# PHY 1102 PHYSICS II LABORATORY BOOKLET

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# Preparation for the Physics II Laboratory Laboratory

# Measuring Instruments

## Purposes

- To learn using analog and digital measuring instruments
- To learn using electronic board (breadboard)
- To read the color codes and to determine the resistor value

## Symbols and Units of Electrical Quantities

In our laboratory studies, we will use the international (SI) unit system for calculations. The symbols and units of some physical quantities are summarized in Table 1.

**Table 1.** Basic electrostatic concepts, symbols and units.

| Physical Quantity | Symbol | SI System | Unit Abbreviations |
|---|---|---|---|
| Electric field | E | Volt/meter | – |
| Electric potential | V | Volt | V |
| Electric charge | Q,q | Coulomb | C |
| Electric current | I,i | Ampere | A |
| Power | P | Watt | W |
| Current density | J | Ampere/meter$^2$ | – |
| Magnetic field | B | Tesla | T |
| Resistor | R | Ohm | Ω |
| Capacity | C | Farad | F |
| Inductance | L | Henry | H |

Upper and lower multiples of all units are indicated by Latin prefixes. The Latin-prefixes, symbols and the multiplification factors of the units are indicated in Table 2.

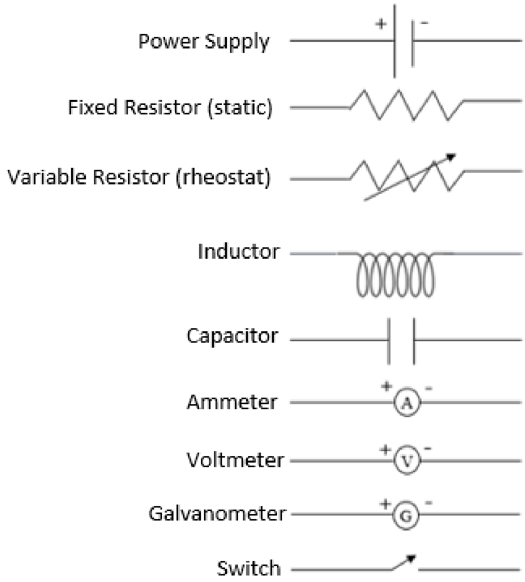
**Table 2.** Prefixes, Symbols and Multiplying Factors.

| Prefix | Symbol | Multiplying Factor | Prefix | Symbol | Multiplying Factor |
|---|---|---|---|---|---|
| deci | d | $10^{-1}$ | tera | T | $10^{12}$ |
| centi | c | $10^{-2}$ | giga | G | $10^{9}$ |
| milli | m | $10^{-3}$ | mega | M | $10^{6}$ |
| micro | µ | $10^{-6}$ | kilo | k | $10^{3}$ |
| nano | n | $10^{-9}$ | hecto | h | $10^{2}$ |
| pico | p | $10^{-12}$ | deca | D | $10^{1}$ |
| femto | f | $10^{-15}$ | | | |
| atto | a | $10^{-18}$ | | | |

**Example:** 1µF = $10^{-6}$ F 1kΩ = $10^{3}$ Ω

In electrical circuits, circuit elements are specified with certain symbols.

## Symbols of Some Circuit Elements




## 1. Analog and Digital Instruments

Analog measuring instruments are instruments that show the measured value with a pointer on divisions of the scale. Although the mechanism of such measuring instruments seems simple, it is possible to make more precisely measurement.


**Figure 1.1** Analog measuring instruments used in the laboratory; milliampere meter, microampere meter, electrometer and power supplies.

In digital measuring instruments, the measured physical value is shown in numbers on a display screen. The structure of digital measuring instruments, which have more features than analog measuring instruments, is more complex. Among these measuring tools, which have advantages and disadvantages compared to each other, analog measuring instruments have the opportunity to make more precise measurements by changing their range, especially at small values. However, it is also more likely to make reading errors using such measuring tools. In digital measuring instruments, measurement errors are less, and the device gives the measurement value directly numerically. We will frequently use both analog and digital measuring instruments in the experiments in our laboratory.


**Figure 1.2** Digital measuring instruments used in the laboratory; digital multimeter and power supplies.

## 1.1 Analog and Digital Power Supplies

Power is known as the amount of energy consumed per unit time. Electrical power is the product of the current provided to a circuit per unit of time by the potential difference occured in the circuit $(P = I.V)$. The unit of electrical power is Watt. We can see a wide variety of electrical power sources around us. The power sources we are most familiar with are batteries and generators. Power sources can be divided into two classes as alternating current sources (AC) and direct current sources (DC). If the current is constant with respect to time and always in the positive direction, it is called as *direct current*. We can obtain such currents directly from various batteries around us. *Alternating current*, unlike direct current, changes over time within regular time intervals, and also flows in the opposite direction. These regular time intervals give the frequency of the alternating current. Devices powered with alternating current must be compatible with the frequency of that current. Such currents are usually provided by generators. Since city electricity is generally produced by generators, it has alternating current. There are both analog and digital power supplies in our laboratory.

## 1.2 Digital Multimeter (Avometer)

Digital multimeters are used to measure current (AC / DC), voltage (AC / DC) and resistance. Because of their features, they are also called AVOmeters (A = amperes, V = volts, O = ohms). Two cables are required to measure any quantity with digital multimeters. One of them is plugged into the 'COM' (COM = common) regardless of the quantity to be measured, the other cable should be plugged into the related entrance according to the corresponding measurement. Similarly, the appropriate scale on the multimeter should be selected for the relevant quantity.


**Figure 1.3** Usage of the digital multimeter

### *Measuring Current with a Digital Multimeter*

In order to measure current, the measurement scale of the device is adjusted to one of the A– (DC) or A~ (AC) scales. If the current value to be measured is unknown (it can be in the range of A or mA), the measurement should be made starting from the largest range. After the measurement scale is set, the blackcable is plugged into the COM (common) entrance and the red cable to the A (or mA depending on the current value to be measured) entrance. Other entrances of the cables are connected in series to the circuit element whose current will be measured. In this case, the internal resistance of the ammeter is added to the resistance of the circuit to which it is connected in series. As a result, the current to be measured decreases as well as there is a voltage drop across the Ammeter. In order to minimize this effect, ammeters are designed with very small internal resistances. If the measurement result shows the current value with a negative sign, it means that the red tip is attached to the side with low voltage.

### *Measuring Voltage with a Digital Multimeter*

In order to measure the voltage, the measurement scale of the device is set to one of the V– (DC) or V~ (AC) scales. If the approximate value of the voltage to be measured is unknown, the measurement should start from the largest range. After adjusting the measurement scale, the blackcable is plugged into the COM (common) entrance and the red cable into the V entrance. The other entrances of the cables are connected to the ends of the circuit element whose voltage will be measured. If the measurement result shows the voltage value with a negative sign, it means that the red tip is attached to the side with low voltage. When measuring voltage in an electrical circuit, the multimeter is connected parallel to the circuit because the voltage values on the paralel arms are equal. The internal resistance of the voltmeter should not change the current through the resistor whose potential difference is measured. Therefore, the internal resistance of voltmeters is ideally infinite, while in practice it is very large. The greater the internal resistance of a voltmeter, the less measurement error will be.

### Reading the Color Codes and Determining the Resistor Value

The most common small resistors are those with carbon components. These have a varying power between 0.25-2 Watt. This strength refers to the maximum power the resistor can withstand without being deformed. Since these resistors are small, it is difficult to write their properties and values on them. Therefore, this difficulty has been overcome by color coding. There are usually 4 colored bands on the resistor.


**A: 1st color (number) B: 2nd color (number) C: 3rd color (multiplier) D: 4th color (tolerance)**

Colors on the resistor are read from left to right. The first three color bands determine the size of the resistor. The values of the resistors may vary slightly due to their imperfections. This fact is called the tolerance of resistance. The band D indicates the tolerance as a percentage. Accordingly, the value of the resistance is read as follows;

$$R = AB.10^C \pm D$$

(Note that in the expression **AB** is a two-digit number!)

**Table 3.** Resistor color codes

| Colors | A | B | C | D (%) |
|---|---|---|---|---|
| Black | 0 | 0 | 0 | – |
| Brown | 1 | 1 | 1 | – |
| Red | 2 | 2 | 2 | – |
| Orange | 3 | 3 | 3 | – |
| Yellow | 4 | 4 | 4 | – |
| Green | 5 | 5 | 5 | – |
| Blue | 6 | 6 | 6 | – |
| Purple | 7 | 7 | 7 | – |
| Grey | 8 | 8 | 8 | – |
| White | 9 | 9 | 9 | – |
| Gold | – | – | -1 | %5 |
| Silver | – | – | -2 | %10 |
| None | – | – | – | %20 |

**Example:** Let's find the value of the resistance according to the color codes given below;

**A: Yellow B: Purple C: Red D: Silver**

According to the color code Table; $R = AB.10^{C} \pm D \rightarrow R = 47.10^{2} \pm \%10$

$$R = (4700 \pm 470)\Omega$$

$$\left.\begin{array}{l} 4700 - 470 = 4230\ \Omega \\ 4700 + 470 = 5170\ \Omega \end{array}\right\} \text{The real value of the resistor can be at this range.}$$

## *Measuring Resistor Value with a Digital Multimeter*

In order to measure the resistance, the measurement scale of the device is adjusted to the Ω scale. For the measurement of mega-ohm (MΩ) resistances, the **M** range of the scale is used, and one of the **k** ranges of the scale is used for the measurement of the resistances of the kilo-ohm (kΩ) order. If the approximate value of the resistance value to be measured is unknown, the measurement should start from the largest range. After the measurement scale is set, the blackcable is plugged into the COM (common) entrance and the red cable into the Ω entrance. The other ends of the cables are connected to the ends of the corresponding resistor and the resistance value is read from the screen of the multimeter. The value read from the multimeter may not be the same as the resistance value read from the color codes. However, as in the example above, it will give a value within the tolerance percentage limits.

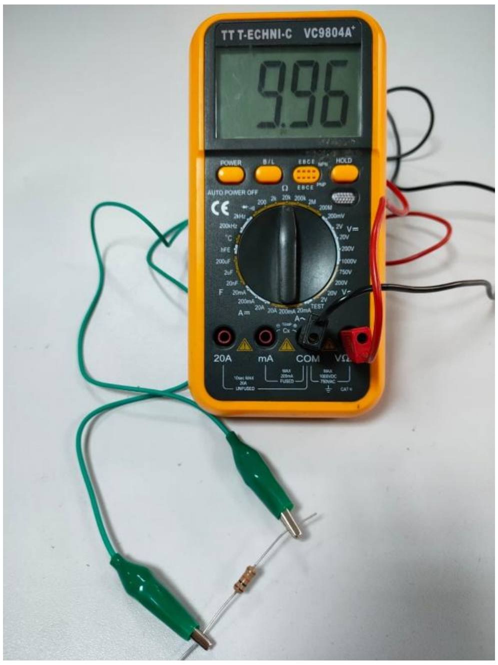



**Figure 1.4** Measuring resistance value with a digital multimeter

## 1.3 Electronic Board (Breadboard)

The electronic board is a rectangular plastic sheet with a lot of small holes on it. These holes allow electronic components to be easily inserted into the prototype. Conductive strips, located under the holes, connect the electronic circuit elements together, forming a circuit without the need for soldering. Electronic board internal structure consists of vertically and horizontally positioned metal clamps connected to each other. The red and blue parts on both sides of the board are the line segments of the breadboard (Figure 1.5). These parts are in transmission along a line from one end to the other. The middle parts of the breadboard consist of conductors placed along the column. The upper part of all these conductors is covered with a plastic consisting of holes drilled to place the electronic components.

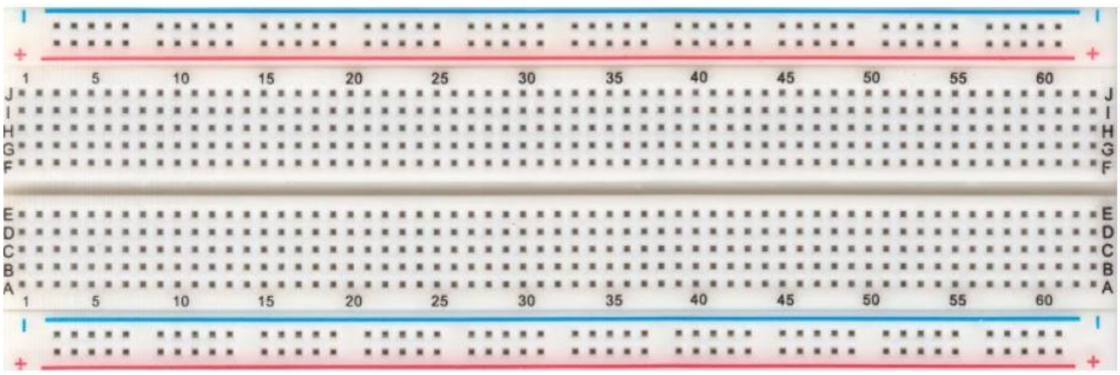



**Figure 1.5** Electronic board (breadboard)

**Things to consider when setting up a circuit in the electronic board;**

- Please do not plug the legs of the same circuit element along the same column. Otherwise, a short circuit occurs between the legs of the element.
- Please do not plug legs of any two circuit elements into the same hole on the electronic board. Set up the circuit so that a circuit element’s leg is placed in one hole.
- If you set up a complex circuit with more than one circuit element, make sure that the legs of the circuit elements do not touch each other.
- While working with polar elements such as capacitors, make sure that the polarities are not reversed on the board.

**References**

1. Dokuz Eylül Üniversitesi, Fen Fakültesi Fizik Bölümü, Fizik II Laboratuvar Föyü, 2016
2. Ankara Üniversitesi Mühendislik Fakültesi, Fizik Mühendisliği Bölümü, Elektrik Laboratuvarı El Kitabı, 2017
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# EXPERIMENT 1: RELATIONS BETWEEN CHARGE, POTENTIAL DIFFERENCE and CAPACITANCE in a PARALLEL PLATE CAPACITOR

## Purposes

- Finding the capacitance of a paralel plate capacitor,
- Analyzing the variation of the change on the capacitor,
- Determining the relations between the charge, the potential difference and the capacitance of the capacitor.

### 2.1 Capacitor and Concept of Capacitance

Systems that carry charge of equal amount and opposite sign and can store large charge under small potential differences are called **capacitor**s. Two parallel conductive plates with an insulating material or space between them form a capacitor. These are called "paralel plate capacitors". The insulator between the plates is called "dielectric material".

The amount of charge $Q$ on a capacitor is directly proportional to the potential difference between conductors ($Q \propto \Delta V$). The largest amount of electrical charge that capacitors can store on them is;

$$Q = C.\Delta V \qquad 2.1$$

The ratio of the magnitude of the charge on one of the conductors to the magnitude of the potential difference between them is defined as the **capacitance** of the capacitor. Since the potential difference will increase as the accumulated charge in the capacitor increases, the $Q/\Delta V$ ratio for the capacitor is fixed. In the SI unit system, capacitance is Coulomb per Volt (Coulomb / Volt) and designated as **farad** (F) in honor of Michael Faraday. Farad is a very large unit of capacity. Therefore, in practice, the capacity of many devices is between microfarad ($10^{-6}$) and picofarad ($10^{-12}$).

#### 2.1.1 The Capacity of The Parallel Plate Capacitor

As in Figure 2.1, the capacity of a capacitor consisting of two paralel plates with a vacuum or air between them is given by the following equation;

$$C = \frac{\varepsilon_0 A}{d} \qquad 2.2$$

In this expression $A$ is the area of the parallel plates, $d$ is the distance between the two plates and $\varepsilon_0$ is the permittivity of free space ($\varepsilon_0 = 8.85\,x\,10^{-12}\,farad/meter\;or\;C^2/N\,m^2$).

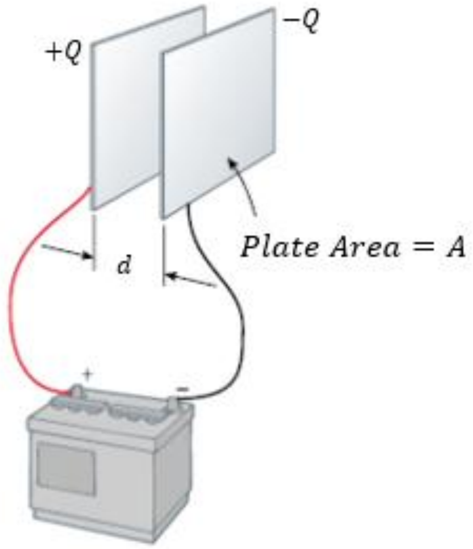



**Figure 2.1** A capacitor consisting of two paralel plates

## 2.2 Tools to be used in the experiment

- Faraday Ice Pail
- Electrometer
- Parallel Plate Capacitor
- Electrostatics Voltage Source
- Charge Producer
- Connection cables, adapter, ruler

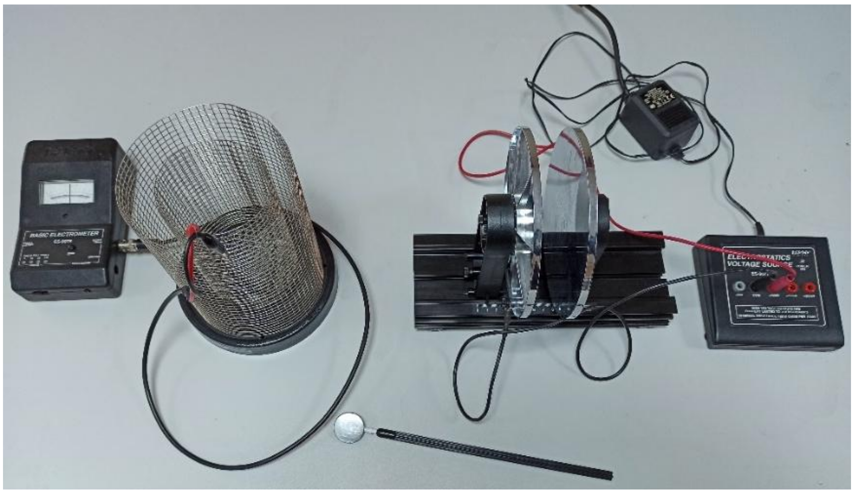


**Figure 2.2** Experiment Setup

### Parallel Plate Capacitor

As seen in Figure 2.3, the paralel plate capacitor consists of two circular plates with a diameter of $R = 18\ cm$. The plates are mounted so that they can move on a skid, scaled in cm. The cables coming from the related inputs of the voltage source are connected to the capacitor through the screws on the back of the plates, and the capacitor is loaded.

**Figure 2.3** Parallel Plate Capacitor

### Electrometer

It is a voltmeter used for direct voltage measurement as well as indirectly for current and charge measurement (Figure 2.4). Due to its high resistivity, it is particularly suitable for charge measurement in electrostatic experiments. It has about 1000 times the sensitivity of a Standard gold leaf electroscope, the center zero indicator directly displays the charge polarity and measures the charge to $(10^{-11})$ Coulomb.

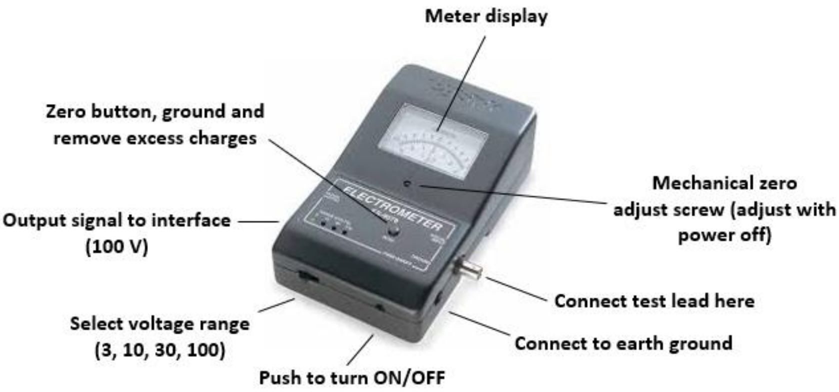



**Figure 2.4** Electrometer

## Electrostatics Voltage Source

It is a high voltage, low current power supply designed only for electrostatic experiments (Figure 2.5). It has 30 Volt DC output for plate capacitor experiments. It has 1000V, 2000V and 3000V outputs for Faraday ice pail and conductive sphere experiments. All voltage outputs except 30 Volt have resistance in series associated with voltage output values limiting the appropriate short circuit output current to around 8.3 µA. 30 Volt output is regulated.


**Figure 2.5** Electrostatic voltage source

## Charge Producer

It consists of a conductive disk covered with aluminum and an insulator holder attached to it (Figure 2.6). It is used to measure charge density on charged conductive surfaces. Faraday ice pail is used to measure the charge density on the rod.

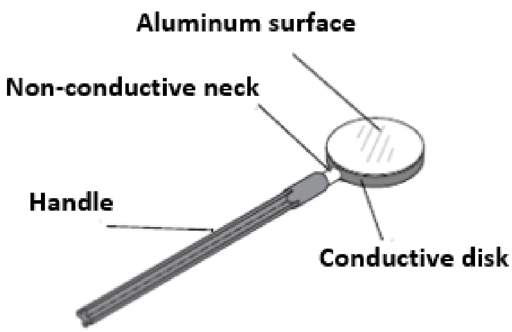



**Figure2.6** Charge producer

**Faraday Cage**

It is obtained by placing two intertwined conductive cages on an insulating table. While measuring, a red-alligated clip is attached to the iner cylinder and a black-alligator clip is attached to the outer cylinder (Figure 2.7).

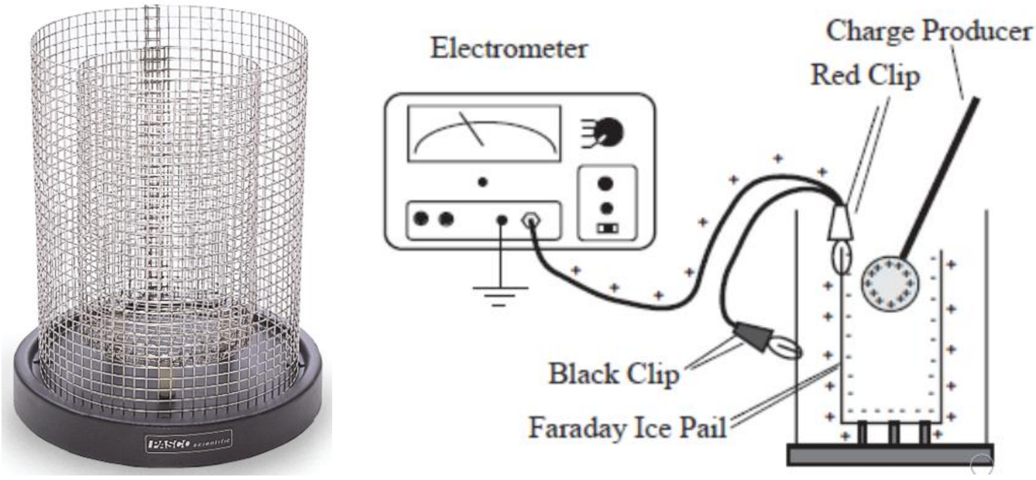



**Figure 2.7** Faraday ice pail

## 2.3 Experimental Procedure

- Set up the experiment equipment shown in Figure 2.8. Tighten the screws on the back of the capacitor plates with attached cables that will load the capacitor. Connect the other ends of the cables to the electrostatic voltage source with the black end plugged into the COM input and the red one to the 1000 V input.
- In order to find the capacitance of the capacitor the amount of charge stored in the capacitor must first be determined by using the expression given in Equation 2.1.
- Load the capacitor by applying a voltage of 1000 V. Use the charge producer and Faraday ice pail to find the charge stored on the capacitor's plates.
- Make sure the charge producer has no charges on it at the beginning. You can touch the rod to the wall or the ground (without rubbing) to neutralize the charge on it.
- Record the value you have measured for the distance between the plates of the capacitor with the help of a ruler or from the cm scale on the capacitor in Table 2.2.
- Wait for a short time by touching the uncharged charge producer to a point close to the center of one of the capacitor plates (Do not try to load the charge producer rod by rubbing it, it is sufficient to touch it).
- The charge producer was charged as a result of electrification by touch. Then, without wasting time, bring the charge producer rod closer to the inner cylinder in the Faraday ice pail without

touching it, as in Figure 2.7. In this case, the inside of the inner cylinder of the Faraday ice pail is charged with the same amount as the rod. But its sign is in contrast with the charge sign of the charge producer rod.

- As soon as you bring the charge producer closer to the inside of the Faraday ice pail, you will observe a voltage deviation in the electrometer. Record this voltage value in the relevant part in Table 2.1 ($V_{rod}$). The charge on the charge producer rod is always proportional to the voltage measured by the electrometer.
- The electrometer has an internal capacitor and its capacity is approximately $C_{electrometer} = 27\ pF$. Replace this capacity value and the potential difference value ($V_{rod}$) you read from the electrometer in Equation 2.1 to calculate the amount of charge collected on the charge producer rod, $Q_{rod}$.
- In electrification by touch, charges are shared in direct proportion to the surface area ($A$). Therefore, the area of the rod and the plate of the capacitor must be calculated in order to determine the charge stored on the capacitor. Thus, the charge $Q_{capacitor}$ of the capacitor can be calculated with the direct proportion to be established between the area of the rod ($A_{rod}$) and the area of one of the plates of the capacitor $(A_{capacitor})$.
- Initially you applied a potential difference of 1000 V from the electrostatic voltage source ($V_{capacitor}$) to charge the capacitor. Using this voltage value and the calculated charge amount of the capacitor ($Q_{capacitor}$) calculate the capacitance ($C_{capacitor}$) value from Equation 2.1.
- Fill the relevant Tables with all data and your results.
- Calculate the capacitance of the paralel plate capacitor with the help of Equation 2.2 and compare your result with your experimental result.
- Discuss your results by repeating your experiment for 2000 V and 3000 V.

## 2.4 Measurement and Results

$$The\ radius\ of\ the\ charged\ producer\ rod\ r_{rod} = \cdots\cdots\cdots\ m$$

$$Capacity\ of\ the\ C_{electrometer} = 27\ pF = 27 \times 10^{-12} F$$

$$\varepsilon_0 = 8.85\ x\ 10^{-12}\ C^2/N\ m^2$$

$$The\ radius\ of\ the\ plate\ of\ the\ capacitor\ r_{plate} = \cdots\cdots\cdots\ m$$

$$The\ area\ of\ the\ charged\ producer\ rod\ \ A_{rod} = \cdots\cdots\cdots\ m^2$$

$$The\ area\ of\ the\ plate\ of\ the\ capacitor\ \ A_{plate} = \cdots\cdots\cdots\ m^2$$

**Table 2.1.** Finding the capacitance of a paralel plate capacitor using the equation $Q = C.\Delta V$.

| | $V_{capacitor}$ $(V)$ | $V_{rod}$ $(V)$ | $Q_{rod}$ $(C)$ | $Q_{capacitor}$ $(C)$ | $C_{capacitor}$ $(pF)$ |
|---|---|---|---|---|---|
| **Experiment 1** | 1000 | | | | |
| **Experiment 2** | 2000 | | | | |
| **Experiment 3** | 3000 | | | | |

**Table 2.2** Finding the capacitance of the paralel plate capacitor using the equation $C = \frac{\varepsilon_0 A}{d}$

| | $V_{capacitor}$ $(V)$ | $d_{capacitor}$ $(m)$ | $C_{capacitor}$ $(pF)$ |
|---|---|---|---|
| **Experiment 1** | **1000** | | |
| **Experiment 2** | **2000** | | |
| **Experiment 3** | **3000** | | |

## References


4. Dokuz Eylül Üniversitesi, Fen Fakültesi Fizik Bölümü, Fizik II Laboratuvar Föyü, 2016.
5. John D. Cutnell, Kenneth W. Johnson, Physics, 8th Edition, John &WileySons, Inc. 2009.
6. Raymond A. Serway, Robert J. Beichner, Fen ve Mühendislik için Fizik 2, 5. Baskı, 2000.

# EXPERIMENT 2: OHM'S LAW and RESISTANCE MEASUREMENTS WITH VOLTMETER-AMMETER METHOD - SERIAL CONNECTED CIRCUITS

## Purposes

- Verification of Ohm's law.
- Measurement of three different resistances whose values are unknown by the voltmeter-ammeter method.
- To compare experimental data obtained by connecting these resistors in series with theoretical results.

## 3.1 Theory

In the static state, there is no electric field (E-field) inside a conductor. Suppose we put oppositely signed charges at both ends of a long metallic conductor like a wire. Thus, the conductor will no longer be in electrostatic equilibrium, and an E-field resulting from the electrical charges at the ends will form inside the conductor. This field drags the charges towards each other and ends when the charges meet so that a state of equilibrium occurs. For example, a good conductor such as copper will reach this equilibrium state very quickly. However, if we constantly put charges at the ends of the conductor, we can keep the conductor out of equlibrium. Connecting the two ends of the wire to an electrical source is necessary for that. Thus, the charges flow from one end to the other to form a current. In such a case, most of the E-field lines in the wire are created by the electrical source, while a small amount is caused by the charges. If the conductor does not have sharp corners, the E-field lines are uniformly distributed throughout the cross sectional area of the conductor. For example, in a conductor of the constant thickness as smooth as possible, the E-field lines will be constant and parallel to the wire If the length of the wire is $l$ and the potential difference between its two ends is ΔV, the E-field inside the wire will be

$$E = \frac{\Delta V}{l}$$

This E-field causes the flow of charges, i.e. the electric current. We can express this as follows: *The amount of dq charge passing through a certain part of the wire in the time interval dt is called electric current.*

$$I = \frac{dq}{dt}$$

If the wire is well insulated, the current value is the same at all points in the conductor due to the conservation of electrical charges. The unit of current in the SI unit system is Ampere (A) and we express it as

$$1\,Ampere = 1\,A = 1\,C/s$$

Electrons are the charge carriers in a metallic conductor, but due to general acceptance the direction of the current is toward the direction of positive charge carriers. In some cases we are concerned with the motion of charge carriers at any point in the conductor. For such a situation, we define the current density. This is the amount of current flowing through a certain section A of the conductor and is given by

$$j = \frac{I}{A}$$

A metallic conductor contains a large number of free electrons. For example, for copper, this value is $8x10^{22}$ free electrons per unit volume. These electrons are in gas structure and fill the entire volume of the metal. In an electrically neutral conductor, the negative charges of free electrons are balanced by the positive charges of ions, this creates the crystal lattice of the metal. In such a metallic conductor, the current is simply a flow of electron gas, during which the ions are stationary. The E-field in a wire pushes the electron gas through the wire, but this electron gas does not accelerate, because the movement of the electron gas is at a constant speed because the friction between the electron gas and the wire is in the opposite direction to the movement and the friction force is balanced by the force exerted by the E-field. Although the electron gas moves at a low velocity (such as $10^{-2}$ m/s) through the wire, each electron individually has higher velocities (the speed of random motion of electrons in a metal is around $10^{6}$ m/s, and this high velocity is due to quantum mechanical effects). The friction between the wire and the electron gas is caused by collisions between ions in the crystal lattice of the wire and electrons (For example, the electron in a copper wire makes $10^{14}$ collisions per second with ions during its motion). Each collision slows down the electron. Thus, the decelerating electron first stops and then moves in the opposite direction. Thus, the electron can never gain the speed to accelerate from the E-field due to the negative effects of collisions. The drift speed or average speed is proportional to the E-field.

$$v \propto E$$

The current in the wire is proportional to the average velocity of the electrons.

$$I \propto v \propto E$$

Since the current is also proportional to the cross-sectional area of the wire, it can be written as

$$I \propto AE$$

Considering that $E = \Delta V/l$, this ratio becomes as follows

$$I \propto \frac{A}{l}\Delta V$$

We can write this as an equation with the proportionality coefficient $\rho$.

$$I = \frac{1}{\rho}\frac{A}{l}\Delta V$$

Here, the coefficient ρ is a quantity depending on the structure of the wire and it is called *resistivity*. Accordingly, the resistance is defined as

$$R = \rho\frac{l}{A}$$

Thus, this expression is Ohm's Law, which is known as

$$I = \frac{\Delta V}{R}$$

What Ohm's law tells us is that the current is proportional to the potential difference between the two ends of the conductor. Ohm's law applies to metallic conductors as well as non-metallic conductors such as Carbon, but it is not a general law, although it has a wide range of applications.

As can be seen from Ohm's law, the unit of resistance is as follows.

$$1\ ohm = 1\ \Omega = 1\ volt/ampere$$

The unit of resistivity is the ohm-meter (Ω.m). The inverse of resistivity is defined as conductivity and its unit is 1 / ohm-meter ($\Omega^{-1}.m^{-1}$).

The resistivity of the material also depends on the temperature. Generally, the resistivity increases with temperature in metals. At low temperatures, the resistivity of metals is very low. Some metals such as lead, tin, zinc and niobium exhibit superconducting behavior. Their resistance disappears as the temperature approaches absolute zero.

Electric circuits have various circuit elements. Resistors are also one of these circuit elements. In circuit diagrams, the resistance symbol is a zigzag line and the resistors can be connected in two ways, in series and in parallel. Consider the case where two resistors are connected in series (Figure 3.1). In this circuit, the potential difference of each resistor is $\Delta V_1$ and $\Delta V_2$ respectively, the net potential difference of the circuit is

$$\Delta V = \Delta V_1 + \Delta V_2$$

Since the current will be the same for both resistors, according to the Ohm's law:

$$\Delta V = IR_1 + IR_2 = I(R_1 + R_2) = IR$$

Consequently, it is seen that the net resistance or equivalent resistance in the series circuit is

$R_{eq} = R_1 + R_2$.

**Note:** In cases where resistors are connected in series, since the charge flowing through the resistor $R_1$ is equal to the charge flowing through the resistor $R_2$, the currents passing through both resistors will be the same.

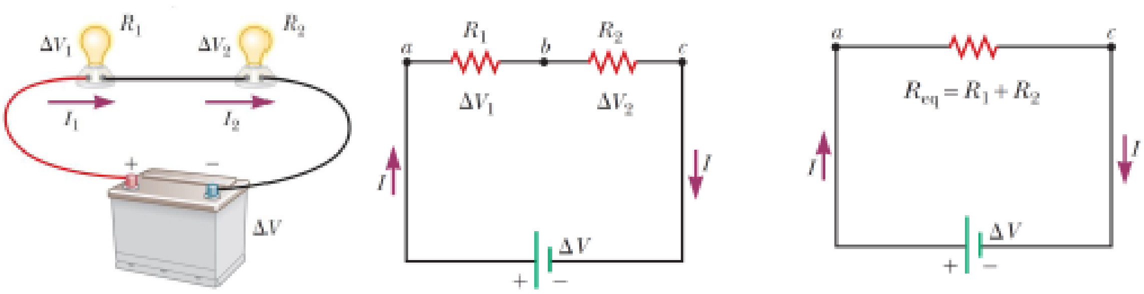



**Figure 3.1** Serial connected resistors.

## 3.2 Tools to be used in the experiment

1. Three different resistors
2. Board
3. Multimeter (Voltmeter, Ammeter, Ohmmeter)
4. Power Supply
5. Connection cables.

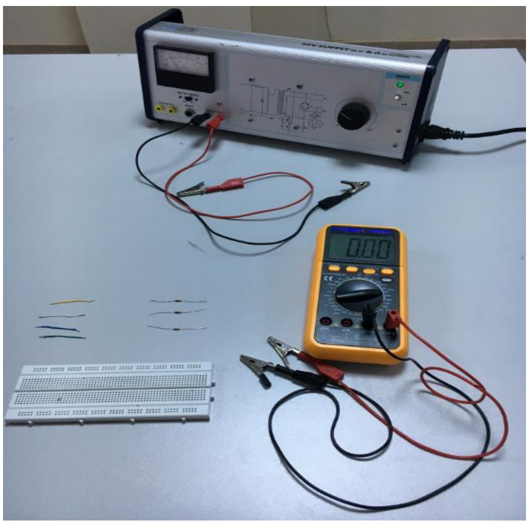


**Figure 3.2** The experimental setup

## 3.3 Experimental Procedure

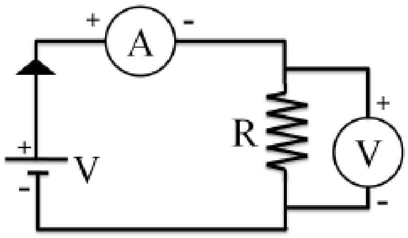



**Figure 3.3** The circuit to be set up to examine the relationship between current and voltage.

- Determine the resistances of the three resistors given to you using the color codes on it.
- Then set up the circuit in Figure 3.3 on the board for all three resistors and fill the table 3.1 by applying different potential differences and determining the I-V values.
- With the help of the data you have obtained, draw the I-V graph for all three resistors (Figure 3.5) and calculate the R resistance values from the graph using the Ohm's law.
- Set up the series connected circuit shown in Figure 3.4 with the help of three resistors whose resistance values you have determined.
- First, measure the potential difference and current values for all three resistors.
- Then measure the potential difference and current value for the series circuit and find the equivalent resistance of the circuit with the help of Ohm's law. Write the results in Table 3.2 and calculate the relative error as a percentage.

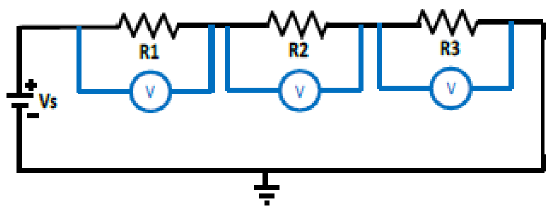
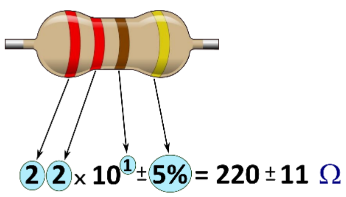



**Figure 3.4** Series connected circuit diagram created with the three resistors you specified.

## 3.4 Measurements and Results

| Renk Kodları | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Siyah | Kahverengi | Kırmızı | Turuncu | Sarı | Yeşil | Mavi | Mor | Gri | Beyaz |
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

| Tolerans | | |
|---|---|---|
| Altın | Gümüş | Renksiz |
| 5% | 10% | 20% |




Resistance values determined by color codes:

$R_1 = \cdots\cdots \pm \cdots\cdots$ **Ω** $R_2 = \cdots\cdots \pm \cdots\cdots$ **Ω** $R_3 = \cdots\cdots \pm \cdots\cdots$ **Ω**

**Table 3.1** Current and voltage values for $R_1$ - $R_2$ – $R_3$ resistors

| **Measurement** | **$R_1$** | | **$R_2$** | | **$R_3$** | |
|---|---|---|---|---|---|---|
| | ***Voltage(V)*** | ***Current(mA)*** | ***Voltage(V)*** | ***Current(mA)*** | ***Voltage(V)*** | ***Current(mA)*** |
| **1** | | | | | | |
| **2** | | | | | | |
| **3** | | | | | | |
| **4** | | | | | | |
| **5** | | | | | | |
| **6** | | | | | | |
| **7** | | | | | | |
| **8** | | | | | | |
| **9** | | | | | | |
| **10** | | | | | | |

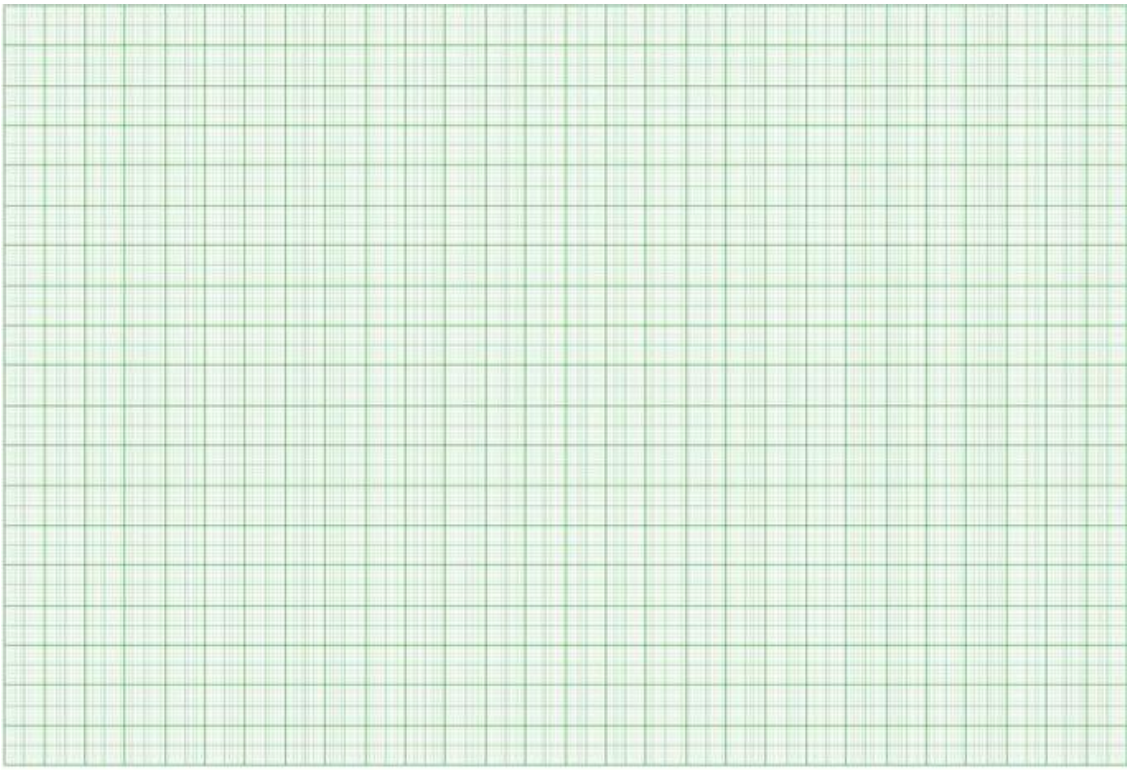


**Figure 3.5** Graph paper for voltage - current graph

<u>Resistance values obtained from the graph:</u>

$R_1$=……………..kΩ $R_2$=……………..kΩ $R_3$=……………..kΩ

**Table 3.2** Current, voltage and calculated resistance values in a series circuit

| *Resistance* | *Current (mA)* | *Voltage (Volt)* | *Resistance R=V/I (kΩ)* | *$R_{graph}$ (kΩ)* | *%Relative Error* |
|---|---|---|---|---|---|
| $R_1$ | | | | | |
| $R_2$ | | | | | |
| $R_3$ | | | | | |
| $R_{eq}$ | | | | | |

## References

1. Dokuz Eylül University, Faculty of Science, Department of Physics, Physics II Laboratory Booklet, 2016.
2. Raymond A. Serway, Robert J. Beichner, Physics for Science and Engineering 2, 5th Edition, 2000.

# EXPERIMENT 3: OHM'S LAW PARALLEL CONNECTED CIRCUITS

## Purposes

Verification of Ohm's law for a circuit consisting of resistors connected in parallel.

## 4.1 Theory

In order to generate current in a conductor, charges move under the effect of the electric field inside the conductor. In this case, there is an electric field inside the conductor. For a conductor with cross section *A* and carrying current *I*, the current density *J* in the conductor is defined as the current per unit area. Since the current is $I = nqv_sA$, the current density is given by

$$J = \frac{I}{A} = nqv_s$$

Here J is in unit $A / m^2$ in SI unit system. This statement is valid only if the current density is regular and perpendicular to the flow direction of the surface. Generally, current density is a vector quantity and can be expressed as:

$$\boldsymbol{J} = nq\boldsymbol{v}_s$$

If a potential difference is applied between the ends of a conductor, a current density ***J*** and an ***E*** field occur within the conductor. If the potential difference is constant, the current in the conductor will also be constant. In some substances found in nature, the current density is directly proportional to the electric field and can be expressed as follows.

$$\boldsymbol{J} = \sigma \cdot \boldsymbol{E}$$

Here $\sigma$ is the proportionality coefficient and gives information about the conductivity of the substance. Substances that fit the equation are said to be compatible with **Ohm's Law** (Georg Simon Ohm (1787-1854)). Substances that obey Ohm's law and thus show a linear relationship between E and J are said to be *ohmic*. Substances that do not obey this law are called *non-ohmic* substances.

Connecting more than one resistor in any circuit by applying the same voltage ($\boldsymbol{V}$) to the ends, so that separate current can pass through each of them, is called **parallel connection**. Parallel-connected circuit elements are divided into paths as shown in Figure 4.2, so the currents passing over the resistors will be different. However, these circuit elements connected in parallel have the same $\boldsymbol{V}$ voltage between their ends. That is, in parallel connection of resistors, the voltage across a resistor connected to the source voltage will be equal to the voltage ($\boldsymbol{V}$) of that connected source.

If a voltage source is connected to a single resistor in the circuit, $\boldsymbol{I}$ current drawn from the source passes through this resistor. However, when the two resistors ($\boldsymbol{R}_1$ and $\boldsymbol{R}_2$) are connected in parallel to the circuit, part of the current drawn from the source ($\boldsymbol{I_1}$) will pass through the resistor $\boldsymbol{R_1}$ ve and the other part ($\boldsymbol{I_2}$) will go through the resistor $\boldsymbol{R_2}$. That is, the current ($\boldsymbol{I}$) drawn from the source will be divided into branches while distributing to the resistors. Therefore, in parallel connection of the resistors, the sum of the currents flowing through the resistors will be equal to the total current ($\boldsymbol{I}$) of the circuit. In a parallel circuit, the current in each resistor is given by Ohm's law. Since the source voltage $\boldsymbol{V}$ will be the same at the parallel resistance ends in the circuit;

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

Thus the equivalent resistance of the circuit is given by

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

## 4.2 Tools to be used in the experiment

1. Three different resistors

2. Board

3. Multimeter (Voltmeter, Ammeter, Ohmmeter)

4. Power Supply

5. Connection cables.

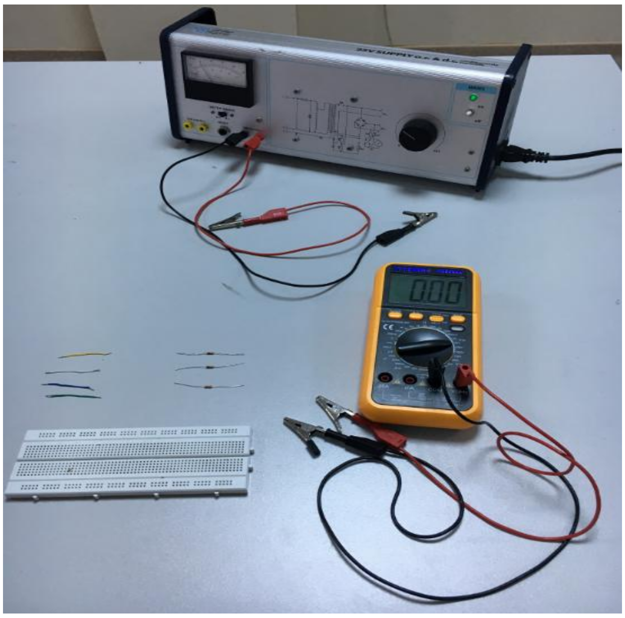


**Figure 4.1** The experimental setup

## 4.3 Experimental Procedure

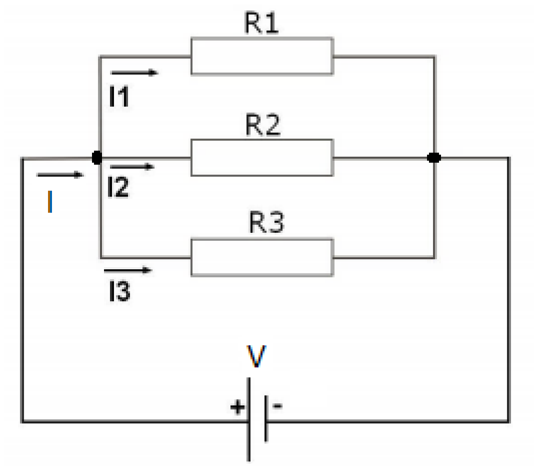


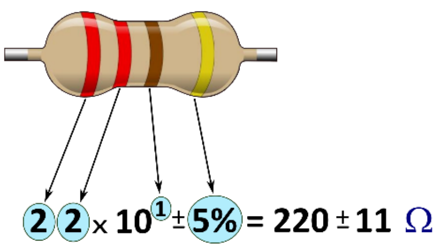

**Figure 4.2** Parallel connected circuit

- Determine the resistances of the three resistors given to you using the color codes on it.
- Measure the values of these three resistors with an ohmmeter and record their values.
- With the help of these three resistors whose values are determined, set up the parallel connected circuit shown in Figure 4.2.
- First, measure the individual potential differences and currents for the three resistors, then measure the potential difference and current for the parallel connected circuit.
- Write the results in Table 4.1. Find the equivalent resistance of the whole circuit with the help of these data and Ohm's law.

## 4.4 Measurements and Results

| Renk Kodları | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Siyah | Kahverengi | Kırmızı | Turuncu | Sarı | Yeşil | Mavi | Mor | Gri | Beyaz |
| **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |

| Tolerans | | |
|---|---|---|
| Altın | Gümüş | Renksiz |
| **5%** | **10%** | **20%** |




Resistance values determined by color codes:

$R_1 =$ .......... $\pm$ ........ $k\Omega$ $R_2 =$ ....... $\pm$ ........ $k\Omega$ $R_3 =$ ........... $\pm$ ........ $k\Omega$

Resistance values measured using ohmmeter:

$R_1 =$ .......... $\pm$ ........ $k\Omega$ $R_2 =$ ....... $\pm$ ........ $k\Omega$ $R_3 =$ ........... $\pm$ ........ $k\Omega$

**Table 4.1** Current, voltage and calculated resistance values in a parallel connected circuit

| ***Resistance*** | ***Current (mA)*** | ***Voltage (Volt)*** | ***Resistance R=V/I (kΩ)*** | ***$R_{ohmmetre}$ (kΩ)*** | ***%Relative Error*** |
|---|---|---|---|---|---|
| $R_1$ | | | | | |
| $R_2$ | | | | | |
| $R_3$ | | | | | |
| $R_{eq}$ | | | | | |

## References


3. Dokuz Eylül University, Faculty of Science, Department of Physics, Physics II Laboratory Booklet, 2016.
4. Raymond A. Serway, Robert J. Beichner, Physics for Science and Engineering 2, 5th Edition, 2000.

# EXPERIMENT 5: WHEATSTONE BRIDGE

## Purposes

Determining the value of the resistance using the Wheatstone bridge.

## 5.1 Theory

Resistance is the strain encountered by an electric current passing through a conductor in an electrical circuit, denoted by "R" and its unit is Ohm (Ω). Resistors are used to keep the current at a certain value by limiting the current in electrical circuits. They are also used to prevent high current flowing over sensitive circuit elements and to divide the current. If the resistance of a conductor is high, the amount of current passing is less, and if the resistance of the conductor is low, the amount of current passing is high. Resistors can be connected in two different ways as series and parallel and they are divided into two groups as fixed value (Wire Resistors, Carbon Resistors, Film Resistors, Integrated Resistors, Smd Resistors) and adjustable (trimpot, potentiometer and rheostat). Apart from these, there are also resistors such as photo resistor (light sensitive, LDR), thermistor (heat sensitive, PTC or NTC) and VDR (voltage sensitive) that are affected by various physical sizes and whose value changes as a result of this effect.

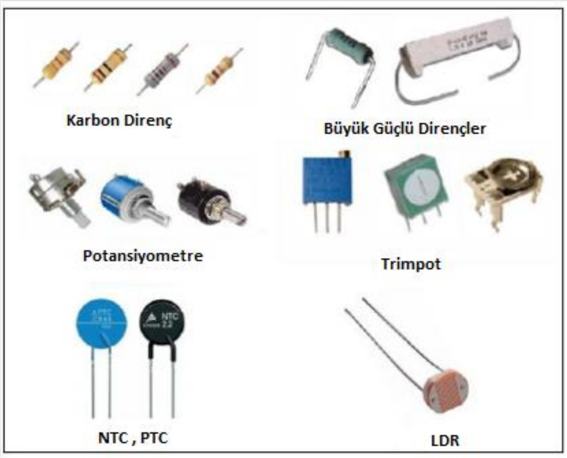



**Figure 5.1** Types of Resistance

There are many methods used to measure resistance. The most direct measurement method is the ammeter - voltmeter method. For the sensitivity of the measurements made by this method, the appropriate measuring ranges of the ammeter and voltmeter and also the internal resistance of at least one of these devices that make accurate readings must be known. The Wheatstone bridge method has a clear advantage over the ammeter - voltmeter method as it is both a comparison and a reset method. With the help of this circuit, the value of an unknown resistance can be found. For this, the circuit in Figure 5.2 is used and this circuit is called the Wheatstone Bridge. In the Wheatstone bridge, an unknown resistor $R$, a variable resistor $R_x$, and two resistors $R_1$, $R_2$ are connected to form the sides of a quadrilateral. There is a battery or direct current source on one of the corners of this rectangle, and a microampmeter with a large resistor on the other.

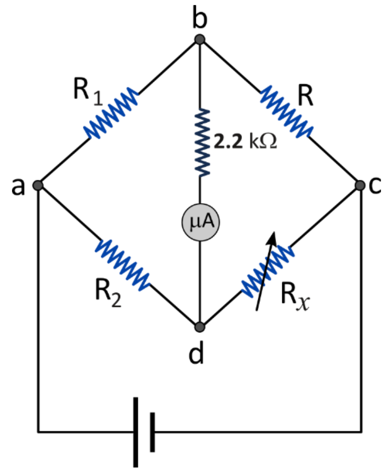



**Figure 5.2** The circuit diagram of the Wheatstone bridge.

Consider the situation before the b – d connection is made. When the circuit is connected to a direct current source, current will flow through the abc and adc branches. When the b – d connection is also made, it is observed that the current flows from the b – d branch of the ammeter at first. By changing the value of the Rx resistance, it is possible to ensure that the current in the b-d arm of the ammeter is zero. In this case, the potential difference between b and d points is zero and the following equations can be written:

$$V_a - V_b = V_a - V_d$$
$$V_b - V_c = V_d - V_c$$

Since the same current $I_1$ flows through the resistors in the upper branches and the same $I_2$ current through the resistors in the lower branches, the potential differences mentioned above can be written as

$$I_1\, R_1 = I_2 \cdot R_2$$
$$I_1\, R = I_2 \cdot R_x$$

Of these relations

$$R = \frac{R_1}{R_2} R_x$$

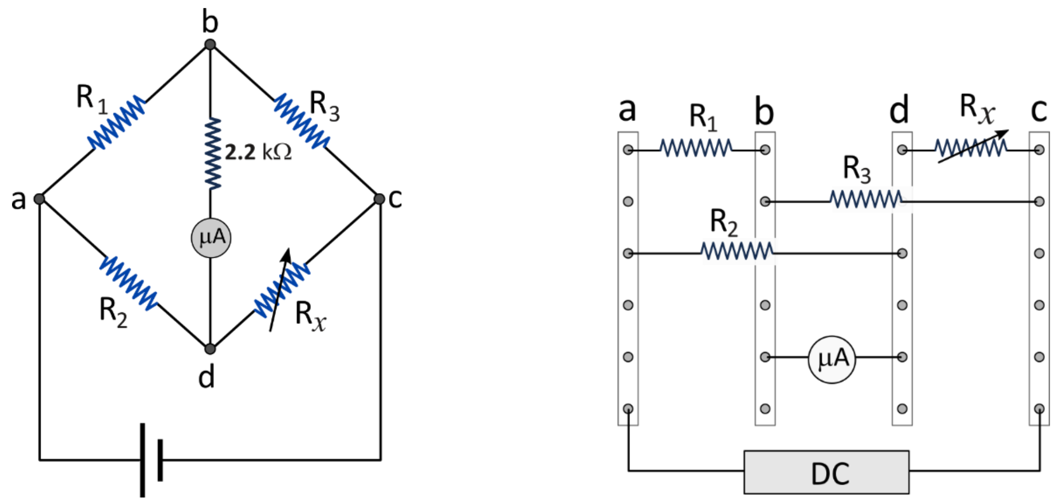
equation is obtained. As you can see, when the bridge is in equilibrium, the product of opposite sides $(R_x\, R_1 = R\, R_2)$ is equal to each other.

## 5.2 Tools to be used in the Experiment

- ✓ Resistors
- ✓ 10 kΩ Rheostat
- ✓ Board
- ✓ Microampermeter
- ✓ Power Supply
- ✓ Conductive wire, connecting cables

## 5.3 Experimental Procedure

The resistors are connected to the breadboard using different value of resistors and Rheostat instead of Rx, as in the circuit diagram in Figure 5.3 (a). This circuit of the Wheatstone bridge can be simplified as in Fig.5.3 (b).




(a) (b)

**Figure 5.3** Wheatstone bridge circuit

- ✓ Voltage is applied between the direct current source and points a-c, and the deviation of the micro-ammeter is observed while increasing the applied voltage.
- ✓ In order to balance the Wheatstone bridge circuit, the rheostat used as $R_x$ variable resistor is adjusted to ensure that the current passing through the microampermeter is ZERO. Current will not flow between b-d at the appropriate resistance value of the rheostat.

- ✓ For the situation where the current passing through the ammeter is zero, the Rheostat is removed and its ends are connected to the multimeter. The value of the resistance $R_x$ can be determined experimentally ($R_x$ (experimental)) by setting the multimeter to read resistance. Table 5.1 is filled in using different resistances.
- ✓ In the case that no current flows through the ammeter, the theoretical value of the unknown Rx resistance ($R_x$ (theoretical)) is calculated using the necessary equation and compared with the experimentally found value. By comparing these values,% relative error is calculated and recorded in the table.

## 5.5 Measurements and Results

**Table 5.1** Measurement results for Wheatstone bridge circuit

| $R_1$ (kΩ) | $R_2$ (kΩ) | $R_3$ (kΩ) | $R_x$ (experimental) (kΩ) | $R_x$ (theoretical) (kΩ) | % Relative Error |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

## References

5. Dokuz Eylül University, Faculty of Science, Department of Physics, Physics II Laboratory Booklet, 2016.
6. Raymond A. Serway, Robert J. Beichner, Physics for Science and Engineering 2, 5th Edition, 2000.

# EXPERIMENT 5: STORAGE and FLOW of ELECTRIC CHARGES

## Purposes

- Investigation of current voltage relationships during the charging a capacitor and its discharge through a resistor.
- Finding the time constant ($\tau$).

## 6.1 Theory

Capacitors consist of two conductive plates with a dielectric medium between them, charged with equal quantitative but opposite sign. The ratio of the amount of charge $Q$ accumulated on the plates of a capacitor to the $\Delta V$ potential difference between these conductive plates is constant and is called the capacitance of the capacitor and is generally denoted by $C$. According to this

$$C = \frac{Q}{\Delta V} \tag{6.1}$$

### 6.1.1 Charging a Capacitor

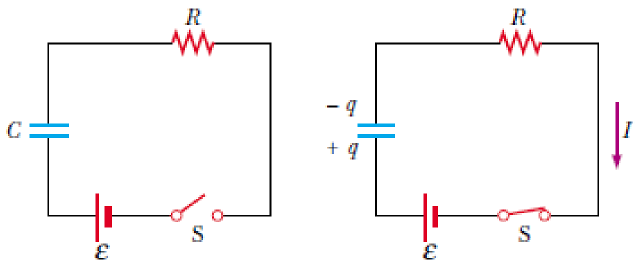



**Figure 6.1** Charging a capacitor (a) Before the switch is closed (b) after the switch is closed circuit diagram

Figure 6.1 shows a simple series RC circuit. Let us assume that the capacitor in this circuit is initially uncharged. There is no current while switch S is open. If the switch is closed at $t = 0$, however, charge begins to flow, setting up a current in the circuit, and the capacitor begins to charge. Let us apply Kirchhoff's loop rule to the circuit after the switch is closed. Traversing the loop in Fig. 6.1 clockwise gives

$$\varepsilon - \frac{q}{C} - IR = 0 \tag{6.2}$$

where $q/C$ is the potential difference across the capacitor and $IR$ is the potential difference across the resistor. We have used the sign conventions discussed earlier for the signs on and IR. For the capacitor, notice that we are traveling in the direction from the positive plate to the negative plate;

this represents a decrease in potential. Thus, we use a negative sign for this potential difference in Equation 6.2.

At the instant the switch is closed ($t = 0$), the charge on the capacitor is zero, and from Equation 6.2 we find that the initial current $I_0$ in the circuit is a maximum and is equal to

$$I_0 = \frac{\varepsilon}{R} \qquad 6.3$$

At this time, the potential difference from the battery terminals appears entirely across the resistor. Later, when the capacitor is charged to its maximum value Q, charges cease to flow, the current in the circuit is zero, and the potential difference from the battery terminals appears entirely across the capacitor. Substituting $I = 0$ into Equation 6.2 gives the charge on the capacitor at this time:

$$Q = C\varepsilon \qquad 6.4$$

The current in all parts of the series circuit must be the same. Thus, the current in the resistance $R$ must be the same as the current between the capacitor plates and the wires. This current is equal to the time rate of change of the charge on the capacitor plates. Thus, we substitute $I = dq/dt$ into Equation 6.2 and rearrange the equation:

$$\frac{dq}{dt} = \frac{\varepsilon}{R} - \frac{q}{RC} \qquad 6.5$$

To find an expression for q, we solve this separable differential equation. We first combine the terms on the right-hand side:

$$\frac{dq}{dt} = -\frac{q - C\varepsilon}{RC} \qquad 6.6$$

Now we multiply by dt and divide by $q - C\varepsilon$ to obtain

$$\frac{dq}{q - C\varepsilon} = -\frac{1}{RC}dt \qquad 6.7$$

Integrating this expression, using the fact that $q = 0$ at $t = 0$, we obtain

$$\int_0^q \frac{dq}{q - C\varepsilon} = -\frac{1}{RC}\int_0^t dt \qquad 6.8$$

$$\ln\left(\frac{q - C\varepsilon}{-C\varepsilon}\right) = -\frac{t}{RC} \qquad 6.9$$

From the definition of the natural logarithm, we can write this expression as

$$q(t) = C\varepsilon\left(1 - e^{-t/RC}\right) = Q(1 - e^{-t/RC}) \qquad 6.10$$

We can find an expression for the charging current by differentiating Equation 6.10 with respect to time. Using $I = \frac{dq}{dt}$, we find that

$$I(t) = \frac{\varepsilon}{R} e^{-t/_{RC}} \qquad 6.11$$

The quantity $RC$, which appears in the exponents of Equations, is called the time constant of the circuit. It represents the time interval during which the current decreases to $1/e$ of its initial value; that is, in a time interval $I = \frac{I_0}{e} = 0.37I_0$

### 6.1.2 Discharging a Capacitor

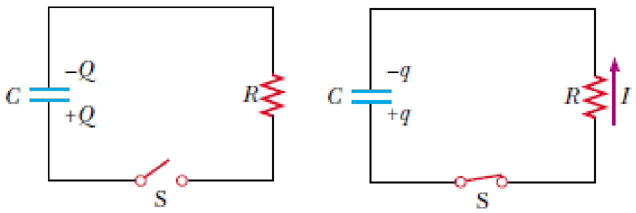



**Figure 6.2** Discharging a capacitor (a) Before the switch is closed (b) after the switch is closed circuit diagram

Now consider the circuit shown in Figure 6.2, which consists of a capacitor carrying an initial charge Q, a resistor, and a switch. When the switch is open, a potential difference $Q/C$ exists across the capacitor and there is zero potential difference across the resistor because $I = 0$. If the switch is closed at $t = 0$, the capacitor begins to discharge through the resistor. At some time $t$ during the discharge, the current in the circuit is $I$ and the charge on the capacitor is $q$. The circuit in Figure is the same as the circuit in Figure except for the absence of the battery. Thus, we eliminate the emf from Equation to obtain the appropriate loop equation for the circuit in Figure.

$$-\frac{q}{C} - IR = 0 \qquad 6.12$$

When we substitute $I = \frac{dq}{dt}$ into this expression, it becomes

$$-R\frac{dq}{dt} = \frac{q}{C} \qquad 6.13$$

$$\frac{dq}{q} = -\frac{1}{RC}dt \qquad 6.14$$

Integrating this expression, using the fact that $q = Q$ at $t = 0$ gives

$$\int_Q^q \frac{dq}{q} = -\frac{1}{RC}\int_0^t dt\, dt \qquad 6.15$$

$$\ln\left(\frac{q}{Q}\right) = -\frac{1}{RC} \qquad 6.16$$

$$q(t) = Qe^{-t/_{RC}} \qquad 6.17$$

Differentiating this expression with respect to time gives the instantaneous current as a function of time:

$$I(t) = \frac{dq}{dt} = \frac{d}{dt}\left(Qe^{-t/_{RC}}\right) = -\frac{Q}{RC}e^{-t/_{RC}} \quad 6.18$$

where $I_0 = Q/RC$ is the initial current. The negative sign indicates that as the capacitor discharges, the current direction is opposite its direction when the capacitor was being charged. We see that both the charge on the capacitor and the current decay exponentially at a rate characterized by the time constant $\tau = RC$.

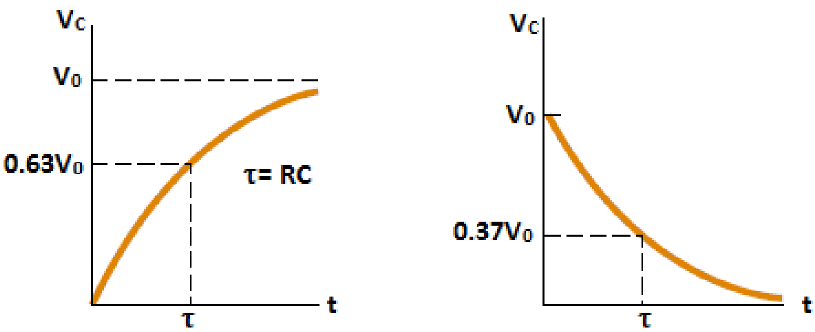



**Figure 6.3** The change in voltage over time during the charging and discharging of a capacitor.

## 6.2 Tools to be used in the experiment

- $R_1$ = 1MΩ, $R_2$= 2.2 MΩ and $R_3$= 0.1 MΩ resistor
- $C_1$ = 100 µF, $C_2$ = 10µF and $C_3$= 470 µF capacitor
- Multimeter
- DC Power Supply
- Chronometer

## 6.3 Experimental Procedure

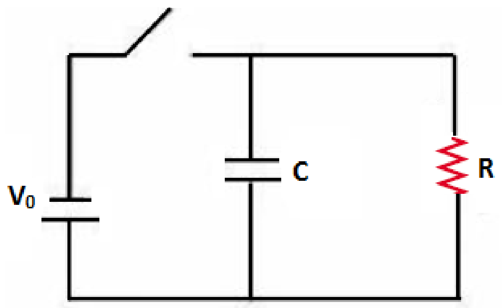



**Figure 6.4** The experimental setup

### 6.3.1 Finding the internal resistance of the voltmeter

- Set up the circuit in Figure 6.4 using a $10\ \mu F$ capacitor without R resistor.
- Connect a voltmeter to the ends of the capacitor. (In this case, the only resistance in the circuit will be the internal resistance of the voltmeter.)
- Fill the capacitor by turning off the switch on the circuit.
- After waiting for a while, read the voltage value from the voltmeter.
- Open the switch. When you turn on the switch, start the stopwatch and observe the voltage decrease and measure the time it takes for the voltage difference between the plates of a discharged capacitor to decrease to $1/e$ of the initial value.
- Find the internal resistance ($R_{int}$) of the voltmeter by substituting $\tau = R_{int}C$.

### 6.3.2 Finding the time constant

- Set up the circuit in Figure 6.4 by using $R_1 = 1M\Omega$ resistor and $C_1 = 100\ \mu F$ capacitor.
- Measure $\tau$ as described above. ($\tau_{exp}$)
- Calculate the time constant theoretically by writing the values of R and C in the formula $\tau = RC$ ($\tau_{theory}$).
- Repeat the experiment using the resistor $R_2 = 2.2\ M\Omega$ and the capacitor $C_2 = 10\ \mu F$ and the resistor $R_3 = 0.1\ M\Omega$ and the capacitor $C_3 = 470\ \mu F$.
- During the calculations, take into account the internal resistance of the voltmeter.

## 6.4 Measurements and Results

### 6.4.1 Finding the internal resistance of the voltmeter

$C = 10\ \mu F$

**Table 6.1** Internal resistance of the voltmeter

| Measurement | $\tau(s)$ |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |

$\tau =$ ............... ± ............... $s$

$R_{internal} =$ .............. ± ...............$M\Omega$

### 6.4.2 Finding the time constant

**Table 6.2** Measured and calculated values

| $\tau\,(s)$ | $R_1 = 1\,M\Omega\ C_1 = 100\ \mu F$ | $R_2 = 2.2\,M\Omega\,C_2 = 10\ \mu F$ | $R_3 = 0.1\,M\Omega\,C_3 = 470\ \mu F$ |
|---|---|---|---|
| $\tau_{exp}$ | | | |
| $\tau_{theory}$ | | | |

## References

1. Dokuz Eylul University, Faculty of Science, Department of Physics, Physics II Laboratory Booklet, 2016.

2. Raymond A. Serway, Robert J. Beichner, Physics for Science and Engineering 2, 5th Edition, 2000.