General Physics II Lab (PHYS-2021)
Experiment MAGN-1:
Earth's Magnetic Field

1 Equipment:

INCLUDED:

1	2-Axis Magnetic Field Sensor	PS-2162
1	Zero Gauss Chamber	EM-8652
1	Rotary Motion Sensor	PS-2120
1	Dip Needle	SF-8619
1	Aluminum Table Clamp	ME-8995
1	25 cm Stainless Steel Rod (threaded)	ME-8988
1	Adjustable Angle Clamp	ME-8744
1	Angle Indicator	ME-9495A
1	850 Universal Interface	UI-5000
1	PASCO Capstone	UI-5400

2 Introduction

The magnitude and direction of the Earth's magnetic field are measured using a Magnetic Field Sensor mounted on a Rotary Motion Sensor. The Magnetic Field Sensor is rotated through 720 degrees in a horizontal plane and then 720 degrees in a vertical plane by rotating the Rotary Motion Sensor pulley by hand. This allows a determination of the horizontal component of the Earth’s magnetic field, the total field and the dip angle. The Magnetic Field Sensor is zeroed using the Zero Gauss Chamber, the walls of which are made of a highly permeable material which redirects the magnetic field around the chamber. This experiment requires a formal Lab Report as described in the “Lab Report Format” document.

3 Theory

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 the Magnetic North Pole (which must therefore have a South polarity). The north end of a compass needle is attracted to the south end of the Earth's magnetic field. So the pole which is referred to as "North Magnetic Pole" is actually a south magnetic pole. Don’t get confused. The physics is straight forward; it’s the language that gets confused.

The total field points at an angle from the horizontal. This angle (θ) is called the dip angle. An example for the Northern hemisphere is shown in Figure 1.

$$\cos \theta = B_{Horizontal}/B_{Total} \qquad \text{Eq. (1)}$$

The Magnetic Field Sensor detects the component of the magnetic field in a direction that is parallel to the clear probe on the sensor. If we rotate the sensor in a horizontal plane, the sensor will detect the component of $B_{Horizontal}$ that lies along the clear probe and is given by

$$B_{90} = B_{Horizontal} \cos \alpha \qquad \text{Eq. (2)}$$

where α is the angle from magnetic north (see Figure 2) and B_{90} is the component of $B_{Horizontal}$ (and of B_{Total}) in the horizontal plane (the 90 refers to the angle read by the angle indicator when horizontal).

If we rotate the sensor in a vertical plane that includes B_{Total}, then the sensor will detect B_{00}, the component of B_{Total} in that plane and is given by

$$B_{00} = B_{Total} \cos \beta \qquad \text{Eq. (3)}$$

Where β is defined in Figure 3. The angle from horizontal, θ, where B_{00} is maximum ($\beta = 0$) will be the dip angle.

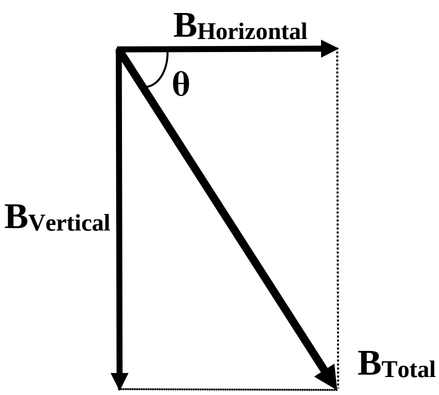

Figure 1: Components of the Magnetic Field (Northern Hemisphere)

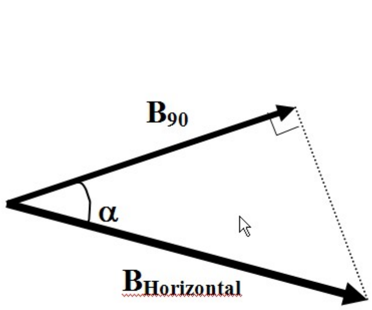

Figure 2: Horizontal Plane

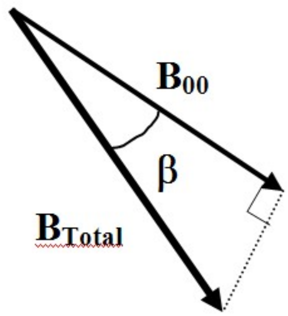

Figure 3: Vertical Plane Defined by B_{Total}

Figure 4: Setup

Figure 5: Alternate Setup

4 Setup

NOTE: During this experiment, keep the apparatus away from all sources of magnetic fields (electrical, computers, computer interface, bar magnets). Also keep away from all ferromagnetic materials (iron, steel chairs and tables). This is essential for good results since the Earth's Field is orders of magnitude smaller than the field near a refrigerator magnet.

1. Attach the Adjustable Angle Clamp to the Rotary Motion Sensor by removing the black cube with the silver attachment bolts from the Adjustable Angle Clamp and screwing the exposed bolt into the black cube on the Rotary Motion Sensor.

2. Assemble the system as shown in Figure 4. Note that the raised key inside the Magnetic Field Sensor handle slides into the notch on the shaft of the Rotary Motion Sensor. Use the provided nonmagnetic stainless steel rod in the table clamp. The table clamp is mostly aluminum. Attach the Adjustable Angle Clamp as high as possible on the stainless steel rod to keep the Magnetic Field Sensor as far away from the rod as possible. Alternately, if a large rod base (ME-8735) and a 90 cm stainless steel rod (ME-8738) or longer are available, setting up on the floor away from the lab table (see Figure 5) will help minimize the presence of stray fields.

3. Plug the Rotary Motion Sensor and the Magnetic Field Sensor into any two *PasPort* inputs on the 850 Universal Interface.

Figure 6: Aligning with North

5 Procedure A: Horizontal Component of the Magnetic Field of the Earth

1. To allow the Magnetic Field Sensor to rotate in a horizontal circle, adjust the Rotary Motion Sensor clamp so the angle indicator reads 90 degrees with the Magnetic Field Sensor on top.

2. Put the Dip Needle in its horizontal orientation and position the base of the Dip Needle directly against the case of the Rotary Motion Sensor as shown in Figure 6. Rotate the Rotary Motion Sensor until the compass needle is aligned with its holding fork (as shown in Figure 6) and the north end of the needle is at the 270 degree mark. Remove the Dip Needle so its magnetic field won't interfere with the experiment.

3. If a level is available, level the top of the case of the Rotary Motion Sensor along its long axis. This is easier with the alternate setup, but possible with shims under the table legs if using the standard setup. If it is off by less than 10 degrees, it won’t noticeably affect the magnitudes of the magnet fields, but will affect the value of the dip angle.

4. Rotate the Magnetic Field Sensor so the length of the probe is perpendicular to the direction of the Earth's field as indicated by the long axis Rotary Motion Sensor case. Slip the Zero Gauss Chamber over the Magnetic Field Sensor probe and press the Tare button on the Magnetic Field Sensor. Release the Tare button and then remove the Zero

Gauss Chamber. The horizontal component of the magnetic field is zero at an angle of 90 degrees from north. Pushing the Tare button here should set the sensor zero to zero at this point. However, the magnetic field strength is only a few hundredths of a mT and the noise is of the same order of magnitude. This means that instead of seeing zero when perpendicular to the field and a field that goes symmetrically above and below zero, the measured field will be shifted vertically a bit by this zero error depending on which reading it uses for zero. This will not affect the experiment at all.

5. Align the Magnetic Field Sensor with the long axis of the Rotary Motion Sensor (as in Figure 6) so it points due north. Click RECORD. **Slowly** (data rate is only 10 Hz) and steadily rotate the Rotary Motion Sensor pulley through two and one quarter revolutions clockwise. Click STOP. It will help if someone holds the cable clear. If the angles on the graph are negative it will not affect anything, but you can get positive angles by deleting this run and repeating the run while rotating in the opposite direction.

6. The field should have its most negative (most positive if you aligned south instead of north) value at 0^0, 360^0, and 720^0. If not, you probably have not aligned the system correctly and need to correct it and repeat the run.

7. Click on Data Summary at the left of the screen. Double click on this run (probably Run #1) and re-label it “Horizontal 1”.
8. Repeat steps 5-7 twice more, labeling the runs “Horizontal 2” and “Horizontal 3”.

6 Procedure B: Total Magnetic Field of the Earth

1. To allow the Magnetic Field Sensor to rotate in a vertical circle, adjust the Rotary Motion Sensor clamp so the angle indicator reads zero degrees. Keep the Rotary Motion Sensor aligned with the Earth's field as shown by the compass needle (Dip Needle).

2. Point the Magnetic Field Sensor probe horizontally.

3. With the Magnetic Field Sensor still horizontal, click RECORD. **Slowly** and steadily rotate the Rotary Motion Sensor pulley through two and one quarter revolutions in a direction so probe turns downward first. Click STOP.

4. Click on Data Summary at the left of the screen. Double click on this run and re-label it “Vertical 1”.

5. Repeat steps 2-4 twice more. Label the runs “Vertical 2” and Vertical 3”.

6. Hold the Dip Needle (still in its horizontal position) on top of the Rotary Motion Sensor case so it is level and align it so the needle points to the 270^0 mark. Rotate the fork 90^0 so the needle pivots in a vertical plane. Allow the needle to come to rest and read the number of degrees it is below horizontal (270^0). Record the value in the table on the Dip

Angle page in line 5 of the Dip Angle table.

7 Analysis

1. Click the black triangle by the Run Select icon on the graph toolbar and select "Horizontal 1". Click the Scale to Fit icon on the graph toolbar.
2. Click the Selection icon on the graph toolbar and drag the handles on the Selection box to highlight the data from just after you began taking data to just before you ended. Stay away from the endpoints.
3. Click the black triangle by the Curve Fit icon and select Sine (see Theory to see why the data should fit a sine curve). The sine curve on the screen may match your data well, but the computer has some problems matching such noisy data. It the curve is clearly wrong, try decreasing the width of the Selection box by moving the beginning and ending handles. The sine curve will suddenly snap to the data, but you may have to play with it a bit.
4. Record the value of the amplitude of the sine curve (A in the Sine box) in the Horizontal row, Run 1 column of the table below. Ignore any minus sign. This is the value for $B_{Horizontal}$ (B_{Total} for the vertical runs) since it is the maximum value if the curve were symmetric about zero.
5. Repeat steps 1-4 for the other two horizontal runs.
6. Repeat steps 1-4 for the three vertical runs recording the amplitudes in the Total row.
7. Note that for both the Horizontal field and the Total Field, the computer calculates the average value and the uncertainty for the fields from your three values.

8 The Dip Angle

1. Click on the black triangle by the Run Select icon on the graph toolbar and select "Vertical 1".
2. Click on the Selection icon and drag the handles on the Selection box to highlight data from just after you started the run to around 400^0 (one full cycle plus a little). Click the Scale to Fit icon.
3. Click the black triangle by the Curve Fit icon and select Sine. As before, you may have to fiddle with the selection box handles to get a fit.
4. Estimate the angle at which the first minimum (first maximum if in magnetic southern hemisphere) occurred. Best way to do this is to pick a horizontal line (constant magnetic field strength) and average the values for the angle where the sine curve crosses the line before the minimum with the angle where it crosses the line after the minimum. This is more accurate that trying to judge the minimum since it is rather flat on the bottom. Enter your value in line 1 of the Dip Angle table. Repeat for the other two vertical runs, entering the values in lines 2 and 3 of the table. Calculate the average of the three values and enter it in line 4.
5. Use the average values of $B_{Horizontal}$ and the total magnetic field, B_{Total}, from the previous page to calculate the dip angle. Enter the value in line 6 of the Dip Angle table.
6. Do the different methods of finding the Dip Angle agree?