IZMIR INSTITUTE OF TECHNOLOGY
Department of Physics

GENERAL PHYSICS II
LABORATORY MANUAL

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physics.iyte.edu.tr

Contents

LABORATORY RULES

1 . Students may enter a laboratory only when a lecturer or demonstrator is present unless special permission has been granted.

2. Eating and drinking in any laboratory is prohibited.

3. Before starting an experiment;

- Check that all apparatus is present and has no obvious defect.

- Report to the person in charge any damaged or missing equipment.

4. During an experiment the student should report to the person in charge;

- any equipment that does not seem to be functioning properly.

- any accidents and breakages that occur.

- NEVER borrow equipment from another bench without permission.

5. Before leaving the laboratory,

- Switch off all power supplies and remove all AC/DC power plugs.

- Disconnect electrical circuits and collect the leads in a neat bundle.

- Ensure that the apparatus has been left tidily.

ANALYSIS OF MEASUREMENTS AND EXPERIMENTAL UNCERTAINTIES

1. RANDOM UNCERTAINTIES

The arithmetic mean $\bar{x}$ of a quantity obtained from a number (N) of readings x_i is the most probable value of that quantity. If the uncertainties are entirely random and is large, then $\bar{x}$ is close to the true value.

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$$

If the uncertainties of measurement are entirely random an estimate of the precision is given by the standard deviation

$$S = \sqrt{\sum_{i=1}^{N} \frac{(x_i - \bar{x})^2}{N-1}}$$

where $(x_i - \bar{x})$ is the deviation of a reading x_i from the mean $\bar{x}$.

The standard error (SE) of the mean $SE = (S/N)^{1/2}$ and the error at a 95% confidence level is $2SE$.

The significance of S can be seen by consideration of the distribution of a large collection of measurements, known as the normal or Gaussian distribution. It can be shown that for large N the probability of an individual reading differing from the mean by more than S is about 32%. $2S$ is about 5% and $3S$ is less than 1%.

In practice, when N **is less than 6 the statistical analysis is not appropriate** and an estimate of the uncertainty may be obtained from the range of values obtained.

2. PROPAGATION OF UNCERTAINTIES

Almost all experiments require calculations to be performed which involve manipulation of the measured uncertainties. In order to calculate the uncertainty in the final result it is necessary to know how the computed or estimated uncertainties in each quantity combine or propagate.

2.1 A General Approach

The easiest method of estimating the uncertainty is to substitute the extreme values of the quantities into the expression and calculate the result. The uncertainty is the difference between this value and the preferred value. e.g.

$\lambda = \frac{d \sin\theta}{n}$

Preferred value
$d = (1.00x10^{-6} \pm 0.05x10^{-6})m$
$\theta = 30.0^o \pm 0.5^o$, and $n = 1$
$\lambda = 10^{-6}xsin\ 30.0^o = 0.50\mu m$

Maximum value of λ is obtained with maximum value of d and maximum value of θ.

$\lambda_{max} = (1 + 0.05)x10^{-6}xsin(30 + 0.5) = 0.53\mu m$

$\lambda_{min} = (1 - 0.05)x10^{-6}xsin(30 - 0.5) = 0.47\mu m$

$\lambda = 0.50 \pm 0.03\mu m$

Note: The same method may be used for any uncertainty calculation e.g.

Density = mass/volume.

$Mass\ \ of\ \ object = (2.00 \pm 0.01)kg$
$Volume\ \ of\ \ object = (2.50 \pm 0.05)x10^{-3}m^3$
$Density(\rho) = 800kgm^{-3}$

Maximum value of ρ obtained using maximum mass and minimum volume

$\rho_{max} = \frac{2.01kg}{2.45x10^{-3}m^3} = 820kgm^{-3}$

Minimum value of ρ is obtained using minimum mass and maximum volume

$\rho_{min} = \frac{1.99kg}{2.55x10^{-3}m^3} = 780kgm^{-3}$

$\rho = 800 \pm 20kgm^{-3}$

2.2 Additions and Subtractions

It is usually fairly easy to write down the possible uncertainty in any single measurement. Thus suppose that in an experiment with a spring the length of the spring is measured with a metre scale. With care such a scale allows you to measure to about 1 mm. If you take a number of careful readings with the scale you should find that they do not differ among themselves by more than this. Thus for one particular reading you may be able to say:

$Length\ of\ spring = 302 \pm 1mm$

If additional masses are added and the spring is re-measured, you may find

$$New\ length\ of\ spring = 488 \pm 1mm$$

Now consider what you know about the change in length. According to our figures the change is equal to 186 mm. But each of the figures may have been wrong by 1 mm. If one of them happened to be too high by this amount while the other was too low, then the uncertainty in the difference would be 2 mm. **To be on the safe side we must assume that the worst has happened.** So we say

$$Change\ in\ length = 186 \pm 2mm$$

The same thing applies if we are concerned with adding the two lengths. The worst possible case will be when both figures were too high or both figures were too low. We assume the worst possiblee case and say

$$Sums\ of\ lengths = 790 \pm 2mm.$$

Thus if you are adding or subtracting two figures the actual uncertainty is the sum of the separate uncertainties.

2.3 Multiplications and Divisions

Now suppose that you are measuring the volume of a cylinder. You measure the diameter d and the length l and then calculate the volume from the equation

$$Volume = \frac{\pi d^2 l}{4}$$

In a case such as this the fractional uncertainty in the volume is the sum of the fractional uncertainty in the length plus twice the fractional uncertainty in the diameter. The fractional uncertainty in the diameter is doubled as a consequence of the fact that it is the square of the diameter that comes into the formula. If the formula had involved d^3, three times the fractional uncertainty would have been added and so on.

To take a very general case, suppose we are concerned with a formula of the type

$$x = \frac{k^a t^b}{m^c n^d}$$

In this case:

$$\frac{\triangle x}{x} = \frac{a \triangle k}{k} + \frac{b \triangle t}{t} + \frac{c \triangle m}{m} + \frac{d \triangle n}{n}$$

Fractional uncertainty in x=a(fractional uncertainty in k)+ b(fractional uncertainty in t) +c(fractional uncertainty in m) + d(fractional uncertainty in n)

This general rule can be proved, but the student is advised to accept the rule and leave the proof until later.

The rule is simple: if you are multiplying together or dividing a number of figures, the possible fractional uncertainty in the result is the sum of the separate fractional uncertainties

3.SIGNIFICANT FIGURES

In quoting a result only one uncertain figure should be retained; then the number of figures indicates the order of accuracy. For example, suppose the speed of light was calculated as $2.988x10^8ms^{-1}$ and is known to 1%. The possible uncertainty is then $0.03x10^8ms^{-1}$

This shows that the third and subsequent significant figures are unreliable, hence we retain only three figures and express the result in its neatest form as
$(2.99 \pm 0.03)x10^8ms^{-1}$

4. GRAPHICAL UNCERTAINTIES

In laboratory work a graph is often used to illustrate the behaviou of system; to assist in the calculation of a quantity or to determine the relationship between variables. It is essential that the graph displays the characteristics of the results and their uncertainties as clearly as possible. This involves the **proper selection of scale and the physical arrangement of the axis.**

The best way to indicate the uncertainties of the variables is to locate the point of the graph by a dot at the centre of bars indicating the range of uncertainty. A method of estimating the uncertainty in the gradient of a straight line is to draw lines of maximum and minimum gradient which are possible fits to the experimental points.The uncertainty in the gradient of the line of best fit is then one half the difference between the maximum and minimum gradients. A similar method can be used to estimate the uncertainty in an intercept. These techniques are illustrated on the graph in Figure 1.

5. THE SI SYSTEM OF UNITS

5.1 Classes of SI Units

There are three classes of SI units. These are:
Base units
Derived units
Supplementary units.

The base units are seven well-defined units: metre, kilogram, second, ampere, kelvin, candela and mole.

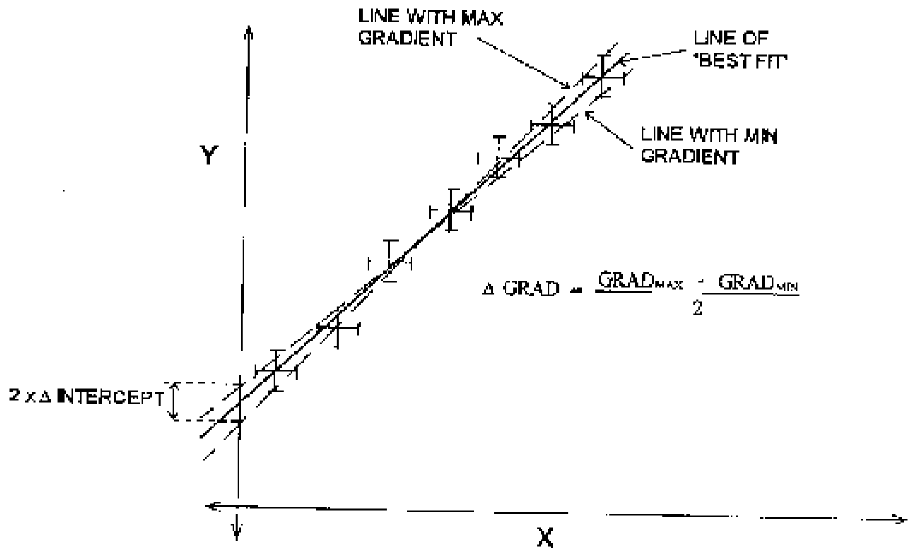

Figure 1:

The derived units are units which can be obtained by combining base units according to the algebraic relations linking the corresponding quantities.

The supplementary units, the **radian** and **steradian** (symbol, rad and sr respectively) are dimensionless quantities used when defining derived units for quantities such as angular frequency.

5.2 Definition of Base Units

metre (unit of length, symbol m)

The metre is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second. Note that the metre is defined in terms of the speed of light.

kilogram (unit of mass, symbol kg)

The kilogram is equal to the mass of the international prototype of the kilogram. Once the mass of a litre of water, it may soon be redefined as the mass of a number of carbon-12 atoms.

second (unit of time, symbol s)

The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom. This is a highly monochromatic **microwave** emission.

ampere (unit of electric current symbol A)

The ampere is that **constant current** which, if maintained in two straight parallel conductors of **negligible circular cross-section**, placed one metre apart **in vacuum**, would produce beetwen these conductors a force equal to $2x10^{-7}$ Newton per metre of length.

Earlier metric systems used the coulomb as the base unit, but it was too hard to measure with sufficient precision.

Kelvin (unit of thermodynamic temperature, symbol K)

The Kelvin is the fraction 1/273.15 of the thermodynamic temperature of the triple point of water. The Kelvin is used to express an interval or a difference in temperature, so it tends to appear in the denominator of derived units.

(Celsius temperature, symbol T, is defined by the expression $T = K - 273.15$)

candela (unit of luminous intensity, symbol cd)

The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency $540x10^{12}$ Hertz and that has a radiant intensity in that direction of 1/683 watt per steradian. This unit is used when the instrument of comparison is the human eye. Its use is in decline.

mole (unit of amount of substance, symbol mol)

The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 12 g of carbon-12. When the mole is used, the elementary entities must be specified. It is properly used as a number, but is often used as a mass.

5.3 Writing of Symbols

Roman lower case is used for symbols of units unless the symbols are derived from proper names, when capital roman type is used for the first letter. These symbols are not followed by a stop.

Unit names and symbols do not change in the plural, even though we often add an "s" in common speech. ($2K$ reads as two degree Kelvins.)

5.4 Derived Units, Special Names

Several derived units have been given special names and may be used to obtain further derived units. This is much simpler than expressing all units in terms of base units. e.g. $1Pa = 1Nm^{-2}$

Table 1 Derived units which have been given special names

PHYSICAL QUANTITY	UNIT	SYMBOL	IN TERMS OF BASE UNITS
activity	becquerel	Bq	s^{-1}
capacitance	farad	F	$m^{-2}kg^{-1}s^4A^2$
conductance	siemens	S	$m^{-2}kg^{-1}s^3A^2$
dose absorbed	gray	Gy	m^2s^{-2}
dose equivalent	sievert	Sv	m^2s^{-2}
electric charge	coulomb	C	s A
electric potential	volt	V	$m^2kgs^{-3}A^{-1}$
electric resistance	ohm	Ω	$m^2kgs^{-3}A^{-2}$
energy, work, heat	joule	J	m^2kgs^{-2}
force	newton	N	$mkgs^{-2}$
frequency	hertz	Hz	s^{-1}
illuminance	lux	lx	$m^{-2}cdsr$
inductance	henry	H	$m^{-2}kgs^{-2}A^{-2}$
luminous flux	lumen	lm	$cdsr$
magnetic flux	weber	Wb	$m^2kgs^{-2}A^{-1}$
magnetic induction	tesla	T	$kgs^{-2}A^{-1}$
power, radiant flux	watt	W	m^2kgs^{-3}
pressure	pascal	Pa	$m^{-1}kgs^{-2}$

5.5 Recommendations for Use of Units

(i) It is **preferable** to indicate the product of **two units with a dot** when there is a risk of confusion with another symbol. When **no dot is used a space should be left between the symbols** for the two units.

(ii) A negative power, horizontal line, or a solidus (/), may be used to express a derived unit obtained from two other units by division.

(iii) The solidus must not be repeated unless parentheses are used to avoid ambiguity.

5.6 Number Notation

The decimal point should be expressed by a dot placed on the line. Then multiplication should be indicated by an "x". If a dot half-high is used for this purpose, the decimal point must be a comma. **A number should never commence with a decimal point.**

Long numbers should be arranged in groups of three with a space, not a comma, separating them. The grouping should start at the decimal point.

A space should be left between the number and the unit.

5.7 Multiples and Sub-multiples

Table 2

FACTOR	PREFIX	SYMBOL	FACTOR	PREFIX	SYMBOL
10^{18}	exa	E	10^{-3}	milli	m
10^{15}	peta	P	10^{-6}	micro	μ
10^{12}	tera	T	10^{-9}	nano	n
10^{9}	giga	G	10^{-12}	pico	p
10^{6}	mega	M	10^{-15}	femto	f
10^{3}	kilo	k	10^{-18}	atto	a

The prefixes hecto, deca, deci and centi are still legal but should be avoided in technical work. An exponent attached to a symbol containing a prefix indicates that the multiple, or submultiple, of the unit is raised to the power of the exponent: e.g. a sand grain of 2 mg has a volume of about $1mm^3$. (The metre is cubed and so is the milli). A **prefix should not appear in the denominator of a derived unit**: e.g. thus the sand grain has a density of about $2Mgm^{-3}$

NOTE: The kilogram is the only base unit containing a prefix, retained for historical reasons. It may appear in the denominator: e.g. a specific activity of $1.5kBqkg^{-1}$, not $1.5Bqg^{-1}$.

5.8 Units which are not within the SI

Some units, not within the SI are in widespread use. They should be converted to SI units before calculations. These are:

minute (min)	tonne (t) (1 Mg)
hour (h)	degree (o)
day (d)	minute (’)
year (a)	second (”)
litre (l,L)	

Jargon survives in all disciplines despite a general willingness to conform (to SI) for the general good. In physics, the following non-SI units have survived:

electronvolt (eV)

The energy acquired by an electron when moved through a potential difference of one volt. (6 eV = 1 aJ approx; 6 MeV = 1 pJ approx)

atomic mass unit (u)

1/12 of the mass of one ^{12}C atom. An energy of 149 pJ or 931 MeV has approximately 1 u of mass. Atomic masses are expressed in u.

light year (ly)

The distance light travels in a year. (1 ly = 10 Pm, approx).

curie (Ci)

An activity of 37 GBq. This number is similar to the number of events per second in a gram of radium.

Other jargon units will be encountered in specialist areas; their conversion factors will be found in the references below.

Other disciplines have their jargon units, too. For instance - engineering has rpm (1 Hz = 60 rpm), geophysics has milligals ($1mgal = 10\mu ms^{-2}$) and surveying has hectares ($1ha = 10^4 m^2$, $1km^2 = 100ha$).

6. UNITS, ERRORS AND DIGITS

When an experimental value is to be reported, it must be put into the standard form. Here is how to do it:

Take a fresh page. Lay out the value to be processed. Rewrite it as you make each of the following corrections:

1. Reduce the units' denominator to base units: (DENOM)
2. Reduce the units' numerator to an appropriate unit: (NUM)
3 . Choose a 10^{3N} prefix which brings the main value to between 1 and 999 (PREFIX)
4. Express the error in the same units as the value: (SAME UNITS)
5. Round the error to one or two significant figures: (SIG. FIG.)
6. Round the main value and error to the same decimal place: (D.P.)
7. Check the spaces and cases: (FORMAT)

A difficult example: $605.643 calories/gK \pm 1.567\%$

$=605643 calorieskg^{-1}K^{-1} \pm 1.567\%$	DENOM
$=2537648.Jkg^{-1}K^{-1} \pm 1.567\%$	NUM
$=2.537648MJkg^{-l}K^{-1} \pm 1.567\%$	PREFIX
$=2.537648 \pm 0.039765MJkg^{-1}K^{-1}$	SAME UNIT
$=2.537648 \pm 0.04MJkg^{-1}K^{-1}$	SIG. FIGS.
$=2.54 \pm 0.04MJkg^{-1}K^{-1}$	D.P.
$=2.54 \pm 0.04MJkg^{-1}K^{-1}$	FORMAT

Practice the following, using pencil, eraser and scratch paper

$2.3 \pm 0.37Jg^{-1}$

$6.71 \pm 0.022Bqcm^{-2}$

$1191300GJ \pm 15TJ$

$171 \pm 9.666666 N/mm^2$
$1050.3 \pm 18.33 hectopascals$
$55 tonnes\ km^{-3} \pm 2\%$
$1.2345 x 10^{-7} g \pm 75875 fg$
$\sim 6 miles, \sim 6 ft, \sim 17 min., \sim 3 kWh, \sim 100 light\ years$
$\sim 60 MeV, \sim 10^{-5} kgs^{-2} A^{-2}$ (magnetic unit)

7. USE OF GRAPHS

This session is designed to give an understanding of the use of graphs. For those who are good at mathematics it will serve as revision, for the rest of you please use the time to master the following:

- Knowledge and understanding of the equation of a straight line.
- Ability to write an equation for a straight line given the graph.
- Ability to draw the graph given the equation without plotting out all the points.
- Understanding of "directly proportional".
- Ability to use a graphical method to show direct proportion in a variety of situations.
- Understanding of the term "inversely proportional".
- Ability to use a graphical method to show inverse proportionality.
- Ability to check equations using log graphs.

7.1 Gradient of a Stright Line

The straight line shown in Figure 2 has a constant gradient. In other words, as point P moves along the line in the direction of x increasing (i.e. from A to B) y changes at a constant rate, and in this case it is a simple matter to find the gradient.

7.1.1 Calculation of Gradient

In moving from A to B the x-coordinate has increased by 10 (from 0 to 10) while the y-coordinate has increased by 5 (from 2 to 7).

$$Gradient = \frac{increase\ in\ y}{increase\ in\ x} = \frac{5}{10} = \frac{1}{2}$$

The gradient is positive as y is increasing as x increases. So we say that the gradient of the line in Figure 2 is 1/2 or 0.5. In fact to find the gradient of the line we can take any two points on the line; e.g. we could have considered the points C add D with co-ordinates (4,4) and (8,6) respectively. To obtain the most accurate answer choose points which are as far apart as is convenient.

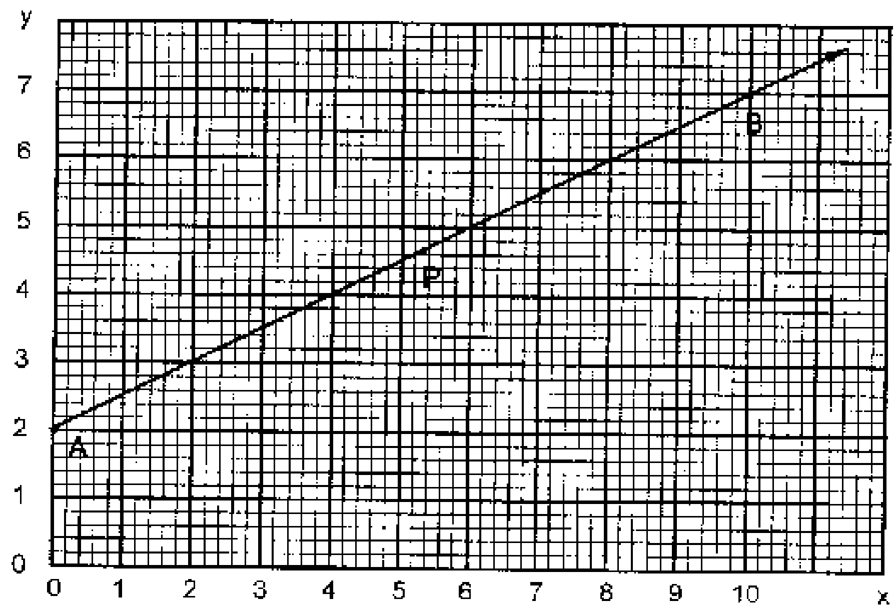

Figure 2:

7.1.2 Equation of a Straight Line

Consider the line shown in Figure 3. What is its gradient? Answer is 2. Now look at the points marked and write down their coordinates. Answer:

A : (0,1)
B : (1,3)
C : (2,5)
D : (3,7)
E : (4,9)

You might like to add a few more points of your own. Can you now find a connection between the y and x coordinates?

The first thing to notice is that the x-coordinate increases by 1 at each step as you go from A to E, and as we would expect the y-coordinate increases by 2 each time, since 2 is the gradient of the line (remember gradient is the change in y for an increase of 1 in x). Can you find the rule which connects y with x? The answer is that to get the y-coordinate you double the x-coordinate and add 1. Since the y-coordinate is referred to simply as 'y' and the x-coordinate as 'x':

$y = 2x + 1$, (gradient)x + (intercept on y axis)

or in general terms $y = mx + c$

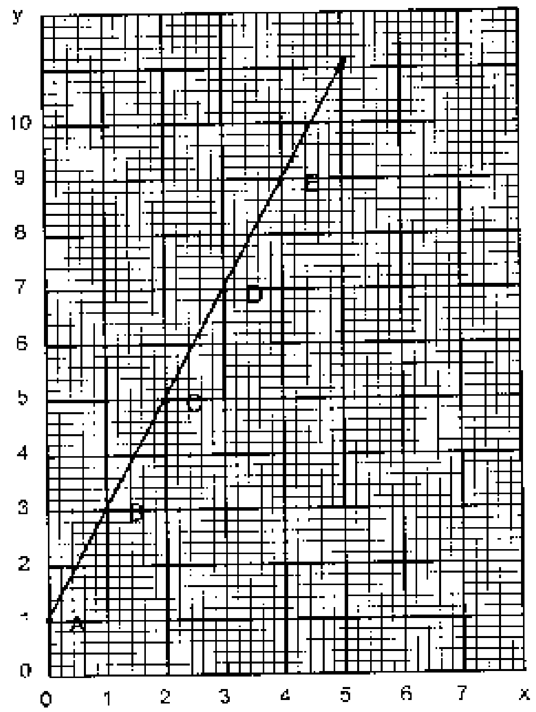

Figure 3:

7.2 Direct Proportion

Imagine you go shopping and buy items at \$3 each. If you tabulated the cost then you would get:

Number of items	cost
1	\$3
2	\$6
3	\$9
.	.
.	.
.	.
10	\$30

Draw a graph of cost on y-axis against number of items on the x-axis. The graph represents a graph of two quantities which are proportional.

$y \propto x$ or $y = kx$

The two main features of a graph showing that two quantities are directly proportional are:

1. the graph is a straight line

2. the graph passes through the point (0,0).

If you added the cost of the journey to the shop then the cost would no longer be directly proportional to the number of items. (If you bought twice the number of items it would cost less than twice as much). The graph would still be a straight line but it would not pass through (0,0), i.e. a **straight line alone is not sufficient proof of direct proportionality**.

Choose a value for the cost of the journey and plot the graph.

Write down the equation of the line. It should be
Cost = \$3 x number of items + cost of journey

Another shopping example, this time the cost of tiling a square room at \$10 a square metre.

side of room	area of room	cost
lm	$1m^2$	\$10
2m	$4m^2$	\$40
3m	$9m^2$	\$90
4m	$16m^2$	\$160

Question

Draw a graph of cost against side of room and of cost against $(side\ of\ room)^2$. What do you find?

Which graph enables you to deduce the relationship between cost and the length of the side of the room?

7.3 Inverse Proportion

The term inverse proportion is often wrongly used. It has a very precise meaning and refers to the situation where doubling one quantity halves the other, trebling one causes the other to be a third etc.

$y \propto \frac{1}{x}$ or $xy = constant$

Question

Which of the following sets of pairs of numbers are inversely proportional?

a	b		c	d		e	f
1	24		1	20		1	144
2	12		2	16		2	48
3	8		3	12		3	32
4	6		4	8		4	16
5	4.8		5	4		5	8
6	4		6	0		6	6

Draw a graph of each. What do you notice?

What graph can you draw to establish without doubt that the two quantities are inversely proportional?

Note: You need a straight line graph before you can be sure about the relationship between two variables.

7.4 Linear Graph from Non-linear Equations

The aim of many experiments is to find an equation relating two variables. If the graph obtained by plotting these two variables is a straight line, it is an easy matter to measure the slope and intercept and write out an equation in the form $y = mx + c$. If the graph is a curve, the solution is not so simple but it is often possible to choose the variables so that a straight line is obtained. Here are distances moved by a trolley from rest after various times.

Time, t	Distance, s
0.7	0.141
1.3	0.372
1.9	0.794
2.3	1.113
2.9	1.850

If s is plotted against t the graph will not be a straight line since s increases much more rapidly than t because the trolley is accelerating.

For an object travelling with constant acceleration from rest, the equation relating acceleration (a), distance (s) and time (t) is

$s = (1/2)at^2$

comparing this with $y = mx + c$ shows that a graph of s against t^2 should be a straight line passing through (0,0) and having a gradient of $(1/2)a$.

Question

How would you check graphically whether experimental results fit the following equations?

1. $F = k/r^2$, where k is constant.
2. $E = (1/2)mv^2$, where m is constant,
3. $V = RE/(R + r)$, when E and r are constant.

7.5 Log Graphs

Sometimes, two variables are related by an equation of the form

$y = Ax^n$

where A and n are unknown constants.
You can use trial and error to try to find n but this would involve graphing;

y against x
y against x^2
y against $1/x$

etc. until you obtained a straight line and, in the end, you might give up without getting a solution. However, if

$y = Ax^n$ then
$log\ y = log(Ax^n)$
$log\ y = logA + log\ x^n$
$log\ y = logA + nlog\ x$

(compare this with) $y = mx + c$.

The graph of $logy$ against $logx$ would be a straight line. The constant n is the gradient and the intercept is $logA$. From this graph we would be able to find both A and n.

Question

Under certain conditions (when heat cannot flow into or out of the gas) the pressure p and volume V are related by the equation

$pV^\gamma = k$

where γ and k are constants.

If you obtained experimental data under these conditions, what graph would you plot to find the values of γ and k and how would you find the values of γ and k?

Question

Theory suggests that the power P dissipated in a heated filament of resistance R is given by an equation of the form

$P = kR^n$

where k and n are constants.
Plot a suitable graph of the following data so that the values of n and k can be found.

P(W)	R(Ω)
4.41	0.91
8.11	1.11
12.59	1.27
17.70	1.41
23.88	1.51

7.6 Use of Graphs-Assignment

1. A 100 watt heater and a thermometer were immersed in a copper calorimeter containing water. The following readings were obtained:

temperature (^oC)	22	36	40	45	49	54	58
time (minutes)	3	4	5	6	7	8	9

Plot a graph of temperature against time (reminder: this means that time should be on the x axis).

The relevant equation is: *power x time = heat capacity x temperature rise*
Compare this equation with the equation of a straight line: $y = mx + c$

From your graph determine the initial temperature of the water and the heat capacity of the calorimeter + water.

2. The tension of a vibrating string is kept constant and its length varied to tune it to a series of tuning forks. The necessary lengths are given below:

Tuning Fork	C	D	E	F	G
frequency of tuning fork (Hz)	256	288	320	384	512

length of string (cm)	117	104	94	78	59

Plot a graph of length against frequency. What possible relationship is there between the frequency of vibration and the length of the string? Draw a suitable graph to confirm this.

Experiment 1

COULOMB'S LAW

Purpose

Verifying the electrostatic force-distance relationship, and the electrostatic force-charge relationship and also determining the Coulomb constant.

Introduction

Let two charged particles (also called point charges) have magnitudes q_1 and q_2 and be separated by a distance r. The electrostatic force of attraction or repulsion between them has the magnitude

$$F = k\frac{q_1 q_2}{r^2}$$

in which k is a constant. Each particle exerts a force of this magnitude on the other particle; the two forces form a third-law force pair. If the particles repel each other, the force on each particle is directed away from the other particle. If the particles attract each other, the force on each particle is directed toward the other particle.

The Coulomb Balance (Figure 12.1) is a delicate torsion balance that can be used to investigate the force between charged objects. A conductive sphere is mounted on a rod, counterbalanced, and suspended from a thin torsion wire. An identical sphere is mounted on a slide assembly so it can be positioned at various distances from the suspended sphere. To perform the experiment, both spheres are charged, and the sphere on the slide assembly is placed at fixed distances from the equilibrium position of the suspended sphere. The electrostatic force between the spheres causes the torsion wire to twist. The experimenter then twists the torsion wire to bring the balance back to its equilibrium position. The angle through which the torsion wire must be twisted to reestablish equilibrium is directly proportional to the electrostatic force between the spheres.

The torsion balance gives a direct and reasonably accurate measurement of the Coulomb force. The most accurate determinations of Coulomb's law, however, are indirect. It can

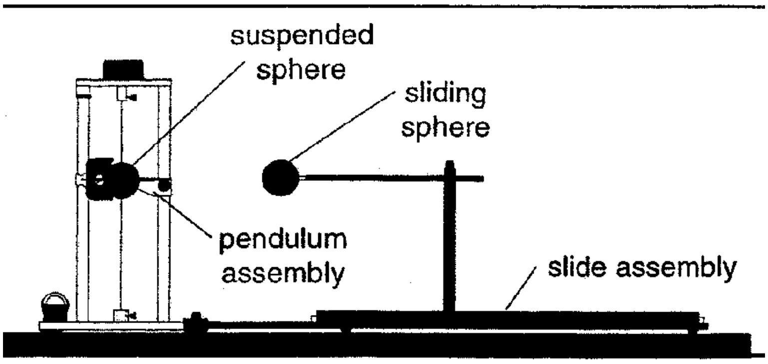

Figure 12.1: The Coulomb Balance

be shown mathematically that if the inverse square law holds for the electrostatic force, the electric field inside a uniformly charged sphere must be everywhere zero. Measurements of the field inside a charged sphere have shown this to be true with remarkable accuracy. The Coulomb force can be expressed by the formula:

$$F = k\frac{q_1 q_2}{r^{2+n}}$$

Using this indirect method, it has been demonstrated experimentally that $n = 2x10^{-16}$.

Tips For Accurate Results

• Perform the experiment during the time of year when humidity is lowest.

• Perform the experiment in a draft-free room.

• The table on which you set up the experiment should be made of an insulating material (wood, masonite, plastic, etc). If a metal table is used, image charges will arise in the table that will significantly affect the results. (This is also true for insulating materials, but the effect is significantly reduced.)

• Position the torsion balance at least two feet away from walls or other objects which could be charged or have a charge induced on them.

• When performing experiments, stand directly behind the balance and at a maximum comfortable distance from it. This will minimize the effects of static charges that may collect on clothing.

• Avoid wearing synthetic fabrics, because they tend to acquire large static charges. Short sleeve cotton clothes are best, and a grounding wire connected to the experimenter is helpful.

• Use a stable, regulated kilovolt power supply to charge the spheres. This will help ensure a constant charge throughout an experiment.

When charging the spheres, turn the power supply on, charge the spheres, then immediately turn the supply off. The high voltage at the terminals of the supply can cause leakage currents which will affect the torsion balance. A supply with a momentary "power on" button is ideal.

• When charging the spheres, hold the charging probe near the end of the handle, so your hand is as far from the sphere as possible. If your hand is too close to the sphere, it will have a capacitive effect, increasing the charge on the sphere for a given voltage. This effect should be minimized so the charge on the spheres can be accurately reproduced when recharging during the experiment.

• Surface contamination on the rods that support the charged spheres can cause charge leakage. To prevent this, avoid handling these parts as much as possible.

• There will always be some charge leakage. Perform measurements as quickly as possible after charging, to minimize the leakage effects.

• Recharge the spheres before each measurement.

Corrections to the Data

The reason for the deviation from the inverse square relationship at short distances is that the charged spheres are not simply point charges. A charged conductive sphere, if it is isolated from other electrostatic influences, acts as a point charge. The charges distribute themselves evenly on the surface of the sphere, so that the center of the charge distribution is just at the center of the sphere.

However, when two charged spheres are separated by a distance that is not large compared to the size of the spheres, the charges will redistribute themselves on the spheres so as to minimize the electrostatic energy. The force between the spheres will therefore be less than it would be if the charged spheres were actual point charges. A correction factor B, can be used to correct for this deviation.

$$B = 1 - 4\frac{a^3}{r^3}$$

where a equals the radius of the spheres and r is the separation between spheres.

Equipments

The Coulomb Balance Set
A kilovolt Power Supply

Part I: Force versus Distance

Procedure

1. Be sure the spheres are fully discharged (touch them with a grounded probe) and move the sliding sphere as far as possible from the suspended sphere. Set the torsion dial to 0^oC. Zero the torsion balance by appropriately rotating the bottom torsion wire retainer until the pendulum assembly is at its zero displacement position as indicated by the index marks.

2. With the spheres still at maximum separation, charge both the spheres to a potential of $5-6kV$, using the charging probe. (One terminal of the power supply should be grounded.) Immediately after charging the spheres, turn the power supply off to avoid high voltage leakage effects.

3. Position the sliding sphere at a position of $20cm$. Adjust the torsion knob as necessary to balance the forces and bring the pendulum back to the zero position. Record the distance r and the angle θ in Table 12.1. Repeat this measurement third times until your result is repeatable to within ± 1 degree and record all your results.

4. Repeat Step 3 for 14, 10, 9, 8, 7, 6 and $5cm$.

Part II: Force Versus Charge

The capacitance of an isolated conductive sphere is given by the equation:

$C = 4\pi\epsilon_o a$

where C is the capacitance, $\epsilon_o = 8.85x10^{-12}F/m$, and a is the radius of the sphere which is $19mm$. For a capacitor, charge q and charging potential V are related by the equation: $q = CV$. You can use this equation to determine the charge on the spheres from your applied charging potential. This is the simplest method for determining the charge on the spheres. Unfortunately, the conducting spheres of the Coulomb Balance are not isolated in this application, so the measured values of q will be only approximate.

Note: A capacitor normally consists of two conductors. The charge on one conductor is $+q$ and the charge on the other is $-q$. V is the potential difference between the two conductors. For an isolated sphere with a charge $+q$, the second conductor is a hypothetical plane at ground potential and with charge $-q$, located at a distance infinitely far from the sphere.

Procedure

With the sphere separation r held at a constant value (choose a value between 7 and 10 cm), charge the spheres and measure the resulting angle. Record your data in Table 12.2. Keep the charge on one sphere constant, and vary the charge on the other (When charging the spheres, they should always be at their maximum separation).

Part III: The Coulomb Constant

In previous parts of this lab, you determined (if all went well) that the electrostatic force between two point charges is inversely proportional to the square of the distance between the charges and directly proportional to the charge on each sphere. This relationship is stated mathematically in Coulomb's Law:

$$F = k\frac{q_1 q_2}{r^2}$$

where F is the electrostatic force, q_1 and q_2 are the charges, and r is the distance between the charges. In order to complete the equation, you need to determine the value of the Coulomb constant, k. To accomplish this, you must measure three additional variables; the torsion constant of the torsion wire (K), so you can convert your torsion angles into measurements of force and the charges, q_1 and q_2. Then, knowing F, q_1, q_2 and r, you can plug these values into the Coulomb equation to determine k.

Measuring the Torsion constant, K

A *torsion constant* for a wire usually expresses the torque required to twist the wire a unit angle, and is normally expressed in newton meters per degree. However, when using the torsion balance, the torque arm is always the same (the distance from the center of the conductive sphere to the torsion wire), so the torsion constant for the balance is more conveniently expressed in newtons per degree.

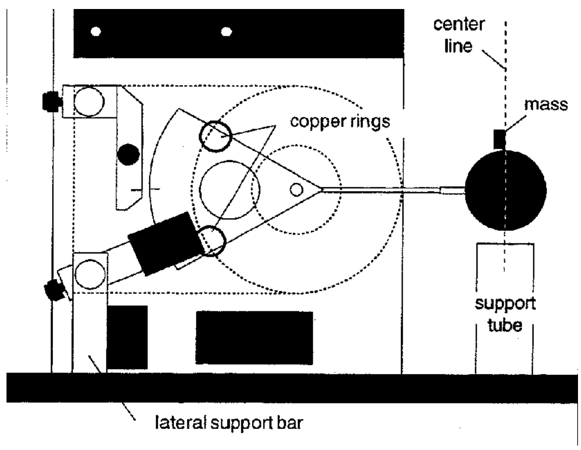

Figure 12.2: Calibrating the Torsion Balance

Procedure

1. Carefully turn the Torsion Balance on its side, supporting it with the lateral support bar, as shown in Figure 12.2. Place the support tube under the sphere.

2. Zero the torsion balance by rotating the torsion dial until the index lines are aligned. Record the angle of the degree plate in Table 12.3.

3. Carefully place the $20mg$ mass on the center line of the conductive sphere.

4. Turn the degree knob as required to bring the index lines back into alignment. Read the torsion angle on the degree scale. Record the angle in Table 12.3.

5. Repeat steps 3 and 4, using the two $20mg$ masses and the $50mg$ mass to apply each of the masses shown in the table. Each time record the mass and the torsion angle.

REPORT SHEET

EXPERIMENT 1: COULOMB'S LAW

Student's Name:
Experiment Date:
Group Member Name(s):
Laboratory Bench Number:
Assistant's Name and Signature:

Data and Calculations

Part I: Force versus Distance

Table 12.1

$V_{charging\ potential}$ = ...

$r(cm)$	θ_1	θ_2	θ_3	θ (θ_{avg})	B	$\theta_{corrected}$	$r^2(cm^2)$

In this part of the experiment, we are assuming that force is proportional to the torsion angle. Determine the functional relationship between the force, which is proportional to the torsion angle θ and the distance r. This can be done in the following ways:

1. Plot $log\theta$ versus $logr$.

Explanation: If $\theta = br^n$, where b and n are unknown constants, then $log\theta = nlogr + logb$. The graph of $log\theta$ versus $logr$ will therefore be a straight line. Its slope will be equal to n and its y intercept will be equal to $logb$. Therefore, if the graph is a straight line, the function is determined.

2. Plot θ versus r^2

Either of these methods will demonstrate that, for relatively large values of r, the force is proportional to $1/r^2$. For small values of r, however, this relationship does not hold.

To Correct Your Data:

1. Calculate the correction factor B for each of the separations r that you used. Record your results in Table 12.1.

2. Multiply each of your collected values of θ by $1/B$ and record your results as $\theta_{corrected}$.

3. Reconstruct your graphs relating force and separation, but this time use $\theta_{corrected}$ instead of θ. Make corrected your new plot on the same graph as your original plot.

Question

How does the correction factor affect your results?

....
....
....
....
....

Part II: Force versus Charge

Table 12.2

V_1, charging potential for the one sphere.

V_2, charging potential for the other sphere.

Capacitance of the spheres, C=............................

r = ...

V_1 (kV)	V_2 (kV)	θ	q_1 (C)	q_2 (C)

Graph angle versus multiply of charges to determine the relationship.

Part III: The Coulomb Constant

Measuring the Torsion Constant, K

Table 12.3

m (mg)	θ	mg (N)	mg/θ (K) $(N/degree)$
20			
40			
50			
70			

Complete the table as follows to determine the torsion constant for the wire:

a. Calculate the weight for each set of masses that you used.

b. Divide the weight by the torsion angle to determine the torsion constant at each weight.

c. Average your measured torsion constants to determine the torsion constant for the wire. Use the variance in your measured values as an indication of the accuracy of your measurement.

$K = K_{avg}$=..........................

Calculations for the Coulomb Constant

The Coulomb constant can now be determined by using any data pair from your force versus distance data. Fill in the Table 12.4.

Table 12.4

Charging potential, $V_1 = V_2$ =..........................

r (cm)	θ	B	$\theta_{corrected}$	$F(N)$	q_1 (C)	q_2 (C)	k (Nm^2/C^2)

1. Convert your torsion angle measurement ($\theta_{corrected}$) to a force measurement, using your measured torsion constant for the torsion wire: $F = K\theta_{corrected}$.

2. Determine the charge that was on the sphere using the equation $q = CV$.

3. Plug your collected data into the Coulomb equation, $F = k\frac{q_1 q_2}{r^2}$ to determine the value of k. Do this for several sets of data. Average your results to determine a value for k.

$k = k_{avg}$=...........................

Experiment 2

EQUIPOTENTIAL AND ELECTRIC FIELD LINES

Purpose

To plot the equipotential lines in the space between a pair of charged electrodes and relate the electric field to these lines.

Introduction

The electric field is a *vector field*; it consists of a distribution of *vectors*, one for each point in the region around a charged object. In principle, we can define the electric field at some point near the charged object as follows: We first place a *positive* charge q_o, called a *test charge*, at the point. We then measure the electrostatic force $\vec{F}$ that acts on the test charge. Finally, we define the electric field $\vec{E}$ at this point due to the charged object as

$$\vec{E} = \frac{\vec{F}}{q_o}$$

Thus, the magnitude of the elctric field $\vec{E}$ at this point is $E = F/q_o$, and the direction of $\vec{E}$ is that of the force $\vec{F}$ that acts on the *positive* test charge. To define the electric fi eld within some region, we must similarly define it at all points in the region.

Although we use a positive test charge to define the electric field of a charged object, that field exists independently of the test charge. We assume that in our defining procedure, the presence of the test charge does not affect the charge distribution on the charged object, and thus does not alter the electric field we are defining.

Michael Faraday, who introduced the idea of electric fields in the 19th century, thought of the space around a charged body as filled with *lines of force*. Although we no longer attach much reality to these lines, now usually called **electric field lines**, they still provide a nice way to visualize patterns in electric fields.

The relation between the field lines and electric field vectors is this:

(1) At any point, the direction of a straight field line or the direction of the tangent to a curved field line gives the direction of $\vec{E}$ at that point, and

(2) The field lines are drawn so that the number of lines per unit area, measured in a plane that is perpendicular to the lines, is proportional to *magnitude* of $\vec{E}$.

This second relation means that where the field lines are close together, E is large and where they are far apart, E is small.

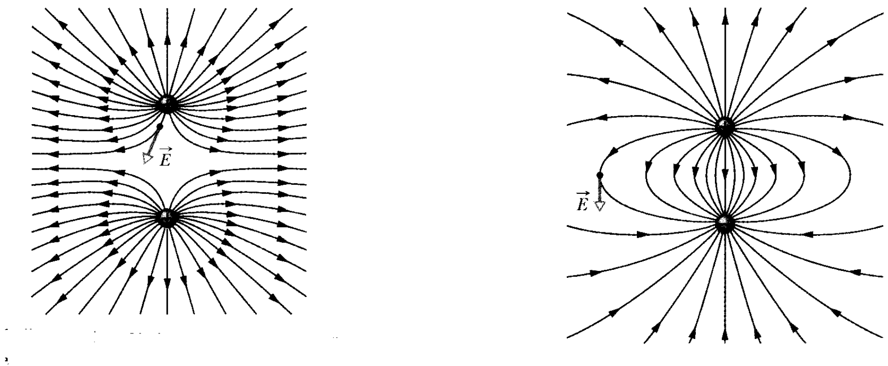

Figure 13.1:

Figure 13.1 shows the field lines for two equal positive charges and the pattern for two charges that are equal in magnitude but of opposite sign, a configuration that we call an **electric dipole**.

Another useful concept that is introduced along with the electric field is the "electrostatic potential energy". The electrostatic potential energy of a test charge q_o placed at point A, in the vicinity of a charge distribution, i.e. in the electric field of the charge distribution, is defined as the work done to bring that charge from infinity to the point A. As is the case with the gravitational field, one is usually interested in the potential energy difference between two points rather than the absolute value of the potential energy at that point. The electrostatic potential energy difference between any two points A and B, say, in the vicinity of a charge distribution is defined as the work done to move a charge from A to B.

$$\triangle U = U_B - U_A = W_{AB}$$

where W_{AB} is the work done to move q from A to B. The "electrostatic potential" is the electrostatic potential energy per unit charge. So as the electrostatic potential difference or simply the potential difference $\triangle V$ between the points A and B will be just the electrostatic potential energy difference per unit charge between A and B,

$$\triangle V = V_B - V_A = \frac{W_{AB}}{q_o}$$

Note that *electric potential is a scalar, not a vector.*

Adjacent points that have the same electric potential form an **equipotential surface**, which can be either an imaginary surface or a real, physical surface. No net work is done on a charged particle by an electric field when the particle moves between two points on the same equipotential surface.

From symmetry, the equipotential surfaces produced by a point charge or a spherically symmetrical charge distribution are a family of concentric spheres. For a uniform electric field, the surfaces are a family of planes perpendicular to the field lines. In fact, Equipotential surfaces are always perpendicular to electric field lines and thus to $\vec{E}$, which is always tangent to these lines. If $\vec{E}$ were not perpendicular to an equipotential surface, it would have a component lying along that surface. This component would then do work on a charged particle as it moved along the surface.

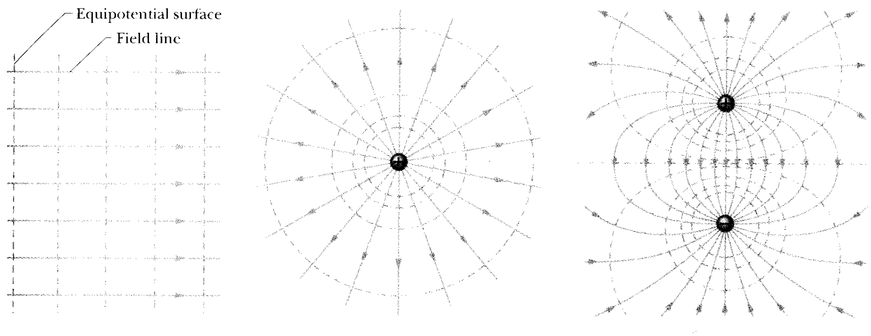

Figure 13.2:

Figure 13.2 shows electric field lines and cross sections of the equipotential surfaces for a uniform electric field and for the field associated with a point charge and with an electric dipole.

Equipments

The Field Mapper Kit
Low Voltage AC/DC Power Supply
Digital Multimeter

Procedure

1. Connect the electrodes to a DC power supply as in Figure 13.3.
2. Apply a voltage of $5 - 20V$ to the electrodes.

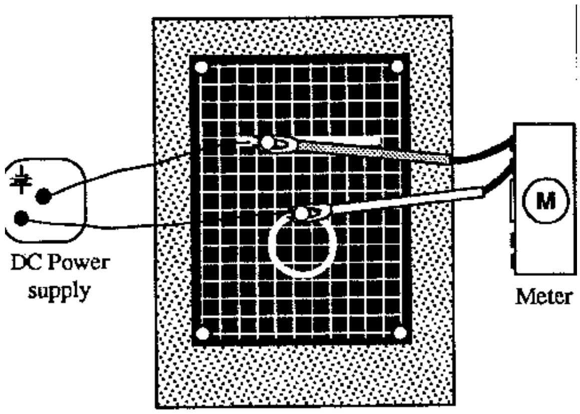

Figure 13.3: Connections of the Electrodes to a DC Power Supply

3. Equipotentials are plotted by connecting one lead of the voltmeter (the ground) to one of the electrode. This electrode now becomes the reference. The other voltmeter lead (the probe) is used to measure the potential at any point on the paper simply by touching the probe to the paper at that point.

To map an equipotential line, move the probe until the desired potential is indicated on the voltmeter. Mark the paper at this point with a soft lead pencil. Continue to move the probe, but only in a direction which maintains the voltmeter at the same reading. Continue to mark these points. Connecting the points produces an equipotential line.

4. To plot electric field lines, neither lead of the voltmeter is connected to an electrode. Instead, the two leads of the voltmeter will be placed on the conductive paper side-by-side at a set distance of separation (one centimeter is a useful separation to use). It is best to tape the two leads of the voltmeter together for this procedure. The technique is to use the voltmeter leads to find the direction from an electrode that follows the path of greatest potential difference from point to point.

Do not attempt to make measurements by placing the leads on the grid marks on the conductive paper. Touch the voltmeter leads only on the solid black areas of the paper. It may be necessary to use a higher voltmeter sensitivity for this measurement than was used in measuring equipotentials.

To plot the field lines on the conductive paper, place the voltmeter lead connected to ground near one of the electrodes. Place the other voltmeter lead on the paper and note the voltmeter reading. Now pivot the lead to several new positions while keeping the ground lead stationary. Note the voltmeter readings as you touch the lead at each new spot on the paper. When the potential is the highest, draw an arrow on the paper from the ground lead to the other lead by using a light-colored pencil (Figure 13.4). Then move the ground lead to the tip (head) of the arrow. Repeat the action of pivoting and touching with the front lead until the potential reading in a given direction is highest. Draw a new arrow. Repeat the action of putting the ground lead at the tip (head) of each new arrow and finding the direction in which the potential difference is highest.

Eventually, the arrows drawn in this manner will form a field line. Return to the electrode and select a new point at which to place the voltmeter's ground lead. Again probe with the other lead until the direction of highest potential difference is found. Draw an arrow from the ground lead to the other lead, and repeat the process until a new field line is drawn. Continue selecting new points and drawing field lines around the original electrode.

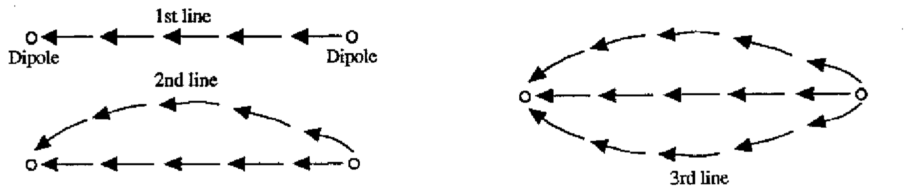

Figure 13.4: Plotting the field lines

The followings are only some suggested experiments in mapping equipotentials and field gradient using the Field Mapper.

a

REPORT SHEET

EXPERIMENT 2: EQUIPOTENTIAL AND ELECTRIC FIELD LINES

Student's Name:
Experiment Date:
Group Member Name(s):
Laboratory Bench Number:
Assistant's Name and Signature:

Parallel Plate Capacitor

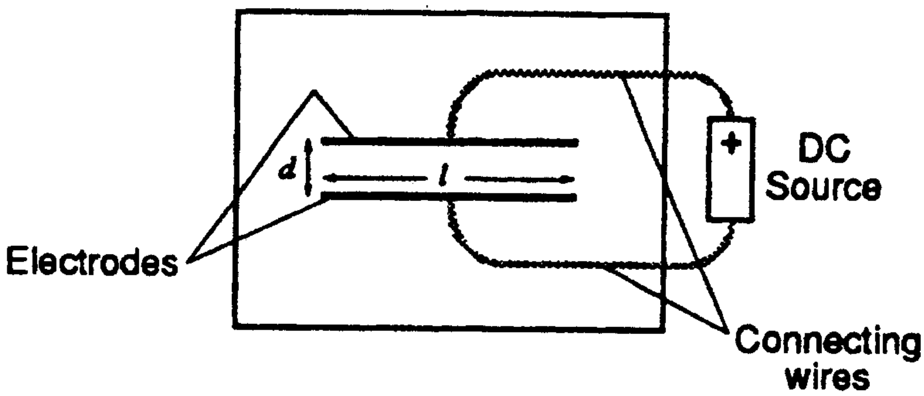

Figure 13.5: Parallel Plate Capacitor

Plot the equipotential and the electric field lines.

1. What is the field outside the capacitor plates?

2. How does the ratio of the plate length (l) versus separation (d) affect the fringing effect at the edges of the plates?

3. What redesign of the plates, or perhaps extra electrodes, could help eliminate the fringing effect?

Circular Source in Paralel Plate Capacitor

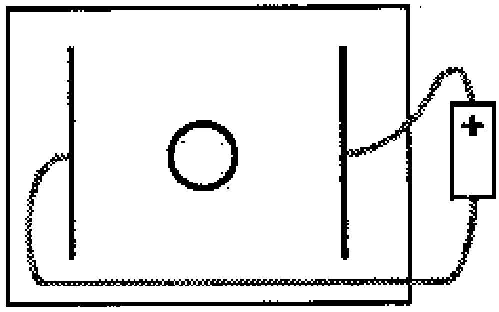

Figure 13.6: Circular Source in Paralel Plate Capacitor

Plot the equipotential and the electric field lines.

1. How does the circular electrode distort the field?

2. What is the potential of the circular electrode? Of the area inside the electrode?

Point Charges

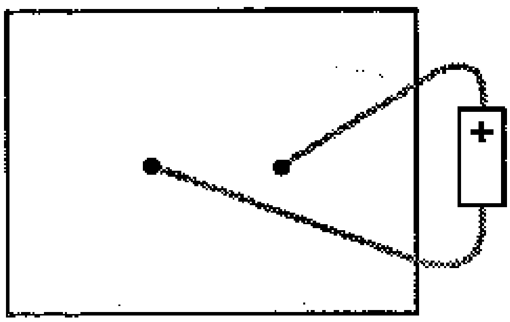

Figure 13.7: Point Charges

Plot the equipotential and the electric field lines.

1. Where is the electric field most nearly uniform?

2. What is the central equipotential shape?

3. What is the equipotential shape close to "point" electrode?

Plot the equipotential and the electric field lines for the following electrode combinations.

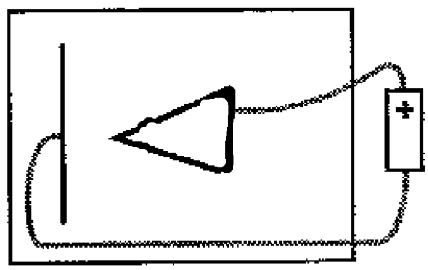

Figure 13.8: Line and Sharp Point

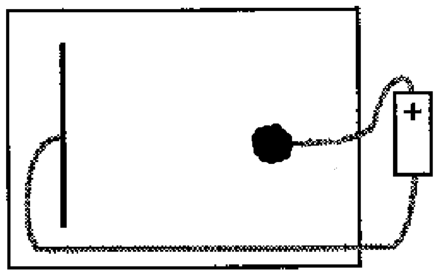

Figure 13.9: Line and Point Source

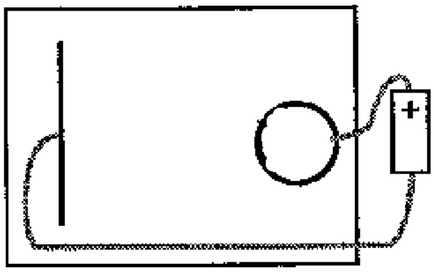

Figure 13.10: Line and Circular Source

Questions

1. What is the relation between the direction of a maximum value field gradient and equipotential line at the same point? (A geometrical relation is desired.)

2. What effect does the finite size of the black paper have on the field?

3. What distortion of the field is produced by the large electrode around the perimeter of the paper?

Experiment 3

BASIC ELECTRICITY

Purpose

To become familiar with the Circuits Experiment Board. To learn how to construct a complete electrical circuit and represent electrical circuits with circuit diagrams.

Introduction

The Electric Circuit

In its simplest form, an electric circuit consists basically of a source, a load and a current path. The *source* can be a battery or any other type of energy source that produces voltage. The *load* can be a simple resistor or any other type of electrical device or more complex circuit. The *current path* is the conductors connecting the source to the load.

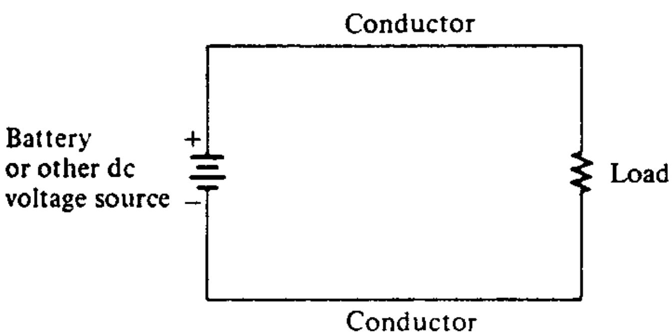

Figure 14.1: A simple electrical circuit

A *closed* circuit is one in which the current has a complete path. An *open* circuit is one in which the current path is *broken* and the current cannot flow. An open circuit represents an infinitely large resistance. A *switch* is the device commonly used to open or close a circuit. An open circuit sometimes is a result of the failure of a component in a circuit, such as a burned-out resistor or lamp bulb.

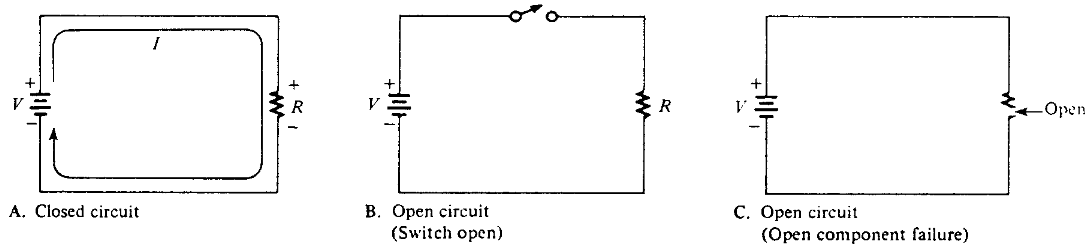

Figure 14.2: Closed and open circuits

A *short* circuit is a near-zero resistance path and occurs when two points accidentally become connected, and current flows through the shorted contact. A short across a component such as a resistor will cause all of the current to flow through the short, bypassing the resistor.

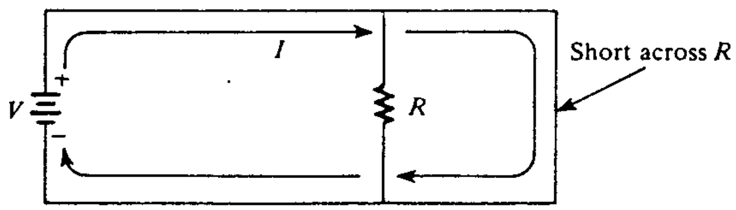

Figure 14.3: Short circuit

Protective Devices and Switches

Protective devices are used in electrical and electronic circuits to protect the circuit from damage due to overcurrent, to prevent fire hazards due to excessive current and to protect personel from shock hazards.

Fuses are used to protect an electrical circuit or an electronic instrument from excessive current. There are several types of fuses, each with various current ratings. The current rating is the maximum amount of current that the fuse can carry without opening. If the current exceeds this amount, the fuse will blow and cause an open that stops the current.

Two types of fuses are found in power applications such as residential wiring: the *plug* type and the *cartridge* type.

In power applications such as commercial, industrial and residental wiring, circuit breakers are replacing fuses in new installations. A circuit breaker can be reset and reused repeatedly, an advantage over fuses, which must be replaced when they go out. Circuit breakers are also commonly used in electronic equipment. There are two types of circuit breakers: magnetic and thermal.

Switches are used to turn current on or off in a circuit. There are several types of switches.

Current

Electrical current is the net movement of electrical charge from one point to another in a conductive material. In other words, current is the *rate of flow of electrical charge* in a conductor. Electrical charge is symbolized by the letter Q, current by the letter I. Since current is the rate of charge flow, it can be stated as follows:

$$I = \frac{Q}{t}$$

Current is measured in a unit called the ampere, abbreviated by the letter A. *One ampere is the amount of current flowing in a conductor when one coulomb of charge moves past a given point in one second.*

Voltage

Normally, in a conductive material such as copper wire, the free electrons are in random motion and have no net direction. In order to produce current, the free electrons *must* move in the same general direction. To produce motion in a given direction, energy must be imparted to the electrons. This energy comes from a voltage source connected to a conductor. The battery is a typical energy source that provides voltage. Keep in mind that *you must have voltage in order to have current.*

Voltage represents the energy required to moves a certain amount of charge from one point to another. Voltage is also known as *eletromotive force* (emf) or *potential difference.*

$$V = \frac{\varepsilon}{Q}$$

Voltage is measured in a unit called the volt, abbreviated V. *One volt is the amount of potential difference between two points when one joule of energy is used to move one coulomb of charge from one point to the other.*

Resistance

Resistance is the opposition to current. It is used in electric circuits to *limit* or control the amount of current that flows. An electrical component having the property of resistance is called a *resistor.* There are many types of resistors in common use, but generally they can be placed in two main categories: *fixed* and *variable.*

Fixed resistors have ohmic values set by manufacturer and cannot be changed easily. Various sizes and construction methods are used to control the heat-dissipating capabilities, the resistance value and the precision. Fixed resistors with value tolerances of 2%, 5%, 10%, 20% are color coded with four bands to indicate the resistance value and the tolerance. This color-code band system is shown in Figure 14.4.

Variable resistors are designed so that their resistance values can be changed easily with a manual or an automatic adjustment. Two basic types of manually adjustable resistors are the *potentiometer* and the *rheostat.*

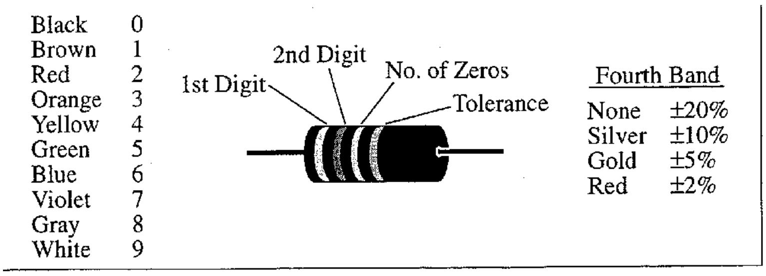

Figure 14.4: Coding of a Resistor

The resistance of a resistor can be determined by the color bands printed on the resistor according to the following rule:

$R = (first\ color\ number)(second\ color\ number)\ x\ 10^{(third\ color\ number)}\ \Omega$

Resistors in Series

Resistors in series are connected end-to-end. A series connection provides only one path for current between two points in a circuit so that the same current flows through each series resistor. For any number of individual resistors connected in series, the total resistance is the sum of each of the individual values:

$R_T = R_1 + R_2 + R_3 + ... + R_n$

Resistors in Parallel

When two or more components are connected across the same voltage source, they are in parallel. A parallel circuit provides more than one path for current. Each parallel path is called a branch. When resistors are connected in parallel, the total resistance of the circuit decreases. The total resistance of a parallel combination is always less than the value of the smallest resistor. For any number of individual resistors connected in parallel, the total resistance is as follows:

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ... + \frac{1}{R_n}}$$

Measurements

Current, voltage and resistance measurements are common in electrical work. Special types of instruments are used to measure these quantities.

Current is measured with an *ammeter* connected in the current path by breaking the circuit and inserting the meter. As you will learn later, such a connection is called a *series* connection. The positive side of the meter is connected toward the positive terminal of the voltage source.

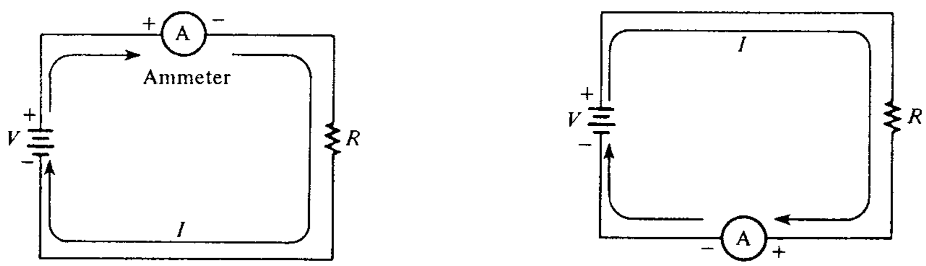

Figure 14.5: Current measurement with an ammeter

Voltage is measured with a *voltmeter* connected across the component. Again as you will learn later, such a connection is called *parallel* connection. The positive side of the meter must be connected toward the positive terminal of the voltage source.

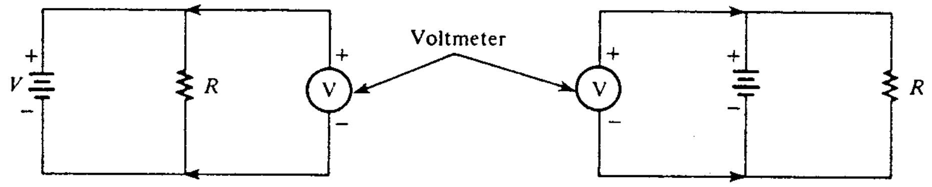

Figure 14.6: Voltage measurement with a voltmeter

Resistance is measured with an *ohmmeter* connected across the resistor. The resistor *must* be removed from the circuit or disconnected from the voltage source in some way. Failure to disconnect the voltage source will result in damage to the ohmmeter.

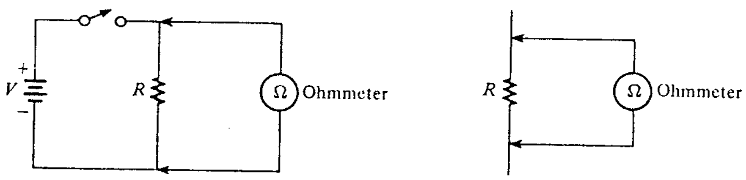

Figure 14.7: Resistance measurement with an ohmmeter

The Circuits Experiment Board (Figure 14.8),which you will use in this experiment, is designed to implement a large variety of basic electrical circuits for experimentation.

Ohm's Law

Ohm discovered that when the voltage across a resistor changes, the current through the resistor changes. He expressed this as $I = V/R$ (current is directly proportional to voltage and inversely proportional to resistance). In other words, as the voltage increases, so does the current. The proportionality constant is the value of the resistance. The current is inversely proportional to the resistance. As the resistance increases, the current decreases.

If the voltage across an "Ohmic" resistor is increased, the graph of voltage versus current shows a straight line (if the resistance remains constant). The slope of the line is the value

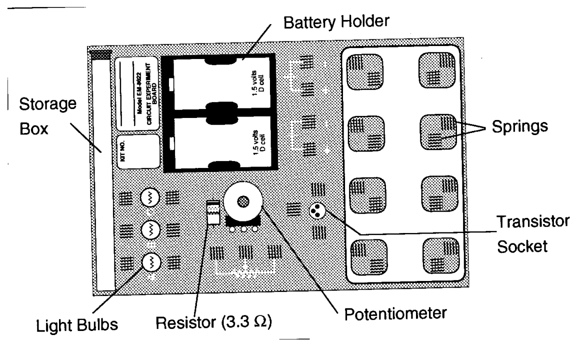

Figure 14.8: Circuits Experiment Board

of the resistance. However, if the resistance changes (that is, if the resistor is "non-Ohmic"), the graph of voltage versus current will not be a straight line. Instead, it will show a curve with a changing slope.

Kirchhoff's Rules

Kirchhoff's voltage law states that the sum of all the voltages around a closed path is zero. In other words, the sum of the voltage drops equals the total source voltage (Figure 14.9). The general form of Kirchhoff's voltage law is

$V_{s1} + V_{s2} + ... + V_{sn} = V_1 + V_2 + ... + V_n$

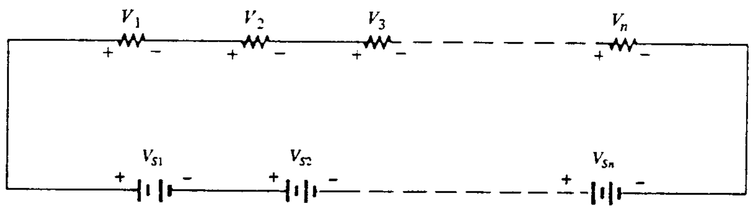

Figure 14.9:

Kirchhoff's current law states that the sum of the currents into a junction is equal to the sum of the currents out of that junction. A junction is any point in a circuit where two or more circuit paths come together. In a parallel circuit, a junction is where the parallel branches connect together. Another way to state Kirchhoff's current law is to say that the total current into a junction is equal to the total current out of that junction (Figure 14.10). The general formula for Kirchhoff's current law is

$I_{in(1)} + I_{in(2)} + ... + I_{in(n)} = I_{out(1)} + I_{out(2)} + ... + I_{out(m)}$

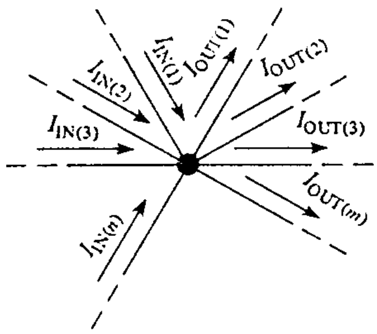

Figure 14.10:

Part I: Resistances in Circuits

Procedure

1. Choose five resistors having different values. Enter those sets of colors in Table 14.1.

2. Determine the coded value of your resistors. Enter the value in the column labeled "Coded Resistance". Enter the tolerance value as indicated by the color of the fourth band under "Tolerance."

3. Use the Multimeter to measure the resistance of each of your five resistors. Enter these values in the table.

4. Determine the percentage experimental error of each resistance value and enter it in the appropriate column.

$$Experimental\ Error = \frac{(Measured\ value - Coded\ value)}{Coded\ value} x100$$

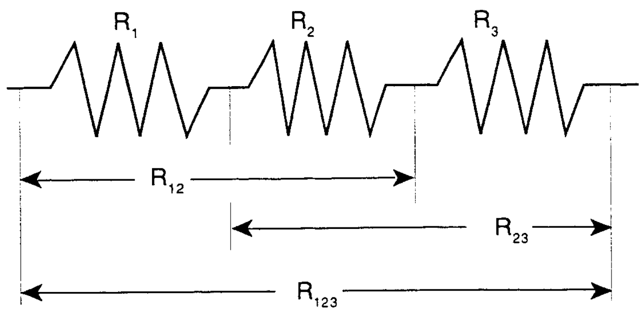

Figure 14.11: Resistors in Series Circuit

5. Now connect the three resistors into the *series circuit* (Figure 14.11), using the spring clips on the Circuits Experiment Board. Measure the resistances of the combinations as indicated on the figure by connecting the leads of the Multimeter between the points at the ends of the arrows. Record your values in Table 14.2. Compare these values with the calculated values.

6. Construct a *parallel circuit* as in Figure 14.12. Measure the resistance values in Table 14.3 and record them. Compare with calculated values.

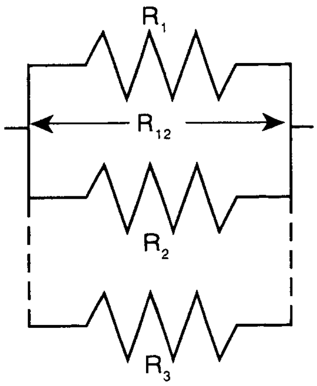

Figure 14.12: Resistors in Parallel Circuit

7. Now construct a *combination circuit* as in Figure 14.13. Measure and record the resistance values shown in the figure. Record these values in Table 14.4 and compare with calculated values.

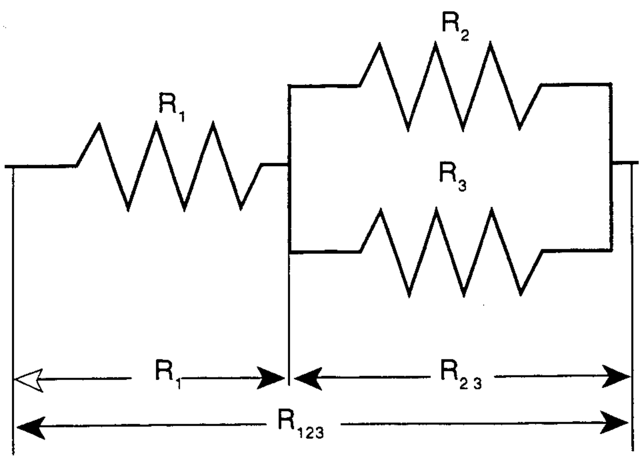

Figure 14.13: Resistors in Combination Circuit

Part II: Voltages in Circuits

Procedure

1. Connect the three resistors that you used before into the series circuit shown in Figure 14.14. Connect two wires to the Power Supply, carefully noting which wire is connected to the negative terminal and which is connected to the positive.

2. Now use the voltage function on the Multimeter to measure the voltages across the individual resistors and then across the combinations of resistors. Be careful to observe the polarity of the leads (red is +, black is -). Record your readings in Table 14.5.

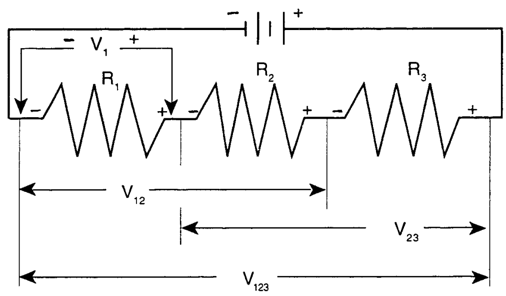

Figure 14.14: Voltage Measurements in Series Circuit

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3. Now connect the parallel circuit (Figure 14.15), using three resistors. Measure the voltage across each of the resistors and the combination, taking care with the polarity as before. Fill in Table 14.6.

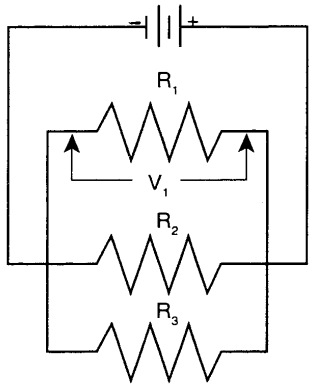

Figure 14.15: Voltage Measurements in Parallel Circuit

4. Now connect the combination circuit as shown in Figure 14.16. Measure the voltages in the figure. Record them in Table 14.7 and compare with calculated values.

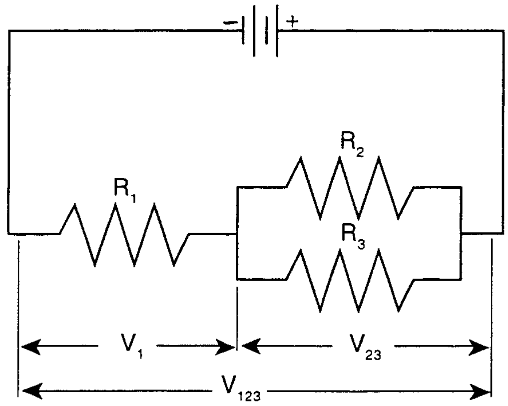

Figure 14.16: Voltage Measurements in Combination Circuit

Part III: Currents in Circuits

Procedure

1. Connect the three resistors into the series circuit (Figure 14.17). Change the leads in your Multimeter, so that it can be used to measure current. Be careful to observe the polarity of the leads (red is +, black is -). Move the Multimeter to the positions, indicated in the figure. Record your readings in Table 14.8 each time interrupting the circuit, and carefully measuring the current.

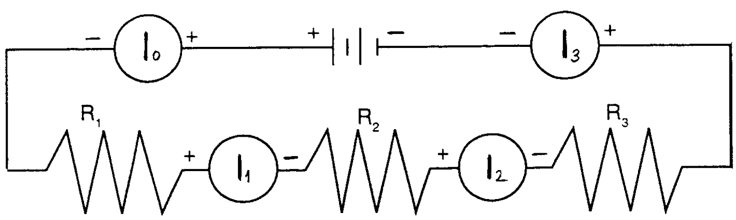

Figure 14.17: Current Measurements in Series Circuit

2. Connect the parallel circuit shown in Figure 14.18. Review the instructions for connecting the Multimeter as an ammeter. Connect it first between the positive terminal of the power supply and the parallel circuit junction to measure I_o. Then interrupt the various branches of the parallel circuit and measure the individual branch currents. Record your measurements in Table 14.9.

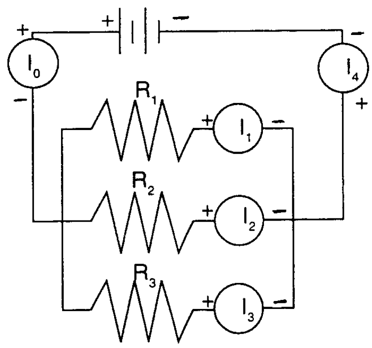

Figure 14.18: Current Measurements in Parallel Circuit

Part IV: Ohm's Law

Procedure

Ohmic Resistors

1. Choose one of the resistors that you have been given.

2. Connect the circuit as shown in Figure 14.19.

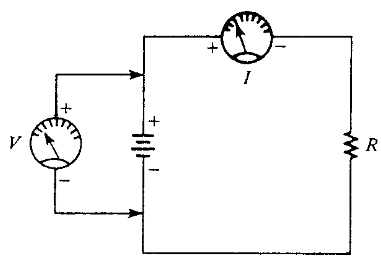

Figure 14.19:

3. As the power supply is OFF, set the Multimeter to **dc** current range and connect it in the circuit to read the current flowing through the resistor.

4. Open the power supply and set the voltage output to 2V.

5. Read the current and enter the value in Table 14.10.

6. Set the voltage output in turn to 4V, 6V, 8V, 10V and 12V, and record the current at each step.

7. Now repeat the procedure with a different value of resistor connected in the circuit instead of the previous one.

Part V: Kirchhoff's Rules

Procedure

1. Connect the circuit shown in Figure 14.20 using any of the resistors you have except the 10Ω one. Record the resistance values in Table 14.11. With no current flowing (the power supply is off), measure the total resistance R_T of the circuit between points **A** and **B**.

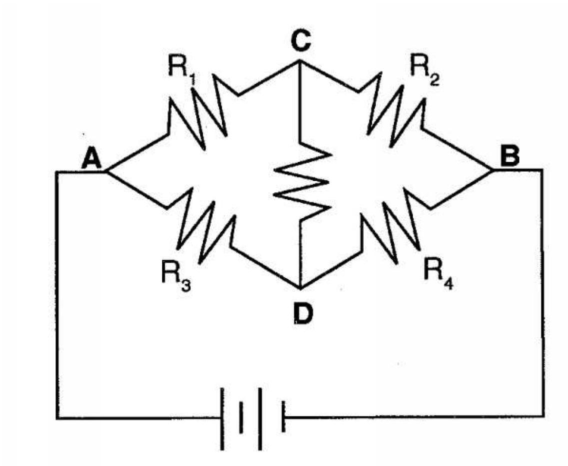

Figure 14.20: The Circuit for Kirchhoff's Rules

2. With the circuit connected to the Power Supply and the current flowing, measure the voltage across each of the resistors and record the values in the table. On the circuit diagram in Figure 14.20, indicate which side of each of the resistors is positive relative to the other end by placing a "+" at that end.

3. Now measure the current through each of the resistors. Interrupt the circuit and place the Multimeter in series to obtain your reading. Make sure you record each of the individual currents, as well as the current flow into or out of the main part of the circuit, I_T. Record your data in Table 14.11.

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REPORT SHEET

EXPERIMENT 3: BASIC ELECTRICITY

Student's Name:
Experiment Date:
Group Member Name(s):
Laboratory Bench Number:
Assistant's Name and Signature:

Data and Calculations

Part I: Resistances in Circuits

Table 14.1

	Colors 1 2 3 4	Coded $R(\Omega)$	Tolerance	Measured $R(\Omega)$	%Error
R1					
R2					
R3					
R4					
R5					

Table 14.2

$R_1 =$ .... $R_2 =$ .... $R_3 =$ ....

	Measured Resistance, Ω	Calculated Resistance, Ω
R_{12}		
R_{23}		
R_{123}		

Table 14.3

$R_1 =$ .... $R_2 =$ .... $R_3 =$ ....

	Measured Resistance, Ω	Calculated Resistance, Ω
R_{12}		
R_{23}		
R_{123}		

Table 14.4

$R_1 =$ .... $R_2 =$ .... $R_3 =$ ....

	Measured Resistance, Ω	Calculated Resistance, Ω
R_1		
R_{23}		
R_{123}		

Questions

1. How does the % Error compare to the coded tolerance for your resistors?

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2. What is the apparent rule for combining resistances in series circuits? In parallel circuits? Cite evidence from your data to support your conclusions.

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Part II: Voltages in Circuits

Table 14.5

V_s = ...

R_1 = ... R_2 = ... R_3 = ...

	Measured value, V	Calculated value, V
V_1		
V_2		
V_3		
V_{12}		
V_{23}		
V_{123}		

Table 14.6

V_s = ...

R_1 = ... R_2 = ... R_3 = ...

	Measured value, V	Calculated value, V
V_1		
V_2		
V_3		
V_{12}		
V_{23}		
V_{123}		

Table 14.7

V_s = ...

R_1 = ... R_2 = ... R_3 = ...

	Measured value, V	Calculated value, V
V_1		
V_{23}		
V_{123}		

Questions

1. What is the pattern for how voltage gets distributed in a series circuit? Is there any relationship between the size of the resistance and the size of the resulting voltage?

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2. What is the pattern for how voltage distributes itself in a parallel circuit? Is there any relationship between the size of the resistance and the size of the resulting voltage?

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3. Do the voltages in your combination circuit follow the same rules as they did in your circuits which were purely series or parallel? If not, state the rules you see in operation.

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Part III: Currents in Circuits

Table 14.8

$V_s =$ ....

$R_1 =$ .... $R_2 =$ .... $R_3 =$ ....

	Measured value, mA	Calculated value, mA
I_o		
I_1		
I_2		
I_3		

Table 14.9

$V_s =$ ....

$R_1 =$ .... $R_2 =$ .... $R_3 =$ ....

	Measured value, mA	Calculated value, mA
I_o		
I_1		
I_2		
I_3		
I_4		

Questions

1. What is the pattern for how current behaves in a series circuit? At this point you should be able to summarize the behavior of all three quantities resistance, voltage and current in series circuits.

2. What is the pattern for how current behaves in a parallel circuit? At this time you should be able to write the general characteristics of currents, voltages and resistances in parallel circuits.

Experiment 4

BASIC ELECTRICITY (Part 4 and 5)

Part IV: Ohm's Law

Ohmic Resistors

Table 14.10

Voltage (V)	Current through R1 (mA)	Current through R2 (mA)
2		
4		
6		
8		
10		
12		

Plot a graph of current against voltage for the readings obtained. Find the value of the resistance.
From your graphs obtain the current that would flow trough the one of the resistors for an applied voltage of 7V.

Part V: Kirchhoff's Rules

Table 14.11

Resistance, Ω	Voltage, V	Current, mA
R_1	V_1	I_1
R_2	V_2	I_2
R_3	V_3	I_3
R_4	V_4	I_4
R_5	V_5	I_5
R_T	V_T	I_T

1. Determine the net current flow into or out of each of the four "nodes" in the circuit.

2. Determine the net voltage drop around at least three of the six or so closed loops. Remember, if the potential goes up, treat the voltage drop as positive (+), while if the potential goes down, treat it as negative (-).

3. Use your experimental results to analyze the circuit you built in terms of Kirchhoff's Rules. Be specific ans state the evidence for your conclusions.

Experiment 5

CAPACITORS AND RC CIRCUITS

Purpose

Determining how capacitors behave in a RC circuit and experimentally obtaining the charging and discharging voltage curves for a capacitor. By using these curves, to determine time constant value of a RC circuit.

Introduction

You can store energy as potential energy in an electric field, and a **capacitor** is a device you can use to do exactly that. Capacitors have many uses in our electronic age beyond serving as storehouses for potential energy. They can be many sizes and shapes. The basic elements of any capacitor are two isolated conductors of any shape. No matter what their geometry, flat or not, we call these conductors *plates.*

When a capacitor is charged, its plates have equal but opposite charges of $+q$ and $-q$. However, we refer to the charge of a capacitor as being q, the absolute value of these charges on the plates. (Note that q is not the net charge on the capacitor, which is zero.)

Because the plates are conductors, they are equipotential surfaces; all points on a plate are at the same electric potential. Moreover, there is a potential difference between the two plates. For historical reasons, we represent the absolute value of this potential difference with V.

The charge q and potential difference V for a capacitor are proportional to each other; that is,

$q = CV$

The proportionality constant C is called the *capacitance* of the capacitor. Its value depends only on the geometry of the plates and *not* on their charge or potential difference. The capacitance is a measure of how much charge must be put on the plates to produce a certain potential difference between them: *The greater the capacitance, the more charge is required.*

Capacitance is directly proportional to the physical size of the plates as determined by the plate area, A. A larger plate area produces a larger capacitance. *Capacitance is inversely proportional to the distance between the plates.* The plate separation is designated d. A greater separation of the plates produces a smaller capacitance.

The insulating material between the plates of a capacitor is called the *dielectric*. Every dielectric material has the ability to concentrate the lines of force of the electric field existing between the oppositely charged plates of a capacitor and thus increase the capacity for energy storage. The measure of a material's ability to establish an electric field is called the *dielectric constant* or *relative permittivity*, symbolized by ϵ_r. *Capacitance is directly proportional to the dielectric constant.* An exact formula for calculating the capacitance in terms of these three quantities is as follows:

$$C = \frac{A\epsilon_r(8.85x10^{-12}F/m)}{d}$$

The SI unit of capacitance is the coulomb per volt. This unit occurs so often that it is given a special name, the *farad* (F).

Series Capacitors

When capacitors are connected in series, the effective plate separation increases, and the total capacitance is less than that of the smallest capacitor. If n capacitors are in series in a circuit, the total capacitance can be found as;

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ... + \frac{1}{C_n}}$$

Parallel Capacitors

When capacitors are connected in parallel, the effective plate area increases, and the total capacitance is the sum of the individual capacitances. If n capacitors are in parallel in a circuit, the total capacitance can be found as;

$$C_T = C_1 + C_2 + C_3 + ... + C_n$$

Charging a Capacitor

A capacitor charges when it is connected to a dc voltage source. As this charging process continues, the voltage across the plates builds up rapidly until it is equal to the applied voltage, V_s, but opposite in polarity. When the capacitor is fully charged, there is no current. A capacitor blocks constant dc. When the charged capacitor is disconnected from the source, it remains charged for long periods of time, depending on its leakage resistance, and can cause severe electrical shock.

Discharging a Capacitor

When a wire is connected across a charged capacitor, the capacitor will discharge. In this particular case, a very low resistance path (the wire) is connected across the capacitor. The charge is neutralized when the numbers of free electrons on both plates are again equal. At this time, the voltage across the capacitor is zero, and the capacitor is completely discharged.

Current during Charging and Discharging

Direction of the current during discharge is opposite to that of the charging current. It is important to understand that there is no current through the dielectric of the capacitor during charging or discharging, because the dielectric is an insulating material. Current flows from one plate to the other only through the external circuit.

The RC Time Constant

In a practical situation, there cannot be capacitance without some resistance in a circuit. It may simply be the small resistance of a wire, or it may be a designed-in resistance. Because of this, the charging and discharging characteristics of a capacitor must always be considered in light of the associated resistance. The resistance introduces the element of *time* in the charging and discharging of a capacitor.

When a capacitor charges or discharges through a resistance, a certain time is required for the capacitor to charge fully or discharge fully. *The voltage across a capacitor cannot change intantaneously*, because a finite time is required to move charge from one point to another. The rate at which the capacitor charges or discharges is determined by the *time constant* of the circuit. *The time constant of a series RC circuit is a time interval that equals the product of the resistance and the capacitance.* The time constant is symbolized by τ, and the formula is as follows:

$\tau = RC$

Recall that $I = Q/t$. The current depends on the amount of charge moved in a given time. When the resistance is increased, the charging current is reduced, thus increasing the charging time of the capacitor. When the capacitance is increased, the amount of charge increases; thus, for the same current, more time is required to charge the capacitor.

The Charging and Discharging Curves

A capacitor charges and discharges following a nonlinear curve, as shown in Figure 15.1. In these graphs, the percentage of full charge is shown at each time-constant interval. This type of curve follows a precise mathematical formula and is called an *exponential curve.* The charging curve is an *increasing exponential*, and the discharging curve is a *decreasing exponential.* As you can see, it takes *five time constants* to aproximately reach the final value.

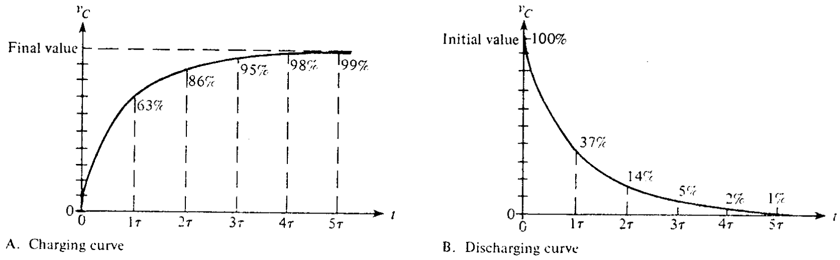

Figure 15.1:

The general expressions for either increasing or decreasing exponential curves are given in the following equations:

$V_c(t) = V_s\ (1 - e^{-t/RC})$

$V_c(t) = V_i\ e^{-t/RC}$

Equipments

Circuits Experiment Board
Digital Multimeter
Power Supply
Capacitors ($100\mu F$, $330\mu F$)
Resistors ($100k\Omega$, $220k\Omega$)

Procedure

1. Connect the circuit shown in Figure 15.2 using a $100k\Omega$ resistor and a $100\mu F$ capacitor. Use one of the spring clips as a "switch". Keeping the switch at open position, turn on the power supply and set its output voltage to $5V$. Connect the Multimeter to the circuit which reads the voltage across the capacitor.

2. Start with no voltage on the capacitor. If there is a remaining voltage on the capacitor, use a piece of wire to "short" the two leads together, draining any remaining charge.

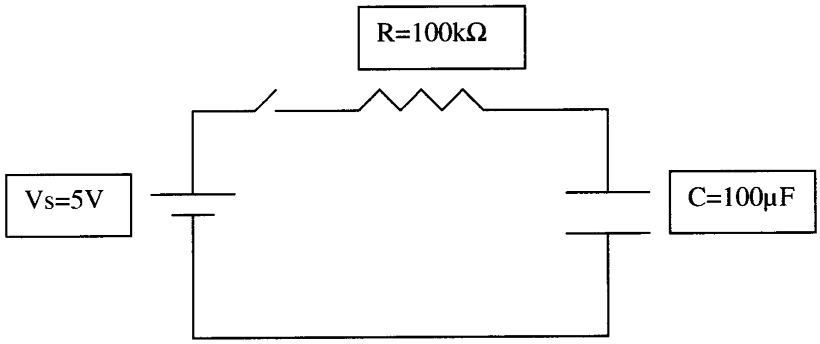

Figure 15.2:

3. Now close the "switch" by touching the wire to the spring clip and start the stopwatch. Observe the capacitor voltage in every five seconds until the voltage increases to a value of $5V$. Record your data in Table 15.1.

4. If you now open the "switch" by removing the wire from the spring clip, the capacitor should remain at its present voltage with a very slow drop over time. This indicates that the charge you placed on the capacitor has no way to move back to neutralize the excess charges on the two plates.

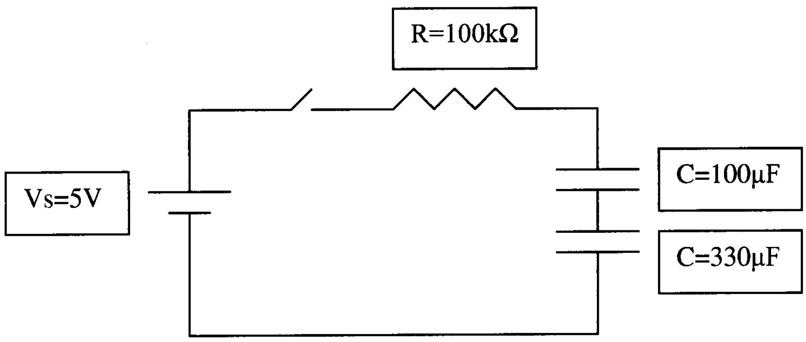

Figure 15.3:

5. Now, you will discharge the capacitor that you charged above, allowing the charge to drain back through the resistor. Observe the voltage readings on the Multimeter as the charge flows back and record them in Table 15.1.

6. Now, do the same procedure for the following circuits; recording the time taken to move from $0.0V$ to the %63 of the power supply output voltage (which is $3.2V$) while charging.

This time is the "time constant" (τ) of the circuit measured experimentally. Record your times along with the resistance and capacitance values in Table 15.2.

Calculate the time constants of the circuits and record them in the table. Compare with the experimental values.

• Replace the $100\mu F$ capacitor with a $330\mu F$ capacitor.

• Return to the original $100\mu F$ capacitor, but put a $220k\Omega$ resistor in the circuit.

• Repeat the procedure $220k\Omega$ resistor with a $330\mu F$ capacitor.

• Return to the original $100k\Omega$ resistor, but use the $100\mu F$ capacitor in series with the $330\mu F$ capacitor (Figure 15.3).

• Repeat the procedure with the $100\mu F$ and the $330\mu F$ capacitors are in parallel (Figure 15.4).

• Now repeat the procedure with the $220k\Omega$ resistor and the capacitors as they are in series and parallel in the circuit.

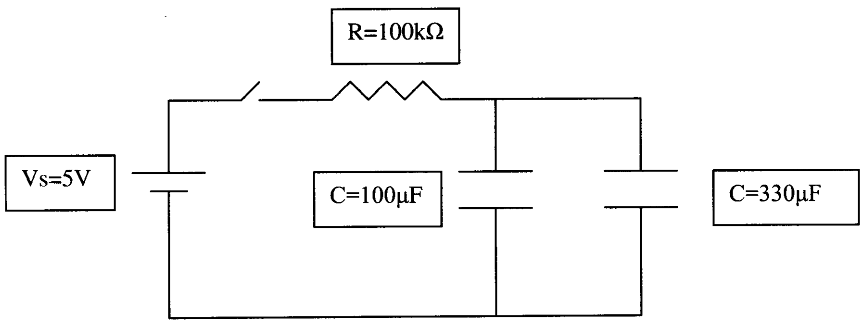

Figure 15.4:

REPORT SHEET

EXPERIMENT 5: CAPACITORS AND RC CIRCUITS

Student's Name:
Experiment Date:
Group Member Name(s):
Laboratory Bench Number:
Assistant's Name and Signature:

Data and Calculations

Table 15.1

V_s=...................... R=...................... C=......................

V_c (charging), V	$t(s)$	V_c (discharging), V	$t(s)$

Using the data in Table 15.1, plot the graphs of the voltage on the capacitor versus time for both charging and discharging curents. Find the time constant of the circuit from the both graphs. Find also the theoretical value of the time constant using the formula $\tau = RC$, and compare it with the values you have found from the graphs.

Table 15.2

Resistance (Ω)	Capacitance (μF)	$\tau_{experimentally}(s)$	$\tau_{theoretically}(s)$

Questions

1. What is the effect on charging and discharging times if the capacitance is increased? What mathematical relationship exists between your times and the capacitance?

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....

2. What is the effect on charging and discharging times if the resistance of the circuit is increased? What mathematical relationship exists between your times and the resistance?

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3. What is the effect on the total capacitance if capacitors are combined in series? What if they are combined in parallel?

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Experiment 6

MAGNETIC FORCE ON A CURRENT-CARRYING WIRE

Purpose

A current-carrying wire in a magnetic field experiences a force that is usually referred to as a magnetic force. In this experiment we will determine that how the magnitude and the direction of this force depends on the magnitude of the current I; the length of the wire L; the strength of the magnetic field B; and the angle between the field and the wire θ.

Introduction

A magnetic field exerts force on electrons in a conductor. Since the electrons cannot escape the wire, this force must be transmitted to the wire itself. Consider a wire carrying current I placed in a region of uniform magnetic field of magnitude B and the direction is perpendicular to the wire. Consider a length L of the wire and one of the conduction electrons drifting with an assumed drift speed v_d.

Charge $q = It = I\dfrac{L}{v_d}$ moves through the segment of wire during the time interval t. The magnetic force on this conductor is

$$F_B = qv_dB = (I\frac{L}{v_d})v_dB$$

Finally, the force is $F_B = ILB$.

If the magnetic field is NOT perpendicular to the current- carrying wire,

$$\vec{F}_B = I\vec{L}x\vec{B}$$

where $\vec{L}$ is a vector of magnitude L and the direction of the conventional current. The magnitude of the force on a current carrying wire is

$F_B = ILB \sin \theta$

where θ is the angle between the direction of current and the magnetic field.

In this experiment we will use the Basic Current Balance (Figure 16.1). With it you can vary three of the variables in the equation; the current, the length of the wire, and the strength of the magnetic field and measure the resulting magnetic force.

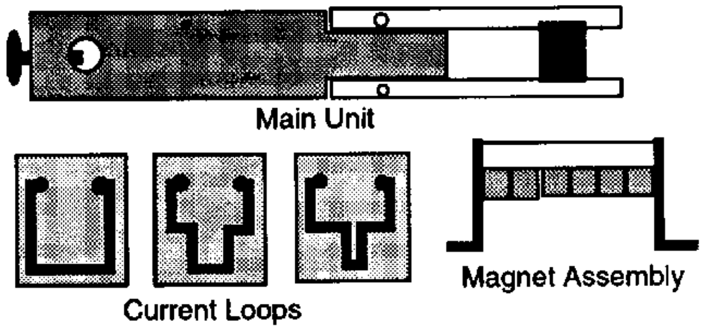

Figure 16.1: Basic Current Balance

By adding the Current Balance Accessory (Figure 16.2), you can also vary the angle between the wire and the magnetic field, thereby performing a complete investigation into the interaction between a current carrying wire and a magnetic field.

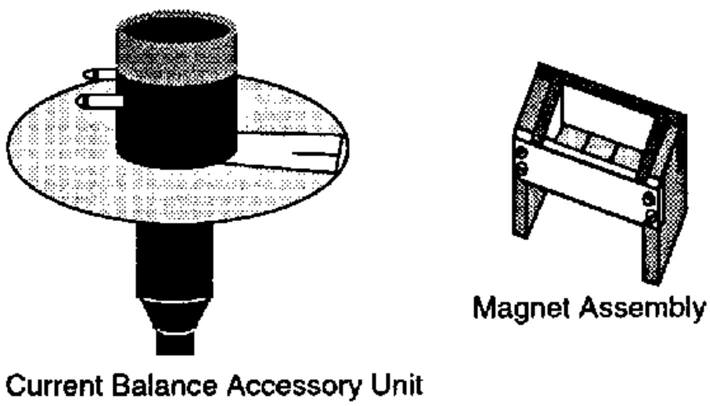

Figure 16.2: Current Balance Accessory

Equipments

Basic Current Balance
Current Balance Accessory
Lab stand
DC power supply (capable of supplying up to $5A$)
DC ammeter (capable of measuring up to $5A$)
Balance (capable of measuring forces with an accuracy of $0.01g$ mass equivalent)

Part I: Force versus Current

Procedure

1. Set up the apparatus as shown in Figure 16.3

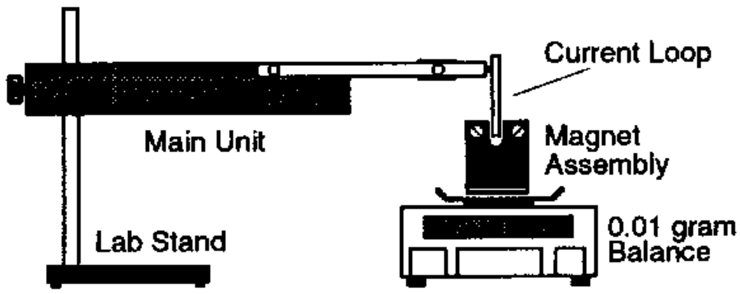

Figure 16.3: Setting up the Basic Current Balance

2. Determine the mass of the magnet holder and magnets with no current flowing. Record this value in the column under "Mass" in Table 16.1.

3. Set the current to $0.5A$. Determine the new "mass" of the magnet assembly. Record this value under "Mass" in Table 16.1.

4. Subtract the mass value with the current flowing from the value with no current flowing. Record this difference as the "Force ".

5. Increase the current in $0.5A$ increments to a maximum of $5.0A$, each time repeating steps 2-4.

Part II: Force versus Length of Wire

Procedure

1. Set up the apparatus as shown in Figure 16.3 again.

2. With no current flowing, determine the mass of the Magnet Assembly. Record this value on the line at the top of Table 16.2.

3. Set the current to $2.0A$. Determine the new "Mass" of the Magnet Assembly. Record this value under "Mass" in Table 16.2.

4. Subtract the mass that you measured with no current flowing from the mass that you measured with the current flowing. Record this difference as the "Force."

5. Turn the current off. Remove the Current Loop and replace it with another. Repeat steps 2-4.

Part III: Force versus Magnetic Field

Procedure

Use the shortest length current loop.

1. Mount a single magnet in the center of the holder.

2. With no current flowing, determine the mass of the Magnet Assembly. Record this value in the first column under "Mass" in Table 16.3 on the appropriate line.

3. Set the current to $2.0A$. Determine the new "Mass" of the Magnet Assembly. Record this value in the second column under "Mass" in Table 16.3.

4. Subtract the mass you measured when there was no current flowing from the value you measured with current flowing. Record this difference as the "Force".

5. Add additional magnets, one at a time. (Make sure the north poles of the magnets are all on the same side of the Magnet Assembly.) Each time you add a magnet, repeat steps 2-4.

Part IV: Force versus Angle

Procedure

1. Set up the apparatus as shown in Figure 16.4

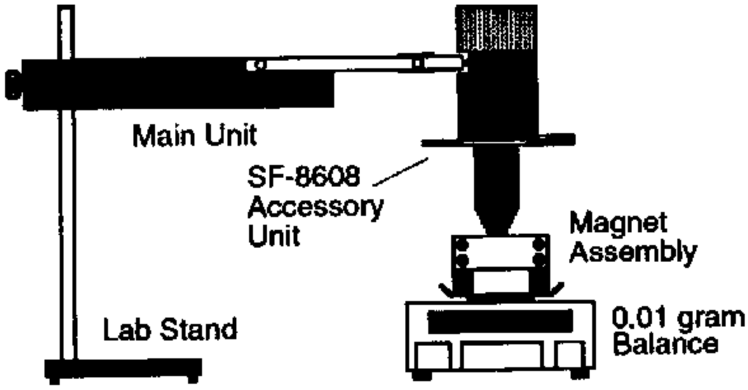

Figure 16.4: Setting up the Current Balance Accessory

2. Determine the mass of the Magnet Assembly with no current flowing. Record this value in Table 16.4 on the appropriate line.

3. Set the angle to θ with the direction of the coil of wire approximately parallel to the magnetic field. Set the current to $1.0A$. Determine the new "Mass" of the Magnet Assembly. Record this value under "Mass" in Table 16.4.

4. Subtract the mass measured with no current flowing from the mass measured with current flowing. Record the difference as the "Force":

5. Increase the angle in 5° increments up to 90°, and then in -5° increments to -90°. At each angle, repeat the mass/force measurement.

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REPORT SHEET

EXPERIMENT 6: MAGNETIC FORCE ON A CURRENT-CARRYING WIRE

Student's Name:
Experiment Date:
Group Member Name(s):
Laboratory Bench Number:
Assistant's Name and Signature:

Data and Calculations

Part I: Force versus Current

Table 16.1

Current (A)	Mass (g)	Force (N)
0.0		
0.5		
1.0		
1.5		
2.0		
2.5		
3.0		
3.5		
4.0		
4.5		
5.0		

Plot a graph of Force (vertical axis) versus Current (horizontal axis).

What is the nature of the relationship between these two variables? What does this tell us about how changes in the current will affect the force acting on a wire that is inside a magnetic field?

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Part II: Force versus Length of Wire

Table 16.2

Mass(g)=.........................

Length (cm)	Mass (g)	Force (N)
1.2		
2.2		
3.2		
4.2		
6.4		
8.4		

Plot a graph of Force (vertical axis) versus Length (horizontal axis).

What is the nature of the relationship between these two variables? What does this tell us about how changes in the length of a current-carrying wire will affect the force that it feels when it is in a magnetic field?

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Part III: Force versus Magnetic Field

Table 16.3

	Mass (g)	Mass (g)	
# of magnets	$I = 0$	$I \neq 0$	Force (N)
1			
2			
3			
4			
5			
6			

Plot a graph of Force (vertical axis) versus Number of Magnets (horizontal axis).

What is the relationship between these two variables? How does the number of magnets affect the force between a current-carrying wire and a magnetic field? Is it reasonable to assume that the strength of the magnetic field is directly proportional to the number of magnets? What would happen if one of the magnets were put into the assembly backwards, with its north pole next to the other magnets' south poles? If there is time, try it.

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Part IV: Force versus Angle

Table 16.4

Angle (θ)	Mass (g)	Force (N)	Angle (θ)	Mass (g)	Force (N)
0			0		
10			-10		
20			-20		
30			-30		
40			-40		
50			-50		
60			-60		
70			-70		
80			-80		
90			-90		

Plot a graph of Force (vertical axis) versus Angle (horizontal axis).

What is the relationship between these two variables? How do changes in the angle between the current and the magnetic field affect the force acting between them? What angle produces the greatest force? What angle produces the least force?

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Experiment 7

ELECTROMAGNETISM AND ELECTROMAGNETIC INDUCTION

Introduction

What is Electromagnetism?

Electromagnetism describes the relationship between electricity and magnetism. Nearly everyone, at some time or another, has had the opportunity to play with magnets. Most of us are acquainted with bar magnets or those thin magnets that usually end up on refrigerators. These magnets are known as permanent magnets. Although permanent magnets receive a lot of exposure, we use and depend on electromagnets much more in our everyday lives. Electromagnetism is essentially the foundation for all of electrical engineering. We use electromagnets to generate electricity, store memory on our computers, generate pictures on a television screen, diagnose illnesses, and in just about every other aspect of our lives that depends on electricity.

Electromagnetism works on the principle that an electric current through a wire generates a magnetic field. This magnetic field is the same force that makes metal objects stick to permanent magnets. In a bar magnet, the magnetic field runs from the north to the south pole. In a wire, the magnetic field forms around the wire. If we wrap that wire around a metal object, we can often magnetize that object. In this way, we can create an electromagnet.

Electromagnetic Induction

Electromagnetic induction is the production of an electrical potential difference (or voltage) across a conductor situated in a changing magnetic field. Michael Faraday was the first to describe this phenomenon mathematically: he found that the size of the voltage produced is proportional to the rate of change of the magnetic flux. This applies whether the flux itself changes in strength or the conductor is moved through it. Electromagnetic induction underlies the operation of generators, induction motors, and most other electrical machines. Faraday's law of electromagnetic induction states that

$$\varepsilon = N\frac{d\phi}{dt}$$

where ε is the electromotive force (emf) in volts, N is the number of turns of wire, and ϕ is the magnetic flux in webers.

Further, Lenz's law gives the direction of the induced emf, thus:

The emf induced in an electric circuit always acts in such a direction that the current it drives around the circuit opposes the change in magnetic flux which produces the emf.

Transformers

A transformer is an electrical device that transfers energy from one electrical circuit to another by means of magnetic coupling. An electrical transformer is the name given to any device for producing by means of one electric current another of a different character. It typically transforms between high and low voltages and accordingly between low and high currents.

Transformers usually have two induction coils or windings. As the changing current flows through the powered or primary winding, it produces a changing magnetic field that grows through the unpowered or secondary windings. This changing magnetic field induces a current in the secondaries. The winding with fewer turns of wire has higher current, at a lower voltage. The winding with more turns of wire has less current, at a higher voltage. The ratio of voltages is proportional to the ratio of the numbers of turns of wire.

Uses of Transformers

If electrical power needs to be transmitted over long distances, the loss is much lower if high voltage is used. But high voltage is dangerous in the home, so transformers are employed to step the voltage up at the power station and back down at the consumer's premises.

Small transformers are often used to isolate and link different parts of radios.

Some transformers are designed so that one winding turns or slides, while the other remains stationary. These can pass power or radio signals from a stationary mounting to a turning mechanism, such as a machine tool head or radar antenna.

Some moving transformers are precisely constructed in order to measure distances. Most often, they have several primaries, and electronic circuits measure the shape of the wave in the different secondaries.

Construction

Transformers often have silicon steel cores to channel the magnetic field. This keeps the field more concentrated around the wires, so that the transformer is more efficient. The core also keeps the field from being wasted in nearby pieces of metal.

Laminated cores are made of many stamped pieces of thin steel. This prevents eddy currents from forming in the cores and wasting power by heating the core. Other types of core are made of nonconductive magnetic materials, such as a ceramic material called ferrite.

High-frequency transformers in low-power circuits where moderate losses are acceptable may have air cores. These save weight and cost.

Power transformers are usually more than 98% efficient which makes them the most efficient devices man can make. The higher-voltage transformers are bathed in nonconductive oil that is stable at high temperatures. This used to be polychlorinated biphenyl, the famous toxic waste, "PCB". Nowadays, nontoxic very stable fluorinated hydrocarbons are preferred. The oil cools the transformer, and helps prevent short circuits. It has to be stable at high temperatures so that a small short or arc will not cause a breakdown or fire.

Equipments

The Complete Coils Set

Low voltage AC/DC power supply

Digital multimeter

Banana connecting leads for electrical connections

Procedure

When an alternating current passes through a coil of wire, it produces an alternating magnetic field. This is precisely the condition needed for the electromagnetic induction to take place in a second coil of wire.

1. Set up the coils and core as shown in Figure 17.1. The coil to the left will be referred to as the primary coil and the one to the right will be the secondary coil. Note that we are putting in an alternating current to the primary at one voltage level, and reading the output at the secondary.

2. With the 400-turn coil as the primary and the 400-turn coil as the secondary, adjust the input voltage to 6 VAC. Measure the output voltage and record your result in Table 17.1.

3. Repeat step 2 after inserting the straight cross piece from the top of the U-shaped core. Record your result. (See Figure 17.2.)

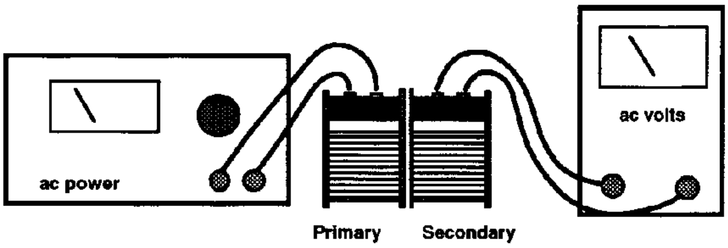

Figure 17.1: Induction Proceed by Passing Magnetic Field Between the Two Coils

4. Repeat step 2 after placing the coils on the sides of the open U-shaped core. Record your result.

5. Finally, repeat step 2 after placing the cross piece over the U-shaped core. Record your result.

6. Using the core configuration which gives the best output voltage compared to input voltage, try all combinations of primary and secondary coils. Use a constant input voltage of 6 VAC. Record your data in Table 17.2.

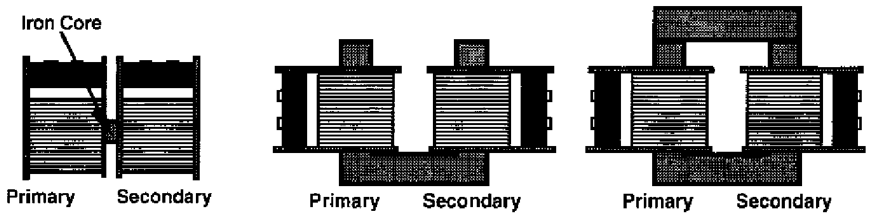

Figure 17.2:

REPORT SHEET

EXPERIMENT 7: ELECTROMAGNETISM AND ELECTROMAGNETIC INDUCTION

Student's Name:
Experiment Date:
Group Member Name(s):
Laboratory Bench Number:
Assistant's Name and Signature:

Data and Calculations

Table 17.1

Number of turns

Primary Coil	Secondary Coil	Input V	Output V	Core

Table 17.2

Core Configuration :——————————

Number of turns

Primary Coil	Secondary Coil	Input V	Output V

Questions

1. Which core configuration gives the maximum transfer of electromagnetic effect to the secondary coil? Develop a theory to explain the differences between configurations.

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2. From your data in Table 17.2, for a primary having a constant number of turns, graph the resulting output voltage versus the number of turns in the secondary. What type of mathematical relationship exists between numbers of turns of wire and the resulting output voltage? Is the data ideal? Why or why not?

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3. Consider further improvements to your transformer. What additional changes might you make to increase the transfer from one coil to the other?

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