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FACULTY OF ARTS AND SCIENCE
DEPARTMENT OF PHYSICS

PHYSICS LABORATORY-II
(ELECTRICITY AND MAGNETISM)

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ISSUES TO BE CONSIDERED ABOUT LABORATORY STUDY:

- The students in the experimental groups will take their measurements in order and make their calculations separately, in addition to helping each other.
- Before coming to the laboratory, the experiment on the subject will be read, and if necessary, the relevant books will be studied. If the responsible lecturer understands that you have entered the experiment without being prepared, he may remove you from the laboratory.
- If there is no opportunity to make up for the experiment, you will be deemed not to have made that experiment.
- Do not touch instruments and devices when entering the laboratory. Only use the tools that have been introduced to you, after waiting for the officer to arrive and getting his permission and advice.
- When you come to the laboratory, be sure to bring graph paper with you.
- After setting up the experiment, have it checked and then start working.
- Do not speak loudly while experimenting in the laboratory.
- Do not disturb your other friends during your studies.
- When coming to the laboratory, always turn off your mobile phones (do not turn them on during the experiment either).
- Before the experiment, listen carefully to the explanations made by the officer and apply them as necessary.
- Use tools carefully and with care. Do not forget that any damage to the tools will be covered by you financially.
- After you have finished your experiment, leave your table absolutely clean and as you received it.
- There is an 80% attendance requirement to the laboratory. Therefore, show the necessary sensitivity to the continuation.
- After each experiment, the report about the experiment will be kept regularly and this report prepared for the next experiment will be checked by the instructor in charge of the experiment.

PREPARATION OF THE EXPERIMENT REPORT:

- On the first page of the report you will prepare (in the middle), write the name of the experiment, the number of the experiment, your name, surname, number, which education you are in and your group. Do not write anything else on this page. The title will be centered and the preparation of the report will be as follows.
- Experiment name: Write the name of the experiment written on the experiment sheet.
- Purpose of the experiment: Write in your own words what you aimed for in your experiment.
- Theory of the experiment: Write the theory of your experiment using different source books.
- Conducting the experiment: First of all, write down how you set up the experiment scheme, the tools you used and how you took the measurements, and then make your calculations.
- If there is a graph that needs to be drawn, draw your graph precisely using millimetric paper.
- Result, differences calculation and interpretation: Interpret your experiment by calculating the differences about the size you calculated in this part of the experiment.
- Reports will be written by hand, computer printouts will not be accepted.

CHAPTER 1. ELECTRICAL FIELD LINES

EXPERIMENT NO: 1

PURPOSE:

Detection of electric field lines using equipotential surfaces

1.1. THEORY:

The electric field is defined as the Coulomb force acting on the (+) unit charge (test charge) placed in the force field. The direction of the electric field at a point is the same as the direction of the force acting on the positive test charge placed at that point.

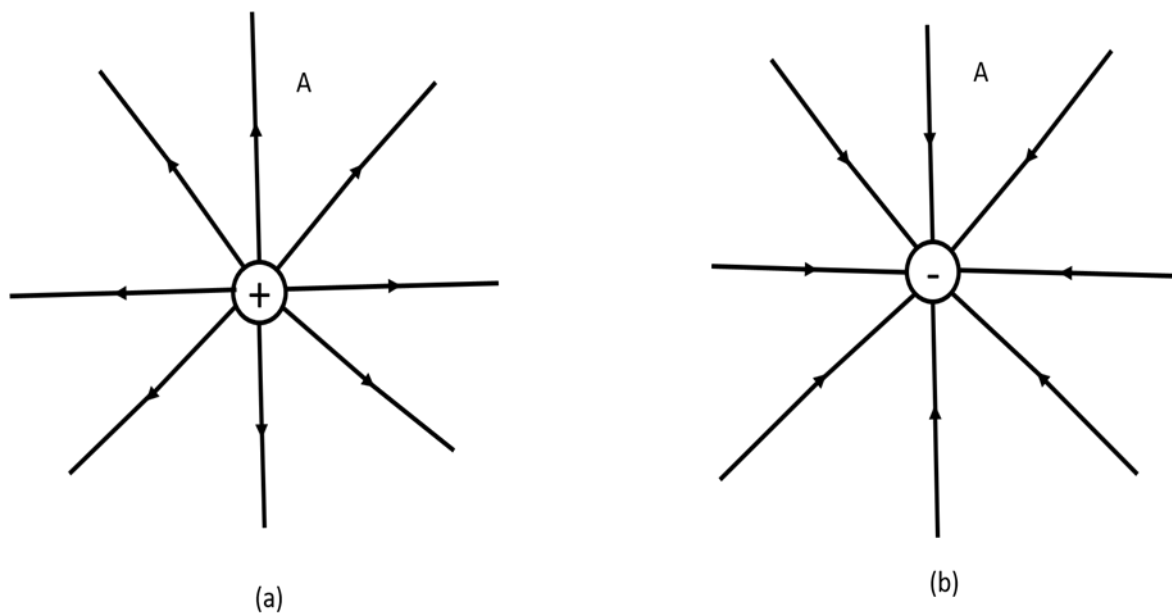


Figure 1-1 Electric field lines

As seen in Figure 1-1, when the positive test charge (A) is placed next to the negative charge, the force acting is directed towards the center of the negative charge. From this, it is concluded that the electric field formed around the negative charge is directed radially towards the inside of the charge. If the

positive test charge (A) is brought close to a positive charge, it will be repelled outward by the positive charge at the center, showing us that the electric field of the positive charge is pointing outward.

Electric field is expressed as;

$$\vec{E} = \vec{F}/q_o \quad (1.1)$$

Its unit is Newton/Coulomb (N/C). If the positive and negative charges are brought together, the electric field lines are oriented such that they exit the positive charge and terminate in the negative charge, as seen in Figure 1-2.

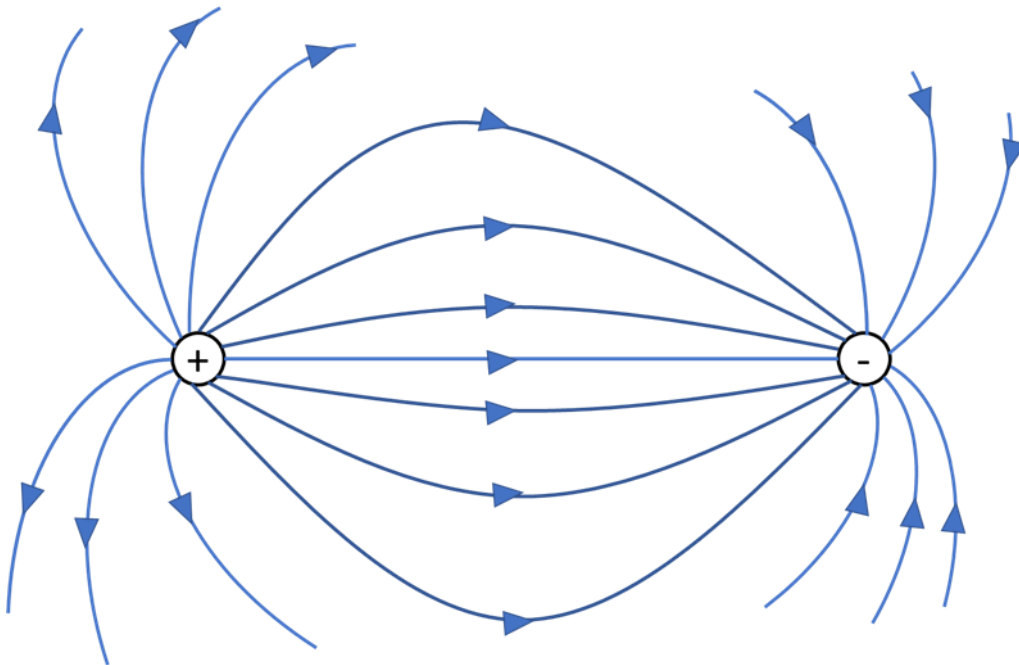


Figure 1-2 Distribution of electric field lines between charges

The relationships between the lines of force and the electric field vector are:

- I. The tangent of the lines of force at any point gives the direction of the electric field at that point.
- II. Field lines are shown frequently where the electric field is large, and sparse where it is small.
- III. If the positive test charge is placed between the loaded parallel plates, it will move along a straight line perpendicular to the plate.

Equipotential surface: The geometric surface formed by points with equal electric potential is called equipotential surface (Seen in Figure 1-3).

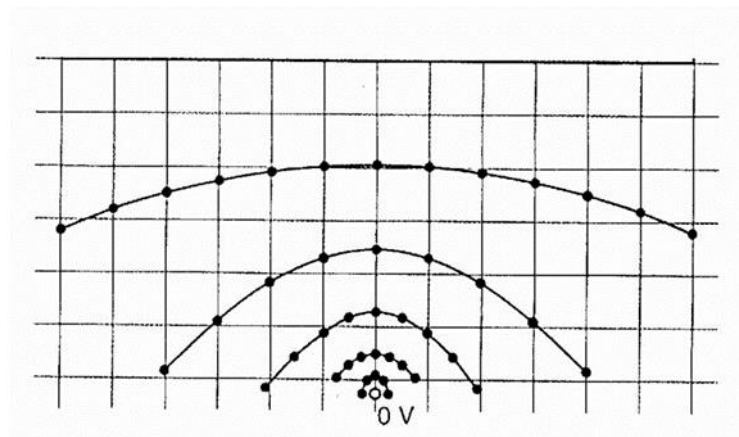


Figure 1-3 Equipotential surfaces

When we move a test charge from one point (A) to another point (B), if no work is done on the charge, these two points are at the same electrical potential. In other words, it is acted on the equipotential surface. The work done by the movement of the load between these two points is expressed as being;

$$W_{AB} = q_o(V_B - V_A) \quad (1.2)$$

When the test charge moves on the equipotential surface, W_{AB} (work done) will be zero since $V_B = V_A$.

A uniform electric field consists of planes perpendicular to equipotential surfaces.

According to this result, electric field lines can be determined using equipotential surfaces.

1.2. EXPERIMENTAL PROCEDURE:

1. To perform the experiment, the circuit in Figure 1-4 is set up and the power supply is switched to DC. The conductive copper sulfate solution in the container provides the load flow in the circuit and the circuit is completed. (Note: Do not activate the circuit until the instructor

responsible for your experiment checks the circuit. The liquid in the container is acidic, so care must be taken).

2. In order to find the equipotential surface points, the fixed electrode is placed at the points indicated on the paper under the container. For each point, the traveling electrode is moved in the solution and the points where the current shows zero value are found.
3. In order to record the equipotential surface points on the data sheet, the point where the fixed electrode is located and the point of the traveling electrode that makes the current zero are recorded on another graph paper outside.
4. Equipotential surfaces are obtained by combining the marked points in order to obtain equipotential surface curves.
5. In order to obtain electric field lines, lines drawn perpendicular to the surfaces at every point will give electric field lines.

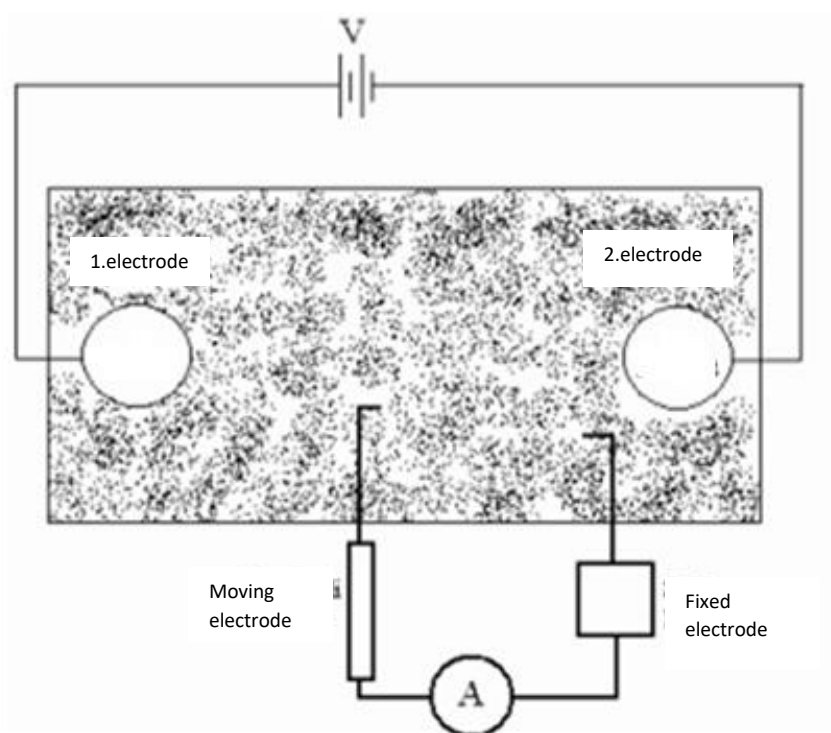


Figure 1-4 Appearance of electric field experimental setup

CHAPTER 2. CAPACITORS

EXPERIMENT NO: 2

PURPOSE:

Examination of capacitors and charges

2.1. THEORY:

A circuit element consisting of two or more conductive plates separated from each other by a dielectric material and used to accumulate charge is called a capacitor. These plates are parallel and oppositely loaded.

If it is assumed that a charge Q is accumulated under the potential of V in the conductive plates, the ratio of this accumulated charge to the potential is constant and it is called the capacitance of the capacitor and is denoted by C . According to this,

$$Q = V.C \quad (2.1)$$

Equation is obtained. Capacitance describes the ability to accumulate charge. Its unit is Farad(F). Because the farad is such a large unit, units like microFarad ($1 \mu\text{F} = 10^{-6} \text{ F}$), nanoFarad ($1\text{nF} = 10^{-9} \text{ F}$), picoFarad ($1\text{pF} = 10^{-12} \text{ F}$) are used.

When the equivalent capacitance of the capacitors is connected in series,

$$\frac{1}{C_{es}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \dots \quad (2.2)$$

It is possible. In the case of parallel connection, the equivalent capacitance is can be written as

$$C_{e\mathcal{S}} = C_1 + C_2 + C_2 + \dots \quad (2.3)$$

2.2. EXPERIMENTAL PROCEDURE:

Establish the circuit in Figure 2-1 by determining the capacitors in the circuit and the V voltage to be supplied from the power supply. The capacitance value of each capacitor is determined as $100 \mu\text{F}$. Make sure the voltage is maximum 6 V . In the experiment, first theoretical calculations and then measurements will be made.

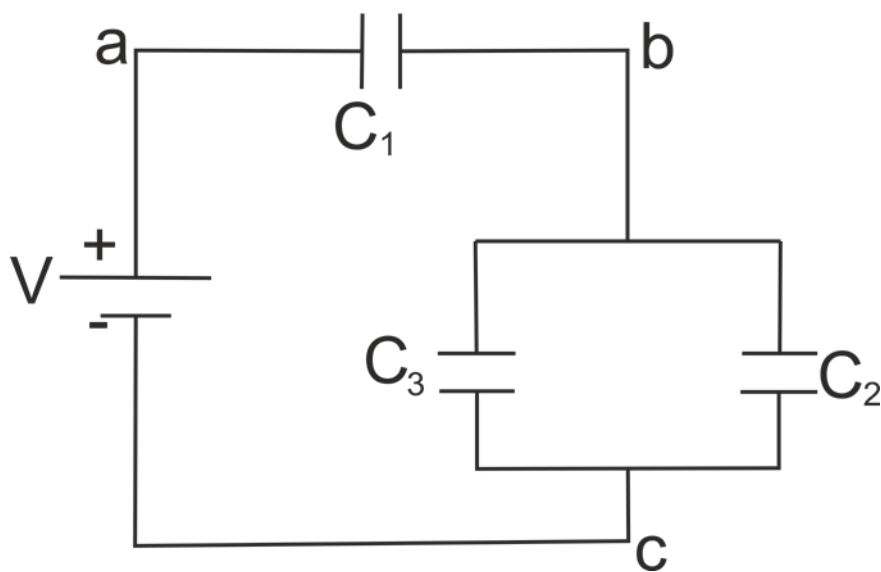


Figure 2-1 Capacitor voltage test setup

Theoretical Calculation: Find the equivalent capacitance of the circuit according to the determined voltage and capacitance values. Then the total load given to the circuit

$$Q_T = C_{e\mathcal{S}} \cdot V \quad (2.4)$$

calculate from the formula. Since all the total charge will pass through the 1st capacitor, $Q_T = Q_1$ will be. It will then be shared by the 2nd and 3rd capacitors at a certain rate. If the 2nd and 3rd capacitors are identical, they share the total charge equally. Calculate the voltages since the capacitances and

charges of the capacitors are known and fill in the column in Table 2-1 that is related to the theoretical calculation.

Experimental Calculation: Measure the voltages in the ab and bc branches of the circuit by turning the multimeter to the potentiometer position and fill in the column related to the experimental calculation in Table 1. Then find the percentages differences between your theoretical calculation and experimental calculation results and interpret these results.

Table 2-1 Voltage values table

	THEORETICAL VALUE	EXPERIMENTAL VALUE	% DIFFERENCES
V_{ab}			
V_{bc}			
$V_T(V_{ac})$			

CHAPTER 3. PARALLEL PLATE CAPACITORS AND DIELECTRIC MATERIALS

EXPERIMENT NO: 3

PURPOSE:

Finding the capacitance in Parallel Plate capacitors and finding the permittivity coefficient of the dielectric material

3.1. THEORY:

A circuit element consisting of two or more conductive plates separated from each other by a dielectric material and used to accumulate charge on it is called a capacitor. These plates are parallel and oppositely loaded. If it is assumed that a charge Q is accumulated under the potential of V in the conductive plates, the ratio of this accumulated charge and potential is constant and it is called the capacitance of the capacitor and is denoted by C . According to this,

$$Q = V.C \quad (3.1)$$

it is possible. Capacitance tells the ability to accumulate charge. Its unit is Farad(F). Since the farad is such a large unit, units such as microFarad ($1 \mu\text{F} = 10^{-6} \text{ F}$), nanoFarad ($1 \text{ nF} = 10^{-9} \text{ F}$), picoFarad ($1 \text{ pF} = 10^{-12} \text{ F}$) are used. Substances that have the ability to reduce electric field strength are called dielectrics. The relative dielectric constant is the ratio of the dielectric permittivity of the material to the dielectric permittivity of the cavity and is calculated with $K = \frac{\epsilon_{\text{material}}}{\epsilon_0}$.

This dielectric constant is 1 for vacuum and greater than 1 for other dielectric materials. For example, this is 1.006 for air and 6 for mica. If a dielectric material is placed between two charged plates, the capacitance of the capacitor changes. The capacitance of a parallel plate capacitor can be written as;

$$C = \varepsilon \frac{A}{d} \quad (3.2)$$

where, A is the surface area of the plate, d is the distance between the plates, and ε is the electrical permeability of the medium. For space, it has the value $\varepsilon_0 = 8,85 \times 10^{-12} \text{ C}^2/\text{Nm}^2$.

3.2. EXPERIMENTAL PROCEDURE:

As seen in Figure 6 below, the capacitance and charge of the parallel plate capacitor with a certain distance d between them under voltage V will be calculated. Under this voltage, one of the plates will be loaded with $+Q$ and the other with $-Q$. Since the amount of charge Q will change when we change the voltage V applied to the plates, the Q/V ratio does not change, that is, the capacitance C remains constant. On the other hand, when we look at the expression $C = \varepsilon \frac{A}{d}$ the capacitance ε depends on A and d . Changing at least one of these quantities will change the capacitance.

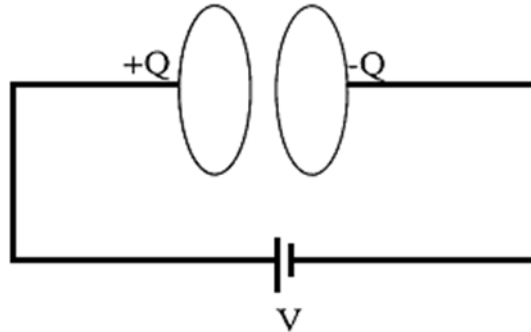


Figure 3-1 Parallel plate capacitor

Stage 1: Find the charge q accumulated in the capacitor for different d distances. To find out, measure the capacitance with a multimeter (by bringing it to the 2 nF). Given the voltage and capacitance supplied to the circuit, find the load value and write it in Table 3-1. Also, since d , A and C are known, find the electrical permeability (ε_{air}) of the medium (air). The average of the ε_{air} values you find for different distances d will give you the average dielectric permittivity of the air. Using this value, find the relative dielectric coefficient of the air with $K = \frac{\varepsilon}{\varepsilon_0}$ and compare it with the theoretical value ($K_{air} = 1,006$).

Table 3-1 Data table of electrical conductivity of air

d (m)	C (F)	A (m^2)	ϵ_{air} (C^2/Nm^2)

Stage 2: Here, we will first find the 'ε' electrical permittivity for mica and paperboard. For this, measure the distance d between the plates and the capacitance C of the capacitor and find the ε value from the expression $C = \epsilon \frac{A}{d}$. After that, find the relative dielectric constants $K = \frac{\epsilon}{\epsilon_0}$ for mica and cardboard and substitute them in Table 3-2.

Table 3-2 Dielectric coefficient data table for mica and paperboard

	d (m)	C (F)	$\epsilon_{material}$ (C^2/Nm^2)	K	$K_{theoretical}$
Mica					6
Cardboard					4

CHAPTER 4. DETERMINATION OF RESISTOR VALUE

EXPERIMENT NO: 4

PURPOSE:

Determining the values of resistors by looking at their colors

4.1. THEORY:

In electrical circuits, resistor means the difficulty opposing the flow of current in an electrical circuit. Its unit is "Ohm" and denoted by " Ω ". Circuit stability and regulating the current flow are among the main tasks of the resistor in the circuit. For this purpose, resistors of different values have been produced and put into use for use in circuits. Resistors play an important role in almost all circuits as basic passive electrical circuit elements. The values of the resistors also differ from each other, since the selection of the resistor should be made in accordance with the intended use of the circuit. A code we call "Color Code" is used to separate the resistors from each other. Resistor color codes are presented in Table 4-1 in detail.

Table 4-1 Resistor colors table

COLOR	1. COLOR (FIRST DIGIT) X	2. COLOR (SECOND DIGIT) Y	3. COLOR (MULTIPLIER) Z	4. COLOR (TOLERANCE) T
BLACK	0	0	10^0	-
BROWN	1	1	10^1	%1
RED	2	2	10^2	%2
ORANGE	3	3	10^3	-
YELLOW	4	4	10^4	-
GREEN	5	5	10^5	%0,5
BLUE	6	6	10^6	%0,25
PURPLE	7	7	10^7	%0,1
GREY	8	8	10^8	-
WHITE	9	9	10^9	-
GOLD	-	-	10^{-1}	%5
SILVER	-	-	10^{-2}	%10

Value of a resistor using Table 4-1 can be calculated as;

$$R = [XY] \times Z \pm T \quad (4.1)$$

When reading the colors, start near the end of the resistor. Let's calculate the value of the resistor seen in Figure 4-1 for a better example;

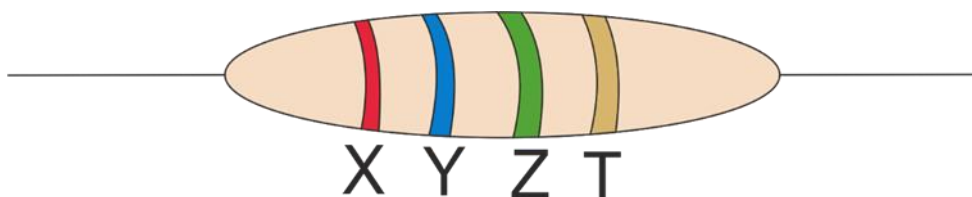


Figure 4-1 The appearance of colors on a clay resistor

Colors are set to X=red, Y=blue, Z=green and T=gold.

According to this, as $R = 26 \times 10^5 \pm \%5 \Omega$ value of the resistor is determined. That is, the value of this resistor is between 2.730.000 Ω and 2.470.000 Ω .

4.2. EXPERIMENTAL PROCEDURE:

The colors on five different randomly selected resistors for the experiment are written in the corresponding places on Table 5. With the help of these values, each resistor value is calculated theoretically. Calculated values are written in the "Theoretical value" section in Table 4-3. The values of the same resistors are measured again with the help of the multimeter's resistor measurement scale and written in the "Experimental Value" section in Table 4-3. The agreement between the theoretical and experimental values is interpreted in the report.

Table 4-2 Data table of theoretical value of resistors

Resistor No:	1. COLOR (FIRST DIGIT) X	2. COLOR (SECOND DIGIT) Y	3. COLOR (MULTIPLIER) Z	4. COLOR (TOLERANCE) T
1. Resistor				
2. Resistor				
3. Resistor				
4. Resistor				
5. Resistor				

Table 4-3 Theoretical and experimental value comparison table of resistors

Resistor No:	Theoretical Value	Experimental Value
1. Resistor		
2. Resistor		
3. Resistor		
4. Resistor		
5. Resistor		

CHAPTER 5. CONNECTING RESISTORS IN SERIAL AND PARALLEL

EXPERIMENT NO: 5

PURPOSE:

Investigation of branching of current by connecting resistors in series and parallel

5.1. THEORY:

If the resistors are connected in series, the equivalent resistor is found as follows:

$$R_{eşdeğer} = R_1 + R_2 + R_3 + \dots \quad (5.1)$$

For resistors connected in parallel, the equivalent resistor value can be calculated as;

$$\frac{1}{R_{eş}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots \quad (5.2)$$

Mixed circuits can be obtained by using parallel and series resistors together.

The current through all resistors in a series circuit is the same. If a resistor is removed from the circuit, no current will flow through that circuit. In parallel circuits, the current is divided into parallel branches. If a resistor is removed from the circuit, the currents flowing through the other branches increase in intensity.

5.2. EXPERIMENTAL PROCEDURE:

The schematic representation of the apparatus to be used in the experiment is shown in Figure 1. Numbers 1 to 11 in the figure indicate switches, while A, B, C and D are lamps. The list of circuits to be made in the experiment is given in the next section. Using the experimental setup, identify the switches that need to be turned off in order to establish the circuits and write them next to the relevant circuits. Record the switches that need to be turned off in order to set up the circuits in Figure 9 in the space next to the circuit in your report.

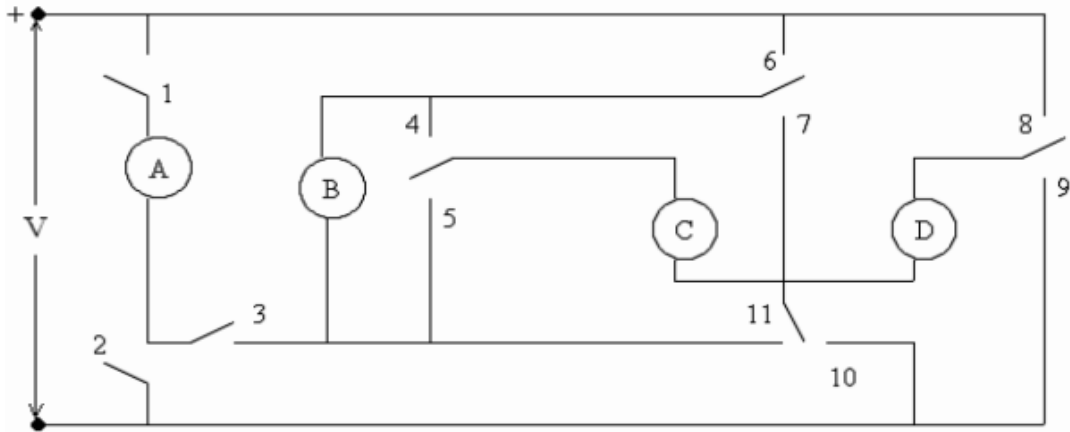


Figure 5-1 Parallel and series circuits experimental setup

Table 5-1 Sample circuits and closed switches

	SAMPLE CIRCUIT	CLOSED KEY
1.	A	
2.	B	
3.	AB SERIES	
5.	AB PARALLEL	

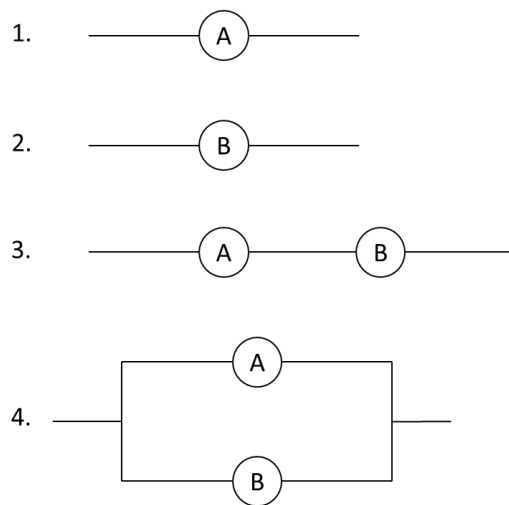


Figure 5-2 Circuits to be obtained with the help of switches

CHAPTER 6. KIRCHHOFF RULES AND WHEATSTONE BRIDGE

EXPERIMENT NO: 6

PURPOSE:

1. Recognition of simple circuit elements, examination of their working principles and physical properties.
2. Application of Kirchhoff's rules in some electrical circuits, measuring a value unknown resistor using a Wheatstone bridge and determining the changes in a resistor in terms of changes in the bridge's equilibrium voltage.

6.1. THEORY:

The circuit element used to reduce the current or divide the voltage in a circuit is called a resistor. The most important feature of a perfect resistor is that there is a direct proportionality between the voltage V between its terminals and the current I flowing through it. This is also called Ohm's law. It is expressed by $V=I.R$. According to this law, if the resistor is kept constant in a circuit and the voltage is increased, the current will increase, and if the voltage is decreased, the current will decrease.

On the other hand, if the voltage is kept constant and the resistor is increased, the current will decrease, and if the resistor is decreased, the current will increase. The unit of resistor is ohm and denoted by Ω . Wire resistors are made by selecting the thickness, length and type of wire according to the desired resistor value and then wrapping this wire on an insulating support. There are three types of resistors used in experiments;

1) CONSTANT RESISTOR: The size and construction of this type of resistor differs according to the current flowing through it. Metal resistors are used at low currents and clay resistors are used at high currents because they are more durable.

2) ADJUSTABLE RESISTOR: If the resistor value needs to be changed or adjusted from time to time in a circuit, an adjustable resistor is used in these circuits.

3) VARIABLE RESISTOR: If the resistor value is desired to change continuously in a circuit, wire wound rheostat is used according to the desired power. They have three ends. The two outer ends are

fixed and the middle end is variable. The current passing through the circuit can be adjusted as desired by moving the arm on the rheostat to the right or left.

Voltmeter: A circuit element that measures the voltage between two points in a circuit. Since the internal resistor of the voltmeter is infinitely large, it is connected in parallel to the circuit.

Amperemeter: It is an instrument used to measure current in a circuit. Its internal resistor is small enough to be considered zero. It is connected in series with the circuit.

Short circuit: In order for current to flow through a resistor, the ends of the resistor must have a different potential. If both points have the same potential, current will not flow through the resistor. This event is called a "short circuit". Some electrical circuits are not easily solvable when Ohm's law is applied. There are some solution rules that facilitate the solution of such circuits. One of them is the Kirchhoff rules.

Kirchhoff's First Rule:

The sum of the currents coming to any point of a closed circuit is equal to the sum of the currents leaving that point.

Kirchhoff's Second Rule:

The algebraic sum of the products of the currents and the resistors in any closed part of an electrical circuit is equal to the algebraic sum of the EMFs. In short, algebraically we can write as,

$$\sum \varepsilon = \sum i.R \quad (6.1)$$

When applying Kirchhoff's rules, the following should be considered:**1.** Random directions are given to the currents. These directions are unimportant. If the current is "+" at the end, the current direction chosen initially is correct, if the current is "-" the current direction selected is reverse.

2. Emf directions of the generators are marked. These directions are accepted from the "-" poles to the "+" pole.

3. Closed circuits and directions of entanglement in these circuits are determined.

4. In the closed circuit, if going in the same direction as the current, the current is taken as “+”, if going in the opposite direction, the current is taken as “-”.
5. While going in the direction of entanglement in a closed circuit, if the positive pole of the generator is exited, emf “+” is taken, if leaving the minus pole, emf “-” is taken.
6. By applying Kirchhoff's rules, equations are formed as many times as unknown quantities.
7. Equations are solved to find the sought values.

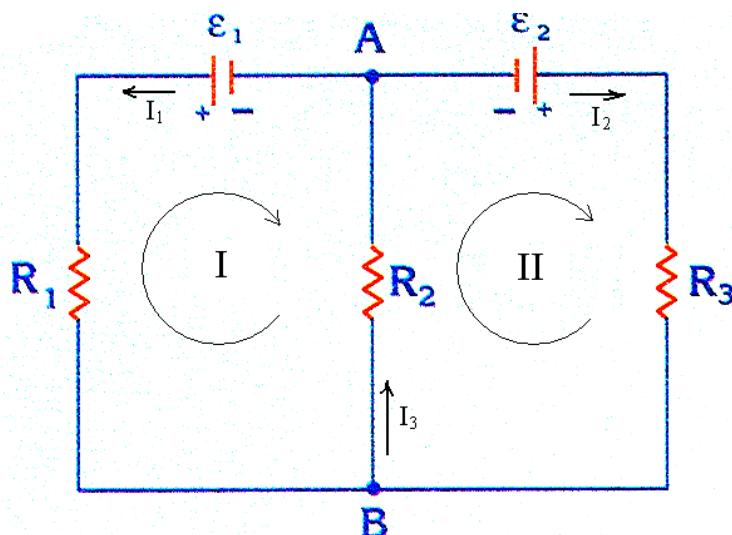


Figure 6-1 Currents and rotation directions chosen for the application of Kirchhoff's rules

For a circuit like Figure 6-1, we can write Kirchhoff's rules as follows:

- i. According to Kirchhoff's first rule; The sum of the currents entering and leaving the B node is equal to each other. Well; It should be $I_3=I_1+I_2$.
- ii. According to Kirchhoff's second rule; The directions of circulation for closed circuits I and II are arbitrarily chosen.

Here, if the rule is applied for the first closed loop;

$$\epsilon_1 = I_1 \cdot R_1 + I_3 \cdot R_3 \quad (6.2)$$

is obtained.

When applied for the second closed loop;

$$-\varepsilon_2 = -I_2 \cdot R_3 - I_3 \cdot R_2 \quad (6.3)$$

equation is obtained.

WHEATSTONE BRIDGE:

A closed circuit consisting of two resistors connected in series, which is formed by connecting two branches in parallel with each other, is shown in Figure 6-2. The system consisting of resistors R_1 , R_2 , R_3 ve R_4 shown in the figure is called a resistor bridge (Wheatstone Bridge). If a potential difference is applied between points a and d of the bridge, currents I_1 , I_2 , I_3 ve I_4 flow through the resistors forming the bridge. A current I_5 passes through the middle arm between the points b, c and the potential difference between b, c V_{bc} is measured with the help of a voltmeter. If R_1 , R_3 , R_4 are known resistors, R_2 variable resistor (rheostat) is changed and the bridge is balanced. R_5 is also a voltmeter here.

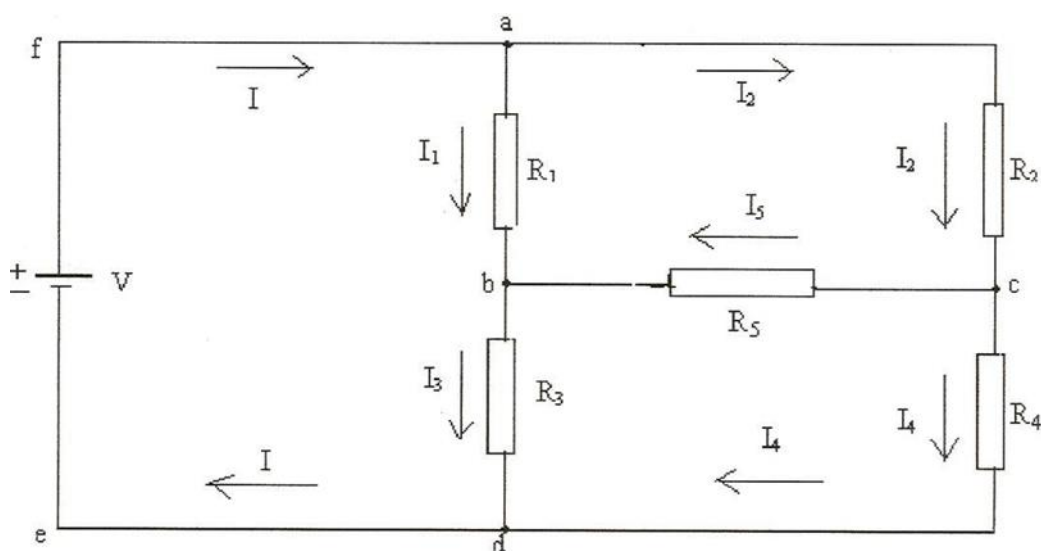


Figure 6-2 Display of currents on the Wheatstone bridge

According to Kirchoff's rules, $I=I_1+I_2$ ve $I_2=I_4+I_5$ ve $I_3+I_4=I$ ve $I_3=I_1+I_5$.

For the equilibrium state of the bridge, if the points b and c shown in the figure are brought to the same potential in any way, that is, if $V_b=V_c$, this situation is called the equilibrium state of the bridge and the voltmeter shows $V_{bc}=0$ (also $I_5=0$). Since $V_{bc}=0$ and $I_5=0$ when the bridge is in equilibrium, it can be clearly seen from the 1st Kirchoff rule that $I_1=I_3$ and $I_2=I_4$. In addition, since R_1 and R_2 are connected in parallel and R_3 and R_4 are connected in parallel, the voltages passing over these parallel arms can be written as $V_{ab}=V_{ac}$ and $V_{bd}=V_{cd}$. By writing it more neatly and taking into account that $V_{ab}=I_1 \cdot R_1$, we can conclude like that :

$$V_{ab} = V_{ac} \Rightarrow I_1 \cdot R_1 = I_2 \cdot R_2 \quad (6.4)$$

$$V_{bd} = V_{cd} \Rightarrow I_3 \cdot R_3 = I_4 \cdot R_4 \quad (6.5)$$

When these two equations are proportional to each other;

$$R_2 = \frac{R_1}{R_3} R_4 \quad (6.6)$$

relation is obtained. Naturally, when equilibrium is established, any of the resistors can be expressed in terms of the other three. Thus, an unknown resistor can be measured using the bridge method, using known resistors. The advantage of this method is that current and voltage values are not required for this measurement and only the bridge is observed to be in balance.

6.2. EXPERIMENTAL PROCEDURE:

Take the resistors with values of $R_1=150 \Omega$, $R_2=$ Rheostat, $R_3=100 \Omega$ and $R_4=50 \Omega$ and set up the circuit in Figure 6-2 to form a bridge. Connect the voltmeter between terminals b and c and connect the power supply according to the figure and complete the circuit. The power supply must be off when installing the circuit. Move the slider of the rheostat (R_2) so that the voltmeter shows zero volts. In this case, the bridge is in equilibrium.

i) Calculate how many ohms of the resistor R_2 should be using the expression given above at equilibrium.

ii) Calculate R_2 once again from the resistive total length of the rheostat.

For this purpose, measure the resistive total length (L) of the rheostat and the balance caulking length (x) with a ruler. If the total rheostat resistor is RL, find R_2 from the equation.

iii) How different is the R_2 measured by both methods from each other? Calculate the differences.

CHAPTER 7. DETERMINATION OF RC TIME CONSTANT

EXPERIMENT NO: 7

PURPOSE:

Determination of time constant in an RC (resistor-capacitor) circuit.

7.1. THEORY:

We know that capacitors allow direct current to flow until they are full (or discharged). The movement of charge between the plates of a charged (or discharged) capacitor from one to the other creates a temporary current in the circuit. Let's examine this behavior by considering a circuit in Figure 7-1. At the beginning, the switch is open and the capacitor whose capacitance we have shown with C is uncharged.

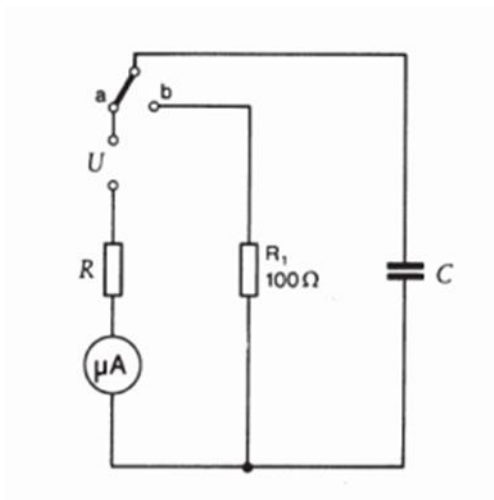


Figure 7-1 Capacitor discharge testing apparatus

When the switch is turned to the a position, the load will start to flow in one direction in the circuit. Since the capacitor is initially uncharged, the current I is limited only by the resistor R , and immediately after the switch is closed (at $t=0$), the current $I_0 = V_0/R$. Over time, charge builds up on the capacitor's plates and the current decreases. The current is zero when the potential difference between the plates of the capacitor is equal to the voltage of the battery. In this last case, the charge of the capacitor is $q_s = C \cdot V_0$. When the current(I)-time(t) graph is drawn, it is easily seen that the graph changes exponentially and this change is;

$$I(t) = I_o e^{-\frac{t}{R.C}} \quad (7.1)$$

it can be expressed by this mathematical equation.

While it can be calculated with the initial current value $I_o = \frac{V_o}{R}$, the R .C expression is called “Time multiplier” and is in time dimension. If the natural logarithm of both sides of the above equation is taken;

$$\ln(I(t)) = -\frac{1}{R.C} t + \ln(I_o) \quad (7.2)$$

equality is achieved. This is a straight line equation with a slope of "m";

$$y = mx + n \quad (7.3)$$

When compared with, it can be easily seen that the slope of the $\ln(I(t)) - t$ graph will be equal to $m = -\frac{1}{R.C}$. Multiplying both sides by -1 so that the equation can be seen more easily can be written as;

$$-\ln(I(t)) = \frac{1}{R.C} t - \ln(I_o) \quad (7.4)$$

7.2. EXPERIMENTAL PROCEDURE:

- 1- Connect the RC experiment setup to the power supply and multimeter as in Figure 1-3 and set up the circuit.
- 2- Turn off the switch on the RC set and wait for the capacitor to charge.
- 3- Complete the table by determining the times when you observe the current values given in Table 1 from the electrometer for the discharge state by opening the switch (**When calculating -ln(I) values, remember that you need to take the current in amps!)**
- 4- Calculate the time constant RC by plotting -ln(I)-t.
- 5- Calculate the error rate (% differences) between the result you obtained and the time constant you calculated using the theoretical R and C values.



Figure 7-2 Capacitor discharge setting up the testing apparatus

Table 7-1 Capacitor discharge data table

V=10 Volt, C = 60 μ F, R = 1 M Ω		
I (A)	t (s)	$-\ln(I)$
$10,0 \times 10^{-6}$		
$9,5 \times 10^{-6}$		
$9,0 \times 10^{-6}$		
$8,5 \times 10^{-6}$		
$8,0 \times 10^{-6}$		
$7,5 \times 10^{-6}$		
$7,0 \times 10^{-6}$		
$6,5 \times 10^{-6}$		
$6,0 \times 10^{-6}$		
$5,5 \times 10^{-6}$		
$5,0 \times 10^{-6}$		
$4,5 \times 10^{-6}$		
$4,0 \times 10^{-6}$		
$3,5 \times 10^{-6}$		
$3,0 \times 10^{-6}$		
$2,5 \times 10^{-6}$		
$2,0 \times 10^{-6}$		
$1,5 \times 10^{-6}$		
$1,0 \times 10^{-6}$		
$0,5 \times 10^{-6}$		

CHAPTER 8. MAGNETIC FIELD IN THE CENTER OF A CURRENT-CARRYING WIRE

EXPERIMENT NO: 8

PURPOSE:

Investigation of the dependence of the magnetic field strength in the center of a current-carrying wire ring on the intensity of the current passing through the wire and the number of turns of the wire

8.1. THEORY:

Definition and Properties of Magnetic Field

At a certain point in space, the electric field \vec{E} was defined as the electric force acting on a test charge (per unit charge) placed at that point. Similarly, the gravitational field \vec{g} at a point in space is the gravitational force acting on a test mass (per unit mass). We can now define the magnetic field vector \vec{B} (sometimes called magnetic induction or magnetic flux density) in terms of a magnetic force that can act on a test object at a point in space. The test object can be taken as a charged particle moving with velocity \vec{V} . For now, let's assume that there is no electric or gravitational field in the charge area. Experiments on the motion of charged particles moving in a magnetic field yield the following results:

1. The magnetic force is proportional to the particle's velocity \vec{V} and the charge q .
2. The magnitude and direction of the magnetic force depend on the velocity vector of the particle and the direction of the magnetic field vector.
3. When a charged particle moves parallel to the magnetic field vector, the magnetic force \vec{F}_B acting on it is zero.
4. When the velocity vector makes an angle θ with the magnetic field, the magnetic force \vec{F}_B acts perpendicular to both \vec{V} and \vec{B} . That is, the force \vec{F}_B is perpendicular to the plane formed by \vec{V} and \vec{B} .
5. The magnetic force acting on a positive charge is opposite to the direction of the force acting on a negative charge moving in the same direction.

6. If the velocity vector makes an angle θ with the magnetic field, the magnitude of the magnetic force is directly proportional to $\sin\theta$. From these observations, the magnetic force can be written as

$$\vec{F}_B = q\vec{V} \times \vec{B} \quad (8.1)$$

Here, the direction of the magnetic force is in the direction of $\vec{V} \times \vec{B}$. The direction of this force is perpendicular to both the velocity vector and the magnetic field vector, by definition of the cross product. That is, it is perpendicular to the plane formed by the velocity vector and the magnetic field vector. Figure 8-1 shows the direction of the force vector as a result of these multiplications.

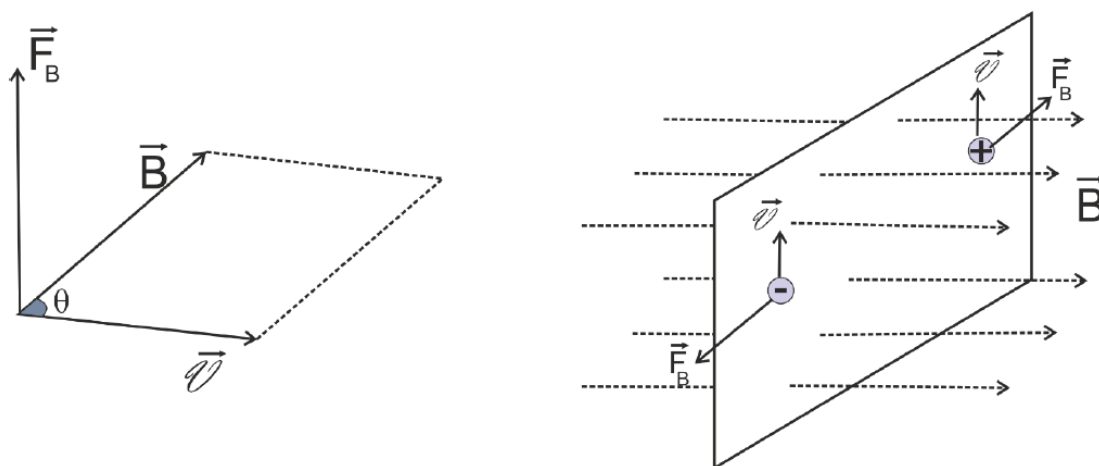


Figure 8-1 Force acting on a charged particle moving in a uniform magnetic field

The direction of $\vec{V} \times \vec{B}$ can be found easily with the "right hand rule". As shown in Figure 8-2, four fingers are rotated from \vec{V} to \vec{B} , while the upright thumb indicates the magnetic force direction. When the charge is negative, the force will be multiplied by "-" and its direction will be opposite to the direction found.

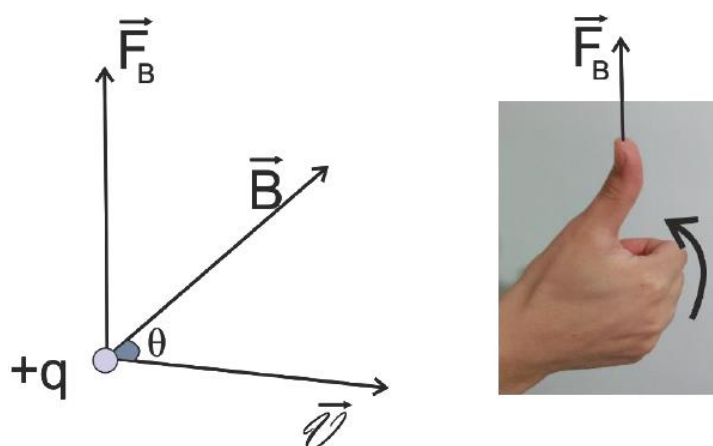


Figure 8-2 Illustration of the right hand rule

Here, the magnitude of the magnetic force can be found by

$$|\vec{F}_B| = q|\vec{v}| \cdot |\vec{B}| \cdot \sin \theta \quad (8.2)$$

There are important differences between electric and magnetic forces;

1. The electric force is always parallel to the electric field, whereas the magnetic force is perpendicular to the magnetic field.
2. The electric force is independent of the velocity of the charged particle. However, the magnetic force can only act on the charged particle if it is in motion.
3. The electric force does work by changing the position of a charged particle, whereas the magnetic force from a stable magnetic field does no work when the particle is displaced.

The magnetic field unit (in the SI system) is Weber per square meter (Wb/m^2). In memory of Nikola Tesla, this unit is also called “Tesla (T)”. This unit can be linked to base units using equations. In a magnetic field with a magnitude of 1 Tesla, a charge of 1 Coulomb moving at a velocity of 1 m/s perpendicular to the field is under the effect of a force of 1 Newton. In practice, Gauss (G) is also used in the cgs system as a magnetic field unit. The conversion factor is $1 \text{ T} = 10^4 \text{ G}$. Conventional magnets can produce magnetic fields of up to about 25000 G or 2.5 T. Superconducting magnets have been made that can produce magnetic fields of approximately

12 000 000 G or 1.2 kT. This is comparable to the value of the magnetic field near the earth's surface. The area of the earth is approximately 0.50 G or 0.5×10^{-4} T.

Magnetic Force Acting on a Current Carrying Conductor

If a single charged particle is under the influence of a force while passing through a magnetic field, it should not be a surprise to you that a current-carrying wire will also experience a force in the magnetic field. This is a result of the current being composed of a large number of charged particles; therefore, the net force acting on the wire is the sum of the forces acting on each charged particle. Accordingly, the force acting on a wire of length \vec{l} through which a current I passes in the magnetic field \vec{B} is given as

$$\vec{F}_B = I(\vec{l} \times \vec{B}) \quad (8.3)$$

The magnitude of the magnetic force can be found by

$$|\vec{F}_B| = I|\vec{l}| \cdot |\vec{B}| \cdot \sin \theta \quad (8.4)$$

This force is perpendicular to both the current-carrying wire and the magnetic field. Here θ is the angle between the current-carrying wire and the magnetic field. The direction of the magnetic field strength is found by the right hand rule. Right hand; Thumbs open to show the direction of current and four fingers to point to the direction of the magnetic field. The direction perpendicular to the palm and outward is the direction of the magnetic field strength. We know that a magnetic field is created around a linear wire through which a current is flowing. A magnetic field is formed around and in the center of a wire loop through which an electric current is flowing.

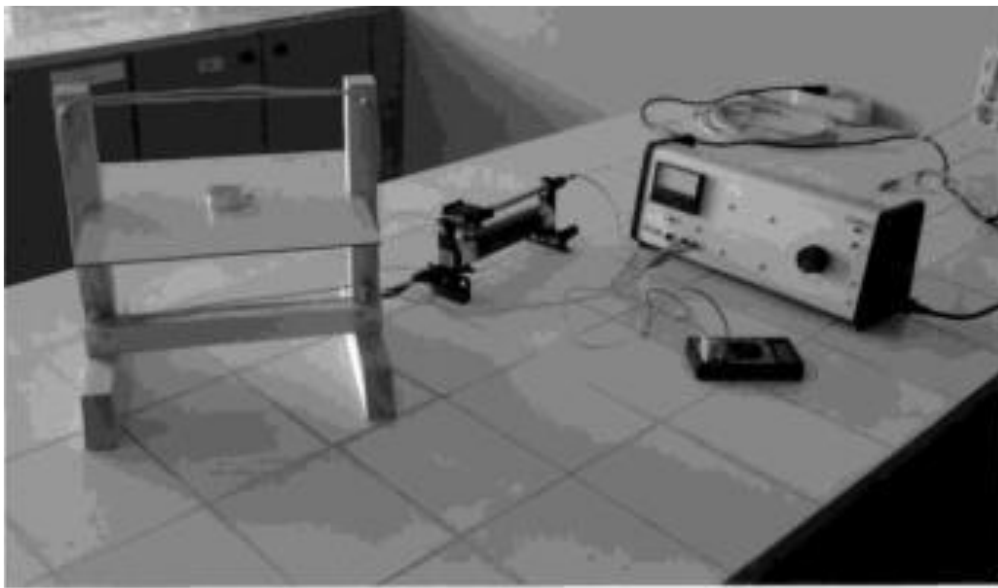


Figure 8-3 Experimental setup for magnetic field measurement

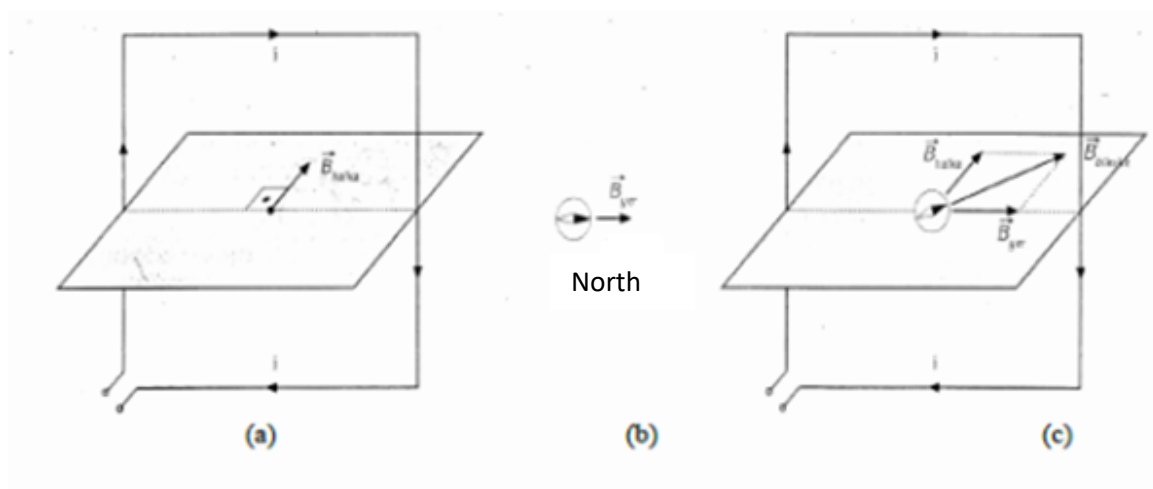


Figure 8-4 Display of magnetic field direction in the experimental setup

The magnetic field vector at the center is perpendicular to the ring plane and its direction is found by the right-hand rule (Figure 8-4a). A compass needle that is not under the influence of another magnetic field indicates the direction of the earth's magnetic field vector (Figure 8-4b). When the compass is placed in the center of the vertically standing ring, the needle stops in the direction of the resultant of the magnetic field vector of the earth and the magnetic field vector formed in the center by the current

passing through the ring (Figure 8-4c). If we call the declination angle of the compass needle θ , the relationship between the magnetic field vectors is, can be found as

$$\tan \theta = \frac{B_{halka}}{B_{yer}} \quad (8.5)$$

From this equation, $B_{halka}=B_{yer}.\tan\theta$ is obtained. Considering that B is constant in the equation, it is seen that B_{halka} and $\tan\theta$ are directly proportional. In this experiment, a compass will be placed in the center of the ring. First, the ring current will be kept constant and the number of turns will be increased. In the second part, the intensity of the current passing through the ring will be changed by keeping the number of turns constant. In both cases, the deflection angles of the compass needle will be determined and the effect of the current passing through the ring and the number of turns on the deflection angle of the needle, and therefore the magnetic field in the center, will be examined. In order to facilitate the application of the test, a square ring will be used instead of a circular ring.

8.2. EXPERIMENTAL PROCEDURE:

Part I: Dependence of Magnetic Field Strength at the Center of the Ring on the Number of Turns

1. Set up the experimental setup so that there is one turn in the ring.
2. Place a millimeter paper on the horizontal aluminum plate in the center. Fix the paper by gluing it with tape so that the lines are parallel to the edges of the sheet.
3. Place the compass on the millimeter paper so that it is in the center of the ring. If necessary, rotate the assembly right/left so that the ring plane is in the direction of the compass needle (north-south direction). In this state, mark the direction of the compass needle on the paper. During the test, be careful not to move the compass and the test setup from its position. For this, tape the assembly from its feet to the table.

NOTE: Make sure that the connecting cables connecting the ring to the power supply and the rheostat stay away from the ring. Thus, you protect the compass from the effects of magnetic fields created by the cables.

4. Make the connections to the DC poles of the power supply. Turn on the power supply and apply electricity to the circuit. By controlling the current by means of a rheostat, ensure that the needle deviates by 10° . In this case, mark the direction of deviation of the needle on the paper and number it as 1. Record the current value and the number of turn on the Measurement Chart as Measurement 1. Disconnect the power from the circuit by turning off the power supply. Do not change the value you set on the rheostat, as the current value passing through the wire will be kept constant in Part I of the experiment. Record the same current value in the table for Measurements 2, 3 and 4.

5. Add one more turn to the ring, carrying current in the same direction as the first. Repeat the experiment. Mark the direction of deviation of the needle and number it as 2. Record the number of turns in the table as Measurement 2.
6. Repeat the experiment with 3 turns for measurement 3 and 4 turns for measurement 4. Make sure that the currents passing through the turns are in the same direction. Mark the deflection directions of the needle and number them as 3 and 4 respectively. Record the number of turns in the table as Measurement 3 and Measurement 4.
7. Lift the compass and separate the millimeter paper from where it is stuck. When the compass needle is in its original position, extend the north-south direction you marked with a ruler. Extend the lines showing the direction of deviation of the pointer and intersect with this line.
8. Measure the declination angles. Record each deviation angle in the table as the measurement with the same number as the number you gave.
9. Draw a $\tan\theta$ -turn number graph.

NOTE: If you can measure the deflection angles of the needle on the compass, you do not need to use paper and mark the declination directions. You can read the declination angles of the needle directly from the compass and record them in the table.

Part II: Dependence of Magnetic Field Strength at the Center of the Ring on the Strength of Current Passing Through the Ring

1. Without changing the position of the ring, place a new millimeter paper on the aluminum plate as you placed the first paper.
2. Place the compass in the center of the ring so that the needle is parallel to the lines of the paper. Do not change the 4 turns in the ring during the experiments in this section.
3. Repeat the experiment by adjusting the current passing through the wire to 1 A for Measurement 5, 2 A for Measurement 6, 3 A for Measurement 7 and 4 A for Measurement 8 with the help of a rheostat. Mark the deflection directions of the needle in each experiment and number them as 5, 6, 7 and 8 respectively. Record the current values in the table.
4. Separate the paper from where it is stuck. Extend the declination lines and cross them with the line showing the north-south direction.
5. Measure the declination angles. Record each deviation angle in Table 1 as the measurement with the same number as the number you gave.
6. Draw the graph $\tan\theta$ -I.

Table 8-1 Current and number of turns data table

Measurement number	Current (A)	Number of turns (N)	Deviation angle (θ)	Tan θ
Part 1				
1				
2				
3				
4				
Part 2				
5				
6				
7				
8				

CHAPTER 9. TRANSFORMERS AND INDUCTION COIL

EXPERIMENT NO: 9

PURPOSE:

Examination of the relations between the output voltage of the transformers and the number of turns of the coils and the induction coil

9.1. THEORY:

In Figure 9-1, the magnetic flux through both coils is zero when the switch is open. If the switch is suddenly closed, the first coil will act as an electromagnet and generate magnetic flux around it. Some of this flux goes through the second coil. Therefore, when the switch is suddenly closed, the flux through the second coil changes. As the current in the main coil rises from zero to its maximum value, an emf occurs in the second coil. When the switch S in the figure is closed, the direction of the current is from b to a.

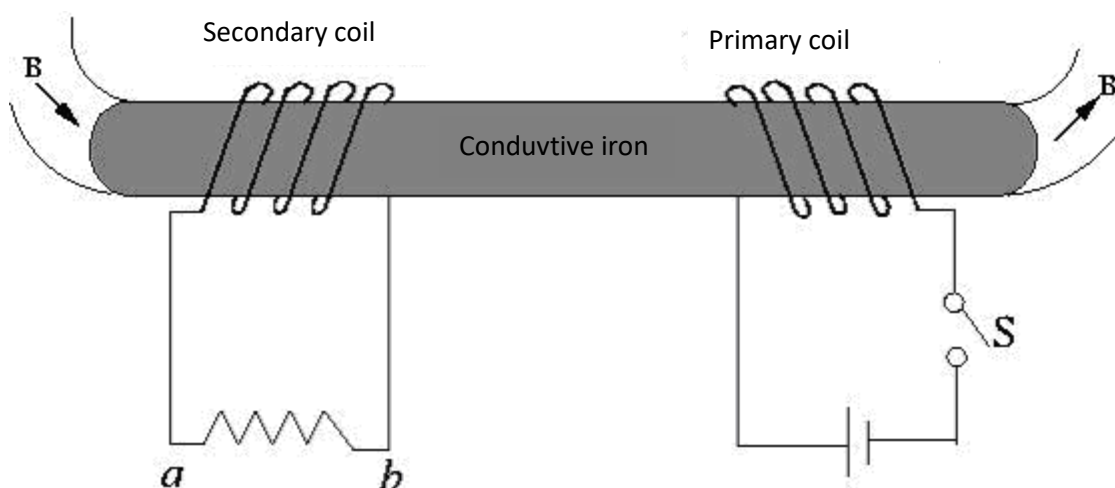


Figure 9-1 Display of transformer mechanism

The magnitude of the emf induced in the second coil; it depends on the number of turns in each coil, the distance of the coils, the orientation of the coils relative to each other and their cross-sectional area.

This induced emf is also proportional to the rate of change of current in the first coil. Therefore for the emf formed in the second coil;

$$\mathcal{E}_S = M \frac{\Delta I_p}{\Delta t} \quad (9.1)$$

expression can be used.

\mathcal{E}_S ; EMF formed in the second coil, ΔI_p ; current change in the first coil and M; are the mutual self-induction coefficients of the coils and the unit of M is V.s/A (Henry). A large M means that the energy transferred to the second coil is large. Since the generation time of the current in the first circuit is greater than the cut-off time, the deviation in the cut-off state should be larger.

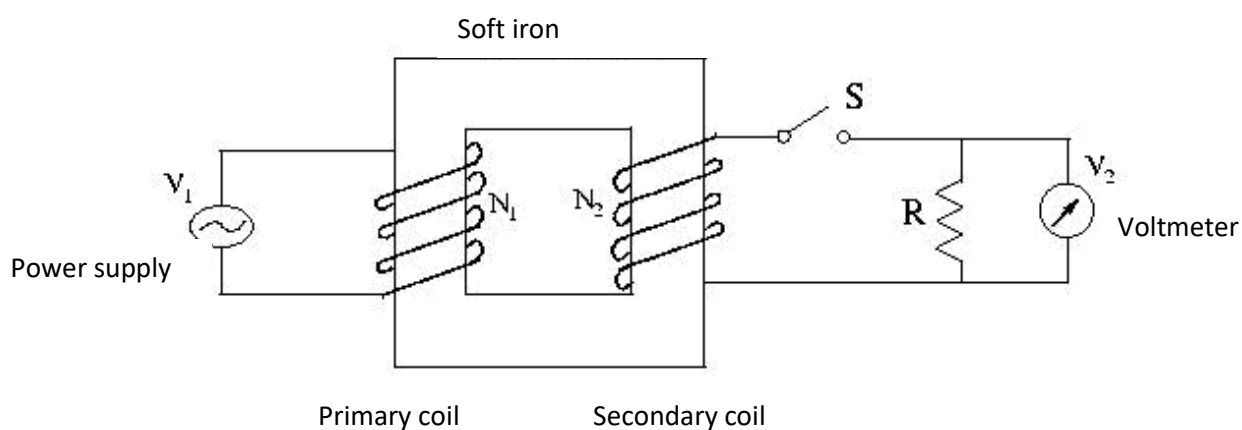


Figure 9-2 Setup of the transformer circuit in the experiment

In its simplest form, a transformer consists of two coils wound around a soft iron as shown in Figure 9-2. The coil on the left side connected to the AC input voltage source is called the primary N_1 wound coil, and the coil on the other side is called the second (secondary) N_2 coil. The purpose of the common iron is to increase the magnetic flux and to provide the environment through which almost all the flux will pass to another coil. According to Faraday's law, the voltage V_1 in the first coil is given by

$$V_1 = -N_1 \frac{\partial \Phi_m}{\partial t} \quad (9.2)$$

Here Φ_m is the magnetic flux through the first turn. The amount of flux passing through the first turn is also equal to the amount of flux passing through the second turn. Similarly, in voltage V_2 is given by

$$V_2 = -N_2 \frac{\partial \Phi_m}{\partial t} \quad (9.3)$$

If these two equations are proportioned, for V_2 output voltage;

$$V_2 = \frac{N_2}{N_1} V_1 \quad (9.4)$$

When N_2 turn is larger than N_1 , V_2 output voltage will be greater than V_1 input voltage. In this case, the transformer works as a booster and in the other case as a step-down.

9.2. EXPERIMENTAL PROCEDURE:

PART I

A coil whose number of turns will not change (one of 300 or 1200 turns can be selected) is attached to the U-shaped iron. This coil is connected to the AC power supply (raise the power supply up to 8 Volts, otherwise it may be dangerous). N_2 turns coil is attached to the other empty arm of the U-shaped iron (any two of the 300, 600, 1200, 1800, 3600 turns coils can be taken for the N_2 turns coil). This coil is connected to the voltmeter and the voltmeter is brought to the AC measurement scale. The U-shaped iron is put in its place in the experiment set with the installed coils and its existing mechanisms and the cover is closed. The power supply is turned on and all output voltages are noted for the windings and voltages specified in Table 1. These processes are also repeated without closing the cover of the U iron in the set. After the desired values are written in the table, the input-output voltage graph is drawn for each coil with different windings using these values. (Note: The graph will be drawn only for the voltage values with the cover closed)

Table 9-1 Data table for the ratio of voltage to number of turns

Number of turns of the Primary Coil	Number of turns of the Secondary Coil	Input voltage (V)	Output voltage (V) (cover is closed)	Output voltage (V) (cover is open)
$N_1 = \dots\dots\dots$	$N_2 = \dots\dots\dots$	2		
		3		
		4		
		5		
		6		
	$N_2 = \dots\dots\dots$	2		
		3		
		4		
		5		
		6		

PART II

In this section, our aim is to find the number of turns of an unknown coil with the help of input and output voltages and N_1 coil. Instead of the N_2 wound coil in Part I, the coil, which will be given at the time of the experiment and whose number of turns is unknown, is placed and the cover is closed. Table 2 is created with the values read from the voltmeters connected to the circuit. Using this table, the input-output voltage graph is drawn for the unknown coil. The number of turns of the coil is found from the slope of the graph.

Table 9-2 Coil data table of unknown number of turns

Number of turns of the Primary Coil	Coil with unknown number of turns	Input voltage (V)	Output voltage (V)
$N_1 = \dots\dots\dots$	$N_2 = ?$	2	
		3	
		4	
		5	
		6	
		7	
		8	

CHAPTER 10. DETERMINATION OF SELF-INDUCTION COEFFICIENT (L) OF A COIL

EXPERIMENT NO: 10

PURPOSE:

Investigation of the behavior of a coil circuit against direct and alternating current

10.1. THEORY:

The behavior of a coil circuit towards direct and alternating current is not the same. It shows greater resistor to alternating current than to direct current. The resistor of such a circuit to alternating current is called the apparent resistor (Z) or impedance.

Let's draw Figure 10-1, which shows the resistor and the coil of a circuit with coils at the ends of which an alternating voltage is applied. In such a circuit, the potential difference V_{AC} between the ends of the circuit at any instant is given by

$$V_{AC} = V_{AB} + V_{BC} \quad (10.1)$$

$$V_{AC} = L \frac{di}{dt} + i.R \quad (10.2)$$

R is the resistor of the circuit, I is the current flowing through the circuit at time t, $\frac{di}{dt}$ is the rate of change of the current, and L is the self-induction coefficient or inductance.

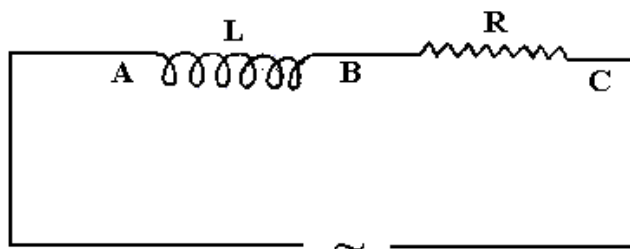


Figure 10-1 Display of resistor R and inductance L under alternating voltage

Ohm-sized $L\omega$ is called “reactance” and is denoted by X_L ($\omega=2\pi f$ and f (frequency of alternating current) $=5\times 10^4\text{ s}^{-1}$). In a circuit with inductance, there is a phase difference of 90° between the potential difference at the ends of the coil and the current in the circuit. Let V_L is the voltage of the coil and V_R is the voltage across the resistor. Their vector sum will be as in Figure 10-2.

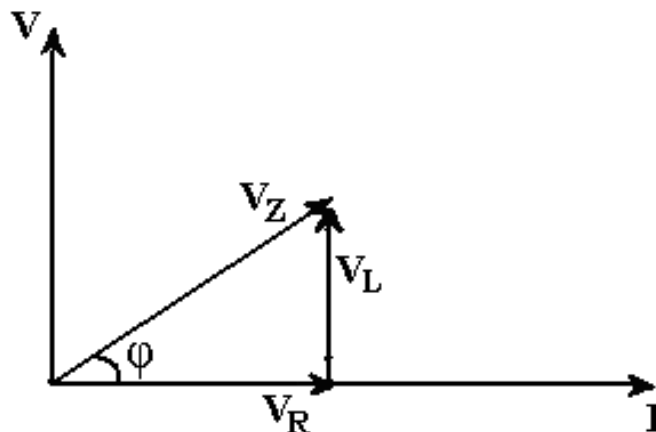


Figure 10-2 Voltages in a circuit with inductance and resistor connected in series

According to the figure;

$$V_Z^2 = V_L^2 + V_R^2 \quad (10.3)$$

$$V_Z = V_{AC} = i.Z \quad (10.4)$$

$$V_L = V_{AB} = i.L.\omega \quad (10.5)$$

$$V_R = V_{BC} = i.R \quad (10.6)$$

$$i^2 Z^2 = i^2 L^2 \omega^2 + i^2 R^2 \quad (10.7)$$

$$Z^2 = L^2 \omega^2 + R^2 \quad \text{and} \quad L = \frac{1}{\omega} \sqrt{Z^2 - R^2} \quad (10.8)$$

Here Z represents the apparent resistor (impedance) of the circuit. If Z and R are measured, L can be easily calculated. In Figure 10-2, the angle between V_R and V_Z is θ . The phase difference between the

current in this circuit and the potential difference at the ends of the circuit is zero. Because the current is in V_R phase. The value of this;

$$\tan \theta = \frac{V_L}{V_R} = \frac{iL\omega}{iR} = \frac{L\omega}{R} \quad (10.9)$$

Angle θ can be calculated with inverse angle equations with known L and R .

In a circuit with inductance, by measuring the effective potential difference (V_e) and effective current strength (i_e) at the ends of the circuit, and applying Ohm's law to circuits with inductance, the impedance (Z) can be calculated from the equation

$$Z = \frac{V_e}{i_e} \quad (10.10)$$

10.2. EXPERIMENTAL PROCEDURE:

Experiment a) Measurement of the resistor R of the current reel using the Ammeter-Voltmeter method

Prepare the assembly in Figure 10-3. Here A and B are the ends of the current reel (L). for E ; use the two elements of the accumulator, close the switch K and move the slider of the rheostat so that a certain current flows through the circuit. Meanwhile, read the potential difference at the ends of the reel from the voltmeter.

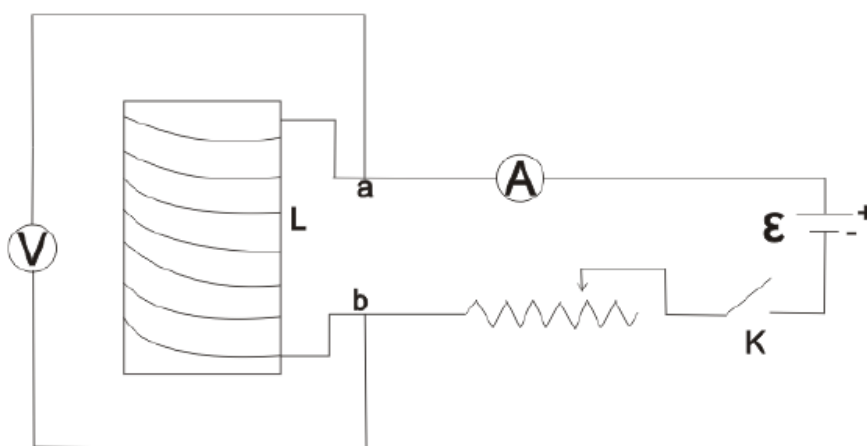


Figure 10-3 Obtaining the R ohmic resistor

Replace the current in the circuit with a rheostat, read the potential difference from the voltmeter for three different values of the current, and fill in the table. Find the average value of the resistor.

Table 10-1 Ohmic resistor measurement data table

I(A)	V(V)	R(Ω)
R_{ort}		

Experiment b) Measuring the Z resistor of the current reel using the Ammeter-Voltmeter method

Remove only the direct current generator (ε) from the circuit without touching the other parts of the circuit you have set up in (a). Instead of ε , use an alternating voltage of 4-6 V from the AC current generator.

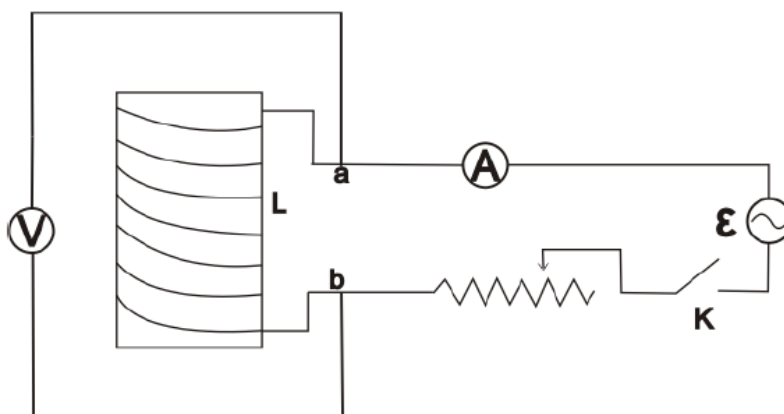


Figure 10-4 Obtaining Z impedance under alternating voltage

Act in the same way and change the intensity of the current in the circuit with the rheostat. Measure the potential difference at the ends of the current reel for three different values of the current passing through the circuit and fill in Table 10-2. Then average of the Z's and calculate the average impedance value Z_{ort} . Substitute the values you found for R and Z in Equation 10-8 and calculate L.

Table 10-2 Impedance value measurement data table

I(A)	V(V)	Z(Ω)
$Z_{ort} =$		

Let us now show that the self-induction coefficient changes with the magnetic permeability of the environment ($\mu_0 = 4\pi \cdot 10^{-7} \text{Wb/m.A}$). For the self-induction coefficient (L) of a current reel,

$$L = \mu_0 \frac{N^2 \cdot A}{l} \quad (10.11)$$

N is the number of turns in the coil, A is the cross-sectional area of the reel, and l is the length of the coil. Since all these values are constant, if we equalize it to a constant such as $\frac{N^2 \cdot A}{l} = k$, therefore

$$L = \mu_0 k \quad (10.12)$$

In this case, as long as the properties of the coil do not change, the L value changes only in direct proportion to the μ_0 magnetic permeability of the environment.