Physics Coursework

Characteristics of Ohmic and Non Ohmic Conductors

Every part of matter is made up of atoms. **Atoms** are called the building blocks of nature. These atoms consist of a nucleus and shells. The protons and neutrons are part of the nucleus and the electrons are distributed in shells around the nucleus. The protons have a positive charge, neutrons are not charged and the electrons are negatively charged. Electrons have no overall mass while neutrons and protons both have a mass of 1 unit. This is how the relative atomic mass is calculated, by adding up the number of protons and neutrons. The electrons are distributed in the shell in order of the amount of energy that they hold. So according to that I will introduce the concept of electricity.

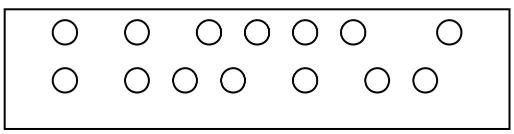
Electricity is a flow of electrons. Electricity can be transferred by some materials and some cannot transfer it. **Conductors** are any materials or substances that can allow heat or electricity to pass through them. Conduction means that heat or current is transferred from atom to atom on its way out. Some materials are good conductors; some are bad conductors while some do not conduct at all. Such materials or substances that do not allow heat or current to pass through are called **insulators**. These insulators usually do not have enough electrons to carry the current and thus they are non-conducting substances. One example is plastic. Electrons carry current. In a substance that has many **free electrons**, current can be carried. Free electrons means that these electrons do not belong to the atom because they are very far from the nucleus and so they can escape easily. These free electrons make certain substances conductors. They are either very far from the nucleus or they are electrons that were part of a bond but now are not part of the ionic bond, thus they are in excess. The free electrons are those electrons that are transferred from a positive to a negatively charged ion. This is called the free electron theory. Electricity is basically the transfer of electrons from one atom to the other. In conductors, the atoms are moving in different directions. But when the potential difference is applied between the ends of the conductor, the atoms line up and move to one direction.

Electric conductivity means that a certain substance can carry an electric current. **Current** is a flow of electrons. So the material that can conduct electricity has to have free electrons to carry this current. Some substances such as the metals cannot be used as solids for electrolysis. Although they are good conductors, when they are solid they do not have the free electrons that are needed for electrolysis because they are solid but they can be used in electrical circuits even though they are solid. Whereas, when they are molten, the electrons are free to move and carry current. The atoms are free and even if electrons have to pass through, they can do so easily. This is true for the ionic compounds. These compounds act like this because their atoms are all combined by transfer of electrons and when they are molten, these atoms are free to carry current because there is no longer a bond between the substances. The electrons that are arranged on the outer shell of the atoms are usually found to be the free electrons. This is because they are far away from the nucleus and thus can be used to carry charges more easily and so they are used. Covalent substances do not usually conduct electricity because the electrons are all shared between the substances and there are no extra or free electrons that can be used to carry charges. Plastic is an example of a covalent substance.

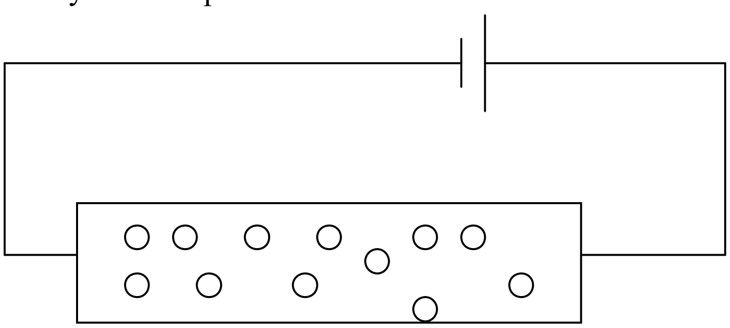
In circuits an **ammeter** is used to measure the current, which is measured in amps, and it is connected in series always. Amps is a measure of the amount of current flowing through the circuit. If the current given is low, then a milliammeter is used. However, for voltage, the **voltmeter** is used and is connected in parallel. It measures the voltage or potential difference in volts. Voltage is the ‘push’ that is applied onto the electrons so that they move through the circuit. The battery or cell provides an electromotive force. This force pushes the electrons into the circuit. From this perhaps we can understand that when the voltage increases, the amps also might increase. From the readings of these two components, graphs are drawn.

When we have to check if the certain substance conducts we can place it in a circuit. When a metal is placed in the circuit, an **electric field** is created. This electric field has charges and these charges have forces on them. So the electrons are accelerated and gain velocity and energy. They will collide with atoms that are vibrating in their lattice site and give some of their energy to it. When they slow or stop the energy is again provided to them by the electric field and they accelerate. The charges thus move to one side and this called a current. The circuit that can be used should consist of a power (d.c. supply), connecting wires, a bulb and the object to be tested. The bulb is used to show whether the substance conducts or not. If correct accurate reading regarding the current and the voltage has to be taken, then the ammeter is connected in series and the voltmeter in parallel. This way we will know how much current is flowing through the circuit if the object is a conductor.
If the object is an insulator then the bulb will not light up and the ammeter will not show any reading.

This is a conductor when no potential difference is applied.



When a potential difference is applied between the ends of the conductor, as shown in the previous circuit, they all line up to move to one side. This is the structure after the potential difference is applied.



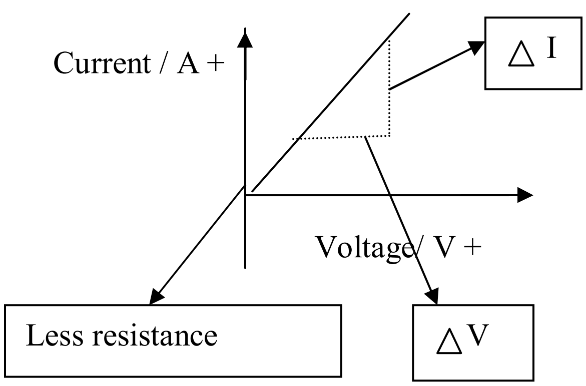
The resistance in metallic conductors increases as temperature increases. The resistance increases because the atoms of the metal start to vibrate and so making it difficult for electrons to pass through. This increases resistance. So whatever the amount of electrons provided, the current will decrease because the resistance has increased. In semiconductors the conductivity varies from the types of semiconductors. There are two types intrinsic and extrinsic semiconductors. This way there is no definite rule for these materials. So this would have to be seen only when I deal with the semiconductors separately.

Silicon and germanium are semiconductors. **Semiconductors** are materials in which the amount of current increases with temperature. So this means that they are better to use if the temperature is high. Since we have now discussed the conductivity of certain substances and the free electron theory, I would now like to introduce the ohmic and non ohmic conductors.
Ohm's Law states that the current flowing through a certain conductor is proportional to the voltage given that physical factors such as temperature are kept under control and constant. Some other factors also affect the ohmic conductors.
There are normally two types of conductors. The two types of conductors are ohmic and non ohmic. **Ohmic Conductors** such as a pure metal such as copper or tungsten obey Ohm's Law given that the temperature and

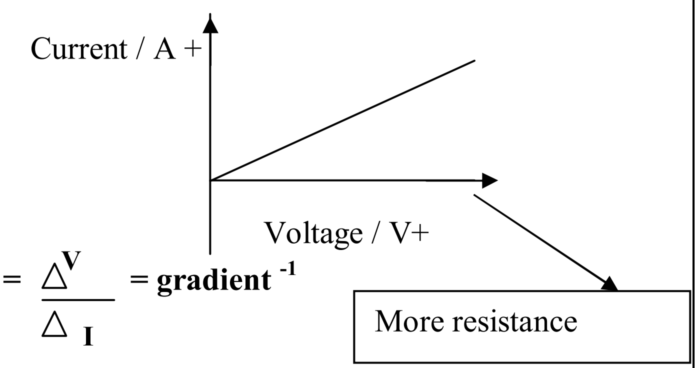
pressure at kept low and constant. The others that do not obey Ohm's Law are called **Non Ohmic Conductors**.

Conductors such as pure metals are ohmic conductors. In this case the ohmic conductors have to be kept under **constant pressure and constant temperature** for them to behave as ohmic conductors. The resistance does not vary according to the current, it remains constant. The current flowing through it also has to be kept less because then it will lose its property of being an ohmic conductor. The temperature at which the metal is used will change as the current flowing through it. To prevent this we have to keep the current value low otherwise it will lose its property of being an ohmic conductor. This is called the **heating effect**. The current that is carried through the metal is due to the free electrons so when the amount of current passing through the wire. When the current is passed through the atoms vibrate more and collide with some of the other atoms and then give out this kinetic energy. Thus as the current flows the kinetic energy of these atoms is increased. Thus this energy is lost as heat and so makes it difficult for the electrons to pass through. The amplitude of the vibrations of the atoms increases and more 'collisions' with atoms are caused by the electrons. Therefore the resistance increases with temperature. This means that it is no longer an Ohmic conductor. The graph that is drawn from taking the reading of current and voltage in a circuit, when the temperature is kept at a low value such as 1 or 2 A is as shown:

Aluminium



Nichrome



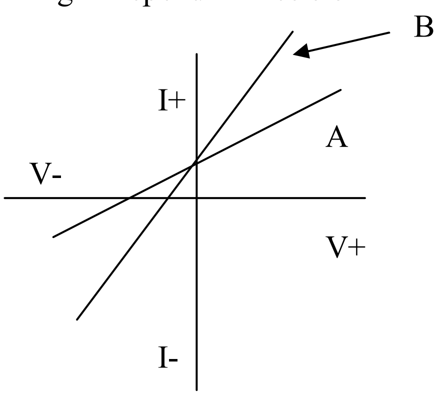
Resistance = $\frac{\triangle V}{\triangle I}$ **= gradient** $^{-1}$

This shows that the line that is formed is a straight line passing through the origin. The first graph and the second graph show a difference in how good each of the conductors is. Comparatively the conductor from which the first graph is drawn is better than that of the second one because although both obey ohm's law by increasing in proportion, the second one increases to a lesser extent so the resistance is more. This means that both are ohmic conductors. We can compare the conductors to be aluminium and nichrome as the two different conductors used in these cases. Nichrome will be the one from the graph on the right is deduced and the graph on the left is from Aluminium. This shows that although both are ohmic conductors, they have different conductivity and that Aluminium conducts better than Nichrome because the graph is steeper. We can deduce that aluminium has more free electrons than nichrome. Thus it is able to carry more electrons and is a better conductor because it has less resistance.

According to the above given formula, the resistance can be noticed by the gradient. The gradient of the graph of Aluminium is more and so the resistance will be less. This will quite the opposite for nichrome. So therefore the Aluminium has less resistance we notice from the graph.

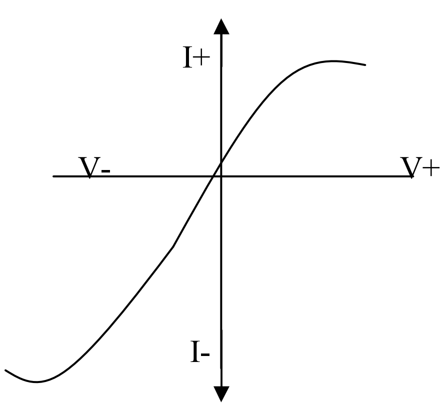
Non ohmic conductors are those that do not obey Ohms Law. This means that the resistance of these conductors changes with current and that the current and the voltage are not proportional. There are different non ohmic conductors. The non ohmic conductors are more useful in industry such as radio receivers. Some of the non ohmic conductors are semi conductors and metallic filaments. The metallic filaments are actually ohmic conductors but when the temperature changes or the current changes or rather, increases they become non ohmic and the shape of the graph changes. The semi conductors such as silicon or germanium are also non ohmic conductors. The semi conductors are again divided such as intrinsic and extrinsic.
The graphs that are obtained from the various non ohmic conductors are as follows.

Light Dependant Resistor

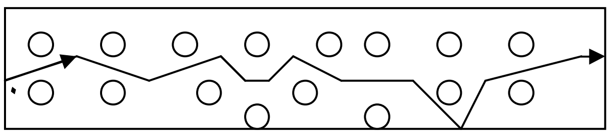


This shows that the listed components are not ohmic conductors. There is no uniformity in the graphs and that the current is not proportional for any of these substances.
LDR. This is the light dependant resistor. The graphs here show the resistance in bright and dimly lit rooms. The LDR reacts differently. The light sensitive part of the LDR is a wavy track of cadmium sulphide. Light energy triggers the release of extra electrons to carry the current when the level of illumination changes accordingly. The line A marks the LDR in the shade while the line B marks the LDR in sunlight. It shows that in the sunlight the graph is more steep and in the shade it will be less steep. The straight lines do not mean that the LDR is an ohmic conductor. The light intensity remains the same. But if the light intensity were to change the resistance also would change. When the value of current is limited the graph is linear whereas when the value of current is not limited the graph would be a curve. The different lines that have been drawn from different light intensities prove this. This proves it is a non ohmic conductor.

Filament Bulb

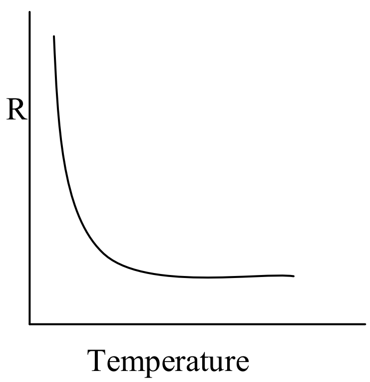


Filament Lamp. The filament lamp is a metallic conductor. Metallic conductors are ohmic conductors. But when the temperature is increased, they are no longer ohmic conductors and thus the resistance changes. According to the free electron theory, the atoms do not allow the electrons to pass through when the temperature is increased. This is the structure if the temperature is increased. Usually tungsten is used because it changes from ohmic to non ohmic only at a very high temperature. At the beginning we can see that the line is straight (linear) but as the amount of current is increased, heating takes place and so the temperature increases. When this happens, the resistance increases and so the amount of current flowing increases but at a slower rate as we can denote from the curve.
Metals are non ohmic conductors at high temperatures. This is shown in the next diagram as to why this it is like this.

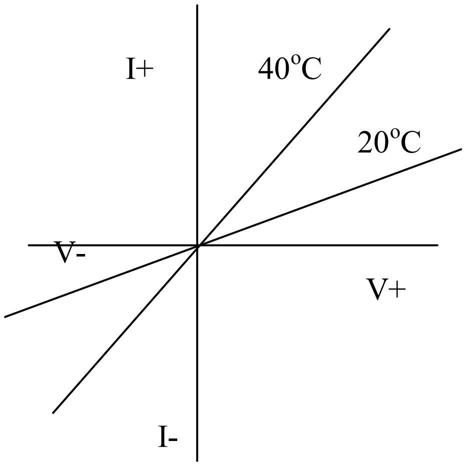


The arrows are marking the path of the free electron. From this we can see because the temperature has been increased, the atoms start vibrating and may even start to move about. This causes the path of the free electron to become distorted and thus it cannot pass smoothly. So it takes time and thus the resistance increases with temperature. This is true for the filament bulb and states the effect of temperature on a metal.

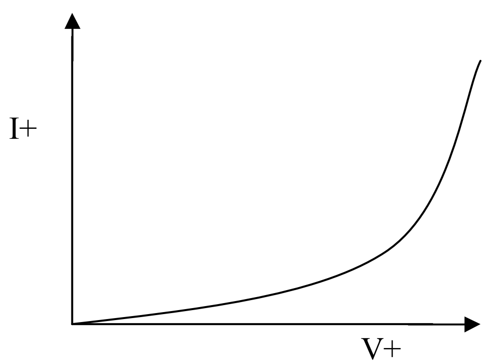
Negative Temperature coefficient Thermistor



In the graph for the Thermistor the axis used are Resistance and temperature. The resistance in ntc (negative temperature coefficient) thermistors increases as the temperature decreases and the resistance decreases as the temperature increases. This is because the as the temperature increases, more electrons become available to carry the charges and so the resistance decreases. In the graph temperature has been used because from this we can deduce the voltage and the current. This is true for all the rest of the semiconductors such as Light dependant resistor, light emitting diode and thermistors. Below shown is the graph for thermistors in general at different temperatures



For the given Thermistor the graph shows the different resistance in different temperatures. At 40°C, there will be less resistance because as we already know the temperature causes the electrons to be freed and carry the current. The thermistor also cannot be taken to be an ohmic conductor because of its straight graph. We can understand from this that the amount of current increases when the temperature increases. This means that the thermistor is not an ohmic conductor. If we take the graph of a normal thermistor we will get a graph like the one shown



This graph proves that the thermistor is not an ohmic conductor.

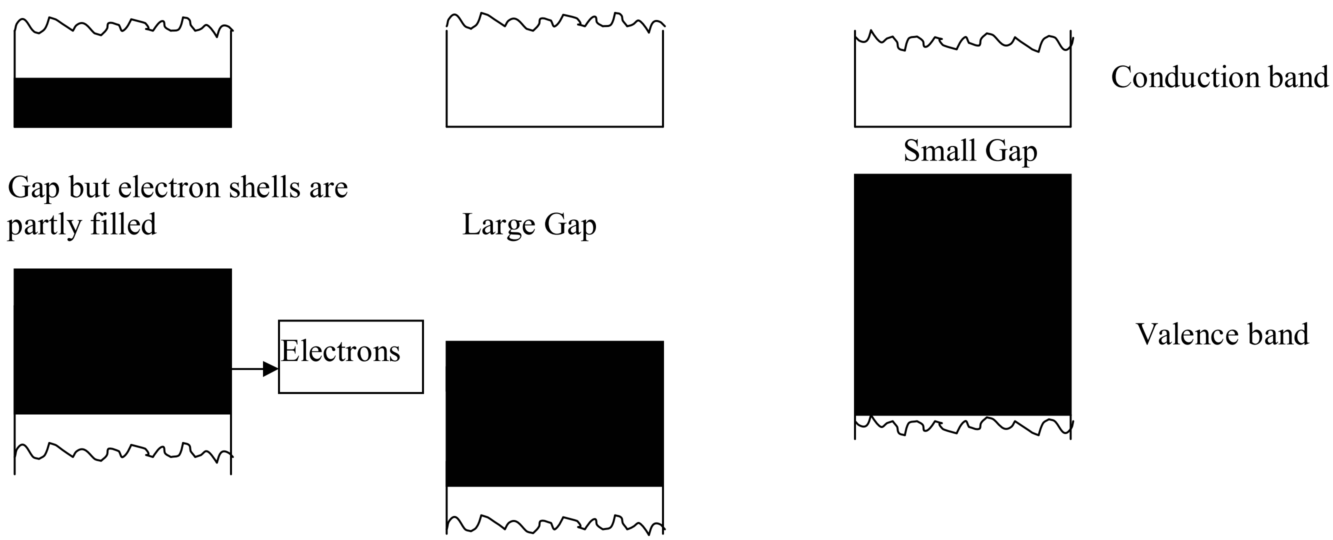
The main differences between the ohmic and non ohmic conductors are as follows

Ohmic Conductors	Non Ohmic Conductors
The magnitude of current remains unchanged when the current or the voltage is reversed.	The magnitude changes as displayed from the above graphs.
The current is proportional to the voltage.	The current is not proportional to the voltage.
Temperature affects current and resistance.	Different factors affect it such as light and temperature.

Since we have now seen what ohmic and non ohmic conductors are, we should also see the details of the semiconductors and the energy band theory.
Semiconductors usually have four electrons in the outer electron shell. They are **tetravalent**. These are called valence electrons. The structure that is formed is a tetrahedral structure. This forms a crystalline structure. There are two types of semiconductors. One type is the **intrinsic semiconductors and the extrinsic semiconductors. Intrinsic semiconductors** are elements and compounds that are semiconductors. Examples include Silicon and Cadmium. When they are in a solid state, the silicon atoms form a covalent bond among themselves to form a lattice. Since they form a covalent bond, they will not conduct electricity as there are no free electrons that will be used to carry the current. So when the lattice is in solid state at 0 K is an insulator. When the temperature reaches room temperature, the valence electron gains enough thermal energy so that the energy that binds them to the nucleus. The covalent bond breaks and so the electron leaves the atom that it is in. This leaves a hole in the atom and it becomes positively charged. Once this happens it is capable of attracting an electron from another atom and the electron from this atom. So now this hole moves from atom to atom and as this happens, the electrons also move from atom to atom, as a result the electrons move along the lattice and thus carry current. So we can deduce that from this that in semiconductors the resistance decreases as the temperature increases. This we already know from this applies to all the semiconductors.
Extrinsic semiconductors are made from intrinsic semiconductors. Adding tiny amounts of another substance makes them extrinsic. The amounts added are very little so that the added atoms are well spaced from each other. This is so that the structure remains the same even if the property changes. These atoms are called impurity atoms and these are used so that it does not form unreliable substances.

Since we have dealt with the conduction of the ohmic and non ohmic conductors, I would like to deal specifically with the **energy band theory**. This theory is linked to the conduction of all these substances we have looked at.
To understand energy bands we need to first see what valence electrons and conduction electrons are. **Valence electrons** are those electrons that are on the outside shell of the atom. In silicon there are 4 valence electrons. For Hydrogen there is 1 valence electron. So when the atoms come together as a cluster they form a lattice. In this lattice the valence electrons come together to form what we call a valence band. This band consists of electrons from the outermost shell of the atoms that form the lattice. The atoms all do not form a single band. There are bands for the first shell, second shell, etc. This is also known as the **energy ladder**. This is formed because the thermal energy is increased and so the electrons move up the shells as they gain energy. The energy levels spread out into bands. The bands increase in size as the temperature increases. This energy band theory can be used to explain the conductivity of semiconductors and metals.
In metals the highest band is only partly filled. This allows the electrons to move up the bands to the unfilled layers. So the electrons have now escaped from the atoms and become free to move through the material. This is called the conduction band. The space between the valence band and the conduction band is very little and thus the metals are able to conduct electricity.
In insulators we can assume that the gap between the valence and the conduction band is more because there is no electron jumping and so no conduction as in the metals. This proves that the outer shell of these materials is full and held firmly to the atom. The conduction band is thus empty. This proves why they cannot conduct electricity.
In intrinsic semiconductors the gap between the valence band and the conduction band is not too much. The electrons can jump across is enough heat is applied. This is true after absolute zero so they would conduct even at room temperature. When the temperature applied is more, more electrons jump across to the conduction band and so the semiconductor can conduct better in increased temperature. The electron jumping

across to the conduction band corresponds to the electron breaking away from an individual atom. It will be called a conduction electron.
The idea of the energy bands is shown below:



The gaps between the valence and the electron bands are the energy gaps.

Now that we know of the semiconductors. Insulators and ohmic and non ohmic conductors we will carry out experiments by forming circuits to check these. For this we first need to plan out the experiment and then perform it. This is shown next.

Now that we have see theoretically what the semiconductors, conductors and insulators are, we have to plan out the experiment. The experiment has to be carried out under certain conditions. Theses conditions we will see now. The tables and the graphs shown will be filled up after the experiment has been carried out.

We will have to carry out the experiment for different materials to note down the readings on the voltmeter and ammeter. The different apparatus that will be used for the experiment are:

- ✓ Nichrome
- ✓ Aluminium

(Nichrome and Aluminium → Length- 60 cm, Thickness- 0.5mm)

- ✓ Filament bulb
- ✓ Bulb holder
- ✓ Thermistor
- ✓ Light Dependant Resistor
- ✓ Digital Ammeter – 20 A
- ✓ Digital Voltmeter – 20 V
- ✓ Rheostat
- ✓ D.C. Supply (Range – 0V--- 12 V)
- ✓ Beaker
- ✓ Plastic Stirrer
- ✓ Tripod Stand
- ✓ Thermometer
- ✓ Oil
- ✓ Bunsen Burner
- ✓ Connecting wires
- ✓ Crocodile Clips

The ammeter is a milliammeter because the current will be in milliamps and so this instrument will be easier to measure the current. The other factors for the metallic wires remains constant and does not change.
The nichrome and the aluminium will be used to check the effect of temperature and the reason these two are chosen is the difference in the level of conductivity. Nichrome has less conductivity than aluminium. The other apparatus used will be the LDR, thermistor. They will be used as the non ohmic conductors. The thermistors will however be tested using oil. This oil will be heated as I will explain later. The rest of the supplies also we will see as we study each of the experiments.
The first experiment will be one for the metal wires, LDR, thermistor and bulb. The circuit diagram looks like this. This circuit diagram will be used to find the IV characteristics of the above components.

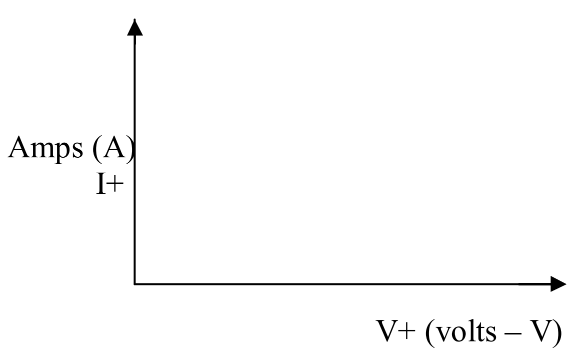
The procedure that involves the above circuit is used for the metallic wires, LDR, filament bulb and also a thermistor. The metallic wires are the ohmic conductors and so will be used to prove Ohms' Law. Whereas from the bulb we will see that the metals do not obey Ohm's Law when excess current is passed through them. The circuit has to be set up as given above. The wires have to be taken of the accurate sizes and thickness as this also affects the resistance of the wire. The rheostat is also attached. The D.C. supply has to be applied to the circuit. The connections can be anyway, positive and negative or negative and positive. We should still get a straight line through the origin. This is one of the characteristics of ohmic conductors. The rheostat will be used to vary the current. Once the ammeter has been set up in series and the voltmeter in parallel, the crocodile clips have to be attached to the metal wires. Using the rheostat we vary the current in steps of 0.1 V and then check the corresponding value of current by checking the ammeter. The reading on the voltmeter can keep the values in check. The readings will then be taken down in a table as shown below. There have to be 10 readings and the current should not exceed more than 1 A, as this will cause the heating effect.

For each of the tables used in the planning I have decided to use a separate column for the decreasing current as a method of checking the accuracy of the readings obtained while the voltage was being increased.

Nichrome wire

Voltage (Volts) V	Current (Amperes) A Increasing	Current (Amperes) A Decreasing	Current Average	Resistance (ohms)
0.1 V				
0.2 V				
0.3V				
0.4V				
0.5 V				
0.6 V				
0.7 V				
0.8 V				
0.9 V				
1.0 V				

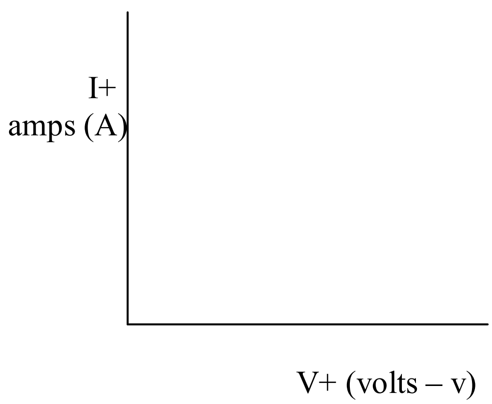
The row decreasing current has been drawn to check the accuracy of the readings with the increasing current. Both the values should be the same. If they are not then we will know that some factor has affected it.
The graph for the nichrome wire can be drawn.



The next one is for the Aluminium wire. The aluminium wire is placed between the points X and Y. The voltage will again be varied in steps of 0.1 V.

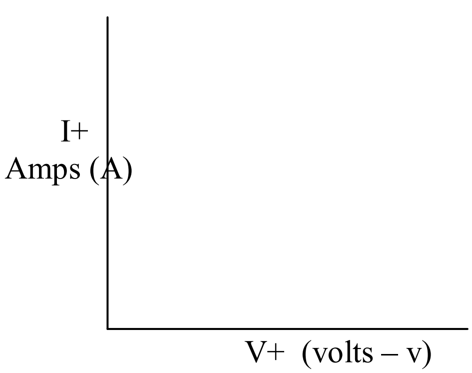
Voltage (Volts) V	Current (Amperes) A Increasing	Current (Amperes) A Decreasing	Current Average	Resistance (ohms)
0.1 V				
0.2 V				
0.3 V				
0.4 V				
0.5 V				
0.6 V				
0.7 V				
0.8 V				
0.9 V				
1.0 V				

The graph for the wire can be drawn.

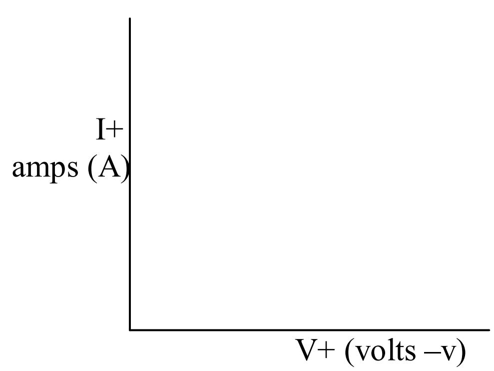


If we compare the two graphs we will see that both conduct electricity but aluminium is a better conductor than nichrome as it has a steeper graph.

Aluminium



Nichrome

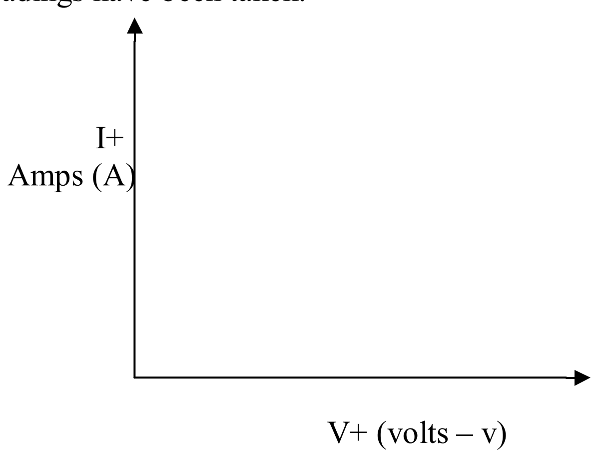


Filament Bulb

This experiment will be done to confirm that the metals also can be non ohmic conductors when subject to high temperature due to the passing of high amounts of current. The same circuit is applied as for the metallic wires. Here the wires can be bound around the lower part of the bulb or else the bulb can be placed in a holder and the wires can be connected to the screws of the holder. So this way we can make sure that the wires are firmly placed and that the readings will be accurate. The value of current can be varied by the rheostat and thus the current will vary. Here the only difference is that we have to pass a high value of current and so the readings can be taken and the graphs can be drawn and compared. The following table can be used. This table is appropriate because the value of current does not need to be limited so I will vary the voltage in steps of 0.4 using the rheostat.

Voltage (Volts) V	Current (Amperes) A Increasing	Current (Amperes) A Decreasing	Current Average	Resistance (ohms)
0.4 V				
0.8 V				
1.2 V				
1.6 V				
2.0 V				
2.4 V				
2.8 V				
3.2 V				
3.6 V				
4.0 V				

We have to check the current with increasing voltage when more voltage is applied. The graph has to be drawn after the readings have been taken.



Light Dependant Resistor

The circuit will remain the same. Only the light intensity changes. This means that at one time the circuit will be placed in the dark or a dimly lit room and then the readings of current and the resistance can be taken. As we know the resistor has to be connected between the points X and Y. The following tables have to be drawn.

Brightly lit

Voltage (Volts) V	Current (Amperes) A Increasing	Current (Amperes) A Decreasing	Current Average	Resistance (ohms)
0.1 V				
0.2 V				
0.3 V				
0.4 V				
0.5 V				
0.6 V				
0.7 V				
0.8 V				
0.9 V				
1.0 V				

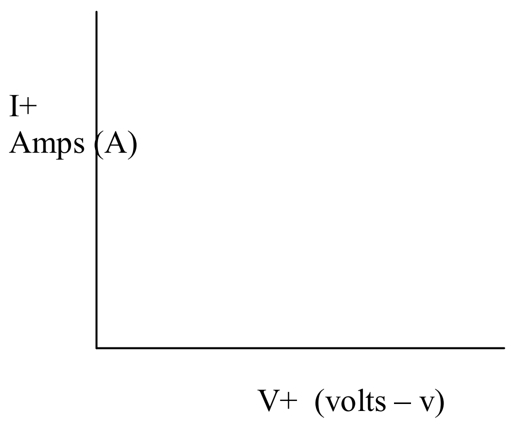
This will be for the brightly lit room. Or when the LDR is covered. This will give the following results as when the voltage is varied in steps of 0.1

Dark or dimly lit room

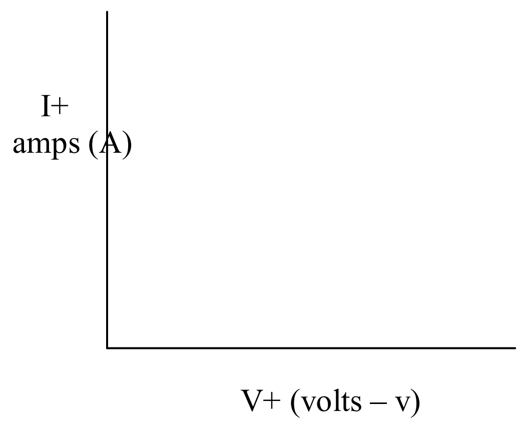
Voltage (Volts) V	Current (Amperes) A Increasing	Current (Amperes) A Decreasing	Current Average	Resistance (Ohms)
0.1 V				
0.2 V				
0.3 V				
0.4 V				
0.5 V				
0.6 V				
0.7 V				
0.8 V				
0.9 V				
1.0 V				

This is for the dimly lit room. The graphs have to be drawn on the same axis so that we can compare them.

Dimly lit room



Brightly lit room.

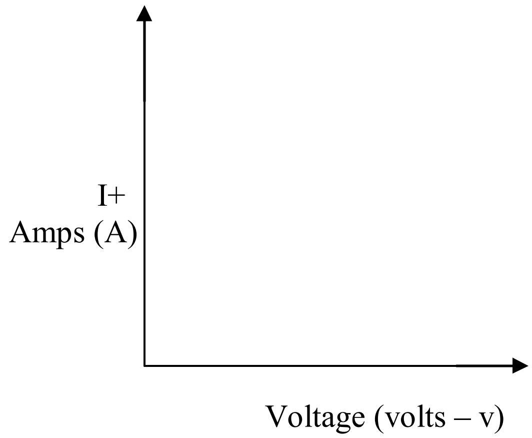


Thermistor

The next will be for the thermistor. The experiment for the thermistor is done in two ways. One will be the circuit as shown above. This will compare the voltage and the current and the resistance and the second one will compare the temperature to the resistance. The thermistor is placed along the gap X and Y and then the current is passed through the circuit. The temperature will be room temperature and then to alter the readings we can also change the temperature of the surroundings to get the voltage and the current and thus find out the resistance. The following table can be drawn.

Voltage (Volts) V	Current (Amperes) A Increasing	Current (Amperes) A Decreasing	Current Average	Resistance (Ohms)
0.1 V				
0.2 V				
0.3 V				
0.4 V				
0.5 V				
0.6 V				
0.7 V				
0.8 V				
0.9 V				
1.0 V				

This we can see for the various temperatures and note it down. The graph can be seen as



The thermistor as we have seen has to be experimented in two ways. In the above experiment we investigated the IV characteristics of the thermistor. Now we will see the other experiment in which the thermistor is immersed in oil and then the oil is heated. The circuit is shown below

The connecting wires are joined onto the supply. The circuit is thus set up as shown above.

The following table can be drawn

Thermistor

For this the voltage will be constant. However voltage can be listed in the table to calculate the resistance. But here I have not inserted it because it will be confusing. 30^0C has been chosen as the starting temperature according to room temperature.

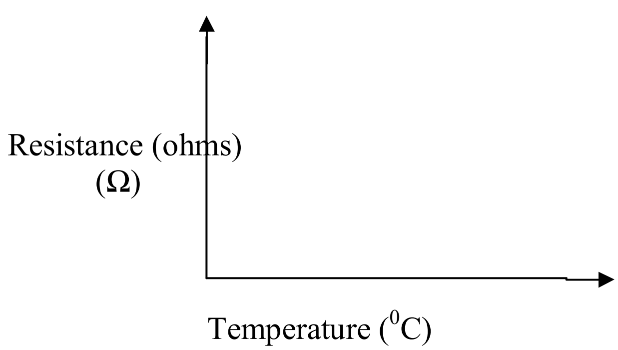
Temperature (^{0}C)	Current (Amperes) A	Resistance (ohms)
30^{0}C		
40^{0}C		
50^{0}C		
60^{0}C		
70^{0}C		
80^{0}C		
90^{0}C		

This was for when the temperature is rising. Now to check this we have to draw a table for the cooling.

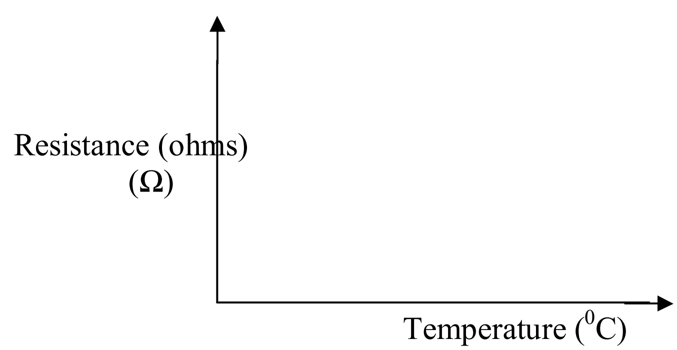
Temperature (^{0}C)	Current (Amperes) A	Resistance (ohms)
90^{0}C		
80^{0}C		
70^{0}C		
60^{0}C		
50^{0}C		
40^{0}C		
30^{0}C		

From that we can draw a graph, either for resistance and temperature for cooling and heating.

Heating



Cooling



While doing the experiments, it is important to know the safety measures taken. The safety measures taken are not only for personal safety but also for the accuracy of the reading of the experiment.

- The oil should be placed in a beaker carefully and not touch any other part of the circuit except for the thermistor.
- Gloves should be worn when handling the hot oil or the Bunsen burner.
- Goggles should be worn in case the oil splashes out.

- The table should be used to check the accuracy of the results noted down by checking the reverse such as decreasing the voltage, temperature, etc.
- It should be noted whether the connections are positive or negative from the supply to the ammeter and voltmeter.
- The ammeter should be connected in series and the voltmeter in parallel.
- The apparatus and the circuit should be placed in order so that they do not fall.
- The experiment can be repeated so that the results can be verified easily.
- Precaution must be taken from the hot oil so that there are no burns.

Prior Test

Before the actual experiment is carried out, it is necessary to carry out the experiment first and then take the readings. This will help us follow the procedures correctly.

For the prior test I was provided with the following:

- ✓ Cells
- ✓ Connecting Wires
- ✓ Digital Ammeter – 20
- ✓ Digital Voltmeter 20 V
- ✓ Nichrome. Thickness – 0.45 mm and length 80 cm
- ✓ Rheostat
- ✓ Crocodile Clips

From this we can notice the difference in the actual apparatus I have listed before. Below given are the differences in the specifications in difference to carry out the experiment for the IV characteristics for the metallic wires. The thermistor and the LDR have not been used so the differences involving them cannot be justified.

Plan	Prior Test
Length of Nichrome wire	
60 cm	80 cm
Thickness of wire	
0.5 mm	0.45 mm
D.C Supply	Batteries/Cells

Besides these the rest of the apparatus remains the same. I performed the prior test only for one metallic wire, in this case Nichrome. This is just to get an idea of the working of the circuit and how to set it up. I was given a briefing into how it is supposed to be done.
The components are not all listed down according to the first plan because this is only the test run and only one conductor is used in the position marked X and Y. So here I have been provided with Nichrome wire of the above specifications. The circuit will remain the same. The ammeter is set as to the correct value. Then the experiment was carried out involving Nichrome. The following results were obtained.

Voltage (Volts) V	Current (A) Increasing	Current (A) Decreasing	Current average	Resistance (ohms)
0.1 V	0.010 A	0.010 A	0.0100 A	10 Ω
0.2 V	0.020 A	0.019 A	0.0195 A	10.2 Ω
0.3 V	0.030 A	0.029 A	0.0295 A	10.17 Ω
0.4 V	0.040 A	0.040 A	0.0400 A	10 Ω
0.5 V	0.050 A	0.060 A	0.0550 A	9.1 Ω
0.6 V	0.060 A	0.070 A	0.0650 A	9.23 Ω
0.7 V	0.080 A	0.070 A	0.0750 A	9.33 Ω
0.8 V	0.090 A	0.080 A	0.0850 A	9.4 Ω
0.9 V	0.110 A	0.130 A	0.1200 A	7.5 Ω
1.0 V	0.130 A	0.120 A	0.1250 A	8 Ω

As we can see here the current does not exceed 1 A and thus the prediction is that it should form a linear graph because the resistance is almost constant and so this proves that there was no heating effect.

The graph is more of a scatter diagram. The line is not exactly straight due to experimental errors that may have occurred. Even the average of the current taken makes a difference as they have been rounded up. The graph is however linear if the line is of best fit and this will give us that nichrome is an ohmic conductor because the current and the voltage are proportional and that the resistance remains nearly the same. The resistance can be calculated using the formula Resistance = gradient $^{-1}$ and according to that the resistance will be

$$\frac{\triangle V}{\triangle I}$$

According to the graph: $\frac{0.8 - 0.6}{0.085 - 0.065}$

$$= \frac{0.2}{0.02}$$

So the answer would be 10. This would be the gradient of the graph inversed. This is the resistance for the nichrome wire and this way can be compared for the resistivity of other conductors. The resistance is thus 10 Ω for this length of the nichrome wire.

Now we can move onto the actual experiment after this experiment has been done. We will however be using all of the supplies listed in the beginning.

Obtaining Evidence

From the above-mentioned materials we will perform the experiment.

I was taken to the lab where I had to carry out each of the experiments and take down the readings individually. The following listed is the difference in specifications form the original equipment provided and the plan.

Planned Equipment	Provided Equipment
Nichrome	
Length – 60 cm	Length – 80 cm
Thickness – 0.5 mm	Thickness – 0.45mm
Aluminium	Constantin
D.C Supply	Battery/Cell

Besides that I will not perform the experiment on the LDR. In addition the bulb holder was not needed so I did not use that to investigate the IV characteristics of the filament bulb.

First I would like to deal with the IV characteristics of the equipment and the components used. Using the circuit as shown before, I set up the experiment and took down the readings. I then drew graphs and showed this finally. This I will list below.

Metallic Conductors

Nichrome

Length- 80 cm
Thickness – 0.45 mm

Voltage (V)	Current Increasing (A)	Current Decreasing (A)	Current Average (A)
0.1 V	0.01 A	0.01 A	0.010 A
0.2 V	0.02 A	0.03 A	0.025 A
0.3 V	0.03 A	0.04 A	0.035 A
0.4 V	0.04 A	0.05 A	0.045 A
0.5 V	0.06 A	0.07 A	0.065 A
0.6 V	0.07 A	0.08 A	0.075 A
0.7 V	0.08 A	0.10 A	0.090 A
0.8 V	0.10 A	0.11 A	0.105 A
0.9 V	0.11 A	0.12 A	0.115 A
1.0 V	0.13 A	0.14 A	0.135 A

The graph is indicated on the next page.

Constantin

Length – 80 cm
Thickness – 0.45 mm

The same specification is taken for constantin like Nichrome so the test is fair.

Voltage (V)	Current Increasing (A)	Current Decreasing (A)	Current Average (A)
0.1 V	0.03 A	0.03 A	0.030 A
0.2 V	0.07 A	0.06 A	0.065 A
0.3 V	0.10 A	0.09 A	0.095 A
0.4 V	0.13 A	0.13 A	0.130 A
0.5 V	0.15 A	0.17 A	0.160 A
0.6 V	0.18 A	0.20 A	0.190 A
0.7 V	0.23 A	0.21 A	0.220 A
0.8 V	0.26 A	0.27 A	0.265 A
0.9 V	0.30 A	0.31 A	0.305 A
1.0 V	0.34 A	0.35 A	0.345 A

Shown below is the IV graph of the above table for Constantin.

Now the results for the experiment involving the Filament Bulb are shown

The specifications for the filament bulb is that it is 6V and has a maximum current of 60 mA.

Voltage (V)	Increasing Current (mA)	Decreasing Current (mA)	Current Average (mA)
0.1 V	3.79 mA	3.88 mA	3.835 mA
0.2 V	6.95 mA	7.02 mA	6.985 mA
0.3 V	9.11 mA	9.11 mA	9.110 mA
0.4 V	10.53 mA	10.45 mA	10.490 mA
0.5 V	11.62 mA	11.67 mA	11.645 mA
0.6 V	12.79 mA	12.85 mA	12.820 mA
0.7 V	13.85 mA	13.9 mA	13.875 mA
0.8 V	14.98 mA	14.93 mA	14.955 mA
0.9 V	15.8 mA	16.76 mA	16.280 mA
1.0 V	16.94 mA	17.05 mA	16.955 mA

The graph is shown below

Thermistor

The thermistor was tested under the room temperature of 25^{o}C. It had a resistance of 10. Below given is the table that was derived from the readings. These are its IV results

Voltage (V)	Increasing Current (mA)	Decreasing Current (mA)	Current Average (mA)
0.1 V	6.4 mA	7.1 mA	6.75 mA
0.2 V	13.8 mA	14.2 mA	14.00 mA
0.3 V	20.8 mA	21 mA	20.90 mA
0.4 V	27.4 mA	29.2 mA	28.30 mA
0.5 V	36.2 mA	37.2 mA	36.70 mA
0.6 V	40.4 mA	44.2 mA	42.30 mA
0.7 V	51.3 mA	53.7 mA	52.50 mA
0.8 V	59.4 mA	62.4 mA	60.90 mA
0.9 V	68.3 mA	71.7 mA	70.00 mA
1.0 V	77.9 mA	80.6 mA	79.25 mA

Below is the graph of these readings

Now we will see the heating and cooling effect of the thermistor. The voltage provided was 1.5 V

Heating Effect This is when the temperature is raising.

Temperature (^oC)	Current (mA)
30^{o}C	13.5 mA
35^{o}C	15.1 mA
40^{o}C	17.5 mA
45^{o}C	19.9 mA
50^{o}C	22.5 mA
55^{o}C	25.6 mA
60^{o}C	28.1 mA
65^{o}C	32.2 mA
70^{o}C	35.5 mA

Cooling Effect

Temperature (^oC)	Current (mA)
30^{o}C	13.5 mA
35^{o}C	15.1 mA
40^{o}C	17.6 mA
45^{o}C	19.2 mA
50^{o}C	22 mA
55^{o}C	24.2 mA
60^{o}C	27.3 mA
65^{o}C	30.1 mA
70^{o}C	32.8 mA

Overall readings

The formula for the resistance will be $\frac{V}{I}$ x 100 because the current reading is in mA.

Temperature (^oC)	Current Increasing (mA)	Current Decreasing (mA)	Current Average (mA)	Resistance (ohms)
30^{o}C	13.5 mA	13.5 mA	13.50 mA	111.11 Ω
35^{o}C	15.1 mA	15.1 mA	15.10 mA	99.34 Ω
40^{o}C	17.5 mA	17.6 mA	17.55 mA	85.47 Ω
45^{o}C	19.9 mA	19.2 mA	19.55 mA	76.73 Ω
50^{o}C	22.5 mA	22 mA	22.25 mA	67.42 Ω
55^{o}C	25.6 mA	24.2 mA	24.90 mA	60.24 Ω

60°C	28.1 mA	27.3 mA	27.70 mA	54.15 Ω
65°C	32.2 mA	30.1 mA	31.15 mA	48.15 Ω
70°C	35.5 mA	32.8 mA	34.15 mA	43.92 Ω