

**EP 116**

**GENERAL PHYSICS  
LABORATORY MANUAL  
(For Food Engineers)**

**MECHANICS,**

**ELECTRICITY**

**and**

**MAGNETISM EXPERIMENTS**

**GENERAL PHYSICS**  
**MECHANICS, ELECTRICITY and MAGNETISM EXPERIMENTS**  
**INTRODUCTION**  
**“EXPERIMENTAL ERRORS”**

## 1. Introduction

In general, experiments are performed to test a theory and to compare with other independent experiments measuring the same quantity. When performing experiments, we should not consider that the job is over once we obtain a numerical value for the quantity we are trying to measure. We should be concern not only with the measured value but also with its *accuracy*. The accuracy is derived from an *experimental error* for the measured quantity. For example, consider a measurement of the gravitational acceleration due to the gravity is obtained as

$$g = 9.77 \pm 0.14 \text{ m/s}^2.$$

We will mention about what we mean by the error (or accuracy)  $\pm 0.14$  in section 3. But, it is sufficient to state that the more accurate the experiment the smaller the error.

This note describes how to determine such measurement errors and how to report your experimental results by including errors to your measured quantity.

## 2. Sources of Errors

There are two fundamentally different sources of errors associated with any measurement procedure; they are *random* and *systematic* errors.

### Random (or statistical) errors

Random errors are errors in measurement that lead to measured values being inconsistent when repeated measures of a constant attribute or quantity are taken. The word random indicates that they are inherently unpredictable, and have null expected value, namely, they are scattered about the true value, and *tend to* have null arithmetic mean when a measurement is repeated several times with the same instrument. All measurements are prone to random error. (see Fig 1). Since random error varies from measurement to measurement, it may be reduced by repeating the same experiment many times.

### Systematic errors

Systematic errors are *biases* in measurement which lead to the situation where the mean of many separate measurements differs significantly from the actual value of the measured attribute. Usually, systematic error is defined as the expected or mean value of the overall error (see Fig. 1). The magnitude of systematic error cannot be reduced by simple repetition of the measurement procedure several times as in the statistical error. The systematic errors may be reduced by calibration of the device.



## Two examples:

An example of random error is putting the same weight on a sensitive electronic scale several times and obtaining readings that vary in random fashion from one reading to the next. The differences between these readings and the true weight correspond to the random error of the scale measurements. A systematic error is an electronic scale that, if loaded with a standard weight, provides readings that are systematically lower than the true weight by (such as) 5 grams.

Suppose a watch has only hour and minute hands, but no second hand. When you try to estimate the time, you will have random error of maximum one minute. If the watch is running slow so that it is wrong by an amount that you are not aware of (say 10 min), the reading will have a 10 min the systematic error too.

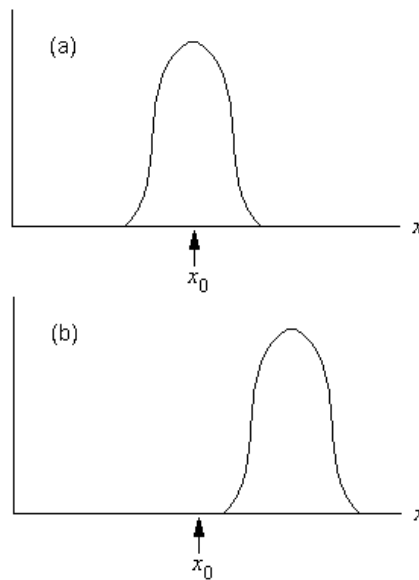


Figure 1: Random and systematic errors. The figures show the result of the repeated measurement of some quantity  $x$  whose true value is  $x_0$  shown by an arrow. (a) Without systematic errors, the effect of random errors is to produce a spread of measurements, centered close to  $x_0$ . (b) Systematic effects shift the mean of the distribution away from the true mean.

## Additional Errors!

One can consider the following three error sources which actually have the origin of both random and systematic errors in an experiment:

\* Limited accuracy of the measuring apparatus: *e.g., a force sensor used in an experiment cannot determine*

*applied force with a better accuracy than, say,  $\pm 0.05$  N.*

\* Limitations and simplifications of the experimental procedure: *e.g., we commonly assume that there is no air*

*friction if objects are not moving fast. Strictly speaking, that friction is small but not equal to zero.*

\* Uncontrolled changes to the environment : *e.g., small changes of the temperature and the humidity in the lab.*

## Total Error

The error associated to a measured quantity in an experiment is a combination of random and systematic errors known as total error. The main objective of a scientific experiment is to minimize total error.

## 3. Definitions

In this section, we will give some fundamental terms used in the measurement systems.

### Error

The error is the difference between true value and measured value of a quantity.

### Uncertainty

The uncertainty is the estimated error for a measurement. Since a true value for a physical quantity may be unknown, it is sometimes not possible to determine the true error of the measurement. So, this term is more sensible for the error computations although the terms error and uncertainty are used instead of each other in literature.

### Accuracy & Precision

The *accuracy* of a measurement system is the degree of closeness of measurements of a quantity to its true (actual) value. The *precision* of a measurement system, also called reproducibility or repeatability, is the degree to which repeated measurements under unchanged conditions show the same results (See Fig. 2).

A measurement system can be accurate but not precise, precise but not accurate. This can be represented by an analogy to the grouping of arrows in a target. (See Fig. 3).

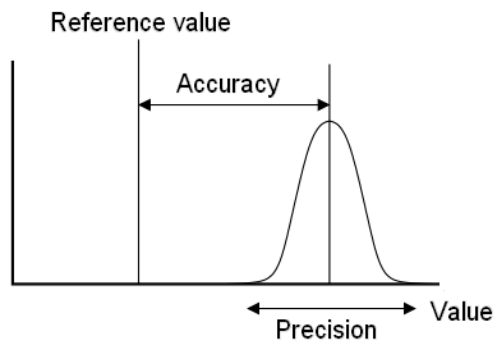


Figure 2: Accuracy indicates proximity of measurement results to the true value, precision to the repeatability or reproducibility of the measurement

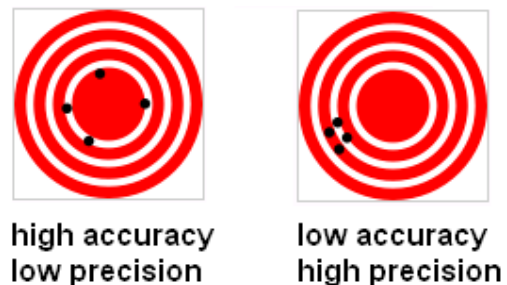


Figure 3: A target analogy for the comparison of accuracy and precision. Arrows that strike closer to the bullseye are considered more accurate. if a large number of arrows are shot, precision would be the size of the arrow cluster.

### Percentage Error

Percentage error measures the accuracy of a measurement by the difference between a measured or experimental value  $E$  and a true or accepted value  $A$ . Percentage error is calculated by

$$PE = \frac{|E - A|}{A} \times 100\% \quad (1)$$

### Percentage Difference

Percentage difference measures precision of two measurements by the difference between the measured or experimental values  $E_1$  and  $E_2$  expressed as a fraction the average of the two values. The equation to use to calculate the percent difference is:

$$PD = \frac{|E_1 - E_2|}{\left(\frac{E_1 + E_2}{2}\right)} \times 100\% \quad (2)$$

### Mean and Standard Deviation

For a set of  $n$  measurements  $\{x_i\}$ , the arithmetic mean, standard deviation and standard error is defined by

$$\bar{x} = \frac{\sum x_i}{n} \quad (3)$$

$$\sigma = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n - 1}} \quad (4)$$

$$\sigma_E = \frac{\sigma}{\sqrt{n}} \quad (5)$$

Final result obtained from this kind of measurement should be reported in the form of  $\bar{x} \pm \sigma_E$ . Note that the square of the standard deviation is known as *variance*.

**EXAMPLE 1:** Consider the data of 10 different measurements for the mass density in  $\text{g/cm}^3$  of a liquid.

$$d = \{1.10, 1.12, 1.09, 1.09, 1.07, 1.14, 1.11, 1.16, 1.07, 1.08\}$$

The mean, standard deviation, variance and standard error of the measurement are as follows:

$$\begin{aligned} \bar{x} &= (1.10 + 1.12 + 1.09 + 1.09 + 1.07 + 1.14 + 1.11 + 1.16 + 1.07 + 1.08)/10 \\ &= 1.103 \text{ g/cm}^3 \end{aligned}$$

$$\begin{aligned} \sigma &= \sqrt{[(1.10 - 1.103)^2 + (1.12 - 1.103)^2 + \dots + (1.08 - 1.103)^2]/9} \\ &= 0.030 \text{ g/cm}^3 \end{aligned}$$

$$\sigma^2 = 0.0009 \text{ (g/cm}^3\text{)}^2$$

$$\sigma_E = 0.03/\sqrt{10} = 0.009 \text{ g/cm}^3$$

The result of the measurement is reported as  $d = 1.103 \pm 0.009 \text{ g/cm}^3$  or  $1.103(9) \text{ g/cm}^3$ .



#### 4. Measurement Errors for Some Devices (Instrumental Limitations)

The values of experimental measurements have uncertainties due to measurement limitations. Here we will show the uncertainty for two mostly used devices in the labs.

##### Ruler

In Fig 4, the pointer indicates a value between 23 and 24 mm. With this millimeter scale one strategy is to take the center of the bin as the estimate of the value, the maximum error is then half the width of the bin. So in this case our measurement is  $23.5 \pm 0.5$  mm. The value of 0.5 mm is the estimate of the random error.

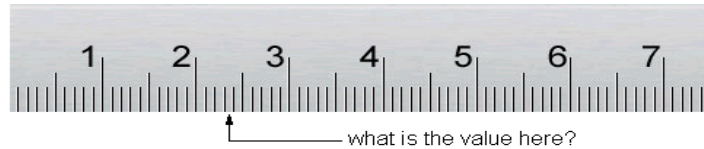


Figure 4: A standard ruler has a maximum uncertainty of  $\pm 0.5$  mm



Figure 5: A digital voltmeter having a maximum uncertainty of  $\pm 0.005$  V for this reading.

##### Digital Measuring Devices

All digital measuring devices has a maximum uncertainty of the order of half its last digit. For example, in Fig 5, for the reading from a digital voltmeter, the uncertainty is  $\pm 0.01/2$  Volts. Thus, assuming the voltmeter is calibrated accurately, the value is  $12.88 \pm 0.005$  V.

#### 5. Error Propagation

In a typical experiment, one is seldom interested in taking data of a single quantity. More often, the data are processed through multiplication, addition or other functional manipulation to get final result. Experimental measurements have uncertainties due to measurement limitations which propagate to the combination of variables in a function.

In statistical data analysis, the propagation of error (or propagation of uncertainty) is the effect of measurement uncertainties (or errors) on the uncertainty of a function based on them.

In general, if  $x, y, z, \dots$  are independent variables having associated errors (standard deviations)  $\sigma_x, \sigma_y, \sigma_z, \dots$  then the standard deviation for any quantity of the form  $f=f(x, y, z, \dots)$  derived from these errors can be calculated from[4]:

$$\sigma_f^2 = \left(\frac{\partial f}{\partial x}\right)^2 \sigma_x^2 + \left(\frac{\partial f}{\partial y}\right)^2 \sigma_y^2 + \left(\frac{\partial f}{\partial z}\right)^2 \sigma_z^2 + \dots \quad (6)$$

Equation (5) is known as the *error propagation formula* used for uncorrelated (independent) measurements. Table 1 shows the variances and standard deviations of simple functions of the real variables  $x$  and  $y$  with standard deviations  $\sigma_x$  and  $\sigma_y$  [4,5].

Table 1: Standard deviations of simple functions for error propagation after application of Eq. (6).

Function	Derivative(s)	Variance	Standard deviation
$f = kx ; k \in \mathbb{R}$	$\frac{\partial f}{\partial x} = k$	$\sigma_f^2 = k^2 \sigma_x^2$	$\sigma_f = k \sigma_x$
$f = x + y$	$\frac{\partial f}{\partial x} = 1$ and $\frac{\partial f}{\partial y} = 1$	$\sigma_f^2 = \sigma_x^2 + \sigma_y^2$	$\sigma_f = \sqrt{\sigma_x^2 + \sigma_y^2}$
$f = x - y$	$\frac{\partial f}{\partial x} = 1$ and $\frac{\partial f}{\partial y} = -1$	$\sigma_f^2 = \sigma_x^2 + \sigma_y^2$	$\sigma_f = \sqrt{\sigma_x^2 + \sigma_y^2}$
$f = xy$	$\frac{\partial f}{\partial x} = y$ and $\frac{\partial f}{\partial y} = x$	$\left(\frac{\sigma_f}{f}\right)^2 = \left(\frac{\sigma_x}{x}\right)^2 + \left(\frac{\sigma_y}{y}\right)^2$	$\sigma_f = f \sqrt{\left(\frac{\sigma_x}{x}\right)^2 + \left(\frac{\sigma_y}{y}\right)^2}$
$f = x/y$	$\frac{\partial f}{\partial x} = \frac{1}{y}$ and $\frac{\partial f}{\partial y} = -\frac{x}{y^2}$	$\left(\frac{\sigma_f}{f}\right)^2 = \left(\frac{\sigma_x}{x}\right)^2 + \left(\frac{\sigma_y}{y}\right)^2$	$\sigma_f = f \sqrt{\left(\frac{\sigma_x}{x}\right)^2 + \left(\frac{\sigma_y}{y}\right)^2}$

**EXAMPLE 2:** Suppose we wish to calculate the average speed (displacement/time) of an object. Assume the displacement is measured as  $x = 22.2 \pm 0.5$  cm during the time interval  $t = 9.0 \pm 0.1$  s. Then,

$$v = \frac{x}{t} = \frac{22.2}{9.0} = 2.467 \text{ cm/s}$$

and

$$\sigma_v = v \sqrt{\left(\frac{\sigma_x}{x}\right)^2 + \left(\frac{\sigma_t}{t}\right)^2} = 2.467 \sqrt{\left(\frac{0.5}{22.2}\right)^2 + \left(\frac{0.1}{9.0}\right)^2} = 0.062 \text{ cm/s}$$

Therefore, the reported result would be  $2.467 \pm 0.062$  cm/s or  $2.467(62)$  cm/s.

## 6. Combining Results of Independent Experiments

Consider we have  $n$  independent experiments with results  $a_i$  and errors  $\sigma_i$  ( $i = 1, \dots, n$ ). We can combine the results from each experiment to form a more accurate result. For this, a weighted sum is performed where experiments with smaller errors contribute more to the combined result.

The statistically correct way to combine independent results is as follows:

$$a = \frac{\sum a_i / \sigma_i^2}{\sum 1 / \sigma_i^2} \quad \text{and} \quad \sigma = \frac{1}{\sqrt{\sum 1 / \sigma_i^2}} \quad (7)$$

Final result should be reported in the form of  $a \pm \sigma$ . Note that when all experimental errors are equal, the form for the combined error is the same as the standard error given in the previous section 3.

**EXAMPLE 3:** For the measured gravitational acceleration data

$9.77 \pm 0.14$ ,  $9.82 \pm 0.10$  and  $9.86 \pm 0.20$  m/s<sup>2</sup>,

the combined result yields:  $9.811 \pm 0.075$  m/s<sup>2</sup> or  $9.811(75)$  m/s<sup>2</sup>.

## 7. Conclusion

Each measurement has an error. Experimental errors (or uncertainties) and their sources have to be well known for the measurements since they are closely related to the accuracy and precision of the results. Depending on your statistics and data type, we can include the magnitude of errors in the measurements in the following ways;

- If you have large enough data (say at least 10 as in Example 1) for measuring a quantity, you can evaluate the mean and standard error of the data using Eqs. (3-5) and present the result in the form of:  $\bar{x} \pm \sigma_E$ . You can ignore the error in each measurement and you do not need to use error propagation formula, Eq. (6).
- If you measure a quantity a few times (only one as in Example 2), you should evaluate your errors by means of error propagation formula, Eq. (6).
- If you have  $n$  independent experiments  $\{a_i \pm \sigma_i\}$ , you can combine the results using Eq. (7).

## 8. Discussions

1. What is a random error? Give an example for it.
2. What is a systematic error? Give an example for it.
3. How can we reduce random and systematic errors in an experiment?
4. What is the difference between percentage error and percentage difference?



**GENERAL PHYSICS  
PART A: MECHANICS  
EXPERIMENT-1  
“VECTOR ADDITION”**

**1. PURPOSE**

The purpose of this experiment is to use the force table to experimentally determine the force which balances two other forces. This result is checked by adding the two forces using their components and by graphically adding the forces.

**2. THEORY**

Many physical quantities can be completely specified by their magnitude alone. Such quantities are called scalars. Examples include such diverse things as distance, time, speed, mass and temperature. Another physically important class of quantities is that of vectors, which have direction as well as magnitude.

**A-) Experimental Method:** Two forces are applied on the force table by using masses over pulleys positioned at certain angles. Then the angle and mass hung over a third pulley are adjusted until it balances the other two forces. This third force is called the equilibrant ( $\vec{F}_E$ ) since it is the force which established equilibrium. The equilibrant is not the same as the resultant ( $\vec{F}_R$ ). The resultant is the addition of the two forces. While the equilibrant is equal in magnitude to the resultant, it is in the opposite direction because it balances the resultant (see Fig.1.1). So the equilibrant is the negative of the resultant:

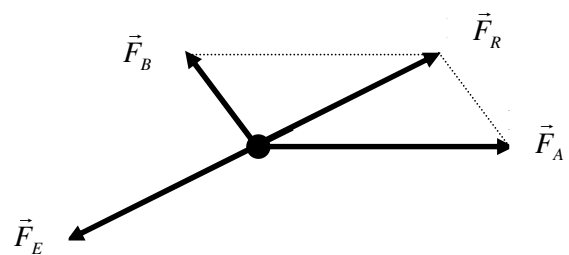
$$-\vec{F}_E = \vec{F}_R = \vec{F}_A + \vec{F}_B \quad (1.1)$$


Figure 1.1: The equilibrant balances the resultant

**B-) Component Method:** Two forces are added together by adding the x- and y-components of the forces. First the two forces are broken into their x- and y-components using trigonometry:

$$\vec{F}_A = A_x \hat{x} + A_y \hat{y} \quad \text{and} \quad \vec{F}_B = B_x \hat{x} + B_y \hat{y} \quad (1.2)$$

where  $A_x$  is the component of the vector  $\vec{F}_A$  and  $\hat{x}$  is the unit vector in the x-direction as shown Fig. 1.2. To determine the sum of  $\vec{F}_A$  and  $\vec{F}_B$ , the components are added to get the components of the resultant  $\vec{F}_R$ :

$$\vec{F}_R = (A_x + B_x) \hat{x} + (A_y + B_y) \hat{y} = R_x \hat{x} + R_y \hat{y} \quad (1.3)$$

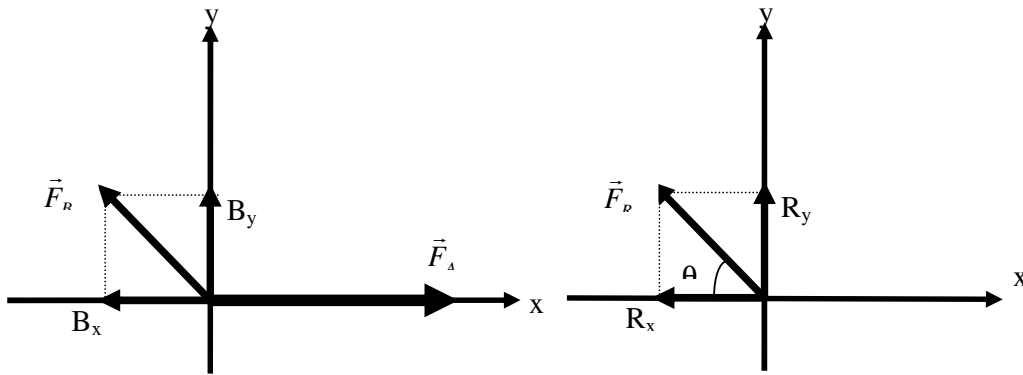


Figure 1.2: Vector Components

To complete the analysis, the resultant force must be in the form of a magnitude and a direction (angle). So the components of the resultant ( $R_x$  and  $R_y$ ) must be combined using the Pythagorean theorem since the components are at right angles to each other:

$$|F_R| = \sqrt{R_x^2 + R_y^2} \quad (1.4)$$

and using trigonometry gives the angle:

$$\tan \theta = \frac{R_y}{R_x} \quad (1.5)$$

**C-) Graphical Method:** Two forces are added together by drawing them to scale using a ruler and protractor. The second ( $\vec{F}_B$ ) is drawn with its tail to the head of the first force ( $\vec{F}_A$ ). The resultant ( $\vec{F}_R$ ) is drawn from the tail of the  $\vec{F}_A$  to the head of  $\vec{F}_B$  as shown in Fig.1.3.



Then the magnitude of the resultant can be measured directly from the diagram and converted to the proper force using the chosen scale. The angle can also be measured using the protractor.

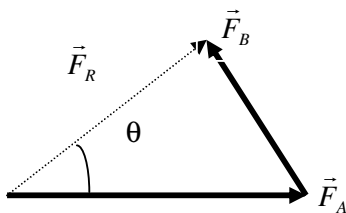


Figure 1.3: Adding vectors head to tail

### 3. EXPERIMENTAL PROCEDURE

1. Assemble the force table as shown in the Assemble section. Use three pulleys (two for the forces that will be added and one for the force that balances the sum of the two forces).
2. If you are using the Ring Method, screw the center post up so that it will hold the ring in place when the masses are suspended from the two pulleys. If you are using the Anchor String Method, leave the center post so that it is flush with the top surface of the force table. Make sure the anchor string is tied to one of the legs of the force table so the anchor string will hold the strings that are attached to the masses that will be suspended from the two pulleys.
3. Hang the following masses on two masses on two of the pulleys and clamp the pulleys at the given angles:

$$\text{Force } \vec{A} = 500 \text{ N at } 0^\circ \quad (1.6)$$

$$\text{Force } \vec{B} = 1000 \text{ N at } 120^\circ \quad (1.7)$$

#### Experimental Method:

By trial and error, find the angle for the third pulley and the mass which must be suspended from it that will balance the forces exerted on the strings by the other two masses. The third force is called the equilibrant  $\vec{F}_E$  since it is the force which establishes equilibrium. The equilibrant is the negative of the resultant:

$$-\vec{F}_E = \vec{F}_R = \vec{F}_A + \vec{F}_B \quad (1.8)$$

Record the mass and angle required for the third pulley to put the system into equilibrium in Table 1.1. (page.16)

### Ring Method of Finding Equilibrium:

1. The ring should be centered over the post when the system is in equilibrium. Screw the center post down so that it is flush with the top surface of the force table and no longer able to hold the ring in position. Pull the ring slightly to one side and let it go. Check to see that the ring returns to the center. If not, adjust the mass and/or angle of the pulley until the ring always returns to the center when pulled slightly to one side.
2. See Fig.1.4 to use this method, screw the center post up until it stops so that it sticks up above the table. Place the ring over the post and tie one 30 cm long string to the ring for each pulley. The strings must be long enough to reach over the pulleys. Place each string over a pulley and tie a mass hanger to it.

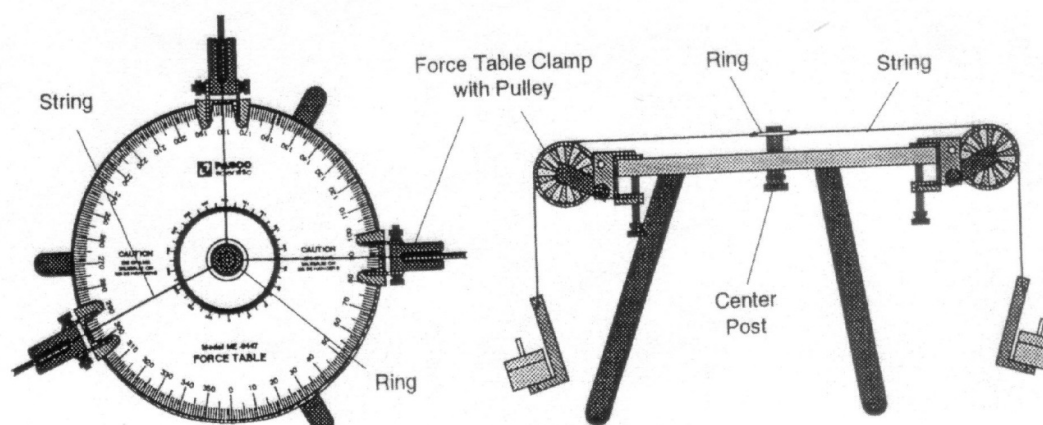


Figure 1.4: Ring method of stringing force table.

### Anchor String Method of Finding Equilibrium:

1. The knot should be centered over the hole in the middle of the center post when the system is in equilibrium. The anchor string should be slack. Adjust the pulleys downward until the strings are close to the top surface of the force table. Pull the knot slightly to one side and let it go. Check to see that the knot returns to the center. If not, adjust the mass and/or angle of the third pulley until the knot always returns to the center when pulled slightly to one side.
2. See figure 1.5, cut two 60 cm lengths of string and tie them together at their centers. Three of the ends will reach from the center of the table over a pulley; the fourth will be threaded down through the hole in the center post to act as the anchor string. Screw the center post down so it is flush with the top surface of the table. Thread the anchor string down

through the hole in the center post and tie that end to one of the legs. Put each of the other strings over a pulley and tie a mass hanger on the end of each string.

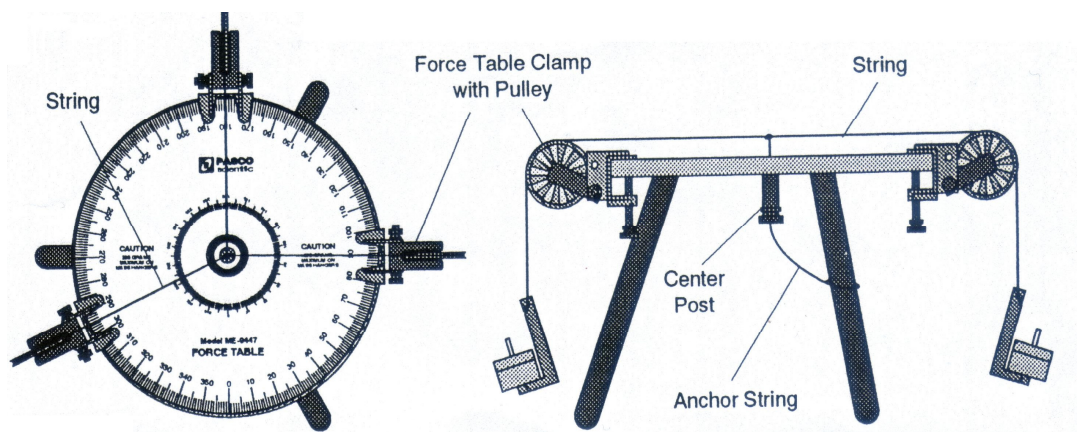


Figure 1.5: Anchor method of stringing force table.

#### 4. DISCUSSIONS AND CONCLUSIONS

1. To determine theoretically what mass should be suspended from the third pulley, and at what angle, calculate the magnitude and direction of the equilibrant ( $\vec{F}_E$ ) by the component method and the graphical method.

##### Component Method:

On a separate piece of paper, add the vector components of Force  $\vec{A}$  and Force  $\vec{B}$  to determine the magnitude of the equilibrant. Use trigonometry to find the direction (remember, the equilibrant is exactly opposite in direction to the resultant). Record the results in Table 1.1.

##### Graphical Method:

On a separate piece of paper, construct a tail-to-head diagram of the vectors of Force  $\vec{A}$  and Force  $\vec{B}$ . Use a metric rule and protractor to measure the magnitude and direction of the resultant. Record the results in Table 1.1. Remember to record the direction of the equilibrant, which is opposite in direction to the resultant.

2. How do the theoretical values for the magnitude and direction of the equilibrant compare to the actual magnitude and direction?
3. Three forces and their resultant and equilibrant. Draw the space diagram as before. Then solve (on a second sheet of graph paper) by the vector polygon method for the resultant and the equilibrant (The vector polygon method is merely an extension of the vector

triangle plot. The last plotted vector should, except for experimental error, close the polygon). Finally, solve for the resultant (magnitude and direction) of the three forces by the analytically method, using the technique of resolving forces into their horizontal and vertical components.

4. Compare the results with the actual experimental values from the force table.
5. Explain how the experiment has illustrated the principles of vector addition. What does the vector equation  $\vec{R} = \vec{F}_1 + \vec{F}_2$  Express? How would you write the same expression in algebraic terms?

Table.1.1 : Data table

Table 1.1		
Method	Equilibrant ( $F_E$ )	
	Magnitude	Direction ( $\theta$ )
Experiment:		
Component: $R_x =$ _____  $R_y =$ _____		
Graphical:		

**GENERAL PHYSICS**  
**PART A: MECHANICS**  
**EXPERIMENT – 2**  
**“FREELY FALLING OBJECT”**

### **1. PURPOSE**

The purpose of this laboratory is to determine the acceleration of gravity by timing the motion of a freely falling object.

### **2. THEORY**

The most common example of motion with (nearly) constant acceleration is that of a body falling toward the earth. In the absence of air resistance we find that all bodies, regardless of their size, weight, or composition, fall with the same acceleration at the same point on the earth's surface, and if the distance covered is not too great, the acceleration remains constant throughout the fall. This ideal motion, in which air resistance and the small change in acceleration with altitude are neglected, is called “free fall”. The acceleration of a freely falling body is called the acceleration due to gravity and denoted by the symbol  $\vec{g}$ . Near the earth's surface its magnitude is approximately  $9.8 \text{ m/sec}^2$ , which  $980 \text{ cm/sec}^2$ , and it is directed down toward the center of the earth.

Up to now, the relationships between kinematics quantities such as velocity and acceleration were not dependent upon any property of nature, but rather on how they were defined. Here, for the first time, we have introduced a quantity, the acceleration of gravity, which reflects a property of nature. We cannot calculate the acceleration of gravity from just our knowledge of the kinematical relationships but rather it must be measured. The value we measure depends on the coordinate system and, hence, the units of measurement. But the fact that all things fall with the same acceleration (in the absence of air friction) is a consequence of natural law.

The acceleration of gravity near the earth's surface is slightly different at different location on earth. The acceleration depends on latitude because of the earth's rotation. It also depends on altitude. But for any given location, the acceleration there is the same for all objects.

The force of gravity at the same rate. Strictly speaking, such experiments must be conducted in a vacuum so that the force of air resistance does not affect the results. For



relatively small, smooth bodies of considerable density, however, the error introduced by conducting such experiments in the atmosphere is quite small.

In any motion problem it should be apparent that three variables- distance, rate, and time- are involved. If the motion uniform, or if the concept of average velocity is used, the motion can be described by the simple equation

$$x=vt \quad (2.1)$$

where  $x$  is distance traveled in time  $t$  and  $v$  is the average velocity for the time interval  $t$ . When motion is non-uniform, that is, where velocity is changing, acceleration is said to take place. If the acceleration is uniform, as from a constant force such as the force of gravity, the acceleration can be defined as the average rate of change of velocity and it is given by the following equation:

$$a = \frac{(v_2 - v_1)}{t} \quad (2.2)$$

where  $v_2-v_1$  represents the change in velocity which occurs in time  $t$ . If a body starts from rest (i.e., $v=0$ ) and is uniformly accelerated by a constant force for a time interval  $t$ , the total distance it will travel is given by the equation

$$x = \frac{1}{2}at^2 \quad (2.3)$$

For the case of a body falling from a height  $h$  under the influence of the acceleration of gravity  $g$ , becomes

$$h = \frac{1}{2}at^2 \text{ and } v^2-v_o^2 = 2gh. \quad (2.4)$$

In this experiment, the “ picket fence” included with the Smart Pulley system has evenly spaced black bars on a piece of clear plastic. When dropped through the photo gate, the bars interrupt the light beam. By measuring the distance between bars, and using the time measurements of the Smart Pulley, the acceleration of the freely picket fence can be calculated.

Note: On using the ”Picket Fence”

- a. When performing free-fall experiments, place a soft pad under the experiment to cushion the fall of the “Picket Fence”, or make sure to catch the bar to keep it from breaking.
- b. For accurate results drop the “Picket Fence” through the Smart Pulley Photo gate vertically as shown in Fig. 2.1.



- c. To achieve vertical alignment of the “Picket Fence” hold it between your thumb and forefinger, centered at the top of the bar, before releasing (See Fig. 2.2).

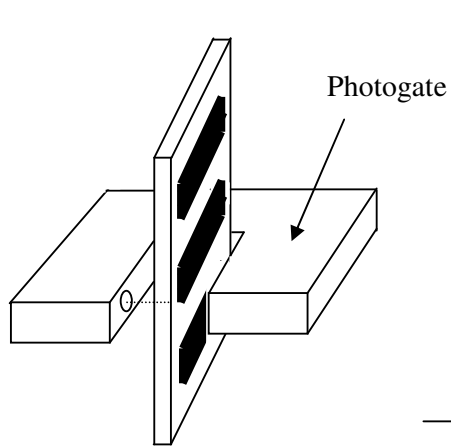


Figure 2.1: Picket Fence

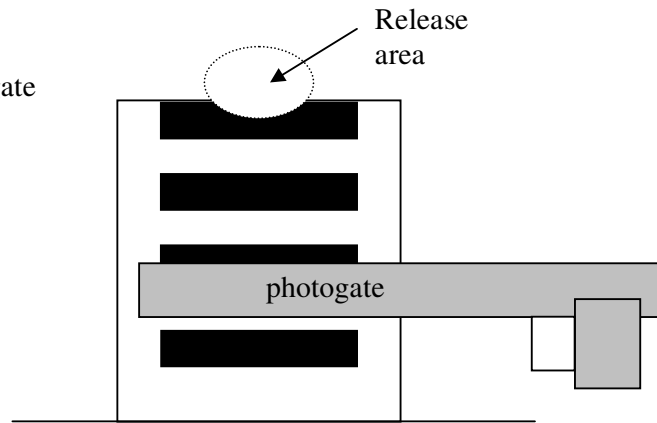


Figure 2.2: Picket Fence

### 3. EXPERIMENTAL PROCEDURE

1. Set up the apparatus as in Fig. 2.3. Measure  $\Delta d$ , the distance between the leading edges of adjacent bars on the picket fence, as shown. Record  $\Delta d$ .

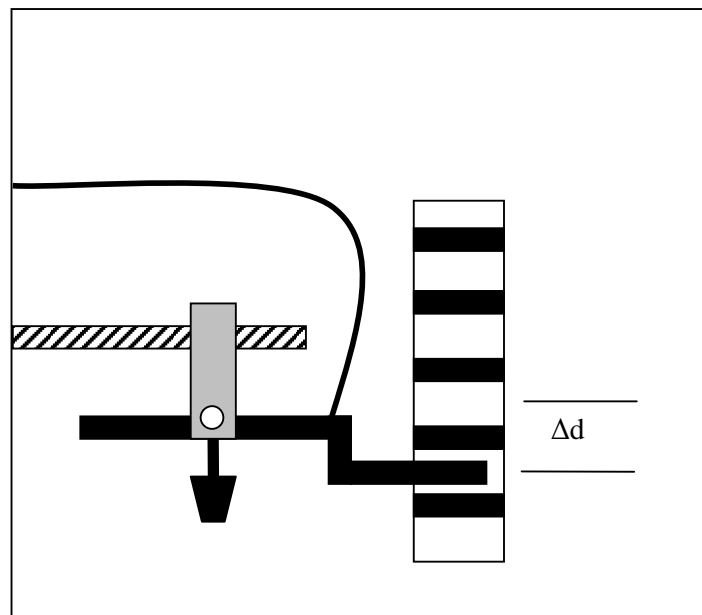


Figure 2.3: Equipment setup

2. Connect the Smart Pulley to your computer. Make sure the proper connections have been made before going on. Insert the Smart Pulley software disk into your computer disk drive and start up the computer.
3. The computer will ask you how the Smart Pulley is connected. Ask your instructor for the correct response, select it, then press <RETURN>.
4. From the Main Menu, select option <M>, but do not press <RETURN>.
5. Hold the picket fence in the gap between the arms of the photogate, as shown in Figure 3. Position the picket fence so that the photogate beam passes through a clear area, so the LED on top of the photogate is not lighted.
6. Now press <RETURN>. Drop the picket fence, being sure to catch it before it hits the floor. Press <RETURN> again to halt the timing process of the computer.
7. When the computer finishes its calculations, it will present you with a menu of data analysis options. Choose <G> to move to the graphing function, then choose <C> to tell the computer that you are monitoring the motion of the picket fence. When you get to the graphing menu, choose <V> which will give you a velocity-time graph.
8. You will now be asked to specify the style of the graph you want. Select <R>,<G> and <S>. (Remember, you must use the space bar so that ON appears to the left of each selection). The letter S indicates that statistical data will be displayed along with the graph. At the top of the graph you will see three numbers. They are:

M= slope of the graph

B= y-direction

R= correlation coefficient (how close the graph is to a straight line)

9. If your graph is a good straight line (as theory says it should be), record the slope of the graph, which is the acceleration, in Table 2.2. Its units are meter/sec<sup>2</sup>.
10. When finished looking at the graph, press <RETURN>. You will now be given several choices. If you are pleased with the graph you obtained, you should press <T> to get a readout of the data from your experiment. Copy the velocities and times into Table 2.1 or follow instructions for printing the data out on a printer.
11. Repeat the experiment at least 5 times. Select <X> to return to the Main Menu, then repeat steps 4-8. You need to record velocities and times for only one of your runs, but record the acceleration for each run.

#### 4. DISCUSSIONS AND CONCLUSIONS

1. Use your data (from one run) to construct a velocity (vertical axis) versus time graph.
2. Average the acceleration from all of your runs.
3. Calculate the slope of your velocity-time graph. Analyze how close the several values for the acceleration of gravity were to each other. Analyze how close your average value was to the standard value of  $9.80 \text{ m/sec}^2$ .

Table 2.1. Free-Fall Velocities and Times					
Interval	Velocity	Total Time	Interval	Velocity	Total Time
1			11		
2			12		
3			13		
4			14		
5			15		
6			16		
7			17		
7			18		
8			19		
9			20		
10			21		

Table 2.2. Free-Fall Acceleration	
Trial	Acceleration
1	
2	
3	
4	
5	
6	
7	

**GENERAL PHYSICS  
PART A: MECHANICS  
EXPERIMENT – 3**

**“ACCELERATION OF A LABORATORY CART ( NEWTON’S SECOND LAW)”**

### 1. PURPOSE

In this experiment, you will investigate the changes that occur with different masses hanging from the thread and with different masses being moved by the resulting forces.

### 2. THEORY

The study of the causes of motion is called dynamics. The laws that govern the motion of an object were described by Newton in 1657- known as Newton’s laws. The laws are physical interms of force and mass. Newton’s first law describes what happens when the near force acting on an object is zero. In that case, the object either remains at rest or continues in motion with constant speed in a straight line. If the net force on an object is zero then the objects acceleration is zero. If  $\Sigma \vec{F} = 0$  then  $\vec{a} = 0$ . And so the object remains at rest or at constant velocity. We used Newton’s 1<sup>st</sup> law in static,  $\Sigma \vec{F} = 0$ .

Newton’s second law describes the change of motion that occurs when a nonzero net force acts on the object. The original translation of **Newton’s second law** was, *The alternation of motion is ever proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed.* Elsewhere in the Principia Newton was clear that by “motion” he meant the product of the velocity and the mass. For the moment, it is sufficient to use Newton’s identification of mass as the “quantity of matter”. Then the second law:

The rate of change of momentum with time is proportional to the net applied force and is in the same direction:

$$\frac{\Delta(m\vec{v})}{\Delta t} = \Sigma \vec{F} \quad (3.1)$$

Where  $\Sigma \vec{F}$  is the net force – that is, the vector sum of all forces acting on a body- and the change in the momentum  $\Delta(m\vec{v})$  is in the direction of  $\Sigma \vec{F}$ .

In the majority of real situations, the mass of an object does not change appreciably, so the change in momentum is just the mass times the change in velocity. Then

$$\frac{\Delta(m\vec{v})}{\Delta t} = m \frac{\Delta\vec{v}}{\Delta t} = m\vec{a} \quad (3.2)$$

The rate of change in momentum of a body is proportional to the net force on the body. In equation from the 2<sup>nd</sup> law states.

$$\Sigma \vec{F} = m\vec{a} \quad (3.3)$$

This leads to the definition of force in terms of the acceleration of  $\vec{a}$  mass.

### 3. EXPERIMENTAL PROCEDURE

- 1- Set up the apparatus as shown in Fig.3.1 connect the Smart Pulley photogate to your computer, and start up the computer.

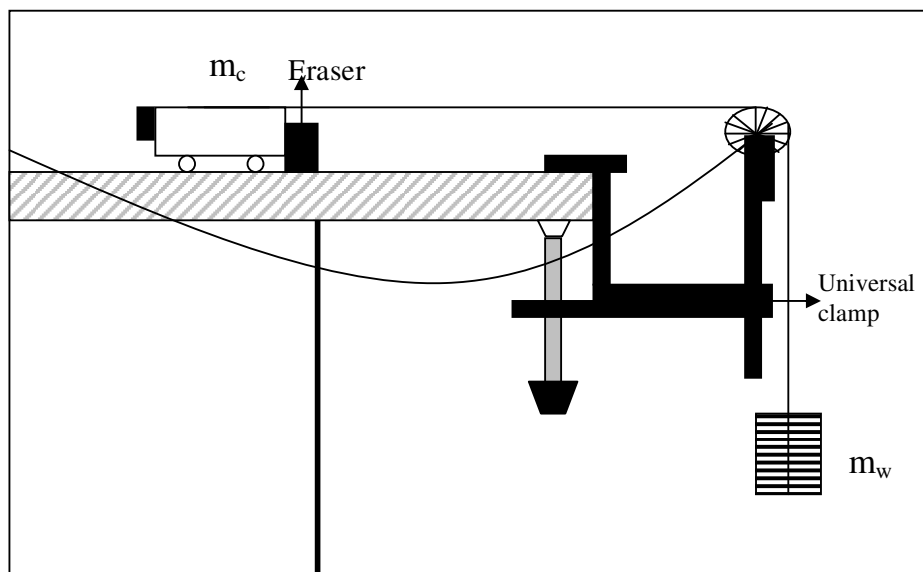


Figure 3.1: Equipment setup

- 2- Place a total of about 200 grams of mass on top of the cart and record the total mass of cart plus added mass as  $m_c$  in your Table 3.1. Place about 20 grams on the mass hanger. Including the mass of the mass hanger, record the total as  $m_w$ .
- 3- Move the cart backwards until the mass hanger almost touches the pulley. With the mass motionless, select <M> on the main menu.
- 4- Now press <RETURN> on the computer. Release the mass hanger which will fall downward, pulling the cart across the table. Stop the timing just before the mass hanger reaches the floor by pressing <RETURN>.
- 5- When the computer finishes converting the times, choose <G> which will move you to the graphing function. When you get to the graphing, select <A> which will interpret the timing as a linear motion. Choose <V> which will give you a velocity-time graph.

- 6- The next choices give you the style of graph wanted. Choose <S> to indicate that statistical data will be displayed along with the graph and <R> to plot the regression or best fit line. To choose these, move the cursor to the choices and push the <SPACE BAR> changing the “OFF” to an “ON” next to the choices. When completed, press <RETURN> to have the computer plot the graph.
- 7- At the top of the graph you should see three numbers. They are:
  - M--- The slope of the graph
  - B --- The y-intercept
  - R --- The correlation coefficient (how close to a straight line it is)
- 8- If the value for R is 1.00 or not less than 0.98, the graph is statistically a good straight line. This indicates that the acceleration is constant. Record the slope of the graph, the acceleration. Its units are in meter/sec<sup>2</sup>. Study the graph as long as you wish, and when finished, press <RETURN>. Press <ESC> until you move to the main menu to make another run.
- 9- Change the applied force (due to m<sub>w</sub>) by moving masses from the cart to the hanger. This changes the force without changing the total mass. Record your new values in the data table. Repeat steps 3-8 at least five times using different values for m<sub>w</sub>.
- 10- Now change the total mass, yet keep the net force the same as in one of your first five runs. Add mass to the cart, keeping the hanging mass the same. Record your new mass values, and the accelerations that you obtain. Repeat at least five times.

#### 4. DISCUSSIONS AND CONCLUSIONS

1. Calculate the net force acting on the cart for each trial that you performed. The net force is the tension in the string (if friction is neglected), which can be calculated as:
 
$$F_{\text{net}} = (m_w m_c) / (m_c + m_w)$$
2. Also calculate the total mass that was accelerated in each trial: (m<sub>c</sub>+m<sub>w</sub>).
3. Graph the acceleration versus the applied force for cases having the same total mass. Graph the acceleration versus total mass for cases with the same applied force. What relationships exist between the graphed variables?
4. Calculated the theoretical acceleration using Newton’s 2<sup>nd</sup> Law: F<sub>net</sub>=ma. Compare the actual acceleration with the theoretical acceleration, determining the percentage difference between the two.
5. Discuss your results. In this experiment, you measured only the average acceleration of the object between the two photogates. Do you have reason to believe that your results

also hold true for the instantaneous acceleration? Explain. What further experiments might help extend your results to include instantaneous acceleration?

Trial #	$m_c$	$m_w$	Experiment Acceleration	Applied Force	Total mass	Theory Acceleration	%Difference
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

**GENERAL PHYSICS  
PART A: MECHANICS  
EXPERIMENT – 4**

**“THE CONSERVATION OF ENERGY”**

**1. PURPOSE**

To investigate the initial gravitational potential energy of the cart are converted to thermal and kinetic energy as the cart slides to a stop and the thermal energy generated on the surfaces is the same as the work done against sliding friction.

**2. THEORY**

A body in motion possesses energy associated with its motion because it can do work upon impact with another object. This energy of motion is called kinetic energy. In applying a force to the particle, we performed an amount of work  $Q = \max$ . The effect of the work done on the particle has been to change its motion. The quantity  $\frac{1}{2}mv^2$  is given the name kinetic energy (KE). More specifically, this equation is called the translational kinetic energy. A particle of mass  $m$  moving with a speed  $v$  possesses a kinetic energy due to its translational motion that is given by

$$KE = \frac{1}{2} mv^2 \quad (4.1)$$

The SI units for kinetic energy are  $\text{kg}\cdot\text{m}^2/\text{s}^2$  or joules, the same as the units for work. We have seen that an object in motion has kinetic energy. Objects may also have energy in other forms. When a spring is stretched, it acquires energy called potential energy. The term potential energy does not mean that the energy is not real energy. Rather, it means that the energy is stored and is available to be converted into work or some other form of energy.

Gravitational potential energy is one of the most familiar forms of potential energy. A mass  $m$  initially at rest on the ground. It is then lifted slowly at a uniform velocity with a constant upward force just strong enough to equal the downward force of gravity  $mg$ . If the log is raised from the ground to a height  $h$ , the work done on the log is the net lifting force times the distance travels, or

$$W = F \times h = mgh \quad (4.2)$$



If the log is released, it will fall. As it falls it accelerates, gaining velocity and kinetic energy, and thereby the ability to do work. Because the log at height  $h$  is capable of doing work if it is released, we say it has potential energy due to its position. More specifically, we say in this case that it has gravitational potential energy. Thus, near the earth's surface an object's gravitational potential energy with respect to some reference level is

$$PE = mgh \quad (4.3)$$

where  $h$  is the height above the reference level. Again, the units are joules. The sum of the body's kinetic energy and potential energy is its total mechanical energy. If the forces are all conservative, the sum of the kinetic and potential energies is a constant. This statement is the law of conservative of energy, which can be written as

$$KE_2 + PE_2 = KE_1 + PE_1 \quad (4.4)$$

Sometimes this last equation is useful way to state the law of conservative of mechanical energy.

### 3. EXPERIMENTAL PROCEDURE

- 1- Place the chart with the frictionless block on the ramp. Set up the ramp (see Fig. 4.1) at a relatively low angle (one that does not cause the friction block to begin sliding down the ramp by itself).

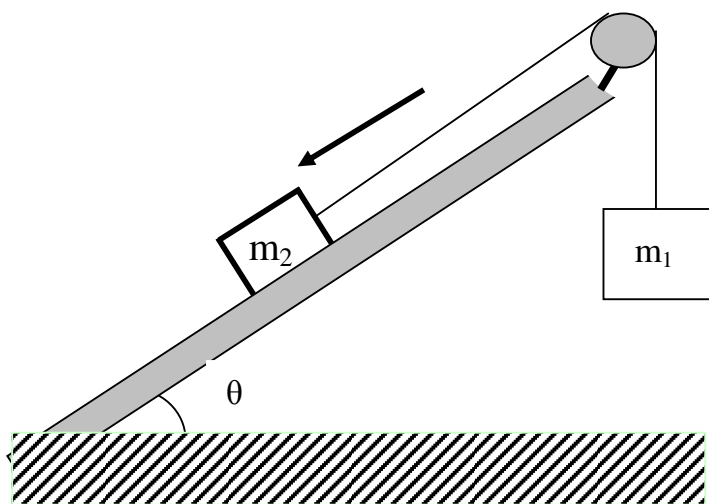


Figure 4.1: Equipment Setup

- 2- When you have gotten to the main menu, select option <M>, the motion timer. In this mode, the computer will measure and record up to 200 time intervals as your pulley spins.
- 3- Now press <RETURN> on the computer. Release the mass hanger which fall downward, pulling the cart across the table. Stop the timing just before the mass hanger reaches the floor by pressing <RETURN>.
- 4- When the computer finishes its calculations, it will display the measured times. Press the space bar on the keyboard to scroll through the data. When you reach the bottom of the ramp, press <RETURN> to move to the next menu.
- 5- At the next menu, choose option <G> to enter the graphing mode, then choose <A> to tell the computer you are using the Smart Pulley to monitor a linear motion. When you get to the graphing menu, choose <D> to select a distance-time graph.
- 6- In the next menu, choose <G>, then press the space bar so your graph will have a grid. Also press <P> followed by <SPACE BAR> so your graph will not have point protectors. Pressing <RETURN> starts the actual graphing routine.
- 7- Examine the graph, then press <RETURN>. You will be shown a new menu. If your graph shows reasonably constant speed, press <T> to see the data.
- 8- Now choose option <A> from the same menu, so you can alter the style of the graph. Choose a velocity-time graph by pushing <V> to display the velocity and time information. Record the first 25 velocities in your data table.
- 9- Place the cart with the friction block on the ramp. Set up the ramp (see Fig. 4.2) at a relatively low angle (one that does not cause the friction block to begin sliding down the ramp by itself).
- 10- Experiment repeat different angle (at least 5 times) and different mass  $m$  (at least 3 times). And repeat step 9.

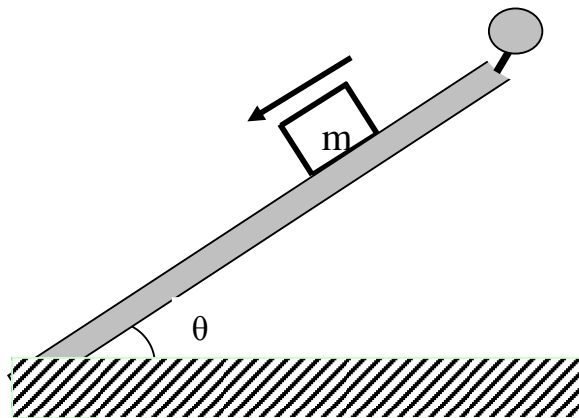


Figure 4.2: Equipment Setup

#### **4. DISCUSSION AND CONCLUSION**

- 1- In your write-up include a description of the motion, a description of the graphs that you obtained, and try to generalize on what the different shapes of graphs mean of the motion they describe.
- 2- Compare your results with your prediction. Compute the percent difference between these two values.

**GENERAL PHYSICS**  
**PART A: MECHANICS**  
**EXPERIMENT – 5**  
**“COLLISIONS (CONSERVATION OF MOMENTUM)”**

**1. PURPOSE**

In this experiment, you will use the Smart Pulley to investigate momentum conservation in inelastic collisions, conservation of energy and momentum in elastic collisions. The colliding objects will be a pair of lab carts with Velcro fasteners. Once the carts collide, they stick together, so the collisions are inelastic and elastic.

**2. THEORY**

**Elastic Collision:** An elastic collision is one in which kinetic energy and momentum are both conserved. A close approximation of such an elastic collision is provided when two pucks, both of which are initially in motion on a frictionless surface collide.

Before collision of the two carts, the situation can be represented as follows:

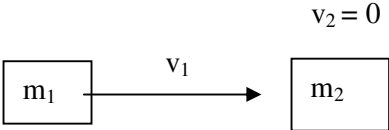


Figure 5.1: Before the an elastic collision

where  $m_1$  = the mass of the first cart,  $v_1$  = the velocity of the first cart,  $m_2$  = the mass of the second cart, and  $v_2$  = the velocity of the second cart, which is zero.

During an elastic collision, the kinetic energy is converted to potential energy and back into kinetic energy as the carts bounce off one another. After the collision, the carts accelerate away from each other, or all the kinetic energy of one cart is transferred to the other cart, which accelerates away from the first cart, has a velocity of zero. When acceleration reaches 0, the situation can be as represented below:



Figure 5.2: After the an elastic collision

The momentum of the system at any point in time is expressed as follows:

$$P = m_1v_1 + m_2v_2 \quad (5.1)$$

Where  $m_1v_1$  are the mass and velocity of the first cart and  $m_2v_2$  are the mass and velocity of the second cart. Since the momentum is conserved after the collision, the following relationship exists:

$$m_1v_1 + m_2v_2 = m_1v_{1\text{after}} + m_2v_{2\text{after}} \quad (5.2)$$

The total kinetic energy (KE) of the system at any moment in time is represented by:

$$KE = \frac{1}{2} m_1v_1^2 + \frac{1}{2} m_2v_2^2 \quad (5.3)$$

After the elastic collision, the kinetic energy and momentum are conserved:

$$\frac{1}{2} m_1v_1^2 + \frac{1}{2} m_2v_2^2 = \frac{1}{2} m_1v_{1\text{after}}^2 + \frac{1}{2} m_2v_{2\text{after}}^2 \quad (5.4)$$

**Inelastic Collision:** If a collision is inelastic then, by definition, the kinetic energy is not conserved. The final kinetic energy may be less than the initial value, the difference being ultimately converted to heat energy or to potential energy of deformation in the collision. In any case the conservation of momentum still holds, as does the conservation of total energy. Before collision of the two carts, the situation can be represented as follows:

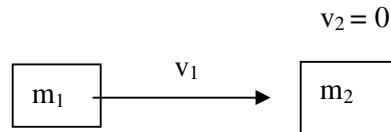


Figure 5.3: Before the inelastic collision

where  $m_1$  = the mass of the first cart,  $v_1$  = the velocity of the first cart,  $m_2$  = the mass of the second cart, and  $v_2$  = the velocity of the second cart, which is zero.

After the collision, the carts stick together and move as one mass, as represented below:

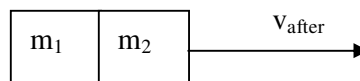


Figure 5.4: After the inelastic collision

The momentum of the system at any point in time is expressed as follows:

$$P = m_1v_1 + m_2v_2 \quad (5.5)$$

where  $m_1v_1$  are the mass and velocity of the first cart and  $m_2v_2$  are the mass and velocity of the second cart. Since the momentum is conserved after the collision, the following relationship exists:

$$m_1v_1 + m_2v_2 = m_{\text{after}}v_{\text{after}} \quad (5.6)$$

where  $m_{\text{after}}$  is the mass of the carts and  $v_{\text{after}}$  is the velocity of the two carts stick together. The total kinetic energy (KE) of the system at any moment in time is represented by:

$$KE = \frac{1}{2} m_1v_1^2 + \frac{1}{2} m_2v_2^2 \quad (5.7)$$

In contrast to the case with momentum, KE is not conserved after the collision:

$$\frac{1}{2} m_1v_1^2 + \frac{1}{2} m_2v_2^2 \neq \frac{1}{2} m_{\text{after}}v_{\text{after}}^2 + \frac{1}{2} m_{\text{after}}v_{\text{after}}^2 \quad (5.8)$$

### 3. EXPERIMENTAL PROCEDURE

#### Part A-) Inelastic Collision

- 1- Set up the apparatus as shown in Fig.5.5. In order to create an elastic collision, put a piece of Velcro fastener on the front side of cart #1 and a piece of the opposite type of Velcro on the back of cart #2. Attach a piece of thread to cart #1. The thread should be about 10 cm longer than the distance from the cart to the floor. Connect the Smart Pulley to your computer, and make sure the proper connections have been made before going on.

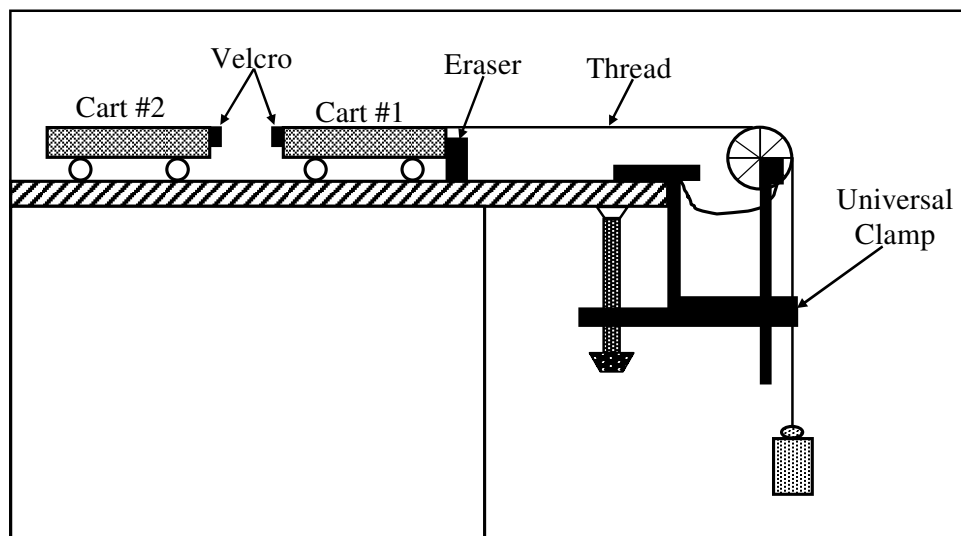


Figure 5.5: Equipment setup for inelastic collision

- 2- Insert the Smart Pulley software disk into your computer disk drive and start up the computer.
- 3- Determine the mass of each of your lab carts. Record these as  $m_1$  and  $m_2$ , respectively, in Table 5.2. Fasten the thread running from cart #1 to the mass hanger by wrapping 4-5 turns of thread around the notched area of the hanger. The purpose of the mass hanger is to keep a small amount of tension on the thread to turn the pulley as the cart moves.
- 4- Move cart #1 until the mass hanger almost touches the floor. With the cart motionless and the holes in the pulley positioned so that the LED on the photogate is off, select <M> on the main menu.
- 5- Give cart #1 a push so that it collides with cart #2 near the center of the table. Continue timing until the thread runs out, then press <RETURN> to halt the timing process.
- 6- When the computer finishes processing the times, move to the graphing function. Select <A> to tell the computer that you are using the Smart Pulley to monitor a linear motion. Next choose <V> which will give you a velocity-time graph.
- 7- When finished looking at the graph, press <RETURN>. Choose <T> to display a table of the velocity-time data. Copy the data Table 1 (you need only be concerned with the data for timing intervals before the collision and 5 intervals after the collision).
- 8- Change the relationship between  $m_1$  and  $m_2$  by adding mass to either of the two carts. Repeat steps 3-7 five times with different mass combinations.

### **Part B-) Elastic Collision**

- 1- Set up the apparatus as shown in Fig.5.6. In order to create an elastic collision, attach a piece of thread to cart #1. The thread should be about 10 cm longer than the distance from the cart to the floor. Connect the Smart Pulley to your computer, and make sure the proper connections have been made before going on.
- 2- Insert the Smart Pulley software disk into your disk drive and start up the computer.
- 3- Determine the mass of each of your lab carts. Record these as  $m_1$  and  $m_2$ , respectively, in Table 5.2. Fasten the thread running from cart #1 to the mass hanger by wrapping 4-5 turns of thread around the notched area of the hanger. The purpose of the mass hanger is to keep a small amount of tension on the thread to turn the pulley as the cart moves.
- 4- Move cart #1 until the mass hanger almost touches the floor. With the cart motionless and the holes in the pulley positioned so that the LED on the photogate is off, select <M> on the main menu.
- 5- Give cart #1 a push so that it collides with cart #2 near the center of the table. Continue timing until the thread runs out, then press <RETURN> to halt the timing process.



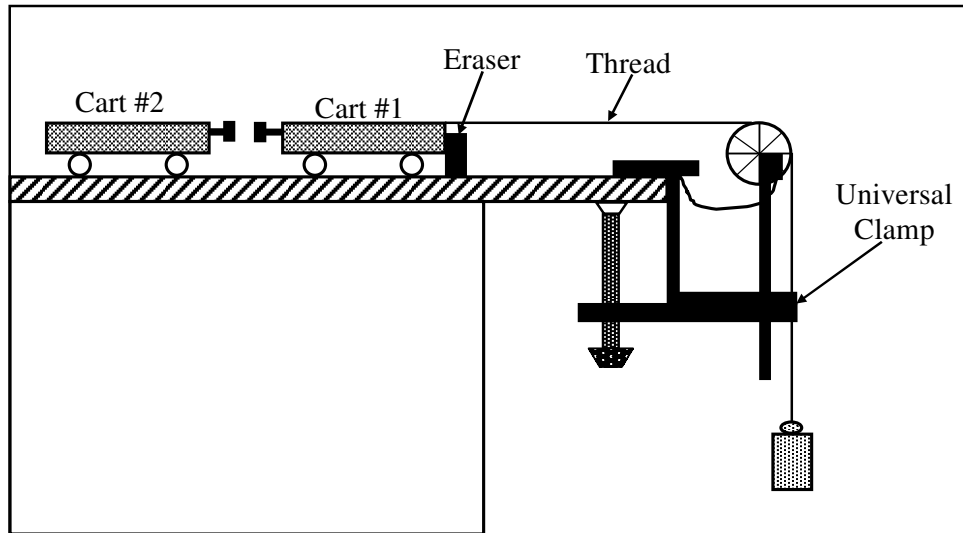


Figure 5.6: Equipment setup for elastic collision

- 6- When the computer finishes processing the times, move to the graphing function. Select <A> to tell the computer that you are using the Smart Pulley to monitor a linear motion. Next choose <V> which will give you a velocity-time graph.
- 7- When finished looking at the graph, press <RETURN>. Choose <T> to display a table of the velocity-time data. Copy the data Table 5.1 (you need only be concerned with the data for timing intervals before the collision and 5 intervals after the collision).
- 8- Change the relationship between  $m_1$  and  $m_2$  by adding mass to either of the two carts. Repeat steps 11-15 five times with different mass combinations.

#### 4. DISCUSSIONS AND CONCLUSIONS

##### For Inelastic Collision:

1. Calculate the momentum of cart #1 immediately before the collision, and the momentum of the combined masses immediately after the collision for each of your trials.
2. Determine the percentage difference between the pre- and post-collision momentum for each trial.

##### For Elastic Collision:

3. Calculate the momentum of cart #1 immediately before the collision, and the momentum of the combined masses immediately after the collision for each of your trial.
4. Determine the percentage difference between the pre- and post-collision momentum and energy for each trial.



Table 5.1: Velocities of Carts									
Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
Before	After	Before	After	Before	After	Before	After	Before	After

Table 5.2: Momenta and Energy of Carts								
Trial	$M_1$	$M_2$	Initial Velocity	Initial Momentum	Initial Energy	Final Velocity	Final Momentum	Final Energy

**GENERAL PHYSICS**  
**PART B: ELECTRICITY and MAGNETISM**  
**EXPERIMENT – 6**  
**“ELECTRIC FIELD”**

### 1. PURPOSE

To study the nature of electric field and to map the equipotential lines and then determine the lines of force for a two-dimension electric field.

### 2. THEORY

The steady field of forces can be represented into two different ways such as an electric or magnetic field. The concept of a field is basic to the development of our knowledge of electric and magnetic phenomena. Thus the concept of field is very important in the understanding many of the phenomena of modern physics. In here, we will be explained briefly electric field phenomena.

#### 2.1. Electric Field

Any charged object always gives rise to an electric field. If a test charge placed near the object will experience a force because of the object's charge and the electric field generated due to this point charge (called as test charge). The direction of the electric field is taken to be the direction of the electric force on the positive test charge. If we want to draw a diagram for the electric field near a positive point charge  $Q$  and a negative point charge  $-Q$ , the electric field lines become as shown in Fig. 6.1.

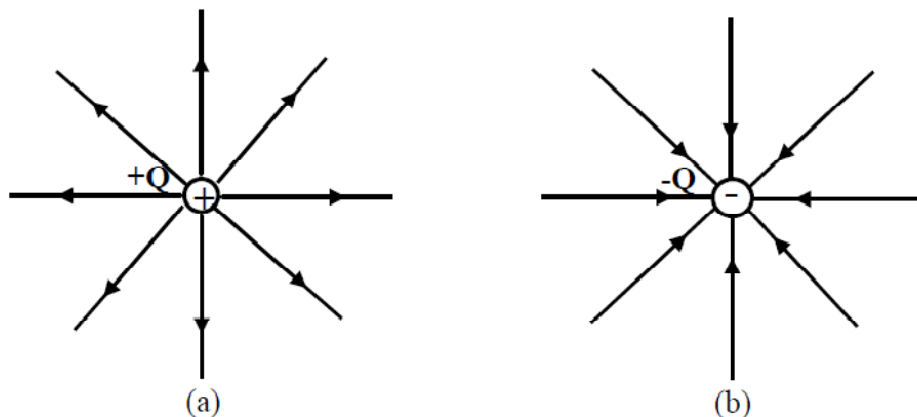


Figure 6.1: Electric field lines outward from positive charges and inward from negative



charges.

Fig. 6.2(a) and (b) show the two possible cases the lines of force for two equal unlike and like charges. To find the direction of the field lines, Michael Faraday introduced the field lines close to the charges are directly radially outward from positive charges and radially inward toward negative charges.

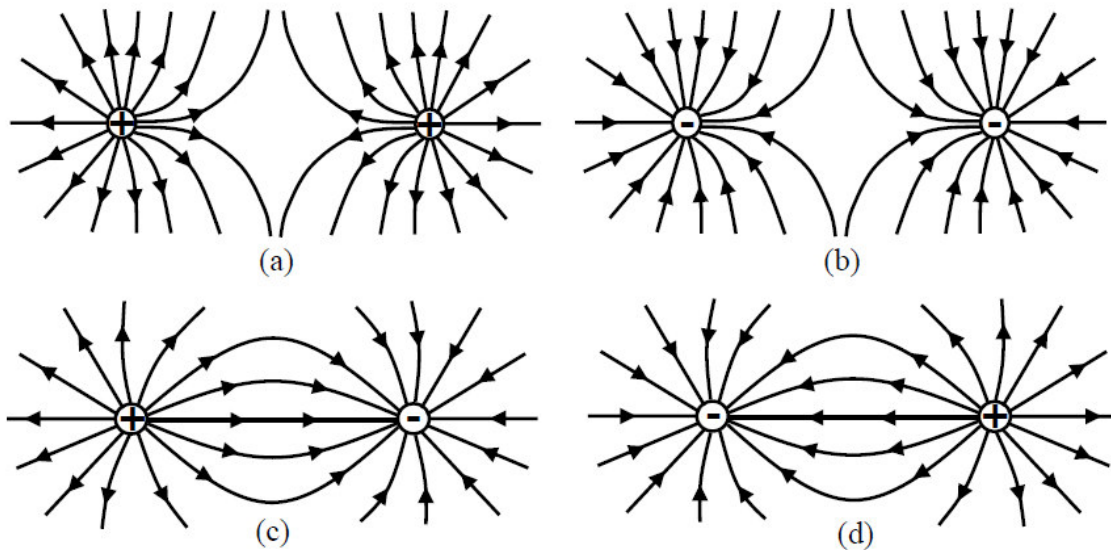


Figure 6.2: a; b-) Electric field lines of force for two equal positive and negative point charges, respectively. c; d-) Electric field lines of force for two equal unlike point charges.

To find the electric field strength  $\vec{E}$  at a point, suppose a positive test charge  $q$  is placed at that point. The force on the test charge will be  $\vec{F}$ . We define electric field strength at that point to be

$$\vec{E} = \frac{\vec{F}}{q} \quad (6.1)$$

where  $E$  has the units Newton per coulomb in order that it to be the force per unit test charge. The field strength is a vector quantity whose direction is that of  $F$ .

## 2.b. Electric Potential

The electric field  $E$  and electric potential  $V$  is intimately related with each other. Since a free test charge would move in an electric field under the action of the present forces from one point to another the work ( $W$ ) is done by the field in moving charges. If external forces act to

move a charge against the electric field, then work is done on the charge by the external force. The work done against electrostatic forces in a moving charge  $q$  from point A to B is independent of the path taken. The electrostatic force is conservative. To find the electric potential difference between two points A and B in an electric field, the test charge  $q$  is now moved from A to B, work is again done, and the ratio of the work  $W$  to the test charge  $q$  is called the potential difference between the point A and B as shown in Figure 6.3. We represent the electric potential difference between two points A and B by  $V_B - V_A$  and it is defined as

$$V_B - V_A = \frac{\text{Work}}{q} = \frac{W_{AB}}{q} \quad (6.2)$$

Its unit is work per charge, namely joules per coulomb. This unit is given a special unit, by Volt (V).

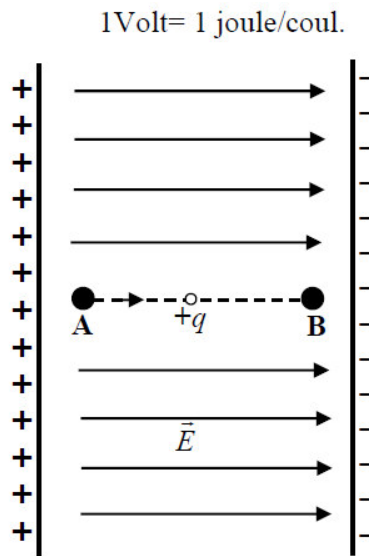


Figure 6.3: Potential difference in an electric field.

Now consider Fig. 6.4 which shows the equipotential lines and surface in the field of a point charge. If a charge is moved along a path such as from M to N which is perpendicular to the lines of force, there is no force component along the path. Therefore, no work will be done in a moving test charge along the path from points N and M. Hence there is no difference in potential between these two points. Both M and N, also all points on the path are the same electric level. No work is done in moving a test charge on a circle centered on the point

charge  $q$ . The difference in potential between these points and all similar points is zero. It can be said that each circle with different radius ( $r_A$  or  $r_B$ ) have different equipotential (equal-potential) line.

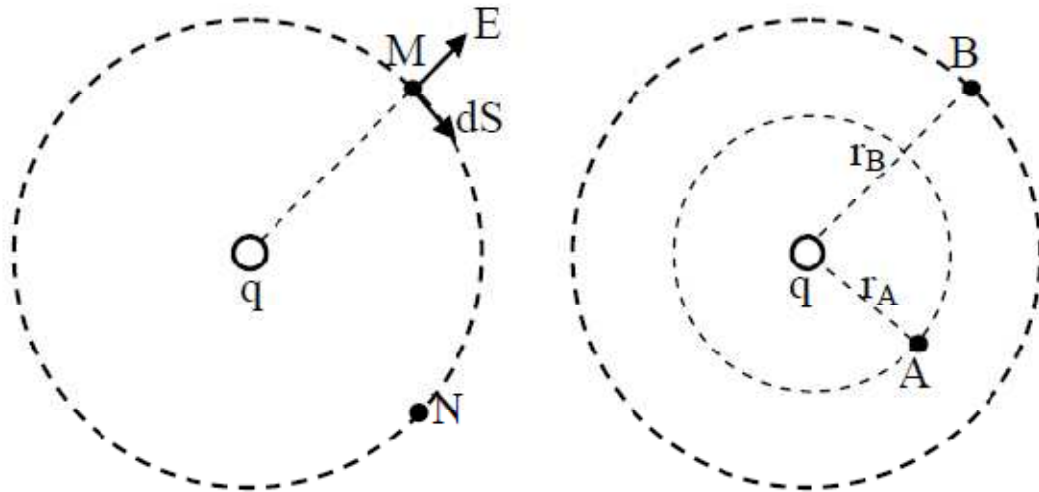


Figure 6.4: Description of equipotential lines and surfaces around a point charge.

### 3. EXPERIMENTAL PROCEDURE

Set-up the electric field-mapping apparatus circuit as shown in below Fig. 6.5.

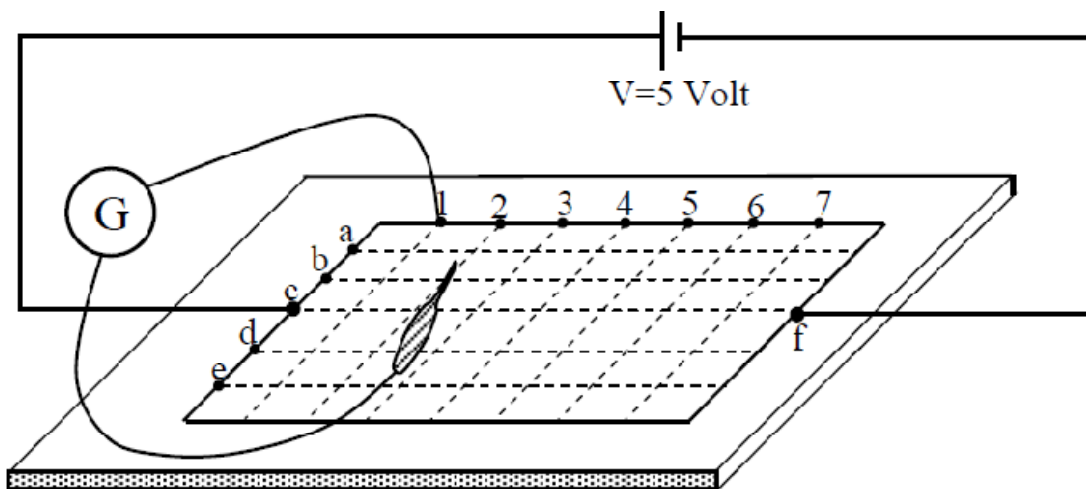


Figure 6.5: Electric field mapping apparatus circuit.

- 6.1-) Take the carbonized layer paper from your laboratory instructor.
- 6.2-) Carefully place it on the board.
- 6.3-) Adjust the power supply (DC-voltage source) to the 5 volt.
- 6.4-) Connect the end of the power supply to the point c and the other end the point F just opposite point c as shown in Fig. 6.5.
- 6.5-) Connect the one end of galvanometer to the point 1 and the other end of galvanometer is free. This free end can be clamped on the carbonized layer paper.
- 6.6-) Clamp the free end of galvanometer on the top of the paper if the needle of the galvanometer is shown zero, read this point from paper and record it. Read minimum five values in this position.
- 6.7-) Move the fixed end of galvanometer to the next point 2 and repeat step 6.6.
- 6.8-) Continue until you have a line for each of the seven possible galvanometer lead positions. Your plot should resemble Fig.6.6.

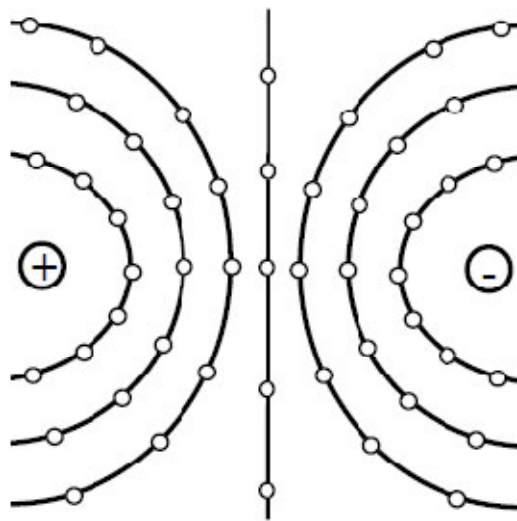


Figure 6.6: Sample plot of equipotential lines when the filed plate which simulates - two charged points - is used.

#### 4. DISCUSSIONS and CONCLUSIONS

- 4.1-) Draw a sheet which is similar to the carbonized layer paper.
- 4.2-) Plot of your data on the sheet which was obtain from your experiment.
- 4.3-) Draw this lines with a different color of pencil.
- 4.4-) How can you expected the electric field lines and compare your result by the Fig. 6.6.

**GENERAL PHYSICS**  
**PART B: ELECTRICITY and MAGNETISM**  
**EXPERIMENT – 7**  
**“RC CIRCUITS”**

### 1. PURPOSE

The purpose of this experiment is to study charging phase and discharging phase (transient phase) of a RC circuit.

### 2. THEORY

When two metal plates are connected across to the terminals of a voltage source, electrical charges move from voltage source to the metal plate. The positive charges are provided by the positive terminal and negative charges are provided by negative charges. On each plate, the electrical charges are equal to each other as shown in Fig.7.1. They are important in the electronic industry since they can be used to store electrical charges. This type of circuit elements is called capacitor.

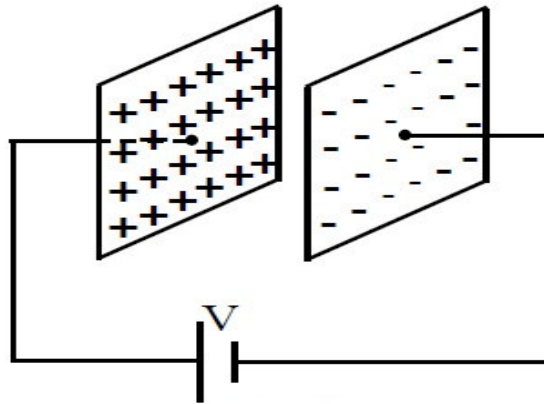


Figure 7.1: Parallel plate capacitor.

#### 2.1. Types of Capacitors

Many types of capacitors are available today. Some of the most common are the mica, ceramic, electrolytic, tantalum and polyester film capacitors.



## 2.2. Charging Phase

Fig.7.2 was designed charging phase and this circuit is called an RC circuit, because of this it involves a series resistance and capacitance combination. Assuming that at the initial case ( $t=0$ ), the capacitor is uncharged. After the switch (S) is suddenly closed the circuit at the charging phases. The electrical charges will from the battery though resistor to the capacitor. The charges should flow until the capacitor full up. For find the potential and flow charges on the capacitor, we can use Kirchoff's circuit law (loop method).

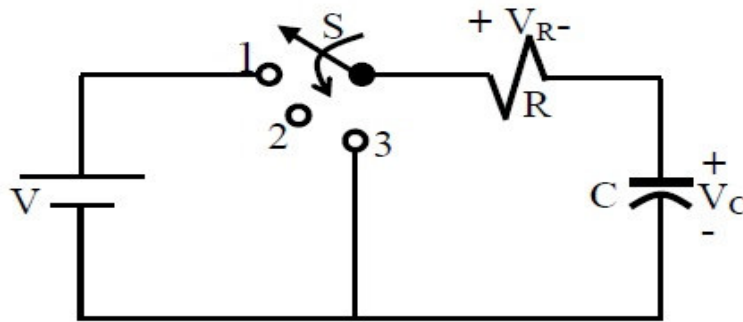


Figure 7.2: Charging phase of a capacitor.

$$V = V_R + V_C \quad (7.1)$$

where  $V_R = IR$ , then substituting this equation into Eq. (7.1)

$$I_R R + V_c = V \quad (7.2)$$

In the above paragraph, we said that charge should flow until the capacitor acquires.

$$Q = C.V \quad (7.3)$$

where C is the capacitance, VC is the potential difference between the plates of capacitor and Q is the electrical charge density on the capacitor. The current in the circuit is also written as

$$I = \frac{dQ}{dt} \quad (7.4)$$

from equations (7.3) and (7.4)

$$I_c = C \frac{dV_c}{dt} \quad (7.5)$$

The current  $I_R$  and  $I_c$  is the same for the resistor and capacitor. The Eq.(7.2) can be written as



$$C \frac{dV_c}{dt} R + V_c = V \quad (7.6)$$

Eq.(7.6) can be solved using the methods of calculus and  $V_c$  will be found that

$$V_c(t) = V(1 - e^{-t/RC})_{\text{charging}} \quad (7.7)$$

Also the current in the charging phase is given as;

$$I_c(t) = \frac{V}{R} e^{-t/\tau}_{\text{charging}} \quad (7.8)$$

The voltage across the resistor is determined by Ohm's law:

$$V_R(t) = V e^{-t/\tau}_{\text{charging}} \quad (7.9)$$

In these equations, RC product is called time constant and its unit is seconds and is shown by simply  $\tau$

$$\tau = RC \quad (7.10)$$

If the switch is moved to position 2 (Fig.7.3), the capacitor will retain its charge for a period of time determined by its leakage current. For capacitor such as the mica and ceramic, the leakage current is very small, so that the capacitor will retain its charge, and hence the potential difference across its plate, for a long period of time.

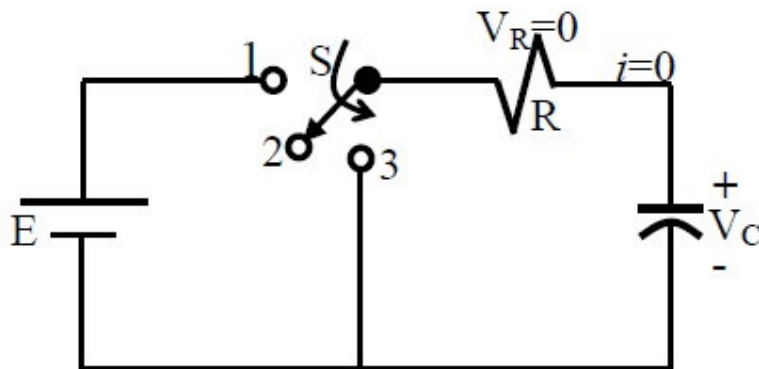


Figure 7.3: Transition phase of a capacitor.

### 3. EXPERIMENTAL PROCEDURE

3.1-) Set up the circuit below (See Fig.7.4) and then bring the switch to position 1 and then record the  $V_c(t)$  and  $I_c(t)$  at appropriate time intervals as much as possible.

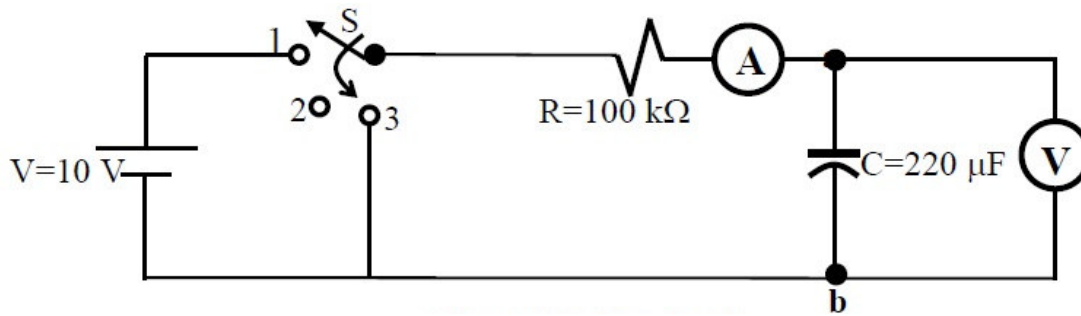


Figure 7.4: RC circuit

3.2-) After  $t=120$  sec, change the switch position to 3 and again record the  $V_c(t)$  and  $I_c(t)$  at appropriate time intervals as much as possible.

#### 4. DISCUSSIONS and COCLUSIONS

4.1-) Tabulate the all current and voltage values that you find in part 3.1 and 3.2 in Table 7.1

Table 7.1. RC Circuit (Write down the values of R and C) (R=.....Ω. ; C=.....F.)					
<u>Charging Phase</u>			<u>Discharging Phase</u>		
Time Interval (in second)	$V_c$ (in Volts)	$I_c$ (in Ampere)	Time Interval (in second)	$V_c$ (in Volts)	$I_c$ (in Ampere)

**GENERAL PHYSICS**  
**PART B: ELECTRICITY and MAGNETISM**  
**EXPERIMENT – 8**  
**“OHM’S LAW” (Series and Parallel Circuits)**

**1. PURPOSE**

To measure the resistance of a resistor by voltmeter-ammeter method (Ohm’s Methods) and also to study the voltage and current varying in simple series and parallel circuits.

**2. THEORY**

**1.1. Ohm’s Law**

A simple relationship exist between the current flowing in a circuit element, (i.e, a resistor) and potential difference (or voltage) across the circuit element. If the current is measured in amperes (A) and denoted by I, the resistance in ohm ( $\Omega$ ), and denoted by R and potential difference in volts (V) denoted by V, then Ohm’s law may be written,

$$I = \frac{V}{R} \tag{8.1}$$

By simple mathematical manipulations, if voltage and current are know, then using ohm’s law we can calculate the resistance or vica versa. If we relate Ohm’s law to the straight-line equation in the following manner.

$$\begin{aligned} V &= R.I + 0 \\ y &= m.x + b \end{aligned} \tag{8.2}$$

We find that the slope (m) of the line is determine directly by the resistance, as show in Fig.8.1.

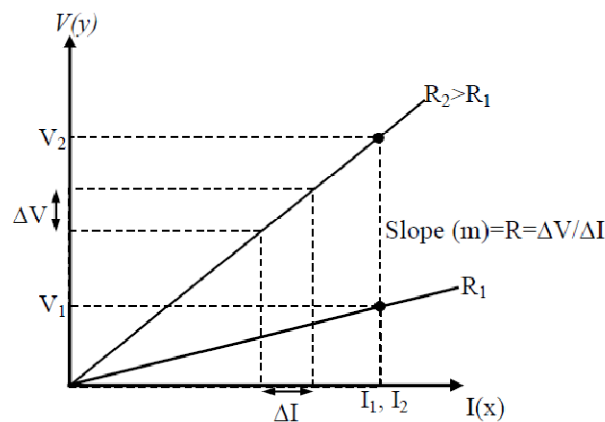


Figure 8.1: V-I graph

Note that for a voltage (ordinate) versus current (abscissa) plot, the closer the line to the vertical axis, the greater the resistance. The curve indicates that for a fixed current ( $I$ ), the greater the resistance, the greater the voltage as determined by Ohm's Law.

## 2.2. Series Circuits

A circuit consists of at least two elements and they have only one point in common that is not connected to a third element. They are providing at least one closed path through which current can flow. Such as two resistors  $R_1$  and  $R_2$  in Fig. 8.2 are in series since they have only one common point  $b$ , there is no other branches connected to this point. The voltage source ( $V$ ),  $R_1$  and  $R_2$  are therefore referred to as a series circuit.

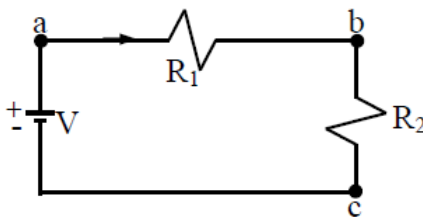


Figure 8.2: Series circuit

In series circuit to find the total resistance, simply add the values of the various resistors. If we assume there are  $N$  resistors in the series circuit, the total resistance  $R_T$  is given by the expression.

$$R_T = R_1 + R_2 + R_3 + \dots + R_N \quad (8.3)$$

where  $R_1, R_2, R_3, \dots, R_N$  are the resistances of each resistors. The current in a series circuit is constant. The current flowing from and returning to the source is the same as that flowing through any one of the circuit components, this the same current flows through all the resistance since there is no alternate path for current flow.

$$I_T = I_1 = I_2 = I_3 = \dots = I_N \quad (8.4)$$

The voltage in a series circuit is equal to the sum at all the potential drops across each component of a series circuit. The total voltage:

$$V_T = V_1 + V_2 + V_3 + \dots + V_N \quad (8.5)$$

where  $V_1, V_2, V_3, \dots, V_N$  are the voltage across each resistor  $R_1, R_2, R_3, \dots, R_N$ , respectively.

## 2.3. Parallel Circuits

Two elements or branches are in parallel if they have two points in common as shown in Fig.8.3. The resistance  $R_1$  and  $R_2$  is parallel with each other. Since each circuit element is in parallel with every other circuit elements, it is called a parallel circuit. In Fig.8.3  $R_1$  and  $R_2$  both have point  $a$  and  $b$  in common. Also voltage source is parallel to  $R_1$  and  $R_2$ .

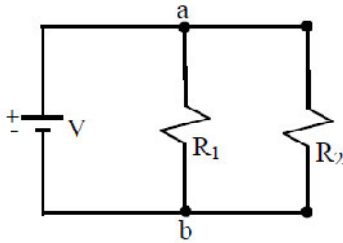


Figure 8.3: Parallel circuit

The total resistance of a parallel circuit is given by

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots \quad (8.6)$$

In words, the reciprocal of the total resistance of a parallel circuit is equal to the sum of the reciprocal of each resistor. In parallel circuit, the total resistance is always less than the resistance of any one of the alternate path. The total current in a parallel circuit is equal to the sum of the currents flowing in the each separate components.

$$I_T = I_1 + I_2 + I_3 + \dots + I_N \quad (8.7)$$

where  $I_T$  total current flowing in a parallel circuit,  $I_1, I_2, I_3, \dots, I_N$  are component currents flowing through separate resistance  $R_1, R_2, R_3, \dots, R_N$ , respectively. Each component current is inversely proportional to the resistance of that component. In a parallel circuit, the voltage is always the same across parallel elements.

$$V_T = V_1 = V_2 = V_3 = \dots = V_N \quad (8.8)$$

where  $V_1, V_2, V_3, \dots, V_N$  are the voltage across the each resistor  $R_1, R_2, R_3, \dots, R_N$ , respectively

### 3. PROCEDURE

#### 3.1. Resistance Measurement By Ohm's Method

- 1- Set up the circuit below Fig. 8.4
- 2- Connect any one resistor between points a and b.
- 3- Change the value of voltage source to 0,2,4,6,8 and 10 volts and read the current (I) and also voltage across  $R_x$  in each cases.
- 4- Remove R, connect another resistance and repeat step 3.

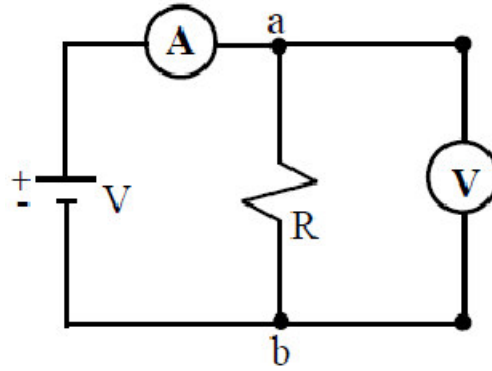


Figure 8.4: Connection of ammeter and voltmeter on an electric circuit

### 3.2. Series Circuit Measurement

Set up below circuit Fig. 8.5.

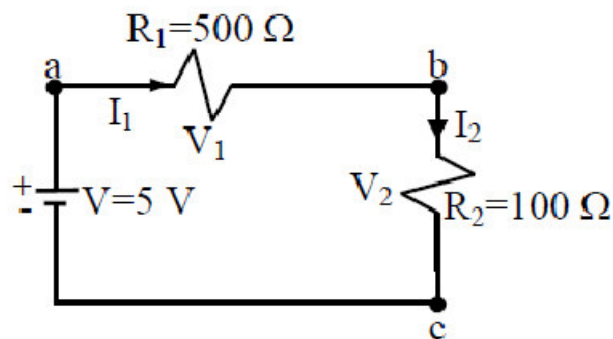


Figure 8.5: Series circuit measurement

- 1- Measure the current  $I_1$  and  $I_2$  flowing through each resistor as shown in Fig. 8.5.
- 2- Measure the voltage across each resistor,  $V_1$  and  $V_2$ .
- 3- Remove voltage source and connect ohmmeter with respect to voltage source and read the value of total series resistance of Fig. 8.5.
- 4- Finally remove  $R_1$  and  $R_2$  measure the resistance of each resistor separately by using ohmmeter, respectively.

### 3.3. Parallel Circuit Measurement

Set up the circuit shown in below Fig. 8.6.

- 1- Measure the currents,  $I_T$ ,  $I_1$  and  $I_2$  flowing through each resistor.
- 2- Measure the voltages  $V_1$  and  $V_2$  across each resistor.
- 3- Remove voltage source and connect ohmmeter with respect to the voltage source and measure the total resistance.
- 4- Again separate  $R_1$  and  $R_2$  and measure resistance of each resistor using an ohmmeter.

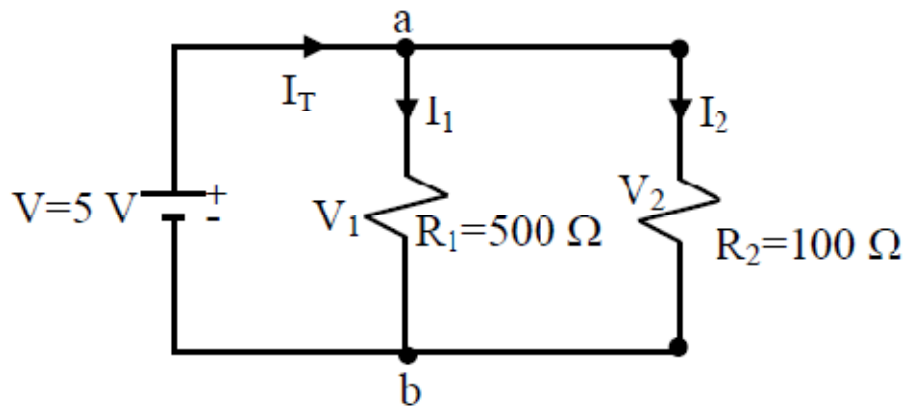


Figure 8.6: Parallel circuit measurement

#### 4. DISCUSSIONS and CONCLUSIONS

4.1)- In part 3.1; plot the values of  $V$  and  $I$  on a graph paper respectively. Fit a straight-line to the plotted points (see Fig.8.1) and obtain the value of  $R$  from the graph by using Eq.8.2. Repeat this step for also other resistor.

4.2)- In part 3.2; tabulate the resistance value of total resistance, separately and also currents and voltages for each resistor into a table. Calculate the resistance of each resistor by using Eq.8.1 (Ohm's Law) and also calculate total resistance of circuit Fig.8.5 by using Eq.8.3.

4.3)- Repeat 4.2 for part 3.3 only calculate total resistance of circuit Fig.8.6 by using Eq.8.6.

**GENERAL PHYSICS**  
**PART B: ELECTRICITY and MAGNETISM**  
**EXPERIMENT – 9**  
**“MAGNETIC FIELD”**

**1. PURPOSE**

To examine the mapping of magnetic field in two dimensional region.

**2. THEORY**

In the Exp.6, we have learned the electric field. In this experiment, we are concerned the other field called as the magnetic field. The phenomenon of magnetism has been observed and studied for about two thousand years. The knowledge of magnetism and magnetic fields has been developed by Coulomb and Oersted.

The most easily a magnet much of our qualitative terminology concerning magnetic fields in terms of bar magnets. A magnetic field in the space around a magnet in which its magnetic influence can be detected. Therefore, we often speak of magnetic fields in terms of bar magnets. The other type of magnet is known as U magnet, as seen in Fig. 9.1. There are two poles of a bar and U magnets. These are defined as north pole and south pole. The north or south poles of magnets repel each other. The south pole of a magnet is always attracted by the north pole of another magnet.

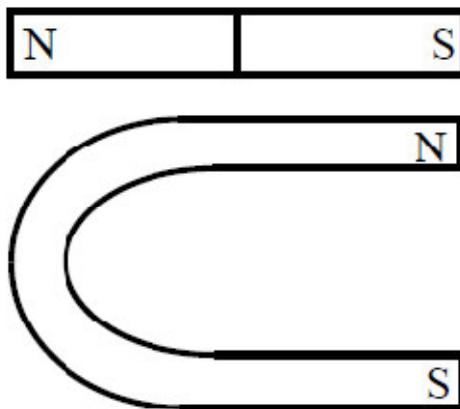


Figure 9.1: U and Bar Magnet.

The two most common detectors used for studying the nature of a magnetic fields are iron filings and the magnetic compass. The magnetic fields are easily plotted by means of compass needles and is capable of indicating the direction of a magnetic field. We can therefore determine the direction of the magnetic field at any point observing the orientation of a small compass needle placed at the point as the direction of compass in which shows the north pole of compass.



If one should move a small compass from point to point, by letting the north pole of the needle dictate the direction to be moved the path resulting from this motion would reveal the direction of the field at all points along which it moved. A line which indicates the direction of a magnetic field at every point is called line of force. This is shown in Fig.9.2.

Notice that the field lines emerge from the north poles and enter south poles. The magnetic field of the earth is always present and also the earth acts like a huge magnet with the magnet's north pole being near the position of the earth's south pole. The earth's geographic north pole is near its magnetic south pole.

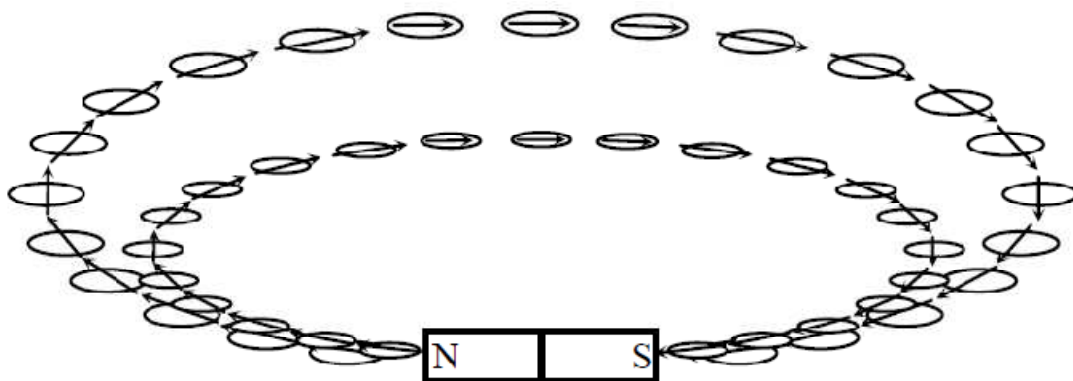


Figure 9.2: A compass needle points in the direction of magnetic field.

When more than one magnet is placed in a particular region, the individual magnetic fields are superimposed upon each other and a compass needle placed in the region will indicate the direction resulting from the interaction of the fields. Since a magnetic field has both magnitude and direction, the resulting field intensity at each point in the field is the vector sum of the components at that point. In order to provide a magnetic field resulting from the interaction of two or more magnets, we shall improvise a magnet board by taping two or more magnets to the under side of a cardboard.

### 3. EXPERIMENTAL PROCEDURE

3.1-) Determine the north-south line of the earth's magnetic field by means of the magnetic compass needle. Be sure that bar magnet and all other pieces of iron are removed from near compass needle during this section of experiment.

- 3.2-
- a-) Place the slotted magnet board on the table.
  - b-) Replace the bar magnet to the slot of board. Attention that the slotted magnet board is parallel to the earth's field and also the long axis of the bar magnet is parallel to the direction of earth's fields in which the north pole of magnet directed toward the south.
  - c-) Cover a large sheet of paper on the board.
  - d-) Outline the position of the bar magnet on sheet. Identify polarities of bar magnet and write the north and south poles of bar magnet on the sheet. Also mark the position

and direction of sheet. At this position; do not change the position of slotted magnet board, magnet and also sheet.

e-) Slowly sprinkle a little iron filings on the paper. Again be sure that there are no any other magnets near slotted board.

f-) You tick one end of the sheet to very well arrange of iron filings.

g-) Sketch very slowly lines of force with a pencil without touching iron filings which make up the magnetic fields lines as indicate by the shape of the iron filings.

#### **4. DISCUSSIONS and CONCLUSIONS**

4.1-) Make careful sketches of the field between the bar magnets (N to S) and also between the poles of U-magnet. Indicate the direction of the lines of force by arrowheads.

4.2-) After you have mapped the lines of force of the magnetic field, draw in the equipotential lines using another colored pencil.