Biot-Savart law: a coil

FizziQ activity · High school · 45 min

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Students measure the magnetic field of a current-carrying coil with the smartphone magnetometer in FizziQ and plot B against I to verify the Biot-Savart law.

Learning objectives

- Measure the magnetic field produced by a current-carrying coil using the smartphone magnetometer
- Vary the current intensity and record the corresponding magnetic field values
- Plot the graph B = f(I) and verify the linear relationship predicted by the Biot-Savart law
- Determine the proportionality constant and relate it to the coil geometry and μ_0
- Identify and evaluate experimental sources of error in magnetometric measurements

Instruments and sensors

Magnetic field meter (Y-component) · Magnetometer

Materials

- Smartphone with the FizziQ application (magnetometer)
- A coil or solenoid
- An adjustable direct current generator
- Connection wires
- A multimeter (optional) to measure precise current
- FizziQ experiment notebook (data logging and curve fitting)
- Note: the protocol remains adaptable to any comparable magnetic field measurement tool.

Protocol

1. Assemble the circuit: connect the coil (or solenoid) to the adjustable DC power supply using connection wires. Insert an ammeter (or multimeter in current mode) in series to measure the current precisely.
2. Open FizziQ and select the Magnetometer sensor. Choose the Y-component of the magnetic field (the component aligned with the coil axis).
3. Before powering on the circuit, calibrate the magnetometer by recording the baseline reading. This accounts for the Earth's magnetic field and any nearby magnetic sources. Note this as B_0.
4. Position the smartphone so that its Y-axis is aligned with the axis of the coil, with the sensor at the center of the coil. Secure the phone so it does not move during the experiment.
5. Set the power supply to the lowest current setting (e.g., 0.1 A). Turn on the circuit and wait 5 seconds for the reading to stabilize. Record both the current (I) and the magnetic field reading (B).
6. Calculate the net field produced by the coil: $B_{coil} = B - B_0$ (subtract the baseline).
7. Increase the current by 0.1 A increments (or appropriate steps for your power supply), recording B and I at each step. Collect at least 8-10 data points.
8. Do not exceed the maximum recommended current for your coil to avoid overheating. If the coil becomes warm, pause between measurements.
9. Enter all data pairs (I, B_coil) in the FizziQ notebook and plot the graph B_coil vs. I.
10. Use the FizziQ curve fitting tool to fit a straight line to the data: B = kI. Record the slope k.
11. Compare the measured slope with the theoretical prediction: for a solenoid, $k = \mu_0 \times n$, where $\mu_0 = 4\pi\times10^{-7}$ T·m/A and n is the number of turns per unit length.

12. Discuss the quality of the linear fit, identify any outliers, and evaluate whether the Biot-Savart law is confirmed by your data.

Expected results

The graph of B_coil versus I should be a straight line passing through or very near the origin, confirming the proportionality predicted by the Biot-Savart law. The slope of the line depends on the coil geometry: for a solenoid with n turns per meter, the theoretical slope is $\mu_0 n$. For example, a solenoid with 1000 turns/m would produce a slope of about 1.26×10^{-3} T/A = 1.26 mT/A. The typical magnetic field values measured will range from a few microtesla (at low currents) to a few hundred microtesla (at higher currents). The coefficient of determination R^2 should exceed 0.98 for careful measurements. Deviations from perfect linearity may occur at high currents (due to coil heating changing resistance) or at very low currents (where the coil field is comparable to environmental magnetic noise). Students should expect measurement uncertainty of ±0.5-1 µT from the magnetometer and ±0.01 A from the ammeter.

Questions

- Why is the magnetic field at the center of a coil proportional to the current? What happens if the current doubles?
- How would the results change if you used a coil with twice as many turns?
- What are the main sources of error in this experiment, and which one contributes most to the uncertainty?
- Why is it important to calibrate the magnetometer before starting the measurements?
- How is the Biot-Savart law applied in the design of MRI machines or electric motors?
- What would happen if you measured the magnetic field at a point off the axis of the coil?

Going further

- Investigate the variation of the magnetic field along the axis of the solenoid (B vs. position) at constant current
- Compare the magnetic field of a single coil with that of a multi-layer solenoid
- Reverse the direction of the current and verify that the magnetic field direction reverses
- Measure the magnetic field at different distances from a long straight wire (instead of a coil) to verify the 1/r dependence
- Use two coils in Helmholtz configuration (same current, same direction, separated by one radius) and map the resulting nearly uniform field