Chapter One

Introduction

1.1 Introduction:

Materials seem to fall naturally into two broad categories, solids and fluids. Solids generally retain their shape under the influence of external forces, although they may show temporary distortions while such forces are applied. Fluids, as the name implies, are materials which can flow and are usually divided into two subcategories: liquids and gases.

These broad categories of different states of matter are not quite as clear-cut as implies a bore, matter can also appear in other forms, such as vitreous (glass-like) materials or plasmas (ionized gases).

Materials are classified to three part according to their conductivities, a conductor such as a metal has a high conductivity and a low resistance, an insulator like glass or vacuum has a low conductivity and the conductivity of a semiconductor is generally intermediate between these (but varies widely with different conditions, such as exposure of the material to electric fields or with specific frequencies of light and, most important, with temperature and composition .(The degree of doping in solid state makes a large difference in conductivity. More doping leads to higher conductivity. The conductivity of a solution of water is highly dependent on its concentration of dissolved salts and sometimes other chemical species which tend to ionize in the solution .The most striking characteristics of metals are their high electrical and thermal conductivities. The metals consist of the atoms of electropositive elements, of which those from the first column of the periodic system, namely the alkails (Li, Na, K…) and the noble metals (Cu, Ag, Au….) are the most important. The single electron in their outermost shell happens to be to a certain extent independent, so stable positive ions with the noble gas configuration remain which must here be treated as lattice particles. In addition numerous quasi-free electrons arise which do not appear in ionic or valence crystals. They produce on the one hand the high conductivity of metals (conduction electrons) and on the other hand, although in a somewhat more complicated manner, the metallic binding. We can know a lot of them if we apply the free electron theory.

The free electron theory of metals assumes that the valence electrons move freely between the holes, but by applying an electric field or a temperature gradient to the metal the free electrons are transferred more readily and thus conduction is more effective.

In this thesis thermal and electrical conductivity of copper and aluminum are determined and the Wiedmann- Franz law is investigated.

1.2 The Importance of the Research:

The importance of this research is to study the electrical conductivity of the most important metals (copper and aluminum).

1.3 The Problem of the Research:

The core problem of this project is retest the ohm's law in calculating the electrical conductivity of metals.

1.4 The Aims of the Research:

The goal of this project is to calculate the electrical conductivity of copper and aluminum with ohm's law.

1.5 Literature Review:

- **Amen Hassan Abu Alhassan-2016- studied** The science of materials and types of materials and installation of atomic bond and types of bonds and solid crystals and the unit cell and metallic crystalline structure, and types of metallic crystalline and conductivity in particular.

  The electrical conductivity account for the alloy were manufactured in the blast furnaces of cast iron and copper, and was valued as follows $12.65\times 10^{7}(\Omega.\mathrm{m})^{-1}$and the result was as predicted.

1.6 Thesis Layout:

This thesis is consist of five chapters, chapter one Introduction, chapter tow discuss the nature of metals and their electrical and physical properties., chapter three discuss The free electron model, chapter four talked about the Electrical conductivity of metals and the experimental part, chapter five consist Results and Discussion.

Chapter Two

Metals

2.1 Introduction:

In this chapter we will discuss the nature of metals and their electrical and physical properties. We will talk about copper metal and aluminum metals because they are the minerals used to draw experimental results [13].

2.2 Metals:

Metals are characterized by high electrical conductivity, and a large number of electrons in a metal are free to move about, usually one or two per atom. The electrons available to move about are called conduction electrons. The valence electrons of the atom become the conduction electrons of the metal.

In some metals the interaction of the ion cores with the conduction electrons always makes a large contribution to the binding energy, but the characteristic feature of metallic binding is the lowering of the energy of the valence electrons in the metal as compared with the free atom.

The binding energy of an alkali metal crystal is considerably less than that of an alkali halide crystal: the bond formed by a conduction electron is not very strong. The interatomic distances are relatively large in the alkali metals because the kinetic energy of the conduction electrons is lower at large inter atomic distances. This leads to weak binding. Metals tend to crystallize in relativity [12].

2.2.1 Aluminum:

Aluminum is a relatively soft, durable, lightweight, ductile, and malleable metal with appearance ranging from silvery to dull gray, depending on the surface roughness. It is nonmagnetic and does not easily ignite. A fresh film of aluminum serves as a good reflector (approximately 92%) of visible light and an excellent reflector (as much as 98%) of medium and far infrared radiation. The yield strength of pure aluminum is 7–11 MPa, while aluminum alloys have yield strengths ranging from 200 MPa to 600 MPa.[9] Aluminum has about one-third the density and stiffness of steel. It is easily machined, cast, drawn and extruded.

Aluminum atoms are arranged in a face-centered cubic (fcc) structure. Aluminum has a stacking-fault energy of approximately 200 mJ/m^2.

Aluminum is a good thermal and electrical conductor, having 59% the conductivity of copper, both thermal and electrical, while having only 30% of copper's density. Aluminum is capable of superconductivity, with a superconducting critical temperature of 1.2 kelvin and a critical magnetic field of about 100 gauss (10 milliteslas).[11] Aluminum is the most common material for the fabrication of superconducting quits [13].

2.2.2 Copper:

Copper, silver, and gold are in group 11 of the periodic table; these three metals have one s-orbital electron on top of a filled d-electron shell and are characterized by high ductility, and electrical and thermal conductivity. The filled d-shells in these elements contribute little to interatomic interactions, which are dominated by the s-electrons through metallic bonds. Unlike metals with incomplete d-shells, metallic bonds in copper are lacking a covalent character and are relatively weak. This observation explains the low hardness and high ductility of single crystals of copper. At the macroscopic scale, introduction of extended defects to the crystal lattice, such as grain boundaries, hinders flow of the material under applied stress, thereby increasing its hardness. For this reason, copper is usually supplied in a fine-grained polycrystalline form, which has greater strength than mono crystalline forms

The softness of copper partly explains its high electrical conductivity (59.6×10^6 S/m) and high thermal conductivity, second highest (second only to silver) among pure metals at room temperature This is because the resistivity to electron transport in metals at room temperature originates primarily from scattering of electrons on thermal vibrations of the lattice, which are relatively weak in a soft metal. The maximum permissible current density of copper in open air is approximately 3.1×10^6 A/m^2 of cross-sectional area, above which it begins to heat excessively.

Copper is one of a few metallic elements with a natural color other than gray or silver. Pure copper is orange-red and acquires a reddish tarnish when exposed to air. The characteristic color of copper results from the electronic transitions between the filled 3d and half-empty 4s atomic shells – the energy difference between these shells corresponds to orange light.

As with other metals, if copper is put in contact with another metal, galvanic corrosion will occur. [9]

CHAPTER Three

The Free Electron Model

3.1 Introduction:

The free electron model is a simple model for the behavior of valence electrons in a crystal structure of a metallic solid. It was developed principally by Arnold Sommerfeld who combined the classical Drude model with quantum mechanical Fermi–Dirac statistics and hence it is also known as the Drude–Sommerfeld model.[8]

3.2 The classical free electron model: (Drude model):

The free electron model, also known as the Durde model after Paul Drude (1863-1906), makes the assumptions, which are suggested by the metallic bonding mechanism .

The basic assumption in this theory is that within a metal the valance electrons of the atoms are free. That is, each atom gives up its valence electrons, which are then free to move about like a gas of electron. For example, sodium atom (Na) has electrons in the states in matellic sodium. The 3s- electron (the valance electron) from each atom becomes free (the remaining bonding $1S^2\ 2S^2\ 2P^6\ 3S^1$ electrons, which along with the nuclei are called the core electrons). The deep potential within the cores and relatively flat potential between the cores is assumed to be flat, because the metal is neutral, an electron attempting to leave it will be pulled back into the metal .[8]

3.2.1 Drude's assumptions:

We have assumed that the valence electrons in a metal are free and that these electrons can be treated by the kinetic theory of gases.

First, we assume that the electrons undergo collisions (by an un–specified interaction), or that the electrons are scattered. These collisions are treated as instantaneous scattering events which mean the time for scattering is very short. Through these collisions the electrons achieve thermal equilibrium corresponding to the metal temperature T. Thus, it is assumed that the electrons emerge from collisions with no memory of their velocities before and are then randomly directed with velocities appropriate to T.

Second, between collisions the electrons travel in straight lines obeying Newton's law. For example, if an electric field is applied in the x-direction then we have $m\ddot{x} = -eE$. Thus the electron will have an additional velocity given by – $(eE/m)t$ for so long as the electric field is applied and so long as the electron is not scattered. However, on the average, the electrons are scattered after a time ., and since after each scattering event they are in thermal equilibrium, a constant electric field will cause the electrons to have an extra average velocity given by $v_d = \left(\frac{eE}{m}\right)\tau$. This is the drift velocity v_d, that is due to the applied electric field. The root mean square velocity v_{rms}, which Drude assumed to be due to the thermal distribution at temperature T, in most metals turns out to be very much larger than v_d (v_{rms} »v_d) Third, all details of the electron scattering are summarized in a relaxation time . This is the average time between scattering events; on the average, the probability that an electron will scatter in a time dt is dt/τ Once an average thermal speed, v_m, and a relaxation time are defined, a mean free path ℓ is specified. It is defined as the average distance traveled by an electron between two collisions and is given by

$$\ell = v_{rms}\tau \tag{3.1}$$

3.3 The Electrical Conductivity:

By applying an electric field E to the metal every electron will be acted upon by a force. This force may act so as either to increase or decrease the magnitude of the velocity of the electron.

$$F = -Ee \tag{3.2}$$

Ohm's law: voltage = current x resistance

To make the terms independent of shape and length we relate the current density J to the electric field E. consider a pieace of metal with a uniform cross-sectional area A and length l. Then we can state Ohm's law in terms of the shape independent conductivity.

$$J = \sigma E \tag{3.3}$$

$$J = i/A \tag{3.4}$$

$$E = V/l \tag{3.5}$$

I,V are current and voltage respectively Substitute equations (2.3) and (2.4) into equation (2.2):

$$\therefore \sigma = \frac{l}{AV} \tag{3.6}$$

From Ohm's law:

$$R = \frac{V}{I} \tag{3.7}$$

The electrical conductivity:

$$\sigma = \frac{l}{A.R} \tag{3.8}$$

Consider the microscopic picture of the free electrons. They move with large velocities, but the directions are random. Suppose that owing to an external field, there is an additional average drift velocity vd, across an area A in a time dt.

The charge that flows through the cross- section area A is:

$$dq = n\,(-e)\,A\,v_d\,dt \tag{3.9}$$

Where n is, the number of electrons. The current:

$$i = \frac{dq}{dt} = \frac{n\,(-e)\,A\,v_d\,dt}{dt} \tag{3.10}$$

$$i = n(-e)Av_d \tag{3.11}$$

By convention we use the positive sign for the current density:

$$i = ne\,v_d A \tag{3.12}$$

$$J = \frac{i}{A} = ne\,v_d \tag{3.13}$$

The electron mobility (u):

$$u = v_d/E \tag{3.14}$$

$$E = v_d/u \tag{3.15}$$

by using equations (2.2), (2.12) and (2.14):

$$\sigma = n\,e\,u \tag{3.16}$$

If we apply an electric field to the electronic gas the equation of motion of the electron becomes:

$$\frac{mdv}{dt} + \frac{mv}{t_0} = eE \tag{3.17}$$

Where mv/to: is the oscillatory force and to is the relaxation time.

$$\frac{mdv}{dt} = 0 \tag{3.18}$$

$$v_d = eE\, to/\, m \tag{3.19}$$

From equation (2.13)

$u = v_d /E$ (Electron mobility)

$$u = e\, t_0 /m \tag{3.20}$$

Substitute equation (2.19) into equation (2.15):

$$\sigma = ne^2\, t_0 /m \tag{3.21}$$

The resistivity ρ (the inverse of the conductivity):

$$\rho = m/(ne^2\, t_0) \tag{3.22}$$

If we suppose that m is the mass of the gas we can calculate to:

$$t_0 = L/V \tag{3.23}$$

Where V, L are mean thermal velocity and mean free path (root mean square velocity) respectively.

At the equilibrium of the electronic gas at the absolute temperature T, the thermal energy is equal to kinetic energy of the electron:

$$½mv^2 = 3/2\, KT \tag{3.24}$$

$$v = (3KT/\, m)½ \tag{3.25}$$

where$K$, is Boltzmann's const. Now substitute equations (2,22) and (2,24) into equation (2.11):

$$\sigma = ne^2\, L/m \div (3KT/\, m)½ \tag{3.26}$$

$$\sigma = const. T^{-1/2} \tag{3.27}$$

$$\rho = const. T^{1/2} \tag{3.28}$$

3.3.1 Some Features of the Electrical Conductivity of Metals:

1. In accordance with Ohm's low, the current density in the steady state is proportional to the field strength.

2. The specific resistivity of metals at room temperature is of the order of 10^{-5}Ohm. cm.

3. Above the Debye temperature the resistively of metals increases linearly with temperature.

4. At low temperatures, but above approximately 20 K, the resistivity of many metals is proportional to T5.

5. For most metals the resistivity decreases with increasing pressure.

6. Above the Debye temperature the ratio of thermal to electrical conductivity is proportional to T, the constant of proportionality being almost the same for all metals (Weidmann- Franz law).

7. Many metals exhibit super-conductivity, i.e their resistivity disappears below a critical temperature Tc , which is different for different materials, e.g. for mercury Tc = 4.15 K [5].

3.4 Transfer of Heat (Conduction of Heat):

There are three distinct methods by which a quantity of heat may be transferred from one place to another. These are: conduction, convection and radiation. In the first two processes the molecules of the body are responsible for the heat transfer, but with the difference that there is no mass movement of molecules in conduction as in the case of convection. Thus the heat conducted along a metal bar heated at one end is due to the molecules at the hot end having their vibratory motions increased [4].

3.4.1 Conduction:

When two parts of a material substance are maintained at different temperatures and the temperature of each small volume element of the intervening substance is measured, experiment shows a continuous distribution of temperature. The transport of energy between neighboring volume elements by virtue of the temperature difference between them is known as conduction.

Conduction however is effective in both solids and fluids. Liquids and gases are in fact bad conductors of heat as also is the bulk of nonmetallic solid substances.

3.4.2 Convection:

Convection is the motion of a heated material, which carries its heat with it. The density of most fluids decreases as the fluid is heated a well known consequence being that hot air arises. A lot solid object surrounded by a fluid will heat the fluid immediately adjacent to it causing the heated fluid to rise and to be replaced by cooler fluid. The result of this process is that currents called convection currents, these have the effect of transporting heat energy away from the body, thus cooling the body- cooling in this manner is called natural convection. More rapid cooling can be achieved by blowing air, for example from a fan, directly at the body, this process is called forced convection.

Now, it is clear from the nature of the solid state that the process of convection cannot occur in solids.[8]

3.4.3 Radiation:

Even in the absence of a surrounding fluid or of any solid connections through which heat could be conducted, a body can still lose heat energy. An isolated body in vacuum cannot lose heat by conduction or convection but will lose heat by radiation [1].

Now, Radiation is the transfer of heat from a hot body to a cold body without appreciable heating of the intervening space.The rate of radiant heat loss from a body increase very rapidly with increasing temperature of the body. This phenomenon is electromagnetic in origin. The energy which we receive from the sun and the most of the heat which we feel from an open fire are examples of the transfer of heat energy by radiation [8].

Chapter Four

Electrical conductivity of metals

4.1 Introduction:

Electrical conductivity in metals is a result of the movement of electrically charged particles.

The atoms of metal elements are characterized by the presence of valence electrons - electrons in the outer shell of an atom that are free to move about. It is these 'free electrons' that allow metals to conduct an electric current.

Because valence electrons are free to move they can travel through the lattice that forms the physical structure of a metal.

Under an electric field, free electrons move through the metal much like billiard balls knocking against each other, passing an electric charge as they move.

The transfer of energy is strongest when there is little resistance. On a billiard table, this occurs when a ball strikes against another single ball, passing most of its energy onto the next ball. If a single ball strikes multiple other balls, each of those will carry only a fraction of the energy.

By the same token, the most effective conductors of electricity are metals that have a single valence electron that is free to move and causes a strong repelling reaction in other electrons. This is the case in the most conductive metals, such as silver, gold, and copper, who each have a single valence electron that moves with little resistance and causes a strong repelling reaction.

Semi-conductor metals (or metalloids) have a higher number of valence electrons (usually four or more) so, although they can conduct electricity, they are inefficient at the task.

However, when heated or doped with other elements semiconductors like silicon and germanium can become extremely efficient conductors of electricity.

Conduction in metals must follow Ohm's Law, which states that the current is directly proportional to the electric field applied to the metal. The key variable in applying Ohm's Law is a metal's resistivity.

Resistivity is the opposite of electrical conductivity, evaluating how strongly a metal opposes the flow of electric current. This is commonly measured across the opposite faces of a one-meter cube of material and described as an ohm meter (Ω·m). Resistivity is often represented by the Greek letter rho (ρ).[6]

4.2 Principle:

The electrical conductivity for copper and aluminum is determined, and the Weidman-Franz law is tested.

4.2. 1Apparatus:

-Multitap transf, 14 VAC/12VDC, 5A.

-Digital multimeter (two)

-Universal measuring amplifier.

-Connecting cord, L = 500mm, red (four).

-Connecting cord, L = 500mm, blue (four).

-Heat conductivity rod, Al.

-Heat conductivity rod, Cu.

-Rheostat, 10 Ω , 5.7A.

4. 2.2 Set-up and Procedure:

-The experimental set-up was performed according to Fig(3.2).

-The voltage was set on the variable transformer to 6V.

-The amplifier was calibrated to 0 in a voltage-free state to avoid a collapse of the output voltage.

-The amplifier was set as follows:

- Input: low drift

- Amplification: 10^4

- Time constant: 0

4.2. 3Theory:

At room temperature, the conduction electrons in a metal have a much greater mean free path than the phonons. For this reason heat conduction in metals is primarily due to the electrons.

The resulting correlation between the thermal conductivity λ and the electrical conductivity σ is established by the Wiedmann-Franz law.

$$\frac{\lambda}{\sigma} = LT \qquad (4.1)$$

The lorentz number L, which can be experimentally determined using equation (3.4), is established by the theory of electron vapour (for temperatures above the Debye temperature):

By quantum theory, the electrical conductivity:

$$\sigma = (n_e e^2 /m^*)t_0 \qquad (4.2)$$

wherem^*, is the effective mass and t_0 , is the relaxation time. The thermal conductivity:

$$\lambda = \frac{1}{3}(\frac{1}{2}\pi^2 n_e KT/TF)\ V_F^2 t_0 \tag{4.3}$$

Where k is the Boltzmann's const, $k = 1.38\ x\ 10 - 23\ J/\ K$

T_F & v_F are the Fermi temperature and velocity respectively. Now dividing equation (3.6) by equation (3.5), we obtain

$$\frac{\lambda}{\sigma} = \frac{\pi^2}{3}\frac{KT}{e^2}.\frac{1}{2}\frac{v_F^2 m^*}{T_F} \tag{4.4}$$

$$T_F = \frac{E_F}{k} \tag{4.5}$$

$$\therefore \frac{\lambda}{\sigma} = \frac{\pi^2}{3}\frac{\left(\frac{k}{e}\right)^2}{E_F}T.\frac{1}{2}\frac{v_F^2 m^*}{T_F} \tag{4.6}$$

$$E_F = \hbar(3\pi^2 n_e)^{\frac{1}{3}}/m^* \tag{4.7}$$

$$E_F = \hbar^2(3\pi^2 n_e)^{\frac{2}{3}}/\ 2m^* \tag{4.8}$$

Substituting equations (2.10) and (2.11) into equation (3.9), we obtain

$$\frac{\lambda}{\sigma} = \frac{\pi^2}{3}\ (k/e)^2 T \tag{4.9}$$

$$\therefore L_Z = \frac{\lambda}{\sigma T} = \frac{\pi^2}{3}.\frac{k^2}{(ev)^2} = 1.4 \times 10^{-8}\frac{W\Omega}{k^2} \tag{4.10}$$

where one electron volt $(ev)\ =\ 1.602\ x\ 10 - 19\ J$,The electrical conductivity is determined by the resistance R of the rod and its geometric dimensions (l = 0.315m, A = 4.91 x 10-4 m2).[14]

$$\sigma = \frac{1}{AR} \qquad (4.11)$$

4.2. 4 Method:

The experimental set-up was performed .After that the rheostat was set to its maximum value and its value has been slowly decreased during the experiment. The resistance was measured and thus the electrical conductivity was determined from the measured values.

Chapter Five

Result and Conclusion

5.1 The Electrical Conductivity For Copper :

5.1.1 The results:

After the experiment with using the ohm's law we get the results in the table below

Table (5.1): Current and voltage for copper

I(A) ± 0.1	V(volt) ± 0.01
9.2	0.98
8.0	0.89
7.3	0.77
6.4	0.63
5.1	0.59
4.3	0.44

5.1.2 Calculation:

The circuit of the experiment is Ohm's (except the amplification that is used to amplify the voltage 10^4 to make it readable by a digital multimeter).

∴the resistance of copper is found to be :

$$R_{cu} = \frac{V}{I} = \frac{5 \times 0.04}{4 \times 4.5 \times 0.4} = 0.11\ \Omega$$

The electrical conductivity is determined by resistance R of the Cu rod and its geometric dimensions($\mathrm{l} = 0.315\mathrm{m}, \mathrm{A} = 4.91 \times 10^{-4} m^2$) By using:

$$\sigma = \frac{1}{A.R}\ (\Omega\mathrm{m})^{-1}$$

$$\sigma = \frac{0.315}{4.91 \times 10^{-4} \times 0.11} = 0.583 \times 10^4$$

Where we used L = 0.315m for the length of the rod.

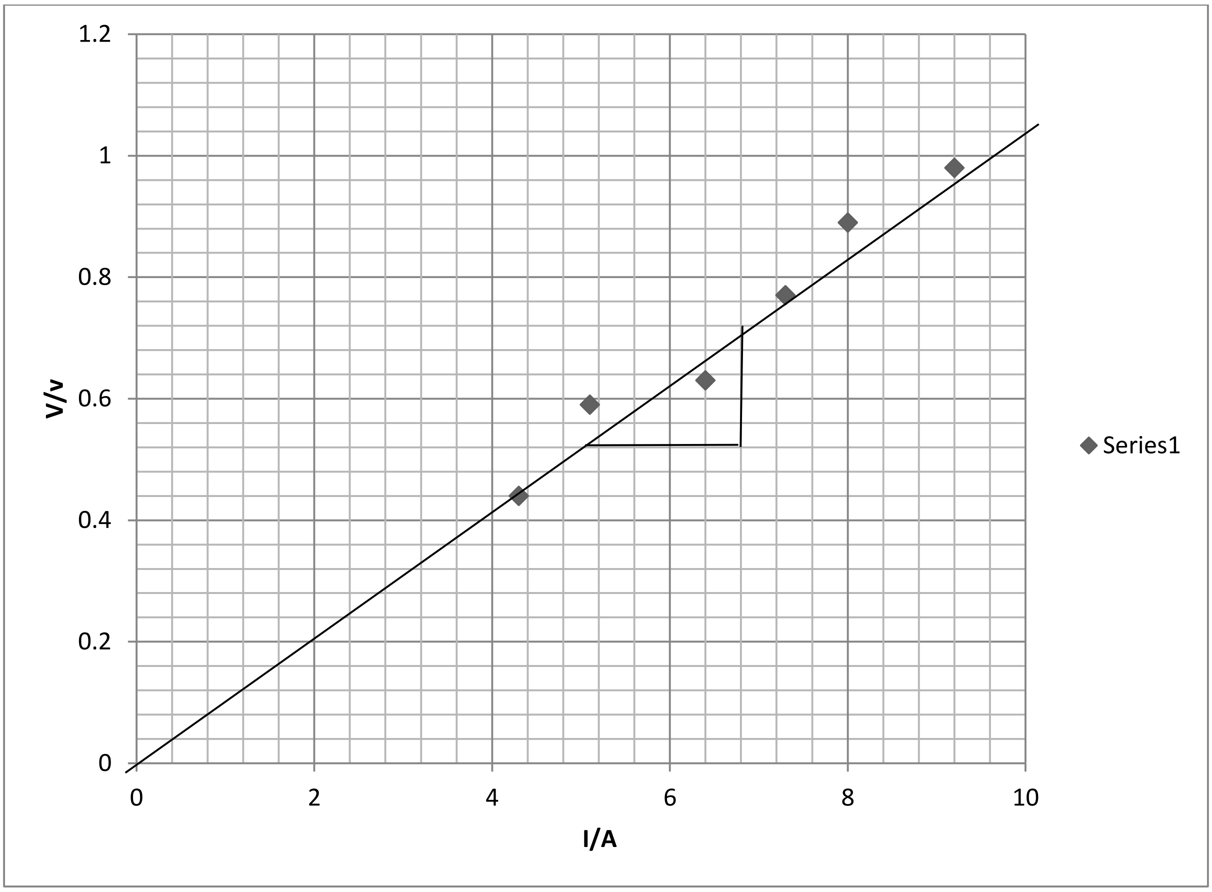

Figure (5.1): Current and voltage for copper

5.2 The electrical conductivity for aluminum :

5.2.1 The value of current and voltage of the aluminum rod:

After the experiment with using the ohm's law we get the results in the table below

Table (5.2): Current and voltage for aluminum

$\mathrm{I(A)} \pm 0.1$	$\mathrm{V(volt)} \pm 0.01$
9.5	1.90
8.7	1.82
7.4	1.70
7.0	1.51
6.3	1.39
5.2	1.14
4.2	0.95
3.5	0.82

5.2.2 Calculation:

The circuit of the experiment is Ohm's (except the amplification that is used to amplify the voltage 10^4 to make it readable by a digital multimeter).

∴ the resistance of aluminum is found to be :

$$R_{cu} = \frac{V}{I} = \frac{12 \times 0.04}{5.5 \times 0.4} = 2.18\ \Omega$$

The electrical conductivity is determined by resistance R of the AL rod and its geometric dimensions($\mathrm{l} = 0.315\mathrm{m}, \mathrm{A} = 4.91 \times 10^{-4} m^2$) By using:

$$\sigma = \frac{l}{A.R}$$

$$\sigma = \frac{0.315}{4.91 \times 10^{-4} \times 2.18} = 0.029 \times 10^{4}\ (\Omega\mathrm{m})^{-1}$$

Where we used l = 0.315m for the length of the rod.

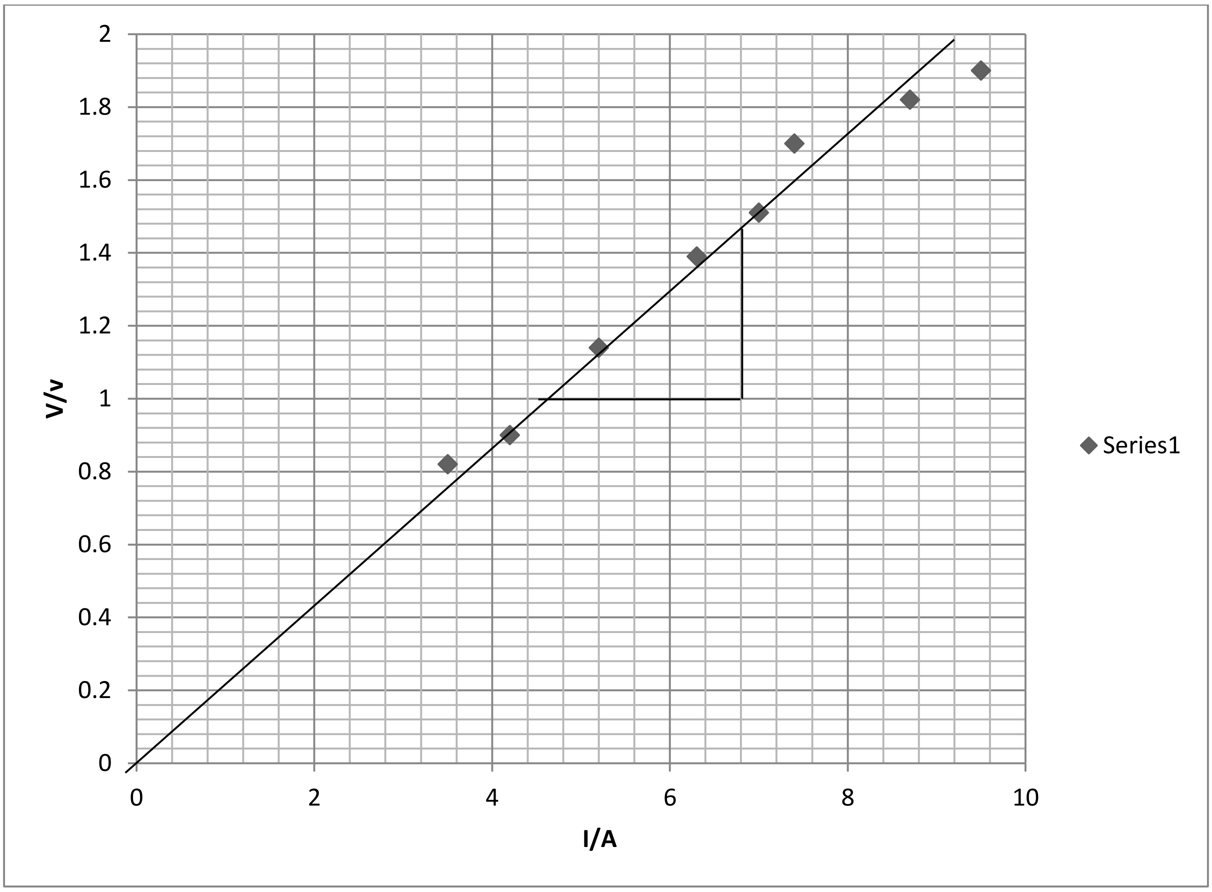

Figure (5.2): Current and voltage for aluminum

5.3 Conclusion:

In this research, electrical conductivity of copper and aluminum was calculated. In practical experiment it was found that the electrical conductivity of the aluminum is higher than the electrical conductivity of the copper, which means that the aluminum is better quality in the electric conductivity of copper and the reason for the use of copper is not its efficiency but rather its cost and its cost compared to aluminum

5.4 Recommendation:

We can use this research to study thermal and super conductivity.

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