Lab 7
Electric Field Mapping

Learning Goals:

- to determine the shape of the electric field in the vicinity of two charge configurations (oppositely charged parallel strips) using conductive paper and a voltage probe.

Apparatus:

PART I: **Mapping the Electric Field**

Qty	Instrument	Instrumental Error	Instrumental Resolution
1	GLX with voltage sensor probes	± 0.020 volts	± 0.005 volts
1	Equipotential and Electric Field Mapper Kit		
1	Power Supply, 15 VDC		
1	paper copy of conducive paper		
1	Tape, stickpins, pencil, colored pen		

PART II: **Mapping the Magnetic Field Around A Permanent Magnet**

Qty	Instrument	Instrumental Error	Instrumental Resolution
1	PASCO Interface (for two sensors)		
1	Magnetic Field Sensor mT	± 0.1%	± 0.005 volts
1	Rotary Motion Sensor	± 0.1%	± 0.005 volts
1	Linear Motion Accessory		
1	Magnet, disk, Neodymium, 0.125" diameter		
1	Zero Gauss Chamber		
1	Recording paper with angular indications		
1	Small magnetic compass	± 3%	

NOTE: During this experiment, keep the magnet away from the computer and from computer disks and other sensitive electronic or storage devices.

Theory:

Electric Field

A field is a region in space where a particular phenomenon is observed and is effects can be measured in physical quantities and units. An electric field exists in a region when a charged object experiences a force on it with a magnitude and direction that varies with its position in the field. An electric field is the effect produced by the existence of an electric charge, such as an electron, ion, or proton, in the volume of space or medium that surrounds it. Another charge placed in the volume of space surrounding the "source" charge has a force exerted on it. The electric force applied by two charges on each other can be obtained from Coulomb's law:

$$\textbf{(EQ1)}\quad F_e = k\frac{q_1 q_2}{r^2}$$

Instead of focusing on the two specific charges q_1 and q_2, we can instead draw an electric field in the space around q_1 that will describe how any other charge will react when placed within this space. Thus, electric fields serve as a more general representation of electric charges and the spaces around them.

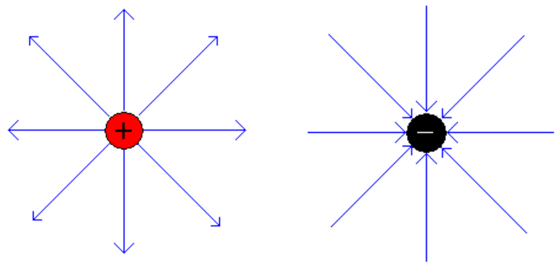
The electric field, **E**, is a vector that measures the electrostatic forces, $\mathbf{F_e}$, felt by a second charge, $\mathbf{q_2}$, placed at some point in space around the initial charge, $\mathbf{q_1}$. In other words:

$$\textbf{(EQ2)}\ \mathbf{E = F_e/q_2 = Kq_1/r^2}$$

where

$\mathbf{E}$ ≡ "electric field strength"
$\mathbf{F_e}$ ≡ "electrostatic force felt by $\mathbf{q_2}$"
$\mathbf{q_2}$ ≡ "charge placed in surround space of $\mathbf{q_1}$"
$\mathbf{K}$ ≡ "electrostatic constant" = 9×10^9 [Nm^2/C^2]
$\mathbf{q_1}$ ≡ "initial charge"
$\mathbf{r}$ ≡ "distance between $\mathbf{q_1}$ and $\mathbf{q_2}$"

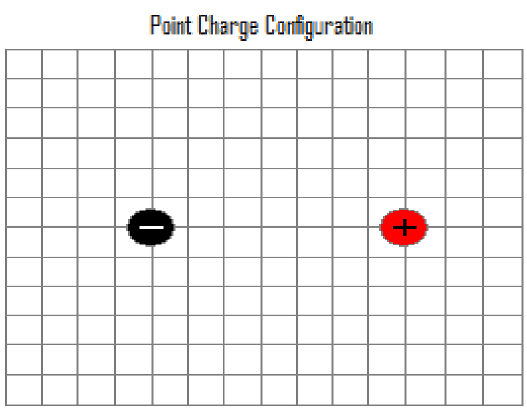
Equation **[EQ2]** only represents the electric field strength at a single point. However, the electric field exists in all the space surrounding the initial charge. When drawing an electric field emanating from an object, the electric field vectors represent which way a <u>positive</u> charge would accelerate due to Coulombic forces if it was placed in the field. The diagram below shows the electric field surrounding a positive and negative charge.

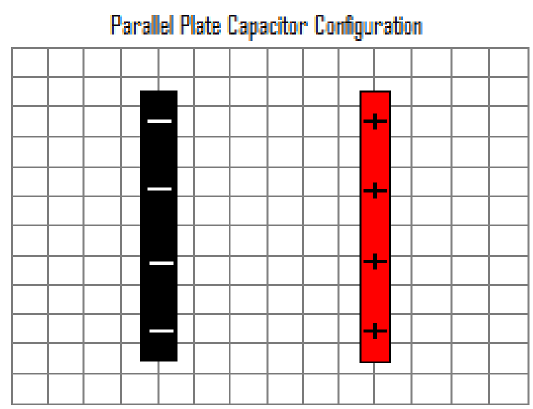


Notice how the blue *electric field lines* represent how a <u>positive</u> charge would react if placed somewhere within that field. For the initial <u>positive</u> (red) charge, they point away from the charge, representing the <u>repulsive</u> Coulomb force that would push the second positive charge away from the first.

For the <u>negative</u> (black) charge, the electric field lines point into the initial charge. This makes sense, because a positive charge placed in that field would feel <u>attractive</u> forces, causing it to accelerate towards the negative charge.

The two electric fields above are the fields surrounding *point charges*, or tiny spots of charge. The electric field strength of point charges has the same *inverse-square of distance* relationship as Coulomb's Law, because they both deal with point charges. As you know, larger objects with excess charges have an overall net charge. These objects create their own unique electric field lines which may differ from those above. Some of these other charged objects include spheres of charge, finite and infinite lines of charge, planes of charge, loops of charge, and several others, each with their own electric field lines surrounding them.



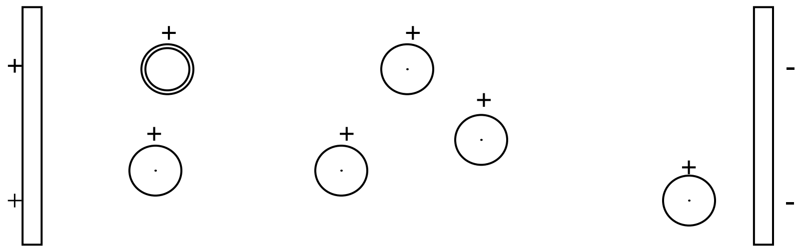


One important electric field configuration you will use is called the *parallel plate capacitor*, which is simply two oppositely charged finite lines of charge separated by a specific distance. One important aspect of the electric field inside the parallel plate capacitor is that the field is *uniform*, or constant. For point charges, the further away from the initial charge that you place your second charge, the weaker the electric field will be. For a parallel plate capacitor, however, no matter where you place a charge within the field, it will accelerate the same way and at the same rate. You will soon see in lecture the importance of creating a uniform electric field.

Your goal in this lab is to use a voltmeter to measure the greatest voltage difference between two points in space of a few charge configurations, and use that information to draw electric field lines like in the picture above. You will be examining point charges (two charged washers) and a parallel plate capacitor (two charged finite lines), and draw the electric field lines for each.

Prelab:

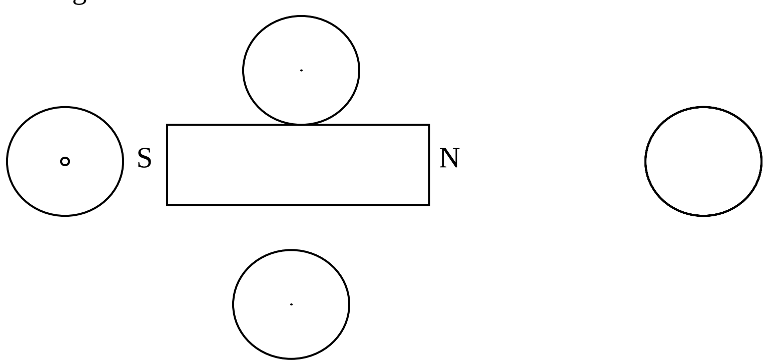
#1 Indicate within the region between the two charged strips, the direction of the electric force acting on the charged sphere at that location. Use an arrow inside each circle.



#2 Indicate inside each circle with a number from one to ten the intensity of the electric force in that region between the parallel charged strips.

#3 Use the graph below to sketch the electric force (y-axis) vs the distance (x-axis) between the parallel charged strips (use the left strip as 0.0 cm and the right strip as 10.0 cm.

#4 Draw inside each circular compass below an arrow indicating the direction of the magnetic field in the region surrounding the bar magnet.

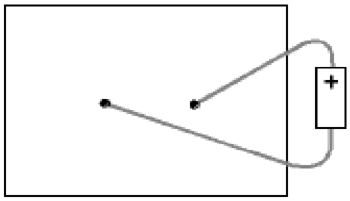


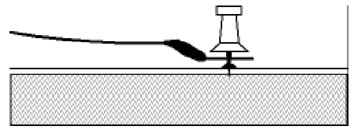
#5 Indicate within each circular compass with a number from one to ten the intensity of the magnetic force in that region surrounding the bar magnet.

#6 Use the graph below to sketch the magnetic force (y-axis) vs. the distance (x-axis) from the North pole of the magnet (use 0.0 cm as the North pole face and plot to 10.0 cm. toward the right away from the pole face.

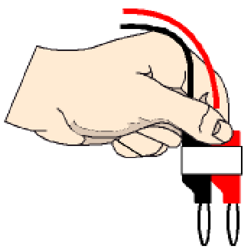
Procedure: Mapping the Electric Field

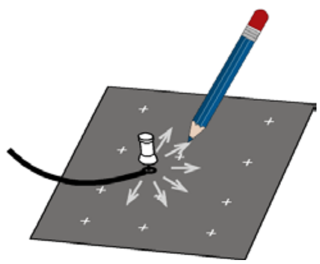
1. Use the GLX in digits display mode. Connect the Voltage Sensor to the GLX.
2. Secure conductive paper with a drawn figure to a flat piece of cork using pushpins.



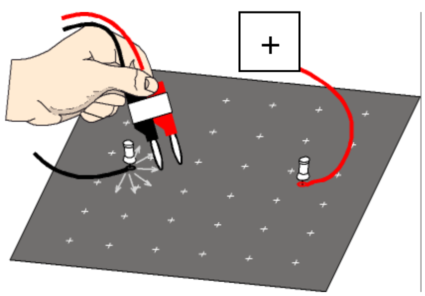


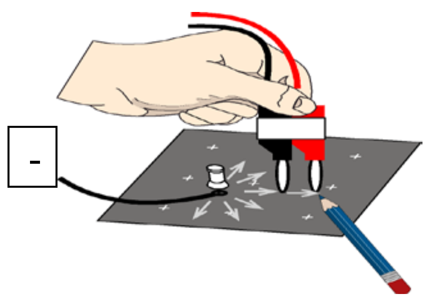
3. Make sure the power supply is “off”. Use a pushpin and **black** wire to connect the left charged conductor to the negative terminal of a DC power supply.
   Connect the right charged conductor to the positive terminal with a **red** wire. Use a pencil to label the two conductors as “**-**” (negative) and “+” (positive) on the **paper copy** of the conductive paper.





4. The ends of the voltage leads of the Voltage Sensor should be taped together so that the two tips are a fixed distance apart.
5. Use the pencil to draw several arrows on the paper copy **pointing away from** the “**-**” (negative, black) charged conductor as shown. (<u>Make the arrows as long as the distance between the tips of the voltage leads</u>.)
6. Remember to read the recording data procedure before you begin. Data recording is easier if a person handles the voltage leads of the Voltage Sensor and a second person monitors the voltage readings.



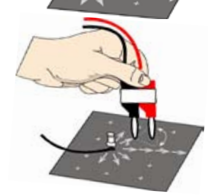


7. <u>For all the voltage measurements</u>, follow the same basic steps.

A. Turn on the power supply and adjust the voltage to 10 volts. Hold the voltage leads at an angle so the tip of the black voltage lead touches the conductive paper. Start with the black probe touching the negative conductor drawn on the conductive paper through which the pushpin is fixed. Do not let the tip of the red voltage lead touch the paper. *Note touch the tip of the voltage leads only on the solid black areas of the conductive paper. Do not touch the grid marks or lines on the paper*.

B. Tilt the red voltage probe downward so both tips touch the conductive paper simultaneously. Keep the black tip stationary but *slowly pivot the red tip side-to-side*. As you move the red tip, the voltage in the display. When the displayed voltage is the highest, stop moving the tip of the red voltage lead.

C. Draw an arrow on the paper copy of the conductive paper from the tip of the black lead to the tip of the red lead.



D. Move the tip of the black lead to the head of the new arrow.

E. Repeat the action by moving the tip of the red lead from side-to-side until the new voltage is at its highest value. Draw an arrow in the direction of the highest voltage. Continue this procedure all the way across the paper to the other charge.

F. Move the voltage leads back to the negative pushpin and select a new point near the pushpin at which to place the tip of the black lead. Continue the process of drawing arrows in the direction of the highest voltage until your new set of arrows forms another distinct line. Map about 5 or 6 lines. Use a pencil to fill in the lines between the arrows on the paper copy. Label these lines as **electric field lines.**

G. Attach one end of a jumper wire to the black lead of the voltage probe and attach the other end of the jumper wire to the pushpin marked negative. Without touching the black voltage probe to the conductive paper, move the red probe over the conducting paper noting locations of equal potential indicated by the Digits display. Mark these locations on the paper copy (P_1, P_2, P_3, etc), connecting equal potential points with a smooth line using a different color pencil. Label these different lines **equipotential lines**. Record along each equipotential line its voltage value.

H. The electric field and equipotential lines should be perpendicular to each. If they are not, check the measured values for accuracy.

I. Calculate the magnitude of the electric field at several locations (P_1, P_2, P_3, etc.) on the electric field lines and note their values on the electric field lines of the paper copy of the conductive paper. The magnitude of each electric field line can be calculated using $E = \Delta V/d$, where $\mathbf{\Delta V}$ is the potential difference between two consecutive equipotential lines and **d** is the distance between the lines measured in meters. The unit for E is nt/coulomb or volt/meter.

J. Record the measured and calculated values in the data table in the notebook. Tape the paper sheet copy of the conductive paper in the notebook.

K. Turn off the power supply.

Part I Mapping the Electric Field

Data: (record in notebook)

1. The paper copy of the conductive paper should include the charge location, polarity, mapped electric field lines with several magnitudes, mapped equipotential lines with several magnitudes.
2. Use the table below to record two sample calculations of the electric field intensity E:

Point 1 Coordinates (x, y)	Point 2 Coordinates (x, y)	Point 1 potential (volts)	Point 2 potential (volts)	ΔV_{12} (volts)	Separation (meters)	E_{12} (nt/coul)
(,)	(,)					
Point 3 Coordinates (x, y)	Point 4 Coordinates x, y	Point 3 potential (volts)	Point 4 potential (volts)	ΔV_{34} (volts)	Separation (meters)	E_{34} (nt/coul)
(,)	(,)					

3. Use the overall pattern of the map of the electric field to complete the following items (with as much detail as possible):
   A. The overall shape of the electric field mapped is ________________________.
   B. The shape of the electric field around an isolated electric charge is _________.
   C. The shape of the electric field if there are two unlike charges near each other is
   ____.

Mapping The Magnetic Field In The Region Of A Permanent Magnet

Learning Goals:

- to measure the magnitude of the magnetic field in the region of a small neodymium magnet as the distance from the magnet increases.
- to use a small magnetic compass to map the direction of the magnetic field in the region around a small neodymium magnet.
- To use a Magnetic Field Sensor on a Rotary Motion Sensor to measure the magnitude and direction of the Earth's magnetic field

Apparatus

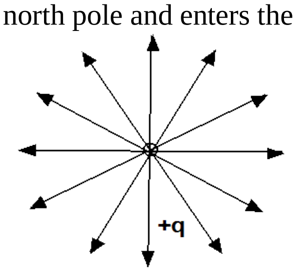
Qty	Instrument	Instrumental Error	Instrumental Resolution
1	GLX data logger and connecting cable	± 1%	
1	Magnetic Field Sensor (two axes) (G)	± 5%	0.01 G
1	Rotary Motion Sensor	± 5%	1 degree
1	Zero Gauss Chamber		
1	Dip Needle	± 5%	1 degree
1	Adjustable Non-Magnetic Angle Clamp		
1	Angle Indicator	± 5%	1 degree
1	Universal Table Clamp		
1	45-cm Stainless Steel Rod (non-magnetic)		
1	Extension Cable		

Background

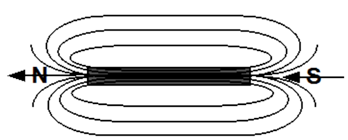
A magnetic field exists in a region where a magnetic material experiences a force on it with a magnitude and direction which varies with its position in the field.

The strength of a magnetic field varies with distance from the magnet. The strength of the magnetic field could vary inversely as the square of distance, as with the strength of a gravitational field or an electrical field. The strength of the magnetic field could vary in a different way relative to distance.

The gravitational field or electric field of a point mass or charge is radial, while the magnetic field of a magnet consists of complete loops that surround and go through the magnet. Note that the direction of the magnetic field exits from the north pole and enters the south pole.



ELECTRIC FIELD LINES



MAGNETIC FIELD LINES

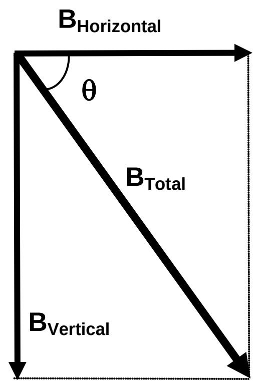
When a moving charged object has a component of its velocity in a direction perpendicular to the direction of the magnetic field, then that charged object experiences a force on it with a magnitude and direction that varies with its velocity and position in the field.

A magnetic compass acts as a detector of a magnetic field because the magnetic field of the compass needle interacts with the magnetic field in question and the needle orients itself parallel to the direction of the magnetic field.

A compass needle can be used to draw magnetic field lines in the vicinity of a permanent magnet by connecting the dots indicating the North and South poles of the compass, and then moving the compass to a new location so that one dot of the next set coincides with one of the dots of the previous location.

If the magnetic field strength of the permanent magnet is much greater than the magnetic field strength of the earth, the direction that the compass needle points will be the vector addition of the magnet's and earth's magnetic filed, which vector addition will closely approximate the magnetic field of the disk magnet when the compass is within a 30 cm radius of the magnet.

A magnetic field sensor will measure both the magnetic field of a permanent magnet and the magnetic field of the earth. If the field is indeed a description of the force experienced by a magnetic material (a metal ball or a compass needle in a particular location in space), the sensor will be measuring the net force on a magnetic material due to the earth and any magnets in the vicinity of the location.



The force on a magnetic material due to the magnetic properties of the earth will, as a force, have a vector description. The sensor can be used to find the magnitude and direction of the magnetic field of the earth if the magnetic field probe has a specific direction of measurement. The sensor used in this experiment measures magnetic field intensity from a direction directly in front of it along its axis. As the magnetic field sensor is pointed toward geographic North (the north end of a compass needle is attracted to the south end of the Earth's magnetic field) the sensor measures a negative value. So the pole that is referred to as "geographic North" is actually a south magnetic pole.

The magnitude of the Earth's field varies over the surface of the Earth. The horizontal component of the Earth's magnetic field points toward magnetic South. The total field points at an angle from the horizontal. An example for the Northern hemisphere is shown in the figure above. If the Earth's magnetic field is a vector, it can be resolved into vertical and horizontal components. The typical compass aligns itself with the horizontal component of the earth's magnetic field and a detector aligned along the dip angle would be measuring the Earth's total magnetic field, if the axis of the dip angle were aligned with that horizontal component. If this be accurate, the relationship between the dip angle and the field vectors will be given by $\cos \theta = B_{horizontal}/B_{total}$

Procedure A: Determine The Direction

1) With the permanent disk magnet in the fixed position of the angle marked paper and with the 180 degree mark facing magnetic North (the north pole of the disk magnet will be oriented toward the magnetic south pole of the earth, see procedure 7), place a magnetic compass on the angular paper. The direction of the compass needle indicates the direction of the magnetic field lines at any point in the region of the permanent magnet, without indicating the intensity of the field at that point along the particular field line.
2) Begin plotting the magnetic field lines of the permanent magnet by placing the compass close to the north pole of the disk magnet. Place a pencil dot at the tip of the compass needle, then move the compass so that the tail of the needle rests on the pencil dot.
3) Mark a new pencil dot at the tip of the compass needle and again move the compass so its tail rests on this new dot. Map the field then by connecting the dots in a smooth curve. Select another starting point for the compass and map the second magnetic field line of the disk magnet.
4) These magnetic field lines indicate direction only; to determine the magnitude iof the field at any point, the sensor can be placed at the point and the value recorded from the sensor. Use the sensor data from the corrected equation of fit in Data A above. Note, the fit is not accurate for positions very close to the face of the magnet. Assign magnitudes along the field line directed from the north pole of the permanent magnet for ten different separation distances. Record these values on the paper used to map the field in procedures 16) – 17)
5) Describe quantitatively the magnitude and direction of the magnetic field lines in the vicinity of the disk magnet.

Data (permanent magnet field lines: direction only)

A. Attach angle paper with magnetic field dots connected with smooth curves. Use arrow heads on the lines indicating exiting the North Pole and entering the North Pole. Attach paper to notebook with clear tape, not staples.

Procedure B: Determine The Magnitude

1) Connect the Magnetic Field Sensor into the GLX and use the cable to connect the Rotary Motion Sensor into the GLX. Use the USB cable to connect the GLX into the computer.
2) Open the *DataStudio* file: 78 Permanent Magnet.ds. This *DataStudio* file has a Graph display of Magnetic Field versus Distance and a Digits display of Magnetic Field (in mT). Data collection rate is 10/sec.

3) If the Magnetic field sensor has an AXIAL switch on top of the sensor, select AXIAL. Also select 100X on the Range Select switch. If the Magnetic Field Sensor has a TARE button on top, press it to zero the sensor.
4) Mount the Magnetic Field Sensor on the linear accessory so that the tip of the sensor is horizontal and travels straight along the direction of the accessory track.
5) Place a compass on a flat surface far from any magnets or metal objects. Note the direction of the North pointing compass needle. This indicates the direction of the earth's magnetic field, B_E. Select 'Monitor Data' from the Experiment menu and observe the reading in the Digits display. **Orient the track so that the sensor reads the largest <u>negative</u> value and faces the south magnetic pole of the earth—where the compass needle indicates geographic North.)** Record this largest negative value in the Data Table.
6) Indicate on angular graph paper, 0, 90, 180, 270 degrees and tape it to a non-magnetic board, and orient the graph paper so that the 0 degree mark faces the magnetic South of the earth indicated by the compass needle and the magnetic field sensor. **For the remainder of the experiment, maintain this paper orientation.**
7) Attach the disk magnet at the center of the angular graph paper so that the north pole of the disk magnetic is pointing toward the 0 degree location. Locate the angular graph paper along the track so that the north end of the magnet is facing the sensor. If all of the above were done correctly, the Magnetic filed sensor reading will be positive and the sensor will be pointing toward the 180 degree mark on the angular graph paper; also the 180 degree mark will be facing magnetic North (geographic South)
8) Click 'Stop' to stop monitoring data. (NOTE: If the reading is higher than the sensor can read, switch the Range Select to 10X.) Turn the pulley on the linear track so that the sensor is very close to the disk magnet and can be drawn away 40 cm with additional rotations of the pulley
9) Click 'Start' to begin recording data. Slowly and smoothly turn the pulley on the topof the Rotary Motion Sensor so the tip of the Magnetic Field Sensor moves away from the magnet in a straight line. When the field strength drops close to zero, click 'Stop' to end data recording.
10) Examine the graph of the magnetic field strength versus distance. Rescale the Graph display to fit the data if necessary. Next, click the 'Fit' menu button and select 'Inverse Square'.
11) Examine the information in the 'Inverse Square Fit' window in the graph display. (NOTE: If the 'Mean Squared Error' is large, click and drag the mouse to select a region of the data. When you release the mouse, the selected data points will be highlighted.)
12) Double click the 'Inverse Square Fit' window to open the 'Curve Fit' window. Record the equation of fit, the Scale Factor (A) and the offset in the data table.
13) Print the graph of Magnetic Field versus Distance, noting in the title that the magnetic field intensity is measured along a magnetic field line perpendicular to the North face of the permanent magnet. Record the Data Table in the notebook and tape the graph in the notebook.
14) If procedures 5) and 6) were conducted as described, the magnetic field probe data includes the maximum horizontal component of the eqrths magnetic field. To correct for this environmental effect, subtract the horizontal component of the earth's magnetic field from the offset and record the equation of fit corrected for the environment's magnetic field of the earth. Record this corrected equation in the data table below in the notebook

Data : (<u>permanent magnet field intensity as a function of the straight line distance from the North pole face of a permanent magnet)</u> (record in notebook)

B. 1. Table

Largest horizontal component of earth's magnetic field	265 milliGauss
Largest value of earth's magnetic field @ 53.5 degree dip angle	446 milliGauss
Equation of Fit	
Scale Factor (A)	
Offset	
Corrected equation of fit	

B. 2. Analysis:

a) Offer evidence to indicate whether the magnetic field strength increases or decreases as the distance from the magnet is increased _______________.

b) Offer evidence whether or not the relationship between magnetic field strength and distance is linear____.

c) Based on the results of the curve fit in the statistics area, describe the relationship between the magnetic field strength and the straight line distance from the magnet ____.

Part III: Measuring the earth's Magnetic Field

NOTE: During this experiment, keep all sources of magnetic fields (electrical, computers, computer interface, bar magnets) away from the apparatus. Also keep all ferromagnetic materials (iron, steel chairs and tables) away from the apparatus.

Procedure: Measuring the Horizontal Component of the Earth's Magnetic Field

1) Connect the Magnetic Field Sensor into the GLX and use the cable to connect the Rotary Motion Sensor into the GLX. Use the USB cable to connect the GLX into the computer.
2) Open the *DataStudio* file: **77 Earth Mag Field.ds**. This file has a Graph display and a Digits display of "B Field" (in gauss) and Angular Position (in degrees).
3) Attach the Adjustable Angle Clamp to the end of the Rotary Motion Sensor. Clamp the Universal Table Clamp to the table and mount a nonmagnetic stainless steel rod in the table clamp. (The table clamp is mostly aluminum.) Attach the Rotary Motion Sensor to the support rod.
4) Screw the handle onto the bottom of the Magnetic Field Sensor. Align the key in the hollow handle with the slot on the Rotary Motion Sensor shaft and slide the Magnetic Field Sensor onto the Rotary Motion Sensor shaft

5) Put the three-step pulley on the side of the Rotary Motion Sensor that is opposite to the Magnetic Field Sensor. (This pulley will be used to rotate the Magnetic Field Sensor by hand.) Put the o-ring on the largest step of the pulley.
6) Slide the Angle Indicator onto the end of the Rotary Motion Sensor, orienting it away from the Magnetic Field Sensor so it won't be in the way when the Magnetic Field Sensor is rotated. Remove the screw and nut from the Angle Indicator because they are ferromagnetic and will interfere with this experiment.
7) Set the Magnetic Field Sensor's gain switch to x100. Set the sensor's direction switch on AXIAL to measure the magnetic field aligned with the sensor probe.
8) To measure the horizontal component of earth's magnetic Field:
    a. Allow the Magnetic Field Sensor to rotate in a horizontal circle by adjusting the Rotary Motion Sensor clamp so the angle indicator reads 90 degrees with the Magnetic Field Sensor on top.
    b. Put the Dip Needle in its horizontal orientation and position the Dip Needle directly below the Rotary Motion Sensor. Align the magnetic field sensor so that it points in the same direction as the compass needle. Remove the Dip Needle so its magnetic field won't interfere with the experiment.
    c. Rotate the Magnetic Field Sensor ninety degrees to the right so the probe is perpendicular to the direction of the Earth's field as was indicated by the compass needle. Slip the Zero Gauss Chamber over the Magnetic Field Sensor probe and press the tare button on top of the Magnetic Field Sensor. This will ensure that the maximum on the Magnetic Field Sensor will not be exceeded during the experiment.
    d. With the Magnetic Field Sensor still aligned as in procedure 8 c), click '*Start*' in *DataStudio*. Slowly and steadily rotate the Rotary Motion Sensor pulley toward the initial direction and then continue ninety degrees past it. If negative angles are recorded by the rotary motion sensor when at the left of center, repeat 8) with the magnetic field sensor probe pointing to the left. Click '*Stop*'
    e. To eliminate magnetic noise from electrical circuits, enter a smoothing factor into the *DataStudio* calculator. [For example, try B = smooth(8,smooth(8,x))]. Click 'Accept' in the calculator window. You should see the graph update with smoother data.

9) Examine the graph of magnetic field intensity (Gauss) vs. angle (degrees). The maximum intensity should occur when the magnetic field probe was pointing in the same direction as the horizontal compass needle. The probe is designed to respond to the magnetic field which enters it parallel to its length. Repeat data collection if necessary.

Measuring the Horizontal Component of the Earth's Magnetic Field Data (record in notebook)

	Minimum intensity left of center	Maximum intensity	Minimum intensity right of center
Theoretical	0.000 (Gauss) @ -90.0 (degrees)	0.265 (Gauss) @ 0.0 (degrees)	0.000 (Gauss) @ +90.0 (degrees)
Experimental	_______(Gauss) @ (degrees)	_________(Gauss) @ (degrees)	_________(Gauss) @ (degrees)

10) Align the Magnetic field sensor so that it points in the direction of the maximum intensity of the horizontal component of the Earth's Magnetic Field found in the Data Table of Part III. Allow the Magnetic Field Sensor to rotate in a vertical circle by adjusting the Rotary Motion Sensor clamp so the angle indicator reads zero degrees with the Magnetic Field Sensor on the side
11) Position the dip needle directly below the Rotary Motion Sensor. Put the dip needle in its vertical orientation and align it so that its support is pointing in the direction of the maximum intensity of the horizontal component of the Earth's Magnetic field.
12) Note the direction of the compass dip needle and align the magnetic field sensor so that it points in the same direction as the compass dip needle. Remove the dip needle so its magnetic field won't interfere with the experiment.
13) Rotate the Magnetic Field Sensor ninety degrees above the dip angle position so the probe is perpendicular to the direction of the Earth's field as was indicated by the compass dip needle. Slip the Zero Gauss Chamber over the Magnetic Field Sensor probe and press the tare button on top of the Magnetic Field Sensor. This will ensure that the maximum on the Magnetic Field Sensor will not be exceeded during the experiment.
14) With the Magnetic Field Sensor still aligned as in procedure 13), click '*Start*' in *DataStudio*. Slowly and steadily rotate the Rotary Motion Sensor pulley toward the initial direction of the dip needle and then continue ninety degrees below it. If negative angles are recorded by the rotary motion sensor when above the dip angle, repeat 13) with the magnetic field sensor probe pointing ninety degrees below the dip angle. Click *'Stop'*
15) To eliminate magnetic noise from electrical circuits, enter a smoothing factor into the *DataStudio* calculator. [For example, try B = smooth(8,smooth(8,x))]. Click 'Accept' in the calculator window. You should see the graph update with smoother data.
16) Examine the graph of magnetic field intensity (Gauss) vs. angle (degrees). The maximum intensity should occur when the magnetic field probe was pointing in the same direction as the compass dip needle. The probe is designed to respond to the magnetic field which enters it parallel to its length. Repeat data collection if necessary. Record the data from the graph in the first table below in the notebook.
17) Use the experimental values of the horizontal component and the total magnetic field to calculate experimental value of the dip angle: $\cos\theta = B_{horizontal}/B_{total}$. Record the experimental values in the second table below in the notebook.

Part III Measuring the Total Magnetic Field of the Earth

Data (record in notebook)

Table #1

	Minimum intensity above center	Maximum intensity	Minimum intensity below center
Theoretical (horizontal being 0.0 degrees)	0.000 (Gauss) @ -36.5 (degrees)	0.446 (Gauss) @ 53.5 (degrees)	0.000 (Gauss) @ 143.5 (degrees)
Experimental	________(Gauss) @ (degrees)	__________(Gauss) @ (degrees)	__________(Gauss) @ (degrees)

Table #2

blank	intensity (horizontal component)	(total)	Dip Angle
Theoretical (horizontal being 0.0 degrees)	0.265 (Gauss)	0.446 (Gauss)	53.5 (degrees)
Experimental	________(Gauss)	__________(Gauss)	(degrees)

Supplement

<u>Measuring the earth's Magnetic Field</u>

To calculate the magnitude and direction of the magnetic field due only to the combined effects of two magnets without the earth's magnetic field at a point P location in the field, use the mathematical example below.

If two magnets are in the earth's magnetic field, the total magnetic field at the point P is the sum of three vector field intensities: $B_{M1} + B_{M2} + B_E$)
To calculate the effect of the two magnets alone, subtract the contribution from the earth's magnetic field from the sum: $B_{M1} + B_{M2} = (B_{M1} + B_{M2} + B_E) - B_E$,

A total value measured by a magnetic field sensor will include the sum of the three fields. To show the method of addition and subtraction of vectors, study the example below: **The total field without the earth's contribution** would be written as $(B_{M1} + B_{M2} + B_E)(\mathbf{i}\cos\Theta + \mathbf{j}\sin\Theta + \mathbf{k}) - B_E(\mathbf{i}\cos 0^0 + \mathbf{j}\sin 0^0 + \mathbf{k})$ for a cylindrical coordinate system where the magnetic field vector of the earth is at 0 degrees.

For example,

given $(B_{M1} + B_{M2} + B_E) = 3.2$ Gauss @ 55^0 at the point P and

given $B_E = 1.0$ Gauss @ 0^0 at the same point P, then

$B_{M1} + B_{M2} = 3.2(0.534\,\mathbf{i} + 0.819\mathbf{j} + 1.00\,\mathbf{k}) - 1.0(1.00\mathbf{i} + 1.00\,\mathbf{k}) = 0.71\mathbf{i} + 2.62\mathbf{j}$ at that point

or $B_{M1} + B_{M2} = \sqrt{(0.71^2 + 2.62^2)}$ **= 2.7 Gauss @ $\tan^{-1}(2.62/0.71)$ or @ 75^0.**