King Saud University
College of Applied Engineering
(Muzahmia Branch)

Physics for Engineering II
(PHYS 1220)

Laboratory Manual
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Experiments are prepared by the following instructors:

Experiment	Prepared and written by
Lab # 1: Confirming Coulomb's law -Measuring with the torsion balance, Schürholz design	Dr. Rihem Farkh
Lab # 2: Capacitors in Series & Parallel	Dr. Rihem Farkh
Lab # 3: Ohm's Law, Measurement of Voltage, Current and Resistance	Dr. Rihem Farkh
Lab # 4: Dependence of Resistance on Temperature	Dr. Abdelouahab Bentrcia
Lab # 5: Resistors in Series & Parallel	Dr. Rihem Farkh
Lab # 6: RC circuit charging and discharging	Dr. Abdelouahab Bentrcia
Lab # 7: Thomson's experiment to measure e/m of an electron	Eng. Altamash Raza
Lab # 8: Measuring the earth's magnetic field with a rotating induction coil (earth inductor)	Eng. Ahmed Nafees
Lab # 9: Measuring the magnetic field on circular conductor loops	Dr. Abdelouahab Bentrcia
Lab #10: Current balance	Eng. Ahmed Nafees
Lab #11: Induced EMF	Eng. Mohamed Nadeem

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Sample Cover Page of the Lab Report

Course ID and Name:	
Semester /Year:	
Experiment number and Title:	
Student's Name:	**Name of Lab Instructor:**
Date of Report Submission:	**Grade:**

Laboratory Safety

General Safety Rules

- Follow directions. Come to lab prepared to perform the experiment. Follow all written and verbal instructions. When in doubt, ask.
- Report all accidents, injuries or breakage to the instructor immediately. Also, report any equipment that you suspect is malfunctioning.
- Use equipment with care for the purpose for which it is intended.
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- Ask the instructor to check all electrical circuits before you turn on the power.
- When working with electrical circuits, be sure that the current is turned off before making adjustments in the circuit.
- Do not connect the terminals of a battery or power supply to each other with a wire. Such a wire will become dangerously hot.
- Return all equipment, clean and in good condition, to the designated location at the end of the lab period.
- Leave your lab area cleaner than you found it.

Experiment
1

Confirming Coulomb's law -Measuring with the torsion balance, Schürholz design

Purpose:

- Determination of the force as function of the distance between the charged spheres.
- Determination of the force as function of the amount of charge on the spheres.

Principles

A free standing sphere charged by Q_1 produces a radially symmetric electric field

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{Q_1}{r^2}\frac{\vec{r}}{r} \qquad (1)$$

$\vec{E}$: electric field of charge Q_1

Q_1: charge of sphere 1

$\varepsilon_0 = 8.85 \cdot 10^{-12}$ As/Vm (permittivity)

r: distance from the center of the sphere

$\frac{\vec{r}}{r}$: unit vector in radial direction from Q_1

A second sphere charged by Q_2 experiences a force $\vec{F}$ when placed in the electric field $\vec{E}$ of charge Q_1:

$$\vec{F} = Q_2\vec{E} \qquad (2)$$

$\vec{E}$: electric field of charge Q_1

Q_2: charge of sphere 2

From equation (I) and (II) we obtain the Coulomb's law

$$\vec{F} = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2}\frac{\vec{r}}{r} \qquad (3)$$

In this experiment the Coulomb force between two charged spheres is measured using the torsion balance (Schürholz design). The force is measured as function of the distance r between the spheres (part 1) and as function of the charges Q_1 and Q_2 to confirm equation (III).

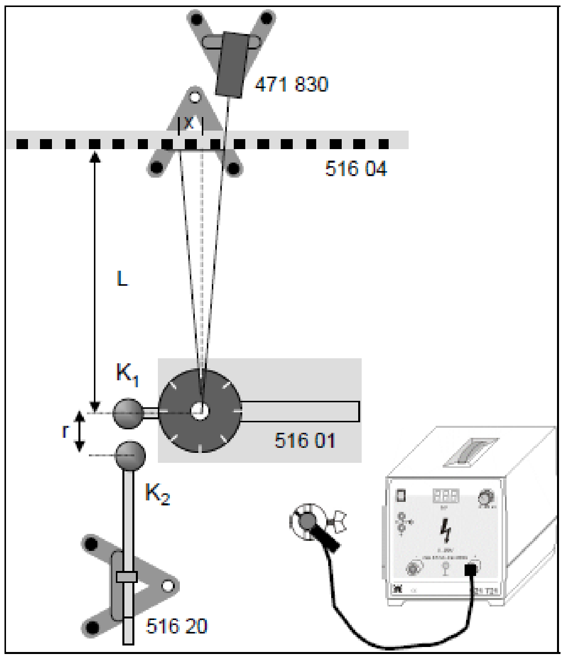


Fig. 1: Schematic diagram of experimental setup (wiring diagram) with the torsion balance to confirm Coulomb's law of electrostatics.

Setup

- Calibrate the torsion balance see part a.) "Carrying out the experiment". Refer also to the instruction manual 516 01 of the torsion balance.
- Insert the metal sphere K_1 with holder into the sensitive system of the torsion balance.
- Mount the He-Ne-Laser and the scale on stand. Adjust the mirror and the He-Ne-Laser at a distance L of at least 2 m (Fig. 1).
- Place the rod with the second metal sphere K_2 in the ad-justable stand.
- Set the marker on the stand guide rod to 3.1 cm and move the stand towards the torsion balance so that the distance between K_1 and K_2 is 1 mm (Fig. 1.). The center points of the spheres are than 3.1 cm apart (sphere diameter 3.0 cm). Thus the marker setting of the guide rod now al-ways gives the distance between the sphere center points. (This only applies if the spheres are not charged. The error of the

Carrying out the experiment

Before measuring the torsion balance has to be calibrated. There are two methods

a) Calibration of torsion balance (static method)

- For static method lay the balance to one side. The stand rod of the upper plate serves as a support.

- Insert the small calibration rod (length 11 cm) into the ro-tary body and adjust it horizontally by turning the wheel at the head of the torsion balance. Mark the position of the pointer.

- Insert the weight (m = 0.5 g) at one of the two groves at the tip of the calibration bar. Return the pointer to the pre-vious mark by turning the wheel at the head of the torsion balance and measure the angle α_1.

- Repeat the experiment with the weight on the opposite grove of the calibration bar to determine the angle α_2.

- Now the restoring torque D can be determined according the following relation (Note: The torque of the calibration bar exerts on both wires, which is the reason of the factor 2):

$$M = m.g.b = D\frac{\alpha}{2}$$
$$D = \frac{2.m.g.b}{\alpha} \qquad (4)$$

m = 0.5 g (calibration mass)

g = 9.81 m/s^2

b = 50 mm (length of calibration bar)

Calibration of torsion balance (dynamic method)

- For dynamic method insert the large calibration rod (length 24 cm) into the rotary body.
- Determine the period of oscillation T (without damping vane) by measuring several times with the stop clock.
- The restoring torque follows from the known oscillation equation:

$$D = 4\pi^2 \frac{J}{T^2}$$

$J = \frac{1}{12} \cdot m \cdot \ell^2 = 2{,}72 \cdot 10^{-4} \mathrm{kgm}^2$ (moment of inertia)

T: period of oscillation

b) Measuring of the force as function of the distance

- Before measuring the torsion balance has to be calibrated.
- Place the sphere K_2 3.1 mm away from sphere K_1 (center points).
- Now charge both spheres by carefully stroking them with a rubbed plastic rod or transferring the charge from the high voltage power supply. The deflection of the light pointer should be of about 20 cm for a sphere distance r of a about 4 mm.
- Measure the displacement x as function of the various distances r between the charged spheres.
- Measure the distance L between the scale and the mirror.

b) Measuring of the force as function of the distance

Table 1: Distance r and deflection x

Table 1: Distance r and deflection x

$\frac{r}{cm}$	$\frac{x}{cm}$
8	
10	
12	
14	
16	
18	
20	

Distance L = 2.05 m

c) Measuring of the force as function of the amount of charge

Table 2: Deflection x for different charges Q_1 and Q_2 at distance of r = 10 cm.

Q_1	Q_2	$\frac{x}{cm}$
Q	Q	
Q	½Q	

Q_2 = 14 nAs

Q_3 = 15 nAs

Evaluation and results

Using equation (VII) allows to determine the electrostatic force F between the charged spheres:

Table 3: Distance r and deflection x

$\frac{r}{cm}$	$\frac{x}{cm}$	$\frac{F * 10^{-5}}{N}$
8	40.9	
10	24.0	
12	16.5	
14	12.0	
16	9.0	
18	7.0	
20	5.9	

Experiment
2

Capacitors in Series & Parallel

Short description:

In this experiment you will determine how voltages are distributed in capacitor circuits and explore series and parallel combinations of capacitors.

Equipment

- Two 10μF capacitors
- Multimeter
- Cables

Theory

Capacitors are electronic devices which have fixed values of capacitance and negligible resistance. The capacitance C is the charge stored in the device, Q, divided by the voltage difference across the device ΔV:

$$C = \frac{Q}{\Delta V} \qquad (1)$$

The schematic symbol of a capacitor has two vertical (or horizontal) lines a small distance apart (representing the capacitor plates) connected to two lines representing the connecting wires or leads).

There are two ways to connect capacitors in an electronic circuit - series or parallel connection.

1- <u>Series</u>

In a series connection the components are connected at a single point, end to end as shown below:

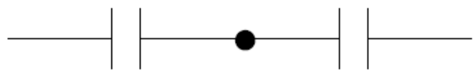


Figure 1: series combination

For a series connection, the charge on each capacitor will be the same and the voltage drops will add. We can find the equivalent capacitance, C_{eq}, from:

$$\frac{Q}{C_{eq}} = \Delta V = \Delta V_1 + \Delta V_2 = \frac{Q}{C_1} + \frac{Q}{C_2} = Q\left(\frac{1}{C_1} + \frac{1}{C_2}\right)$$

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$$

so that for N capacitors the equivalent capacitance is given by:

$$\frac{1}{C_{eq}} = \sum \frac{1}{C_i} \qquad (2)$$

2- <u>Parallel</u>

In the parallel connection, the components are connected together at both ends as shown below:

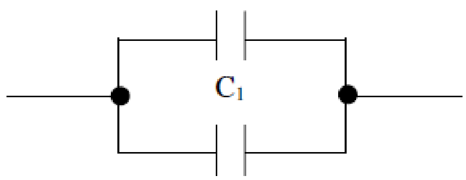


Figure 2: parallel combination

For a parallel connection, the voltage drops will be the same, but the charges will add. Then the equivalent capacitance can be calculated by adding the charges:

$$Q = C_{eq}\Delta V = Q_1 + Q_2 = C_1\Delta V + C_2\Delta V = (C_1 + C_2)\Delta V$$

$$C_{eq} = C_1 + C_2$$

so that for N capacitors the equivalent capacitance is given by:

$$C_{eq} = \sum C_i \qquad (3)$$

Experimental Procedure

1- Make sure that each capacitor is discharged (V=0) by touching the ends of the lead wire to the terminals of the capacitor.
2- Use the capacitance meter to measure the capacitance of each capacitor. Record the values in your data table.
3- Wire the capacitors in series as shown in figure 1**.** Pay attention to the polarity of capacitors and the way they are connected.
4- Using a capacitance meter, measure the capacitance of the series combination (connect the meter to the free ends). This is $C_{eq,measured}$

5- Disconnect the capacitors, discharge each capacitor as you did before and wire the circuit in parallel as shown in figure 2.
6- Using a capacitance meter, measure the capacitance of the parallel combination. This is $C_{eq,measured}$

Analysis

- For both parallel connection and series connection, calculate the percentage error between the predicted (calculated) and measured values of the equivalent capacitor.
- In your opinion, what is the source of the error?

Series connection		Parallel connection	
Calculated	Measured	Calculated	Measured
C_1	C_1	C_1	C_1
C_2	C_2	C_2	C_2
C_{eq}	C_{eq}	C_{eq}	C_{eq}

Experiment
3

Ohm's Law, Measurement of Voltage, Current and Resistance

Purpose

In this experiment you will learn to use the multi-meter to measure voltage, current and resistance.

Equipment

Variable DC power supply, resistor (1MΩ), multimeter, and ammeter.

Theory

The measurements of voltage, current, and resistance that you will make will be made using direct current (D.C.). D.C. refers to direct current which flows in only one direction down a wire. Usually it is a steady current, meaning that its magnitude is constant in time. "D.C." can also be used to refer to voltage. Of course, unlike current, voltage does not "flow". Instead, "D.C. voltage" (or "D.C. potential") means a constant voltage which has only one polarity. One of the major concepts that will be used in this experiment is Ohm's law. This law states the relation among the three quantities voltage, current, and resistance:

$$\mathbf{V = IR}$$

where I is the current measured in units of amperes, (I), V is the voltage in units of volts, (V) and R is the resistance in units of Ohms, (Ω).

Figure 1 shows the standard symbols for showing a battery and a resistor in a circuit. Remember that current flows from positive to negative, representing the flow of positive charge in the wire.

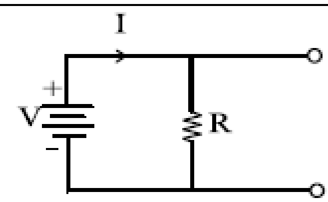


Figure 1: Diagram showing a voltage forcing a current to flow through a resistor.

The Experiment

Part 1:

1- There are two ways to find out what the value of any given resistor is.

- **a.** You can measure the resistance using the function marked Ω on your multi-meter. (kΩ means kilo-ohms or ohms x 1000. MΩ means mega-ohms or ohms x 1,000,000.)
- **b.** Measure several different resistors with your ohmmeter and record the values in Data Table 1.

Resistor	Measured Resistance (Ω)	Resistance value	% diff
Resistor 1			
Resistor 2			

Part 2:

1- Connect the circuit as shown by the diagram in Figure 2. Use the variable power supply and a 1MΩ resistor. Adjust the power supply voltage to 5 volts.

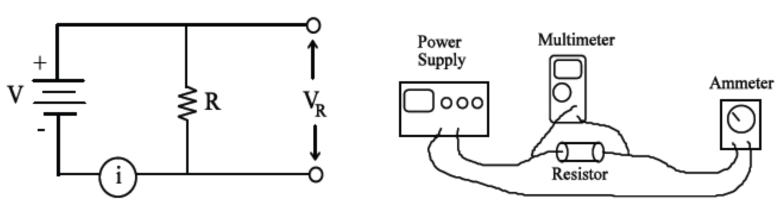


Figure 2A Figure 2B

Figure 2 - A: Circuit diagrams, B: Actual connections for the circuit shown on the left

2 - Use the multi-meter to measure the voltage across the resistor (V_R).

3. Use the ammeter to measure the current through the resistor (I).

4. Record your measurements of voltage and current in Data Table 2.

5. Repeat steps 2 through 4 for 10 different values of voltage, in steps of 1V. Record all measurements in your table.

Part 3 – Analysis:

1. Plot data in Table 2, with current on the x-axis and voltage on the y-axis. As you may have noticed, Ohm's law is an equation in the form of a straight line:

$$\mathbf{V = RI} \quad => \quad \mathbf{y = mx + b}$$

In the case of Ohm's law, we have (ideally) the slope m = R and the y-intercept b = 0. Fit a straight line to the data. What value do you get for the resistance? (Important: in order to get your slope (R) in units of Ohms, you must have current in units of Amperes and voltage in units of Volts. If you originally recorded your current data in units of milliamps, or some other unit, be careful to convert back to Amps!)

2. Measure the resistor you used with the ohmmeter. Is the value similar to the value you calculated from the slope of your line? Calculate the percent difference between the two values of R.

Data Table 2

Power Supply Voltage, V	Voltage Across Resistor, VR,	Current, I (A)

Trend line equation (y=): ___________________
Slope = ______________
R (theoretical value) = ___________
Percent difference of Slope and R= _________________

Questions

1. In Part 2 of the experiment, was the value of the resistance you obtained from your graph within the tolerance given by the resistor's color code? Explain.
3. List some possible sources of error that might have affected your measurements in Part 2 of the experiment.
4. Is a plot of current vs. voltage ALWAYS a straight line? Explain why or why not.

Experiment

4

Dependence of Resistance on Temperature

Purpose

- Understand the dependence of resistance on temperature
- Determine the temperature coefficient of a resistor constructed from an unknown.

Theory

The resistance of a resistor varies with temperature. This variation can be simplified to a linear function over a reasonable temperature range as follows:

$$R = R_o[1 + \alpha(T - T_o)] \qquad (1)$$

Hence:

$$\alpha = \frac{1}{R_0}\frac{\Delta R}{\Delta T} = \frac{1}{R_0} slope \qquad (2)$$

Where

$$\Delta R = R - R_0 \text{ and } \Delta T = T - T_0. \qquad (3)$$

Equipment and Materials

- 1 Resistor
- 1 Power supply
- 1 ohmmeter
- 1 Switch
- 1 thermometer

Procedure

a. Connect the circuit shown in Fig. 1 below (Note: Your instructor will check your circuit).

b. Before closing the switch, measure the resistance and the temperature of the resistor.
c. Close the switch and start measuring both resistance and temperature by taking steps of 1 degree Celsius.
d. Take 20 measurements and write down the results in table 1.

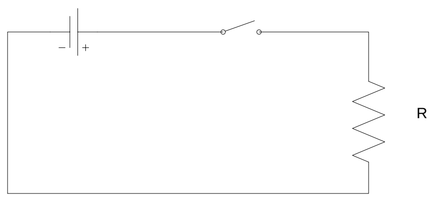


Fig.1: Experimental setup.

Analysis and discussion

a. Plot the graph R versus T.
b. Select a region in which the curve is a linear and select two points in this region $P_0(T_0, R_0)$ and $P_1(T_1, R_1)$.
c. Calculate the slope of the curve using the two points as follows:

$$\text{Slope} = (R_1 - R_0)/(T_1 - T_0).$$

d. Calculate the temperature coefficient using equation (2).
e. Compare the result obtained with the temperature coefficients detailed in Appendix 1 and determine which material that most probably has been used in constructing the resistor used in this experiment.

Table 1: resistance versus temperature

Temperature (Celsius)	R (ohm)
20	
20.5	
21	
21.5	
22	
23	
24	
25	
27	
29	
30	
31	
32	
33	
35	
36	

37	
38	
40	
42	
44	
46	
48	
50	
52	
54	
56	
58	
60	

Table 27.1

Resistivities and Temperature Coefficients of Resistivity for Various Materials

Material	Resistivity[a] $(\Omega \cdot m)$	Temperature Coefficient[b] $\alpha[(°C)^{-1}]$
Silver	1.59×10^{-8}	3.8×10^{-3}
Copper	1.7×10^{-8}	3.9×10^{-3}
Gold	2.44×10^{-8}	3.4×10^{-3}
Aluminum	2.82×10^{-8}	3.9×10^{-3}
Tungsten	5.6×10^{-8}	4.5×10^{-3}
Iron	10×10^{-8}	5.0×10^{-3}
Platinum	11×10^{-8}	3.92×10^{-3}
Lead	22×10^{-8}	3.9×10^{-3}
Nichrome[c]	1.50×10^{-6}	0.4×10^{-3}
Carbon	3.5×10^{-5}	-0.5×10^{-3}
Germanium	0.46	-48×10^{-3}
Silicon	640	-75×10^{-3}
Glass	10^{10} to 10^{14}	
Hard rubber	$\sim 10^{13}$	
Sulfur	10^{15}	
Quartz (fused)	75×10^{16}	

[a] All values at 20°C.

[b] See Section 27.4.

[c] A nickel–chromium alloy commonly used in heating elements.

Experiment

5

Resistors in Series & Parallel

Purpose

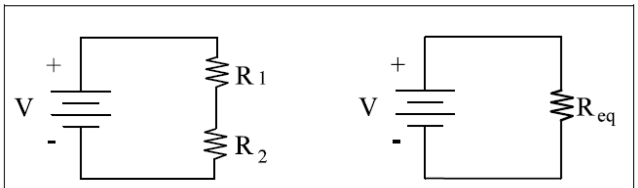
In this experiment you will set up three circuits: one with resistors in series, one with resistors in parallel, and one with some of each. This experiment should show you the difference between resistors in series and parallel.

Equipment

Resistors (R1 = R2=1 MΩ,), multimeter, and DC power supply

Theory

In the first part of this experiment we will study the properties of resistors, which are connected "in series". Figure 1 shows two resistors connected in series (a) and the equivalent circuit with the two resistors replaced by an equivalent single resistor (b). Remember that, when resistors are connected in series, each one "sees" the same current.
$R_{eq} = R_1 + R_2$



(a) The actual circuit. *(b) The equivalent circuit*
Figure 1. Resistors connected in series.

Of course, this equation can be extend to any number of resistors in series, so that for N resistors the equivalent resistance is given by:

$$R_{eq} = \sum R_i \quad for\ \ i = 1..N$$

In the second part of this lab we'll hook them together as in Figure 2.

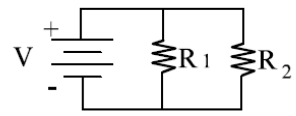


Figure 2: Two resistors in parallel

We say these resistors are connected in parallel. In series they were connected one after the other, but in parallel, as the name suggests, they are 'side by side' in the circuit. When resistors are in parallel, the current flowing from the battery will come to a junction where it has a “choice” as to which branch to take.

Resistors in parallel “see” different currents, but they each experience the same potential difference (voltage). We used this property of resistors in parallel to derive an equation for calculating the equivalent resistance:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$

It’s important to remember that after you do this calculation, you will have gotten **$1/R_{eq}$**. You have to flip that over in order to get **R_{eq}**!

Here’s an example: If we have **R_1** = 270 Ω and **R_2** = 330 Ω we would find **R_{eq}** as follows:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{270} + \frac{1}{330} = 0.006734\Omega^{-1}$$

So, $R_{eq} = 148\,\Omega$

We can generalize this equation to any number of resistors, just the way we did for resistors in series. As in the case for series we can generalize this law to any number of resistors:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + .. + \frac{1}{R_N} = \sum \frac{1}{R_i}$$

The Experiment

1- Part 1

1. Take two resistors. Measure the resistance of each resistor individually using the ohmmeter (i.e., the multimeter). Record the values in Data Table 1.
2. Now, connect the resistors in series, as shown in Figure 1a, and connect them to the power supply that is set at 12 V. Record the voltage across each resistor, using the multimeter. Record the measured values in Data Table 1.

Data Table 1

R_1 (measured)		V_1 (measured)		I_1 (calculated)	
R_2 (measured)		V_2 (measured)		I_2 (calculated)	

Questions: Part 1

1. Are the voltages V1 and V2 equal to each other? Why or why not?
2. Calculate the total voltage V = V1 + V2. Explain why it has the value it does.
3. Use Ohm's law to calculate the current through each resistor. (e.g., V1=I1*R1, so I1=V1/R1). For this calculation, use the measured value of the resistances. Record these calculated values in the table above. Is the result what you expected? Why?

Part 2

In this part of the experiment, you will experimentally test the addition law for resistors in parallel.

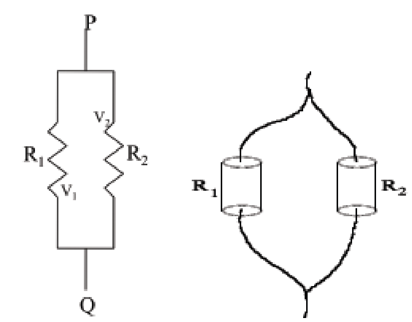


Figure 4: Two resistors attached in parallel

1. Take two resistors. Measure the resistance of each resistor individually using the ohmmeter (i.e., the multimeter). Record the values in Data Table 2.
2. Now, connect the resistors in parallel, as shown in Figure 4, and connect them to the power supply that is set at 12 V. Record the voltage across each resistor, using the multimeter. Record the measured values in Data Table 2.
3. Calculate the equivalent resistance ($\mathbf{R_{eq}}$) of the circuit, based on your *measured* values of R1 and R2. Enter the value at the top of Data Table 2.
4. Measure the equivalent resistance of the circuit using the ohmmeter. This is the resistance between points **P** and **Q** in Figure 4a. Record the value at the top of Data Table 2.
5. Use Ohm's law, with your *measured* value of $\mathbf{R_{eq}}$, to calculate the total current in the circuit. Enter the value at the top of Data Table 2.

Data Table 2

R_1 (measured)		V_1 (measured)		I_1 (measured)	
R_2 (measured)		V_2 (measured)		I_2 (measured)	

R_{eq}=…… **R_{eq} (**measured**) =……** **I total =…….**

Questions: Part 2

1. Is your measured value of Req similar to your calculated value? Explain.
2. Are V1 and V2 equal to each other? Explain.
3. Are I1 and I2 equal to each other? Explain.
4. Compare Itotal to the I1 and I2. What do you notice?

Experiment

6

RC circuit charging and discharging

Purpose

- Understand the charging and discharging transient processes of a capacitor
- Understand the physical meaning of the RC constant
- Determine the RC constant.

Theory

When an uncharged capacitor and a resistor are initially connected in series to a voltage source, charge will flow in the circuit until the capacitor becomes fully charged, at which point the charge stored on its plates is $Q = C\ V_C$, where C is the capacitance (in Farads) of the capacitor, and V_C is the voltage across this capacitor. When the voltage source is removed and replaced by a simple piece of wire, the charge on the capacitor returns to zero; the capacitor discharges.

The voltage on the capacitor of a discharging RC circuit is given by

$$V_C\,(t) = V_0\ e^{-t/\tau} \tag{1}$$

and for a charging RC circuit by

$$V_C\,(t) = V_0\,(1-e^{-t/\tau}) \tag{2}$$

Where τ= RC and is referred to as the time constant of the circuit, since it determines the rate of the exponential decay or rise of the voltage, and V_0 equals the maximum potential difference across the capacitor.

Equipment and Materials

- 1 Resistor 1 MΩ
- 1 Capacitor 10 μF
- 1 Power supply

- 1 Voltmeter
- 1 Switch
- 1 Timer

Procedure

Charging Circuit

e. Connect the circuit as shown in Fig.1 (Note: Your instructor will check your circuit).
f. Set the switch to position 2 so that the capacitor is discharged from any residual charge.
g. Set the power supply to 12V
h. Set the switch to position 1 and start the timer simultaneously. Using the timer and the voltmeter, take the voltage across the capacitor (V_C) every 10 seconds for at least 2 time constants (200 seconds) and write down the results in Table 1.

Discharging Circuit

b. Set the switch to position 2 and start the timer simultaneously. Using the timer and the voltmeter, take the voltage across the capacitor (V_C) every 10 seconds for at least 2 time constants (200 seconds) and write down the results in Table 1.

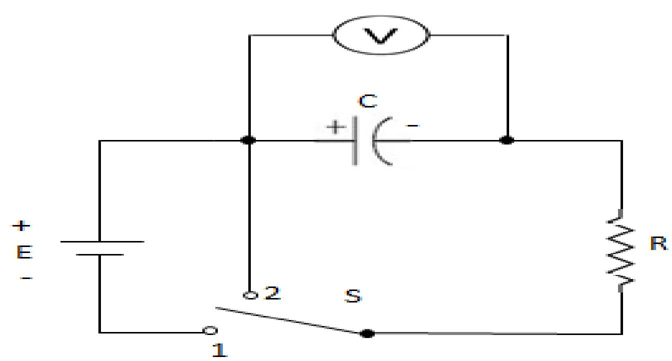


Fig.1: Experimental setup.

Analysis and discussion

a. Plot the graph V_C versus t for charging.
b. Determine the charging time constant (τ) from the plot (remember that τ corresponds to the time at which the voltage across the capacitor equals to $0.63V_C$).
c. Plot a graph V_C versus t for discharging.
d. Determine the discharging time constant (τ) from the plot (remember that τ here corresponds to the time at which the voltage across the capacitor equals to $0.37V_C$).
e. Compare between the measured value of time constant (τ) and the calculated time constant (τ = RC). Calculate the percentage error.

f. Discuss any source of the error in your conclusion.

Table 1

Time (second)	Charging V_C (V)	Discharging V_C (V)
0		
10		
20		
30		
40		
50		
60		
70		
80		
90		
100		
110		
120		
130		
140		
150		
160		
170		
180		
190		
200		

Experiment
7

Thomson's experiment to measure e/m of an electron

Purpose

- Investigation of the deflection of electrons in the electrical field of a plate capacitor
- Investigation of the deflection of electrons in the magnetic field of a Helmholtz pair of coils.

Theory

When the electrons move in the magnetic and electric field, these field exert force on the electrons. Due to this force exerted by the magnetic and (or) electric field, the path of electron deflected. To see this deflection we use the Thomson tube setup.

In the Thomson tube all the electrons pass a slit aperture behind the anode and tangentially hit a luminous screen with a cm grid which is set up at an angle to the path of the light. Here the electron beam becomes visible and allows quantitative analysis. At the outlet of the slit aperture a plate capacitor is mounted where the electron beam can be vertically deflected by an electrostatic field. In addition the electron beam can be deflected in the magnetic field of a Helmholtz pair of coils.

In the electric field an electron moves on a parabola-shaped curve. If the electron is accelerated by a given anode voltage Ua and then passes through the electric field of a plate capacitor with the voltage UP and the distance between the plates is d, the following applies for the path

$$y = \frac{\mathrm{E}}{4\mathrm{Ua}}.\mathrm{x}^2 \qquad (1)$$

Applying the correction factor, we get

$E_{exp} = 0.75\ E_{theo} = 0.75U/d$ (2)

Where d is the distance between the capacitor plate and U is the voltage.

In the magnetic field of a Helmholtz pair of coils, at right angles to the axis of the beam an electron will move on a circular track. For the curve along a circular track the following applies.

$y = r - \sqrt{r^2 - x^2}$ with $r = \left(\frac{2.m.Ua}{e.B}\right)^{1/2}$ (3)

The radius r depends on the anode voltage Ua and the magnetic field B of the pair of coils.

$B = \mu_{0}(4/5)^{3/2} . \frac{N.I}{R}$ (4)

Where : I is current, N is no. of windings and R is radius of coil.

Equipment and Materials

- Thomson tube.
- Pair of coils.
- 2 voltage sources.
- Power supply.

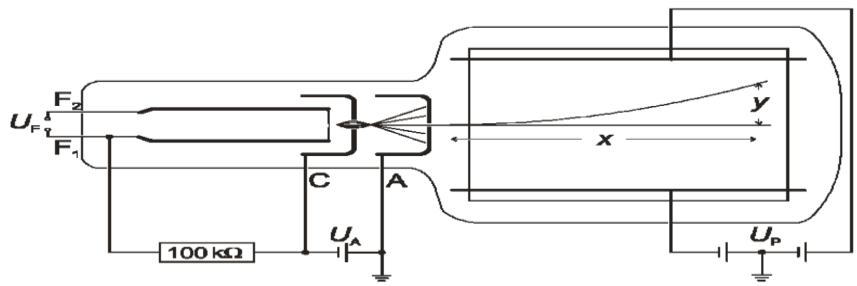


fig. 1 deflection in electric field

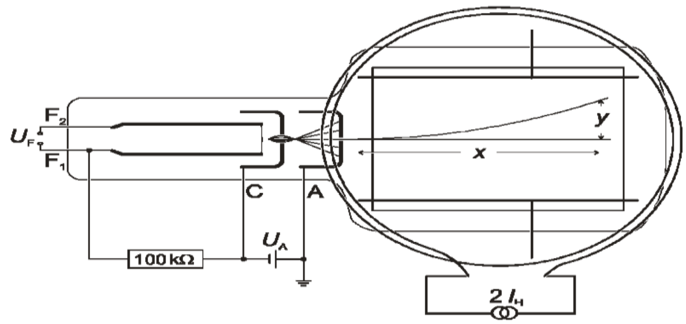


Fig.2 deflection in magnetic field

Procedure

- Make the connections as shown in Fig. 1 for the deflection in the electric field
- Make the connection as shown in Fig. 2 for the deflection in the magnetic field.
- The 100kΩ resistance is integrated in the tube stand (555 600).

For setting up, the steps described below are required:

a. Carefully insert the Thomson tube into the tube stand.
b. Connect sockets F1 and F2 on the tube stand for the cathode heater to the 10 kV output at the rear of the high voltage power supply.
c. Connect socket C on the tube stand (cathode cap of the Thomson tube) to the negative pole and socket A (anode) to the positive pole of the 10 kV high voltage power supply and in addition earth the positive pole.
d. Place the Helmholtz pair of coils in the positions marked with H (Helmholtz geometry) on the tube stand. A deviation from the Helmholtz geometry will lead to systematic errors in the calculation of the magnetic field. For this reason such a deviation should be kept as small as possible.
e. Adjust the height of the coils in such a way that the centers of the coils are aligned to the level of the beam axis.
f. Connect the coils in series to the direct current power supply so that the current indicated at the power supply corresponds to that flowing through the coils.
g. Ensure that the current flows in the same direction through the coils.
h. Connect one capacitor plate to the positive pole at the right-hand output, the other to the negative pole of the left hand output of the second 10 kV high voltage power supply and earth the middle socket of the high voltage power supply.

Carrying out the experiment

I. Measure the distance d between the capacitor plates.
II. Switch on the high voltage power supply. Now the cathode is being heated.

III. Slowly increase the anode voltage Ua and observe the beam slowly increasing in brightness at the center of the luminous screen.

Deflection in an electric field

I. While Ua < 5 kV is kept at a fixed value slowly increase the voltage at the capacitor plates UP and observe the change to the beam.
II. For different values of UA and UP read the value pairs (x; y) for the track from the luminous screen.
III. Then return the voltage UP to zero.

Deflection in the magnetic field

I. While Ua < 5 kV is kept at a fixed value slowly increase the current I through the Helmholtz pair of coils and observe the change to the beam.
II. For different values of Ua and I read the value pairs (x; y) from the luminous screen.

Analysis and discussion

a. If the voltage at the capacitor plates is increased, the electrons are deflected on a parabola-shaped track.
b. The direction of the deflection depends on the polarity of the applied voltage, the degree of the deflection on the applied voltage.
c. For Ua = 4.0 kV and various values of U_P value pairs (x; y) were read off.
d. The results are shown in the table below

x/cm	y/cm		
	U_p=2.0 KV	U_p=3.0 KV	U_p=5.0 KV
1.0	0.0	0.0	0.0
2.0	0.0	0.1	0.1
3.0	0.2	0.2	0.3
4.0	0.3	0.4	0.6
5.0	0.5	0.6	0.9
6.0	0.6	0.9	1.3
7.0	0.8	1.2	1.8
8.0	1.1	1.6	2.3
9.0	1.4	2.0	

Experiment
8

Measuring the earth's magnetic field with a rotating induction coil (earth inductor)

Purpose

- Determination of the components of the earth's magnetic field
- Determination of the inclination angle of the earth 's magnetic field.

Theory

When circular induction coil with N turns and an area $A = \pi \cdot R^2$ rotates at a constant angular velocity ω in an homogenous magnetic field B around its diameter d as an axis it is permeated by a magnetic flux

$$\phi = \pi.R^2.N.B.\cos(\omega.t) \qquad \text{(I)}$$

ω: angular velocity
R: radius of the induction coil
N: turns of the induction coil

Equation (I) assumes that the axis of rotation is perpendicular to the magnetic field B.

The magnetic field B can be determined from the amplitude of the induced voltage Uby

$$U = -\frac{d\phi}{dt} = \pi.R^2.N.B.\omega.\sin(\omega.t) \qquad \text{(II)}$$

Using the revolution time $T = 2\pi /\omega$ we find for the peak value of the induced AC voltage:

$$\hat{U} = \frac{2\pi^2 NR^2}{T}.B = a.B$$

(III)

$$a = \frac{2\pi^2 NR^2}{T} \qquad \text{(IV)}$$

For a rotation of the coil around the z-direction of a Cartesian coordinate system

the voltage amplitude

$$U_z = a.\sqrt{{B_x}^2 + {B_y}^2} \qquad \text{(V)}$$

is induced in the earth's magnetic field

$$\vec{B} = \begin{pmatrix} B_x \\ B_y \\ B_z \end{pmatrix} \qquad \text{(VI)}$$

For reasons of symmetry the following equations apply for orientations in the x or y

direction

$$U_x = a.\sqrt{{B_y}^2 + {B_z}^2} \qquad \text{(VII)}$$

$$U_y = a.\sqrt{{B_z}^2 + {B_x}^2} \qquad \text{(VIII)}$$

The components of the earth's magnetic field can be calculated by resolving the system of equations (V), (VII) and (VIII):

$$B_x = \sqrt{\frac{-U_x^2 + U_y^2 + U_z^2}{2a^2}} \qquad \text{(IX)}$$

$$B_y = \sqrt{\frac{U_x^2 - U_y^2 + U_z^2}{2a^2}} \qquad \text{(X)}$$

$$B_z = \sqrt{\frac{U_x^2 + U_y^2 - U_z^2}{2a^2}} \qquad \text{(XI)}$$

In particular, we have for the total value of the earth's magnetic field:

$$B = \sqrt{B_x^2 + {B_y}^2 + {B_z}^2} = \sqrt{\frac{U_x^2 + U_y^2 + U_z^2}{2a^2}} \qquad \text{(XII)}$$

The angle of the dip υ of the earth's magnetic field can be obtained by the relation:

$$\tan \upsilon = \frac{B_z}{\sqrt{B_x{}^2 + B_y{}^2}} = \sqrt{\frac{U_x^2 + U_y^2 - U_z^2}{2U_z^2}} \qquad \text{(XIII)}$$

This formula is mathematically correct, but due to unavoidable measurement imprecision the argument of the square root might become negative when the experiment is carried out close to the equator. For a solution see the end of this leaflet. In this experiment the axis of rotation of the induction coil is aligned in the x-, y- and z-direction of a rectangular time coordinate system successively. The amplitude of the induced voltage is measured as function of with CASSY in each case. From the recorded signals the amplitude and frequency is used to determine the strength and angle of the dip of the earth's magnetic field.

Equipment and Materials

- 1 Pair of Helmholtz coils
- 1 Sensor CASSY
- 1 µV-box
- 1 CASSY Lab
- 1 Connecting lead Ø 2.5 mm^2, 200 cm, red
- 1 Connecting lead Ø 2.5 mm^2, 200 cm, blue
- 1 Experiment motor
- 1 Control unit for experiment motor
- 1 PC with Windows 2000/XP/Vista

Procedure

Carrying out the experiment with experiment motor

- Load the CASSY example file "earth magnetic field". It has to be loaded from the hard disk by using the button or pressing the function key F3.
- Clear the example data by using the button or pressing the function key F4.
- Set the speed of the experiment motor to zero.
- Switch on the motor carefully and increase gently the speed to approximately 0.3 revolutions per second.
- Guide the twisted connecting leads by hand so that they are wound up by the experiment motor. Ensure that they are not get caught in the chuck while the conductor loop is rotating.
- Start the measurement of the induced voltage as function of time by pressing the function key F9 or using the button alternatively.
- The measurement stops automatically after 20s. For details of the

measurement parameters press two times to see the settings in the menu "measuring parameter".

- Make sure that the motor is switched off after the measurement is finished. Reverse the experiment motor's direction and stop the motor in good time.
- Change the axis of rotation to the x-direction and repeat the measurement for the same angular velocity.
- Finally turn the experiment motor by 90° degree to measure the induction voltage as function of time for the y- direction as axis of rotation.
- Measure the diameter d of the induction coil.

Carrying out the experiment without experiment motor

- Load the CASSY example file "earth magnetic field". It has to be loaded from the hard disk by using the button or pressing the function key F3.
- Clear the example data by using the button or pressing the function key F4.
- Start the measurement of the induced voltage as function of time by pressing the function key F9 or using the button alternatively.
- Rotate the induction coil manually around the z-direction.

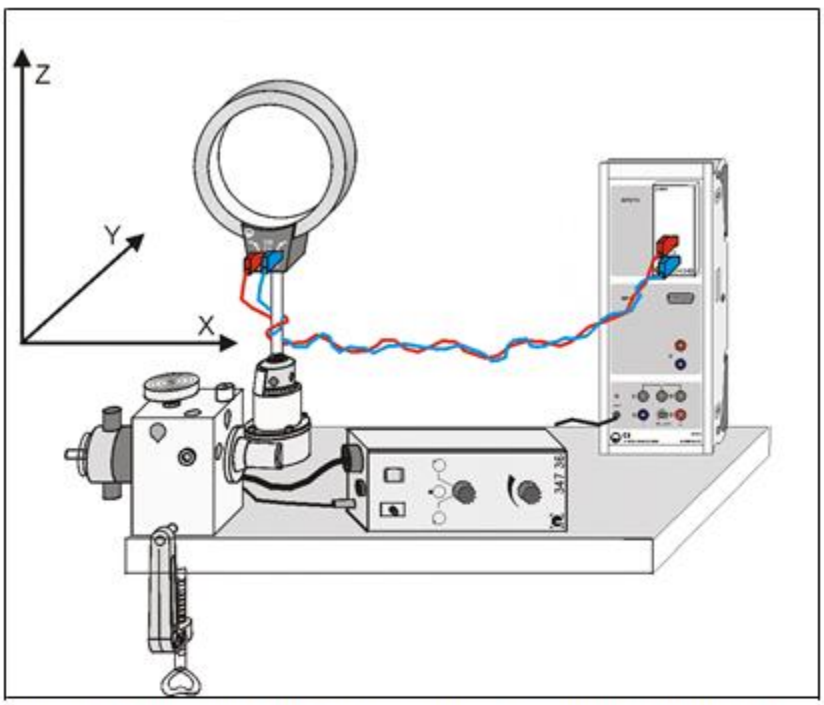


Fig. 1: Experimental setup with experiment motor (schematically).

Analysis and discussion

Evaluation and results

To determine the components of the earth’s magnetic field the amplitude and frequency has to be determined. There are several ways to determine the frequency.

Method I

- Click right mouse button in the display and choose “Set Marker/Measure Difference” (Fig. 2).
- Click e.g. on a zero voltage position and repeat this at the position after the period T.
- Alt T allows you to display the result of the status line in the display (Fig. 2).

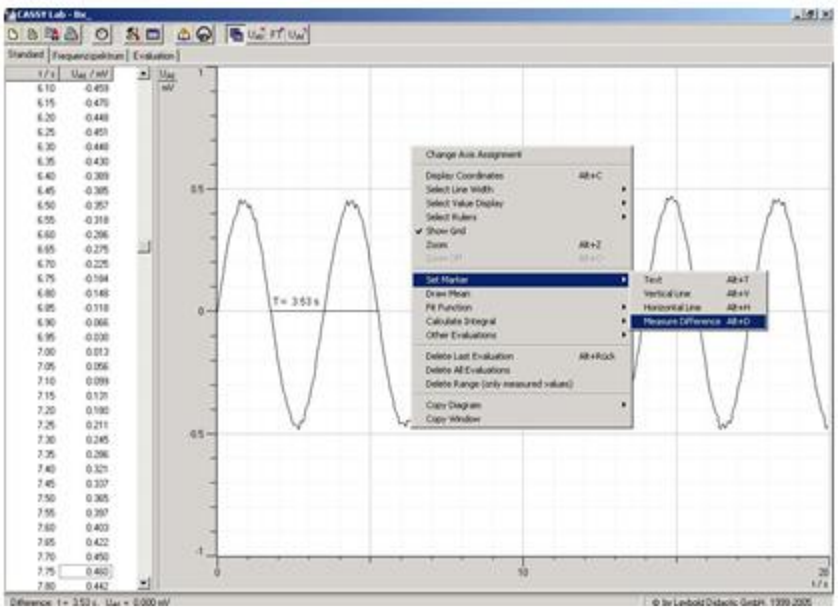


Figure 2: Determination of frequency (Method I)

Method II

- Click on the tab “Frequency Spectrum”.
- Click right mouse button in the display and choose “Other Evaluations” / “Calculate Peak Center” (Fig. 3).
- Mark the peak by dragging the mouse over the experimental data.
- Alt T allows you to display the result of the status line in the display (Fig. 3).

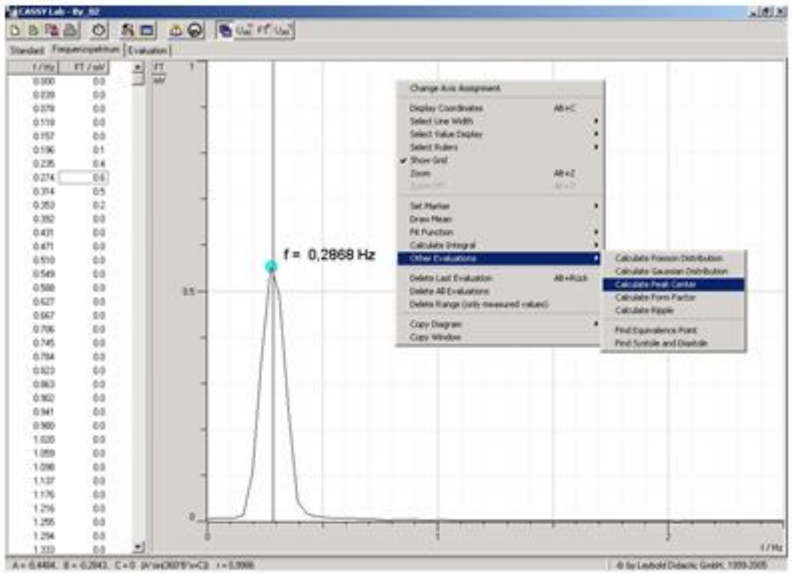


Figure 3: Determination of Frequency (Method II)

To determine the components of the earth's magnetic field the amplitude has to be determined. There are two ways to determine the amplitude of the induced voltage:

Method I

- Click right mouse button in the display and choose "Set Marker/Measure Difference".
- Click e.g. on a zero voltage position and repeat this at a position of maximum voltage.
- Alt T allows you to display the result of the status line in the display.

Method II

- Invoke the fitting tool by a clicking the right mouse button in the display and choose "Fit Function" / "Free Fit" or use the speed up key Alt F.
- First select the appropriate fit function – here:

$$f(x,A,B,C,D) = A*\sin(360*B*x+C) \qquad \text{(XIV)}$$

- Enter appropriate estimate values (Starting values) for the fit parameter (Fig. 4)

  A = U_0 = 1 mV (amplitude -read from y-axis of the diagram)

  B = 0.3 Hz (frequency -about 1 Hz)

  C = 0 (phase shift - zero due to measure conditions)

D = 0   (additional fit parameter -not used)

- Select “Display result automatically as a new channel”.
- Continue with the button “Continue with Range Marking”
- Alt T allows you to display the result of the fit quickly in the display.

-

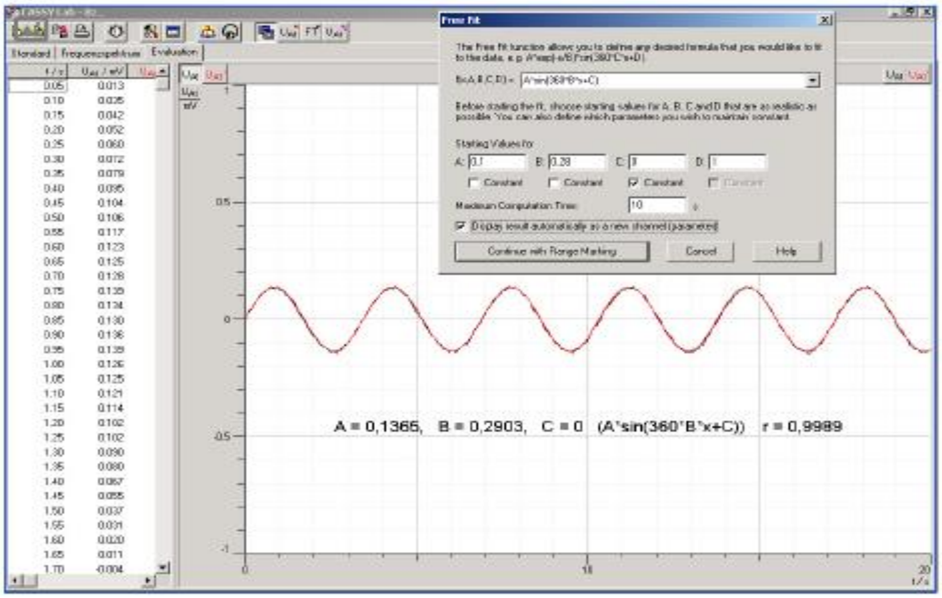


Figure 4: Induced voltage U_Z

The result of the fit for the three different axes of rotation is summarized in the following table:

Table 1: Components of the induced voltage obtained by the fit of equation (XIV) to the experimental data.

$\frac{U_x}{mV}$	$\frac{U_y}{mV}$	$\frac{U_z}{mV}$	$\frac{T}{s}$
0.47	0.45	0.13	3.51

With the coil parameter d = 13.5 cm and N = 320 the strength of the earth’s magnetic field can be determined using equation (IV) and (XII):

$$B = \sqrt{\frac{0.47^2+0.45^2+0.13^2}{2\times 8.2^2}} = 73.9\ \mu T$$

Using equation (XIII) the angle of the dip be calculated:

$$\tan \upsilon = \sqrt{\frac{0.47^2+0.45^2-0.13^2}{2\times 0.13^2}} = 3.48 \quad \rightarrow \quad \upsilon = 73^{\circ}$$

The obtained result can be checked easily by using the dip circle. The value obtained using the dip circle is $\vartheta = 70^0$.

Experiment
9

``

Measuring the magnetic field on circular conductor loops

Purpose

- Measuring the magnetic field of circular conductor loops as a function of the loop radius and the distance from the loop.

Theory

According to Biot-Savart's law, the magnetic field B at a point P for a conductor traversed by the current I is made up of the contributions:

$$d\vec{B} = \frac{\mu_0 I}{4\pi}\frac{d\vec{s}\times\vec{r}}{r^2} \qquad (1)$$

Where μ_0 (= 4π x 10^{-7} T. m / A) is the permeability of free space; I is the current in Ampères (A); $d\vec{s}$ is an elemental vector along the direction of current flow with the unit of length in meters (m); $\vec{r}$ is the position vector of the point at which the magnetic field is evaluated, with its origin at the position of the elemental length vector (its units are length in meters); and $\vec{B}$ is the magnetic field vector, which has units of Tesla or Weber/meter^2. You can think of this expression as a means of calculating the magnetic field generated by a current of magnitude I flowing along a small piece of wire with a length $d\vec{s}$ and a negligible cross-sectional area. The geometry is shown in Fig. 1. This equation is often referred to as the Biot-Savart Law.

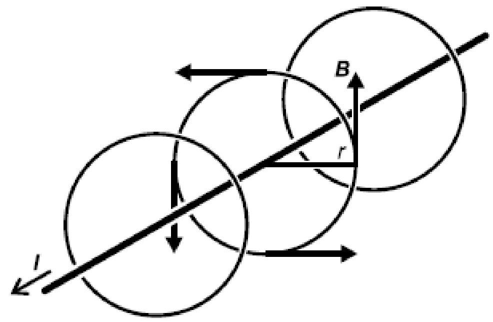


Fig. 1: Magnetic field of an infinitely long wire

Analytic solutions can be given only for conductors with certain symmetries. The magnetic field of a circular conductor loop with the radius R at a distance x on the axis through the center of the loo is given by:

$$B = \frac{\mu_0 I}{2} \frac{R^2}{\left(R^2 + x^2\right)^{3/2}} \qquad (2)$$

Its field lines are parallel to the axis (see Fig. 2).
In this experiment, the magnetic field of the above-mentioned conductor is measured by means of an axial or a tangential B-probe respectively. The Hall sensors of the B-probes, which are particularly thin, are sensitive to field components perpendicular to their surface.

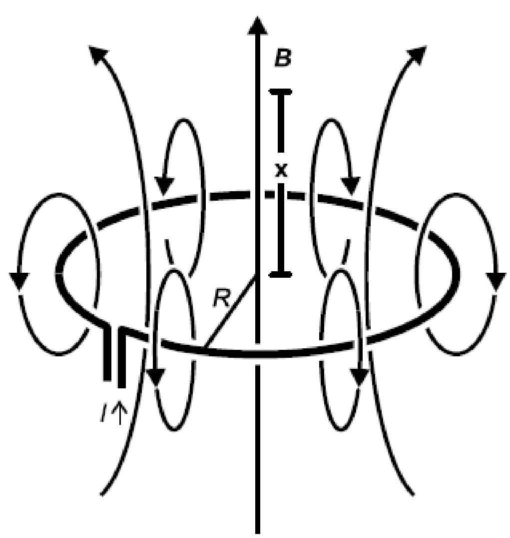


Fig. 2: Magnetic field of a circular conductor loop

Equipment and Materials

- 1 set of 4 current conductors 516 235
- 1 teslameter 516 62
- 1 axial B-probe 516 61
- 1 tangential B-probe 516 60
- 1 multicore cable, 6-pole 501 16
- 1 high current power supply 521 55
- 1 small optical bench 460 43
- 1 holder for plug-in elements 460 21
- 2 Leybold multiclamps 301 01
- 1 stand base, V-shape, 28 cm 300 01
- 1 set of two-way plug adapters 501 644
- Connecting leads, Ø 2.5 mm2

Procedure

1. The experimental setup is illustrated in Fig. 3.
2. – Replace the holder for the straight conductor with the adapter for conductor loops **(b2)**, and attach the 40 mm conductor loop.
3. – Connect the conductor loop by plugging connecting leads into the sockets of the holder for plug-in elements **(a)**.
4. – Connect the axial B-probe to the teslameter, and adjust the zero of the teslameter (see instruction sheet of the teslameter).
5. – Next mount the axial B-probe in a Leybold multiclamp with the left edge of the multiclamp lying at the scale mark 70.0 cm. Align the B-probe towards the centre of the conductor loop.
6. – Align the conductor loop as precisely as possible with the Hall sensor **(c2)**.
7. – Increase the current *I* from 0 to 20 A in steps of 2 A. Each time measure the magnetic field *B*, and take the measured values down.
8. – Replace the 40 mm conductor loop with the 80 mm conductor loop and then with the 120 mm conductor loop. In both cases iIncrease the current *I* from 0 to 20 A in steps of 2 A, measure the magnetic field *B*, and take the measured values down.

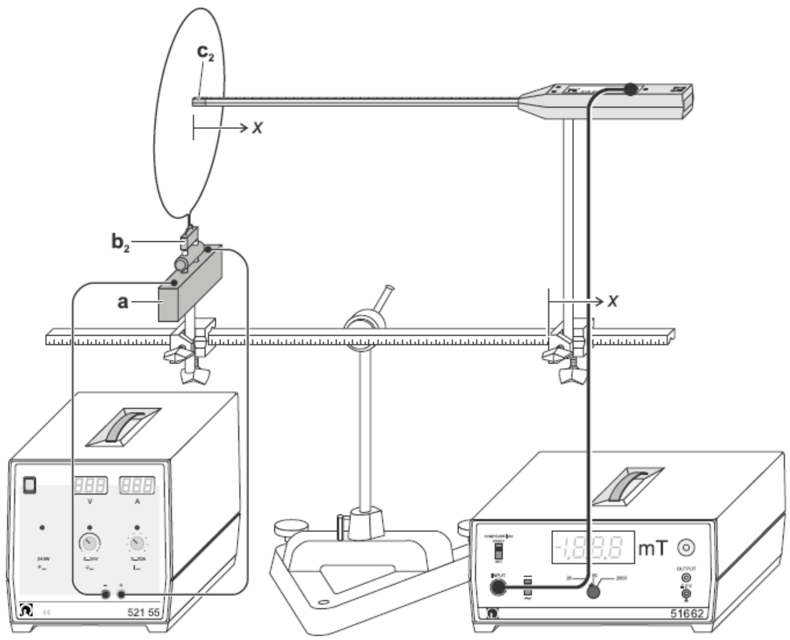


Fig .3: Experimental setup for measuring the magnetic field at circular conductor loops.

Analysis and discussion

g. Use equation (2) to calculate theoretical values of the magnetic field for the 40mm, 80mm and 120mm conductor loops respectively.
h. Plot the graph B versus I for different conductor loops and for both theoretical and measured values.
i. Comment the graphs and discuss any sources of error between graphs of theoretical and measured magnetic field values.

Table 1: The magnetic field B of the 40 mm conductor loop as a function of the current I

Current I (A)	Theoretical B (mT)	Measured B (mT)
0		
2		
4		
6		
8		
10		
12		
14		
16		

18		
20		

Table 1: The magnetic field B of the 80 mm conductor loop as a function of the current I

Current I (A)	Theoretical B (mT)	Measured B (mT)
0		
2		
4		
6		
8		
10		
12		
14		
16		
18		
20		

Table 1: The magnetic field B of the 120 mm conductor loop as a function of the current I

Current I (A)	Theoretical B (mT)	Measured B (mT)
0		
2		
4		
6		
8		
10		
12		
14		
16		
18		
20		

Experiment
10

Current Balance

Purpose

- To measure the force acting upon a conductor placed in magnetic field
- Compare the force with various parameters (like length, current, angle, and magnetic field).

Theory

This equipment is designed to measure the force acting upon an electric conductor, placed in a magnetic field. When an electric conductor with length L, is within a magnetic field B, and a current I is running through the conductor, this will be acted upon by a force, which can be calculated by the following formula (also known as Laplace's law):

$$\mathbf{F = B \cdot I \cdot L}$$

This formula presupposes that the magnetic field is perpendicular to the conductor. The equipment consists of a holder with 6 interchangeable magnets, a holder for wire frames, and 6 wire frames with conductors of different length. With this equipment the different parameters in the formula above can be variated one by one. The force is measured indirectly. The magnet holder is placed on a balance which you tare. The force is found by applying Newton's third law. In this situation it means that the force acting upon the conductor from the magnetic field is equal in magnitude, but opposite in direction, to the force acting upon the magnetic field from the current in the conductor. If the force acting on the conductor is directed upwards, the force acting on the magnetic holder will be directed downwards which results in an apparent increase of the weight of the magnet holder. Since the force is proportional to the weight ($F = m \cdot g$), the force can easily be calculated. The equipment contains 6 wire frames with conductors of different length, so it is easy to make an experiment where one changes the length of the conductor. Even more easy is it to change the current through a certain conductor, this can be done on the power supply. As the magnets in the magnet holder cannot be relied upon to have exactly the same strength, one cannot use the amount of magnet as a measure of the magnetic field strength, but it is possible to disassemble the magnet holder, and remove one or more magnets. The strength of the magnetic field can be measured by means of a teslameter. For a more detailed description of the experiment, please refer to the experimental section.

The current balance is used to perform measurements which verify Laplace's Law. This law relates the force on a conductor to the conductor length, the magnitude of the current through the conductor, the magnetic field strength and the angle between the direction of current flow and the magnetic field:

$$\mathbf{F = I \cdot L \cdot B \cdot SinV}$$

F: Force on the wire due to the magnetic field (newton).
B: Magnetic field strength (tesla).
I: Current (ampere).
L: Length of wire (meter).
V: Angle (degrees) between the B-field and the direction of the current.

Equipment and Materials

- Power supply with stabilized DC, 3630.00 or 3640.00
- Ammeter 3810.70 or
  Digital multimeter type 386215 - or the like
- Laboratory Balance with 10 mg resolution and atleast 200 g capacity
- Base triphod 0006.00
- Rod 0008.50
- Test cables
- Teslameter 4060.50

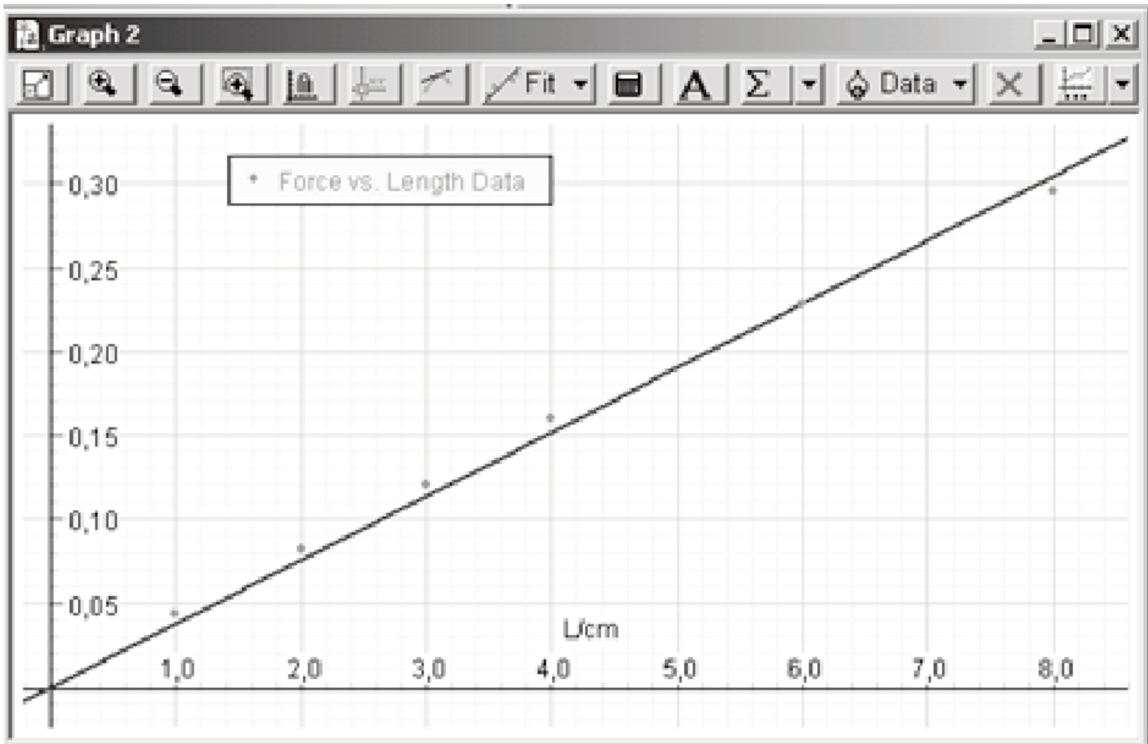
Procedure

The experimental procedure can be described as follows in that the equation parameters are changed one at a time:
– the force is proportional to the length of the conductor
– the force is proportional to the current
– the force varies as the sine of the angle V between the current and the B-field
– the force is proportional to the strength of the B-field (qualitative)

Analysis and Discussion

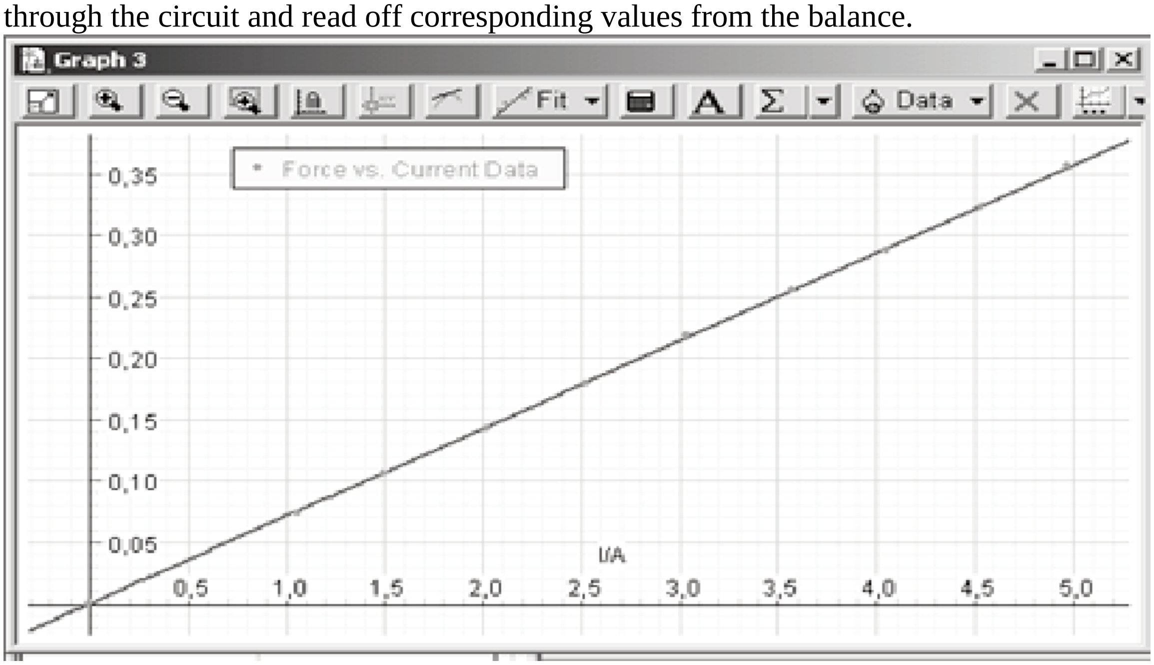
Force vs. length:

Set up the equipment so that the magnet assembly rests upon a sensitive balance, and the arm of the current weight is positioned to support conductors of various lengths completely within the region of uniform magnetic field. Begin with the L=1 cm conductor in position, set the current to zero (e.g. by breaking the circuit), and zero the balance if possible (press the tara button). Now set the current to a constant value, e.g. 4,0 amperes, and take a reading from the balance. Repeat this process for various conductor lengths. Note that the values observed may be positive or negative depending upon the orientation of the B-field. Change the direction of current flow if required to obtain positive values, if that is preferred. Values in grams may be converted to a true force by using Newton's second law: F = m · g. For example, a value of "5 grams" corresponds to a force of 0,005 kg * 9,82 m/s^2 =0,0491 N.



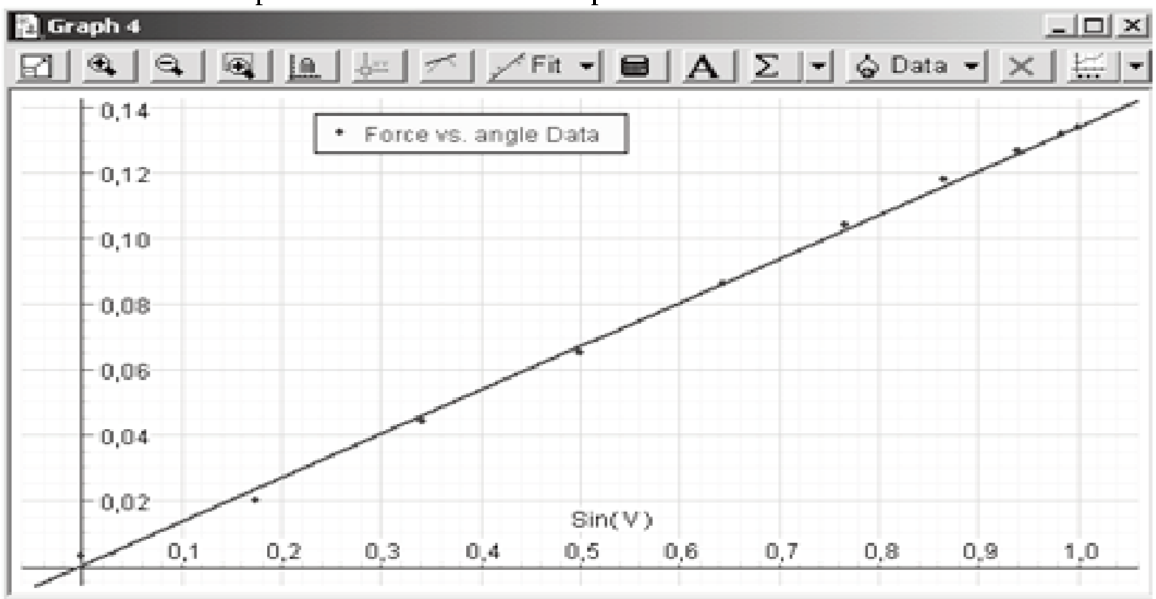
Force vs. current:

Again the equipment should be set up so that the magnet assembly rests on the sensitive balance, and the arm of the current weight is positioned to support a conductor. Now use the longest conductor length e.g. L = 8 cm. Set the current to zero by breaking the circuit, and zero the balance as before. Keeping the conductor length constant, change the current through the circuit and read off corresponding values from the balance.



Force vs. angle:

The equipment is prepared as before, however with the introduction of the goniometer assembly with the coil instead of the single conductor accessory. Be careful to adjust the goniometer so that the moveable angle indicator reads zero, when the horizontal (bottommost) conductors of the coil are parallel to the magnetic field. Zero the sensitive balance with no current flowing. Now supply a constant current of e.g. 4 amperes, and adjust the angle between the conductors and the magnetic field in 10 degree increments. Read off corresponding “force” values from the balance. Note that magnetic forces also act on the vertical segments of the coil but in opposite directions and parallel to the surface of the sensitive balance. These small forces tend to twist the coil (as in a motor) but have no effect upon the vertical force component which we measure.



Experiment
11

Magnetic Field Induced by a Current-Carrying Wire

Purpose

In this experiment you will investigate the interaction between current and magnetic fields. You will:

- Determine the direction of the B field surrounding a long straight wire using a compass (Oersted's experiment),
- Find the induced voltage in a small inductor coil, and show that the magnitude of the B field decreases as 1/r.

Theory

When a current I exists in a long straight wire, a magnetic field B is generated around the wire. The field lines are concentric circles surrounding the wire, as shown in Figure 1.

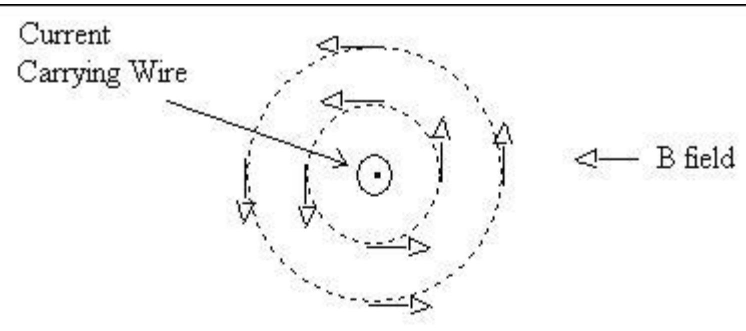


Figure 1: B field near a current-carrying wire.

In Figure 1, the current *I* is shown coming out of the page toward you. The magnitude of the magnetic field (*B*) as a function of *I* and the distance (*r*) away from the wire is given by:

$$B = \frac{\mu . I}{2\pi r}$$

Where $\mu_0 = 4\pi \times 10^{-7}$ Tm/A, *I* is in Amperes, *r* is in meters, and *B* is in Tesla. (The direction of *B*, of course, is given by the right hand rule. (Note that this equation is actually derived assuming that the long straight wire is actually infinitely long!!)

If the current in the long straight wire is constant in time, the *B* field created by that current will also be constant in time. In this case, the direction of the *B* field can be determined by observing its effect on a small compass placed in the vicinity of the long straight wire. This is basically Oersted's experiment.

If the current in the long straight wire is an alternating current produced by a sine wave generator, the *B* field surrounding the wire will also be time-varying. A changing magnetic field can induce a current in a wire, because it induces an electromotive force. This is Faraday's law, and is part of the endless hall of mirrors of reciprocal interactions between electricity and magnetism that we have been emphasizing in class. Faraday's law states that the induced emf in a coil of wire (in this case, that's the "inductor coil") placed near the long straight wire is

$$\mathcal{E} = \frac{\Delta \Phi}{\Delta t}$$

Where $\Delta\Phi$ is the magnetic flux, which can be changed by changing the magnetic field. (The flux
Can be changed by a few other things too, which we will discuss in class!) So, if the magnetic field going through the inductor coil is changing, alternating in magnitude and direction because of the sine-wave generator, an alternating voltage will be induced in the wire. In other words: The current in the long wire oscillates because it is coming from a sine wave generator….which makes the *B* field around the wire oscillate….which makes the induced emf in the small "inductor coil" oscillate too! (Which makes an oscillating current in the inductor coil…And yes, the current in the inductor coil will generate a tiny little *B* field of its own…)

According to Faraday's law, this induced voltage in the coil is proportional to the rate of change of the magnetic flux through the coil, and hence to the magnitude of the time-varying *B* field. Therefore, a measurement of the voltage induced in the coil, as the coil is placed at different distances from the wire, provides a relative measure of the magnitude of the *B* field at different distances from the wire. Note that the quantity actually measured is an alternating electric voltage, but its magnitude is proportional to the *B* field and will be taken to be a relative measurement of the *B* field at a given point. In other words, we are not measuring *B* directly. We are measuring the emf caused by *B*, and by measuring the emf at different distances *r*, we can infer how *B* changes as a function of distance.

Equipment and Materials

DC power supply, function generator, oscilloscope, inductor coil, small compass, and long straight wire apparatus.

Procedure

Part 1: Determination of the Direction of the B Field around a Current-Carrying Wire:

1. Connect the circuit shown in Fig. 2 using the direct current power supply. Stand the long wire apparatus on its end so that the long wire is vertical.

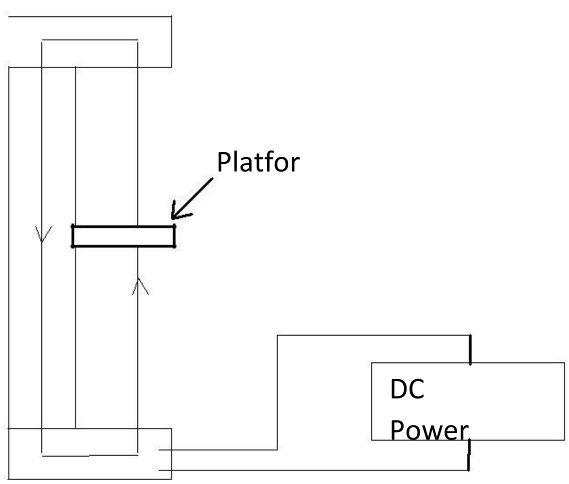
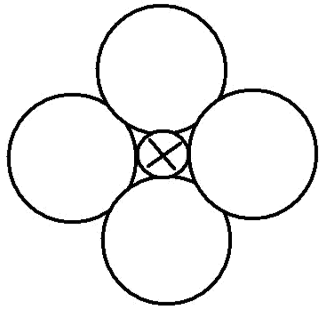


Fig. 2 Long wire apparatus connected to the Direct Current Power

2. Turn on the power supply. (Notes: the DC power supply you will use for this experiment is the same as the one you used before; the power supply needs to be set to the maximum voltage).

3. Place the compass on the platform at various positions around the wire, and record the direction of the compass needle at each position. Record your measurements in Data "Table" 1.

Indicate the compass direction at the positions shown. The X in the center is showing the direction of the current in the wire (into page). A dot indicates current flowing perpendicularly out of the page. (See Question 2 below) is this direction correct for your experimental set up? If the direction is wrong, change it to the correct direction by swapping the wires from the power supply.



Data “Table” 1

Part 2: Determination of Magnitude of the B Field as a Function of Distance from the Wire

1. Connect the circuit shown in Fig. 3 using the long wire apparatus and the sine wave generator. Turn the generator to maximum amplitude.

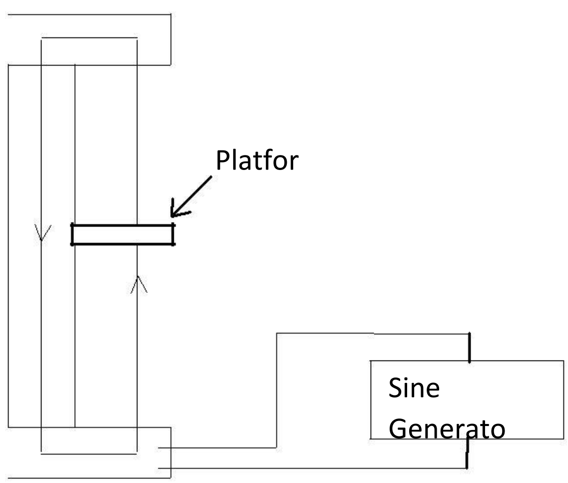


Fig. 3 Long wire apparatus connected to the Sine Wave

2. Connect the inductor coil to the oscilloscope. Place the inductor coil on the platform as shown in Fig. 4. Line up the coil with the ruler attached to the platform.

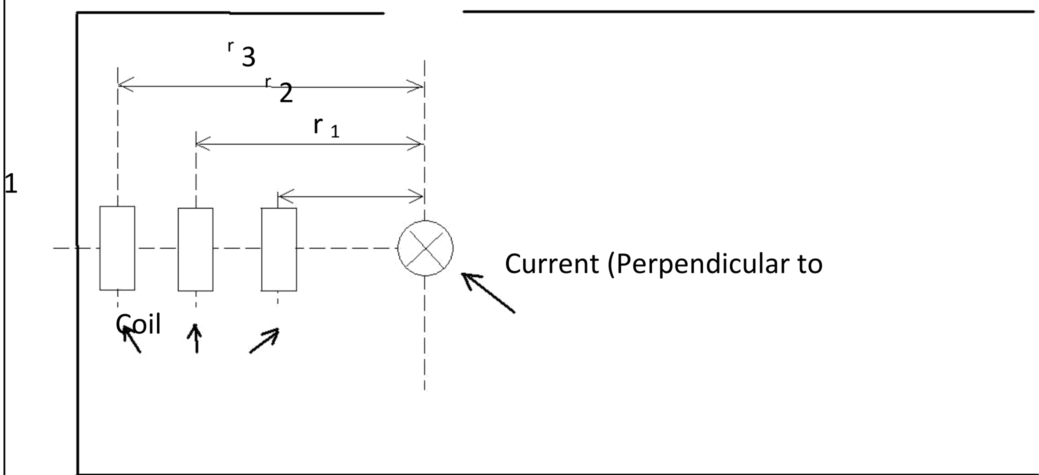


Fig. 4 View of the platform looking down from above. The current is perpendicular to the page alternating into and out of the page.

3. The amplitude of the induced voltage on the oscilloscope will depend upon the frequency of the generator sine wave. Adjust the frequency until you get a large amplitude voltage signal (about 2 Volts peak-to-peak).

4. Measure the voltage induced in the inductor coil as a function of *r*. The quantity *r* is the distance from the center of the coil to the center of the wire. Take data from *r* = 2.0 cm to *r* = 9.0 cm in increments of 1 cm. The reason that data is not taken for *r* less than 2 cm is the fact that at distances close to the wire, the *B* field is not even approximately uniform over the cross-section. Record the values of the voltage in the Data Table 2 under the column labeled *B* (trial 1). If this were a true measure of the *B* field, the units would be Tesla. The measured quantity is really a voltage which is proportional to *B*.

5. Repeat step 4 two more times measuring the induced voltage as a function of distance and recording the values in the Data Table 2 under Trial 2 and Trial 3.

6. Calculate the average "*B*" from Trials 1, 2 and 3.

<u>Data Table 1</u>

r (*cm*)	*1/r* (cm^{-1})	*B* *Trial 1*	*B* *Trial 2*	*B* *Trial 3*	*B* *(Average)*
2.0					
3.0					
4.0					
5.0					
6.0					
7.0					
8.0					
9.0					

Analysis and discussion with Question.

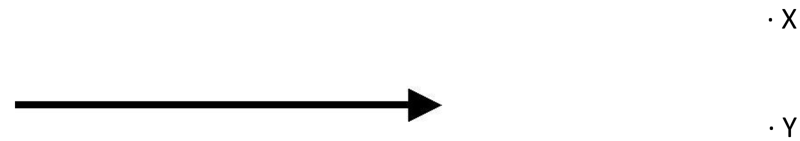
1. Explain how the earth's magnetic field could affect your results in Part 1. Based only on your data in Data Table 1 above, can you tell what side of the laboratory is facing (magnetic) North?

2. In Part 1, use the direction of the compass needles and the right hand rule to determine whether the current in the wire is going up or down.

3. Why does the plot of "B" vs. 1/r look like a straight line?

4. When the direct current is 2.00 A in a single wire of the bundle of 10 wires, the total current in the bundle of wire that approximates the long straight wire is 20.0 A. What is the magnitude of the B field 3.00 cm from this long straight wire carrying a current of 20.0 A? What is the magnitude of the B field 9.00 cm from the wire carrying 20.0 A?

5. A constant current is in a long straight wire in the plane of the paper in the direction shown below by the arrow. Point X is in the plane of the paper above the wire, and point Y is in the plane of the paper but below the wire. What is the direction of the B field at point X? What is the direction of the B field at point Y?



Direction at X =________________________

Direction at Y= ________________________

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