

MAGNETS

Opposites attract

This guide offers exercises and experiments at a variety of levels on magnetism. It's an opportunity to revisit the subject matter covered in the Magnetism chapter of the Explor CYT curriculum (former teaching manual for the Canton Vaud). Even though magnetism is not developed as a theme in the PER, it could be a good subject to use as the basis for a OCOM project. It's also a good foundation from which students can then do experiments for further exploration and to discover some of its technological applications.

Please note that the **MOTORS** worksheet provides an interesting application on electromagnets, allowing students to build a small motor in a single period with minimal materials required. In this document, you'll also find an interdisciplinary activity that can be undertaken in the OCOM context to build an alternator and thus generate electricity.

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Concepts covered

Physique

- Magnetism
- Electromagnets and permanent magnets
- Current and voltage
- Balance of forces

Sciences

- Magnetic field and migration

Activity duration

**Introduction to theoretical concepts
and exercices:** 4 periods

Practical activity: 3 periods

■ TERRESTRIAL MAGNETISM

Magnetism is first introduced by its most familiar concrete application, the compass. If students have never used a compass, they will have an opportunity to do so.

As is pointed out on Figure 1 in the student guide, the Earth's magnetic South Pole (confusingly called the North Pole) is very close to its geographical North Pole.

An article on the history and current research on magnetic poles:

nationalgeographic.fr/actualite/antarctique-la-traque-du-pole-sud-magnetique-continue/7913930

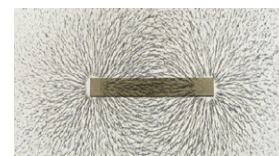
National Geographic, *Antarctique: La traque du Pôle Sud magnétique continue*, Marie Dias-Alves

Since these poles are generated by the liquid iron core of the planet which is in constant movement, the magnetic poles can move 40 km per year, and even inverse over much longer periods:

fr.wikipedia.org/wiki/Inversion_du_champ_magnetique_terrestre

Wikipédia, *Inversion du champ magnétique terrestre*

To observe the field lines around a magnet, a magnetic rod can be dusted with iron filings. Place a transparency sheet or a piece of Plexiglas over the magnet so the filings can be easily recuperated.



Extension: construct a compass using a magnetized brad fastener mounted on a pointer. A magnet can also be placed in a receptacle floating on the water, like a cork equipped with a magnetized pointer.

Here's another compass project using a geometric construction of the wind rose:

sciencejunior.fr/experiences/construire-une-boussole

Science Junior, *Expérience: construire une boussole*, Aloïs, décembre 2010

■ PERMANENT MAGNETS

Challenge

Get two nails to stick together

Students will magnetize nails using the influence of the natural magnet. They will observe the transitory effect of the magnetization of iron or other metals.

Making the magnetization disappear could be an extension of the exercise. Friction or taps accelerate the process. The intensity of the nail's magnetization can also be tested depending on its proximity to the magnet or time passed in its vicinity.

Extension: measure the force of different magnets by lifting items of different weights.

THE REVOLUTION: THE “ARTIFICIAL” OR ELECTROMAGNET

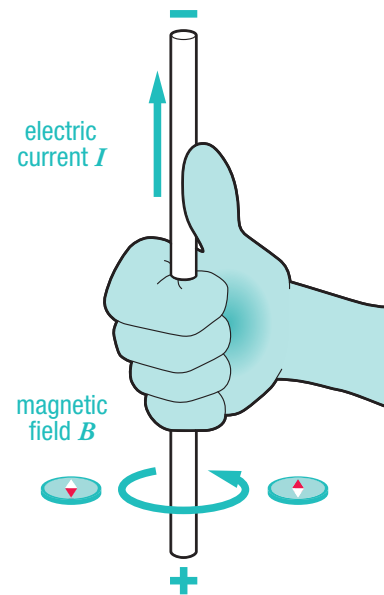
Experiment: Verify the relationship between electric current and magnetic field



In this setup, to avoid overheating the circuit, include an additional resistant element such as a lightbulb, particularly if using a generator. This is an opportunity to refer to the Joule effect, if this concept has been previously covered with students. If a battery is used, an electric wire can be briefly connected to one terminal or the other, but it heats up rapidly. In all these experiments, students must be reminded to respect warnings on devices or bulbs and not exceed specified limits.

With this experiment, students will observe that when electricity is flowing through the wire, the needle of the compass moves. The magnetic field is weak around a wire with a small current. It's thus best to install the wire in a north-south orientation. In this way they will observe a symmetrical deviation in the needle when the direction of the current is changed.

Ask the students to change the direction the current is flowing in the wire, to place the the compass to one side, over, and under the wire if they don't think of it themselves. Before or after the quiz, make sure to emphasize the orientation of the magnetic field caused by the current flowing in the wire. You can give students this tip: the right thumb is positioned along the wire in the direction of the electric current. The tips of the other fingers indicate the direction of the circular magnetic field around the wire.



Quiz

Sketch the orientation of the compass needle. The red needle indicates north.

In this exercise, we assume that the electric current in the wire is large enough that the terrestrial magnetic field is negligible compared to the field created by the current. Pay careful attention to the position of the compass in relation to the wire. (cf. remark on the experiment)

Remind students to see if the wire is above or below the compass.

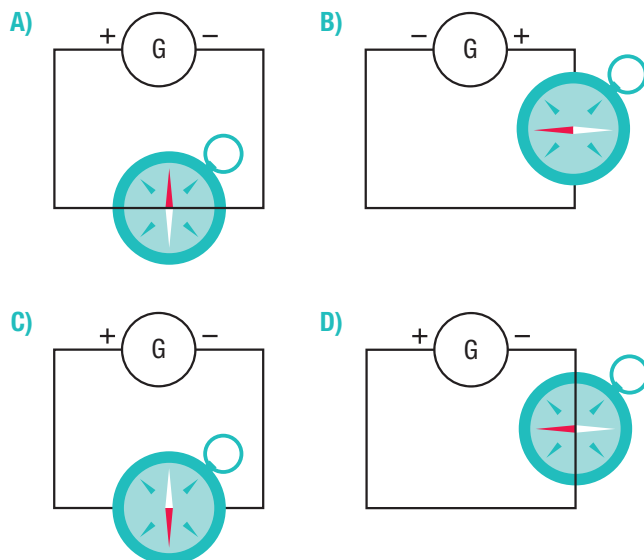
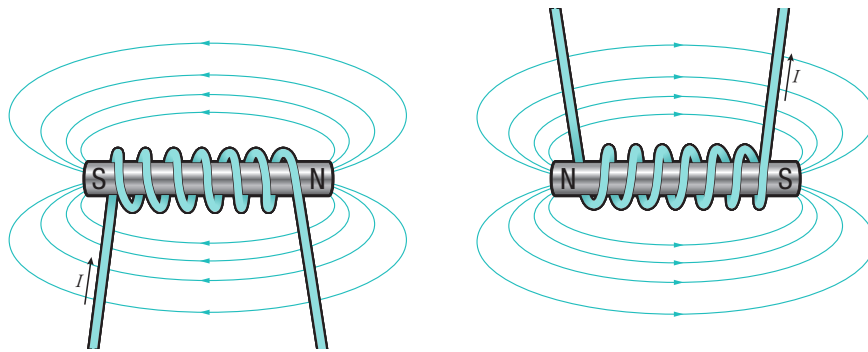


Figure 6 in the student guide shows how to add together magnetic fields generated by each turn of the wire in the core of the solenoid. The individual loops cancel each other out. In practice, the coils are tightly wound, as in Figure 7. The field at the center of the coil is more homogeneous. When the coil is longer than it is wide, it is called a solenoid. In addition to being coiled closely together, the individual coils are laid on top of each other in several layers. An old mobile phone charger can be taken apart as an illustration of these solenoids.

To amplify the field of an electromagnet, a soft iron core can be placed in the solenoid. Under the effect of the magnetic field of the electromagnet, it will itself also become a magnet. This effect is developed in the “permanent magnets” section of the student guide. It will be interesting to see if students use this concept when they tackle the following problem.

Quiz

Using the “right hand rule” and making comparisons with the illustrations of the section on “artificial” or electromagnets, students should be able to indicate the direction of the current and lines of the field.

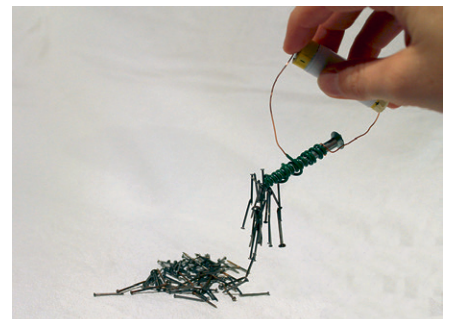


Challenge

Who can pick up the most metal with his/her electromagnet?

A blade will enable students to strip the electric wire so it can be hooked up to a battery. The wire can be wrapped around a screw, nail, pencil and toothpick- Using a ferromagnetic core for the electromagnet increases the overall magnetic field generated.

The more times the wire is wrapped around the core, the more stronger the electromagnet.



There is a link to a short video on how electromagnets work on that page of guide.

VÉRIFIONS...

the intensity B of the magnetic field in a solenoid is determined using the following relationship established by Ampere:

$$B = \frac{\mu_0 \cdot I \cdot N}{l}$$

B the intensity of the magnetic field in teslas [T]

N the number of times the wire is wrapped around the solenoid (coil)

l length of the solenoid in meters [m] (Fig. 7)

I intensity of the current in amperes [A]

μ_0 magnetic permeability of a vacuum: $\mu_0 = 4\pi \cdot 10^{-7}$ [Tm/A]

The length of the solenoid must be larger than its diameter for the formula to be valid.

For short coils the function can be adapted as follows:

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

r the radius of the coil

C) In this experiment, the function adapted to the short coil is: $B = \frac{\mu_0 \cdot I \cdot N}{2r}$

As we will experimentally verify that the magnetic field is proportional to the number of coils on the solenoid and the intensity of the electric current running in the wire, it's not useful to give the students two formulas.

To be able to quantify the field, we will try to measure the attraction of a magnet to the solenoid. Measurements in part **D)** and **E)** require patience. Ask students to think of other ways to test the force of the magnet – move a tin can, lift a small object, etc.

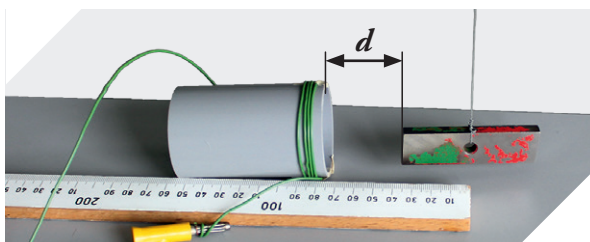
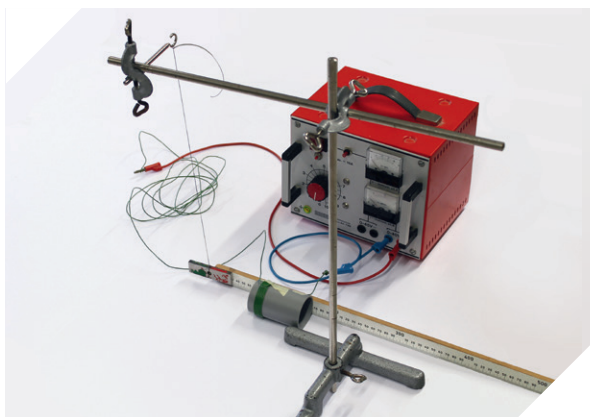
It's hard to get accurate measurements. Even so, it's possible to clearly show that the intensity of the magnetic field increases with the current and the number of coils. Here are some examples of measurements obtained.

D) For 5 coils:

I [A]	d [cm]
1	0.3
2	0.5
3	0.7
4	0.9
5	1.0

E) For 5A:

N	d [cm]
5	1.0
10	1.7
20	3.5
30	6.2



■ ALL THIS IN NUMBERS...

The students learn to calculate the intensity of the magnetic field in the interior of a solenoid as a numerical application of a value to a function (Exercise 1) then are asked to tackle proportional or inverse-proportional situations (Exercise 2).

As an extension, you could sketch for the students the intensity of the field as a function of distance from the wire. Since the intensity of the field in Teslas is very weak for small currents, it's also an opportunity to use scientific notation.

Exercise 1

$$B = \frac{\mu_0 \cdot I \cdot N}{l} = \frac{4\pi \cdot 10^{-7} \cdot 5 \cdot 500}{0,1} \approx 0.031 \text{ T} = 3.1 \cdot 10^{-2} \text{ T}$$

Exercise 2

The intensity of the field is ...

	True	False
• 3 times greater if I triple the number of coils	<input checked="" type="checkbox"/>	<input type="checkbox"/>
• 3 times greater if I space out the coils so it's 15 cm long	<input type="checkbox"/>	<input checked="" type="checkbox"/>
• twice as large if I use a 4 A current	<input checked="" type="checkbox"/>	<input type="checkbox"/>
• larger if the coils are smaller in diameter	<input type="checkbox"/>	<input checked="" type="checkbox"/>
• identical if the current is two times less intense and there are twice as many coils	<input checked="" type="checkbox"/>	<input type="checkbox"/>
• identical if there are twice as many coils but the solenoid is the same	<input type="checkbox"/>	<input checked="" type="checkbox"/>
• identical if there are twice as many coils but the solenoid is two times longer	<input checked="" type="checkbox"/>	<input type="checkbox"/>

Exercise 3

We appreciate the permanent magnet's ability to stick to the fridge for a long time without using electricity.

On the other hand, to pick up a car or can of soup or to drop them again, we appreciate being able to start or stop the current running in an electromagnet.

For Solar Impulse's electric motors, we need two kinds of magnets. This exercise can be done at the same time as the one in [MOTORS](#). Electromagnets are used in loudspeakers, MP3 headphones, etc.

TO EXPLORE FURTHER...

These three exercises are geared for students who know how to solve an equation and who have already done vector addition in the context of a chapter on forces in physics.

Exercise 4

$$B_{\text{Earth}} = B_{\text{coil}}$$

$$B_{\text{Earth}} = \frac{\mu_0 \cdot I \cdot N}{l}$$

$$47 \cdot 10^{-6} = \frac{4\pi \cdot 10^{-7} \cdot I \cdot 80}{0.06}$$

$$| \cdot 0.06$$

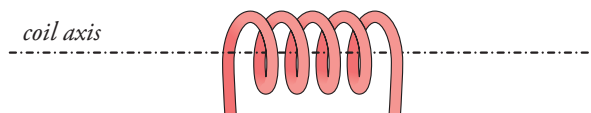
$$2.82 \cdot 10^{-6} = 4\pi \cdot 10^{-7} \cdot I \cdot 80$$

$$| : (4\pi \cdot 10^{-7} \cdot 80)$$

$$I \approx 2.8 \cdot 10^{-2} \text{ A} = 28 \text{ mA}$$

Exercise 5

You may need to explain to students that the axis of the solenoid is the axis of revolution for the cylinder that it forms.



If needed, show students who have difficulty that the earth's magnetic field and the magnetic field of the solenoid are perpendicular to one another and must be equal in intensity because the angle formed by the needle is 45° .

$$B_{\text{Earth}} = B_{\text{coil}}$$

$$B_{\text{Earth}} = \frac{\mu_0 \cdot I \cdot N}{l}$$

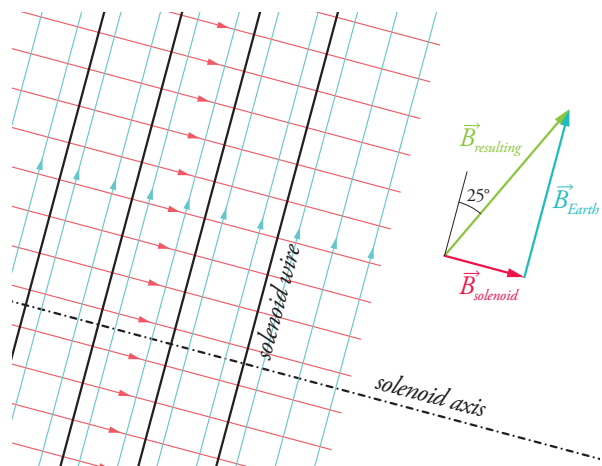
$$47 \cdot 10^{-6} = \frac{4\pi \cdot 10^{-7} \cdot 0.08 \cdot N}{0.1}$$

$$47 \cdot 10^{-6} = 3.2\pi \cdot 10^{-7} \cdot N$$

$$| : (3.2\pi \cdot 10^{-7})$$

$$N \approx 47 \text{ coils}$$

Exercise 6



$$\tan 25^\circ = \frac{B_{\text{coil}}}{B_{\text{Earth}}}$$

$$B_{\text{coil}} = \tan 25^\circ \cdot B_{\text{Earth}}$$

$$\frac{\mu_0 \cdot I \cdot N}{l} = \tan 25^\circ \cdot B_{\text{Earth}}$$

$$| \cdot \frac{l}{\mu_0 \cdot N}$$

$$I = \tan 25^\circ \cdot B_{\text{Earth}} \cdot \frac{l}{\mu_0 \cdot N}$$

$$I = \tan 25^\circ \cdot 47 \cdot 10^{-6} \cdot \frac{0.05}{4\pi \cdot 10^{-7} \cdot 100}$$

$$\approx 0.0087 \text{ A} = 8.7 \text{ mA}$$