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Performing various measures to study the magnetic field intensity variations around an inducting coil

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Objective

The goal of the activity is to investigate the surroundings of an isolated copper coil, fed with a low voltage direct current source. Using the Biot-Savart law, measurments of magnetic flux intensity in different directions around the coil will allow students to determine the field-line distribution in space.

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Introduction and theory

There is a constantly increasing amount of uses given to magnets and induced magnetic fields. Much of modern technology uses electro-magnetic induction as an electrical power source, but we know very little about the effects that magnets or the geometric characteristics of coils have on the resulting field-line space-distribution around them. An example of this can be given by comparing the amount of iron dust that a magnetized nail attracts to different curvatures on its surface.

? **How are distance and orientation relevant to interactions between magnets?**

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Introduction and theory

What action do you have to perform in order to identify the presence of a magnetic field?

What is the main feature of magnetic field lines?

Theoretical

It is well known that magnetic fields originate due to the presence of an electric current or a stream of moving charged particles (Oersted's experiment). It is also known by Galilean relativity that movement directions depend on relative position. The Biot-Savart law presents a mathematical expression for the magnitude and direction in a certain point in space of the magnetic field intensity (B) generated by a current (I) at a distance (R) of such point.

$$\vec{B} = \frac{\mu_0 I}{2\pi \cdot R}\left(\hat{i} \times \hat{r}\right)$$

Magnetic field intensity → $\vec{B}$

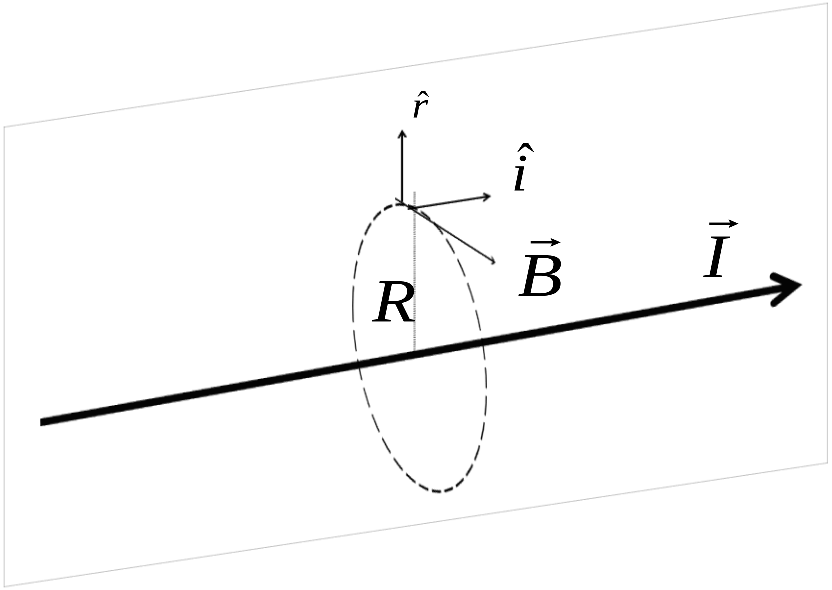
Electric current → I

Distance to curent → R

Direction of field line → $\left(\hat{i} \times \hat{r}\right)$

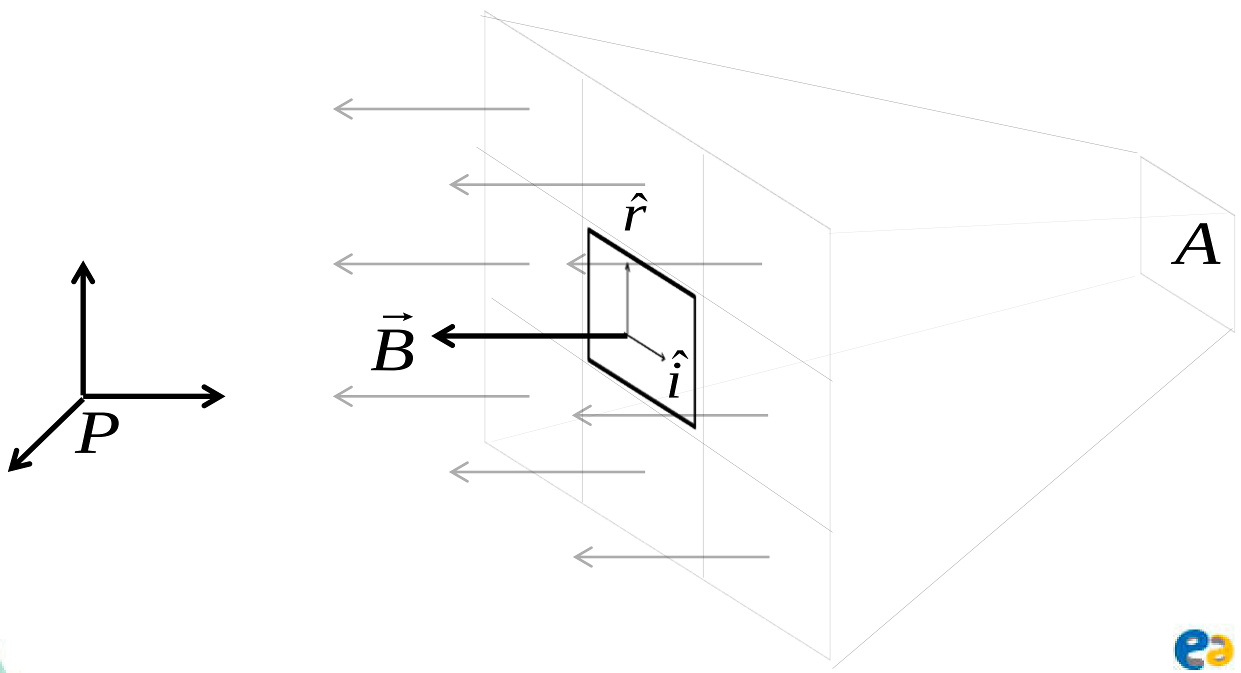
Introduction and theory

Magnetic field intensity is then a quantity that indicates a specific magnitude and direction of effect on every point around the electric current. This direction is always perpendicular to both current and position directions and it points out according to the vector product between each one's unitary vectors.



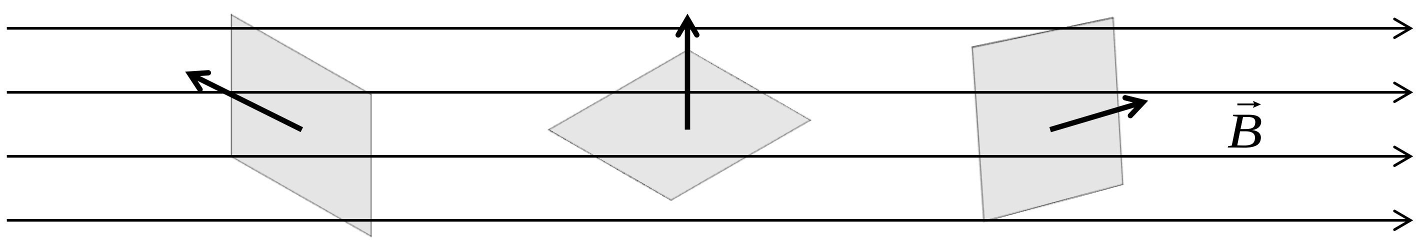
Introduction and theory

Now, to determine a specific direction for a measure of magnetic field intensity from a certain point "P", the perpendicular plane of this direction - containing both current and relative position between current and measuring area directions is used. Thus, a generalization for magnetic intensity in space is made, as the amount of field lines that perpendicularly cross a certain amount of surface.



This generalization allows us to interpret measures of magnetic field intensity as a flux density per unit of area, showing the amount and direction of magnetic lines in space that cross a certain oriented surface.

Magnetic flux → $$\Phi = \vec{B} \bullet \vec{A}$$ ← Surface unit



$\Phi < 0$ $\Phi = 0$ $\Phi > 0$

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Introduction and theory

Now students are encouraged to raise a hypothesis which must be tested with an experiment.

?

If a magnetic sensor is used to measure intensity along the interior and exterior of an electrified coil, how similar would the results be? How will the field lines behave near the coil's edges?

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Activity description

Students will measure magnetic intensity along an electrified coil's axis, an exterior parallel line to the axis and an exterior perpendicular line to the axis. To perform these measurements they will use the Labdisc magnetic sensor.

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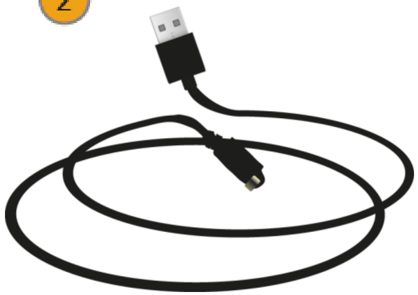
Resources and materials

1. Labdisc magnetic sensor
2. USB cable
3. 5vDC power source

- 30 cm plastic ruler
- 65 turns and 4.5 cm diameter isolated 1 mm copper coil

1

2



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Biot-Savart Law

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Using the Labdisc

Labdisc configuration

To collect intensity measurements with the Labdisc magnetic sensor, follow these steps:

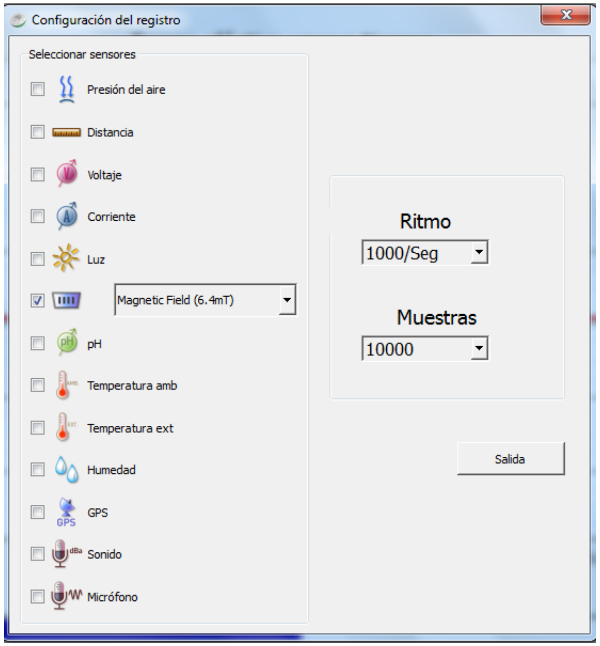
1. Open the GlobiLab software and turn on the Labdisc.

2. Click on the Bluetooth icon in the bottom right corner of the GlobiLab screen. Select the Labdisc you are using currently. Once the Labdisc has been recognized by the software, the icon will change from a grey to blue color 

.
If you prefer a USB connection follow the previous instruction clicking on the USB icon. You will see the same color change when the Labdisc is recognized 

.

3 Click on  to configure the Labdisc. Select “Magnetic Field” in the “Logger Setup” window, enter “1000/Sec” for the sample frequency and enter “10000” for the number of samples.



Using the Labdisc

4. Once you have finished the sensor configuration start measuring by clicking .
5. Once you have finished measuring stop the Labdisc by clicking .

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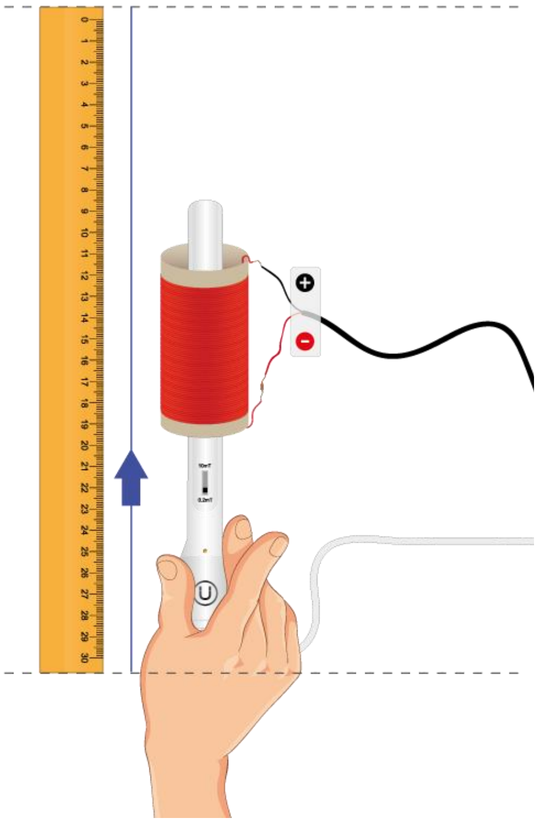
Experiment



1. Set the components as shown in the picture.

2. Move the probe as indicated by the arrow line.

    - Keep a steady rate of 3 cm/sec

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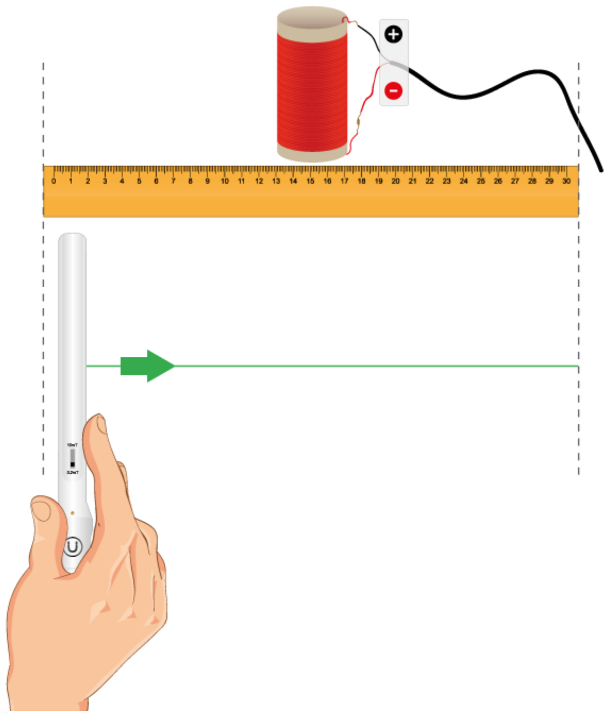
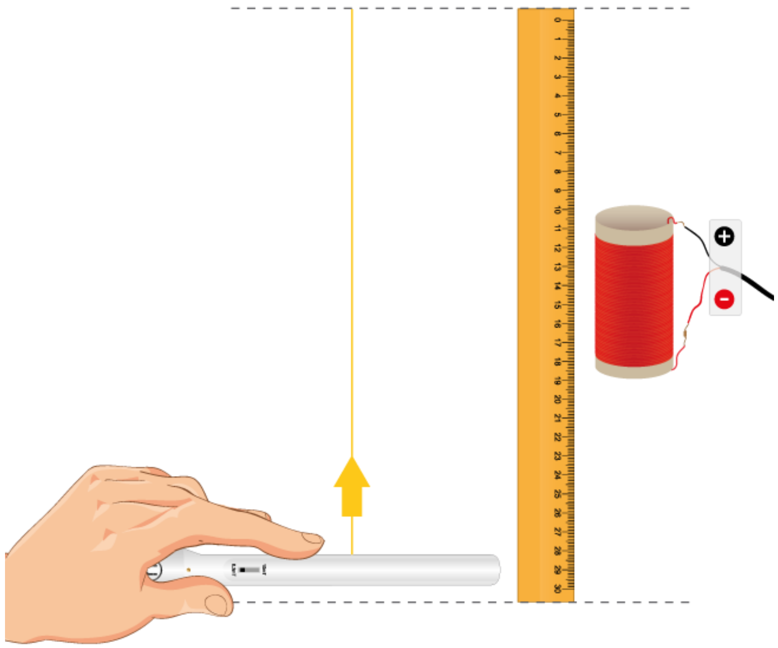
Experiment

3 Repeat the procedure above using these two other configurations:





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Results and analysis

1. In each of the graphs indicate the points where the plot’s curvature changes using the two tools: and
2. Consider your movement of the probe as a constant speed of 3 cm/sec for each case and use the time scale as a distance scale.
3. After this, use the tool to relate these points with special features of the coil.

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Results and analysis

Compare the measurements at the middle, center and edges of the coil in all graphs. How do these relate to your initial hypothesis?

What do negative values represent on the graphs?

What relation has the (+) and (-) power source connection set up on the results?

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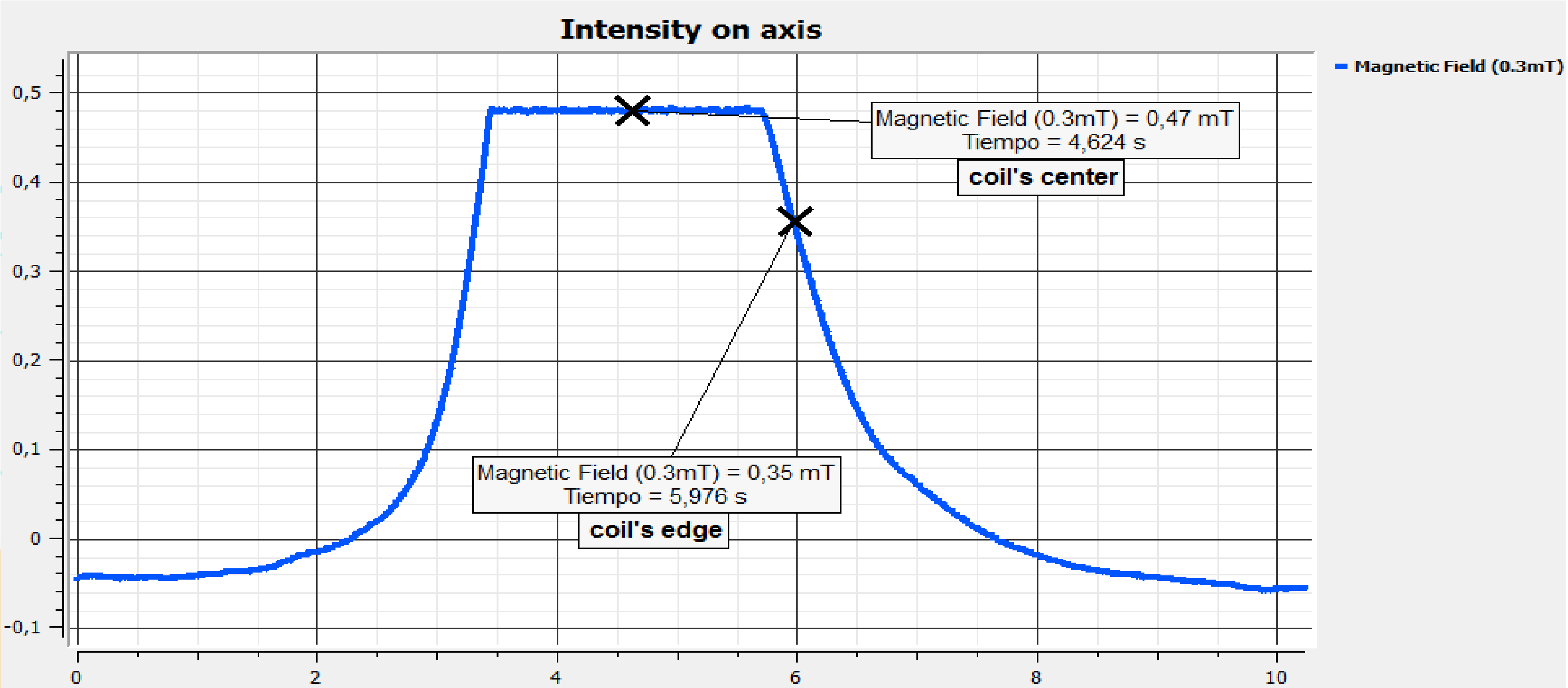
Results and analysis

The graph below should be similar to the one the students came up with:



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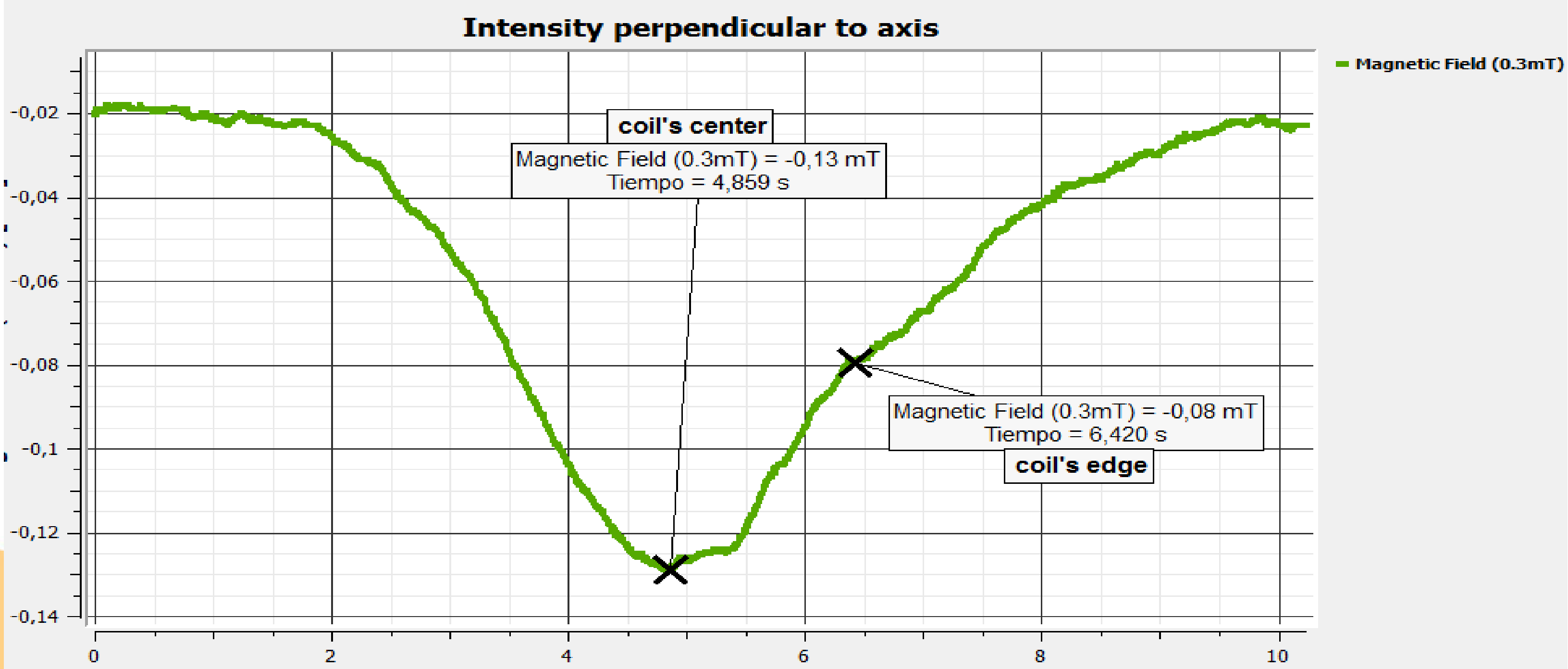

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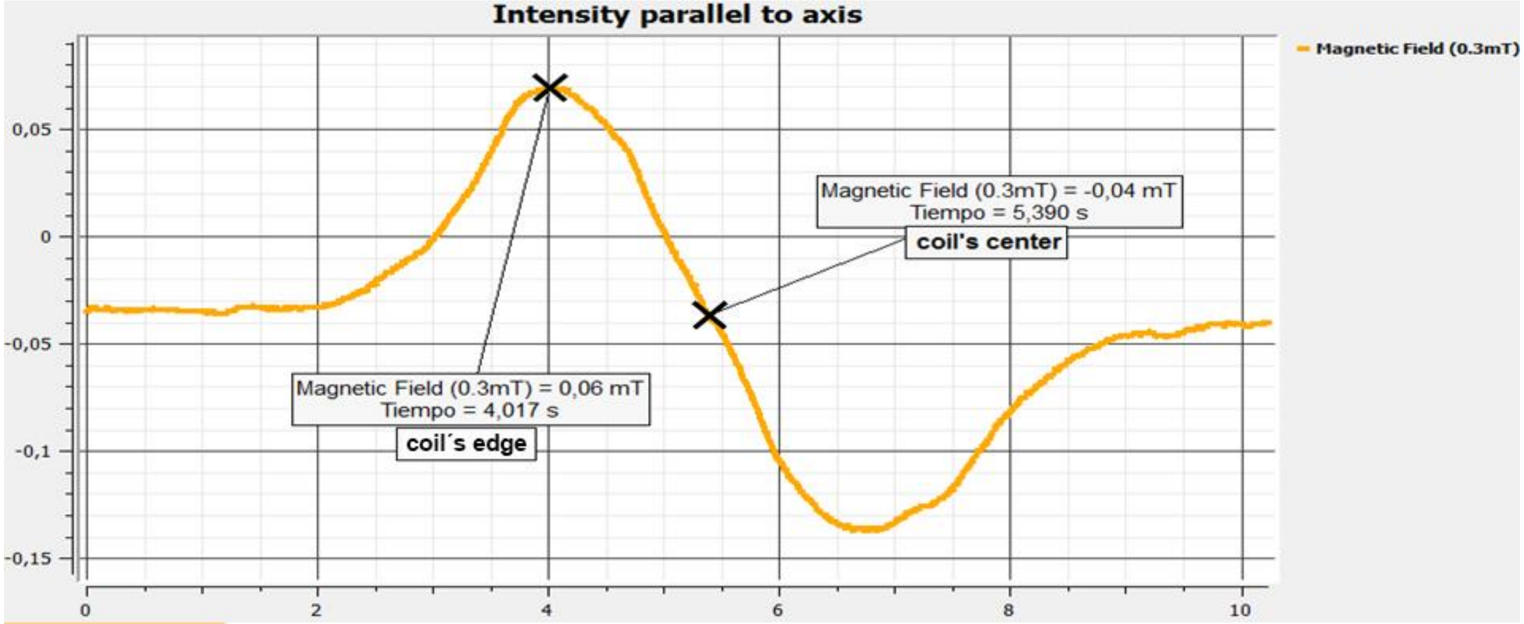

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Conclusion

For each graph, determine the regions where magnetic field lines are more compressed. Is there a relation between them and the coil's geometry?

Students could present any graph according to the position of the sensor and the coil in each case. They could account the relation between the curvature changes on the graph and the field line distribution variations near the coil edges, center, and middle part.

Consider, for all three graphs the Biot-Savart law and the (+) and (-) connection set up to predict the direction of the field lines near both edges of the coil. Is this prediction consistent with the results?

Students could determine and draw the direction of the field lines around each of the coil's edges and surroundings using the coil's cylindrical symmetry, the Biot-Savart law, and the results from all three measurements.

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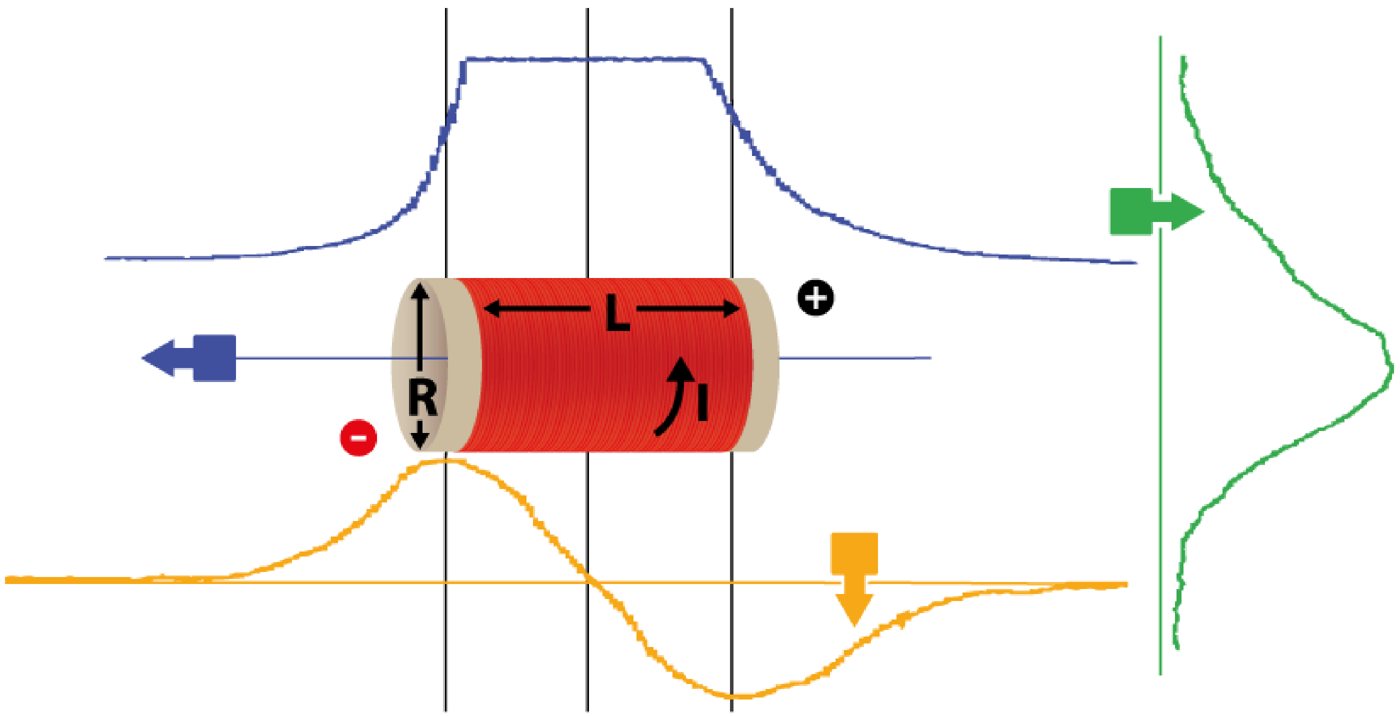
Conclusion



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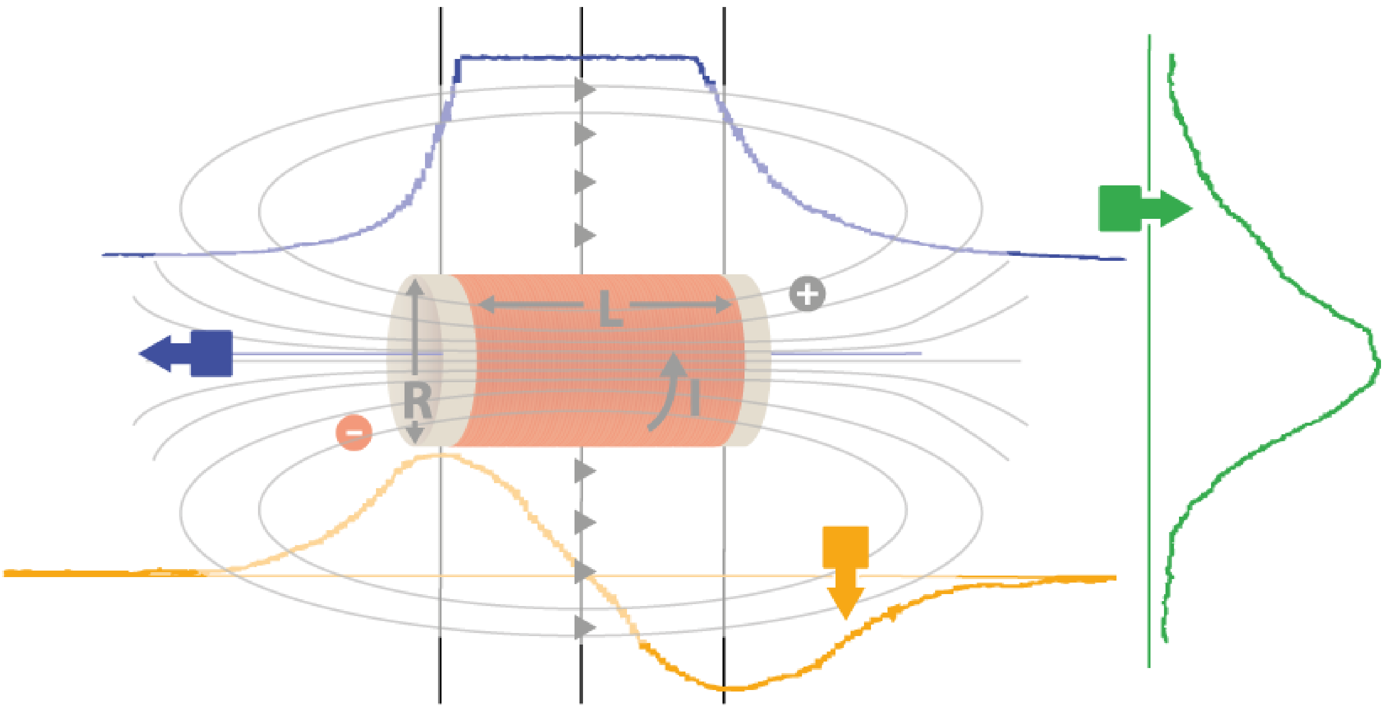

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Activities for further application

Can this knowledge be useful for creating strong magnetic fields?

Students could recognize that magnetic intensity is related with the amount and direction of field lines that cross a certain surface in a certain region of space. Thus, by studying the space distribution of field lines in different configurations of magnets and coils, it is possible to design specific systems that can bend or accumulate them in a small region.

What effect can a moving magnet have on a piece of conductor wire? Is this effect any different if the wire is curved as a ring? Use the Biot-Savart law to justify your answer and the Labdisc magnetic sensor to test it.

Students can justify their answer by using the vector product between current and relative position directions as a reference for field direction. Then determine the magnetic flux variation across the area that is constrained by the wire ring.

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