NAME PERIOD DATE

11. MAGNETIC FIELD STRENGTH

STRUCTURED

Driving Question | Objective

How is the strength of the magnetic field at the center of a current-carrying coil dependent on the coil current and radius? Experimentally determine a mathematical relationship between the current, radius, and the magnetic field at the center of the current-carrying coil.

Materials and Equipment

- Data collection system
- PASCO 2-Axis Magnetic Field Sensor[1]
- Sensor rod[1]
- PASCO Sensor Extension Cable
- PASCO AC/DC Electronics Laboratory[2]
- Magnet wire or enameled wire, fine gauge (~10 m)
- Power supply, 18-VDC, 3-A
- 4-mm banana plug patch cord (2)
- Wire lead[2]
- Support rod, 45-cm
- Table clamp
- Right angle clamp
- Beakers of different diameter (5)
- Sandpaper
- Scissors or wire cutters
- Ruler

[1]www.pasco.com/ap35 — PASCO 2-Axis Magnetic Field Sensor

[2]www.pasco.com/ap04 — PASCO AC/DC Electronics Laboratory

Background

Sources of magnetic fields include permanent magnets and moving electrical charges, such as those in a current-carrying wire. The magnitude of a magnetic field created by a current-carrying wire can be easily adjusted by varying the current in the wire or changing the physical properties of the wire. Though a magnetic field is created by a straight, current-carrying wire, coiling the wire into a loop strengthens the magnetic field at the center of the coil. The magnetic field can be made even stronger by increasing the number of loops, which makes the magnetic field easier to measure.

In this activity you use a sensor to measure the magnetic field at the center of a current-carrying coil as both the radius of the coil and the current through the coil are varied. Data from these measurements are then used to determine the mathematical relationship between the radius, current, and strength of the magnetic field.

The SI unit of magnetic field is “tesla.” Because the magnetic fields measured in this activity are small, the unit of mT is used for convenience.

Safety

Follow these important safety precautions in addition to your regular classroom procedures:

- Do not allow current to flow through the wires any longer than a few seconds. The wires (and possibly the power supply) can become hot and cause burns and damage equipment.

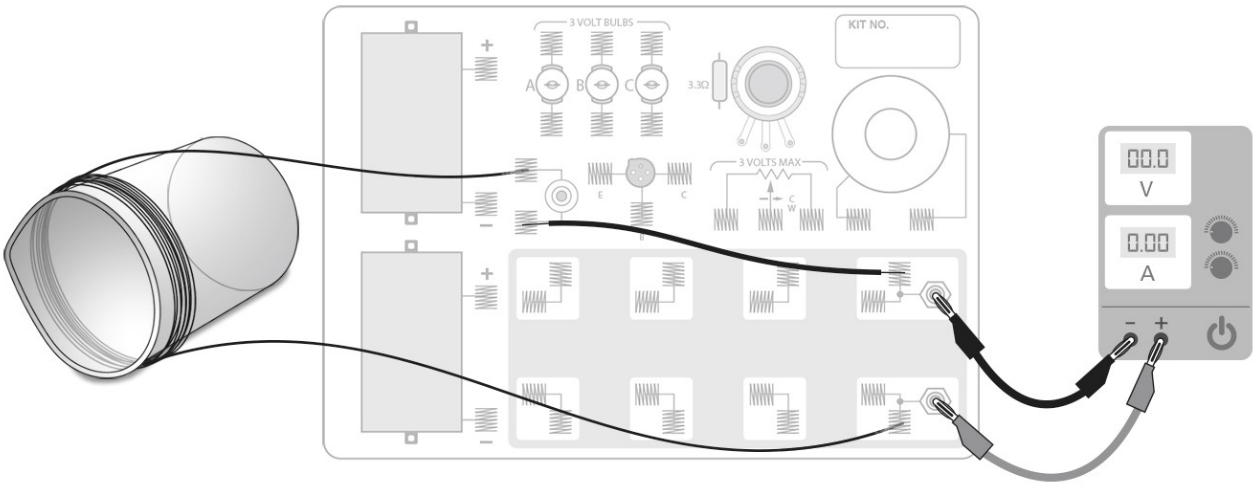
Procedure

Part 1 – Magnetic Field and Current

SET UP

1. Wrap 10 loops of wire around the top of a 100-ml (or smaller) beaker, forming a coil. Leave about 20 cm of straight wire on each end and use sandpaper to sand off about 1 cm of insulation from the tips of each end of the wire.

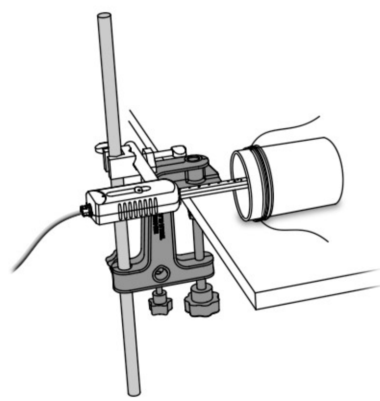
2. Connect the power supply, coil, and switch on the AC/DC Electronics Board as shown.



3. Turn the power supply on, press and hold the switch on the circuit board, and adjust the power supply so that 0.50 A of current is output to the coil. Release the switch every few seconds and after the adjustment is complete.

   NOTE: Do not hold the switch for more than a few seconds. Repeatedly press the switch to adjust the power supply if needed, waiting for 1–2 seconds between adjustments.

4. Mount the magnetic field sensor using the support rod, the sensor rod, and clamps so the tip of the probe is held at the center of the coil, as shown.



5. Connect the magnetic field sensor to the data collection system using the sensor extension cable and then create a digits display of Magnetic Field Strength (Axial) with units of mT.

COLLECT DATA

6. Begin recording data and then press the Tare button on the magnetic field sensor to zero the measurement.

7. Press the push-button switch to close the circuit, quickly note the magnetic field value, and release the push-button switch.

8. Stop data collection and record the magnetic field value into Table 1.

9. Repeat the data collection steps for current values of 1.0, 1.5, 2.0, 2.5, and 3.0 A. Record each corresponding magnetic field value into Table 1.

Part 2 – Magnetic Field and Radius

SET UP

10. Use the same equipment and setup from Part 1 in Part 2.
11. Build four additional coils with different radii by wrapping wire around the top of four other beakers with different diameters. Use 10 loops of wire in each coil, leave about 20 cm of straight wire on each end, and use sandpaper to sand off about 1 cm of insulation from the tips of each end.

    NOTE: Be sure to wrap the same number of wire loops around each beaker.
12. Connect the coil with the smallest radius to your circuit, and then position the magnetic field sensor so the tip of the probe is held at the center of the coil.
13. Press and hold the switch on the circuit board, releasing it every few seconds as you did before, and adjust the power supply so that 3.0 A of current is output to the coil. Release the switch after the adjustment is complete.

    NOTE: Do not hold the switch for more than a few seconds. Repeatedly press the switch to adjust the power supply if needed, waiting for 1–2 seconds between adjustments.

COLLECT DATA

14. Begin recording data and then press the push-button switch to close the circuit. Hold the push-button switch down for a few seconds.
15. Release the push-button switch and stop data collection.
16. Use the tools on your data collection system to determine the magnetic field while current was flowing through the coil. Record this value in Table 2 in the Data Analysis section.
17. Measure the outside diameter of the beaker to determine the radius of the coil and record this value in Table 2.
18. Repeat the data collection steps for the other four coils. Record all corresponding magnetic field and radius values into Table 2.

Data Analysis

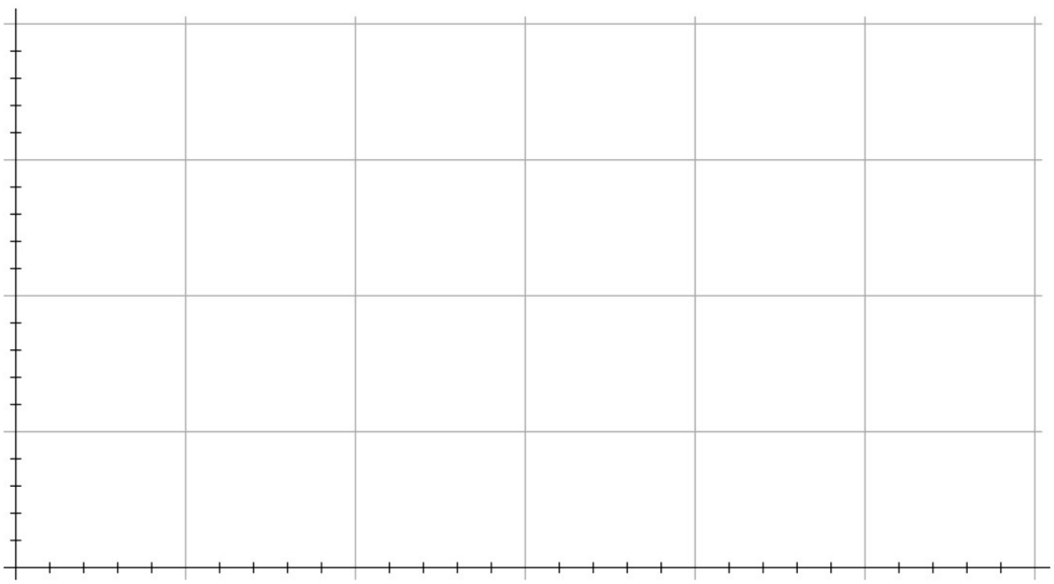
Part 1 – Magnetic Field and Current

Table 1: Magnetic field and current for a current-carrying coil with constant radius

Current (A)	Magnetic Field (mT)
0.50	
1.0	
1.5	
2.0	
2.5	
3.0	

1. Plot a graph of *magnetic field* versus *current* in the blank Graph 1 axes. Be sure to label both axes with the correct scale and units.

Graph 1: Magnetic field versus current of a current-carrying coil with constant radius



2. Draw a line of best fit through your data in Graph 1. Determine and record the equation of the line here:

   Best fit line equation: ________________________________

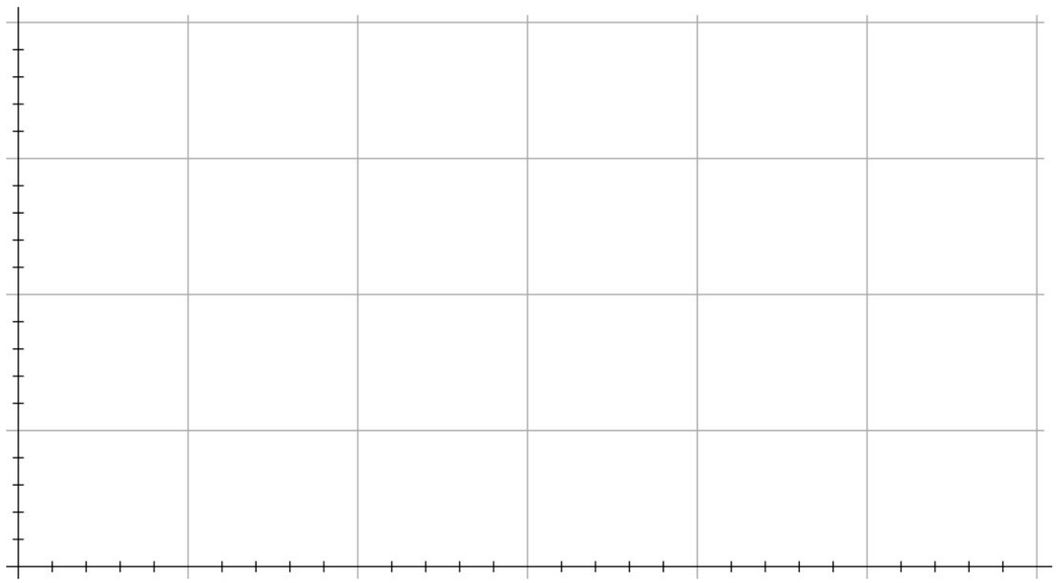
Part 2 – Magnetic Field and Radius

Table 2: Change in magnetic field as the coil radius changes, keeping the current constant

Radius (cm)	1/Radius (cm^{-1})	Magnetic Field (mT)

3. Plot a graph of *magnetic field* versus *radius* in the blank Graph 2 axes. Be sure to label both axes with the correct scale and units.

Graph 2: Magnetic field versus radius of a current-carrying coil with constant current



4. How does the magnetic field change as the radius increases?

____

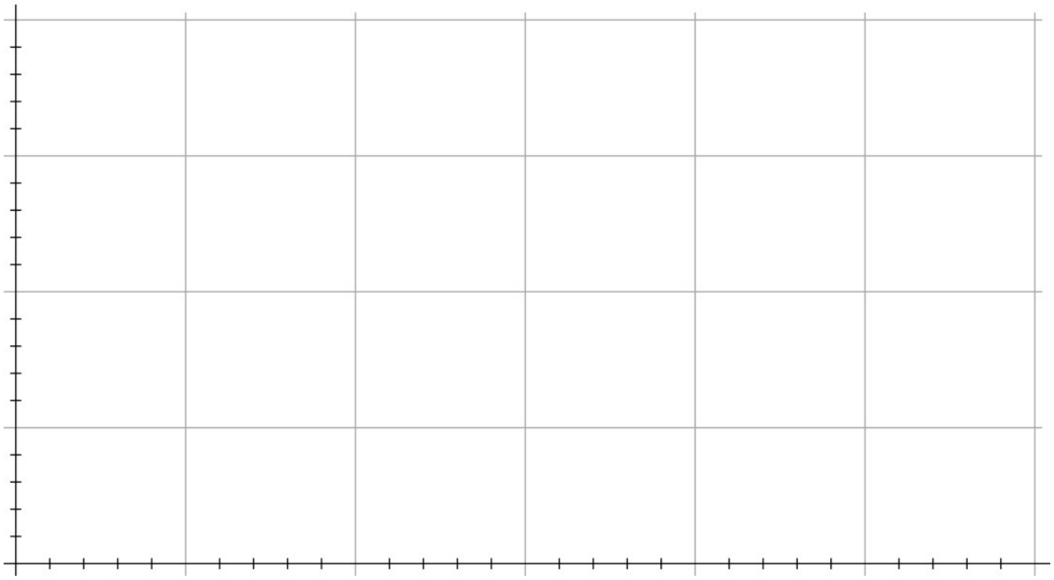
____

____

5. Calculate the inverse radius (1/radius) for each coil and record the results in Table 2.

6. Plot a graph of *magnetic field* versus 1/*radius* in the blank Graph 3 axes. Be sure to label both axes with the correct scale and units.

Graph 3: Magnetic field versus 1/radius of a current-carrying coil with constant current



7. Draw a line of best fit through your data in Graph 2. Determine and record the equation of the line here:

   Best fit line equation: ____

Analysis Questions

1. Based on your data, how is the magnetic field mathematically related to the current in a current-carrying coil? Use terms such as proportional, inversely proportional, linear, or quadratic in your response.

2. Based on your data, how is the magnetic field mathematically related to the radius of a current-carrying coil? Use terms such as proportional, inversely proportional, linear, or quadratic in your response.

❓ 3. The magnetic field B created by a long, straight, current-carrying wire is given by the equation

$$B = \frac{\mu_0}{2\pi}\frac{I}{r}$$

where I is the current, r is the distance from the wire to the point where the magnetic field is measured, and μ_0 is the vacuum permeability constant. How is your data related to this equation?

____

____

____

❓ 4. The magnetic field at the center of a current-carrying coil is given by the equation

$$B = N\frac{\mu_0}{2}\frac{I}{r}$$

where N is the number of loops and r is the radius of the coil. Use the slope value from a best fit line of a magnetic field strength versus inverse radius graph to determine an experimental value for the vacuum permeability constant μ_0.

❓ 5. Calculate the percent error between your experimental value and the actual value of the vacuum permeability constant μ_0: $4\pi \times 10^{-7}$ T·m/A.

$$\text{Percent error} = \left|\frac{\text{Actual} - \text{Experimental}}{\text{Actual}}\right| \times 100$$

❓ 6. What are factors that might have caused error in your experimental value for the vacuum permeability constant?

____

____

____

Synthesis Questions

❷ 1. A current of 5 A is flowing in a 3-m long straight wire.

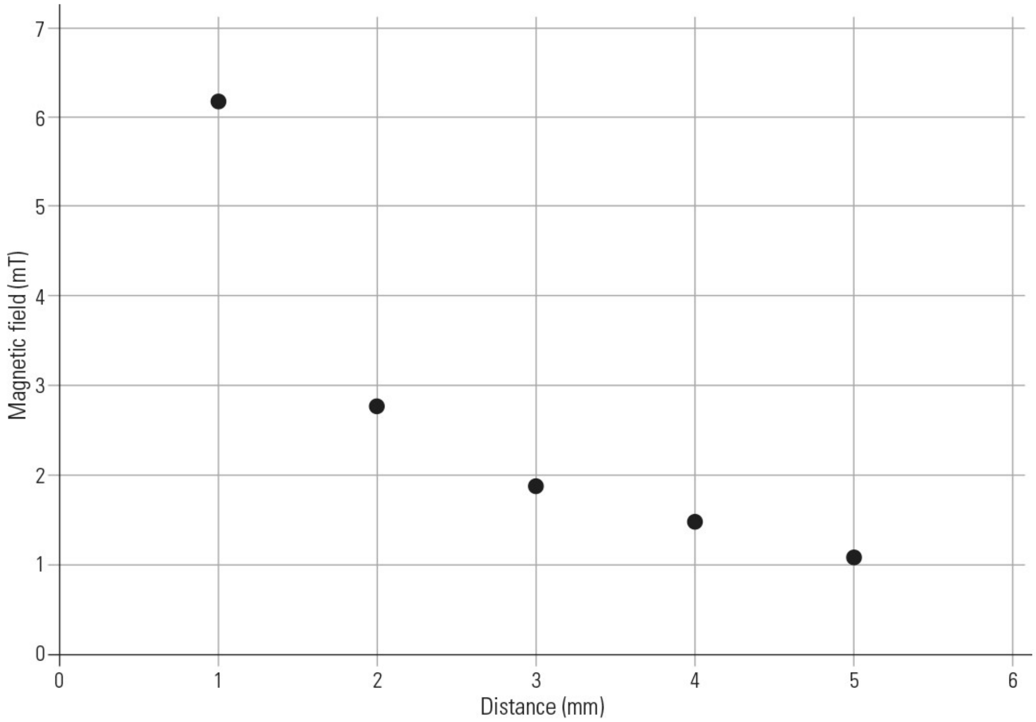
   a. If one loop is created with this wire, what would be the magnetic field at the center of the loop?

   b. If the wire is straightened, what would be the magnetic field at a distance from the wire equal to the radius of the loop?

   c. Why is the magnetic field stronger at the center of the loop than at the same distance from the straight wire even though the same length of wire and same current are used?

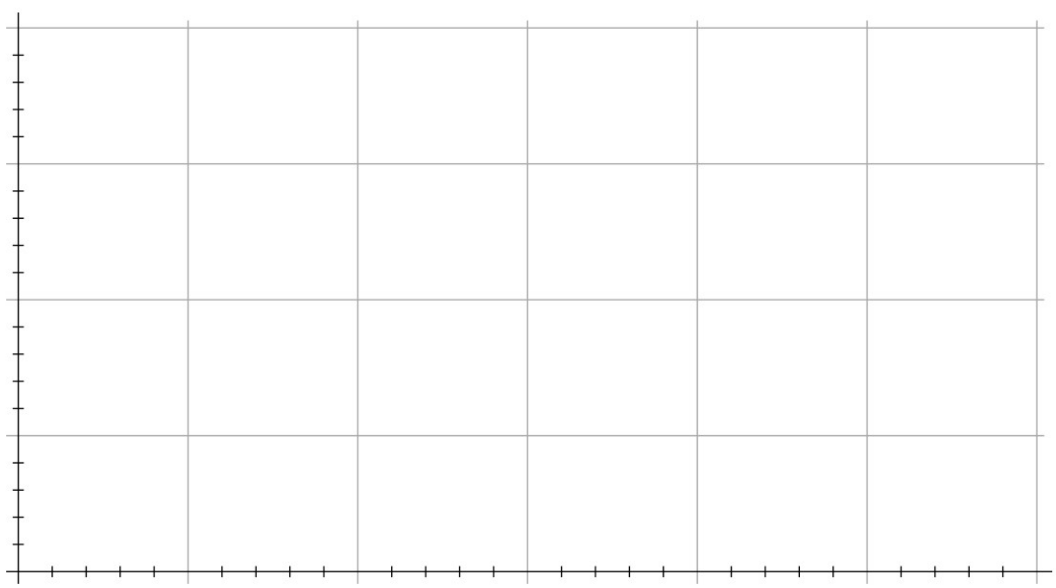
❷ 2. Graph 4 shows sample data of magnetic field versus distance for the magnetic field created by a long, straight, current-carrying wire.

Graph 4: Sample data of magnetic field versus distance for a long, straight, current-carrying wire



a. Linearize the data in Graph 4 and then plot that data in Graph 5.

Graph 5: Linearized data of magnetic field versus distance for a long, straight, current-carrying wire



b. Draw a line of best fit through your data in Graph 5. Determine and record the equation of the line here:

Best fit line equation: ____________________________

c. Use the slope in the best fit line equation to determine the current through the wire.

d. How much current would be required in a single loop with a radius of 1.0 mm to create a magnetic field of the same magnitude as that obtained 1 mm from the straight wire?

e. How much current would be required to create a magnetic field of 1.0 T at a distance of 1.0 mm from the straight wire?