YILDIZ TECHNICAL UNIVERSITY

FACULTY OF ARTS AND SCIENCES DEPARTMENT OF PHYSICS

(FIZ1002) PHYSICS 2 LABORATORY EXPERIMENT CYCLE

Spring Semester of the 202…- 202… Academic Year

Name-Surname :

Student No :

Department :

Group No :

Experiment 1- Charges and Fields

Experiment 2- Charging and Discharging of a Capacitor

Experiment 3- Ohm's Law and Kirchhoff's Rules

Experiment 4- Magnetic Force Acting on a Current-Carrying Conductor

Experiment 5- Investigation of Motion of Charged Particles in Electric and Magnetic Fields and Determination of e/m_e Ratio

EXPERIMENT 1

Charges and Fields

Purpose: To charge conductive objects, measure the force exerted by charged objects on each other, and observe Coulomb's law.

Equipment: Pencil, eraser, calculator

1. Background Information

Amber (the fossilized resin of an extinct pine tree) acquires the ability to attract light objects when rubbed against a woolen fabric. In ancient Greek, this property was referred to as "electricity." Today, we use the same term to describe all phenomena caused by electric charges.

Objects can become charged through friction. Additionally, it is possible to charge objects by conduction (contact) and induction. For this process, a charged object must be present. In nature, there are two types of electric charges: positive charge (protons) and negative charge (electrons). Like charges repel each other, whereas opposite charges attract. A charged object can also attract a neutral object.

Objects are composed of atoms. If an atom has an equal number of electrons and protons, it is neutral. If an atom has more electrons than protons, it carries a net negative charge; if it has more protons than electrons, it carries a net positive charge. When a glass rod is rubbed with a silk cloth, it loses electrons and becomes positively charged, while the silk cloth gains an equal amount of electrons and becomes negatively charged. During this frictional process, the total net charge of the system remains unchanged. This principle is known as the **law of charge conservation**, which is analogous to the law of energy conservation.

The smallest unit of charge found in nature is the charge of an electron (or a proton). All net charges are integer multiples of this fundamental charge **e**, meaning that charge is quantized.

$$Q = Ne \tag{1}$$

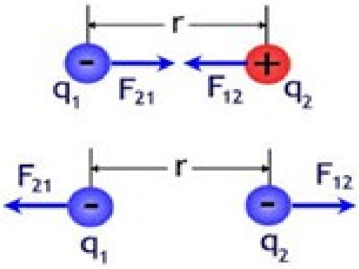
Electric charge, like mass, is a fundamental property of matter.

Coulomb's Law

Charges exert electric forces on each other. Coulomb discovered that this electric force is directly proportional to the product of the charges and inversely proportional to the square of the distance between them. The electric force is expressed as follows:

$$\vec{F}_{12} = k\frac{q_1 q_2}{r^2}\hat{r} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{r} \qquad (2)$$

$$\vec{F}_{12} = -\vec{F}_{21} \qquad (3)$$



(4)

$$k = 8.98x10^{9}\,\frac{Nm^2}{C^2} \qquad \varepsilon_0 = \frac{1}{4\pi k} = 8.85x10^{-12}\,\frac{C^2}{Nm^2}$$

In this equation, kkk is the proportionality constant, and ε_0 represents the permittivity of free space. The direction of the force vector lies along the straight line connecting the charges.

Coulomb's law is valid for stationary, point charges. It can also be applied to spherically charged objects, provided that the distance between them is greater than the sum of their radii. However, it cannot be directly applied to arbitrary charge distributions. Nevertheless, such distributions can be analyzed by approximating them as systems composed of multiple point charges using the **superposition principle**.

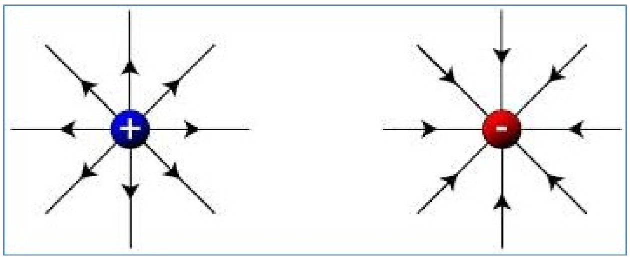
Electric Field

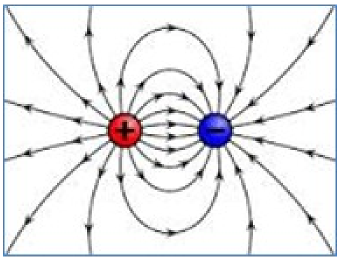
Charges exert electric forces on each other through an electric field. The concepts of scalar and vector fields are widely used in all areas of physics. A vector field has both direction and magnitude, and the electric field is an example of a vector field.

The electric field is defined as the ratio of the Coulomb force acting at a given point to a test charge placed at that point.

$$\vec{E} = \frac{\vec{F}}{q_{test}} = \frac{1}{4\pi\varepsilon_0}\frac{q_{source}}{r^2}\hat{r} \qquad (5)$$

The test charge is assumed to be small enough that it does not influence the field itself. It serves only as a tool for determining the magnitude and direction of the field. The electric field is defined at every point in space except at the location of the charge itself.





The electric field is presented using **electric field lines**. The **electric field vector** is tangent to these field lines at any given point. The lines originate from positive charges and terminate at negative charges, and they never intersect.

The **strength of the electric field** is proportional to the number of field lines passing through a unit area perpendicular to the lines.

**** IMPORTANT NOTE: DUE TO THE USE OF A HIGH VOLTAGE SOURCE, CAREFUL WORK IS REQUIRED.****

2. Experiment

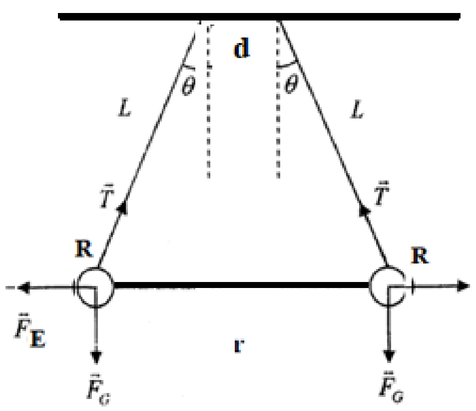


Figure 1

1. The experimental setup is introduced to the student.

The experimental setup consists of two metal spheres of identical radius and mass, suspended from a rod by conductive wires of equal length. When the spheres are suspended in contact with each other, the distance between the suspension points of the wires is d.

2. The millimeter scale is placed on the optical bench, and the distance between the centers of the spheres is measured

3. Since the radii of the spheres are known to be 0.6 cm, the proportionality constant (dimensionless) is given by:

$$Proportionality\ constant\ (dimensionless) = \frac{1.2\ cm}{measured\ distance\ (cm)}$$

Thus, throughout the experiment, the distance measured from the scale can be multiplied by the proportionality constant to calculate the actual distance.

4. The high voltage source is turned on, and its value is gradually and continuously increased until it reaches 9000V, ensuring that the spheres become charged.

5. The spheres, charged with the same amount of charge, are then separated. The system is allowed to reach equilibrium before proceeding.

6. The mass of the spheres, their radius, the length of the string, and the applied potential difference are recorded in Table 1. The proportionality constant is also written in Table 1.

7. When the separated spheres come to rest, the distance between the centers of the spheres is measured using the scale on the screen. By multiplying this measured distance by the proportionality constant, the actual distance is calculated and recorded as the value of rrr in the table.

8. Using the actual distance rrr, it can be seen from the above Figure 1 that:

$$r = 2(L)\sin(\theta) + d$$

This equation can be used to calculate the angle θ.

9. Using Figure 1, the experimental electric force can be calculated from the following expression

$$F_E = mgtan(\theta)$$

10. The amount of charge on the spheres is calculated based on the applied voltage and the capacitance of the spheres.

$$V(r) = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R}$$

The theoretical electric force is then calculated using Coulomb's law. The results are recorded in Table 2.

11. The distance between the spheres is changed, and the same procedures are repeated.The charge on the spheres and the electric force are calculated for each new distance. The results are recorded in Table 2.

12. The calculated charge value Q is divided by the charge of the electron (1.6×10−19C), which is the smallest charge found in nature, to calculate the number of charges accumulated on the spheres:

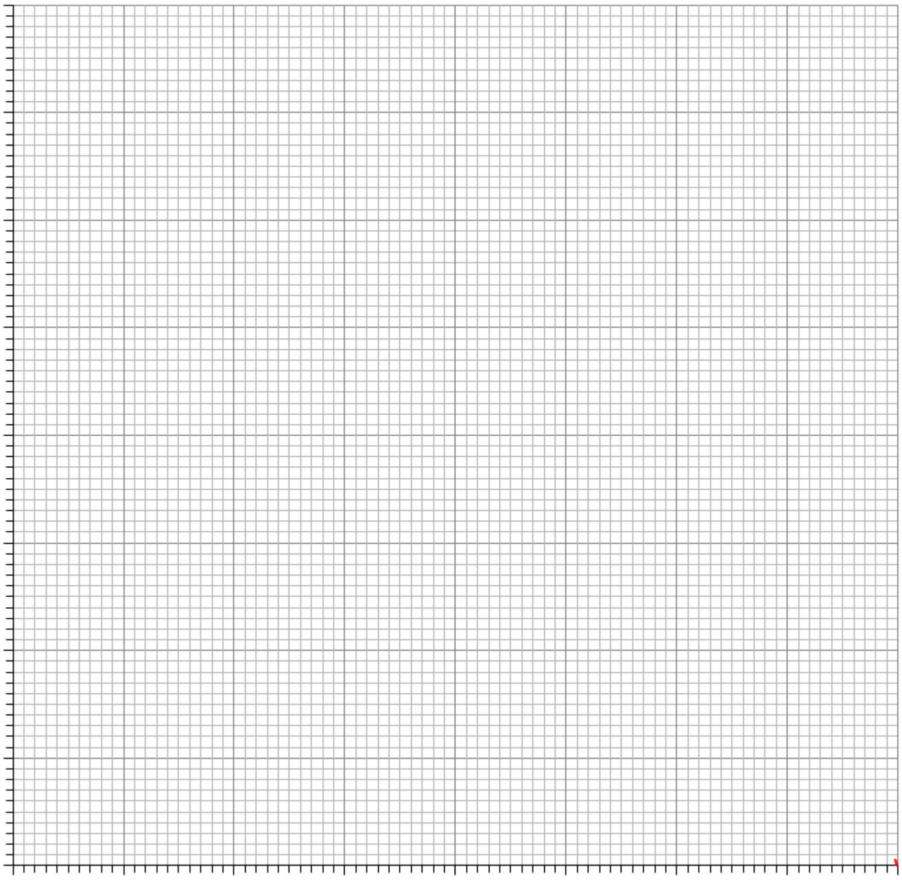
Table 1

m (kg)	L (m)	R (m)	V (volt)	Proportionality constant
0.0004	0.235	0.006	9000	

Table 2

d (m)	F_G (N)	r (m)	θ(°)	$Q_1 = Q_2$ (nC)	F_E (N) Experimental	F_E (N) Theoretical	Number of elementary charges (Q/e)

13. The experimental electric force as a function of distance, $F_{experiment}=f(r)$ is plotted based on the data obtained from the experiment.



EXPERIMENT 2

Charging and Discharging of a Capacitor

Purpose: Determination of the capacitance of a capacitor and life constant of a RC circuit.

Equipments: Resistance, capacitor, power supply, voltmeter, stopwatch, graph paper.

1. Introduction

A capacitor is a passive two-terminal electrical component used to store energy electrostatically in an electric field. The forms of practical capacitors vary widely, but all contain at least two electrical conductors separated by a dielectric (insulator); for example, one common construction consists of metal foils separated by a thin layer of insulating film.

When there is a potential difference across the conductors, an electric field develops across the dielectric, causing positive charge to collect on one plate and negative charge on the other plate. Energy is stored in the electrostatic field. An ideal capacitor is characterized by a single constant value, capacitance, C. This is the ratio of the electric charge on each conductor to the potential difference between them. The SI unit of capacitance is the Farad, which is equal to one coulomb per volt.

$$C = Q_0 / V_0 \qquad (1)$$

For practical applications µF, nF, pF is used. The capacitance of a capacitor depends on the geometry of the conductor, the dielectric constant of the insulator.

$$C = \varepsilon_0 \frac{A}{d} \qquad (2)$$

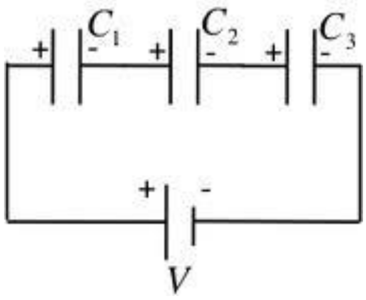
Where A is the area of the parallel plates and d is the distance between the plates. The charge in a capacitor changes as a function of time while charging and discharging.

The relation of the charge and the voltage is as follows;

$$q(t) = C.V(t) \qquad (3)$$

Capacitors in Series and Parallel:

The schematic diagram is shown for capacitors in series. The plates connected to the power supply is charged directly, the others get charged by induction. Hence, every capacitor's plates have equal positive and negative charges. The sum of the voltage on every capacitor equals to the potential of the power supply. ($V_0=V_1+V_2+V_3+...$)

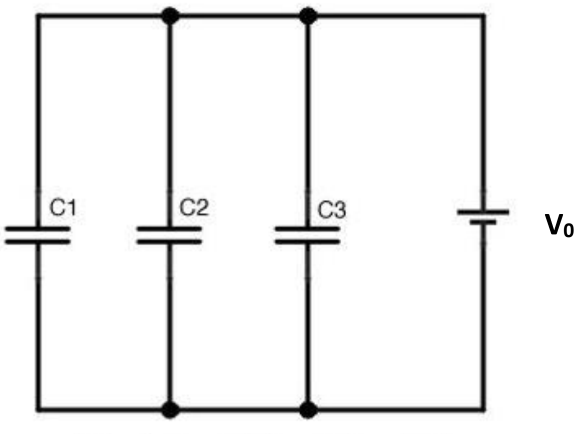


The total voltage difference from end to end is apportioned to each capacitor according to the inverse of its capacitance. The entire series acts as a capacitor *smaller* than any of its components.

$$\frac{1}{C_{eq}}=\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}+....=\sum_i\frac{1}{C_i} \tag{4}$$

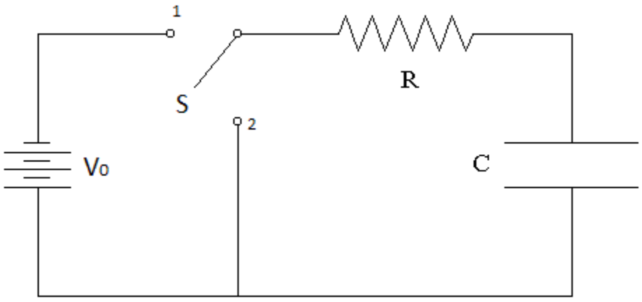
In the figure capacipors are connected in parallel. In this concept, each capacitor holds different amount of charges. The potential difference of all the capacitors are same with the voltage of power supply ($V_0=V_1=V_2=V_3=...$). when capacitors are in parallel, the charges which the capacitors hold are directly proportional to the capacitance of the capacitors. The equivalent capacitance is the sum of all the capacitances of the capacitors in the circuit.

$$C_{eq}=C_1+C_2+C_3+....=\sum_i C_i \tag{5}$$



Charging and Discharging a capacitor through a Resistance:

A resistor–capacitor circuit (RC circuit), is an electric circuit composed of resistors and capacitors driven by a voltage supply.



When the switch is in position 1, power supply gets connected to the circuit, time dependent electric current starts to flow in the circuit I(t) and the capacitor gets charged (charge). When the switch is open, the power supply becomes unconnected to the circuit and the capacitor gets uncharged through the resistor (discharge). In position 2, the potential difference on the edges of the capacitor changes by time.

To Charge a capacitor in a RC Circuit

In the figure-2 when the switch in position 1, the capacitor gets charged. If Kirchoff voltage rule is applied to circuit components for a time t,

$$V_0 - I(t).R - \frac{q(t)}{C} = 0 \qquad (6)$$

Where V_0 is the power supply voltage, I(t).R product is the potential on the resistor and q(t)/C is the voltage on the capacitor. I=dq/dt is used in equation (6), it becomes,

$$\frac{dq}{dt} = \frac{V_0}{R} - \frac{q}{RC} \qquad (7)$$

By using the initial conditions of t=0 and q=0,

$$\int_0^q \frac{dq}{q - V_0 C} = -\frac{1}{RC}\int_0^t dt$$

$$\ln\left(\frac{q - V_0 C}{-V_0 C}\right) = -\frac{t}{RC}$$

This brings out the following equation,

$$q(t) = V_0 C\left(1 - e^{-t/RC}\right) \tag{8}$$

The time derivative of the equation (8) is,

$$I(t) = \frac{V_0}{R} e^{-t/RC} \tag{9}$$

From equations (3) and (8), the potential difference on the capacitor in any time is,

$$V_C(t) = V_0\left(1 - e^{-t/RC}\right) \tag{10}$$

When $t \to \infty$, voltage, charge and current go to a single value as follows,

$V_C(t) \to V_0 \quad q(t) \to Q_0 \quad I \to 0$

Usually, this t value is assumed as t≅5τ.

Discharging a Capacitor in a RC Circuit

When the switch is in position 2, the power supply would be out of the circuit and the capacitor starts to discharge through the resistor. If the Kirchoff rule is applied,

$$\left(-I(t)R - \frac{q(t)}{C} = 0\right) \tag{11}$$

Using the initial conditions; t=0 q=Q, in a time t, equation (11) becomes,

$$q(t) = Qe^{-t/RC} \tag{12}$$

The potential difference of the capacitor and the current flowing through the current during discharging will be as follows,

$$V_C(t) = V_0 e^{-t/RC} \tag{13}$$

$$I(t) = -\frac{Q}{RC} e^{-t/RC} \tag{14}$$

When $t \to \infty$, Vc, q and I values go to zero and capacitor returns to the initial condition in Figure-2. The RC value in the equations above is called time constant and it is shown with τ.

$$\tau = RC \tag{15}$$

Question: determine the dimension and the unit of time constant.

The time on charging and discharging in a RC circuit is presented by τ, time constant. It is the time required to decrease of the current of the circuit to e^{-1} times to the initial current during charge and discharging.

2. Experiment

1. Set up the circuit by choosing a R_1C_1 pair. Take the switch to desharge position to verify the t=0, q(t)=0 initial condition. Set the output voltage of the power supply to 10V.

Before the experiments be sure that the multimeters are connected right and the capacitors are uncharged.

2. Bring switch to charge position. Measure the elapsed time for the every 1 V voltage change on the capacitor and measure the voltage on the resistor at the same time. Write the values down in Table. Bring the switch to discharge position as soon as 7V is measured on the capacitor and observe the decrease of the voltage on the capacitor and continue to measure the time untill the voltage value reaches 1V on the capacitor. Also continue to measure the voltage on the resistor for each 1V voltage drop on the capacitor. Do not stop measuring the time by the stopwatch for whole experiment.

R_1=		C_1=		
V_C(V)	t(s)	V_R(V)	I(μA)	lnI(μA)
1				
2				
3				
4				
5				
6				
7				
6				
5				
4				
3				
2				
1				

3. Plot V_C=f(t) graph for charging and discharging.

4. Using Ohm's Law $I = V_R/R$, calculate the I curent values and lnI values and write them down in the table.

5. Plot ln(I)=f(t) graph for charging and determine the time constant of the circuit using the slope of the graph. Calculate the error.

τ_{R1C1} (s) (Charge)
Theoretical value=
Experimental Value=
$\%Error = \frac{\lvert \tau_{Theoretical} - \tau_{Experimental} \rvert}{\tau_{Theoretical}} . 100 =$

EXPERIMENT 3

Ohm’s Law and Kirchhoff’s Rules

Purposes:

1. Determination of the unknown R_1, R_2, R_{SERIES} and $R_{PARALLEL}$ resistances with ohm's law (Ohm’s Law).

2. Determination of the potential differences across all elements and the current on each circuit component in the multi-loop circuits (Kirchhoff’s Rules).

3. Power calculation of the circuit elements and comparison of produced and dissipated power on the circuit (Kirchhoff’s Rules).

1. Introduction

Current, Resistor and Ohm’s Law: An electric current is a flow of electric charges in a given time interval. The SI unit of electric current is the ampere (A), which is equal to a flow of one coulomb of charge per second.

$$I = \frac{q}{t} \quad (1)$$

The direction of the current is opposite the direction of flow of electrons. The cell, battery and generators are sources of electrical energy in electrical circuits which allow for the movement of charge carriers by creating the potential difference between terminals to which they are connected. A battery is called either a source of electromotive force or, more commonly, a source of emf. The emf ε of a battery is the maximum possible voltage that the battery can

provide between its terminals and it is given by

$$\varepsilon = \frac{w}{q} \quad (2)$$

where w is the work done by generator, q is the charge.

Ohm's law states that the current through a conductor between two points is directly proportional to the potential difference across the two points. Introducing the constant of proportionality, the resistance one arrives at the usual mathematical equation that describes this relationship:

$$I = \frac{V}{R} \quad (3)$$

where I is the current through the conductor in units of amperes, V is the potential difference measured across the conductor in units of volts, and R is the resistance of the conductor in units of ohms. More specifically, Ohm's law states that the *R* in this relation is constant, independent of the current.

Resistors in Series and Parallel:

The circuit, which is shown in figure 1a, connected in series. For series combination of two resistors, the current is the same in both resistors because the amount of charge that passes through R_1 must also pass through R_2 in the same time interval. The potential difference applied across the series combination of resistors will divide between the resistors. In figure1a, because the voltage drop from a to b equals IR_1 and the voltage drop from b to c equals IR_2, the voltage drop from a to c is

$$\varepsilon = \Delta V = IR_1 + IR_2 = I(R_1 + R_2) \tag{4}$$

The potential difference across the battery is also applied to the equivalent resistance R_{eq} .
In this case, the current passing through the circuit is

$$I = \frac{\varepsilon}{R_1 + R_2} \tag{5}$$

Where, we have indicated that the equivalent resistance has the same effect on the circuit because it results in the same current in the battery as the combination of resistors. Combining these equations, we see that we can replace the two resistors in series with a single equivalent resistance whose value is the sum of the individual resistances:

$$\Delta V = IR_{eq} = I(R_1 + R_2) \tag{6}$$

$$R_{eq} = R_1 + R_2$$

The equivalent resistance of three or more resistors connected in series is

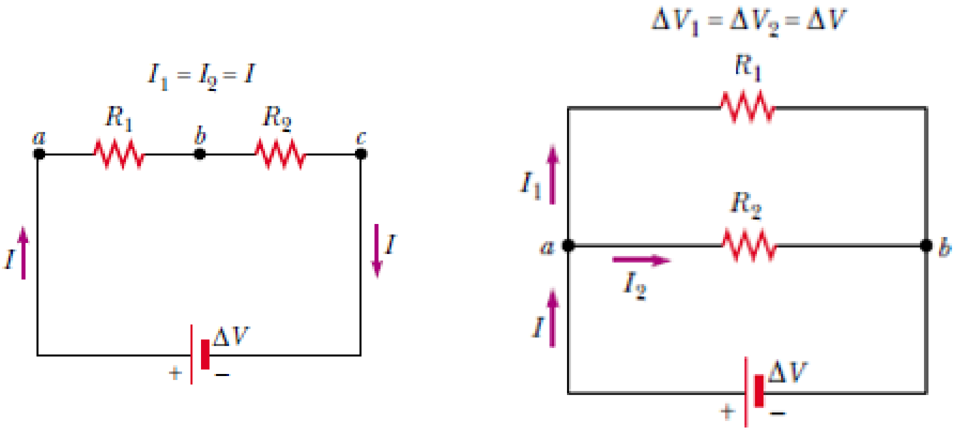
$$R_{eq} = R_1 + R_2 + R_3 + ... \tag{7}$$

This relationship indicates that the equivalent resistance of series connection of resistors is the numerical sum of the individual resistance and is always greater than any individual resistance.

The circuit, which is shown in figure 1b, connected in parallel. Because the electric charge is conserved the current I, that enters to a point must be equal the total current leaving that point:

$$I = I_1 + I_2 \tag{8}$$

where, I_1 is the current in R_1 and I_2 is the current in R_2. The potential differences across the resistors is the same when resistors are connected in parallel.



(a) **(b)**

Figure 1 **(a)** A series connection for two-resistor circuit, **(b)** A parallel connection for two-resistor circuit.

Because the potential differences across the resistors are the same, the expression $\Delta V = IR$ gives

$$I = I_1 + I_2 = V + \frac{\Delta V}{R_2} = \Delta V\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = \frac{\Delta V}{R_{eq}} \qquad (10)$$

From this result, we see that the equivalent resistance of two resistors in parallel is given by,

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} \qquad (11)$$

An extension of this analysis to three or more resistors in parallel gives,

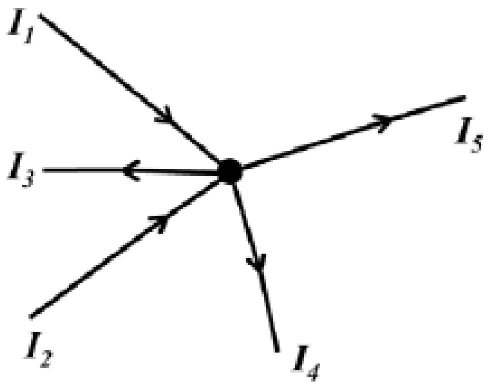
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_n} \qquad (12)$$

We can see from this expression that the inverse of the equivalent resistance of two or more resistors connected in parallel is equal to the sum of the inverses of the individual resistances. Furthermore, the equivalent resistance is always less than the smallest resistance in the group.

Kirchhoff's Rules: Simple circuits can be analyzed using the expression *ΔV= IR* and the rules for series and parallel combinations of resistors. Very often, however, it is not possible to reduce a circuit to a single loop. The procedure for analyzing more complex circuits is greatly simplified if we use two principles called Kirchhoff 's rules:

i. Junction rule. The sum of the currents entering any junction in a circuit must equal the sum of the currents leaving that junction (Figure 2):

$$\sum I_{in} = \sum I_{out} \quad (13)$$



$$I_1+I_2=I_3+I_4+I_5$$

Figure 2

ii. Loop rule. The sum of the potential differences across all elements around any closed circuit loop must be zero:

$$\sum_{\substack{closed\\loop}} \Delta V = 0 \quad (14)$$

When applying Kirchhoff's second rule in practice, we imagine traveling around the loop and consider changes in electric potential, rather than the changes in potential energy. You should note that the following sign conventions when using the second rule:

- Because charges move from the high-potential end of a resistor toward the low potential end, if a resistor is traversed in the direction of the current, the potential difference ΔV across the resistor is "*–IR*" (Fig. 3a). If a resistor is traversed in the direction opposite the current, the potential difference ΔV across the resistor is "*+IR*" (Fig. 3b).
- If a source of electromotive force (emf) is traversed in the direction of emf (from - to +), the potential difference ΔV is $+\varepsilon$ (Fig. 3c). If a source of emf is traversed in the direction opposite the emf (from + to -), the potential difference ΔV is $-\varepsilon$ (Fig. 3d).

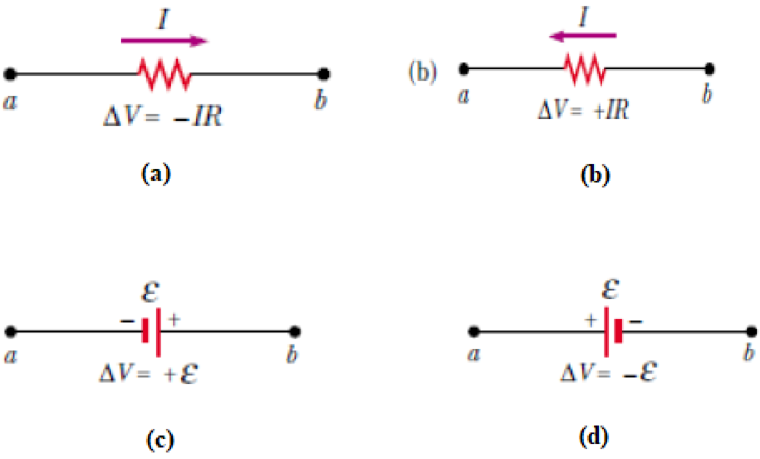


Figure 3 Potential differences in circuit elements.

Power Calculation in Electrical Circuit Elements:

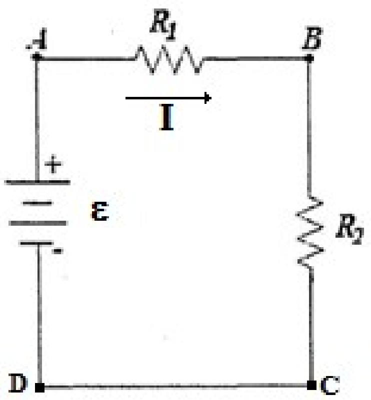


Figure 4

The Kirchhoff's expression is written for closed circuit in Figure 4;

$$\varepsilon - IR_1 - IR_2 = 0 \tag{15}$$

$$\varepsilon = IR_1 + IR_2 \tag{16}$$

Expression (16) is obtained. If both sides of the equation are multiplied by the current *I*,

$$\varepsilon\, I = I^2R_1 + I^2R_2 \tag{17}$$

expression (17) obtained. Where, I^2R_1 and I^2R_2 terms are expressed as the power dissipation as Joule Heat in the R_1 and R_2 resistances. The multiplication of εI n the equation gives the power produced by the power supply with emf ε. In other words, produced active power is equal to the dissipated power:

$$P_\varepsilon \;= P_{R_1} + P_{R_2} \tag{18}$$

Measurement instruments: The current passing from circuit is measured with ammeter; potential difference is measured with a voltmeter. Both quantities can be measured with a multimeter. Ammeter is connected in series with the circuit elements. Ideally, an ammeter should have zero resistance so that the current being measured is not altered. Voltmeter is connected in parallel and it should have infinite resistance so that no current exists in it.

2. Experiment

Ohm's Law:

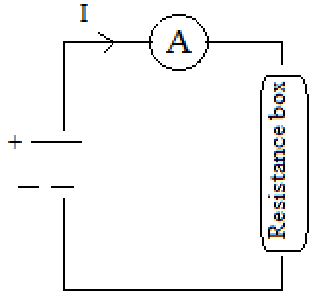


Figure 5

1. Chose two resistors from resistance box and set the circuit as shown Figure 5.

   Adjust power supply to values which is in Table 1. Read the current passing from resistor and write down to Table1.

Table 1

V(V)	I_1(mA)	R_1=…………….	I_2(mA)	R_2=…………….
		$R_{1calculation}$ ($k\Omega$)		$R_{2calculation}$ ($k\Omega$)
2				
5				
7				
9				
15				
		$R_{1\ ave.}$=		$R_{2\ ave.}$=
		$R_{1\ graph}$=		$R_{2\ graph}$ =

2. Draw **V=f(I)** graph for each conductor, find resistance values, compare the average of the resistors values which are calculated and write the results down to Table 1.
3. Connect the resistors in series, as repeating the measurements which is in step 1, write the results down Table 2.
4. Connect the resistors in parallel, as repeating the measurements which is in step 1, write the results down Table 2.
5. Draw **V=f(I)** graphs for series and parallel connected resistors. Find the equivalent resistance values, compare the average of the resistors values which is calculated and write the results down to Table 2.

Table 2

<table>
<tr><th rowspan="2">V(V)</th><th rowspan="2">I (mA)</th><th>Connected in series</th><th rowspan="2">I (mA)</th><th>Connected in parallel</th></tr>
<tr><th>$R_{calculation}$ ($k\Omega$)</th><th>$R_{calculation}$ ($k\Omega$)</th></tr>
<tr><td>3</td><td></td><td></td><td></td><td></td></tr>
<tr><td>6</td><td></td><td></td><td></td><td></td></tr>
<tr><td>10</td><td></td><td></td><td></td><td></td></tr>
<tr><td>12</td><td></td><td></td><td></td><td></td></tr>
<tr><td>14</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td>$R_{average}$=

R_{eq}=

R_{graph}=</td><td></td><td>$R_{average}$=

R_{eq}=

R_{graph}=</td></tr>
</table>

Conceptual Questions

1. Do all conductor materials obey Ohm's Law? Give an example.
2. Is it true that the direction of the current through the battery is always from the negative to positive terminal, or not? Please explain.
3. How should connect the resistances to be the equivalent resistance is greater than the resistance of each resistor? Please give an example of three resistors.

Questions for research

1. An ammeter with the internal resistance of 0.10 mA measures maximum 0.3 mΩ. Which series resistor turns into the ammeter voltmeter can measure between 0-3 V?
2. How to find the value of the internal resistance of a battery?

Kirchhoff's Rules:

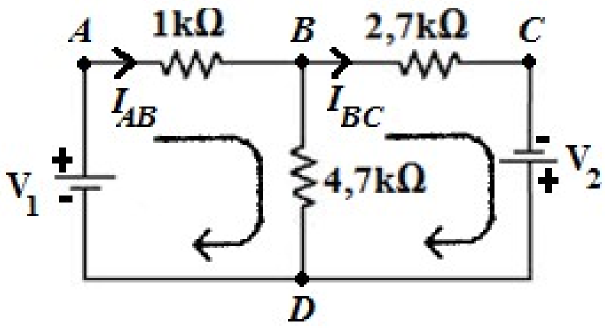


Figure 6

1. Set the circuit as shown Figure 6. Measure the current intensity and voltage differences on each resistance and write them down Table 3.
2. Using Kirchhoff's Rules, calculate the current passing from each resistor and potential difference between the terminals of resistor. Write results down Table 3.
3. Calculate the relative errors and write them down Table 3.

Table 3

	V_1 (V)	V_2 (V)	I_{AB} (mA)	V_{AB} (V)	I_{BC} (mA)	V_{BC} (V)	I_{BD} (mA)	V_{BD} (V)
Measurement Values								
Theoretical Values								
Relative Error								

4. Calculate the power and the relative error for each component of the circuit. Write results down the Table 4.

Table 4

	$P_{1k\Omega}$	$P_{2,7k\Omega}$	$P_{4,7k\Omega}$	P_{V_1}	P_{V_2}	Total $P_{dissipation}$	Total $P_{produced}$	$P_{difference}$
Experimental Values								
Theoretical Values								
Relative Error								

Conceptual Questions

1. If there is a difference between produced and dissipated power in the experiment, describe the reasons for this.
2. Which is the condition that potential difference between the ends of a battery condition becomes greater than its electromotive force?
3. Nowadays, the cars typically use 12V battery. 6V battery was used years ago, why has changed and why not 24V?

EXPERIMENT 4

Magnetic Force Acting on a Current-Carrying Conductor

Purpose: Measurement of force acting on a current- carrying conductor and observation of induction electromotor force in a uniform magnetic field.

Equipments: DC power supply, dynamometer, multimeter, magnet.

Introduction

The magnetic force that acts on a charge q moving with a velocity $\vec{v}$ in a magnetic field $\vec{B}$

$$\vec{F}_B = q\vec{v} \times \vec{B}$$

The direction of this magnetic force is perpendicular both to the velocity of the particle and to the magnetic field. The magnitude of this force is

$$F_B = |q|vB\sin\theta$$

where θ is the small angle between $\vec{v}$ and $\vec{B}$. The SI unit of $\vec{B}$ is tesla (T), where $T = \frac{N}{A.m}$

The Magnetic Force acting on Electric Charge:

When the particle's velocity vector makes any angle $\theta \neq 0$ with the magnetic field, the magnetic force acts in a direction perpendicular to both $\vec{v}$ and $\vec{B}$ that is, $\vec{F}_B$ is perpendicular to the plane formed by $\vec{v}$ and $\vec{B}$(Fig. 1a). The magnetic force exerted on a positive charge is in the direction opposite the direction of the magnetic force exerted on a negative charge moving in the same direction (Fig. 1b).

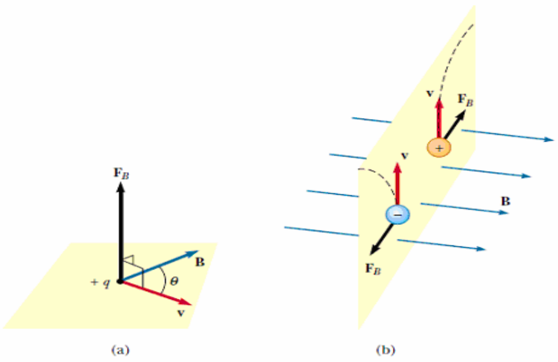


Figure 1. The direction of the magnetic force $\vec{F}_B$ acting on a charged particle moving with a velocity $\vec{v}$ in the presence of a magnetic field $\vec{B}$ **(a)** The magnetic force is perpendicular to both $\vec{v}$ and $\vec{B}$. **(b)** Oppositely directed magnetic forces $\vec{F}_B$ are exerted on two oppositely charged particles moving at the same velocity in a magnetic field.

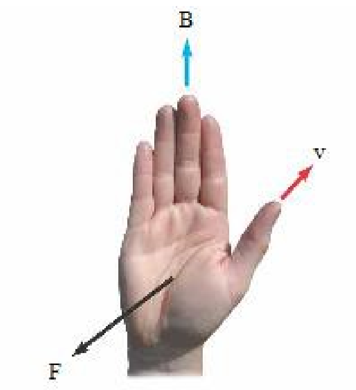


Figure 2. Right-hand rule; the vector $\vec{v}$ is in the direction of your thumb and $\vec{B}$ in the direction of your fingers. The force $\vec{F}_B$ on a positive charge is in the direction of your palm, as if you are pushing the particle with your hand.

Figure 2 reviews right-hand rule for determining the direction of the cross product $\vec{v} \times \vec{B}$ and determining the direction of $\vec{F}_B$. Here, the thumb points in the direction of $\vec{v}$ and the extended fingers in the direction of $\vec{B}$. Now, the force $\vec{F}_B$ on a positive charge extends outward from your palm. The advantage of this rule is that the force on the charge is in the direction that you would push on something with your hand outward from your palm. The force on a negative charge is in the opposite direction.

Magnetic Force Acting on a Current-Carrying wire:

The straight segment of wire of length L and cross-sectional area A, carrying a current $\vec{I}$ a uniform magnetic field $\vec{B}$ is shown in Figure 3. The magnetic force exerted on a charge q moving with a drift velocity v_d is $q\vec{v}_d \times \vec{B}$. To find the total force acting on the wire, we multiply the force $q\vec{v}_d \times \vec{B}$ exerted on one charge by the number of charges in the segment. Because the volume of the segment is AL, the number of charges in the segment is nAL, where n is the number of charges per unit volume. Hence, the total magnetic force on the wire of length L is

$$\vec{F}_B = (q\vec{v}_d \times \vec{B})nAL$$

We can write this expression in a more convenient form, the current in the wire is $I = nqv_dA$. Therefore,

$$\vec{F}_B = I\vec{L} \times \vec{B}$$

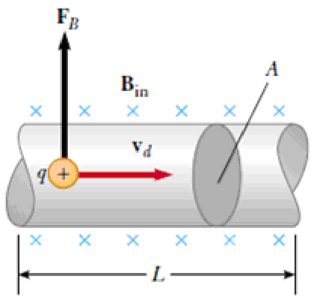


Figure 3. A segment of a current-carrying wire in a magnetic field $\vec{B}$. The magnetic force exerted on each charge making up the current is $q\vec{v}_d \times \vec{B}$ and the net force on the segment of length L is $I\vec{L} \times \vec{B}$.

Experiment

The set used in experiment is shown in Figure 4.

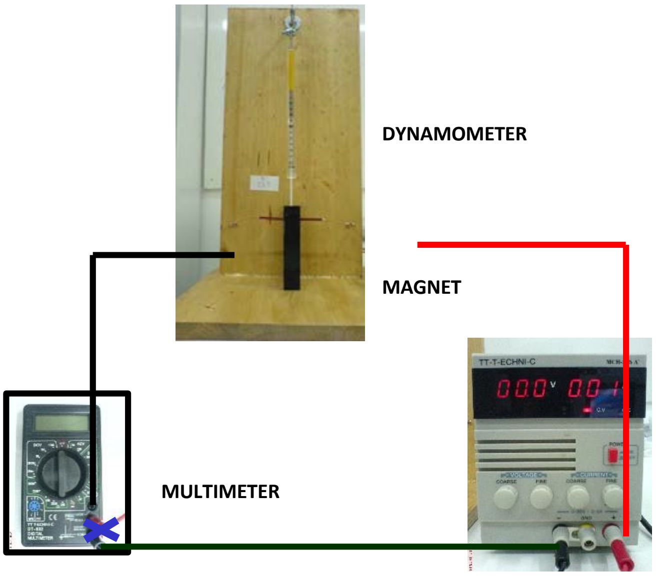


Figure 4. The experiment set-up.

1. Set the multimeter (10 A) to current read setting.
2. While the current zero in the set write the F_0 value down in Table-1. This force is the total weight of the conductive rod and cables.
3. Firstly, turn on multimeter then the power supply and give current to set-up.
4. Using current adjustment switch on power supply, adjust the currents which are in table1 and write down $F_{dynamometer}$ in Table 1.
5. Subtract F_0 from the $F_{dynamometer}$ (which is seen from dynamometer) and write down $F_{dynamometer} - F_0$ in Table 1.
6. The angle between $\vec{L}$ and $\vec{B}$ is 90° in this experiment. Magnetic force is calculated from the $F_M = ILB\sin\theta$ correlation (the length of wire is L=*2.5 cm*, the magnetic field is B=*0.50 T*).

Table 1

I(A)	$F_{dynamometer}$ (N)	F_0=…………N $F=F_{dynamometer}-F_0$	F_m= ILBsin θ (N)	F_m- F
0				
1.0				
1.5				
2.0				
2.5				
3.0				
3.5				
4.0				
4.5				

7. **Verification of right-hand rule:** Determine the direction of the current through the conductors and magnetic force. Find direction of magnetic force as using right- hand rule.
8. **Observation of Induction Emf:**

   Install the experimental set-up and adjust multimeter to mA and connect cable which is between magnets to multimeter directly (Figure 5).

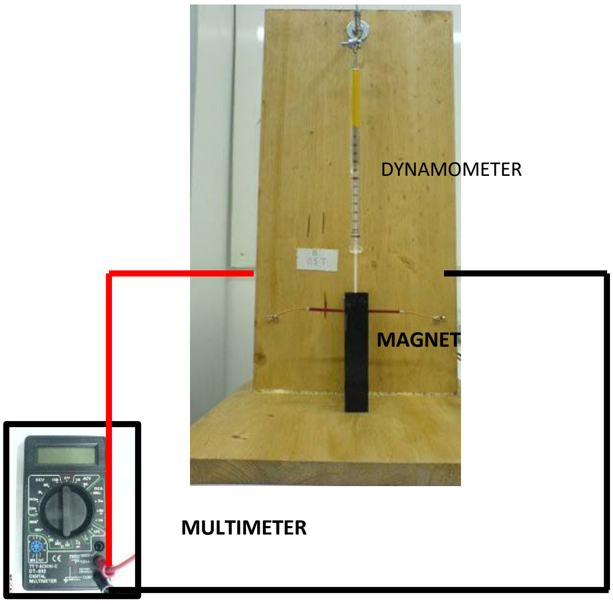


Figure 5

Pull down the copper conductor wire which is inside the magnet and release it suddenly. Please note that a current passing from multimeter with this sudden motion. Explain the reason for this current? The magnitude of this current depends on what?

EXPERIMENT-5

Investigation of Motion of Charged Particles in Electric and Magnetic Fields and Determination of Charge-to-Mass (e/m) Ratio for the Electron

Purpose: Investigation of electrons acting in a uniform electric and magnetic fields, determination of e/m ratio experimentally.

Equipments: The cathode ray tube, high voltage sources, multimeters, Helmholtz coil, scientific calculator, graph paper, pencil, eraser.

Introduction

Investigation of Electron Trajectories in a Uniform Electric Field

Emitted electrons from the filament of the cathode ray tube are accelerated under a V_A voltage. The trajectory of electrons projected at constant speed across a uniform electric field in a direction perpendicular to the field is shown in Figure 1.

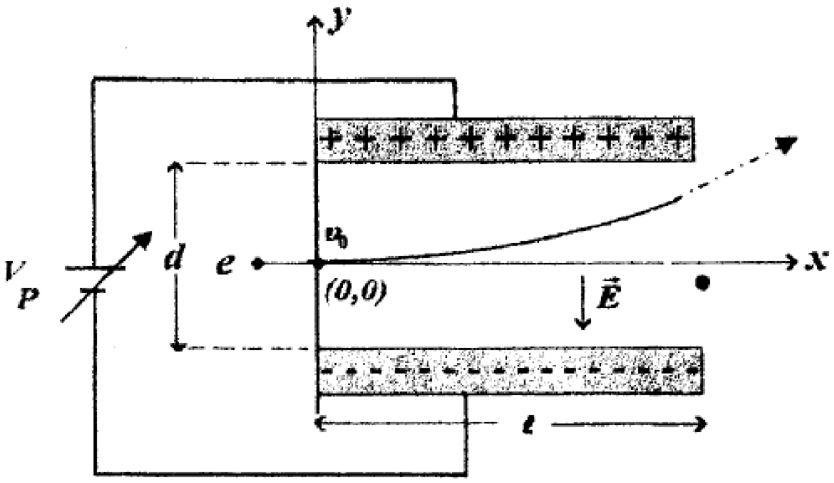


Figure 1 The parabolic trajectory of an electron entering a uniform electric field in a direction perpendicular to the field.

Electrons make linear motion in the x-axis and the constant acceleration in the y-axis. Electric force on electron is $\vec{F} = m\vec{a} = q\vec{E}$. The position of the electron at any moment is

$$x = v_0 t \tag{1}$$

$$y = \frac{1}{2}at^2 = \frac{1}{2}\frac{e}{m}Et^2 \tag{2}$$

These are parametric equations. Trajectory equation is obtained, if time parameter is changed.

$$y = \frac{1}{2}\frac{e}{m}\frac{E}{v_0^2}x^2 \qquad (3)$$

Velocity of the electron is determined from law of conservation of energy;

$$eV_A = \frac{1}{2}mv_0^2 \Rightarrow v_0 = \sqrt{\frac{2eV_A}{m}} \qquad (4)$$

Electric field between the plates applied V_P voltage with the distance d is expressed by the equation (5).

$$E = \frac{V_P}{d} \qquad (5)$$

In this case, equation (3) turns into;

$$y = \frac{V_P}{4dV_A}x^2 \qquad (6)$$

In the equation (6), applied acceleration and deflection voltages (V_A, V_P) and the distance between the plates (d) are constant, so that the trajectory equation is expressed as;

$$y = constant\ x^2 \qquad (7)$$

This is the equation of a parabola.

Motion of an Electron in a Uniform Magnetic Field

When a particle having charge q and velocity $\overrightarrow{v_0}$ enters to a uniform magnetic field perpendicularly, it moves in a circular trajectory. Depending on the sign of the particle, it turns in a clockwise or counter clockwise. The trajectory of an electron in a magnetic field directed into to the page is shown in Figure 2(a). A uniform magnetic field is produced by Helmholtz coils in this experiment.

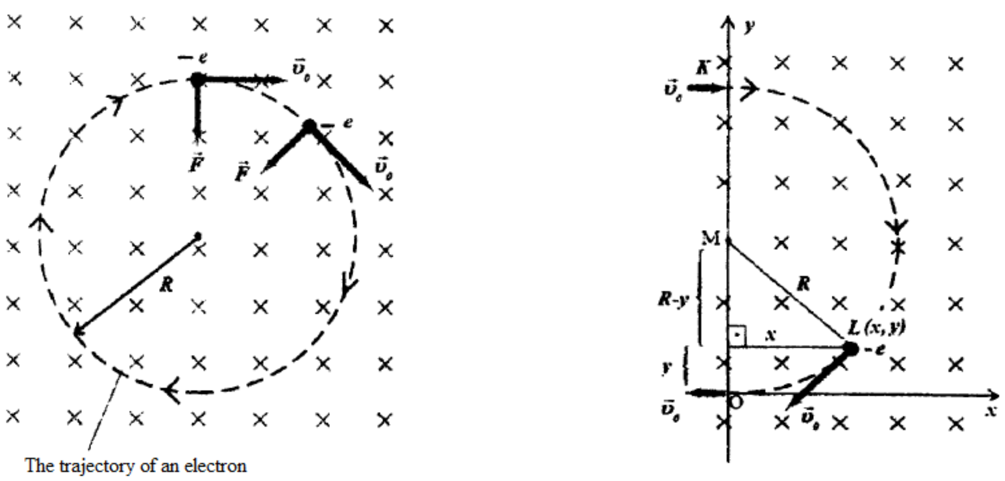


Figure 2 (a) The circular trajectory of an electron in a magnetic field directed into the page **(b)** The coordinates of any point L on the trajectory.

The constant magnetic force on the electron is given by the equation;

$$F = ev_0 B \sin\theta \tag{8}$$

where, the magnetic force plays the role of centripetal force. Radius of the trajectory is defined from Newton's law ($\sum F_r = ma_r$);

$$ev_0 B = m\frac{v_0^2}{R} \Rightarrow R = \frac{mv_0}{eB} \tag{9}$$

Using formula (4), it is obtained;

$$R = \frac{1}{B}\sqrt{\frac{2mV_A}{e}} \tag{10}$$

Radius R of the circular trajectory is also found by using the Pythagorean theorem in Figure 2(b).

$$R = \frac{x^2 + y^2}{2y} \tag{11}$$

Determination of e/m Ratio

If the electrons move under the presence of a uniform electric field $\vec{E}$ and a magnetic field $\vec{B}$, it will experience a force called as "Lorentz force".

$$\vec{F}_{Lorentz} = \vec{F}_{Elec.} + \vec{F}_{Mag.} = e\vec{E} + e\overrightarrow{v_0} \times \vec{B} \tag{12}$$

Lorentz force can be zero for an appropriate the electric and magnetic fields perpendicular to each other. For this case, $\vec{F}_{Lorentz} = 0 \Longrightarrow \vec{E} = \overrightarrow{v_0} \times \vec{B}$ is obtained. Using formula (4) and (5) for $\overrightarrow{v_0}$ and $\vec{E}$, we can get e/m ratio.

$$\frac{e}{m} = \frac{V_P^2}{2d^2B^2V_A} \tag{13}$$

The Helmholtz Apparatus

The device consists of two identical coils with *N* turns and *r* radius, with a distance of *l* between them. Identical currents (I) flow in the same direction in both coils. In this case, a uniform magnetic field is formed along the axis of the coils. The magnetic field between the coils is found from the Biot-Savart law.

$$B = \frac{32 \times 10^{-7}\pi NI}{5\sqrt{5}r} \tag{14}$$

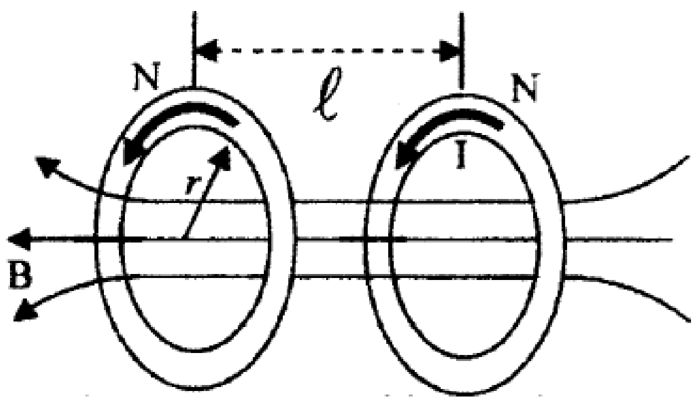


Figure 3 The magnetic field lines of the Helmholtz coils

Experiment

Investigation of Electron Motion in an Electric Field

1. Electrons emitted from the filament of the cathode ray tube are accelerated by a high V_A voltage and electrons that strike the slanted screen cause the fluorescent material to glow, and thus the beam of electrons is visible as a trajectory on the screen (Figure 4).

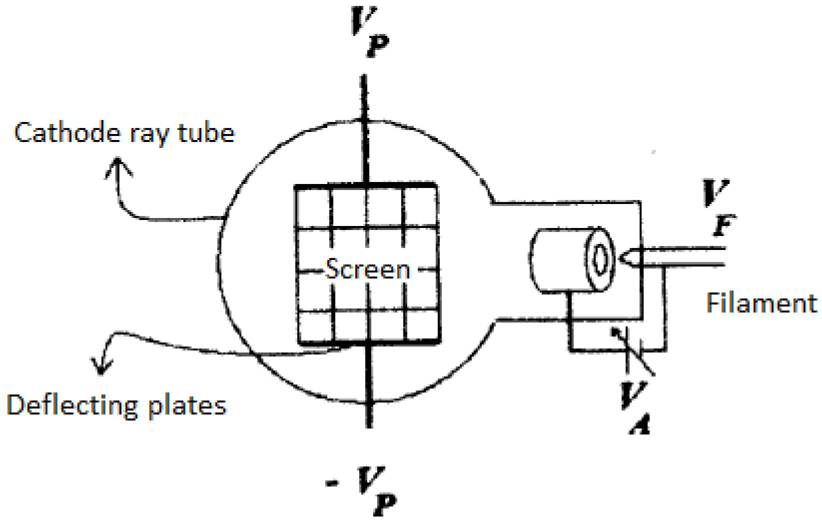


Figure 4 Experimental setup

2. The separation between two plates is 5.2 cm. Set the acceleration voltage V_A to 4000V and the deflection voltage V_P to 1250V. Write down the coordinates (x, y) of the beam of electrons at the fluorescent screen in Table 1.

3. Plot $y = f(x)$ and $y = f(x^2)$ graphs. Calculate gradient of $y = f(x^2)$ graph.

4. Compare $y = gradient.x^2$ with the equation (6). Interpret them.

Table 1

$x(cm)$	$y(cm)$	$x^2(cm^2)$
0		
2		
4		
6		
8		
10		

$y = gradient.x^2$	$V_P/(4dV_A)$

Investigation of Electron Motion in a Magnetic Field

1. Set the acceleration voltage V_A to 3000V and the current I of Helmholtz coils to 0,41A.

2. Read the coordinates (x, y) of the beam of electrons on the fluorescent screen and calculate radius R using equation (6). Write down the obtained results in Table 2.

Table 2

$x(cm)$	$y(cm)$	$R(cm)$
2		
3		
4		
5		
6		
	$R_{Average}$	

3. Calculate the magnetic field using equation (14). ($N = 320$ and $r = 0,068m$)

$$B = \frac{32\times10^{-7}\pi NI}{5\sqrt{5}r} = \dots\dots\dots\dots\dots\dots\dots\dots$$

4. Calculate radius R using equation (10). ($e = 1,6 \times 10^{-19}C$ and $m = 9,1 \times 10^{-31}kg$)

$$R = \frac{1}{B}\sqrt{\frac{2mV_A}{e}} = \dots\dots\dots\dots\dots\dots\dots$$

5. Compare and interpret values of R and $R_{Average}$.

Determination of e/m Ratio

1. Observe the deflected beam of electrons on the fluorescent screen by setting the acceleration voltage V_A to 3000V and the deflection voltage V_P to 700V. Set an optimum current I of Helmholtz coils to go through x-axis of the electron beam. Write down the optimum current I in Table 3 for $V_P = 700V$. Repeat it for different V_P values as in Table 3.

2. Calculate the magnetic fields using equation (14). ($N = 320$ and $r = 0,068m$)

3. Find e/m ratios using equation (13). Calculate average of them.

Table 3

$V_A(V)$	$V_P(V)$	$I(A)$	$B(T)$	$e/m(C/kg)$
3000	700			
3000	800			
3000	900			
			$(e\ /\ m)_{Average}$	