.16**
12	**8**	**1.36**	**5.88**
12	**7**	**1.26**	**5.56**
12	**6**	**1.16**	**5.17**
12	**5**	**1.04**	**4.81**
12	**4**	**0.92**	**4.35**
12	**3**	**0.78**	**3.85**
12	**2**	**0.63**	**3.17**
12	**1**	**0.4**	**2.5**
12	**0**	**0**	∞

On the third repeat I got the following results:

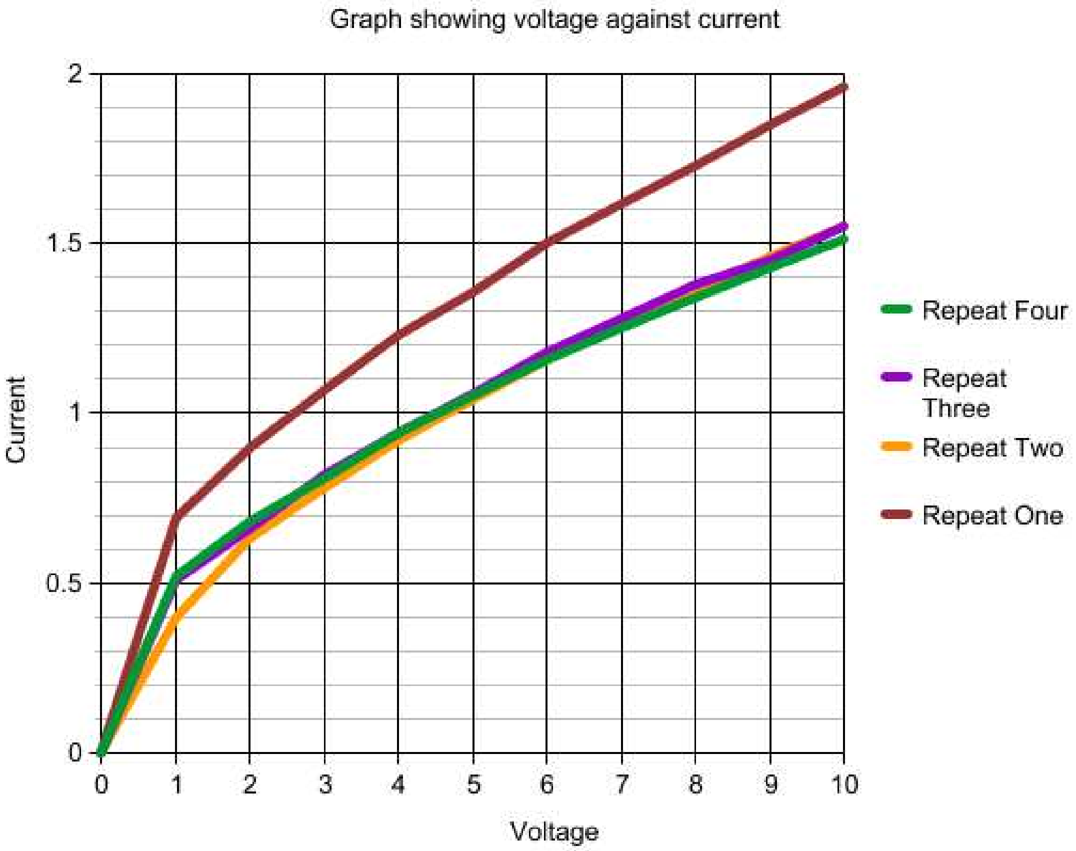
EMF	**Voltage across bulb (V)**	**Current across bulb (I)**	**Resistance of bulb (V/I)**
12	**10**	**1.55**	**6.45**
12	**9**	**1.45**	**6.21**
12	**8**	**1.38**	**5.80**
12	**7**	**1.28**	**5.47**
12	**6**	**1.18**	**5.08**
12	**5**	**1.06**	**4.72**
12	**4**	**0.94**	**4.26**
12	**3**	**0.82**	**3.66**
12	**2**	**0.66**	**3.03**
12	**1**	**0.51**	**1.96**
12	**0**	**0**	∞

On the forth repeat I got the following results:

EMF	**Voltage across bulb (V)**	**Current across bulb (I)**	**Resistance of bulb (V/I)**
12	**10**	**1.51**	**6.62**
12	**9**	**1.43**	**6.29**
12	**8**	**1.34**	**5.97**
12	**7**	**1.25**	**5.60**
12	**6**	**1.16**	**5.17**
12	**5**	**1.05**	**4.76**
12	**4**	**0.94**	**4.26**
12	**3**	**0.81**	**3.70**
12	**2**	**0.68**	**2.94**
12	**1**	**0.52**	**1.92**
12	**0**	**0**	∞

ANALYSING

So I can see the general trend of my results, and spot any anomalous data, I have drawn a simple I-V graph, which includes all my repeats.



As you can see from this graph, my repeats 2 to 4 are very similar but my first repeat isn't. This means that repeat one is anomalous data, and I won't use it when taking the averages of the resistance for each of the vo ltages, of each repeat.

When taking this standard deviation, of bulbs 2 to 4 , I get the following table:

Voltage	**Resistance (repeat2)**	**Resistance (repeat3)**	**Resistance (repeat4)**	**Average**	**Standard Deviation**
10	**6.45**	**6.45**	**6.62**	**6.51**	**0.1**
9	**6.16**	**6.21**	**6.29**	**6.22**	**0.07**
8	**5.88**	**5.80**	**5.97**	**5.88**	**0.09**
7	**5.56**	**5.47**	**5.60**	**5.54**	**0.07**
6	**5.17**	**5.08**	**5.17**	**5.14**	**0.05**
5	**4.81**	**4.72**	**4.76**	**4.76**	**0.05**
4	**4.35**	**4.26**	**4.26**	**4.29**	**0.05**
3	**3.85**	**3.66**	**3.70**	**3.74**	**0.1**
2	**3.17**	**3.03**	**2.94**	**3.05**	**0.12**
1	**2.5**	**1.96**	**1.92**	**2.13**	**0.32**
0	**0**	**0**	**0**	**0**	**0**

I decided that because I excluded my anomalous first repeat, my standard deviation was very small, so drawing error bars onto a graph would be useless.

RESISTIVITY OF MY BULB

Using the equation

$$R = \frac{\rho l}{A}$$

I worked out the resistivity for each repeat, then the average resistivity across all the repeats.

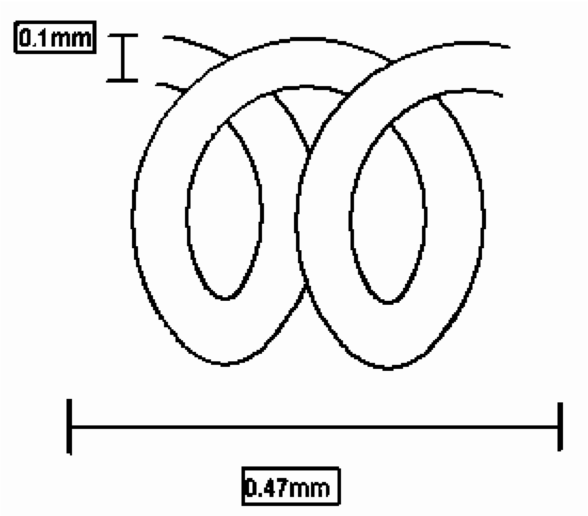
The re-arranged formula looked like this:

$$resistivity = \frac{resistance\ x\ cross\ sectional\ area}{length}$$

Or

$$\rho = \frac{RA}{l}$$

As we can see from the above formulas, I need to know the area of the filament in the bulb and the length of the filament in the bulb, I couldn't find these values for a 24 Watt bulb on the internet, so I have to crack open a bulb and using a micrometer and eyepiece graticule, I could examine these factors. Thankfully the bulb was a low voltage bulb and so only had a single coil, as higher voltage bulbs have a coiled coil, and which would be very hard to measure. The results I got were:



This basically means that the cross sectional area of the filament is:

Using πr^2 I worked out the cross sectional area to be:

0.03141mm

Inputting this into our equation I get

$$\rho = \frac{R\ x\ 0.03141}{l}$$

And I already have measured the length of the filament to be 0.47mm, so I can add this into the equation also.

$$\rho = \frac{R\ x\ 0.03141}{0.47}$$

And so to work out the resistivity for my bulbs, on each of the repeats, I just have to input R, being the resistance I recorded earlier , again I only used my last 3 repeats to avoid anomalous data.

In doing this I put my results into a table, and got:

Voltage	Resistivity bulb2(Ωm)	Resistivity bulb3(Ωm)	Resistivity bulb4(Ωm)	Average (Ωm)
10	0.431052128	0.431052128	0.442413	0.434839
9	0.411671489	0.415012979	0.420359	0.415681
8	0.392959149	0.387612766	0.398974	0.393182
7	0.371573617	0.365558936	0.374247	0.37046
6	0.34551	0.339495319	0.34551	0.343505
5	0.321451277	0.315436596	0.31811	0.318333
4	0.290709574	0.284694894	0.284695	0.2867
3	0.257294681	0.244597021	0.24727	0.249721
2	0.211850426	0.202494255	0.19648	0.203608
1	0.167074468	0.130986383	0.128313	0.142125
0	0	0	0	0

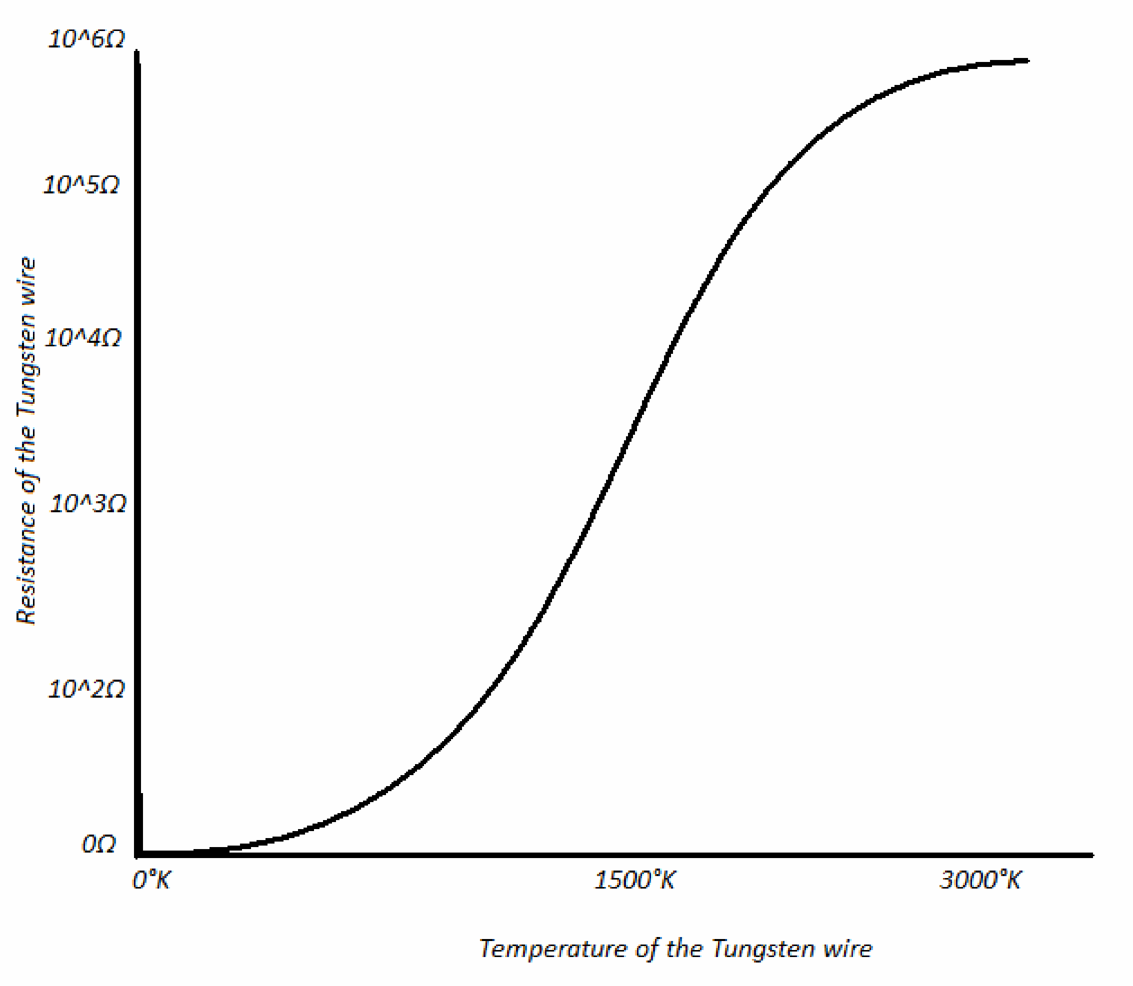
TEMPERATURE COEFFICIENT

As I have previously discussed, the resistance of a wire would be affected by temperature, as of the collision processes happening in the wire. This means that the resistance of a wire will increase as the temperature increased. This change is proportional, as the outcome (resistance) is dependent on the input (temperature or heat as coldness is just an absence of heat) and can be described by the equation:

$$\frac{\Delta R}{R_0} = \alpha \Delta T$$

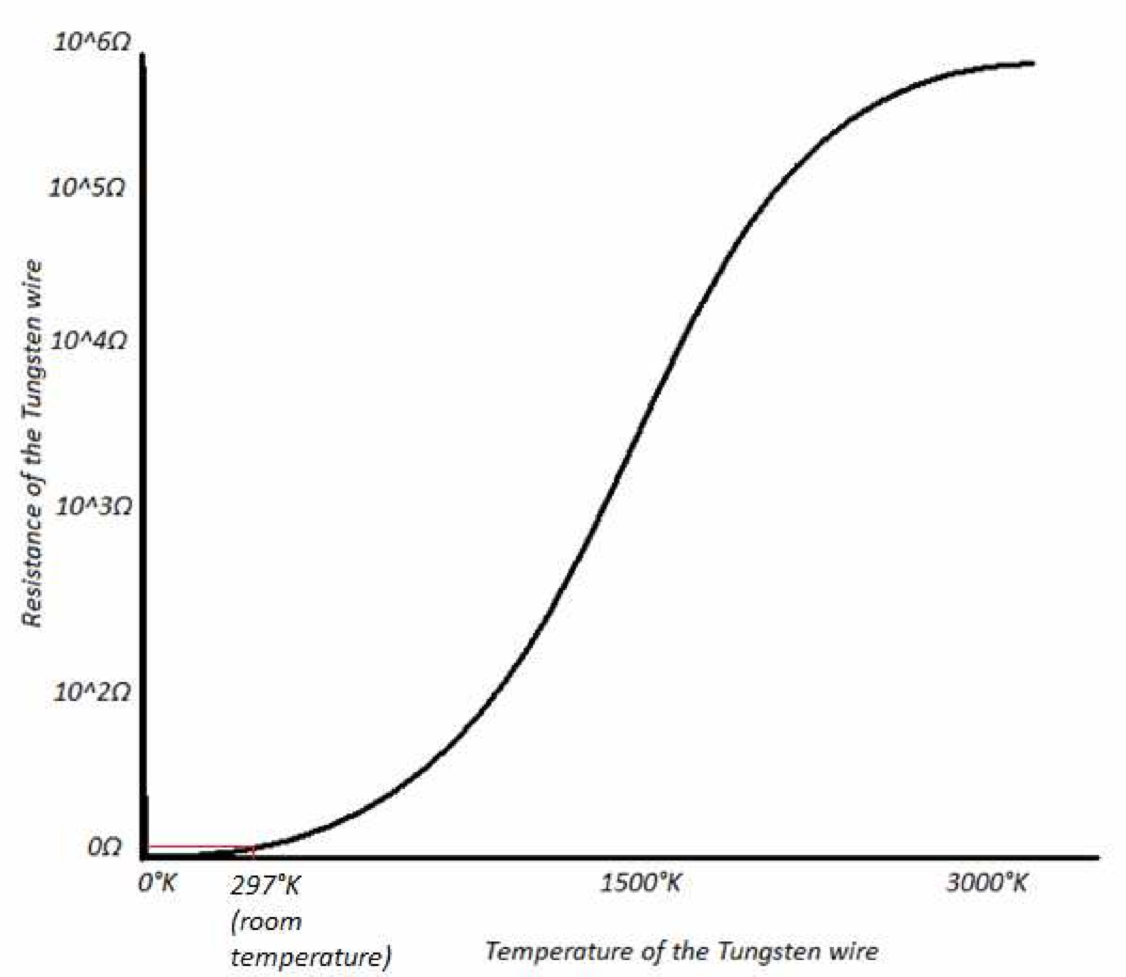
Where α is the temperature coefficient of resistance , R□ is the initial resistance, ΔR is the change in resistance and ΔT is the change in temperature. This equation basically shows what I have discussed, that the higher the temperature, or the larger positive change in temperature (which can be –ve or +ve) the greater the resistance and change in resistance. This is basically shown in my results, as I increased the voltage (which would thus increase the temperature) the resistance and resistivity increase.

The graph that shows the relationship between temperature and resistivity at high temperatures is as follows:



As we can see at absolute temperature (0°K) the resistance in the wire is 0 Ω, this is called superconductivity.
Superconductivity is where the resistance in the wire is 0 Ω and there is no interior magnetic field in the wire.

Also from the graph above I can predict what the resistance of my wire would be at room temperature.



As you can see it's quite a small resistance in comparison to the resistance at higher temperature (like when I turn my bulb on). This graph also demonstrates the amount of resistance there is in the tungsten filament when it heats up.

To make it the resistance at room temperature clearer I drew out this graph:

OTHER EQUATIONS

Working out the resistivity, resistance, voltage and current means I can also work out a lot of other values in the circuit, such as the energy in the circuit and the power i n the circuit.

The power in the circuit can be worked out by:

$$P = I^2R$$

Where I is current, R is resistance and P is power . Using this equation I have worked out how power corresponds to resistivity as you can see in my table below.

Voltage (V)	Power (W)	Resistance (Ω)
10	15.094262	0.434839
9	12.862421	0.415681
8	10.719732	0.393182
7	8.75	0.37046
6	6.956752	0.343505
5	5.2479	0.318333
4	3.764136	0.2867
3	2.42757	0.249721
2	1.359456	0.203608
1	0.519168	0.142125
0	0	0

The other value I can work out is Energy used . I can do this by using the equation

$E = VIt$

Where E is energy, V is volts, I is current and t is time. So if I say that I took the measurements at 6 volts in 30 seconds, then I can work out the energy used up in those 30 seconds by inputting my other data values. At 6 volts my current was 1.16 and if I left the bulb running for 30 seconds, using the formula above I can work out that I used up 201.6 joules

EVALUATION OF EXPERIMENT

I think my experiment yielded good results because they had very small error bars and so proved to be precise. They were also reasonable and what I expected so they proved to be reasonably accurate.

I expected the resistivity to increase as voltage increases. I deduced this from using the two equations:

$R = V/I$

Where, as I increase the voltage, the resistance increases and according to

$$R = \frac{\rho l}{A}$$

As the resistance increases so does the resistivity and so an increased voltage increases resistivity. This is reflected in my results.

I think that my experiment went well, I used suitable procedures which worked, and I got sensible results. I did however receive some anomalous results in my first repeat, but I excluded these from my data.

The actual limitations of my experiment that I couldn't control were things like, external temperature, obviously the limitations of the equipment I used couldn't control the environmental temperature around the experiment, so I haven't taken into account any change in temperature as it is out of my control so I couldn't do anything about it. Also the accuracy and precision of my voltmeter and ammeter would have an effect on my results, this would cause a systematic error and so my graph's gradient and thus calculated resistance would still be the same. There could also be random fluctuations in the school's power supply, or in my power pack, which could result in a temporary random error in my results. I don't think this happened though, as all my data was very similar, excluding the first repeat. Apart from these factors I think my results are reasonably accurate and precise, they were what I predicted and my 2nd, 3rd and 4th repeats proved to be precise.

I think next time I conduct this experiment; I could do it in a controlled atmosphere, so environmental factors, like temperature and pressure don't have as much of an effect.

The actual value of resistivity for tungsten is 0.0000000528 Ωm at room temperature. The value I got for this according to my results is: 0.0000054 Ωm. This difference would be because of the level of control and accuracy that I had over my equipment and environment. I think that to do this experiment and get the results nearer the standard value of resistivity for tungsten I would need to have this control over the environment, I would need to do more repeats, I would n eed to take a lot of other factors into account and I would need to use expensive voltmeters and ammeters, that will provide a better accuracy and precision.