34. Magnetic Field: Coil

Driving Questions

How is the electromagnetic field strength within a coil affected by changes in current through the coil wire, and the number of wire turns in the coil?

Background

Coils are widely used in variety of electromagnetic devices such as:

- Transformers that allow electricity to be delivered long distances
- Pickups that convert the movement of metal guitar strings into electrical currents that are amplified through speakers
- Voice coils within loudspeakers
- Poly-phase coils within electric motors that convert electrical energy to mechanical energy
- Coils within a generator convert mechanical energy into electrical energy.

The strength of the magnetic field inside a coil governs the effectiveness of these devices, so it is important to understand what influences the strength of the magnetic field inside a coil.

Materials and Equipment

For each student or group:

- Data collection system
- Current sensor
- Magnetic field sensor
- Sensor extension cable (optional)
- Coils of varying turns but the same radius (3)
- Meter stick
- DC power supply, 10-V 1-A minimum
- Patch cord, 4-mm banana plug (3)

Safety

Add these important safety precautions to your normal laboratory procedures:

- Keep the coil away from any sensitive electronic equipment.
- Keep liquids away from the power supply.

Sequencing Challenge

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

◯	◯	◯	◯
Measure and record the magnetic field at the center of the coil.	Attach the magnetic field sensor to the data collection system. Connect the power supply to the coil.	Repeat previous steps for all other coils.	Record the current within the coil and the radius of the coil.

Procedure

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

Note: When you see the symbol "�" with a superscripted number following a step, refer to the numbered Tech Tips listed in the Tech Tips appendix that corresponds to your PASCO data collection system. There you will find detailed technical instructions for performing that step. Your teacher will provide you with a copy of the instructions for these operations.

Part 1 - Number of turns in a coil versus magnetic field

Set Up

1. ☐ Start a new experiment on the data collection system. �[1.2]

2. ☐ In this activity, what quantities will you measure, and in what units?

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3. ☐ What tools will you use to help you make these measurements?

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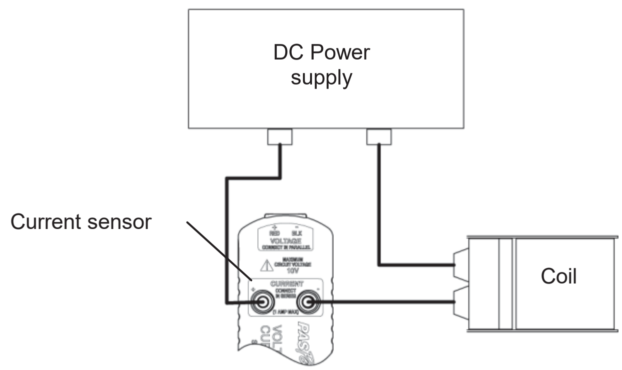
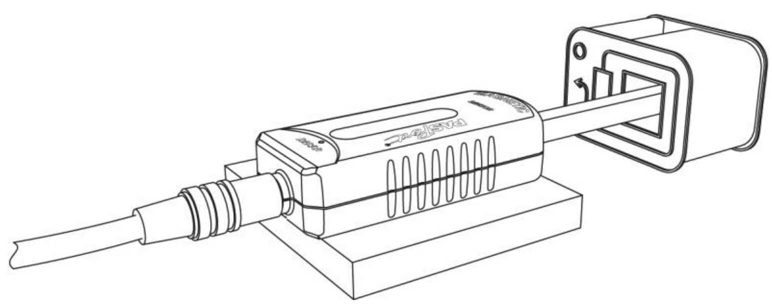
4. ☐ Connect the magnetic field sensor and the current sensor to the data collection system. �(2.2)

5. ☐ Measure the radius of the coils you will be using and record this value in the Data Analysis section.

6. ☐ Using patch cords, connect the negative terminal from the power supply directly to one of the terminals on the first coil. Connect the positive terminal from the power supply to the positive terminal on the current sensor, and then connect the negative terminal on the current sensor to the second terminal on the coil.



7. ☐ Position the tip of the magnetic field sensor inside the coil at the center such that the probe of the sensor is perpendicular to the plane of the coil.



8. ☐ Set up the data collection system to monitor current and magnetic field in a digits display. �(7.3.2) (6.1)

9. ☐ Turn on the power supply, and adjust the voltage until the current measured by the current sensor is approximately 0.5 A.

Collect Data

10. ☐ Record the current value in the Data Analysis section.

11. ☐ Record the number of turns in the coil and magnetic field strength in Table 1 in the Data Analysis section.

12. ☐ Turn off the power supply, disconnect the coil, and replace it with the next coil.

13. ☐ Reposition the coil and magnetic field sensor, and then turn the power supply back on. Adjust the voltage until the current is the same magnitude as was used with the previous coil.

14. ☐ Record the number of turns in the coil and the magnetic field strength in Table 1 in the Data Analysis section.

15. ☐ Turn off the power, disconnect the coil, and replace it with the last coil.

16. ☐ Reposition the coil and magnetic field sensor, and then turn the power supply back on. Adjust the voltage until the current is the same magnitude as was used with the previous coils.

17. ☐ Record the number of turns in the coil and the magnetic field strength in Table 1 in the Data Analysis section.

Analyze Data

18. ☐ Sketch a graph of Magnetic Field versus Turns of the Coil in the space provided in the Data Analysis section.

19. ☐ What type of mathematical relationship does the data appear to be in the first approximation?

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20. ☐ How would you verify this relationship?

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Part 2 - Current versus magnetic field

Set Up

21. ☐ Using the same set up as in Part 1, turn the voltage all the way down on the power supply.

22. ☐ Put the data collection system into manual sampling mode without manually entered data. �(5.2.2)

23. ☐ Display Magnetic Field on the *y*-axis of a graph with Time on the *x*-axis. �(7.1.1)

24. ☐ Change the variable on the *x*-axis from Time to Current. �(7.1.9)

25. ☐ How do you think the magnetic field will change with respect to current? Use the data collection system to draw a prediction, and then copy the prediction to the Magnetic Field versus Current graph in the Data Analysis Section. Be sure to label the graph axis. �(7.1.12)

Collect Data

26. ☐ Start recording a set of manually sampled data. �(6.3)

27. ☐ Increase the voltage slightly until the current increases about 0.1 A.

28. ☐ Record the data point, and then adjust the voltage until the current increases approximately another 0.1 A. �(6.3)

29. ☐ Continue collecting data points every 0.1 A until you have data points that range from 0 to 1.0 A, and then stop Data Collection. �(6.3)

Note: your teacher may choose a different current range to measure based on the coils you are using. Do not exceed the current rating of the coil you are using.

Analyze Data

30. ☐ Sketch the Magnetic Field versus Current graph from the data collection system to the space provided in the Data Analysis section.

31. ☐ Based on this graph, what do you think the relationship is between the strength of the magnetic field and the current through the coil?

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32. ☐ Apply a linear curve fit to the graph on the data collection system. �(9.5)

33. ☐ Add the curve fit to the Magnetic Field versus Current sketch in the Data Analysis section.

34. ☐ Save your experiment as instructed by your teacher. �(11.1)

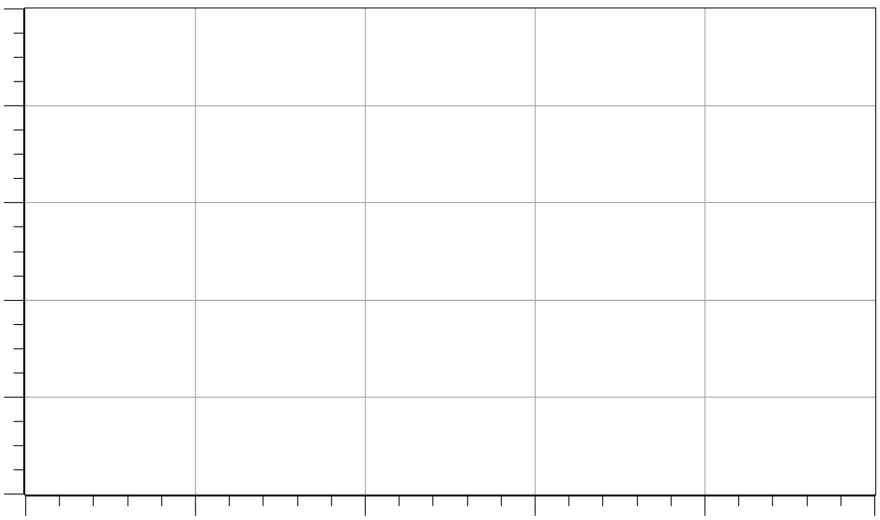
Data Analysis

Current in the coils:__________________ Radius of the coils:____________________

Table 1: Number of Turns in the Coil and Magnetic Field

Number of Turns in the Coil	Magnetic Field (T) Measured	Magnetic Field (T) Calculated	Percent Difference

Magnetic Field versus Number of Turns in the Coil



1. ☐ The theoretical strength of the magnetic field inside a circular coil depends upon the number of turns of wire N, the magnitude of the current in the wire I, and the radius of the coil R:

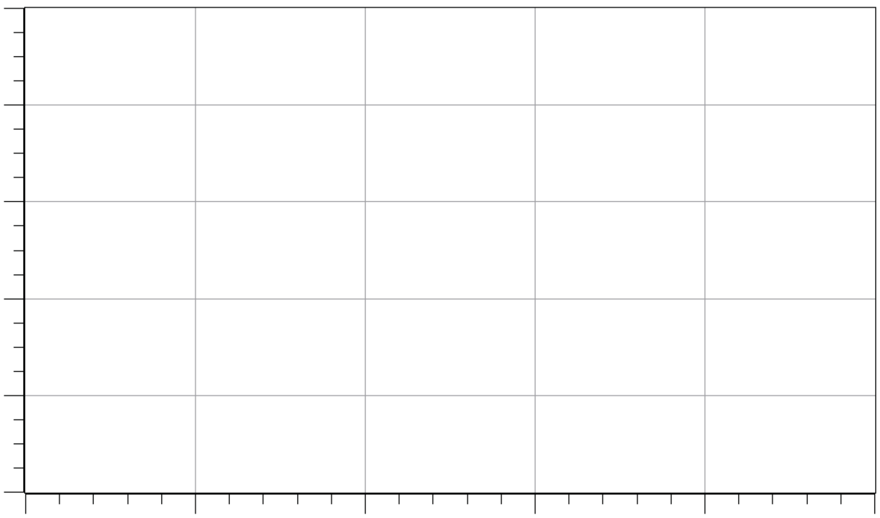
$$B = N(\frac{\mu_0 I}{2R})$$

Where μ_0 is a constant ($\mu_0 = 4\pi \times 10^{-7}$ N·A^{-2}).

Calculate the Theoretical value for the coils you used and add these values to the data table.

2. ☐ Compare your measured values to your calculated values for the magnetic field strength within each coil. Find the percent difference and add these values to the data table.

Magnetic Field versus Current



Analysis Questions

1. How do you account for the differences in your calculated values versus your measured values?

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2. Is there a pattern in your results? If so, explain.

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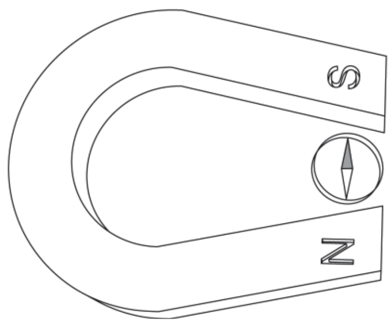
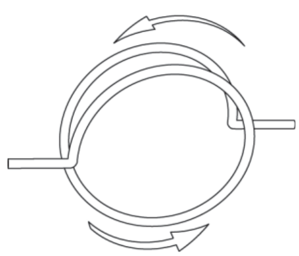
Synthesis Questions

Use available resources to help you answer the following questions.

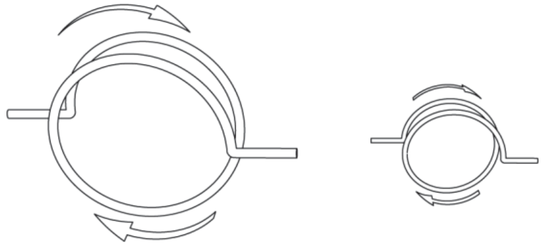
1. **The needle in a compass acts like a tiny bar magnet. When the needle is placed between the poles of the magnet the red end of the compass needle points toward the south pole of the magnet. It is hypothesized that the earth acts as a large electromagnet because of the flow of molten material within it. When the same compass is used on earth, the red end of the compass needle points toward the Earth's north pole. Account for this apparent disparity.**



2. **In the loop below, current flows counter clockwise. In what direction is the magnetic field inside the loop?**



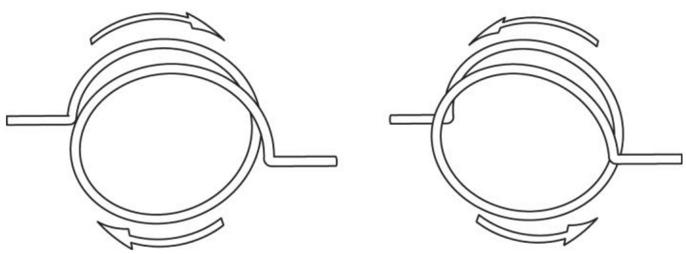
3. In the figure below, the loop to the right has a radius half that of the loop to the left. What must happen to the current in the loop on the right in order to maintain the same magnetic field strength in the center of the coil, as the loop to the left?



Multiple Choice Questions

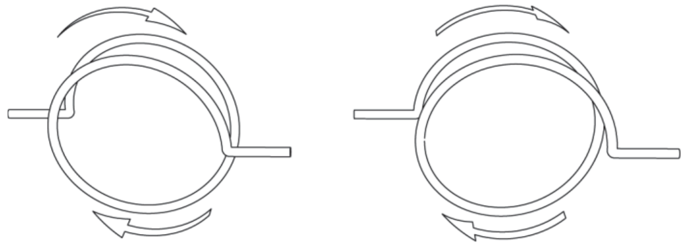
Select the best answer or completion to each of the questions or incomplete statements below.

1. The two loops below have the same current and the same radii. The current in the loop on the left is clockwise; whereas, the current in the loop on the right is counterclockwise. In what direction is the magnetic field at the point between them?



- **A.** Out of the paper.
- **B.** Into the paper.
- **C.** The magnetic fields of the coils at the point between them cancel.
- **D.** Upward.

2. The two loops below have the same current and the same radii. Both currents are clockwise. In what direction is the magnetic field at the point between them?



A. Out of the paper.

B. Into the paper.

C. There is no magnetic field at the point between them.

D. Upward.

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. Two main types of magnets are ____________ magnets and electromagnets. A wire carrying a ____________ induces a magnetic field around it. When the wire is wound into a circle, it is called a coil. The magnetic field strength at the center of a coil depends upon the current and ____________ of the coil. If the coil contains many different turns, the magnetic field strength will ____________. The current is ____________ proportional to the magnetic field strength. The ____________ is inversely proportional to the magnetic field strength.

Key Term Challenge Word Bank

Paragraph 1

Coil

Current

Directly

Increase

Field

Inversely

Magnets

Voltage

Permanent

Radius