i2022 MagnetiSiM

HOW ON EARTH DO WE MEASURE EARTH'S MAGNETIC FIELD?

<u>Activity 1</u>: Introduction to Magnetism

<table>
<tr><td>1.</td><td>What is magnetism?</td></tr>
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- Magnetism is part of the electromagnetic force, one of the four fundamental forces in nature. Magnetic materials experience magnetic force when they interact with a magnetic field.

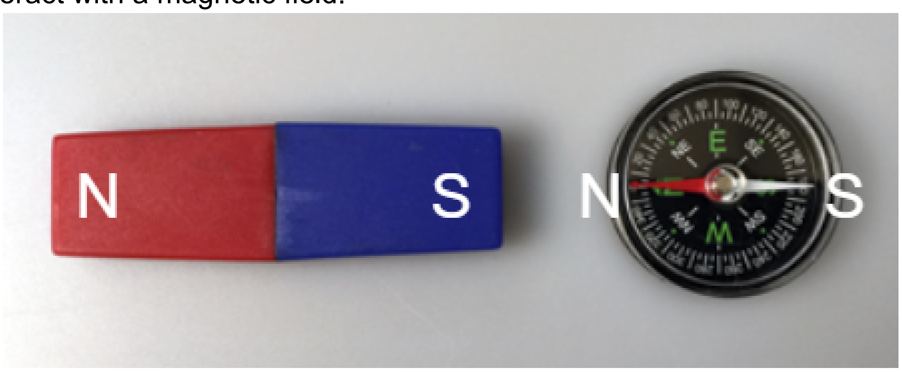

Image Reference: What Are Magnetic Poles? How Can You Tell Which Pole is Which? | Dowling Magnets

- **Two sources of magnetic fields:**
  - Moving electric charge (electric current) will generate a magnetic field perpendicular to the motion.

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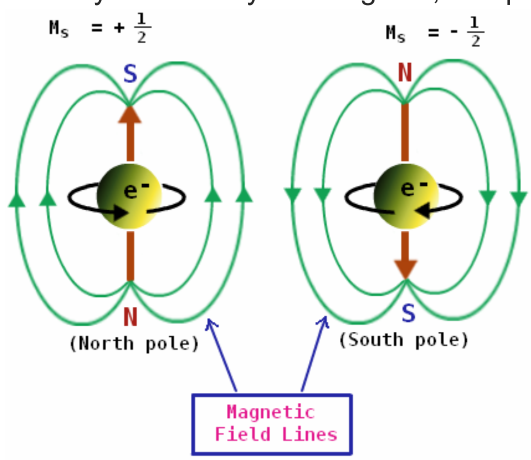
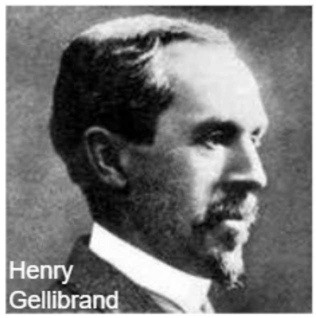
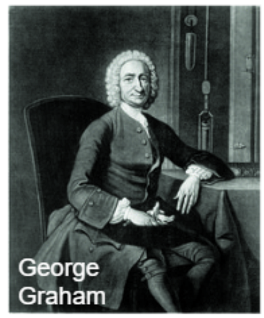
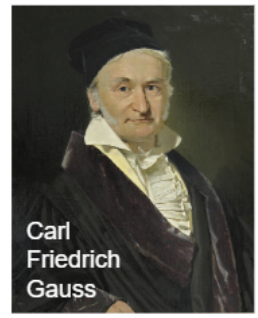
	 ● Elementary particles like electrons, protons, and neutrons have a property called **spin**. They act like tiny bar magnets, and produce a magnetic field. 
2.	**The unit for magnetic field.**
	● The SI unit for the magnetic field is **Tesla** (T). Example: a typical fridge magnetic is about ***0.005 T.*** ● We use microTesla (μT) or Gauss (G) for smaller magnetic fields. - A microTesla is 1,000,000 of a Tesla so the fridge magnet would be ***500 μT*** - A Gauss is 10,000 of a Tesla, so the fridge magnet would be ***50G***
3.	**History of the study of geomagnetism.**
	● The study of the Earth's magnetic nature started in the early 17th century. In 1600, William Gilbert published the ground-breaking *De Magnete* which includes his novel experiment of reproducing a slanting compass needle. Gilbert concluded that the Earth was a giant magnet from his studies. ● In 1635, mathematician Henry Gellibrand discovered that the angle between the magnetic north and the geographic north changes over time.

- In 1725, British watchmaker George Graham measured the variation of magnetic declination by observing the movement of a magnetic needle. He recorded the angle changed by about half a degree within 6 hours in a day.

- In 1832, German mathematician and physicist Carl Friedrich Gauss measured the absolute Earth's magnetic field. He also developed a mathematical model that successfully describes the field.



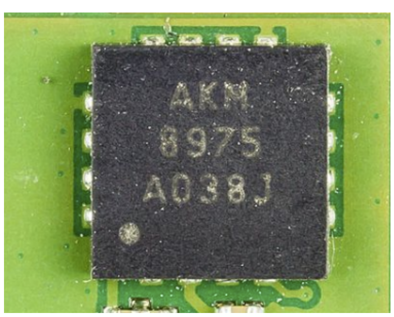


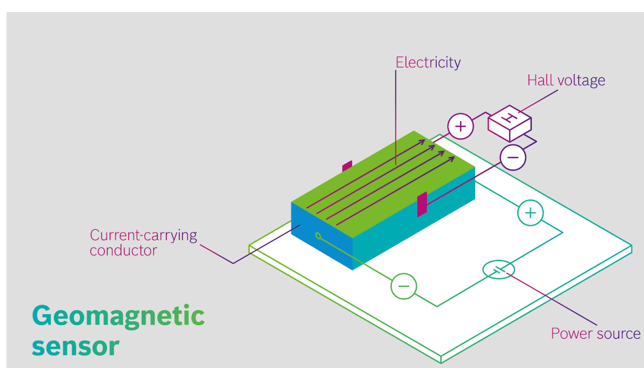


References:
https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1002/swe.20062
https://www.nature.com/articles/297285a0.pdf?origin=ppub

4. **How is magnetism measured by phones?**

The sensor to detect magnetism around us is called a magnetometer. When a magnetic field is present, the electrons flowing in the sensor will be attracted to the north direction of the magnetic field. The electron deflection causes a voltage difference which is called the Hall voltage. The sensor detects the Hall voltage to measure the strength of the magnetic field.





References:
[MEMS Expertise | Bosch Sensortec (bosch-sensortec.com)]
[MEMS magnetic field sensor - Wikipedia]

5. **Reading Quizzes**

1. A compass north points to the (a) geographical north (b) magnetic north (c) geographical south (d) magnetic south.

	2. The strength of a magnetic tape in a magnetic recording device is about 25 μT, which is equivalent to ___ T. 3. Who was the first to measure the Earth's magnetic field? (a) William Gilbert (b) George Graham (c) Henry Gellibrand (d) Carl Gauss.

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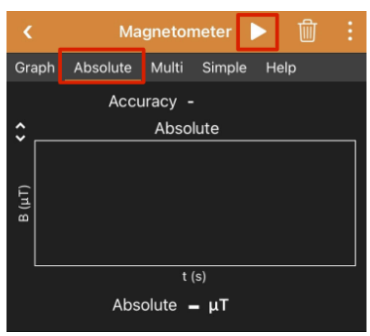
Activity 2: Find the magnetometer location on your phone.

1. Download the "Phyphox" app on iPhone or Android.

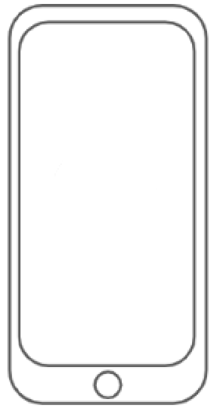
2. Select "Magnetometer" on the main menu.

3. Select "Absolute" on the menu and hit start.



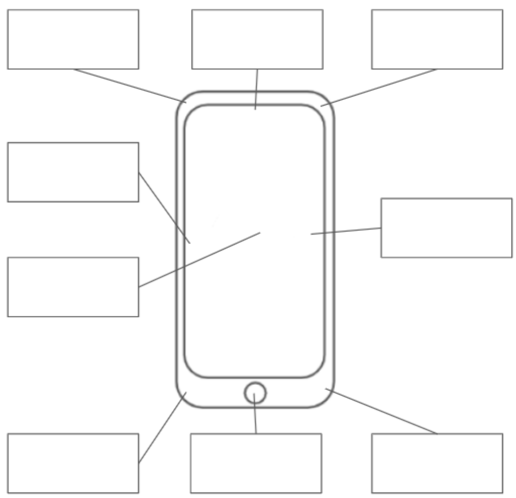
4. Place your phone on a table. Pause the measurement to record the **absolute magnetic field** and the unit. What is your value? _______

5. Predict where you think the sensor is by placing an x on a part of the phone diagram.



Front

6. Take a nail or a scissor, hold it above your phone at a certain spot, and record the values. Be sure to keep the distance between the magnet and phone the same.



Front

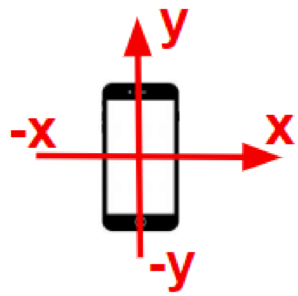
7. Do you observe a change in the **absolute magnetic field value** near the objects? Compare the values from your results - at what location gives the largest change in the absolute magnetic field?

8. Based on your results, where is the sensor located on your phone? Was your prediction correct?

Activity 3: Find the coordinate system of the magnetometer on your phone.

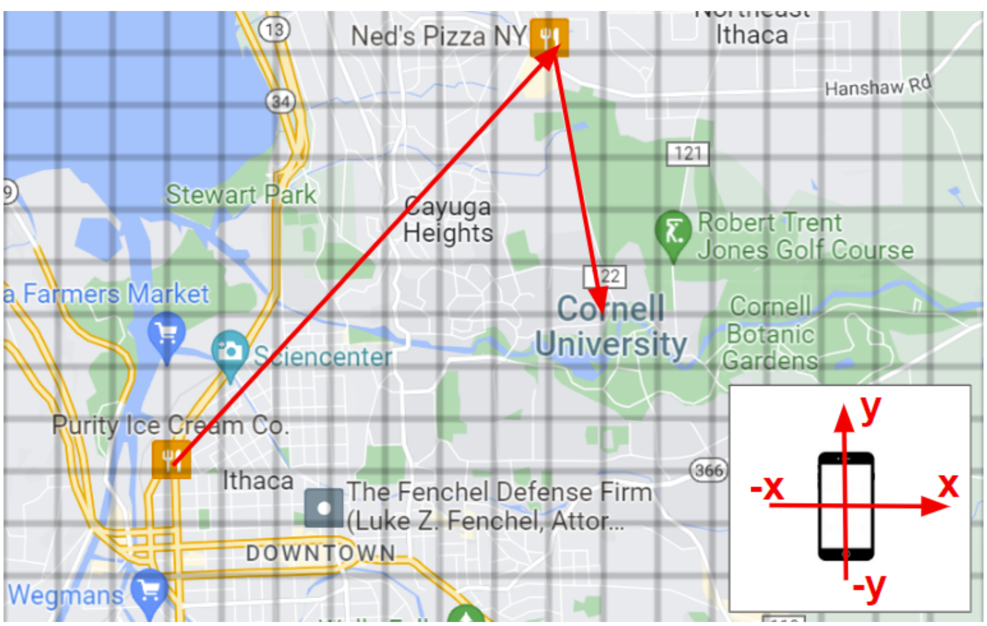
1. A coordinate system is a system that defines positions in space. We can take measurements according to different orientations of the coordinate system.

2. Suppose we want to use our phone as a reference coordinate system to measure distances. The reference coordinate system looks like the figure below:

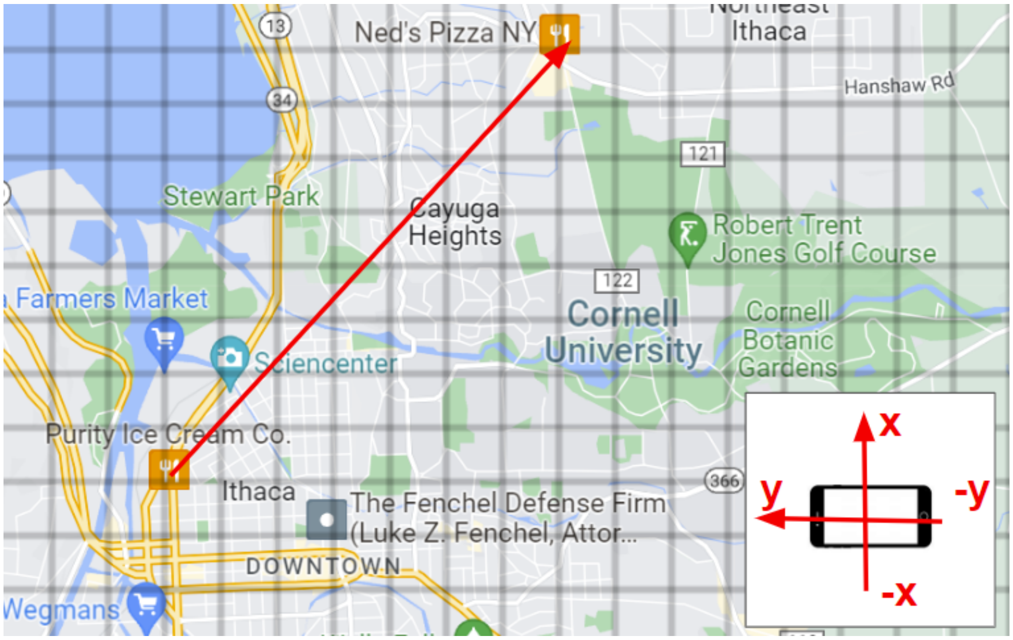


3. Question: In the figure below, how many grids in the x and y direction will someone need to move to get from **Purity Ice Cream** to **Ned's Pizza**?
   Answer: ____ grids in +x direction and ____ grids in +y direction.

   Question: In the figure below, how many grids in the x and y direction will someone need to move to get from **Ned's Pizza** to **Cornell University**?
   Answer: ____ grids in +x direction and ____ grids in +y direction.



4. Let us rotate the coordinate system by 90° counterclockwise. Answer the following:
   Question: In the figure below, how many grids in the x and y direction will someone need to move to get from **Purity Ice Cream** to **Ned's Pizza**?
   Answer: ____ grids in +x direction and ____ grids in +y direction.

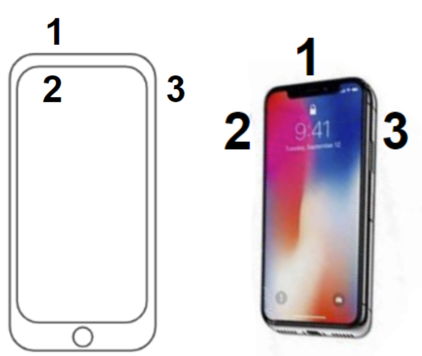


5. The phone magnetometer works in a similar way. It has a coordinate system embedded in itself and measures the magnetic field in x, y, and z directions accordingly. Let's find out the orientation of the magnetometer's coordinate system!

6. Open the Phyphox magnetometer on your phone and select "**Multi**" in the menu.

7. Measure the initial magnetic field (without any magnetic objects nearby) and record the x, y, and z components of the magnetic field in the table.

8. Place your phone on a table, hold a weak magnet near your phone (***keep the weak magnet at least 10 cm from your phone!***) at the three locations: (1) on the upside of your phone (2) on the right side of your phone (3) above your phone. Ignore the positive and negative signs for now. (*Note: ignore the negative sign for now.*)



Top View   Side View

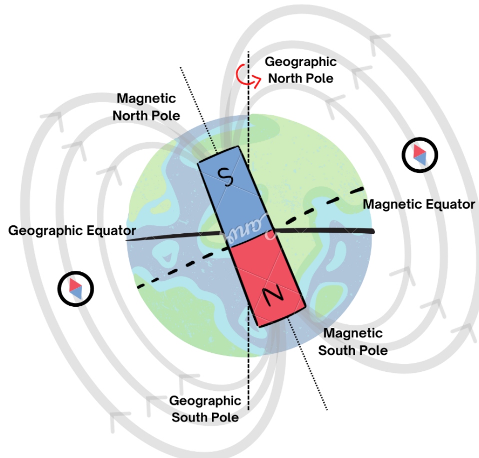
	x-component (μT)	y-component (μT)	z-component (μT)
Initial value			
Position 1			
Position 2			
Position 3			

9. For each component, observe the change in magnetic field at position 1, 2, and 3. Fill out the following statements.
    a. For the x-component, the magnetic field has the **largest** change at position ___ .
    b. For the y-component, the magnetic field has the **largest** change at position ___ .
    c. For the z -component, the magnetic field has the **largest** change at position ___ .

10. According to the results above, label the coordinate system of the magnetometer on your phone with x, y, and z.

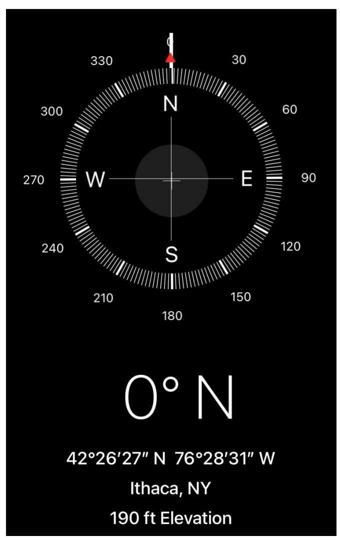
Activity 4: Measure the Earth's Magnetic Field

1. We can think of the Earth as a giant magnet with magnetic field lines pointing away from the magnetic north pole and towards the magnetic south pole.



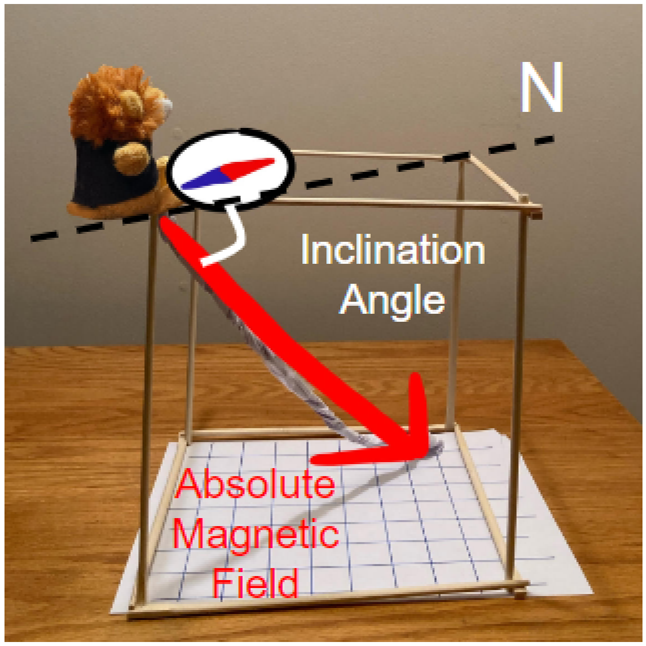
Notice the magnetic field lines form an angle with the Earth's surface. We can visualize this angle by utilizing the magnetometer on our phone.

2. Launch a compass app on your phone and find the magnetic north.



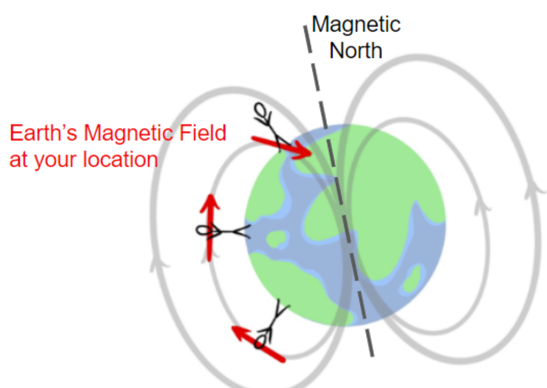
We have aligned our phone magnetometer to the magnetic field line, facing to the magnetic north as shown.

3. In the figure, the compass points towards the **magnetic north**. The red arrow represents the **total magnetic field**. This angle between the total magnetic field and the Earth's surface is called the **inclination angle**.



*This example illustrates the position at the **Northern Hemisphere***

<u>Question</u>: In what direction would the absolute magnetic field point in the **Southern Hemisphere** and along the **equator**?

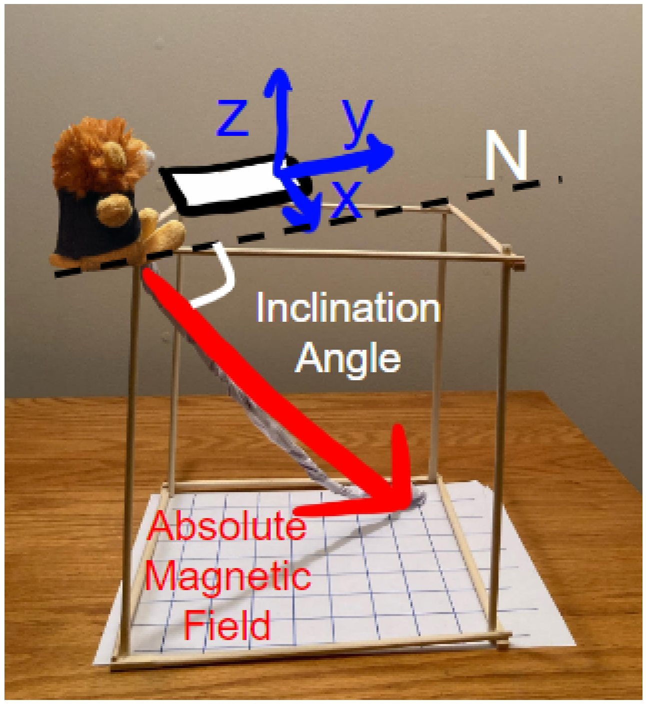


4. Still facing the **magnetic north**, hold your phone horizontally with the screen facing up. Launch the Phyphox magnetometer and select "Multi". Hit start.

   Slowly rotate your phone from left to right (with the screen still facing up) until the **x-component is close to zero**. meter. Pause the measurement and record your values.

x-component (μT)	y-component (μT)	z-component (μT)

5. From the figure below, can you see why the x-component is zero?



The **total magnetic field** points downwards and towards the magnetic north. The downwards direction corresponds to the **negative z-direction** of the phone magnetometer and the magnetic north direction corresponds to the **positive y-component** of the phone magnetometer.

6. To calculate the **total Earth's magnetic field**, use the formula:

Total Earth's Magnetic Field $= \sqrt{x^2 + y^2 + z^2}$

Calculated Earth's Magnetic Field (μT)

What do you notice about your calculated Earth's magnetic field and the absolute value of the magnetic field on your phone's magnetometer?

The absolute Earth's magnetic field should be in the range of 25 μT and 65 μT. Compare your result with the theoretical value on this website: https://www.ngdc.noaa.gov/geomag/calculators/m.

Link for explanation of magnitude.

7. To calculate the **inclination angle**, use the formula:

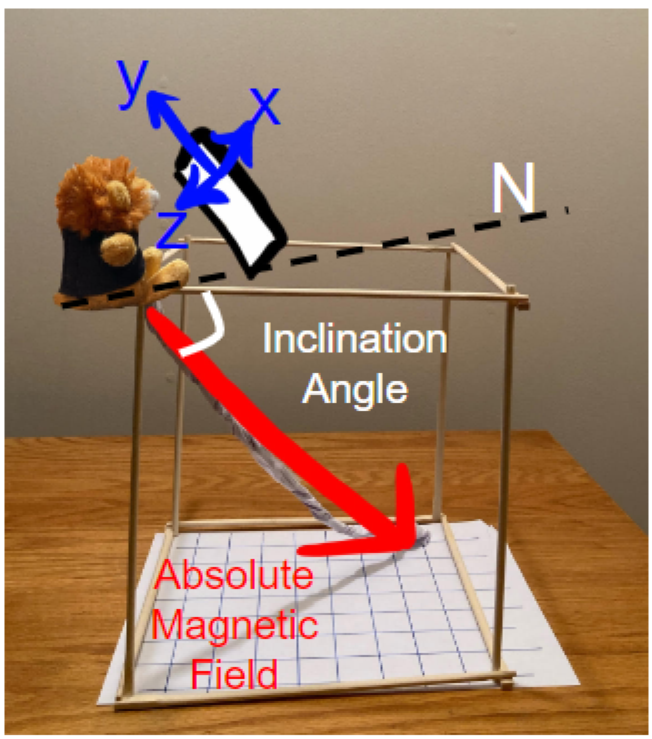
Inclination Angle = $ctan^{-1}(\frac{z}{y}) \times \frac{180}{\pi}$ (degree)

Calculated Inclination Angle (Degree)

8. Next, still *facing the magnetic north*, slowly rotate the phone *upwards* with the screen facing to yourself. Rotate until both the **x-component** and the **z-component** are zero. Pause the measurement and record the values.

x-component (μT)	y-component (μT)	z-component (μT)

9. From the figure below, can you see why both the x and z components of the magnetic field are zero?



This is because we now have aligned the total magnetic field to the y-component of the magnetometer. The x-component and z-component are perpendicular to the total magnetic field now. There is no magnetic field in the x-component and z-component.

10. Compare the angle between your phone and the ground with the angle you calculated in step 7!

11. Upload the **measured absolute magnetic field** from step 6 and your calculated inclination angle to the IEEE SiM website!

    Note: The inclination angle decreases to zero as we approach the equator and increases to 90 degrees as we approach the geographical north and south poles.

    Note: The magnetic field decreases as we approach the equator and increases as we approach the geographical north and south poles.