PHYSICS - II LABORATORY MANUAL FOR ENGINEERING UNDERGRADUATES (ELECTRICITY)

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Contents

1. ELECTRICAL FIELDS AND POTENTIALS IN THE PLATE CAPACITOR

Equipment	**:**	Plate capacitor, electric field meter, 0-600V DC power supply, digital multimeters
Purpose	**:**	• To investigate the relationship between voltage and electric field strength, with a constant plate spacing. • To investigate the relationship between electric field strength and plate spacing, with a constant voltage.

1.1. Experimental Principle

Maxwell's equations for the electric field ***E*** in the plate capacitor are as below:

$$\bar{\Delta} \times \vec{E} = -\vec{B}$$

$$\bar{\Delta} \cdot \vec{D} = \rho$$

For the steady-state case in the charge-free space between the plates, Maxwell's equations could be written as:

$$\vec{\Delta} \times \vec{E} = 0 \quad (1)$$

$$\vec{\Delta} \cdot \vec{D} = 0 \quad (2)$$

If one plate is placed in the *yz* plane and the other parallel to it at a distance of *d*, and if boundary disturbances due to the finite extent of the plates are disregarded, it follows from Eq.2 that $\vec{E}$ lies in the *x* direction and is uniform. Since the field is irrotational (rot $\vec{E}$ = 0) it can be represented as the gradient of a scalar field φ:

$$\vec{E} = -\mathrm{grad}\varphi = -\frac{\partial\varphi}{\partial x}$$

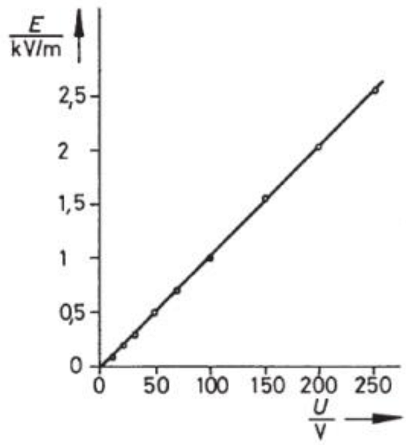
while $\vec{E}$, because of its uniformity, may also be expressed as the quotient of differences

$$E = \frac{\varphi_1 - \varphi_2}{x_1 - x_2} = \frac{U}{d} \quad (3)$$

where the potential difference is equal to the applied voltage *U* and *d* is the distance between the plates.

In Fig.1.1, it shows that electric field strength as a function of the plate voltage. As shown in Fig.1, with constant spacing *d*, *E* is proportional to the voltage

With a constant voltage *U*, the field strength *E* varies in reverse proportion to the spacing *d* between the plates. The electric field strength as a function of the plate spacing is shown in Fig.1.2.



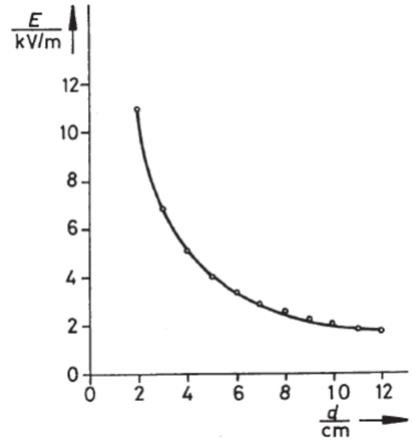


Figure 1.1. Electric field strength as a function of the plate voltage.

Figure 1.2. Electric field strength as a function of the plate spacing

If the measured values are plotted on a log-log scale (Fig.1.3), then because

$$\log E = \log \frac{U}{d} = \log U - \log d$$

a straight line is obtained.

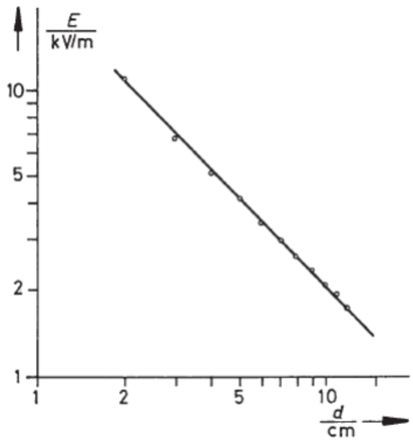


Figure 1.3. The plot of log *E*-log *d*

1.2. Experimental Procedure

1. The experimental set up is as shown in Fig.1.4. The electric field meter should first be zero-balanced with a voltage of 0 V.
2. Measure the electric field strength for plate voltages in Table 1.1 at plate spacing of d=10 cm and record them

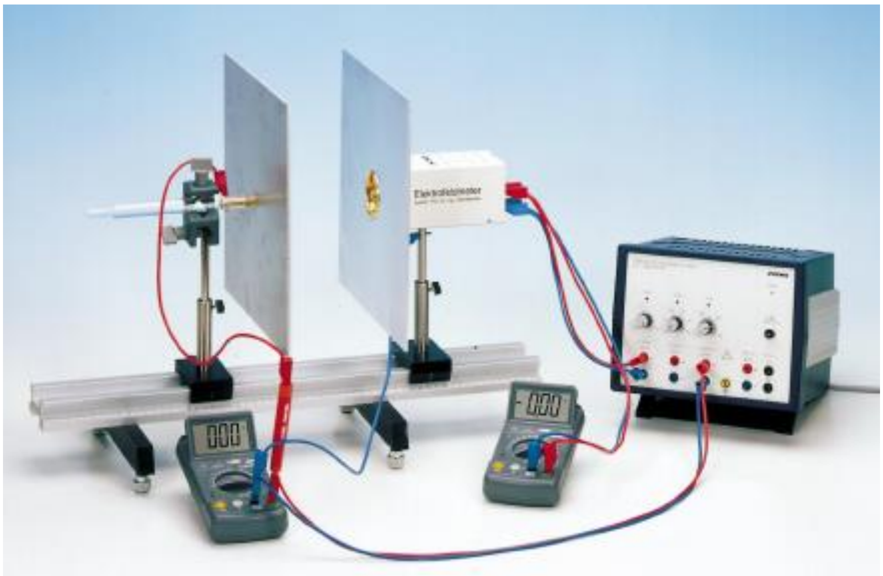


Figure 1.4. Experimental setup

3. Adjust the plate voltage to 200 V.
4. Measure the electric field strength as a function of the distance between the two capacitor plates and record them in Table 1.2.
5. Draw graph of both measured values and calculate the error.

Table 1.1.

Plate Voltage (V)	E (kV/m)
20	
40	
60	
80	
100	
120	
140	
160	
180	
200	

Table 1.2.

Plate Spacing (cm)	E (kV/m)
2	
4	
6	
8	
10	
12	

2. FREQUENCY OF ALTERNATING CURRENT

Equipment	:	Power supply with output of 10-15 V, ammeter (max 2 A), rheostat, thin wire of 1 m length with known mass, wooden wedges to fasten the wire, pulley, pan, various masses, magnet (U shape)
Purpose	:	Measuring the frequency of alternating current using standing wave method

2.1. Experimental Principle

When a conducting wire carrying an electric current *i* is placed in a magnetic field *B*, the magnetic force on infinitesimal segment of the wire *dL* is written as:

$$d\vec{F} = id\vec{L} \times \vec{B} \quad (1)$$

In the case of a straight wire and a uniform magnetic field the force becomes:

$$F = i\, B\, L\, sin\theta \quad (2)$$

where θ is the angle between the wire and the magnetic field. An alternating current causes an alternating force on the wire and the frequency of the force is equal to the alternating current frequency. If we measure the frequency of this force with an appropriate experimental setup, then we measure the frequency of the alternating current.

The experimental setup is shown in Fig.2.1. One end of the wire (length of *L*) is attached to the point A while the other end is connected to a pan by passing the wire over the right wedge and a fixed pulley on the point B. Various masses are put on the pan to change the tension of the wire with different forces. The U magnet is placed at *L*/2 and the wire is laid between the poles of the magnet. The wire is connected to a rheostat and the output of an AC power supply and an ammeter at the points A and B, respectively.

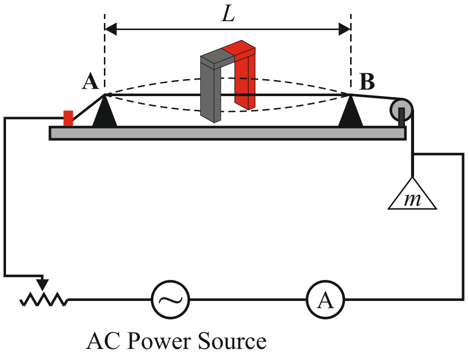


Figure 2.1. *Experimental setup*

The influence of the magnetic force leads the wire to start vibrating up and down. If the frequency of the magnetic force (frequency of the alternating current) equals to the neutral frequency of the wire then, the wire begins to vibrate with the highest amplitude (resonance situation). The masses are used to ensure this condition.

In the resonance situation, a standing wave is seen on the wire which causes nodes on A and B points and an antinode in the middle of the wire. In this case the length of the wire between A and B points (*L*) can be written in terms of the wave length of the standing wave (λ):

$$L = \frac{\lambda}{2} \quad (3)$$

On the other hand the speed of propagation (υ) of the transverse wave vibrations on the wire is:

$$\upsilon = \lambda f \tag{4}$$

here *f* represents the frequency of the vibration. This speed can also be given in terms of the force stretching the wire (P) and length density (μ) of the wire:

$$\nu = \sqrt{\frac{P}{\mu}} \tag{5}$$

Finally, using equations (3), (4), and (5), the vibration frequency *f* is obtained as:

$$f = \frac{1}{2L}\sqrt{\frac{P}{\mu}} \tag{6}$$

Thus, the frequency of the alternating current, equals to the vibration frequency, can be measured with known L, P and μ.

2.2. Experimental Procedure

1. Set the experiment up as shown on the Fig.2.1.
2. Apply a current between 0-1 A by turning the power supply on.
3. See a standing wave on the wire by changing the weight on the pan. You should see nodes at A and B points and an antinode in the middle of the wire.
4. Continue to increase gradually the total mass on the pan and observe the amplitude of the vibration.
5. When you reached maximum amplitude (resonance situation) stop increasing the mass.
6. Turn the power supply off, find the total weight by measuring the mass of the pan and masses that you used ($P = mg$). Measure the length of the wire (L) located between A and B points.
7. Take a sample from the wire and measure the length and mass of the sample. Find the length density of the wire (μ) by dividing the mass by the length of the wire.
8. Substitute these values in Eq.6 to calculate the frequency.
9. Calculate the error on the derived frequency.

3. MEASUREMENT OF THE FORCE ACTING ON A CURRENT-CARRYING WIRE

Equipment : Digital balance, current supply, current loops with different lengths, a set of swing coils, 2 magnet assemblies, lab stand and stick, connecting cables.

Purpose : To observe the force acting a current (*I*)-carrying wire located in a homogeneous and static magnetic field $\vec{B}$ and to explore the magnetic force how it varies with length of wire L and current *I*.

3.1. Experimental Principle

A current-carrying wire in a magnetic field experiences a force that is usually referred to as a magnetic force. This magnetic force on a current carrying wire is described by Lorentz equation

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

where $\vec{L}$ is a vector that points in the direction of the current with a magnitude equals to the length of the wire, $\vec{B}$ is the strength of the magnetic field and, *I* is the magnitude of the current.

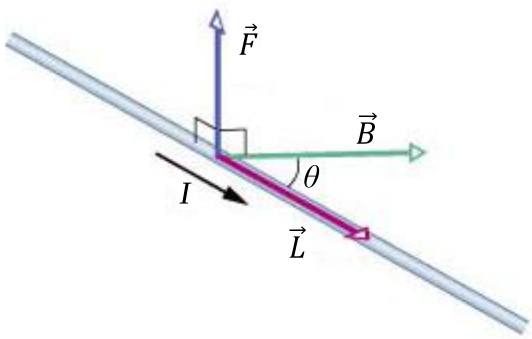


Figure 3.1. *A current-carrying wire placed in a magnetic field*

The magnitude of the force is given as

$$F = ILBsin\theta$$

where θ is the angle between $\vec{L}$ and $\vec{B}$ as shown in Fig.3.1.

If the magnetic field is assumed to be perpendicular to the direction of current flow, equation in scaler terms will be simplified to

$$F = ILB$$

Current will flow through the already prepared (prefabricated) current loops shown in Fig.3.2. *L* is the horizontal length of the wire passes through the pole region of the magnet, referred as test length. This length can be changed from 1 to 7 units and each unit nearly has 1 cm length. Test lengths used in the experiment should be recorded. Current loops will connect to a direct-current supply which has an ammeter. If the magnetic field is assumed to be as shown in Fig.3.2 (going into the page), the direction of the current flow should be as shown in the figure to create the force in the direction intended.

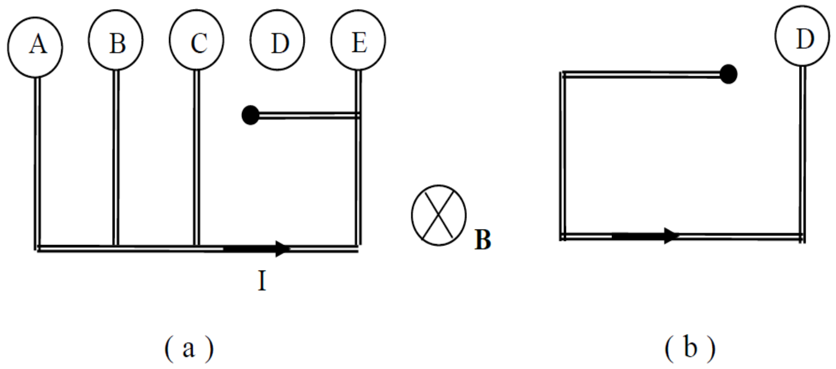


Figure 3.2. *Current loop with connection points (a) front view, (b) rear view*

Table 3.1. Various wire lengths.of the current loop.

Current loop	**Test length L**
AB or BC	1 unit
AC or CE	2 unit
BE or ED	3 unit
AE	4 unit
CD	5 unit
BD	6 unit
AD	7 unit

3.2. Experimental Procedure

NOTE: Current loop should not exceed 5 A current.

3.2.1. Magnetic force as function of current

1. Place the magnet assembly with spaced 5 mm on the balance.
2. Select the current loop which has the longest L and record this length.
3. Plug the current circuit, which includes the current loops, into the ends of the Main Unit, with the foil extending down as shown in Fig.3.3.

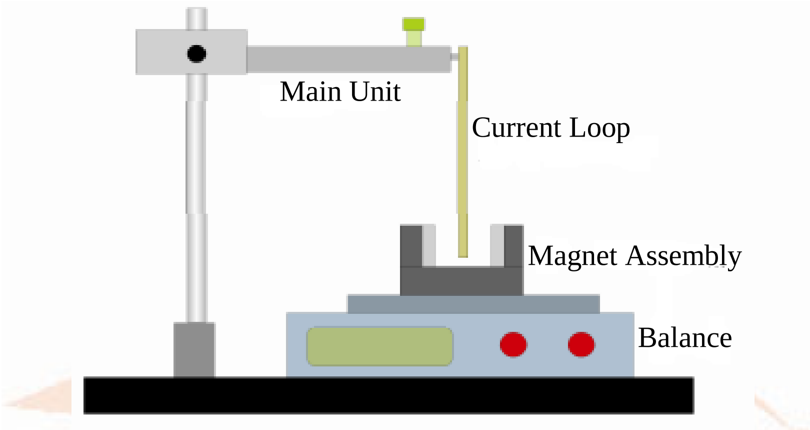


Figure 3.3. *Setup of Current Balance (side view)*

4. Place the horizontal portion of the current circuit so that it passes through the pole region of the magnets as shown below. Make sure that the plane of the current circuit is parallel to the magnet group and do not touch to it. If it is required, set the highness of the Main Unit.
5. Push the tare button of the digital balance in absence of current in the circuit and see the 0.00 g on the display.
6. Connect current supply to the circuit (see Fig.3.4)

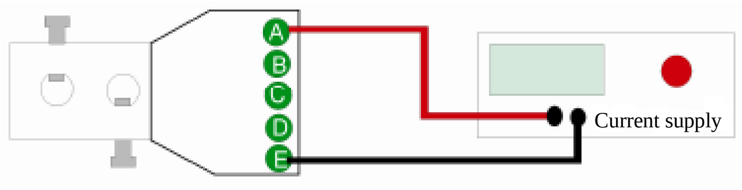


Figure 3.4. *Top view of Main Unit and connection current supply to Main Unit*

7. Increase current in 0.5 A increments up to 5.0 A. Read the new mass of the magnet group for each current value from digital balance. If the current increasing decreases the mass, thus the direction of current within the magnetic field is not as shown in Fig.3.2. In this case, reverse the connections on the Main Unit.
8. Fill Table 3.2 using the current values and the mass values as a function of current.
9. Calculate magnetic forces F multiplying the mass values by g=9.81 m/s^2 and write these into Table 3.2.
10. Plot the magnetic force (F) as a function of the current (I).
11. Draw an optimum line over the experimental dots and calculate the slope of the line.
12. The slope of the line corresponds to $L{\cdot}B$ as seen in Eq.2 (vector multiplication the length of wire passing the current with the magnetic field).
13. Find power of the magnetic field produced by magnet using the slope of the line.

Table 3.2

Current (A)	Measured Mass (g)	Magnetic Force
0.5		
1		
1.5		
2		
2.5		
3		
3.5		
4		
4.5		
5		

3.2.2. Magnetic force as a function of the length of wire

1. Set the current to 0 keeping the experimental setup before.
2. Connect the current circuit to Main Unit setting to the shortest length of wire.
3. Read 0.00 g on display pushing "tare" button of the digital balance.
4. Adjust the current 3 A, record the value on the display of the balance.
5. Set the current to 0 and disconnect the current supply from Main Unit.
6. Repeat the steps 3, 4 and 5 for different lengths of wire.
7. Fill Table 3.3 using the lengths of wire and the corresponding mass values.
8. Calculate the magnetic forces F multiplying the mass values by g=9.81 m/s^2 and write these into Table 3.3.
9. Plot the magnetic force (F) as a function of the length of wire (L).
10. Find the optimum slope of line.
11. The slope of this line equals to the multiplication of $I \cdot B$ (as seen in Eq.2). This is vector multiplication the current with magnetic field force. Find power of the magnetic field produced by magnet using the slope of line. Compare this value with the value, which obtained in Section 3.2.1.

Table 3.3

Current (A)	Length	Measured Mass (g)	Magnetic Force
AB or BC	1 unit		
AC or CE	2 unit		
BE or ED	3 unit		
AE	4 unit		
CD	5 unit		
BD	6 unit		
AD	7 unit		

4. OHM'S LAW

Equipment : Resistors, ammeter, power source, banana cables, graph paper
Purpose : To verify Ohm's Law experimentally and determine unknown resistor values

4.1. Experimental Principle

When a voltage or potential difference (V) is applied across a material, the current (I) in the material is found to be proportional to the voltage, $I \propto V$. The resistance (R) of the material is defined as the ratio of the applied voltage and the resulting current—that is,

$$R = \frac{V}{I} \tag{1}$$

For many materials, the resistance is constant, or at least approximately so, over a range of voltages. A resistor that has constant resistance is said to obey Ohm's law or to be "ohmic." From Eq.1, it can be seen that the unit of resistance is the volt/ampere (V/A). However, the combined unit is called the ohm (Ω), in honor of Georg Ohm (1787–1854), a German physicist, who developed this relationship known as Ohm's law. Note that to avoid confusion with a zero; the ohm is abbreviated with a capital omega (Ω) instead of a capital O. A plot of V versus I for an ohmic resistance is a straight line (Fig.4.1). Materials that do not obey Ohm's law are said to be "nonohmic" and have a nonlinear voltage-current relationship. Semiconductors and transistors are nonohmic.

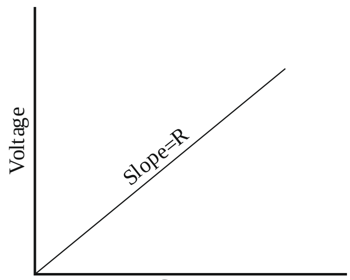


Figure 4.1 *A voltage-versus-current graph for an ohmic resistance is a straight line, the slope of which is equal to the value of the resistance* ($R = V/I$).

In common practice, Ohm's law is written as

$$V = IR \tag{2}$$

where it is understood that R is independent of V. Keep in mind that Ohm's law is not a fundamental law such as Newton's law of gravitation. It is a special case, there being no law that materials must have constant resistance.

4.1.1. Resistances in Parallel

The current in a parallel circuit (Fig.4.2) divides among the resistors such that

$$I = I_1 + I_2 \tag{3}$$

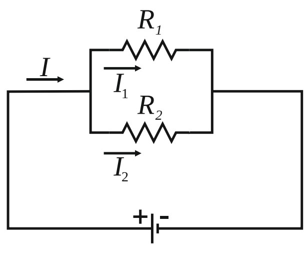


Figure 4.2 *Resistors in parallel*

The current through each resistor is given by Ohm's law (for example, I_1=V/R_1), and Eq.3 may be written as

$$I = I_1 + I_2 = \frac{V}{R_1} + \frac{V}{R_2} = V\left(\frac{1}{R_1} + \frac{1}{R_2}\right) \tag{4}$$

An equivalent resistance (R_p) can replace the parallel resistances in the circuit in Fig.4.2. This equivalent circuit would be as in Fig.4.3.

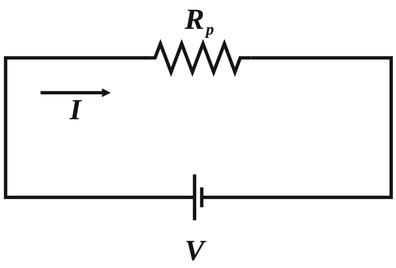


Figure 4.3 *Equivalent circuit of Fig.2*

According to the Ohm's Law, total current must be equal to

$$I = \frac{V}{R_p} \tag{5}$$

Substituting Eq.5 in Eq.4, equivalent resistance for the resistances in parallel get as

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} \tag{6}$$

4.1.2. Resistances in Series

Resistors are said to be connected in series when connected as in Fig.4.4 (The resistors are connected in line, or "head to tail" so to speak, although there is no distinction between the connecting ends of a resistor).

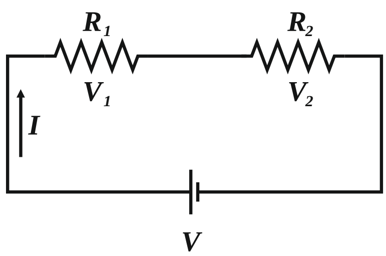


Figure 4.4 *Resistors in series*

Total voltage V in Fig.4.4 must be equal to sum of voltages on each resistor:

$$V = V_1 + V_2 \tag{7}$$

Same current I pass through each resistor in series circuit. So, Eq.7 can be written as

$$V = IR_1 + IR_2 = I(R_1 + R_2) \tag{8}$$

An equivalent circuit as in Fig.4.5 can be replaced by Fig.4.4.

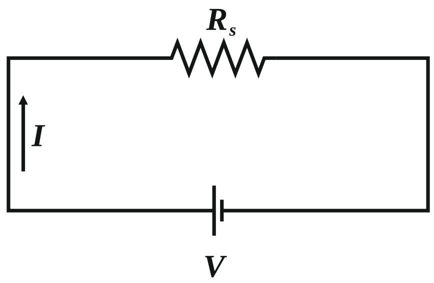


Figure 4.5 *Equivalent circuit of Fig.4*

According to this, total voltage and equivalent resistance of the resistors in series can be written as,

$$V = IR_s$$
$$IR_s = I(R_1 + R_2) \tag{9}$$

and

$$R_s = R_1 + R_2 \tag{10}$$

4.2. Experimental Procedure

1. Set the circuit up for resistor R_1 given in Fig.4.6. ("A" denotes ammeter)

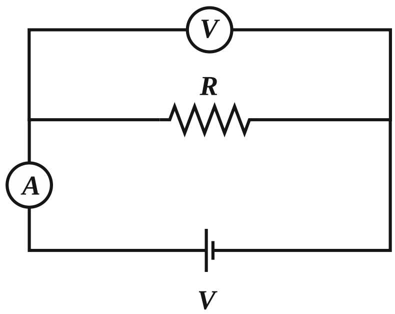


Figure 4.6 *Experimental setup for R_1 and R_2*

2. Adjust the voltage values using power source knob and measure the corresponding current values for each voltage (Record data in Table 4.1).

Table 4.1

Readings	Voltage (V)	Current (mA)
1		
2		
3		
4		
5		
6		

3. Plot voltage versus current graph and calculate its slope. The slope gives you R_1 value. (Place voltages values on vertical axes and current values on horizontal axes and DO NOT forget to convert mA to A)

4. Set the circuit up for resistor R_2 given in Fig.4.6.
5. Adjust the voltage values using power source knob and measure the corresponding current values for each voltage (Record data in Table 4.2).

Table 4.2

Readings	Voltage (V)	Current (mA)
1		
2		
3		
4		
5		
6		

6. Plot voltage versus current graph and calculate its slope. The slope gives you R_2 value.
7. Set the circuit up for resistors in parallel given in Fig.4.7.

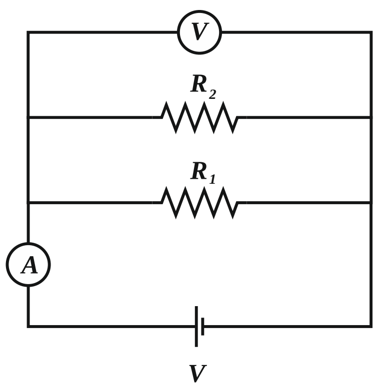


Figure 4.7 *Experimental setup for resistors in parallel*

8. Adjust the voltage values using power source knob and measure the corresponding current values for each voltage (Record data in Table 4.3).

Table 4.3.

Readings	Voltage (V)	Current (mA)
1		
2		
3		
4		
5		
6		

9. Plot voltage versus current graph and calculate its slope. The slope gives you R_p value.
10. Set the circuit up for resistors in series given in Fig.4.8.

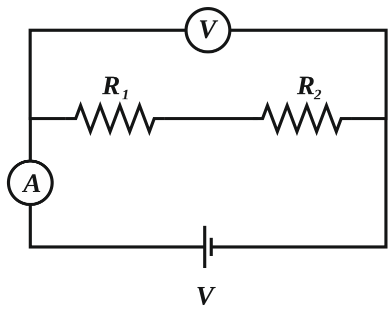


Figure 4.8 *Experimental setup for resistors in series*

11. Adjust the voltage values using power source knob and measure the corresponding current values for each voltage (Record data in Table 4.4).

Table 4.4

Readings	Voltage (V)	Current (mA)
1		
2		
3		
4		
5		
6		

12. Plot voltage versus current graph and calculate its slope. The slope gives you R_s value.
13. Calculate R_p and R_s values using Eq.6 and Eq.10, respectively and compare them with the values, which are obtained from the slopes of the graphs in steps 9 and 12.

4.3. Results

R_1 (Ω)	R_2 (Ω)	R_p (Ω)		R_s (Ω)	
		From slope	From Eq.6	From slope	From Eq.10

5. DETERMINATION OF CAPACITANCE IN AC CIRCUITS

Equipment	**:**	Voltmeter, ammeter, rheostat, lamp, capacitor
Purpose	**:**	To Determine the capacitance of a capacitor (*C*), observing the phase shift between the current and the voltage on the capacitor

5.1. Experimental Principle

As shown in Fig.5.1, in a circuit consisting of a resistor (*R*), inductor (*L*) and capacitor (*C*) in series with an AC power supply, the current equals to

$$I = \frac{V}{Z}$$

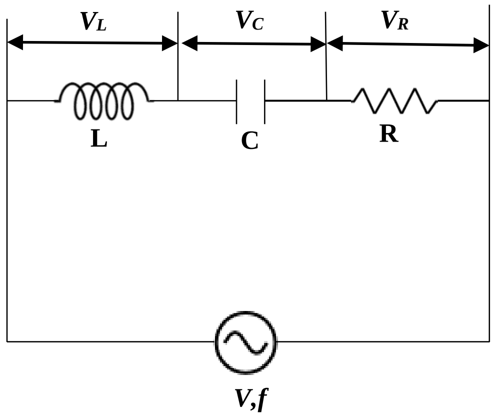


Figure 5.1.

where $Z = \sqrt{R^2 + X^2}$ represents the impedance, $X = X_L - X_C$ represents the reactance, $X_L = 2\pi f L$ represents the inductive reactance, $X_C = 1/(2\pi f C)$ represents the capacitive reactance. The phase shift between the current and the voltage is

$$\phi = arctan\frac{X}{R}$$

If there are only capacitor in the circuit ($R = 0$ and $Z = X_C$), the potential difference between capacitor terminals is

$$V_C = IX_C = \frac{I}{2\pi f C}$$

and the phase shift is

$$\phi = -\frac{\pi}{2}$$

If there is only resistor in the circuit ($X = 0$), the phase shift between the current and the voltage is zero.

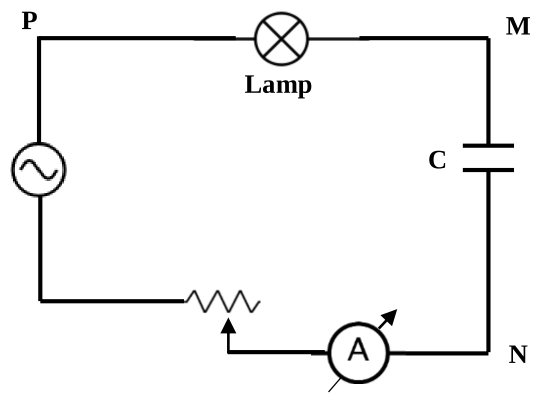


Figure 5.2.

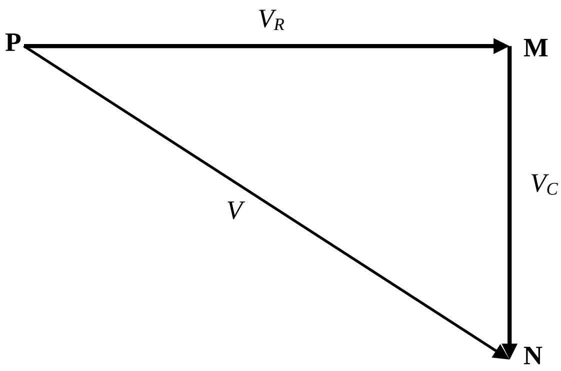


Figure 5.3.

5.2. Experimental Procedure

1. Set the circuit up shown in Fig.5.2. **Wait the instructor to connect your circuit to the mains!**
2. Read the effective value of the current with the ammeter.
3. Read the value of V_R, V_C and V between points PM, MN and PN with the voltmeter.
4. Draw the triangle shown in Fig.5.3.
5. Find the phase shift between the voltage of the capacitor, V_C and the current I and the phase shift between the total voltage, V and the current, I of the circuit with the angle meter.
6. Find the value of C (the capacitance of the capacitor) using the following equation:

$$V_C = \frac{I}{2\pi f C}$$

Note: f=50 Hz.

ATTENTION!!!!

To avoid accidents when measuring the voltage, drive the current to the circuit after connecting a voltmeter.