Measuring Magnetic Fields

To solve problems, scientists ask scientific questions. They determine the best methods to answer the question, collect the data, and analyze it to draw evidence-based conclusions that answer the question. You will be practicing these steps in the **process of science** in this lab.

Learning objectives:

- Students will be able to explain factors that impact magnetic field strength.
- Students will be able to apply and analyze steps in the **process of science** (scientific literacy).
- Students will be able to calculate **average** (quantitative literacy).
- Students will be able to identify and analyze **assumptions** (quantitative literacy).

Materials needed:

- Physics Toolbox Sensor Suite downloaded to a smartphone or tablet. See icon below.
- USGS article: Monitoring the Earth's Dynamic Magnetic Field

The air glows when Earth's magnetic field deflects particles from the Sun. (source: Noel_Bauza on pixabay.com)

The Earth has a magnetic field, which can be measured using an instrument called a magnetometer. This magnetic field is primarily generated by the movement of liquid iron and other metals that conduct electrons in Earth's interior. This flow generates the planet's magnetic field because magnetic fields are produced whenever electric charges, such as electrons, are in motion. See the USGS article Monitoring the Earth's Dynamic Magnetic Field for more information about how and why we monitor Earth's magnetic field.

Magnetometers cannot measure a magnetic field from a distance. Instead, they need to be in it and measure it at that specific location. This is different from instruments that measure light, such as a telescope, where the light can be measured from far away.

1. Read the preceding paragraphs. Which of the following does NOT generate a magnetic field?

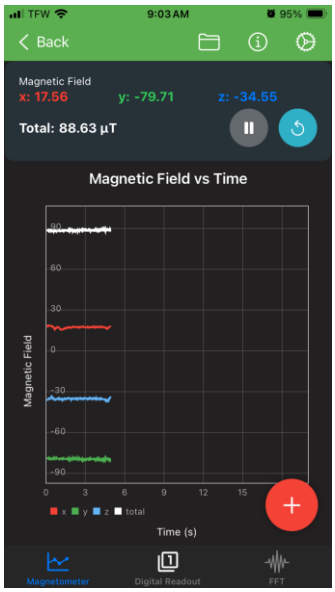
- ○ Earth, where there is liquid iron flowing in its interior (iron conducts electrons)
- ○ Moon, where there is solid iron in its interior (iron conducts electrons)
- ○ Jupiter, where there is liquid metallic hydrogen flowing in its interior (liquid metallic hydrogen conducts electrons)

2. How can we measure the magnetic field of Jupiter or Saturn?

- ○ Send a spacecraft with a magnetometer to orbit Jupiter, within its magnetic field
- ○ Point a magnetometer from Earth towards Jupiter
- ○ Send a magnetometer to the Moon, beyond Earth's magnetic field, and point it towards Jupiter

Part 1: Navigating the Physics Toolbox Sensor Suite Magnetometer

Download the free app Physics Toolbox Sensor Suite and open it. Scroll down to find the magnetism section and open the magnetometer. It should look similar to the screen shown.



Images showing the Physics Toolbox Sensor Suite icon and magnetometer screen.

The white line in the graph and the text on top represent the total magnetic field measured. The red, blue, and green lines show the magnetic field measured in three different directions. The units for magnetic field are microTesla, which is abbreviated µT, and nanoTesla, which is abbreviated nT. There are 1000 nanoTestla in 1 microTesla.

3. When you read the graph on the magnetometer, what does it show?

- ○ The total magnetic field (in µT) versus magnetic field in different directions (in µT)
- ○ The x magnetic field (in µT) versus the y magnetic field (in µT)
- ○ The magnetic field (in µT) versus time (in seconds)

4. Put your phone down on a non-metal flat surface. What happens to the magnetic field measurements when you slowly spin your phone?

- ○ The total magnetic field and direction magnetic fields change
- ○ The total magnetic field changes, and the direction magnetic fields stay approximately the same
- ○ The total magnetic field stays approximately the same, and the direction magnetic fields change
- ○ The total magnetic field and direction magnetic fields stay approximately the same

Part 2: Collecting data about magnetic field strength

What is the magnetic field strength at my location?

The magnetometer on your phone measures the magnetic field where your phone is located. Consider the above scientific question about local magnetic field strength. Using the Physics Toolbox Sensor Suite Magnetometer app, you will collect data to answer this question. The methods to collect data have been figured out for you, but you will need to collect the data and analyze it to use as evidence to critically think about the conclusion proposed below.

To fill in Data Table 1, hold your phone in your hand and measure the magnetic field strength at 5 different locations more than 5 feet apart. Try to avoid being within a few feet of anything. To make the measurement, either hit the pause button on the magnetometer or take a screenshot.

Scientists calculate **averages** to get more accurate results by reducing differences that happen by chance and error in measurements. You will take multiple measurements and average them together. To calculate the average add up your measurements, then divide by the total number of measurements.

Data Table 1

Location	Total magnetic field strength (μT)
Average	

5. List two locations where you made your measurements: _____

6. How did you calculate your **average**?

- ○ I added together each magnetic field strength.
- ○ I added together the highest and lowest magnetic field strength and divided by 2.
- ○ I added together 5 magnetic field strength measurements and divided the total by 5, one for each measurement.
- ○ I added together each magnetic field strength measurement in the table and divided by 7, one for each row in the table.
- ○ I found the magnetic field strength that was in the middle, with two higher and two lower.

7. What is the **average** total magnetic field strength that you measured? _____ μT

A fellow student proposes the following conclusion statement, "**The magnetic field strength for Earth is 500 μT**."

8. Based on the data you collected, do you agree or disagree with that statement?
- ○ I agree because the statement is supported by the data I collected
- ○ I disagree because the statement is not supported by the data I collected

9. Why do you agree or disagree with that statement, based on your data?
- ○ I agree with the statement because my average is similar to 500 μT.
- ○ I disagree with the statement because my average is less than 500 μT. I measured approximately 2-7 μT.
- ○ I disagree with the statement because my average is less than 500 μT. I measured approximately 20-70 μT.
- ○ I disagree with the statement because my average is more than 500 μT. I measured approximately 2,000-7,000 μT.
- ○ I disagree with the statement because my average is more than 500 μT. I measured approximately 20,000-70,000 μT.

Scientists make **assumptions** when they are determining the methods to use to answer a scientific question. An assumption is something that is accepted to be true before data are collected or analyzed, so it is not a conclusion made from the data.

10. What is NOT an **assumption** you made when agreeing or disagreeing with the statement based on your data?
- ○ You are in a location where Earth's magnetic field is relatively normal.
- ○ Buildings near your measurement location have not changed the magnetic field significantly.
- ○ Earth has a similar magnetic field everywhere.
- ○ Earth's magnetic field strength is 500 μT.
- ○ Any magnets near your phone's magnetometer have not changed the magnetic field significantly.

Part 3: Analyzing data about the magnetic field on other planets

How does Earth's magnetic field compare to the field on other planets?

Let's compare our measurement of Earth's magnetic field compared to the magnetic field of other planets. Scientists have used spacecraft to collect the following data to answer the above question about Earth's magnetic field. What conclusions can you make from the Data Table 2?

Data Table 2

Planet	Magnetic Field Strength (μT)	Magnetic Field Strength (nT)	Note about Planet Core/Interior
Earth	25-65	25,000-65,000	Liquid iron
Moon	0.001-0.01	1-10	Solid iron
Mars	1.5	1500	Mostly solid iron
Jupiter	420	420,000	Liquid metallic hydrogen

11. Select the evidence-based conclusion that answers the question regarding the Earth's magnetic field compared to other planets.

- ○ The field strength on Earth is stronger than the Moon, Mars, and Jupiter.
- ○ The field strength on Earth is stronger than the Moon, and weaker than Mars and Jupiter.
- ○ The field strength on Earth is stronger than the Moon and Mars and weaker than Jupiter.
- ○ The field strength on Earth is weaker than the Moon, Mars, and Jupiter.

12. How did you find evidence to draw your conclusion for answering the question regarding the Earth's magnetic field compared to other planets?

- ○ I looked at the Magnetic Field Strength (μT) column and compared it to the other Magnetic Field Strength (nT) column for each planet.
- ○ I looked at one of the Magnetic Field Strength columns and compared the numbers for each planet.
- ○ I looked across the row for each Planet and compared the magnetic field with the Note about the Planet Core/Interior.
- ○ I looked at the row for Earth and compared the Magnetic Field Strength (μT) to the other Magnetic Field Strength (nT)

13. What is a scientific question that could be answered by calculating the **average** magnetic field strength in each column?

- ○ How strong is a typical magnetic field in our Solar System?
- ○ Which planet in our Solar System has the strongest magnetic field?
- ○ How does the magnetic field strength for Earth compare to other planets?
- ○ What does the magnetic field strength tell us about the planet's interior?

14. Magnetic fields are important because they help to deflect charged particles from the Sun from hitting Earth. Based on the data in Data Table 2, where would you most need to worry about charged particles from the Sun and why?

- ○ Jupiter because its interior contains metallic hydrogen.
- ○ Earth, Moon, and Mars because their interiors contain iron.
- ○ Earth and Jupiter because they have the largest magnetic fields.
- ○ The Moon and Mars because they have the smallest magnetic fields.

15. Based on the data in Data Table 2, what is the characteristic of the interior of planets with strong magnetic fields?

- ○ They have iron.
- ○ They have liquid metal.
- ○ They are large.
- ○ They have metal.

16. What evidence did you use to draw this conclusion?

- ○ I looked at the column with data about the planet interior and saw that most have iron.
- ○ I looked at the column with data about the magnetic field strength and saw that the numbers varied.
- ○ I looked at the rows for the planets with large magnetic fields and found that they have liquid metal.
- ○ I looked at the rows for all the planets and found that they all have metal.

17. Based on the data in Data Table 2, what interpretation can you make about why planets have different magnetic field strengths?

- ○ Liquid metal generates a stronger magnetic field than solid metal.
- ○ Planets with iron in their interior, such as Earth, Moon, and Mars, have stronger magnetic fields.
- ○ Planets with large core sizes compared to the size of the planet, such as Earth and Venus, have stronger magnetic fields.
- ○ Planets with stronger magnetic fields, such as Earth, Mars, and Jupiter, are closer to the Sun.

18. What are two **assumptions** you made when you interpreted the data in Data Table 2?

- ☐ Scientists have accurately determined the composition of the interior of planets.
- ☐ Earth's magnetic field is assumed to deflect most charged particles from hitting the surface.
- ☐ Planets' interiors are assumed to be related to the magnetic field more than another cause not in the table.
- ☐ Jupiter is assumed to have the strongest magnetic field, ten times stronger than Earth's and thousands of times stronger than the Moon's and Mars'.

Part 4: Planning methods to answer a scientific question

Has Earth's magnetic field changed strength in the past?

Some rocks, such as volcanic rocks, can record the strength of the magnetic field when they form. You can use a magnetometer to measure the magnetic field strength and direction within a rock.

The methods section of a scientific study gives the specific step-by-step strategy used to collect data to answer a scientific question. You are asked the above scientific question about the strength of Earth's magnetic field. What methods would you use to collect data to answer the scientific question? You are just figuring out how you would answer the question, and you will not collect the data.

Here are the steps (out of order) to answer the scientific question. Put the steps in order (Step 1, Step 2, etc.). One step will not be used.

- Identify volcanic rocks that formed at different times in Earth's past.
- Use a magnetometer to measure the magnetic field strength for each rock.
- Record the magnetic field strength in the table for each rock.
- Calculate the average magnetic field strength of all rocks together.
- Create a table in which to record the data. Fill in the table with the rock ages.

19. Step 1 is to research published information to identify volcanic rocks that formed at different times in Earth's past. What is Step 2?

20. What is Step 3?

21. What is Step 4?

22. What would the table you create to answer this question look like?

- ○ There would be two columns, rock age and magnetic field strength. Each row would be a different rock.
- ○ There would be two columns, rock location and notes. Each row would be a magnetic field measurement.
- ○ There would be one column, magnetic field measurement. Each row would list the measurement.
- ○ There would be two columns, rock age and rock location. Each row would be a different rock.

23. What is NOT an **assumption** made when using these methods?

- ○ Each rock selected is typical of rocks of that age.
- ○ The measurement made of the rock is accurate.
- ○ The instrument that made the measurements is accurate.
- ○ Earth's magnetic field strength varied over time.

24. Select **three** changes to the methods that would address the weaknesses caused by the assumptions made.

- ☐ Collect more than one rock for each age and calculate the average.
- ☐ Use a more sophisticated table with additional rows and columns.
- ☐ Measure each rock more than one time and calculate the average.
- ☐ Calculate the average for the first five rocks collected, then the next five, etc.
- ☐ Use several instruments to take the same measurements and calculate the average.

By making these measurements, scientists have learned that Earth's magnetic field has changed strength, location, and direction in the past!

25. Once you have finished planning your methods, what part of the **process of science** are you ready to begin next?

- ○ Ask a scientific question
- ○ Determine the methods to use
- ○ Make observations and collect data
- ○ Analyze data and develop conclusions
- ○ Share results and conclusions

Part 5: Collecting data about impacts on local magnetic fields

What affects measurements of magnetic field strength?

We have examined Earth's magnetic field as a whole. However, the local magnetic field strength can vary. You will examine what may cause these variations and how you can use that information to learn about your surroundings.

Consider the scientific question above about things that affect the strength of the magnetic field. Using the Physics Toolbox Sensor Suite Magnetometer once more, you will collect data to answer this question. The methods to collect data have been figured out for you, but you will need to collect the data and analyze it to use as evidence to critically think about the conclusion proposed below.

Using the Physics Toolbox Sensor Suite Magnetometer collect data to fill in the Data Table 3 below. Hold your phone against five different surfaces and objects (steel, plastic, wood, concrete or rock, glass). Measurements for something that uses electricity that's on have been entered for you, but feel free to check the numbers for yourself!

For each location, measure the "Total magnetic field strength (μT)," not the magnetic field strength in different directions, on the app. Calculate the **average**.

Data Table 3

Location	Measurement #1: Magnetic field strength (μT)	Measurement #2: Magnetic field strength (μT)	Measurement #3: Magnetic field strength (μT)	Average: Magnetic field strength (μT)
Plastic				
Steel (iron)				
Wood				
Concrete or rock				
Glass				
Something powered on with electricity	2,557.37	2,475.21	1,915.61	

26. What did you put your phone against to measure how wood affects the magnetic field (e.g. table, door frame, floor, chair, shelf, etc.)? _____

27. What did you put your phone against to measure how steel (which includes iron) affects the magnetic field (e.g. fridge, microwave oven, stove, radiator, etc.)? _____

28. What part of the **process of science** did you just do, when you filled in Data Table 3?

- ○ Ask a scientific question
- ○ Determine the methods to use
- ○ Make observations and collect data
- ○ Analyze data and develop conclusions
- ○ Share results and conclusions

29. What is the **average** magnetic field strength for something that is powered on with electricity?

_____

30. Let's say that you calculate the average for each column. What is a scientific question that could be answered by calculating the **average** of the columns instead of the rows?

- ○ What is the lowest magnetic field strength measured?
- ○ How does the magnetic field strength for glass compare to that of steel (iron)?
- ○ Are there any measurements of magnetic field strength larger than 2,557.37 μT?
- ○ Is the first measurement of magnetic field strength larger than the following measurements?

A fellow student proposes the following statement, "**Plastic and electricity most affect magnetic field strength."**

31. Based on the data you collected in Data Table 3, do you agree or disagree with that statement?

- ○ I agree because the statement is supported by the data in the table
- ○ I disagree because the statement is not supported by the data in the table

32. What part of the **process of science** did you just do, when you determined whether you agreed with the statement?

- ○ Ask a scientific question
- ○ Determine the methods to use
- ○ Make observations and collect data
- ○ Analyze data and develop conclusions
- ○ Share results and conclusions

33. More specifically, which part of the statement is supported by the data in Data Table 3?

- ○ Plastic most affects magnetic field strength.
- ○ Electricity most affects magnetic field strength.
- ○ Plastic and electricity affect magnetic field strength. All of the statement is accurate.
- ○ None of the statement is accurate.

34. In what location did you measure the highest magnetic field strength? _____
(Plastic, Steel, Wood, Concrete/rock, or Glass)

35. In what location did you measure the lowest magnetic field strength? _____
(Plastic, Steel, Wood, Concrete/rock, or Glass)

36. Based on the data in Data Table 3, how would you fix the statement above?

- ○ Plastic and iron most affect magnetic field strength.
- ○ Iron and wood most affect magnetic field strength.
- ○ Wood and electricity most affect magnetic field strength.
- ○ Iron and electricity most affect magnetic field strength.
- ○ Plastic and electricity most affect magnetic field strength. (No changes)

Magnetic surveys allow us to locate buried objects or features if they distort the Earth's magnetic field.

37. Based on the data you collected in Data Table 3, which one of these could a magnetometer find buried underground?

- ○ Forgotten paved road
- ○ Large plastic containers
- ○ Fallen log
- ○ Old soda bottles
- ○ Steel storage tank

38. If you were to tell your friends or family about using the app, your measurements, and what you learned from it, what part of the **process of science** would you be part of?

- ○ Ask a scientific question
- ○ Determine the methods to use
- ○ Make observations and collect data
- ○ Analyze data and develop conclusions
- ○ Share results and conclusions

A student brainstormed different ways they could communicate the key findings in Data Table 3:

- Option 1: Create a graph in the shape of a pie, with each of the 18 measurements drawn as a slice of the pie.
- Option 2: Create a graph with bars or dots that show the average magnetic field strength at each location.
- Option 3: Write a paragraph comparing the average magnetic field strength for each location.
- Option 4: Record a video ranking the average magnetic field strength while showing the location.
- Option 5: Create a journal of pictures of each location where the measurements were made.

39. How would you communicate the key findings in Data Table 3? Option #_____ (Include only one option, although there is more than one option that could be a good communication strategy)

40. Some rocks can preserve the planet's magnetic field when they form, as mentioned earlier. What is an important characteristic of these rocks?

- ○ They need to contain iron.
- ○ They need to contain volcanic pieces.
- ○ They need to contain electricity.
- ○ They need to contain ancient trees and plants.

41. If you were to design a spacecraft to measure the magnetic field on another planet, where would you put the magnetometer?

- ○ In the center of the spacecraft to protect it from the sun.
- ○ At the end of a long pole to move it away from the electrical components.
- ○ On the feet to put it in contact with the rocks.
- ○ Along the solar panels to keep it near the part that generates electricity.

Reflection

42. Which question in this lab connects to your personal experience? Consider the lab topic, math skills, and the process of science. You may also consider your lived experience or stories you've encountered. To earn credit, list the question number and explain how it relates in 2-3 sentences.