Electromagnets – ID: 12631

Time required
45 minutes

Topic: Electricity and Magnetism

- *Describe the magnetic field around an electromagnet.*
- *Relate the strength of a solenoid-type electromagnet to the number of turns of wire on the electromagnet.*

Activity Overview

In this activity, students will create a solenoid-type electromagnet using two different methods of coiling the wire around the core. They will use a sensor to determine the relationship between the number of turns of wire and the magnetic field strength for each method.

Materials

To complete this activity, each student pair or student group will require the following:

- *TI-Nspire™ technology*
- *Vernier Magnetic Field Sensor*
- *Vernier EasyLink™or Go!®Link interface*
- *16-gauge electrical wire (at least 1.5 m)*
- *iron or steel nail or bolt, at least 8 cm long and 1 cm in diameter*
- *electrical tape*
- *blank sheet of paper*
- *pen or pencil*
- *two D-cell batteries*
- *wire strippers (if the wire is insulated)*
- *masking tape (optional)*

TI-Nspire Applications

Notes, Data & Statistics

Teacher Preparation

Students may not have experimented with electromagnets before. You may wish to allow them to experiment with the materials to explore electromagnets qualitatively before carrying out the activity.

- *Make sure the batteries students are using are fully charged. This investigation can be done with a single battery per student pair, but the resulting magnetic fields will be weaker.*
- *If the wire students use is not insulated, they should wrap electrical tape around the parts of the wire they will touch. The wire may become warm as current flows through it, and the electrical tape will help prevent burns. If the wire is insulated, students should use the wire strippers to remove about 2 cm of the insulation from each end of the wire. Alternatively, you may strip the wire for the students.*
- *The screenshots on pages 2–6 demonstrate expected student results. Refer to the screenshots on page 7 for a preview of the student TI-Nspire document (.tns file).*
- ***To download the .tns file, go to education.ti.com/exchange and enter "12631" in the search box.***

Classroom Management

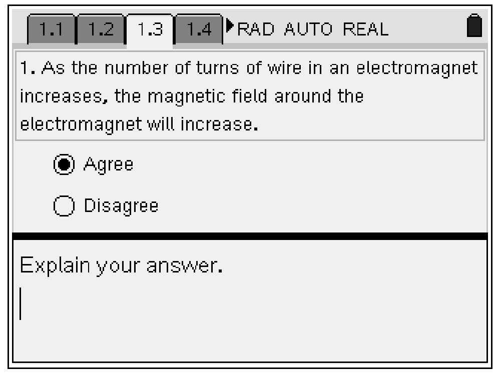
- *This activity is designed to be* ***student-centered****, with the teacher acting as a facilitator while students work cooperatively. Students can answer the questions in the .tns file using the Notes application or on blank paper.*
- *In some cases, these instructions are specific to those students using TI-Nspire handheld devices, but the activity can easily be done using TI-Nspire computer software.*

The following questions will guide student exploration in this activity:

- How does the method of wrapping wire around a core affect the magnetic field around an electromagnet?
- How does the number of turns of wire around a core affect the intensity of the magnetic field around an electromagnet?

Students will first create an electromagnet by progressively wrapping wire around the full length of the core. They will collect data on how the number of turns of wire on the core affects the magnitude of the magnetic field around the electromagnet. They will then repeat the experiment, but they will "stack" the successive coils around the same part of the core.

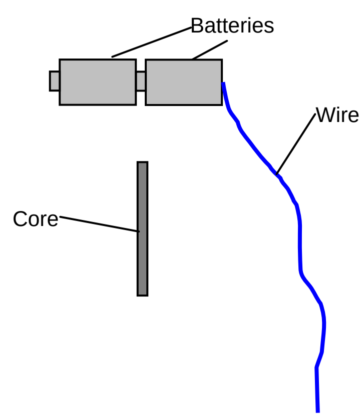
Problem 1 – Progressively wrapped coils



Step 1: Students should open the file **PhysWeek34_electromagnets.tns** and read the first two pages. They should then answer question 1, which is an agree/disagree question. (Students can press ctrl tab to move between the question and the explanation section.)

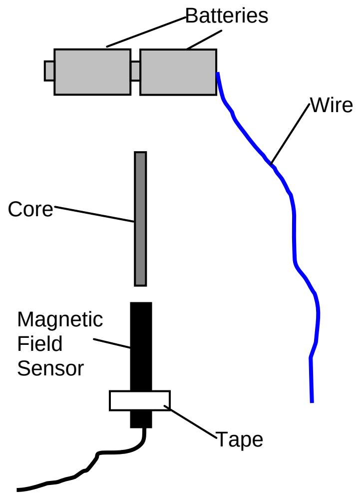
Q1. As the number of turns of wire in an electromagnet increases, the magnetic field around the electromagnet will increase.

A. *There is no correct answer to this question; students are asked whether they agree with the statement and then asked to explain their answers. Encourage students to be as specific as possible in their explanations.*

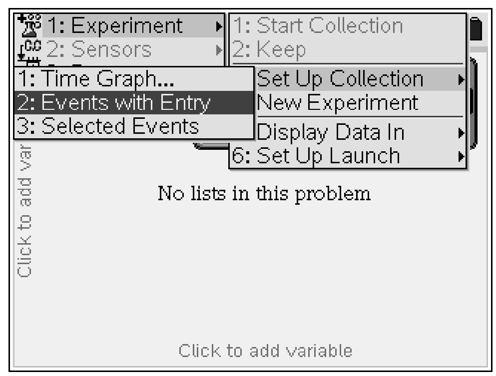


Step 2: Next, students should read page 1.4 and then set up the batteries, wire, and core as shown to the right. (Make sure students mark the position of the core so that they can accurately reposition it for each trial. Students should use electrical tape to tape the batteries together.) They should use masking tape or electrical tape to hold the batteries in place on the table top. They should also use electrical tape to tape one end of the wire to the negative terminal of the battery. They should then connect a Vernier Magnetic Field Sensor to an EasyLink interface (if using a handheld) or a Go!Link interface (if using a computer). They should set the range switch on the Magnetic Field Sensor to the 6.4 mT setting.

Step 3: Students should connect the interface to their handhelds or computers. When prompted, they should choose to display their data in a new *Data & Statistics* application.



Step 4: Students should tape the Magnetic Field Sensor down so that its tip is about 1 cm away from one of the ends of the core of the electromagnet, as shown to the right. They should wait for the magnetic field reading to stabilize and then zero the sensor (**Menu > Sensors > Zero**). Students will probably get better results if they change the units displayed from millitesla (mT) to gauss (G). Students can change the units from the **Sensors** menu (**Menu > Sensors > Units**).



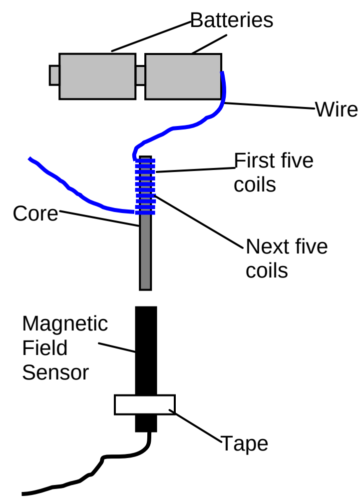
Step 5: Next, students should set up the data collection software to **Events with Entry** mode (**Menu > Experiment > Set Up Collection > Events with Entry**).

Step 6: Students should wrap the wire around the end of the core that is farther from the Magnetic Field Sensor. They should wrap the wire so that there are five coils of wire around the core. They should use electrical tape to hold the wire in place around the core. (Make sure students wrap the wire around the core such that the turns of wire are touching. Students will need to keep the density of turns constant as they add more wire, so they should wrap the wire compactly enough that they can fit a large number of turns on the core.)

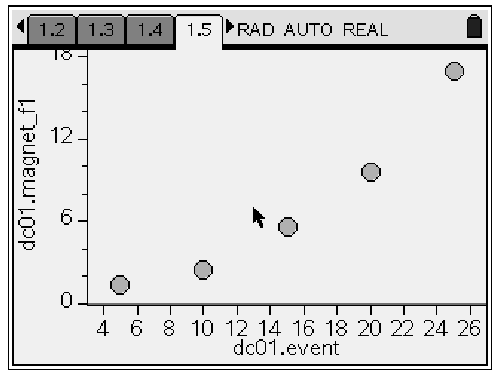
Step 7: Students should touch the free end of the wire to the free positive terminal of the battery pair. They should make sure the wire makes good contact with the terminal.

Step 8: Once the magnetic field reading has stabilized, students should collect a data point. They should use 5 for the data value (because there are five turns of wire around the core). Once they have collected the data point, they should move the free end of the wire away from the positive battery terminal.

Step 9: Next, students should wrap five more coils of wire around the core, immediately next to the previous coils, as shown to the right. They should again use electrical tape to hold the wire in place. They should then replace the electromagnet in its original position. (They may need to use masking or electrical tape to hold the electromagnet in position.)



Step 10: Students should repeat steps 7–9 until they have wrapped the wire along the entire length of the core. (For the sample data shown, the core was able to accommodate 25 coils of wire.) For each data point, students should use the number of coils on the core as the data value.



Step 11: Once they have collected all their data, students should end the data collection, close the data collection box, and disconnect the interface. They should examine their data and answer questions 2–4.

Q2. Was your answer to question 1 correct? If not, explain the errors in your reasoning.

A. *Students' answers will vary. Encourage metacognitive thinking to help students identify errors in their reasoning.*

Q3. Describe the relationship between the number of coils in the electromagnet and the strength of the magnetic field around the electromagnet.

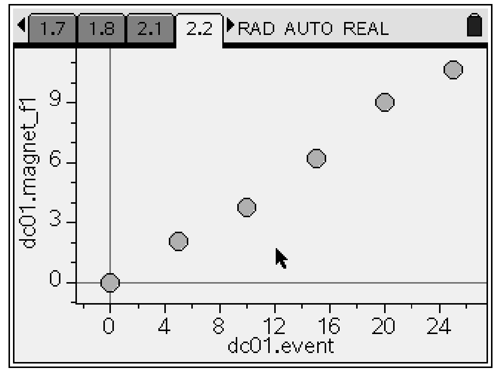
A. *As the number of coils of wire around the core increases, the magnetic field around the electromagnet increases.*

Q4. Explain the shape of the graph.

A. *The graphs should be nonlinear. The nonlinearity is a result of the progressive lengthening of the electromagnet as the number of coils increases. (The electromagnet is properly defined to be the coils of wire and the portion of the core enclosed by those coils. Therefore, the part of the core that extends past the coils is not included in the length of the electromagnet.) As more coils are added, the length of the electromagnet increases. In addition, the "end" of the electromagnet moves closer to the Magnetic Field Sensor. These two effects combine to yield the nonlinear relationship seen in the graph. If you wish, you may have students experiment with different patterns of wrapping—for example, have them start wrapping the coils at the end of the core that is closer to the Magnetic Field Sensor and wrap successive coils farther and farther from the sensor. Students can explore how the pattern of wrapping affects the magnetic field. If you wish, you may also have students use the Regression tool to identify the best-fit curve for the data. (A quadratic curve will most likely provide the best fit.) If you wish, you may have students extend this activity by asking them to predict what will happen if they remove the nail from the electromagnet to leave only a solenoid. Have them remove the nail and measure the magnetic field produced by the coil (the solenoid). Encourage them to discuss their predictions and results.*

Problem 2 – "Stacked" coils

Step 1: Students should read the text on page 2.1. They should then repeat steps 3–10 from problem 1, with the following exceptions: Instead of wrapping the first five coils of wire around the end of the core, students should wrap them around the middle of the core, and instead of wrapping successive coils along the length of the core, students should wrap successive coils on top of one another (making the coil of wire around the core quite thick).



Step 2: Students should collect data for the same number of coils that they collected data for in problem 1. For example, if they were able to fit 25 coils of wire on the core in problem 1, they should collect data for up to 25 coils of wire for this data set, as well. Once students have collected all their data, they should answer questions 5 and 6.

Q5. Compare the graph of field strength vs. number of turns for the stacked wire to the graph for progressive wrapping (from problem 1). Explain any differences.

A. *In both cases, the magnetic field strength around the electromagnet increases as the number of turns increases. However, when the coils are stacked, the increase is approximately linear, instead of having the nonlinear relationship apparent in the progressively wrapped electromagnet. Stacking the coils removes the effects of varying length and distance from the Magnetic Field Sensor that caused the nonlinearities in the progressively wrapped electromagnet. Therefore, the stacked coils more accurately represent an idealized electromagnet, in which magnetic field strength is linearly proportional to the number of coils per unit length of the electromagnet. If you wish, you may have students use the Regression tool to identify the best-fit equation for the data. If you wish, you may have students carry out another extension activity to test the effects of current on magnetic field strength. Students should design and carry out an experiment to test the effects of increasing the number of batteries (i.e., the current) in the circuit. Encourage them to discuss their results. They could also try connecting the batteries in parallel, as well as in series, to explore the effect.*

Q6. Which of the following solenoid-type electromagnets would probably have the strongest magnetic field? Assume current is the same in all of the electromagnets and that the coils of wire extend for the full length of each electromagnet.

A. *B; the relevant parameter in determining magnetic field strength (assuming current is constant) is the number of coils per unit length of the electromagnet. The electromagnet in the second option has the highest coil density: 3 coils/cm.*

Electromagnets – ID: 12631

(Student)TI-Nspire File: *PhysWeek34_electromagnets.tns*

1.1 1.2 1.3 1.4 RAD AUTO REAL

ELECTROMAGNETS

Physics

Electricity and Magnetism

1.1 1.2 1.3 1.4 RAD AUTO REAL

A solenoid is a coil of wire. When current runs through the wire, a magnetic field forms around the solenoid. The magnetic field can be increased by wrapping the wire around a magnetically susceptible core (such as an iron or steel rod).

1.1 1.2 1.3 1.4 RAD AUTO REAL

1. As the number of turns of wire in an electromagnet increases, the magnetic field around the electromagnet will increase.

- ◯ Agree
- ◯ Disagree

Explain your answer.

1.1 1.2 1.3 1.4 RAD AUTO REAL

Create an electromagnet (specifically, a solenoid with an iron or steel core) using wire, a battery, and a nail or bolt. Investigate the relationship between the number of turns of wire in the solenoid and the strength of the magnetic field around the solenoid.

1.2 1.3 1.4 1.5 RAD AUTO REAL

2. Was your answer to question 1 correct? If not, explain the errors in your reasoning.

1.3 1.4 1.5 1.6 RAD AUTO REAL

3. Describe the relationship between the number of coils in the electromagnet and the strength of the magnetic field around the electromagnet.

1.4 1.5 1.6 1.7 RAD AUTO REAL

4. Explain the shape of the graph.

1.5 1.6 1.7 2.1 RAD AUTO REAL

Repeat your investigation, but instead of adding turns along the length of the nail or bolt, stack the turns of wire on top of one another.

1.6 1.7 2.1 2.2 RAD AUTO REAL

5. Compare the graph of field strength vs. number of turns for the stacked wire to the graph for successive wrapping. Explain any differences.

1.7 2.1 2.2 2.3 RAD AUTO REAL

6. Which of the following solenoid-type electromagnets would probably have the strongest magnetic field? Assume current is the same in all of the electromagnets, and that the coils of wire extend for the full length of each electromagnet.

- ◯ 5 cm long, 10 coils
- ◯ 2 cm long, 6 coils
- ◯ 8 cm long, 8 coils