Chapter One

Introduction

1.1 Introduction

A magnet is a material or object that produces a magnetic field. This magnetic field is invisible but is responsible for the most notable property of a magnet [4].

The most popular legend accounting for the discovery of magnets is that of an elderly Cretan shepherd named Magnes. Legend has it that Magnes was herding his sheep in an area of Northern Greece called Magnesia, about 4,000 years ago. Suddenly both, the nails in his shoes and the metal tip of his staff became firmly stuck to the large, black rock on which he was standing. To find the source of attraction he dug up the Earth to find lodestones (load = lead or attract). Lodestones contain magnetite, a natural magnetic material Fe_3O_4. This type of rock was subsequently named magnetite, after either Magnesia or Magnes himself [4].

There are two dipoles of magnet north and south but the concept of poles should not be taken literally: it is merely a way of referring to the two different ends of a magnet. The magnet does not have distinct north or south particles on opposing sides.

The magnetic field is defined as the area that thronging the magnet and its effect appears in it [1] [2].

The magnetic field can be used in generation of electricity, magnetic trains, medical fields and in home recording devices.

Magnetic Permeability is defined as the measure of the ability of a material to support the formation of a magnetic field within itself. Hence, it is the degree of magnetization that a material obtains in response to an applied magnetic field. Magnetic permeability is typically represented by the (italicized) Greek letter μ [4].

1.2 Research Problem

Research problem is related to the lack of research in determination of magnetic properties of matter.

1.3 Literature Review

Many attempts were made to see how magnetic properties changes with structure.

In the work done by Simon Rast etal. Magnetic properties of nanomagnetic and biomagnetic systems are investigated using cantilever magnetometry. In the presence of a magnetic field, magnetic films or particles deposited at the free end of a cantilever give rise to a torque on the mechanical sensor, which leads to frequency shifts depending on the applied magnetic field. From the frequency response, the magnetic properties of a magnetic sample are obtained. The magnetic field dependences of paramagnetic and ferromagnetic thin films and particles are measured in a temperature range of 5–320 K at a pressure below 10^{-6} mbar. We present magnetic properties of the ferromagnetic materials Fe,Co and Ni at room temperature and also for the rare earth elements Gd, Dy and Tb at various temperatures. In addition, the magnetic moments of magneto tactic bacteria are measured under vacuum conditions at room temperature. Cantilever magnetometry is a highly sensitive tool for characterizing systems with small magnetic moments. By reducing the cantilever dimensions the sensitivity can be increased by an order of magnitude.

A seminal paper was also published by R.Skomski.In this work Magnetic nanostructures, such as dots and dot arrays, nanowires, multilayers and nanojunctions, are reviewed and compared with bulk magnets. The emphasis is on the involved physics, but some applications are also outlined, including permanent magnets, soft magnets, magnetic recording media, sensors, and structures and materials for spin electronics. The considered structural length scales range from a few interatomic distances to about one micrometre, bridging the gap between atomic-scale magnetism and the macroscopic magnetism of extended bulk and thin-film magnets. This leads to a rich variety of physical phenomena, differently affecting intrinsic and extrinsic magnetic properties. Some specific phenomena discussed in this review are exchange-spring magnetism, random-anisotropy scaling, narrow-wall and constricted-wall phenomena, and Curie temperature changes due to nanostructuring and nanoscale magnetization dynamics.

Another work is done by Rudolf Hergt etal.In this work Loss processes in magnetic nanoparticles are discussed with respect to optimization of the specific loss power (SLP) for application in tumour hyperthermia. Several types of magnetic iron oxide nanoparticles representative for different preparation methods (wet chemical precipitation, grinding, bacterial synthesis, magnetic size fractionation) are the subject of a comparative study of structural and magnetic properties. Since the specific loss power useful for hyperthermia is restricted by serious limitations of the alternating field amplitude and frequency, the effects of the latter are investigated experimentally in detail. The dependence of the SLP on the mean particle size is studied over a broad size range from superparamagnetic up to multidomain particles, and guidelines for achieving large SLP under the constraints valid for the field parameters are derived. Particles with the mean size of 18 nm having a narrow size distribution proved particularly useful. In particular, very high heating power may be delivered by bacterial magnetosomes, the best sample of which showed nearly 1 kW g^{-1} at 410 kHz and 10 kA m^{-1}. This value may even be exceeded by metallic magnetic particles, as indicated by measurements on cobalt particles.

A very interesting study is made by Xavier Batlle and Amilcar Labarta.In this work some of the most relevant finite-size and surface effects in the magnetic and transport properties of magnetic fine particles and granular solids are reviewed. The stability of the particle magnetization, superparamagnetic regime and the magnetic relaxation are discussed. New phenomena appearing due to interparticle interactions, such as the collective state and non-equilibrium dynamics, are presented. Surface anisotropy and disorder, spin-wave excitations, as well as the enhancements of the coercive field and particle magnetization are also reviewed. The competition of surface and finite-size effects to settle the magnetic behaviour is addressed. Finally, two of the most relevant phenomena in the transport properties of granular solids are summarized namely, giant magnetoresistance in granular heterogeneous alloys and Coulomb gap in insulating granular solids.

1.4 Objectives of the study

The aim of this study is to measure magnetic Permeability of the materials.

1.5 Presentation of the Thesis

In This Thesis measurement of magnetic Permeability of the materials were done in four chapters. Chapter one is the introduction and literature review. Chapter two concurred with Magnetic Properties of Matters. While chapter three is devoted for Ac circuits. And finally chapter four shows the materials, methods, results, discussions and conclusion.

Chapter Two

Magnetic Properties of Matters

2.1 Introduction

Magnetic field is one of the physical fields that plays an important role in technology [9]. This requires devoting this chapter to study magnetic properties of atoms as well as bulk matter.

2.2 Magnetic field and Current

Currents of electric charges generate a magnetic field. All moving charged particles produce magnetic fields [3]. Moving point charges, such as electrons, produce complicated but well known magnetic fields that depend on the charge, velocity, and acceleration of the particles. As example of the magnetic field of a moving charge, we consider a circular loop of radius r carrying a current I as in Fig (2.2.1) bellow.

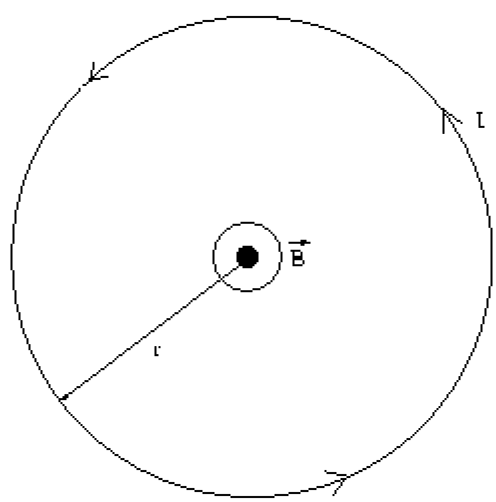

Figure (2.2.1) Magnetic field of a current circular loop

The magnitude of the magnetic field is given by:

$$B = \mu_0 I/2r \qquad (2.2.1)$$

The direction of the magnetic field indicated can be remembered by the following rule:
Curl the fingers of your right hand in the direction of the current around the loop - your thumb then indicates the direction of the magnetic field. This is the magnetic field just at the center of the loop, and away from the center the magnetic field changes in both magnitude and direction.
The association of a magnetic field with a current loop enables us to understand qualitatively the formation of permanent magnets. At the atomic level materials are composed of essentially stationary nuclei around which electrons orbit. The orbiting electrons can be considered as current loops, and thus each atom has its own magnetic field. In non-magnetic materials the magnetic fields of all the atoms are randomly oriented, resulting in no net magnetic field, but in permanent magnets interactions between the atoms favor the individual atomic magnetic fields to be aligned, producing a net macroscopic magnetic field.

2.3 Atomic Magnetic Moment

From the classical expression for magnetic moment:

$$m = IA \tag{2.3.1}$$

An expression for the magnetic moment from an electron in a circular orbit around a nucleus can be deduced. It is proportional to the angular momentum of the electron [6]. The effective current is:

$$I = - e/T = ev/2\Pi r \tag{2.3.2}$$

Which can be rewritten as:

$$I = -e\, m\, vr/\ 2\Pi\ m_e\, r^2$$

Where:

T = period of orbit.

m_e = mass of electron.

r = radius of the nucleus.

$-e$ = electron charge.

So that the magnetic moment is:

$$\mu = IA = -e/\ 2m_e \times L \tag{2.3.3}$$

L = orbital angular momentum = mvr.

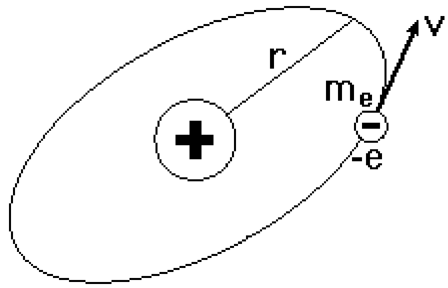

Figure (2.3.1) Electron orbit around the nucleus

An atom's magnetic moment comes from electron spin. The magnetic moment associated with electron spin is:

$\mu_{spin} = \hbar /2m$ (2.3.4)

$\hbar = h/2\pi$, where h is Planck's constant.

For an atom, individual electron spins are added to get a total spin and individual orbital angular moment are added to get a total orbital angular momentum. These two then are added using angular momentum coupling to get a total angular momentum. The net magnetic moment of an atom is the vector sum of its orbital and spin magnetic moments.

2.4 Magnetic Classifications of Matter

Magnetic susceptibility is the physical quantity describing material properties in the external magnetic field [4].
All materials can be classified by value of magnetic susceptibility into four groups:

2.4.1 Diamagnetic Materials

Diamagnetic materials have a very weak negative susceptibility, typically of order -10^{-6}. That is to say, the relative permeability is slightly less than 1. Consequently, when a diamagnetic material is placed in a magnetic field, $B < \mu_0 H$.All materials are diamagnetic. Some materials may also be paramagnetic or ferromagnetic, and their positive paramagnetic or ferromagnetic susceptibilities may be larger than their negative diamagnetic susceptibility, so that their overall susceptibility is positive. But all materials are diamagnetic, even if their diamagnetism is hidden by their greater para- or ferromagnetism. A proper account of the mechanism at the atomic level of the cause of diamagnetism requires a quantum mechanical treatment, but we can understand the phenomenon qualitatively classically. We just have to think of an atom as being a nucleus surrounded by electrons moving in orbits around the nucleus. When an atom (or a large collection of atoms in a macroscopic sample of matter) is placed in a magnetic field, a current is induced within the atom by electromagnetic induction. That is, the electrons are caused to orbit around the nucleus, and hence to give the atom a magnetic moment, in such a direction as to oppose the increase in the magnetic field that causes it.

Langevin Theory in diamagnetic [4] [9]:

A current loop has a magnetic moment μ, so for the orbiting electron we get:

$$\mu = iA = -e\omega/2\pi \times 2\pi\, r^2 = -e\omega\, r^2/2 \quad (2.4.1.1)$$

Centrifugal force given by:

$$F_c = mv_0^2/r = m\omega_0^2 r^2/r = m\omega_0^2/r \quad (2.4.1.2)$$

ω_0 = Angular frequency of the movement in the clockwise direction.

r = radius of the orbit.

$$m\omega_0^2 r = F_e \quad (2.4.1.3)$$

F_e = Electrical force resulting from the attraction of the nucleus to electrons.

There is extra force exist when a magnetic field is applied known as Lorentz force(F_L) and when the electron in the same orbit Angular frequency changes because of the extra force so Equation of motion be in the form:

$$F = m\omega^2 r = F_e - F_L = m\,\omega_0^2 r - e\, r\, \omega\, B \quad (2.4.1.4)$$

$$F = mv^2/r = m\,\omega^2 r^2/r \quad (2.4.1.5)$$

$$\omega_0^2 - \omega^2 = e\,\omega\, B/m \quad (2.4.1.6)$$

$$\omega \approx \omega_0$$

$$\omega_0 - \omega = \Delta\,\omega \quad (2.4.1.7)$$

$$\omega_0^2 - \omega^2 = (\omega_0 - \omega)\,(\omega_0 + \omega) = (2\omega)\,(\Delta\,\omega) = 2\,\omega\,\Delta\,\omega \quad (2.4.1.8)$$

And:

$$\Delta\,\omega = eB/\,2m \quad (2.4.1.9)$$

This frequency $\Delta\omega$ is Larmor frequency as in:

$$\omega_L = \Delta\omega \qquad (2.4.1.10)$$

This results in effective current:

$$i = -ef = \omega_L \times e/2\pi = (-eB/2m)\, e/2\pi \qquad (2.4.1.11)$$

And when the magnitude of magnetic dipole moment is consider:

$$M_a = iA = -e\,\omega_L / 2\pi \times \pi R^2 = -e\,\omega_L \times R^2/2 \qquad (2.4.1.12)$$

This moment is generated when applying a magnetic field, the change in magnetic dipole moment given by:

$$M_a = -e\,R^2/2\ \Delta\omega \qquad (2.4.1.13)$$

From eq (2.4.1.11):

$$M_a = -e^2 R^2 B/4m = -(e^2 B R^2)/(4m) \qquad (2.4.1.14)$$

$$R^2 = 2/3\, r^2 \qquad (2.4.1.15)$$

Where:

R = the radius of rotation of the electron around the magnetic field.

So eq (2.4.1.14) becomes:

$$M_a = -e^2 B\, r^2/6m \qquad (2.4.1.16)$$

$$x^2 + y^2 + z^2 = r^2 \quad , x = y = z$$

$$3z^2 = r^2 \quad , \quad z^2 = 1/3\, r^2$$

$$R^2 = 2/3\, r^2 \quad , \quad R^2 = r^2 - z^2 \qquad (2.4.1.17)$$

Intensity of magnetization M given by:

$$M = n\,z\,M_a = -n\,z\,e^2 r^2 B/6m = -n\,z\,e^2 r^2 \mu_0 H/6m \qquad (2.4.1.18)$$

Where:

z = the number of electrons of external crust of the atom.

n = Atomic density

Diamagnetic susceptibility in SI units is:

$X_D = M/H = - \mu_0 \, n \, z \, e^2 \, r^2 / 6m$ (2.4.1.19)

2.4.2 Paramagnetic Materials

In paramagnetism, the atoms or molecules of the substance have net orbital or spin magnetic moments that are capable of being aligned in the direction of the applied field. They therefore have a positive (but small) susceptibility and a relative permeability slightly in excess of one. Paramagnetism occurs in all atoms and molecules with unpaired electrons; e.g. free atoms, free radicals, and compounds of transition metals containing ions with unfilled electron shells. It also occurs in metals as a result of the magnetic moments associated with the spins of the conducting electrons. Paramagnetism is the tendency of the atomic magnetic dipoles, due to quantum-mechanical spin angular momentum, in a material that is otherwise non-magnetic to align with an external magnetic field. This alignment of the atomic dipoles with the magnetic field tends to strengthen it, and is described by a relative magnetic permeability, μ_r greater than unity (or, equivalently, a small positive magnetic susceptibility greater than zero. In pure paramagnetism, the external magnetic field acts on each atomic dipole independently and there are no interactions between individual atomic dipoles. Such paramagnetic behavior can also be observed in ferromagnetic materials that are above their Curie temperature. Paramagnetic materials attract and repel like normal magnets when subject to a magnetic field. Paramagnetic materials in magnetic fields will act like magnets but when the field is removed, thermal motion will quickly disrupt the magnetic alignment. In general paramagnetic effects are small (magnetic susceptibility of the order of $\chi_m \sim 10^{-3}$ to 10^{-5}).

From Quantum Theory of Paramagnetic:

$M_a = U_m = g \, (-e/2m) \, \hbar \, J$ (2.4.2.1)

Where:

U_m = Magnetic moment of the atom = M_a

g = Landau coefficient.

J = the total angular momentum.

Suppose that one level splits into tow levels in the presence of a magnetic field then:

$n = (n_1 + n_2)$ (2.4.2.2)

Where:

n = Total number of atoms.

n_1 = the number of electrons with positive spin on the first level.

n_2 = the number of electrons with negative spin on the second level.

From Maxwell Boltzmann distribution we find that:

$$n_1 = e^{\Delta E/kT} \quad (2.4.2.3)$$

$$n_2 = e^{-\Delta E/kT} \quad (2.4.2.4)$$

$$n = n_1 + n_2 = e^{\Delta E/kT} + e^{-\Delta E/kT} \quad (2.4.2.5)$$

$$n_1/n = e^{\Delta E/kT}/e^{\Delta E/kT} + e^{-\Delta E/kT} \quad (2.4.2.6)$$

$$n_2/n = e^{-\Delta E/kT}/e^{\Delta E/kT} + e^{-\Delta E/kT} \quad (2.4.2.7)$$

Magnitude of magnetism that occurs from n atoms is:

$$M = g\,\beta\, m_s\,(n_2 - n_1)$$

$$= g\,\beta m_s\,(e^x - e^{-x})/n)\, n = (e^x - e^{-x}/e^x + e^{-x})\, g\,\beta m_s n \quad (2.4.2.8)$$

We can but:

$$x = \Delta E/kT = g\,\beta m_s\; H/RT \quad (2.4.2.9)$$

When $e^x \approx 1 + x,\ x << 1$

$$e^x - e^{-x}/e^x + e^{-x} = (1 + x) - (1 - x)/(1 + x) + (1 - x) = 2x/2 = x$$

Then:

$$M = n\, m_s\, \beta g \times g\, \beta m_s\, H/kT$$

$$= n g^2 m^2_s\, \beta^2 \times H/KT \quad (2.4.2.10)$$

$g = 2$, $m_s = 1/2$

$$M = n\,\beta^2\; H/KT \quad (2.4.2.11)$$

So magnetic susceptibility x is:

$$X = M/H = n\,\beta^2/KT \quad (2.4.2.12)$$

2.4.3 Ferromagnetic Materials

A phenomenon in some magnetically ordered materials in which there is a bulk magnetic moment and the magnetization is large. The electron spins of the atoms in the microscopic regions, domains, are aligned. In the presence of an external magnetic field the domains oriented favorably with respect to the field grow at the expense of the others and the magnetization of the domains tends to align with the field. Above the Curie temperature, the thermal motion is sufficient to offset the aligning force and the material becomes paramagnetic. Certain elements (iron, nickel and cobalt), and alloys with other elements (titanium, aluminium) exhibit relative magnetic permeabilities up to 104 (ferromagnetic materials). Some show marked hysteresis and are used for permanent magnets, magnetic amplifiers etc. In ferromagnetic substances, within a certain temperature range, there are net atomic magnetic moments, which line up in such a way that magnetization persists after the removal of the applied field. Below a certain temperature, called the Curie point (or Curie temperature) an increasing magnetic field applied to a ferromagnetic substance will cause increasing magnetization to a high value called the saturation magnetization. This is because a ferromagnetic substance consists of small magnetized regions called domains. The total magnetic moment of a sample of the substance is the vector sum of the magnetic moments of the component domains. Ferromagnetism is a phenomenon by which a material can exhibit a spontaneous magnetization, and is one of the strongest forms of magnetism. It is responsible for most of the magnetic behavior encountered in everyday life, and is the basis for all permanent magnets (as well as the metals that are noticeably attracted to them).

2.4.4 Antiferromagnetism

Phenomenon in some magnetically ordered materials in which there is an anti-parallel alignment of spins in two interpenetrating structures so that there is no overall bulk spontaneous magnetization. In ferromagnetic materials, it is energetically favorable for the spins atomic to align, leading to spontaneous magnetization. However, in antiferromagnetic materials, the conditions are such that it is energetically favorable for the spins to oppose, leading to no overall magnetization In materials that exhibit antiferromagnetism, the spins of magnetic electrons align in a regular pattern with neighboring spins pointing in opposite directions. This is the opposite of ferromagnetism. Generally, antiferromagnetic materials exhibit antiferromagnetism at a low temperature, and become disordered above a certain temperature; the transition temperature is called the Néel temperature. Above the Néel temperature, the material is typically paramagnetic. The antiferromagnetic behaviour at low temperature usually results in diamagnetic properties, but can sometimes display ferrimagnetic behaviour, which in many physically observable properties are more similar to ferromagnetic interactions. The magnetic susceptibility, χ_m of an antiferromagnetic material will appear to go through a maximum as the temperature is lowered; in contrast, that of a paramagnet will continually increase with decreasing temperature.

Chapter Three

Alternating Current and Magnetic Induction

3.1 Introduction

This chapter is concurred with the properties of resistors, capacitors and circuits coils under the action of alternating current (AC).

3.2 Faraday's Law

Electromagnetic induction was first discovered by Michael Faraday, who made his discovery public in 1831 [5].

Electromagnetic or Magnetic induction is the production of an electromotive force or voltage across an electrical conductor due to its dynamic interaction with a magnetic field [5].

Electromagnetic induction is a term used to describe the production of EMFs by two apparently quite different mechanisms: (1) the movement of a conductor through a region of space where there is a magnetic field and (2) the existence of a changing magnetic field in some region of space.

Faraday's law states that the EMF is given by the rate of change of the magnetic flux:

$$\mathcal{E} = -\, d\emptyset \,/\, dt = -\, A\, dB/dt \qquad (3.3.1)$$

Where $\mathcal{E}$ is the electromotive force (EMF), $\emptyset$ is the magnetic flux, B is the magnetic flux density, and A is the area of the circuit.

3.3 Applications of Motional EMFS

Electromagnetic induction has found many applications in technology such as Generation of electrical power, an electromagnetic blood flow meter, Electrical components such as inductors and transformers, and devices such as electric motors and generators.

3.4 Alternating current (AC)

An alternating current is an electric current in which the flow of electric charge periodically reverses direction [5].

AC is the form in which electric power is delivered to businesses and residences. The usual wave form of alternating current in most electric power circuits is a sine wave in the form:

$$i = i_m \sin\omega t \qquad (3.4.1)$$

Where:

i_m = maximam current.

ω = angular frequency.

3.5 Mathematics of AC voltages

Alternating currents are accompanied (or caused) by alternating voltages. An AC voltage v can be described mathematically as a function of time by the following equation:

$$V(t) = V_m.\sin\omega t \qquad (3.5.1)$$

Where:

V_m: is the peak voltage (unit: volt),

ω : is the angular frequency (unit: radians per second)

The angular frequency is related to the physical frequency, f(unit = hertz),

which represents the number of cycles per second, by the equation.

$$\omega = 2\pi f \qquad (3.5.2)$$

t: is the time (unit: second).

3.6 RMS and Effective Values

Circuit currents and voltages in AC circuits are generally stated as root-mean-square or rms values rather than by quoting the maximum values. The root-mean-square for a current is defined by:

$$I_{rms} = \sqrt{(I^2)_{avg}} \qquad (3.6.1)$$

That is, you take the square of the current and average it, then take the square root. When this process is carried out for a sinusoidal current.

$$[I^2_m \sin^2 \omega t]_{avg} = I^2_m/2 \quad \text{so} \quad I_{rms} = \sqrt{(I^2)_{avg}} = I_m/\sqrt{2} \qquad (3.6.2)$$

Since the AC voltage is also sinusoidal, the form of the rms voltage is the same. These rms values are just the effective value needed in the expression for average power to put the AC power in the same form as the expression for DC power in a resistor. In a resistor where the power factor is equal to 1.

Since the voltage and current are both sinusoidal, the power expression can be expressed in terms of the squares of sine or cosine functions, and the average of a sine or cosine squared over a whole period is = 1/2.

$P_{avg} = V_{rms} I_{rms}$ (3.6.3)

3.7 Resistors, Capacitors and Inductors in AC circuits

3.7.1 Resistor in AC Circuits

Consider a purely resistive circuit with a resistor connected to an AC generator, as shown in Figure (3.7.1) below.

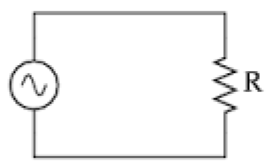

Figure (3.7.1) A purely resistive circuit

If we apply Ac it's intensity

$i=i_m \sin \omega t$ (3.7.1.1)

in this resistor of a resistive R then the Voltage between the ends of the conductor is:

$v = v_m \sin \omega t$ (3.7.1.2)

Where the resistance is equal:

$R = v_e/i_e= (v_m/\sqrt{2})/ (i_m/\sqrt{2})$

$R = v_m/i_m$ (3.7.1.3)

3.7.2 Inductor in AC Circuits

Consider now a purely inductive circuit with an inductor connected to an AC generator, as shown in Figure (3.7.2) below.

Figure (3.7.2) A purely inductive circuit

If we apply Ac it's intensity

$i = i_m \sin \omega t$ (3.7.2.1)

in inductor L then voltage between the ends of the coil is:

$v = L di/dt = L\ i_m\ d \sin \omega t/dt$

$= L\ i_m\ [\omega \cos \omega t]$

$= \omega\ L\ i_m \cos \omega t$

$= \omega\ L\ i_m \sin (\omega t + 90)$

Then:

$v = \omega\ L\ i_m \sin (\omega t + 90)$ (3.7.2.2)

The maximum value of the voltage is in sin =1

$V_m = \omega\ L\ i_m$ (3.7.2.3)

The reactance inductive is equal to:

$X_L = v_e/i_e = (v_m/\sqrt{2})/\ (i_m/\sqrt{2})$

$= v_m/i_m = \omega\ L\ v_m/i_m$ (3.7.2.4)

3.7.3 Capacitor in AC Circuits

In the purely capacitive case, both resistance R and inductance L are zero. The circuit diagram is shown in Figure (3.7.3) below.

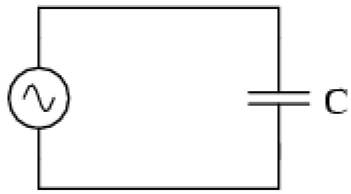

Figure (3.7.3) A purely capacitive circuit

If we apply Ac it's intensity:

$i = i_m \sin \omega t$ (3.7.3.1)

in condenser then the capacity is equal:

C = Q/V

The voltage between the ends of the capacitor:

C = Q/V

Since the current intensity i is equal to:

i = - dQ/dt so, i = dQ

Hence:

$Q = \int dQ = -\int idt$

$Q = cv \quad , \quad v = (1/c)\, Q$ (3.7.3.2)

Then the voltage between the ends of the capacitor is:

$v = 1/c \int dQ$

$v = +1/c \int idt$

$= +1/c \int i_m \sin \omega t \, dt$

$= v = (-i_m/\omega c) \cos \omega t$

$v = i_m/\omega c \sin (\omega t - 90)$ (3.7.3.3)

$= - (i_m/\omega c) \sin (\omega t + 90)$

The maximum value of the voltage is in sin=1, and when:

$v_m = (i_m/\omega c) (-1)$ (3.7.3.4)

The reactance capacitive is:

$X_c = v_e/i_e = (v_m/\sqrt{2})/ (i_m/\sqrt{2})$

$= v_m/i_m = -1/\omega c$ (3.7.3.5)

3.8 AC circuits

In general Ac circuits can be connected in series or in parallel.

3.8.1 The RL Series Circuit

Consider RL series circuit as shown in Figure (3.8.1) below.

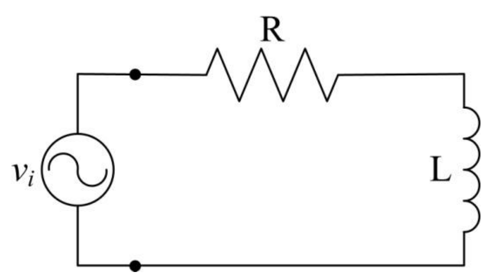

Figure (3.8.1) RL series circuit

If we apply Ac it's intensity:

$i = i_m \sin \omega t$ (3.8.1.1)

in the above circuit then the Overall voltage equal:

$V = V_R + V_L = R_i + L\, di/dt$

Thus:

$V = R_i + L\ i_m\ d\ \sin\omega t/dt$

Therefore:

$V = R_i + \omega\ Li_m \cos\omega t$

Hence:

$V = R\ i_m \sin\omega t + X_L\ i_m \cos\omega t$ (3.8.1.2)

The voltage can be written as:

$V = V_m \sin(\omega t + \phi)$ (3.8.1.3)

$V = V_m \cos\phi \sin\omega t + V_m \sin\phi \cos\omega t$ (3.8.1.4)

By comparing the Coefficients of sin ωt, cos ωt in the equations (3.8.1.2) and (3.8.1.4) we find:

$V_m \sin\phi = X_L\ i_m$

$V_m \cos\phi = R\ i_m$ (3.8.1.5)

From eq (3.8.1.5) we can find the phase difference ϕ is:

$\tan\phi = V_m \sin\phi / V_m \cos\phi$

$= X_L\ i_m / R i_m$

$\tan\phi = X_L/R$ (3.8.1.6)

We can find V_m by Squaring sides of the equation in eq (3.8.1.5):

$V^2_m \sin^2\phi + V^2_m \cos^2\phi = X_L^2\ i^2_m + R^2\ i^2_m$

Then:

$V^2_m (\sin^2\phi + \cos^2\phi)$

$= i^2_m (R^2 + X^2_L)$

Therefore:

$V_m = \sqrt{(R^2 + X^2_L)}\ i_m$ (3.8.1.7)

The Circuit resistance Z is equal:

$Z = v_e/i_e = (v_m/\sqrt{2})/(i_m/\sqrt{2}) = v_m/i_m$

$Z = \sqrt{(R^2+X^2_{\ L})}$ (3.8.1.8)

3.8.2 The RC Series Circuit

Consider RC series circuit as shown in Figure (3.8.2) below.

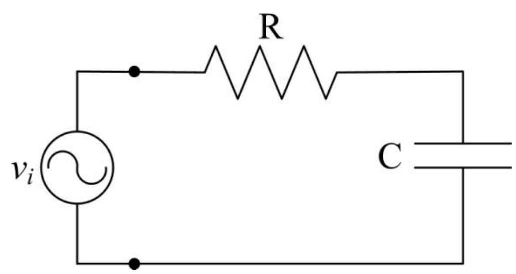

Figure (3.8.2) RC series circuit

If we apply Ac it's intensity:

$i = i_m \sin \omega t$ (3.8.2.1)

in the above circuit then Overall voltage equal:

$V = V_R + V_C = R_i + q/c$ (3.8.2.2)

$i = dq/dt$, $\int i\ dt = \int dq = q$

Since:

$q = \int idt$

$v = R_i + 1/c\int i\ dt$

We find that:

$v = R_i + i_m/c \int \sin\ \omega t\ dt$

$v = R_i\ -\ \ i_m/\ \omega c \cos\omega t$

So:

$V = R\, i_m \sin\omega t + X_c\, i_m \cos\omega t$ (3.8.2.3)

This is means that:

$V = V_m \sin(\omega t + \phi)$ (3.8.2.4)

Then:

$V = V_m \cos\phi \sin\omega t + V_m \sin\phi \cos\omega t$ (3.8.2.5)

By comparing eq (3.8.2.3) and eq (3.8.2.5):

$V_m \sin\phi = X_c\, i_m$

$V_m \cos\phi = R\, i_m$ (3.8.2.6)

Finding the Phase difference ϕ from the relation:

$\text{Tan}\,\phi = V_m \sin\phi / V_m \cos\phi = X_c\, i_m / R\, i_m = X_c/R$

Then:

$\text{Tan}\,\phi = X_c/R$ (3.8.2.7)

By squaring and adding sides of the eq (3.8.2.6) we find that:

$V^2_m \sin^2\phi + V^2_m \cos^2\phi = X^2_c\, i^2_m + R^2\, i^2_m$

Hence:

$V^2_m (\sin^2\phi + \cos^2\phi) = (X^2_c + R^2)\, i^2_m$

$V^2_m = (X^2_m + R^2)\, i^2_m$

$V_m = \sqrt{(X^2_c + R^2)}\ \ i_m$ (3.8.2.8)

The Circuit resistance Z is equal to:

$Z = v_e/i_e = (v_m/\sqrt{2})/(i_m/\sqrt{2}) = v_m/i_m$

$= \sqrt{(X^2_c + R^2)} = Z$

3.8.3 Parallel RC Circuit

Consider Parallel RC circuit as shown in Figure (3.8.3) below.

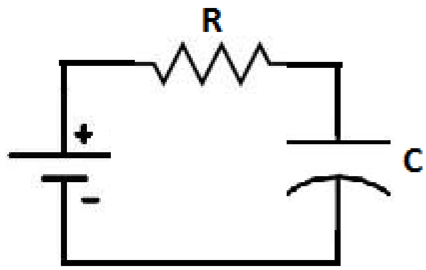

Figure (3.8.3) Parallel RC circuit.

If we apply a voltage equal:

$V = V_m \sin \omega t$ (3.8.3.1)

Between the ends of parallel resistance and capacitor the total current is equal:

$i = i_R + i_C = i_R + c\, dv/dt$ (3.8.3.2)

Since:

$Q = cv$

$i_C = dQ/dt = c\, dv/dt$

Using eq (3.8.3.1) we find that:

$I = V/R + Cv_m\, d \sin\omega t/dt = V/R + Cv_m\, [\omega \cos\omega t]$

Therefore:

$I = V/R + Cv_m[\omega \cos\omega t]$

$I = V/R + \omega\, Cv_m \cos\omega t$

Since:

$y_R = 1/R,\ y_C = \omega c = -1/X_c$

Therefore:

$i = y_R V_m \sin\omega t + y_C V_m \cos \omega t$ (3.8.3.3)

This current can be written as:

$i = i_m \sin(\omega t + \phi)$ (3.8.3.4)

Therefore the current will be:

$i = i_m \cos\phi \sin\omega t + i_m \sin\phi \cos\omega t$ (3.8.3.5)

By comparing the Coefficients of $\sin\omega t$, $\cos\omega t$ in the equations (3.8.3.3) and (3.8.3.5) we find:

$i_m \sin\phi = y_C V_m$

$i_m \cos\phi = y_R V_m$ (3.8.3.6)

The phase difference ϕ can be found from eq (3.8.3.6):

$\tan\phi = i_m \sin\phi / i_m \cos\phi = y_C V_m / y_R V_m$

$= y_C / y_R$

$\tan\phi = y_C / y_R$

Finding i_m by squaring both sides of eq (3.8.3.6):

$i^2_m (\sin^2\phi + \cos^2\phi) = (y^2_C + y^2_R) V^2_m$

$i_m = \sqrt{(y^2_C + y^2_R)}\ V_m$ (3.8.3.7)

The impedance y is:

$y = i_e / v_e = (i_m/\sqrt{2})/(v_m/\sqrt{2}) = i_m/v_m = \sqrt{(y^2_C + y^2_R)}$ (3.8.3.8)

3.8.4 The RLC Series Circuit

Consider now the series RLC circuit shown in Figure (3.8.4) below.

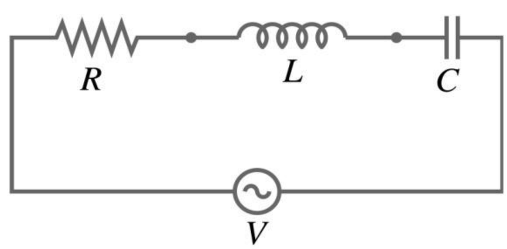

Figure (3.8.4) A series RLC Circuit

If we apply Ac it's intensity:

$i = i_m \sin \omega t$ (3.8.4.1)

in the above circuit thenthe Overall voltage equal:

$V = V_R + V_L + V_C = R\, i + L di/dt + 1/c\int i\, dt$

By differentiating:

$R_i + L\omega\ \ i_m \cos\omega t + i_m/c \int \sin \omega t\, dt$

$V = R\, i_m \sin \omega t + (X_L + X_C)\, i_m \cos \omega t$ (3.8.4.2)

V can be written as:

$V = V_m \sin(\omega t + \phi)$ (3.8.4.3)

$V = V_m \cos\phi \sin\omega t + V_m \sin\phi \cos \omega t$ (3.8.4.4)

By comparing Coefficients of sinωt, cosωt in (3.8.4.2) and (3.8.4.4) we find:

$V_m \sin\phi = (X_L + X_C)\, i_m$

$V_m \cos\phi = R\, i_m$ (3.8.4.5)

Finding the Phase difference ϕ:

$\tan\phi = V_m \sin \phi / V_m \cos \phi = (X_L + X_C)\, i_m / R\, i_m$

$\tan\phi = (X_L + X_C)/R$ (3.8.4.6)

Finding Maximum voltage:

By squaring both sides of the equation (3.8.4.5) we find:

$V^2_m \sin\phi + V^2_m \cos\phi = (X_L + X_C)^2\, i^2_m + R^2\, i^2_m$

$V^2_m\ (\sin^2\phi + \cos^2\phi) = [(X_L + X_C)^2 + R^2]\, i^2_m$

$V_m = \sqrt{(X_L + X_C)^2 + R^2}\ \ i_m$ (3.8.4.7)

The Circuit resistance Z is equal to:

$Z = v_e/i_e = v_m/\sqrt{2}\ /\ i_m/\sqrt{2} = v_m/i_m$

$= \sqrt{(X_L + X_C)^2 + R^2}$ (3.8.4.8)

3.8.5 Parallel RLC Circuit

Consider the parallel RLC circuit illustrated in Figure (3.8.5) below.

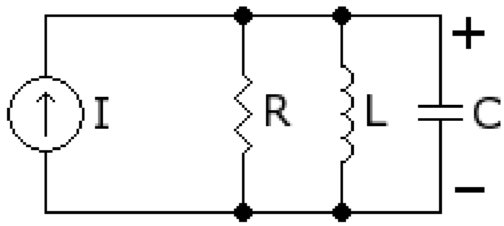

Figure (3.8.5) Parallel RLC circuit

Total current in this circuit is:

$i = i_R + i_L + i_C$

$= y_R v + 1/L \int v\, dt + c \frac{dv}{dt}$ (3.8.5.1)

And when the voltage is equal to:

$V = V_m \sin\omega t$

Passes in the circuit, Then the Intensity of total current equal to:

$i = y_R v - (V_m/\omega L) \cos\omega t + (\omega c\, v_m) \cos\omega t$ (3.8.5.2)

The current can be written as:

$i = i_m \sin(\omega t + \phi)$

$i = i_m \cos\phi \sin\omega t + i_m \sin\phi \cos\omega t$ (3.8.5.3)

By comparing eq (3.8.5.2) and eq (3.8.5.3) we find:

$i_m \sin\phi = (y_L + y_C) V_m$

$i_m \cos\phi = y_R V_m$ (3.8.5.4)

The phase difference ϕ between I and v is:

$\tan\phi = i_m \sin\phi / i_m \cos\phi = (y_L + y_C) V_m / y_R V_m$

$= \text{Tan } \phi = (y_L + y_C)/y_R$

The maximum value of the current is given by:

$i^2_m (\sin^2 \phi + \cos^2 \phi) = [(y_L + y_C)^2 + y^2_R] V^2_m$

$i_m = \sqrt{}(y^2_R(y_L+y_C)^2 \ V_m$

The total impedance y is:

$y = i_e/v_e = (i_m/\sqrt{2})/ (v_m/\sqrt{2}) = i_m/v_m$

$y = \sqrt{}(y^2_R(y_L+y_C)^2$ (3.8.5.5)

Chapter Four

Materials and Methods and Results

4.1 Introduction

This section deals with some of the studies and the practical part of the search for. And identification tools, results, discussion and conclusion.

4.2 Materials

The equipments used in this work are:

AC/DC Power Supply:

Made in Germany by Ley Bold.

$I_{min} = 0$ - $I_{max} = 5A$, $V_{min} = 0$ - $V_{max} = 15$volt.

Coil:

Made in Germany by Ley Bold.

Model No: 56 2 13.

N = 250 turns , A = 1.5 mm , R = 0.6Ω , $I_{max} = 5A$.

Microvolt meter:

Made in USA by Kelthley.

Model No: DMM 177.

$V_{min} = 1$microvolt - $V_{max} = 1000$volt.

Ammeter:

Made in USA.

$I_{min} = 0$ - $I_{max} = 20$ A.

Rheostat:

Made in Holland by Huygens Laboralorium.

Model No: 801754.

R = 27.5Ω , I = 5.2A.

Wires.

4.3 Method

The circuit was connected .Air coil was used, The current changed in every time using the Rheostat .Secondly the core of the coil filled by Aluminum, The Aluminum replaced by copper. Finally Copper was replaced by Iron and the readings were taken in each time.

4.4 Results

Air coil was used at first, the current changed in every time using the Rheostat, the voltage readings were taken. The results are shown in the table below.

Table (4.1) Readings of V and I of a coil filled with Air

Voltage (mV)	Current (μA)
0.74296	0.3228
0.73188	0.29824
0.7219	0.27544
0.71248	0.25007
0.70445	0.23233
0.69389	0.20784
0.68476	0.18585
0.6781	0.16891
0.66784	0.1368
0.65786	0.114

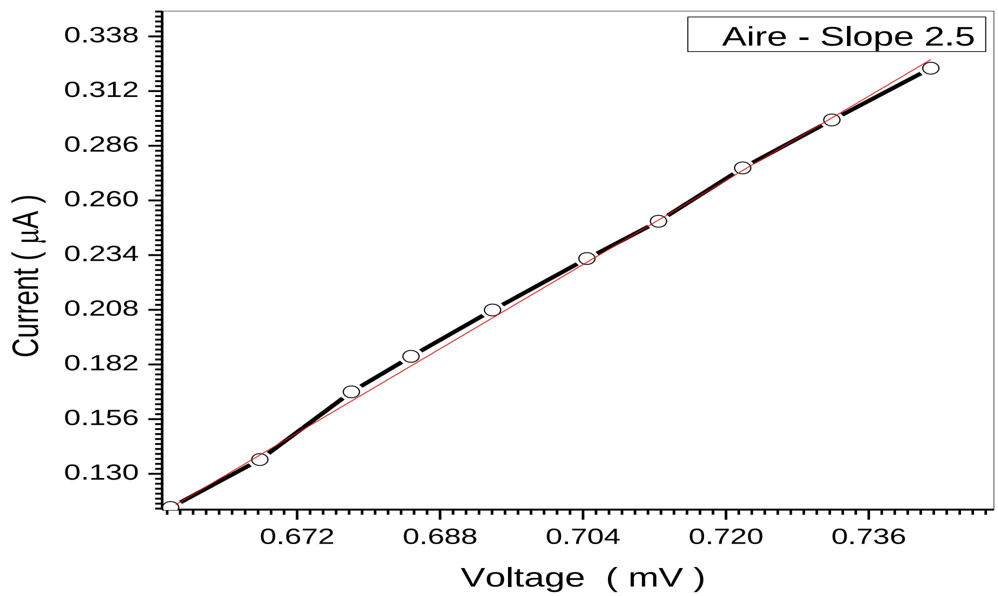

Figure (4 .1) the relationship between the voltage and current for Air

Finding the magnetic Permeability μ of Air from the equation:

L = AμN

μ = L/AN

Where:

A = area cross section = 1.5 mm.

N = number of turns = 250.

L = self-inductance of the coil.

From the graph since:

V/I = slope = $2\Pi f$L

f= frequency of the supply.

L = $1/2\Pi f \times$ slope = 7.961×10^{-6} Henry.

$\mu = L/AN = 7.961 \times 10^{-6}/1.5\times\ 10^{-3} \times 250 = 2.123 \times 10^{-5}$ H/m.

Coil core filled with Al, the results are shown in the table below.

Table (4.2) Readings of V and I for Al

Voltage (mV)	Current (μA)
0.52	0.099
0.51144	0.09152
0.50521	0.08721
0.49921	0.08239
0.49	0.07654
0.48225	0.07047
0.47403	0.06438
0.46804	0.06031
0.46354	0.05727
0.4598	0.05448
0.45506	0.05094
0.45231	0.04865
0.44982	0.04636

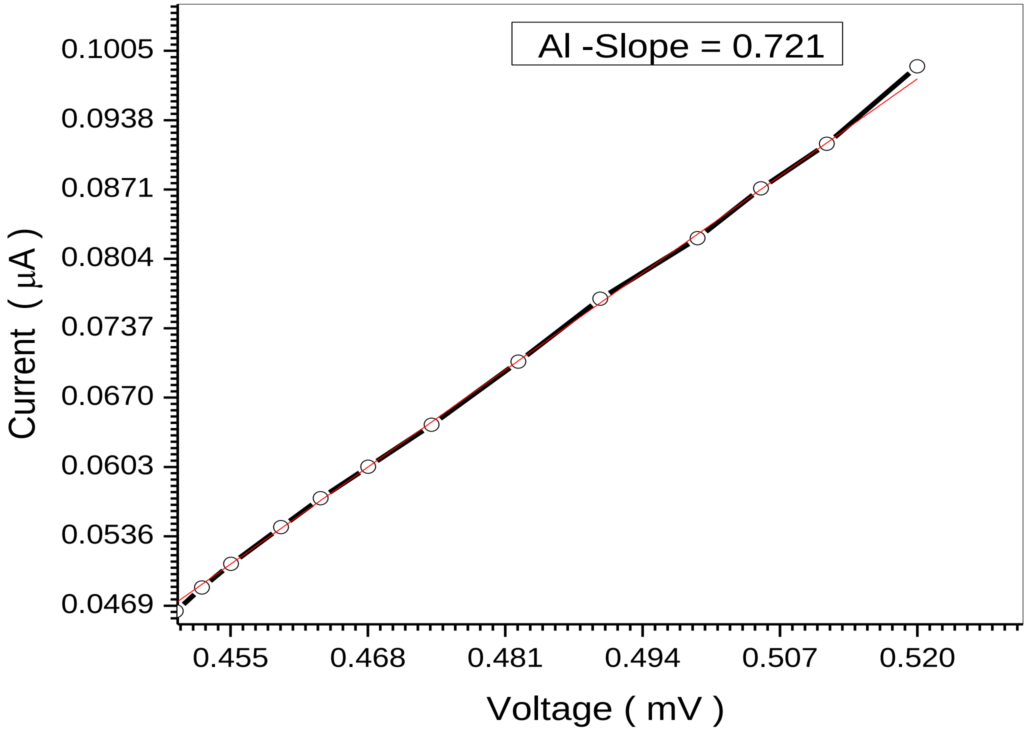

Figure (4 .2) the relationship between the voltage and current for Al

Magnetic Permeability μ of Al:

L = $1/2\Pi f \times$ slope = 2.296×10^{-6} Henry.

μ = L/AN = $2.296 \times 10^{-6}/1.5 \times 10^{-3} \times 250 = 6.123 \times 10^{-6}$ H/m.

Al replaced by Copper, the results are shown in the table below.

Table (4.3) Readings of V and I for Copper

Voltage (mV)	Current (μA)
0.81	0.034
0.7952	0.0327
0.77965	0.03151
0.76957	0.03053
0.75707	0.02958
0.74763	0.02864
0.73419	0.02755
0.72261	0.02671
0.715	0.026

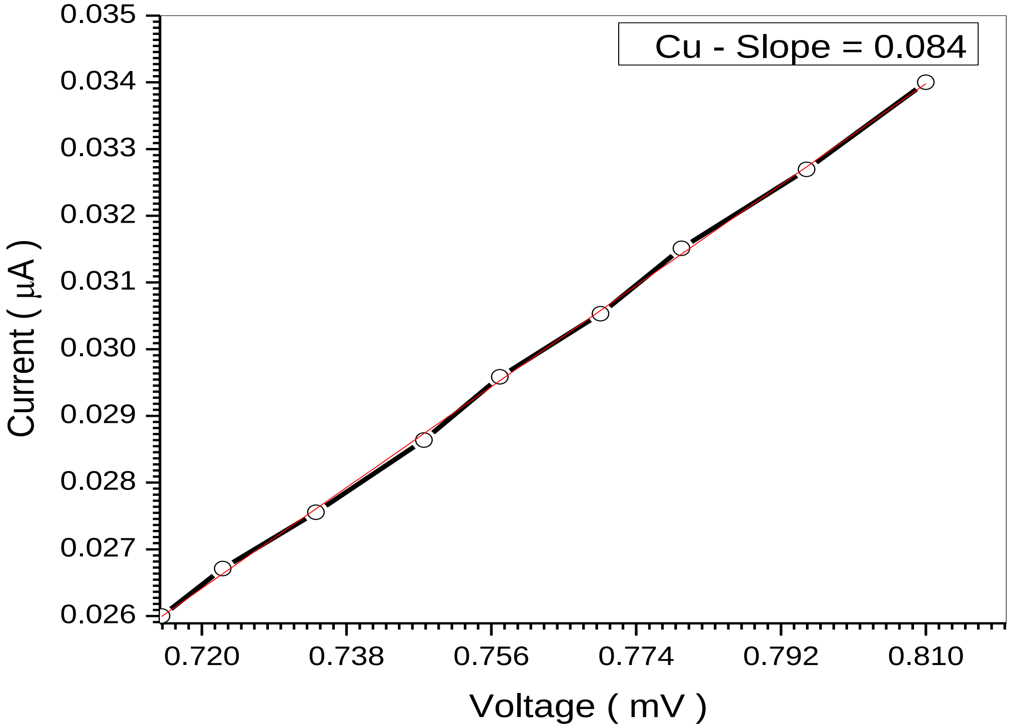

Figure (4.3) the relationship between the voltage and current for Copper

Magnetic Permeability μ of Copper:

L = $1/2\Pi f \times$ slope = 2.675×10^{-7} Henry.

μ = L/AN = $2.675 \times 10^{-7}/1.5 \times\ 10^{-3} \times 250 = 7.1 \times 10^{-7}$ H/m.

Finally Copper replaced by Iron, results are shown in the table below.

Table (4.3) Readings of V and I for Iron

Voltage (mV)	Current (μA)
2.75091	0.02167
2.7323	0.02128
2.68031	0.02032
2.62946	0.01936

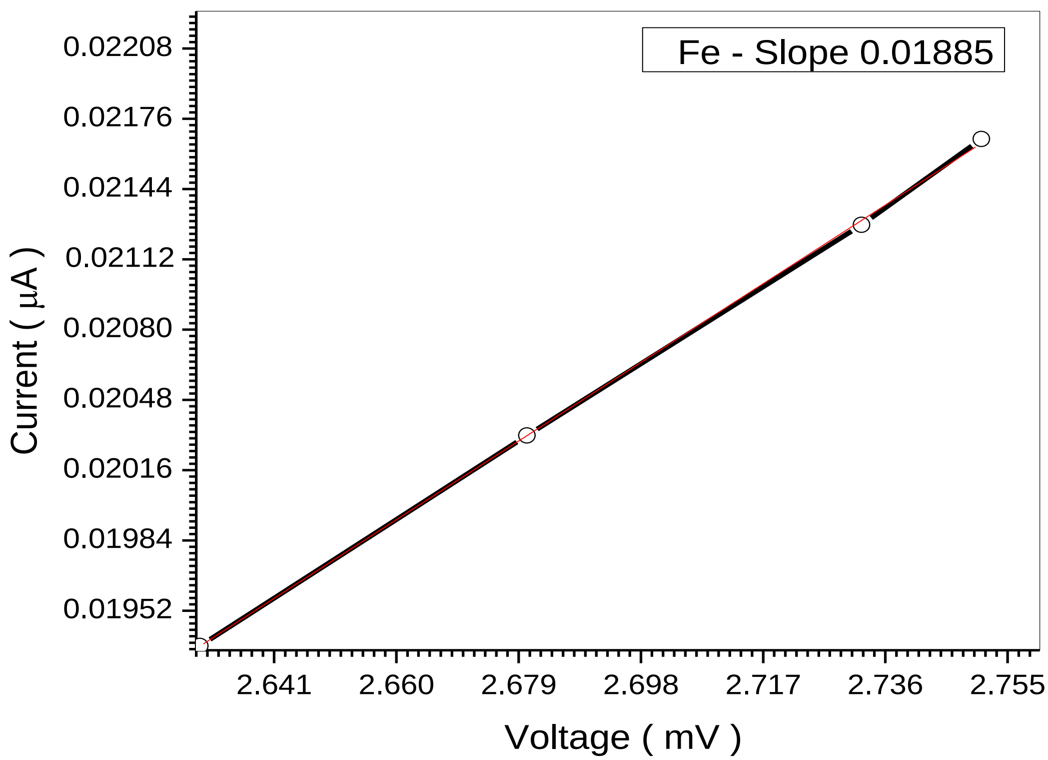

Figure (4.4) the relationship between the voltage and current for Fe

Magnetic Permeability μ of Fe:

L = $1/2\Pi f \times$ slope = 6.003×10^{-8} Henry.

μ = L/AN = $6.003 \times 10^{-8} / 1.5 \times 10^{-3} \times 250 = 1.6 \times 10^{-4}$ H/m.

4.5 Discussion

The magnetic Permeability for Air , Aluminum (Al) and , Copper (Cu) and Iron (Fe) was found from figure (4.1,2,3,4) respectively to be 2.123×10^{-5} H/m for Air , 6.123×10^{-6} H/m for Al , 7.1×10^{-7} H/m for Copper and 1.6×10^{-4} H/m for Iron. Comparing these values with the standard ones, $1.25663753 \times 10^{-6}$ H/m for Air, 1.256665×10^{-6} H/m for Al, 1.256629×10^{-6} for Copper and 6.3×10^{-3} for Iron. It's clear that the values agree to a good degree of precision with the standard ones.

4.6 Conclusion

It was concluded that, it's very easy to find magnetic Permeability for materials by using simple electric circuits.