2023

Physics Lab. 2 Laboratory Booklet

Prepared by the PHYSICS DEPARTMENT for DEU Engineering Faculty Students.

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Preparation for the Physics II Laboratory Experiments

Laboratory Measuring Instruments

DEU Faculty of Science

Physics Department

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: $1\mu F = 10^{-6}$ F $1k\Omega = 10^3\ \Omega$

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

Symbols of Some Circuit Elements
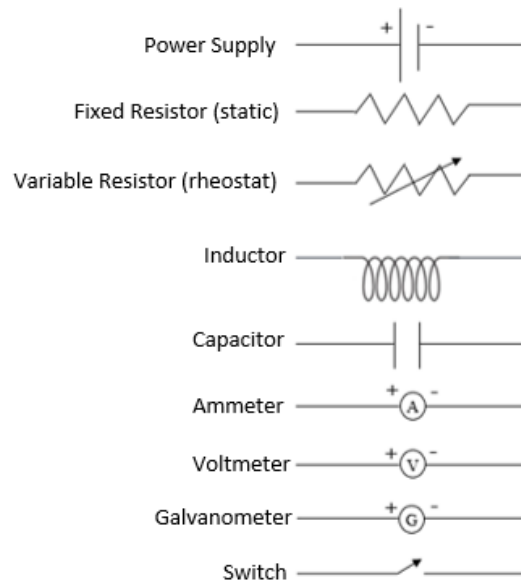
1. Analog and Digital Instruments

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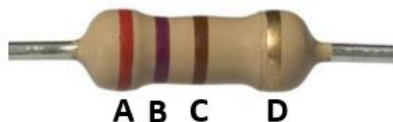
A: 1st color (number) B: 2nd color (number) C: 3rd color (multiplier) D: 4th color (tolerance)

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 <u>two-digit number</u>!)

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

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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.
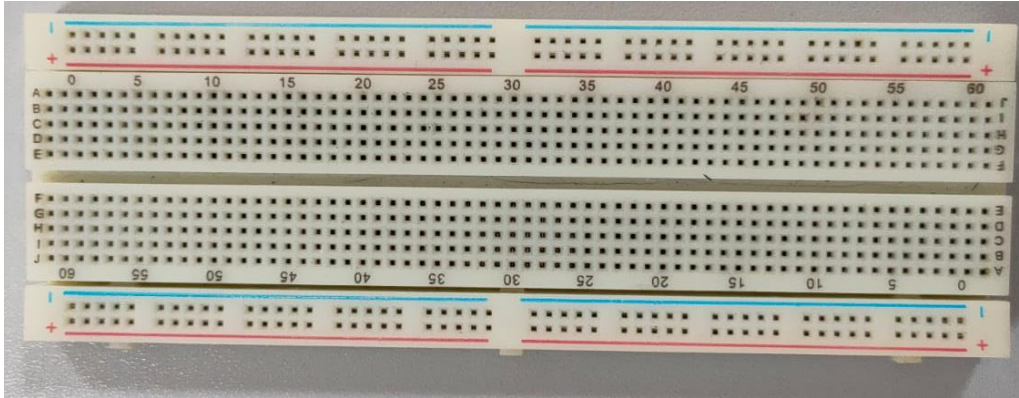
Figure 1.5 Electronic board (breadboard)

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

3. Çukurova Üniversitesi Fen Edebiyat Fakültesi, Elektrik ve Manyetizma Laboratuvarı, 2009.

Measurement, Basic Concepts, and Uncertainty in Measurement

1. Measurement

In general, the measurement process can be defined as comparing one quantity to another with the same character. That is the process of determining the amount (numerical value) of a physical quantity according to a predetermined standard of the same character. The predetermined standard is called as **unit**. For example, if an object has a mass of 7 kg, it is said that the mass of this object is 7 times the unit defined as 1 kg. In other words, measuring a quantity means determining the unit of that quantity and how many times it contains the unit.

The tool used in the measuring process is called the **measuring tool**. Measurement tools can be divided into two groups as analog and digital. Gauge tools are in the form of a ruler that is divided into measurement units, and the difference between closest two lines is called as scale (measuring) unit. In a digital measuring instrument, the last digit can usually be taken as the scale unit (this may not always be the case, it should be determined from the measurement (calibration) values provided by the manufacturer).

The measurement process can be examined in two groups;

Direct measurement: These are the measurements made directly with measuring instruments. For example; measuring the potential difference (voltage) using a voltmeter, measuring the current value with an ammeter, measuring the temperature with a thermometer, etc.

Indirect measurement: Measurements made by calculating a quantity with the help of other quantities that can be measured directly. For example; measuring the electric field at a point between two parallel opposite charged plates (by proportioning the potential difference to the distance between the plates, both determined by direct measurements).

Two important concepts to be consider during the measuring process are **accuracy** and **precision**. Accuracy indicates the closeness of a measured value to the true value. Precision indicates how well a number of independent measurements agree with one another. The meaning and comparison of the concepts of accuracy and precision are given in Figure 1.1 and Figure 1.2.
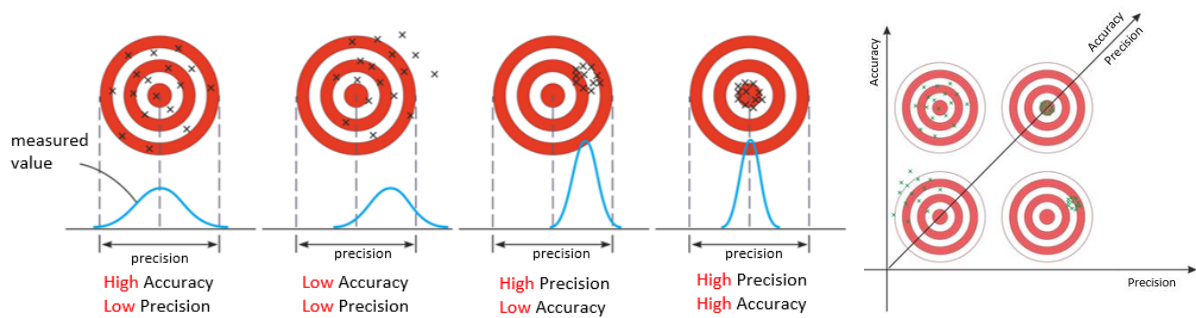
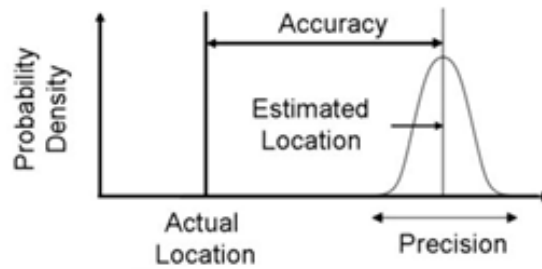Figure 1.1 The relation between the concepts of accuracy and precision.

Figure 1.2 The relation between the concepts of accuracy and precision.

1.1 Error (Uncertainty)

The difference between any physical measured value and its actual value is called as error. Here error is not "mistake" or "defect" but "**uncertainty**". Depending on the sensitivity of the measuring instrument and the experimental method followed in the measurement, the result of the measurement will be within a certain range. In other words, if the measurement results are expressed with errors will be meaningful. For example, let's measure a physical quantity (length, time, voltage, electric current,… etc.) of an object as x_1. The result of the x_1 measurement will be somewhat close to the true value of x. If we take a second x_2 measurement, we see that this result differs slightly from the x_1 measurement result. If we make a large number of measurements, we will get a different value for each measurement. Accordingly, it is not possible to determine the true value of x exactly. For this reason, we can take into account how and around which value the measurement results are distributed. Including this information, we express the measurement result as follows;

$$Result = \underbrace{most\ probable\ value}_{mean\ value} \pm \underbrace{precision}_{error\ or\ uncertainty} \qquad\qquad 1.1$$

Here, the most probable value is the value around which the measurements are distributed, that is the value predicted to be closest to the true value.

Absolute Error: The difference between the actual value x of a measured physical quantity and the measured value x_0 is called as absolute error.

$$\Delta x = |x - x_0| \quad \rightarrow \quad Result = x \pm \Delta x \qquad 1.2$$

Since the true value is unknown, the absolute error cannot be known. But its approximate value can be determined by some methods.

Relative Error: It is defined as the ratio of the absolute error occurring in the measurement to the actual value.

$$Relative\ Error = \frac{\Delta x}{x} \quad , \quad Percent\ Relative\ Error = \frac{\Delta x}{x} 100 \qquad 1.3$$

1.2 Sources of Error

Systematic Errors: These errors are caused by the measuring instruments used, the method followed in the experiment and external influences. These errors affect the result only in one aspect. We can eliminate systematic errors by changing the test method, using more precise measuring instruments or making the necessary corrections at the end of the experiment. Examples of systematic errors are given in Figure 1.3. Accuracy can be consider as the measure of systematic error that reveals the difference of the measured value from the true value (Figure 1.3).
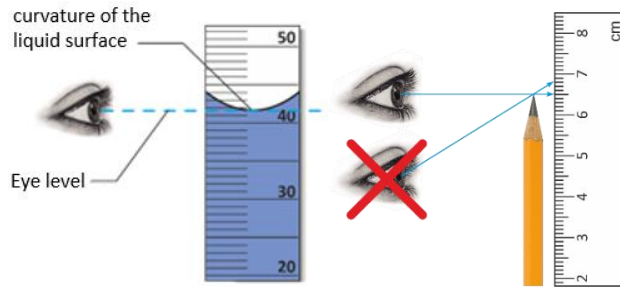

Figure 1.3 Systematic Errors.

Random (Statistical) Errors: These errors are caused by the natural behavior of the measured physical quantity. These errors affect the result in dual aspect. We can reduce the statistical errors by increasing the number of measurements, and their effect on the accuracy of the measured quantity can be calculated by statistical analysis. For example, fluctuations in measured physical quantities such as temperature, electrical voltage, gas pressure cause the statistical errors. Systematic error and random error comparison is given in Figure 1.4.
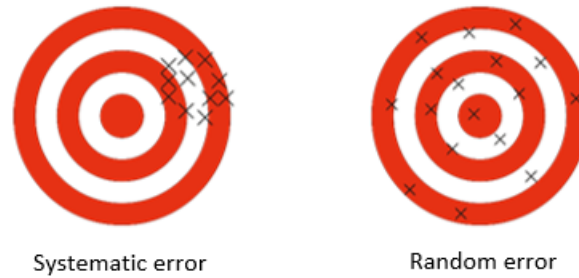
Figure 1.4 Systematic errors and random errors.

In general measurement results can be shown as following;

$$t = (34.5 \pm 0.7) \times 10^{-3} \, s$$

$$t = 34.5 \, 10^{-3} s \pm 2\%$$

$$x = 10.3^{+0.7}_{-0.3} \, cm$$

$$m_e = (0.51099906 \pm 0.000000 \, 15) \, \text{MeV/c}^2$$

$$m_e = 0.51099906 \, (15) \, MeV/c^2$$

$$n = 9.109 \times 10^4 \, mol \pm 0.3 \, ppm$$
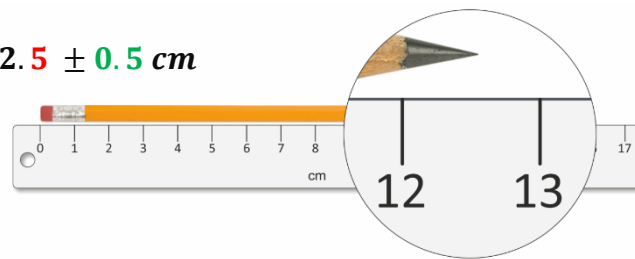
* ppm: *part per million*

1.3 Significant Figures

The numbers that indicate a measurement result, known to be accurate, and the last predicted one are called as significant figures.

Example 1.1

Suppose we want to measure the length of a pencil shown in the figure. First, let's use a cm scale ruler.
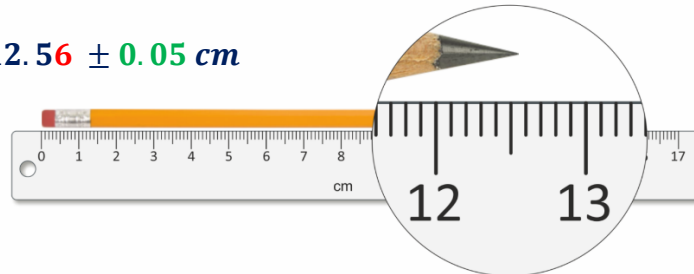

$$L = 12.5 \pm 0.5 \, cm$$

This pen is between 12 cm and 13 cm in length. 12 is an exactly known number that makes sense. The number 5 after the comma is not clear (it may be 4 or 7 etc.) but it is meaningful because it contains information about the length of the pencil. If we expressed the result as 12.57, the number 7 used in the last digit would have no meaning. While the number 5 contains uncertainty, it is not possible to determine the last number 7. Therefore, this measurement result can be expressed with 3 significant figures. Since the scale unit is cm, the maximum value of uncertainty in this process will be the half of it. So it is 0.5 cm.

Suppose we make the same measurement with a mm scale ruler.

$$L = 12.56 \pm 0.05 \ cm$$

This pen is between 12.5 cm and 12.6 cm in length. 12.5 is an exactly known number that makes sense. Although the number 6 after the comma is not clear (it may be in 4, it may be in 7, etc.), it is meaningful because it contains information about the length of the pen. If we expressed the result as 12.564, the number 4 used in the last digit would not have any meaning. While the number 6 contains uncertainty, it is not possible to determine the last number, 4. Therefore, this measurement result can be expressed with 4 significant figures. Since the scale unit is mm, the maximum value of uncertainty in this process will be the half of it. So it is 0.05 cm.

The place of the comma has no importance for significant figures. You should express a length as 0.0565 m or 56.5 mm, the number of significant figures will be 3. The zeros here have no meaning, they just show the order of magnitude. While expressing a measurement result, not all of the written zeros may be meaningful. Figure 1.5 indicates which zeros are meaningful and which ones are not.

Leading zeroes are never significant   Captive zeroes are always significant

0.0082002

0.008200

Trailing zeroes are only significant
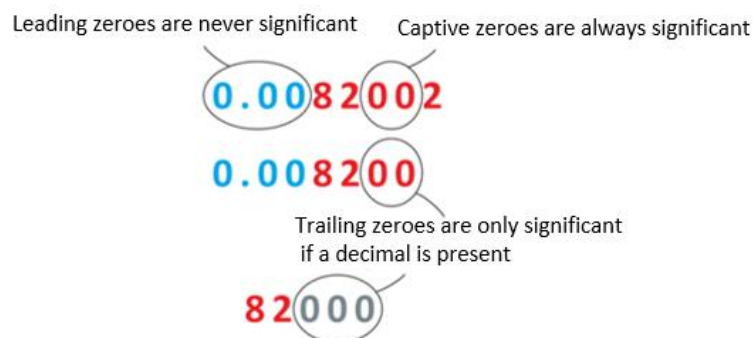if a decimal is present

82000

Figure 1.5 Significant Figures

So, the zeros at the end of a number matters only if these are behind the decimal point. Otherwise, it is difficult to say that they make sense. For example, consider the result of a measurement of 8200. It is not clear whether the zeros are meaningful or not. The number of significant digits in 8200 may be

at least two, three or four. To avoid ambiguity, the location of the decimal point should be specified or scientific notation should be used as shown below.

$$8.200 \times 10^3 \text{ four significant figures}$$

$$8.20 \times 10^3 \text{ three significant figures}$$

$$8.2 \times 10^3 \text{ two significant figures}$$

1.3.1 Significant Figures and Arithmetic Operations

Addition and Subtraction Operations

When adding or subtracting measured quantities, the precision of the result is as much as the precision of the quantity with least sensitivity in the sum or difference. All numbers up to this sensitivity limit are significant.

Example 1.2
Add **11.67 cm** given with **1/10 cm** sensitivity, **0.25 mm** given with **1/100 cm** sensitivity and **7.4 cm** given with **cm** sensitivity.

$$\begin{array}{r} 11.6\textbf{7} \\ 0.02\textbf{5} \\ +\quad 7.\textbf{4} \\ \hline 19.\textbf{095} \end{array}$$

Least precise number is **7.4 cm** with only one digit after decimal. So,the result should be given in mm sensitivity. **Rounding** need to be done.

Result:19.1 cm (three significant figures)

Measured values	The biggest	The smallest
11.67 ± 0.05	11.72	11.62
0.025 ± 0.005	0.030	0.020
7.4 ± 0.5	+ 7.9	+ 6.9
	19.65	18.540

Measurement result should be in the following range:

$$19.650 > l > 18.540$$

The most probable value $x_{avg.} = \dfrac{19.650+18.540}{2} = 19.095 \ cm$

Uncertainty in addition operation $\Delta x = \dfrac{19.650-18.540}{2} = 1.11$

Even the third significant figure can be questioned in this example.

The measurement result $x = x_{avg.} \pm \Delta x = 19.1 \pm 1.1 \ cm$

Multiplication and Division Operations

As a result of the multiplication process, the number of significant digits (in some cases more than one) of the least sensitive measured multiplier is preserved.

Example 1.3

What is the volume of a case whose side lengths, measured using tools with different sensitivities, are $25.32\ cm$, $30.5\ cm$ and $10.123\ cm$?

$$Volume\ =\ (25.32\ cm)\ x\ (30.5\ cm)\ x\ (10.123\ cm)\ =\ 7817.588\ cm^3$$

The multiplier with the smallest significant number among the factors is $30.5 cm$. The number of significant numbers is 3. Therefore, the volume should be indicated with **3 (or 4)** significant figures.

$$Volume =\ 7.82 \times 10^3\ cm^3\ =\ 7.82\ dm^3$$

Measured value	The biggest	The smallest
$25.32\ \pm 0.05$	25.37	25.27
10.123 ± 0.005	10.128	10.118
$30.5\ \ \ \pm 0.5$	x 31.0	x 30.0
	7965.368	7670.456

Measurement result should be in the following range:

$$7965.368\ >\ V\ >\ 7670.456$$

The most probable value $V_{avg.} = \dfrac{7965.368 + 7670.456}{2} = 7817.912\ cm^3$

There are two exact numbers (7... numbers) in the result, the next numbers are uncertain.

But $7.82\ x\ 10^3 cm^3$ is the mean value.

Uncertainty in multiplication operation $\Delta V = \dfrac{7965.368 - 7670.456}{2} = 147.456 cm^3$.

Even the third significant figure can be questioned in this example.

The measurement result $V = V_{avg.} \pm \Delta V = 7.82 \pm 0.15\ dm^3$

1.4 Identifying Errors and Error Propagation

If the measured value of a physical quantity is determined by a single direct measurement, the most probable value consist of exact cetain digits and the next number is decided by an estimation. Largest value of the error (uncertainty) in the measurement should be the half of the scale unit (difference between the nearest two lines in the measurement device). However, in general, repeated measurement should be prefered. Repeated measurements not only give you a better idea of the true value, but also enable you to characterize the measurement uncertainty. Often the number of repeated measurements in the laboratory is small, usually 5 to 10.

In case of N<10, the most probable value and uncertainty in measurement can be found as given below.

Mean ($\bar{x}$)	The average of all measured values of x ("The most probable value")	$\bar{x} = \dfrac{1}{N}\displaystyle\sum_{i=1}^{N} x_i$

Range (R)	The spread range of the data set. This is the difference between the maximum and minimum values of x.	$R = x_{max.} - x_{min.}$
Uncertainty (Δx)	The uncertainty in the measurement process; is the half of difference between the highest and lowest values of the measurement results.	$\Delta x = \dfrac{R}{2} = \dfrac{x_{max.} - x_{min.}}{2}$
Uncertainty İn the mean	The real value of x will be in a range around x_{avg}. This range gradually decreases as the number of measurements N increases $\left(1/\sqrt{N}\right)$.	$\Delta \bar{x} = \dfrac{\Delta x}{\sqrt{N}} = \dfrac{R}{2\sqrt{N}}$
Measured value	The final reported value of a measurement of x contains both the average value and the uncertainty in the mean	$x = \bar{x} \pm \Delta \bar{x}$

If the effect of random errors on the measurement is dominant, it can be mathematically shown that the measurement results are normally distributed by increasing the number of measurements ($N \to \infty$). The most probable value of the measured quantity is x_{avg} and the actual value is between values of $\bar{x} \pm \sigma_{\bar{x}}$ with 68% probability (see Figure 1.6). If the result is desired to be given at 95% confidence interval, the uncertainty should be $\Delta x = 1.79 \sigma_{\bar{x}}$.
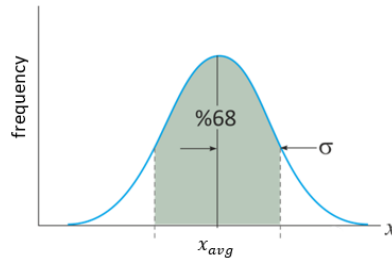

Figure 1.6 Gaussian distributed errors.

In the case of N >> 10 (10 -- 10^2), it would be a more correct approach to make calculations as follows;

Mean ($\bar{x}$)	The average of all measured values of x ("The most probable value")	$\bar{x} = \dfrac{1}{N} \sum_{i=1}^{N} x_i$
Uncertainty (Δx)	The uncertainty in the measurement process; is the standard deviation of the distribution.	$\sigma = \sqrt{\dfrac{1}{N-1} \sum_{i=1}^{N} (x_i - \bar{x})^2}$
Uncertainty İn the mean	The real value of x will be in a range around x_{avg}. This range gradually decreases as the number of measurements N increases $\left(1/\sqrt{N}\right)$.	$\Delta \bar{x} = \dfrac{\sigma}{\sqrt{N}}$

Measured value	The final reported value of a measurement of x contains both the average value and the uncertainty in the mean.	$x = \bar{x} \pm \Delta\bar{x}$

Example 1.4

The value of the resistance R in an electrical circuit was measured four times and the following values were obtained;

$R_1 = 50.1\ \Omega, R_2 = 49.7\ \Omega, R_3 = 49.6\ \Omega, R_4 = 50.2\ \Omega$

Mean Value:	$\bar{R} = \dfrac{50.1 + 49.7 + 49.6 + 50.2}{4} = 49.9\ \Omega$
Mean Deviation:	$\Delta\bar{R} = \dfrac{\|50.1 - 49.9\| + \|49.7 - 49.9\| + \|49.6 - 49.9\| + \|50.2 - 49.9\|}{4}$ $= 0.25\ \Omega$ $R = \bar{R} \pm \Delta\bar{R} \;\rightarrow R = \mathbf{49.9 \pm 0.25\ \Omega}$

The mean deviation can be used for simplicity of the error. However, with increasing the number of measurements, it does not express well that the mean value approaches the real one. Therefore, we can see that the calculation using the following method expresses the measurement result well. Or for N>10 it would be appropriate to use the standard deviation for uncertainty. In order not to be confused with the resistance R, the distribution range of the measured values is written as "Range".

$Range = 50.2 - 49.6 = 0.6$

$\Delta Range = Range/2 = 0.30$

$\Delta\bar{R} = \dfrac{Range}{\sqrt{N}} = \dfrac{0.30}{\sqrt{4}} = 0.15\ \Omega$

$\Delta\bar{R} = \dfrac{\sigma}{\sqrt{4}} = \dfrac{0.3}{\sqrt{4}} = 0.15\ \Omega$

$R = \mathbf{49.9 \pm 0.15\ \Omega}$

Error Propagation

We have examined in detail above how to find the most probable value and uncertainty of directly measured physical quantities. Now suppose we want to calculate a quantity that cannot be measured directly (the density of an object, the velocity of an object, the circumference of a triangle). Consider $\bar{x}, \bar{y}, \bar{z}\ldots$ to be mean values and $\Delta x, \Delta y, \Delta z \ldots$ as uncertainties of the directly measurable physical quantities $x, y, z \ldots$ The mean and uncertainty of q can be found by the following equations:

$$q = f(x, y, z, \cdots), \quad \Delta q = \sqrt{\left(\frac{\partial f}{\partial x}\Delta x\right)^2 + \left(\frac{\partial f}{\partial y}\Delta y\right)^2 + \left(\frac{\partial f}{\partial z}\Delta z\right)^2 \cdots}, \quad q = \bar{q} \pm \Delta q$$

Example 1.5

The potential difference of the resistor R in an electrical circuit is measured as V. The energy consumed per unit time in R resistor (the power of R resistor) is given by the relation $P = V^2/R$. What is the uncertainty in the measurement of the power P? (Uncertainties in R and V are given as 1%).

$$\frac{\partial P}{\partial V} = \frac{2V}{R}, \quad \frac{\partial P}{\partial R} = -\frac{V^2}{R^2} \qquad\qquad \Delta P = \sqrt{\left[\left(\frac{2V}{R}\right)^2 \Delta V^2 + \left(-\frac{V^2}{R^2}\right)^2 \Delta R^2\right]}$$

Dividing all the terms by $P = V^2/R$;

$$\frac{\Delta V}{P} = \sqrt{\left[4\left(\frac{\Delta V}{V}\right)^2 + \left(\frac{\Delta R}{R}\right)^2\right]}$$
$$= \sqrt{\left[4(0.01)^2 + (0.01)^2\right]}$$
$$= \%2.236$$

Calculated errors for some commonly used functions

Process	Absolute error (Uncertainty)
$y = a + b \quad or \quad y = a - b$	$\Delta y = \sqrt{\Delta a^2 + \Delta b^2}$
$y = ab \quad or \quad y = a/b$	$\frac{\Delta y}{\bar{y}} = \sqrt{\left(\frac{\Delta a}{\bar{a}}\right)^2 + \left(\frac{\Delta b}{\bar{b}}\right)^2}$
$y = \lambda a^n$	$\frac{\Delta y}{\bar{y}} = \lvert n \rvert \frac{\Delta a}{\bar{a}}$
$y = \lambda \ln \mu a$	$\Delta y = \lambda \frac{\Delta a}{\bar{a}}$

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   Makine Mühendisliği Lab., 30.09.2018

Experiment 1

EQUIPOTENTIAL LINES

AND

ELECTRIC FIELD LINES

DEU Faculty of Science

Physics Department

Purposes

- Mapping the equipotential lines of two oppositely charged planar and circular conductors.

- Obtaining the electric field lines using equipotential lines.

1.1 Preparation Questions

1) Define the concepts of electric field and electric potential.

2) What is the equipotential surface? Please explain.

1.2 Electric Field and Electric Potential

The gravitational field g at a point in space was known to be equal to the gravitational force F_g acting on a test particle of mass m divided by that mass: $\left(g = \frac{F_g}{m}\right)$. A similar approach to electric forces was developed by Michael Faraday. In this approach, an electric field is set to exist in the region of space around a charged object. When another charged object enters this electric field, an electric force acts on it. As an example, consider Figure 1.1, which shows a small positive test charge $+q_0$ placed near a second object carrying a much greater positive charge Q. We define the strength (magnitude) of the electric field at the location of the test charge to be the electric force per unit charge.
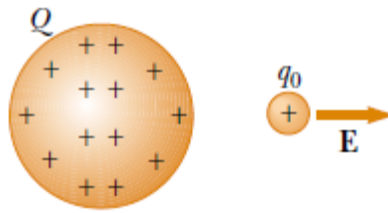

Figure 1.1 A small positive test charge q_0 placed near an object carrying a much greater positive charge Q experiences an electric field E directed as shown.

$$E = \frac{F_e}{q}$$

1.1

The direction of the electric field, which is a vector quantity, is in the direction of the force acting on the positive charge at that point. Force unit is Newton (N), unit of charge is Coulomb (C), unit of electric field is Newton / Coulomb (N/C).

The force acting on the $+q_0$ trial charge at a point r away from a point $+Q$ charge is $F_e = kQq/r^2$ according to Coulomb's law. Accordingly, the strength of the electric field at a point r away from a point charge Q is;

$$E = \frac{F_e}{q} = \frac{kQq/r^2}{q} = k\frac{Q}{r^2}$$

1.2

The electric field lines of a positive charge point outward from the charge, and the field lines of a negative charge towards the charge. The number of electric field lines is directly proportional to the charge, the greater the electric charge, the more (close to each other) electric field lines around it. The divergence of the electric field lines indicates that the field strength is getting weaker. Figure 1.2 shows the electric field lines formed around point charges.
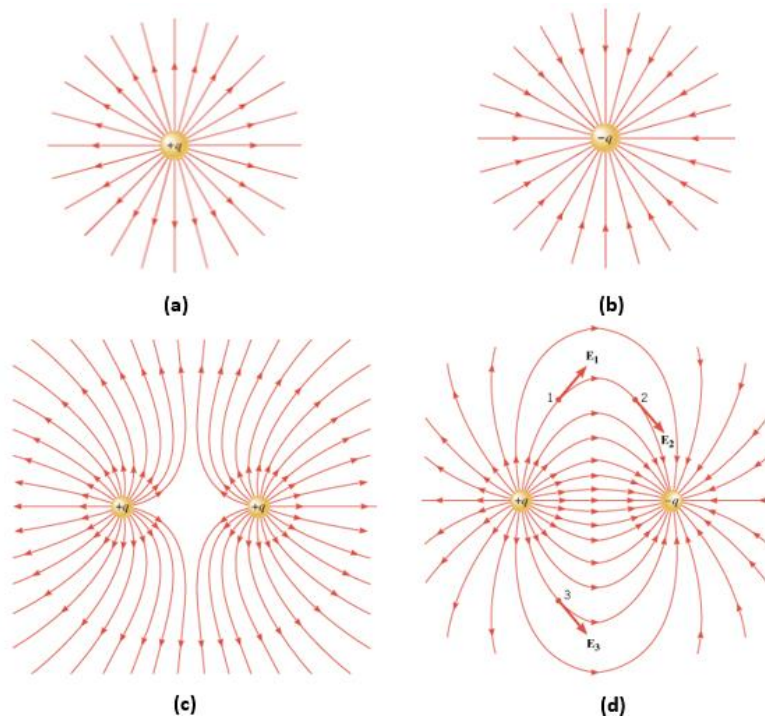
Figure 1.2 Electric field lines formed around point electric charges. **(a)** positive point charge, **(b)** negative point charge, **(c)** two positive charges of equal magnitude, **(d)** two positive and negative charges of equal magnitude.

The electric field between two parallel plane plates with the same amount of different charges is uniform except at the ends of the plate. The force acting on the charge q in such a uniform electric field is in the field direction and its magnitude depends on the definition of the electric field is;

$$\vec{F}_e = q\vec{E}$$

1.3

If the charge q is positive, the force is in the same direction with the field, if it is negative, the force is in the opposite direction with the field (Figure 1.3).
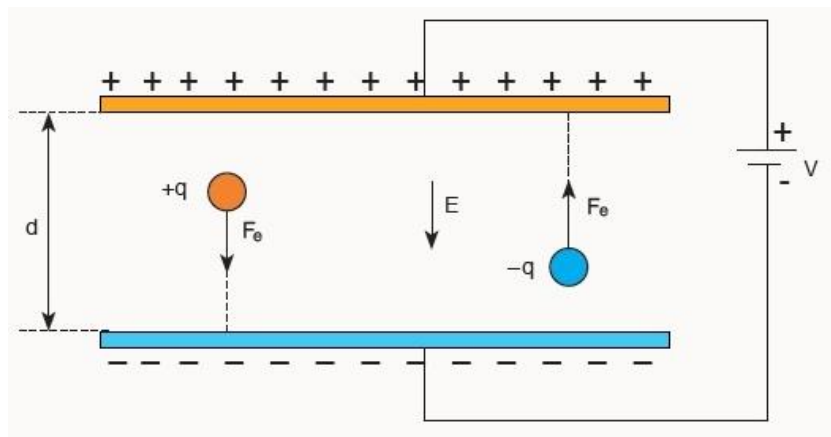
Figure 1.3 Electric field between two charged parallel plates

In Figure 1.4, the potential difference between K and L points in the region between the charged parallel plates is equal to the work done by moving unit charge of +1 from K to L and its value is;

$$V_{KL} = Ed$$

<div align="right">1.4</div>

Because there is a force in the direction of displacement when a test charge of q is carrying from K to L. On the other hand, when moving the charge q from point M to point N, these forces will not do work because the electrical forces are perpendicular to the direction of displacement. The fact that the electrical forces did not do work by moving the +1 unit charge from M to N indicates that the potential difference between these two points is zero. In fact, the potentials of all points on the dashed line where the M and N points lie are the same. This line is called the equipotential line. In addition, surfaces that contain points of the same potential are called *equipotential surfaces.*
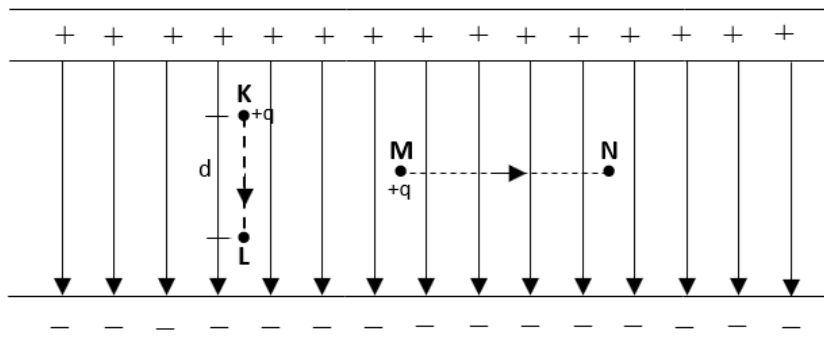

Figure 1.4 Potential difference between points K and L is $V_{KL} = Ed$, potential difference between points M and N is $V_{MN} = 0$. The dashed lines in the figure show the equipotential surfaces and the solid lines show the electric field lines.

In Figure 1.5, equipotential lines and electric field lines around a $+q$ charge are shown. <u>Field lines are always perpendicular to the equipotential line at that point.</u>
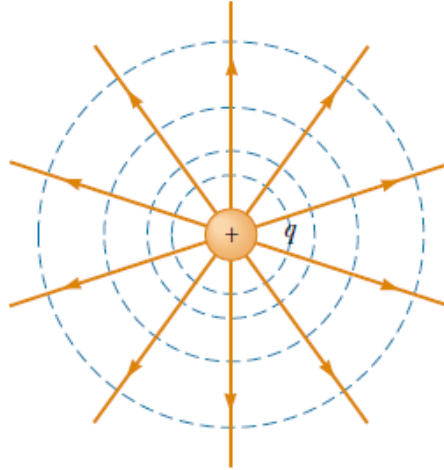

Figure 1.5 Equipotential surfaces (dashed blue lines) and electric field lines (solid orange lines) for a $+q$ charge. Equipotential lines are perpendicular to the electric field lines at each point.

1.3 Tools to be used in the experiment

- Conductive paper and drawing paper
- Parallel plates and circular electrodes
- Connection cables, probes and push pins
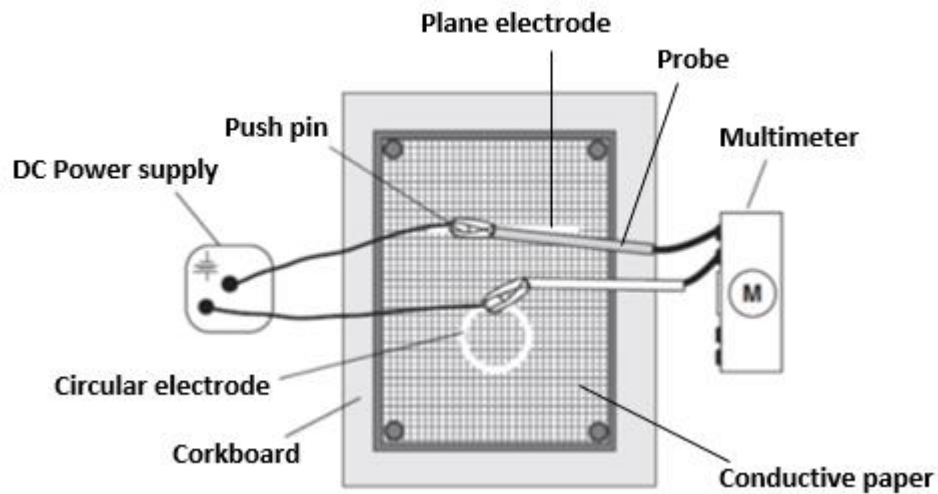- Multimeter
- DC Power Supply

Figure 1.6 Experiment setup. The figure shows plane plate and circular electrodes together.

1.4 Experimental Procedure

- Mount the conductive paper on the corkboard using push pins, then mount the two parallel plates 3 cm apart from each other on the conductive paper. Similarly, draw two parallel plates 3 cm apart on your drawing paper.

- Clamp the connecting cables between the push pins and plane plates. The other ends of the cables will be plugged into the DC inputs of the power supply.

- Apply a 5V potential difference from the power supply to the plates. Thus, one of the plates will be positively charged while the other is negative.

- To measure the potential difference of the charged parallel plates on the multimeter; set your multimeter to be a voltmeter (scale at V— and one probe plugged into COM and the other to V input). Then touch one probe (+) and the other probe (−) to the charged plate and hold it steadily. The voltage value you measure from the multimeter may not be exactly the same as the voltage value you measure from the power supply. Use the value on the multimeter in your measurements.

- To measure the potential difference at the midpoint of the charged parallel plates, hold one probe on the multimeter steady on the (+) or (−) charged plate, touch the other probe to the midpoint of the plates and measure the potential difference value on the multimeter. Mark

the point where you touched the probe on your drawing paper and write the value you measure from the multimeter on it.

- Then try to find the same potential difference value from the multimeter by moving the probe at the middle of the plates at different points on the conductive paper. Mark each point you have determined on your drawing paper and write your potential difference values that you measure from the multimeter on it.

- Determine the potential difference value at any point between the two plates (even outside the plates) by moving the probe away from the midpoint, then look for other points where you will find the same potential value. Identify at least three points for a single potential difference value and connect these points on the drawing paper.

- After obtaining the potential differences for the parallel plates, repeat the same process for the charged circular electrodes.

- These lines that you combine on your drawing paper are equipotential lines. From these lines, try to identify electric field lines and their directions.

1.5 Measurements and Results

Using Equation 1.4, calculate the magnitude of the electric field between the parallel plates, taking into account the potential difference between two plates placed with 3 cm intervals. You can use the formula $\delta E = E \left(\left| \frac{\delta V}{V} \right| + \left| \frac{\delta d}{d} \right| \right)$ to calculate the uncertainty in the electric field result.
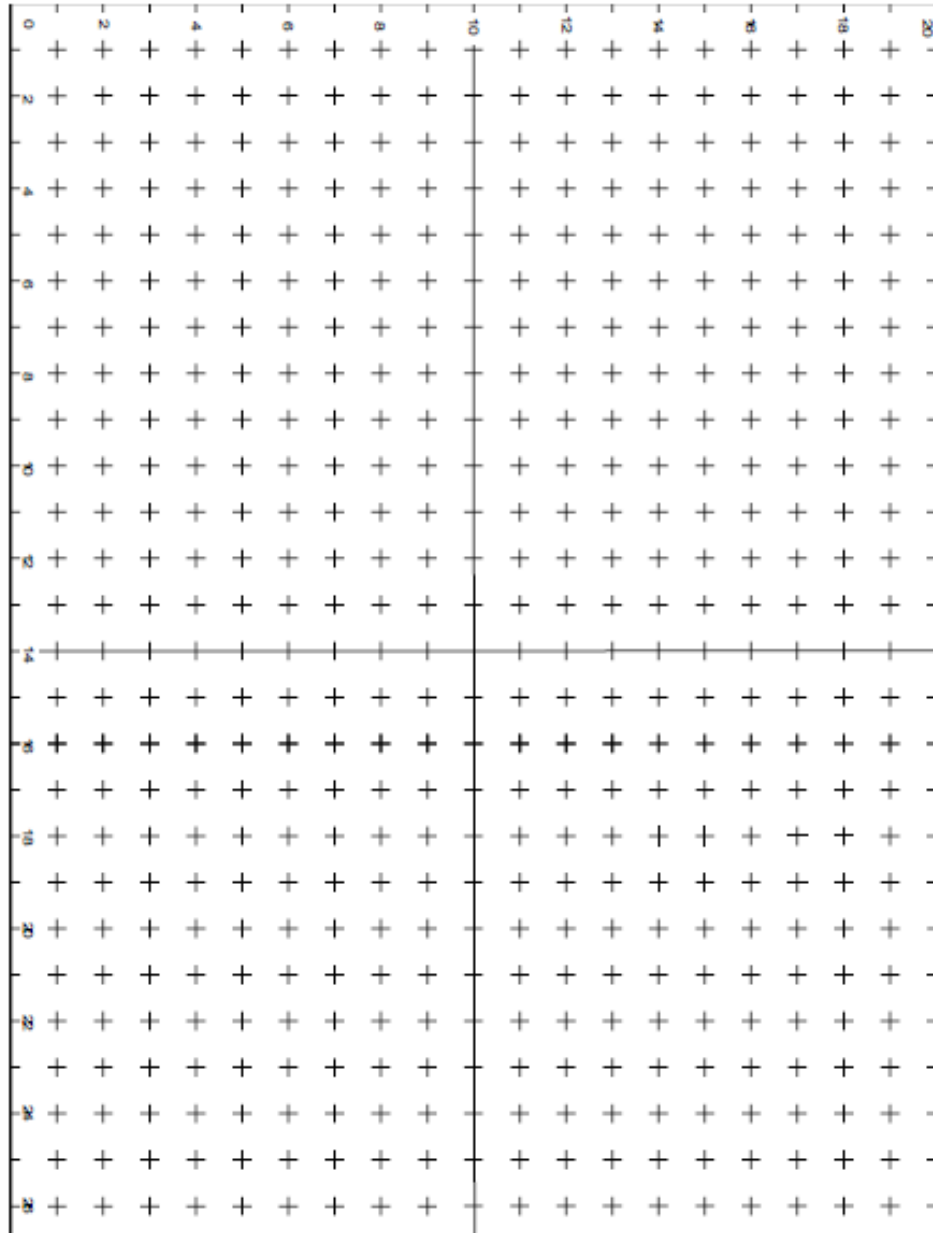
Electric potential between the plates   **Distance between the plates**

$V \pm \delta V =$......................... $d \pm \delta d =$.....................

Magnitude of the electric field

$E \pm \delta E =$...............................

1.6 Questions

1) Calculate the electrical potential created by a $+Q$ charge at a point A located about r away.

2) Two charges of $2x10^7$ ve $5x10^7$ Coulomb are 60 cm apart from each other. Find the electric potential and electric field magnitude that occur at the midpoint of the two charges.

3) A negative charge is moving in the direction of a uniform electric field. Does the potential energy of this charge decrease or increase?

References

1. PASCO Charge Equipotential and Field Mapper, Model No. ES-9060.

2. PASCO Conductive Paper PK-9025B.

3. Dokuz Eylül Üniversitesi, Fen Fakültesi Fizik Bölümü, Fizik II Laboratuvar Föyü, 2016.

4. John D. Cutnell, Kenneth W. Johnson, Physics, 8th Edition, John & Wiley Sons, Inc. 2009.

5. Raymond A. Serway, Robert J. Beichner, Fen ve Mühendislik için Fizik 2, 5. Baskı, 2000.

Experiment2

Relations Between Charge, Potential Difference and Capacitance in a Parallel Plate Capacitor

DEU Faculty of Science

Physics Department

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 Preparation Questions

1) Briefly explain what is a capacitor, its structure and in which areas it is used.

2) Please explain the concept of capacitance.

3) How do the potential difference and electric field change when a dielectric is placed between the plates of a charged capacitor?

2.2 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;

$$Q = C.\Delta V \hspace{4cm} 2.1$$

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}).

2.2.1 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;

$$C = \frac{\varepsilon_0 A}{d} \hspace{4cm} 2.2$$

In this expression A is the area of the parallel plates, d is the distance between the two plates and ε_0 is the permittivity of free space ($\varepsilon_0 = 8.85\ x\ 10^{-12}\ farad/meter\ or\ C^2/N\ m^2$).
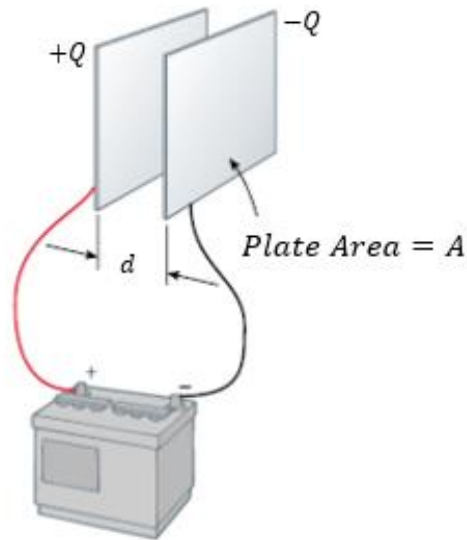

Figure 2.1 A capacitor consisting of two paralel plates

2.3 Tools to be used in the experiment

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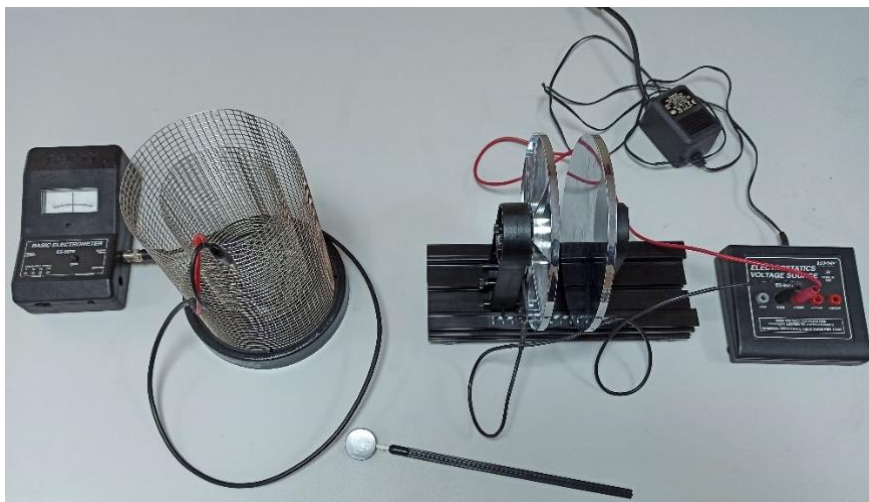- Connection cables, adapter, ruler

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.
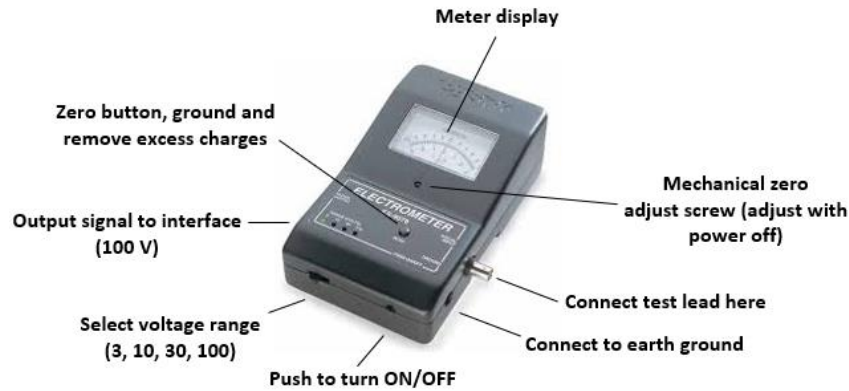
Figure 2.4 Electrometer

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.
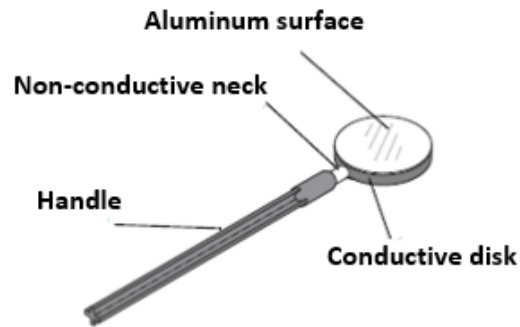

Figure2.6 Charge producer

Faraday Ice Pail

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).
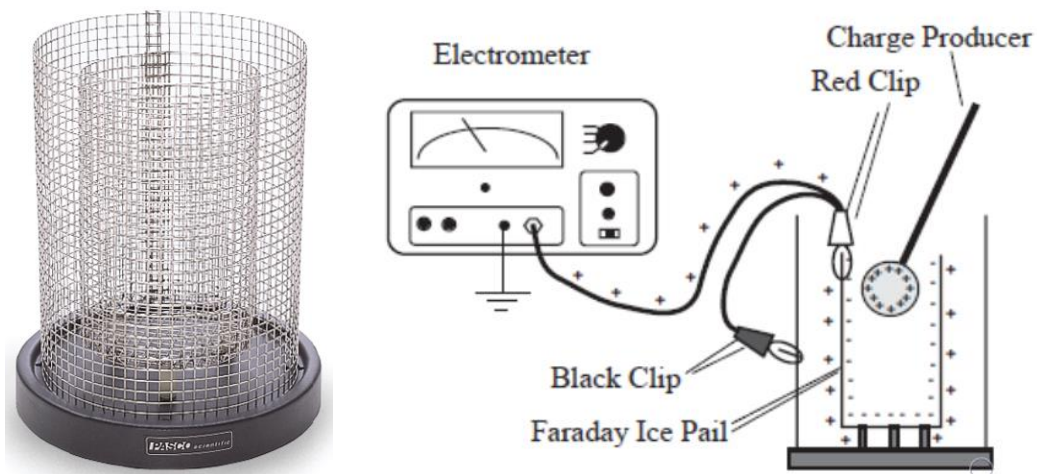

Figure 2.7 Faraday ice pail

2.4 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.

2.5 Measurement and Results

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

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

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

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

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

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

	$V_{capacitor}$	V_{rod}	Q_{rod}	$Q_{capacitor}$	$C_{capacitor}$
	(V)	(V)	(C)	(C)	(pF)

Experiment 1	1000				
Experiment 2	2000				
Experiment 3	3000				

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

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		

2.6 Questions

1) What change in the capacitance of the paralel plate capacitor did you observ when you applied a potential difference of 1000 V, 2000 V, and 3000 V from the electrostatic voltage source? Please explain.

2) How can you increase the capacitance of the paralel plate capacitor?

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 3

OHM'S LAW and RESISTANCE MEASUREMENTS WITH VOLTMETER-AMMETER METHOD - SERIAL CONNECTED CIRCUITS

DEU Faculty of Science

Physics Department

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 Preparation Questions

3)   Define the concepts of resistance, resistivity, and conductivity and indicate their units.

4)   Define the concepts of current and potential difference and write their units. Specify the characteristics of the voltmeter and ammeter.

5)   What is Ohm's law? Describe briefly.

6)   Briefly describe the current and voltage connections in circuits where resistors are connected in series.

3.2 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 8×10^{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 ρ.

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

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 (Ω^{-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 ΔV_1 and ΔV_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.
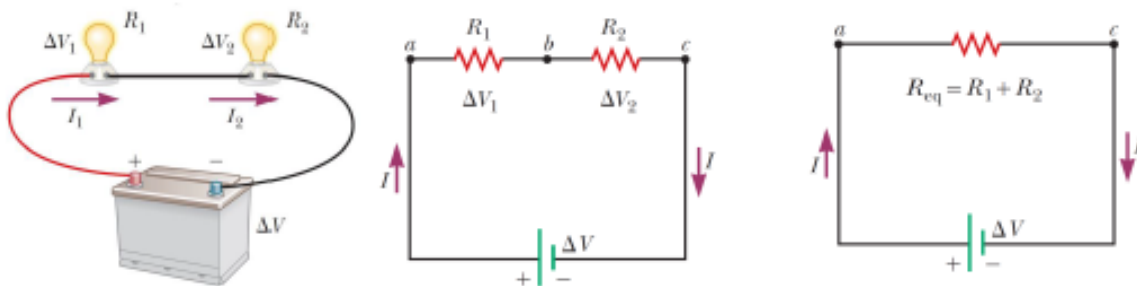

Figure 3.1 Serial connected resistors.

3.3 Tools to be used in the experiment

1. Three different resistors

2. Board

3. Multimeter (Voltmeter, Ammeter, Ohmmeter)
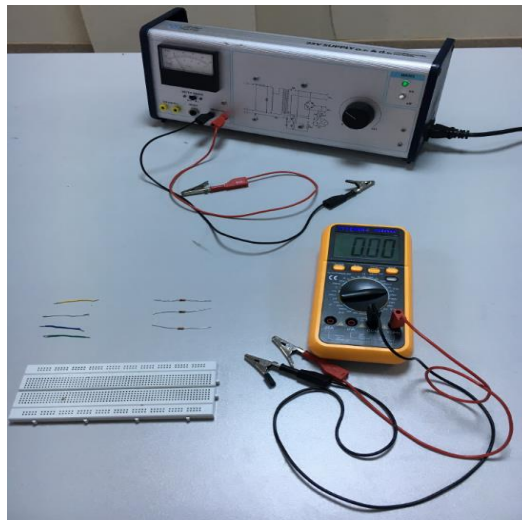
4. Power Supply

5. Connection cables.

Figure 3.2 The experimental setup
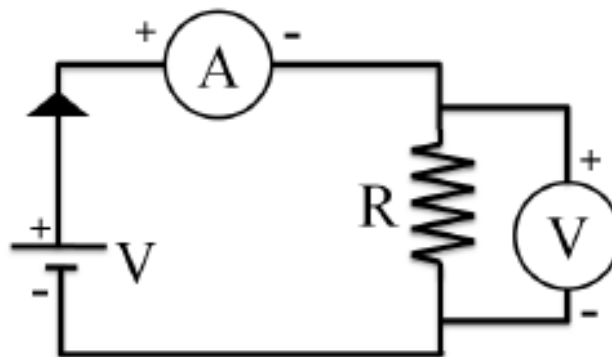
3.4 Experimental Procedure

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.
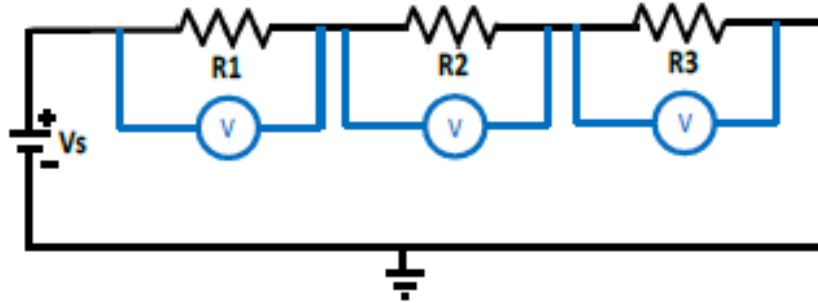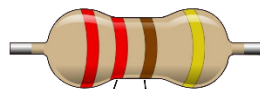

Figure 3.4 Series connected circuit diagram created with the three resistors you specified.

3.5 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%

$$2\,2 \times 10^{1} \pm 5\% = 220 \pm 11 \ \Omega$$

Resistance values determined by color codes:

$R_1 = \cdots\cdots \pm \cdots\cdots \ \Omega$ $\qquad$ $R_2 = \cdots\cdots \pm \cdots\cdots \ \Omega$ $\qquad$ $R_3 = \cdots\cdots \pm \cdots\cdots \ \Omega$

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

Measuremen	R₁		R₂		R₃	
	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

Resistance values obtained from the graph:

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

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}					

3.6 Questions

1) Do all materials that conduct current obey the Ohm's Law? Give an example.

2) Is the direction of the current flowing through a battery always from negative to positive? Explain.

3) How should the resistors be connected so that their equivalent resistance is greater than the resistance of each resistor? Give an example of three resistances.

4) How to find the value of the internal resistance of a battery?

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 4

OHM'S LAW - PARALLEL CONNECTED CIRCUITS

DEU Faculty of Science

Physics Department

Purposes

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

4.1 Preparation Questions

7)   What is Ohm's law? Describe briefly.

8)   Briefly describe the current and voltage variations in circuits where resistors are connected in parallel.

4.2 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 carrying current I with cross section A, the current density $\vec{J}$ in the conductor is defined as the current per unit area. Since the current is $I = nqv_s A$, the current density is given by

$$\vec{J} = \frac{I}{\vec{A}} = nq\vec{v_s}$$

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

$$\vec{J} = nq\vec{v_s}$$

If a potential difference is applied between the ends of a conductor, a current density $\vec{J}$ and an electric field $\vec{E}$ 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:

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

Here σ is the proportionality coefficient and gives information about the conductivity of the substance. Materials 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* materials.

Connecting more than one resistor in any circuit by applying the same voltage (V) to their ends, so that separate currents can pass through each of them, is called **parallel connection**. The current through parallel-connected circuit elements is divided into paths as shown in Figure 4.2, so the currents passing through each resistor will be different. However, these circuit elements connected in parallel have the same 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 (V) of that connected source.

 If a voltage source is connected to a single resistor in the circuit, I current drawn from the source passes through this resistor. However, when the two resistors (R_1 and R_2) are connected in parallel to the circuit, one part of the current drawn from the source (I_1) will pass through the resistor R_1 ve and the other part (I_2) will go through the resistor R_2. That is, the current (I) drawn from the source will be divided into branches while distributing through 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 (I) of the circuit. In a parallel circuit, the current through each resistor is given by Ohm's law. Since the source voltage V will be the same for the parallel resistors 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

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

4.3 Tools to be used in the experiment

1. Three different resistors

2. Board

3. Multimeter (Voltmeter, Ammeter, Ohmmeter)
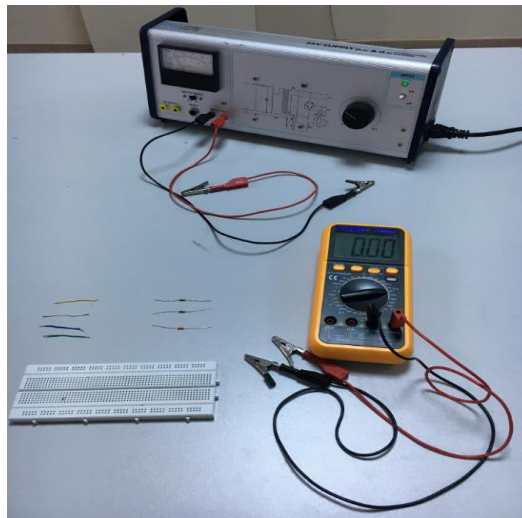
4. Power Supply

5. Connection cables.

Figure 4.1 The experimental setup
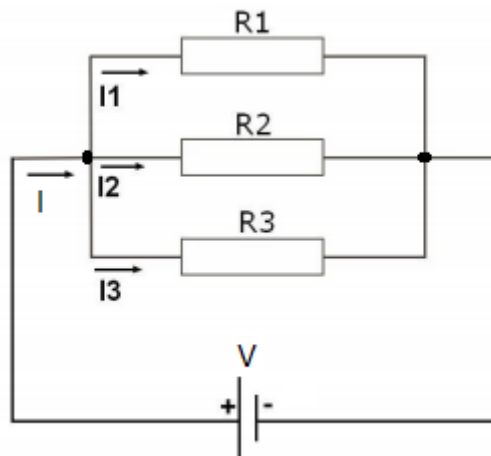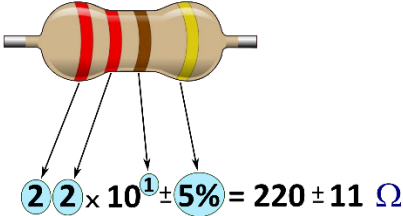
4.4 Experimental Procedure

Figure 4.2 Parallel connected circuit

- Determine the resistances of the three resistors given to you using the color codes on them.

- Measure the resistances of these three resistors with an ohmmeter and record these values.

- Set up the parallel connected circuit shown in Figure 4.2 with the help of these three resistors whose values you have determined,.

- 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.

4.5 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%

$$2\;2 \times 10^{1} \pm 5\% = 220 \pm 11\ \Omega$$

Resistance values determined by color codes:

$$R_1 = \cdots\cdots \pm \cdots\cdots\ \Omega \qquad R_2 = \cdots\cdots \pm \cdots\cdots\ \Omega \qquad R_3 = \cdots\cdots \pm \cdots\cdots\ \Omega$$

Resistance values measured using ohmmeter:

$R_1 = \ldots\ldots\ldots k\Omega$ 　　　　　　$R_2 = \ldots\ldots\ldots k\Omega$ 　　　　　　$R_3 = \ldots\ldots\ldots k\Omega$

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}					

4.6 Questions

1) How close are the equivalent resistances you measured and calculated to each other in this experiment?

2) If there is a difference between the values you have measured and calculated, what may be the reason for this difference?

3) What are the sources of error in this experiment?

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 5

WHEATSTONE BRIDGE

DEU Faculty of Science

Physics Department

Purposes

Determining the value of the resistance using the Wheatstone bridge.

5.1 Preparation Questions

1) Describe where the Wheatstone bridges are used.

2) Explain what the resistance of a conductor depends on.

5.2 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.
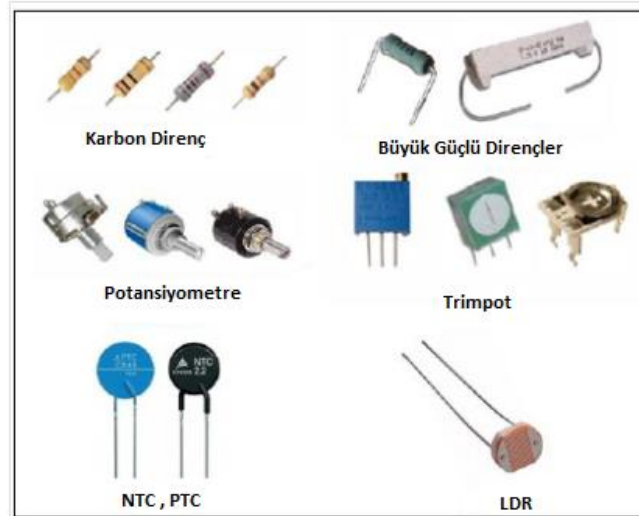
Figure 5.1 Types of Resistance

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.
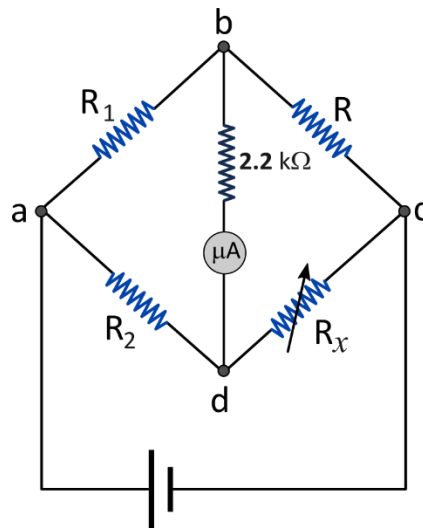
Figure 5.2 The circuit diagram of the Wheatstone bridge.

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.

5.3 Tools to be used in the Experiment

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

5.4 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).
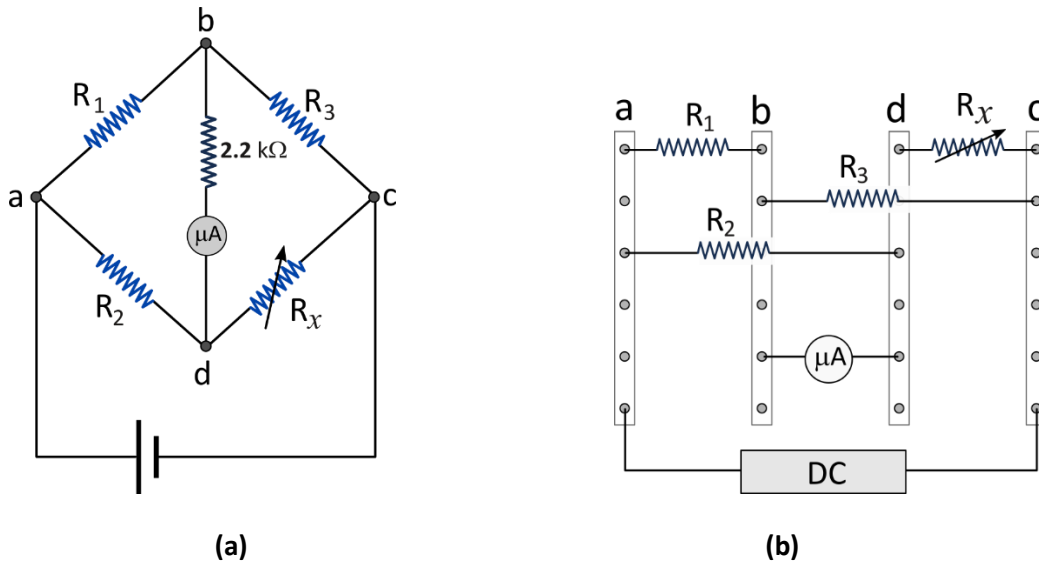

| (a) | (b) |

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

R₁ (kΩ)	R₂ (kΩ)	R₃ (kΩ)	R_x (experimental) (kΩ)	R_x (theoretical) (kΩ)	% Relative Error

5.6 Questions

1) What is the meaning of zero current passing through b-d points?

2) Can this experiment be done using alternating current?

3) Can values of small resistors be found with the help of Wheatstone bridge? What should be used in the experimental setup to find resistance in the order of Ω?

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 6

Storage and Flow of Electric Charges

DEU Faculty of Science

Physics Department

Purposes

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

6.1 Preparation Questions

1. Define capacitance of capacitor and state its unit.

2. Give examples of usage areas of capacitors.

3. Define time constant (τ).

6.2 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 ΔV 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

$$C = \frac{Q}{\Delta V}$$ 6.1
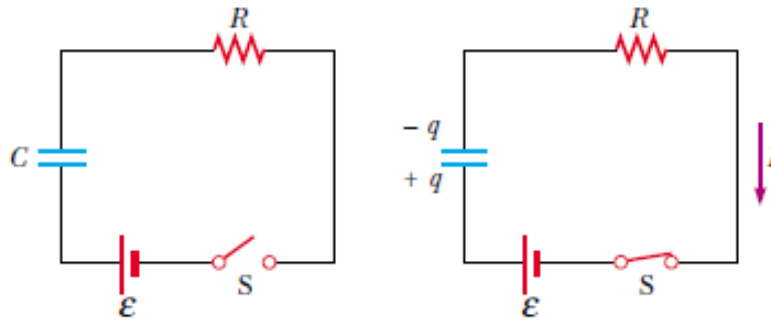
6.2.1 Charging a Capacitor

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

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

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

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:

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

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:

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

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

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

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

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

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

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

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

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

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

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

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

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 $I = \frac{I_0}{e} = 0.37 I_0$
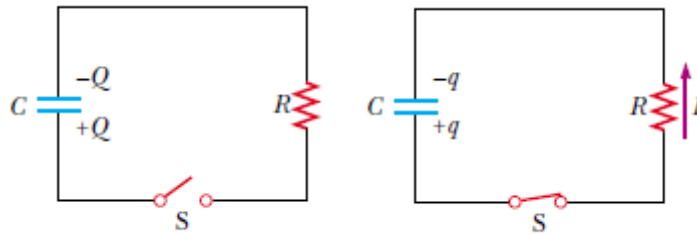
6.2.2 Discharging a Capacitor

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.

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

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

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

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

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

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

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

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

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

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

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 $\tau = RC$.
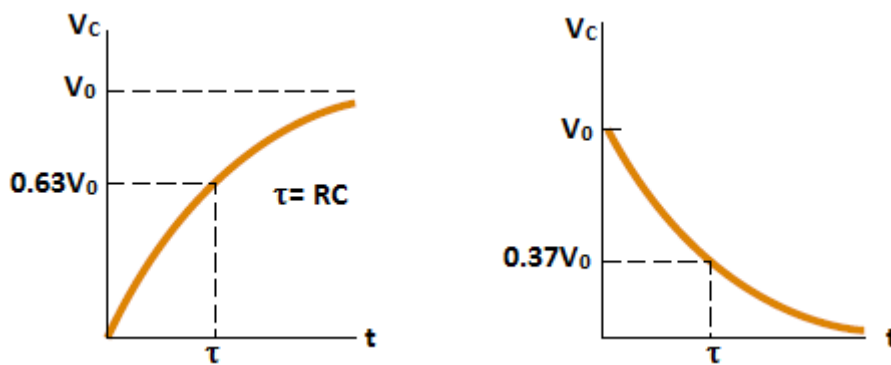

Figure 6.3 The change in voltage over time during the charging and discharging of a capacitor.

6.3 Tools to be used in the experiment

- $R_1 = 1M\Omega$, $R_2 = 2.2\ M\Omega$ and $R_3 = 0.1\ M\Omega$ resistor

- C_1 = 100 μF, C_2 = 10μF and C_3= 470 μF capacitor
- Multimeter
- DC Power Supply
- Chronometer

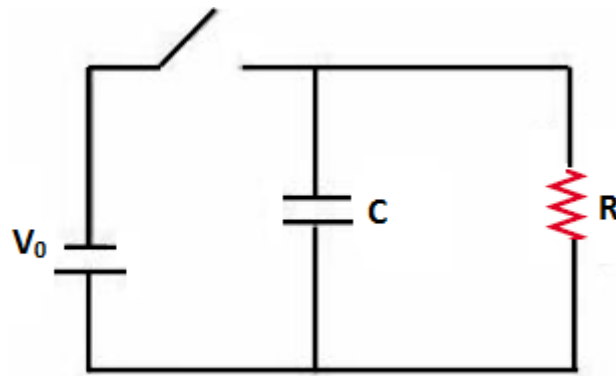## 6.4 Experimental Procedure

Figure 6.4 The experimental setup

6.4.1 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 $\tau = R_{int}C$.

6.4.2 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 τ as described above. (τ_{exp})
- Calculate the time constant theoretically by writing the values of R and C in the formula $\tau = RC$ (τ_{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.

6.5 Measurements and Results

6.5.1 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	

$$\tau = \ldots\ldots\ldots\ldots \pm \ldots\ldots\ldots\ldots\ s$$

$$R_{internal} = \ldots\ldots\ldots\ldots \pm \ldots\ldots\ldots\ldots M\Omega$$

6.5.2 Finding the time constant

Table 6.2 Measured and calculated values

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

6.6 Questions

1. Show that the RC has time dimension.

2. How does not including the internal resistance of the voltmeter in the calculations affect the time constant? Explain.

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.

Experiment 7

Magnetism

Properties of Helmholtz Coils

DEU Faculty of Science

Physics Department

Purposes

Determining the magnitude of magnetic field near a magnet using Helmholtz coils.

7.1 Preparation Questions

1. What are the sources of magnetic field?

2. What are the main differences between Magnetic field and Electric field? Explain.

3. What are the features of Helmholtz coil?

7.2 The Biot–Savart Law

Shortly after Oersted's discovery in 1819 that a compass needle is deflected by a current-carrying conductor, Jean-Baptiste Biot (1774–1862) and Félix Savart (1791–1841) performed quantitative experiments on the force exerted by an electric current on a nearby magnet. From their experimental results, Biot and Savart arrived at a mathematical expression that gives the magnetic field at some point in space in terms of the current that produces the field. That expression is based on the following experimental observations for the magnetic field $d\vec{B}$ at a point *P* associated with a length element $d\vec{s}$ of a wire carrying a steady current I (Fig. 7.1):

• The vector $d\vec{B}$ is perpendicular both to $d\vec{s}$ (which points in the direction of the current) and to the unit vector $\hat{r}$ directed from *ds* toward *P*.

• The magnitude of $d\vec{B}$ is inversely proportional to r^2, where *r* is the distance from $d\vec{s}$ to *P*.

• The magnitude of $d\vec{B}$ is proportional to the current and to the magnitude *ds* of the length element $d\vec{s}$.

• The magnitude of $d\vec{B}$ is proportional to sinθ where θ is the angle between the vectors $d\vec{s}$ and $\hat{r}$.

These observations are summarized in the mathematical expression known today as the Biot–Savart law:

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I\,d\vec{s}\times\hat{r}}{r^2} \qquad\qquad 7.1$$

where μ_0 is a constant called the permeability of free space $\mu_0 = 4\pi\times10^{-7}\,T.m/A$. Note that the field $d\vec{B}$ in Equation 7.1 is the field created by the current in only a small length element $d\vec{s}$ of the conductor. To find the *total* magnetic field $\vec{B}$ created at some point by a current of finite size, we must sum up contributions from all current elements $I\,d\vec{s}$ that make up the current. That is, we must evaluate $\vec{B}$ by integrating Equation 7.1:

$$\vec{B} = \frac{\mu_0 I}{4\pi}\int\frac{d\vec{s}\times\hat{r}}{r^2} \qquad\qquad 7.2$$

where the integral is taken over the entire current distribution.

There are similarities between the Biot-Savart law and the Coulomb's law. The magnitude of the magnetic field varies as the inverse square of the distance from the source, as does the electric field due to a point charge. However, the directions of the two fields are quite different. The electric field

created by a point charge is radial, but the magnetic field created by a current element is perpendicular to both the length element $d\vec{s}$ and the unit vector $\hat{r}$ r, as described by the cross product in Equation 7.1. Hence, if the conductor lies in the plane of the page, as shown in Figure 7.1, $d\vec{B}$ points out of the page at P and into the page at P$'$.

Another difference between electric and magnetic fields is related to the source of the field. An electric field is established by an isolated electric charge. The Biot–Savart law gives the magnetic field of an isolated current element at some point, but such an isolated current element cannot exist the way an isolated electric charge can. A current element must be part of an extended current distribution because we must have a complete circuit in order for charges to flow. Thus, the Biot–Savart law (Eq. 7.1) is only the first step in a calculation of a magnetic field; it must be followed by an integration over the current distribution, as in Equation 7.2.
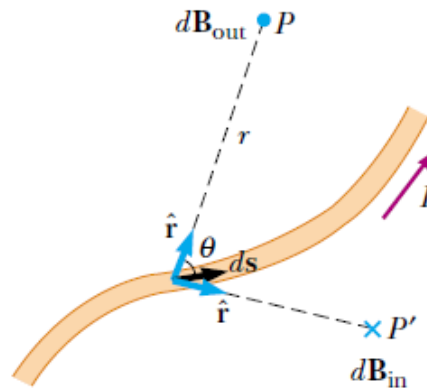

Figure 7.1 The magnetic field $d\vec{B}$ at a point due to the current I through a length element $d\vec{s}$ is given by the Biot–Savart law. The direction of the field is out of the page at P and into the page at P'.

Consider a circular wire loop of radius R located in the yz plane and carrying a steady current I, as in Figure 7.2. The magnetic field at an axial point P a distance x from the center of the loop

$$\vec{B} = \frac{\mu_0 I}{4\pi}\int \frac{d\vec{s} \times \hat{r}}{r^2} \quad \Longrightarrow \quad B_x = \frac{\mu_0 I R^2}{2(x^2 + R^2)^{3/2}} \qquad 7.3$$
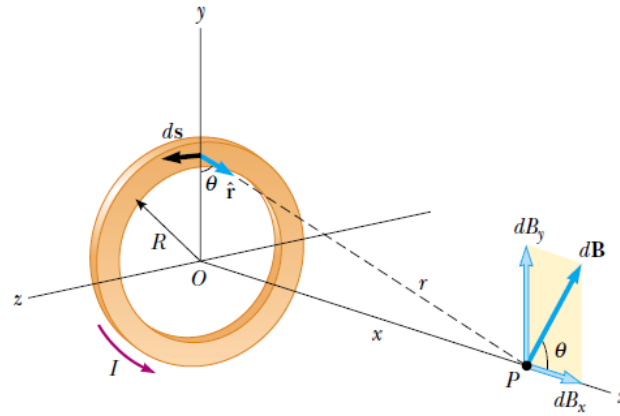
Figure 7.2 Geometry for calculating the magnetic field at a point P lying on the axis of a current loop.

7.3 Tools to be used in the experiment

- Helmholtz coil
- Power supply
- Microoampermeter
- Hall Probe
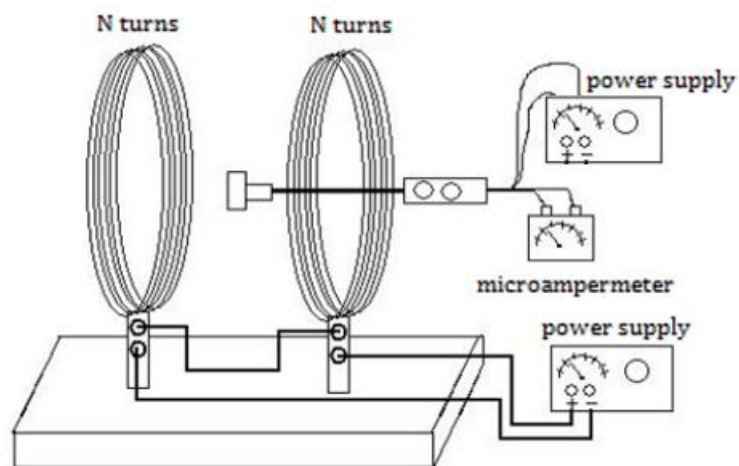- Bar Magnet

7.4 Experimental Procedure

Figure 7.3 Determination of the magnetic field of Helmholtz coils

- Set up the circuit in Figure 7.3. Connect the red-black end of the Hall probe to the power supply. Connect the other two free ends to a microampermeter and calibrate the Hall probe.
- Connect the power supply so that the current flows through the coils in the same direction.
- Connect an ampermeter to the circuit to measure the current flowing through the coils.
- Measure and note the distance between the coils. Place the Hall probe at the midpoint of this distance. Pay attention not to change the position of the probe in the next experimental steps.
- Ensure current flows through the circuit by adjusting the voltage of the power supply. Note this value to Table 7. 1.
- Note the deviation in the microampermeter to which the Hall probe is connected.
- Calculate the magnetic field formed in the middle of a Helmholtz coil theoretically using Equation 7.3 and note the value in Table 7.1 (the number of turns is written on the coils).
- Repeat the above steps several times by increasing the current value.
- Using the data in Table 7.1, draw the graph of the magnitude of magnetic field-deviation. This curve will be used as the calibration curve.
- Bring the Hall probe without touching close to one of the poles of the magnet.
- Note the deviation in the microampermeter.
- Using the calibration curve, determine the magnitude of magnetic field corresponding to the deviation obtained.
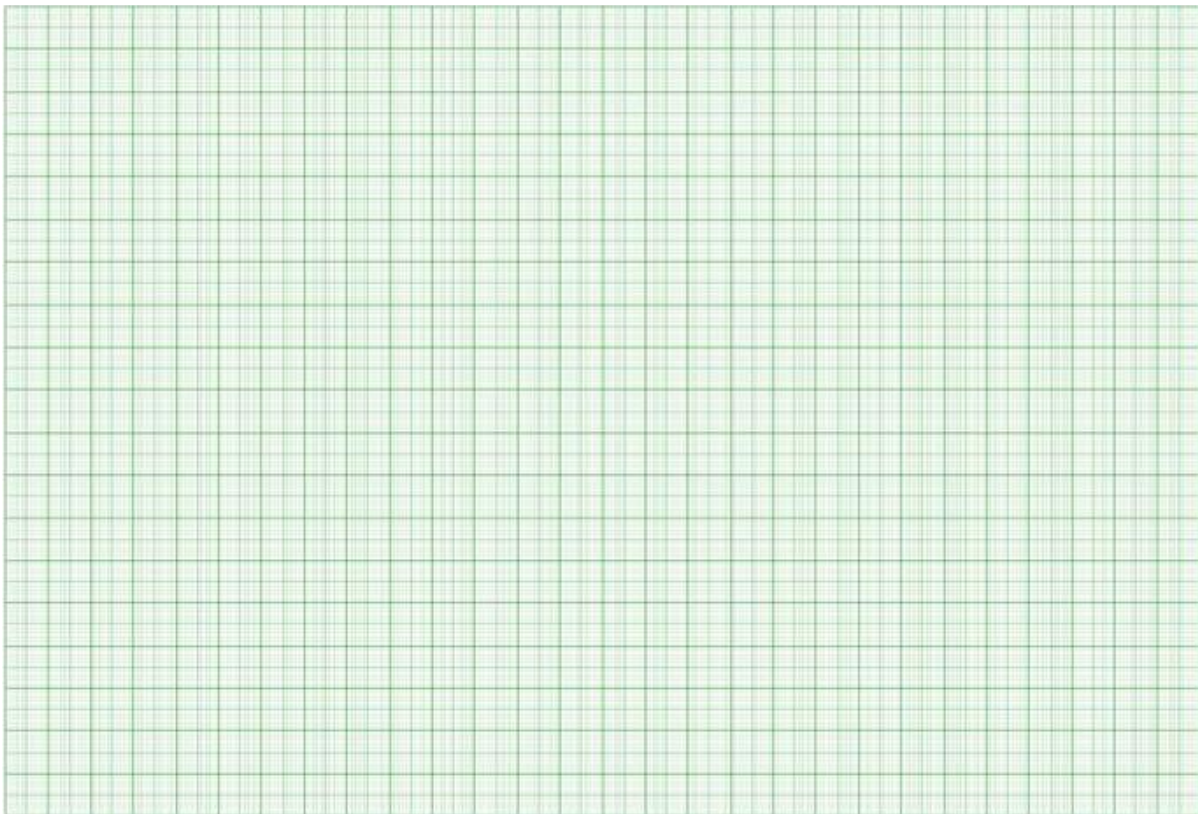
7.5 Measurements and Results

Table 7.1 Calibration curve data

Measurement	Current (A)	Deviation (mA)	B (T)
1			
2			
3			
4			
5			
6			

7			
8			
9			
10			

Figure 7.4 The graph of Deviation-Magnitude of Magnetic field

7.6 Questions

1. Which conditions should be met in order to increase the magnetic field formed by the Helmholtz coil? Please describe briefly.

2. A current in a conductor produces a magnetic field that can be calculated using the Biot–Savart law. Because current is defined as the rate of flow of charge, what can you conclude about the magnetic field produced by stationary charges? What about that produced by moving charges?

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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.

Experiment 8

Transformers

DEU Faculty of Science

PhysicsDepartment

Purposes

To verify the relationship between the number of turns, the voltage and the current in a transformer's coils.

8.1 Preparation Questions

1. What is a Transformer? Whatare the types according to the purpose of use, where are they used?

2. What is the working principle of Transformers?

8.2 Faraday's Law

Faraday's law of induction states that the emf induced in a circuit is directly proportional to the time rate of change of magnetic flux through the circuit:

$$\varepsilon = -\frac{d\Phi_B}{dt} \qquad 8.1$$

where $\Phi_B = \int \vec{B}.d\vec{A}$ is the magnetic flux. If the circuit is a coil consisting of N loops all of the same area and if Φ_B is the magnetic flux through one loop, an emf is induced in every loop. The loops are in series, so their emfs are added; thus, the total induced emf in the coil is given by the expression

$$\varepsilon = -N\frac{d\Phi_B}{dt} \qquad\qquad 8.2$$

Suppose that a loop enclosing an area A lies in a uniform magnetic field $\vec{B}$, as shown in Figure 8.1. The magnetic flux through the loop is equal to $BA\cos\theta$; hence, the induced emf can be expressed as

$$\varepsilon = -\frac{d}{dt}(BA\,cos\theta) \qquad\qquad 8.3$$

From this expression, it is seen that an emf can be induced in the circuit in several ways:

- The magnitude of $\vec{B}$ can change with time.
- The area enclosed by the loop can change with time.
- The angle θ between $\vec{B}$ and the normal to the loop can change with time.
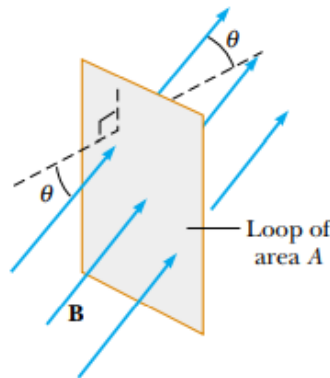

Figure8.1 A conducting loop that encloses an area A in the presence of a uniform magnetic field $\vec{B}$. The angle between $\vec{B}$ and the normal to the loop is θ.

8.2.1 Transformers

When electric power is transmitted over great distances, it is economical to use a high voltage and a low current to minimize the I^2R loss in the transmission lines. The consumer device at the receiving end of such lines, requires power at a low voltage (for safety and for efficiency in design). Therefore, a device, that can change the alternating voltage and current without causing appreciable changes in the power delivered, is required. Transformers are devices that increase or decrease current (I) or voltage (V) to the required value in alternating circuits.

AC transformer consists of two coils of wire wound around a core of iron, as illustrated in Figure8. 2. The coil on the left, which is connected to the input alternating voltage source and has N_p turns, is called the primary winding (or the primary). The coil on the right, consisting of N_s turns is called the secondary winding (or the secondary). The purpose of the iron core is to increase the magnetic flux through the coil and to provide a medium in which nearly all the magnetic field lines through one coil pass through the other coil.

Faraday's law states that the voltage across the primary is

$$\Delta V_p = -N_p \frac{d\,\Phi_B}{dt}$$
<div align="right">8.4</div>

where Φ_B is the magnetic flux through each turn. If we assume that all magnetic field lines remain within the iron core, the flux through each turn of the primary equals the flux through each turn of the secondary. Hence, the voltage across the secondary is

$$\Delta V_s = -N_s \frac{d\,\Phi_B}{dt}$$
<div align="right">8.5</div>

Solving Equation 8.4 for $d\,\Phi_B/dt$ and substituting the result into Equation 8.5,

$$\Delta V_s = \frac{N_s}{N_p} \Delta V_p$$
<div align="right">8.6</div>

When $N_s > N_p$ the output voltage ΔV_s exceeds the input voltage ΔV_p. This setup is referred to as a step-up transformer. When $N_s < N_p$ the output voltage is less than the input voltage, and this is a step-down transformer.
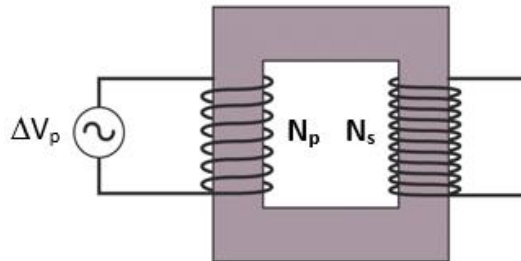

Figure8.2 Transformer consists of two coils wound on the same iron core.

In an ideal transformer, where there are no losses, the power $\Delta V_p I_p$ supplied by the source is equal to the power $\Delta V_s I_s$ in the secondary circuit. That is,

$$\Delta V_p I_p = \Delta V_s I_s \qquad\qquad 8.7$$

N_p, N_s being the number of turns of the coils in the primary and secondary parts, respectively,

$$\frac{N_p}{N_s} = \frac{\Delta V_p}{\Delta V_s} = \frac{I_s}{I_P} \qquad\qquad 8.8$$

In the absence of a ferromagnetic core, the magnetic field lines formed in the primary winding will be transferred to the secondary circuit, but in this case, the transformer will not work efficiently as a large loss will occur. The efficiency for the transformer in Figure 8.2 is the ratio of the power $\Delta V_s I_s$ in the secondary circuit to the power $\Delta V_p I_p$ supplied by the source.

$$\frac{I_s \Delta V_s}{I_p \Delta V_p} \qquad\qquad 8.9$$

8.3 Tools to be used in the experiment

- Coils with different number of turns
- Iron core
- Multimeter
- AC power supply

8.4 Experimental Procedure

- Put two coils with different winding numbers side by side as in Figure 8.2, without using iron core.
- Connect a voltmeter to both coils. Apply alternating current to the primary side.
- Observe the relationship between the voltage values across the primary and secondary side. Interpret your observation results. Record the measurement results in the table 8.1.
- Connect an ampermeter to both coils. Observe the relationship between the current values across the primary and secondary side. Record the measurement results in the table 8.1.
- Put two coils with different winding numbers side by side as in Figure8.2, and connect them by using iron core.

- Connect a voltmeter to both coils. Apply alternating current to the primary side. Record the measurement results in the table.

- Connect an ampermeter to both coils. Record the measurement results in the table 8.2.

- Calculate the efficiency using Equation 8.9 and record in the table.

- Interpret your observation results. Discuss the difference(s) between the observation (or measurement) results and the corresponding reasons.

8.5 Measurements and Results

Table8.1 Transformer consisting of two coils without using an iron core

Measurement	N_p	N_s	ΔV_p (V)	ΔV_s (V)	I_p (A)	I_s (A)	Efficiency (%)
1							
2							

Table8.2 Transformer consisting of two coils wound on an iron core

Measurement	N_p	N_s	ΔV_p (V)	ΔV_s (V)	I_p (A)	I_s (A)	Efficiency (%)
1							
2							

8.6 Questions

1. Does Equation 8.8 apply to non-ideal transformers? Explain.

2. What is the purpose of ferromagnetic iron core used in the experiment?

3. Explain what you would observe if you applied DC (direct current) to the system instead of AC (alternating current) in this experiment.

References

1. Dokuz EylulUniversity, Faculty of Science, Department of Physics, Physics II LaboratoryBooklet, 2016.

2. Raymond A. Serway, Robert J. Beichner, PhysicsforScienceandEngineering 2, 5th Edition, 2000.