Innovation in science education

A simple DIY kit for the study of magnetic fields

Abstract

In this project, students plan and carry out experiments in which they determine the size of the magnetic field in coils or solenoids, and investigate correlations between the dimensions of the coil, the number of turns in the coil, the current passing through the coil, and the size of the magnetic field.

The investigations are carried out using a simple and inexpensive DIY kit, consisting of PVC tubes with different diameters, used to make coils by looping wire around the pipes. The size of the magnetic field is determined by using a Hall sensor placed inside the coil.

What is innovative in this project?

The project is an example of an open problem in which the students have to plan and carry out the experimental study on their own.

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Project description

Until recently, it was not possible to measure the size of the magnetic field by direct methods. You had to use indirect methods, e.g. induction. This problem was solved when educational technology vendors like Vernier and Pasco introduced Hall sensors in their sensor program.

Until then, you had to use magnetic field lines (introduced by Michael Faraday, naming them “lines of force”) to show the presence, the direction and the strength of the magnetic field.

The DIY kit

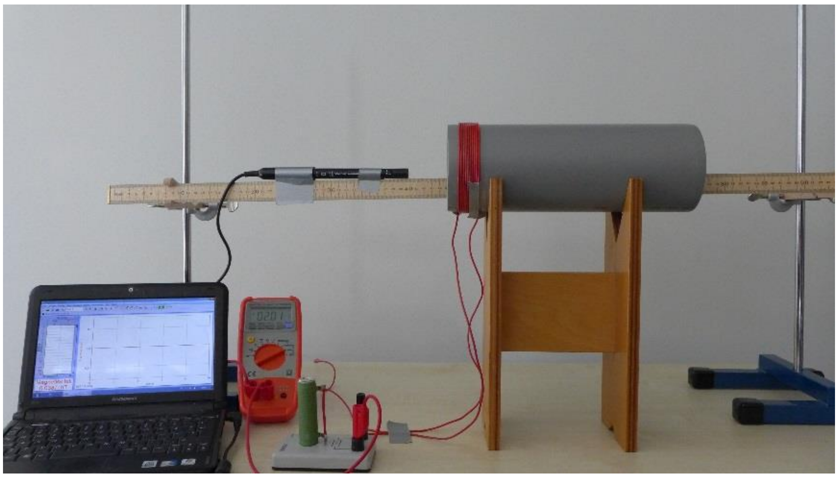
The DIY kit contains these parts:

- 4 PVC tubes, length 30cm, diameters 32, 50, 70 and 110mm
- Resistance 4Ω
- Insulated wire 7m with banana plugs
- 2 wooden test tube clamps

All the parts are kept in a plastic container 34cm·24cm·16cm

Besides this, you need a Hall sensor with interface, and some ordinary lab equipment.

The experimental setup



Place the Hall sensor in a fixed position, e.g. mounted on a wooden meter stick. Make a coil by looping the insulated wire around one of the PVC pipes. Connect the coil to the power supply, in a series with the resistor and a digital multimeter.
Turn off the power supply before zeroing the Hall sensor.

Hypothesis and controlled experiments

In this project, students plan and carry out experiments in which they determine the size of the magnetic field in coils or solenoids, and investigate correlations between the dimensions of the coil, the number of turns in the coil, the current passing through the coil, and the size of the magnetic field.

To do this, the students must carry out controlled experiments, only changing one variable at a time in order to establish a cause and effect relationship.

Before doing the experiment, the students should make a hypothesis to predict the effect of varying the independent variable (the cause) on the dependant variable (the effect), e.g.

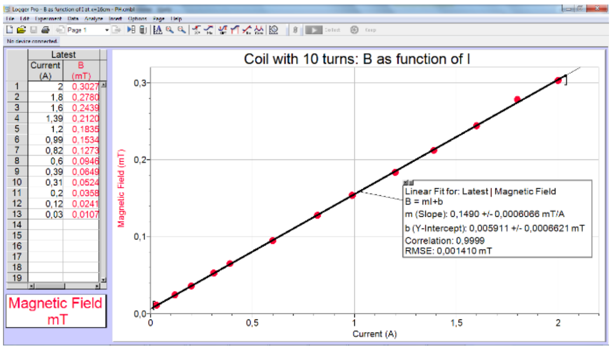
- the magnetic field in the center of a coil depends linearly on the size of the current in the coil
- the magnetic field in the center of a coil depends linearly on the number of turns in the coil
- the magnetic field in the center of a coil is inversely proportional to the radius of the coil

Experimental results

Varying the current through the coil is easy. To measure the relationship between the number of turns in the coil and the magnetic field in the center of the coil, you have to remove one turn at a time.
The predictions mentioned above are shown to be correct, thereby establishing the following relationships

$B = k \cdot I$ (with the number of turns N and radius R kept constant)

$B = k \cdot N$ (with the number of turns N and the current I kept constant)



	Latest	
	Current (A)	B (mT)
1	2	0,3027
2	1,8	0,2780
3	1,6	0,2439
4	1,39	0,2120
5	1,2	0,1835
6	0,99	0,1534
7	0,82	0,1273
8	0,6	0,0946
9	0,39	0,0649
10	0,31	0,0524
11	0,2	0,0358
12	0,12	0,0241
13	0,03	0,0107
14		
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17		
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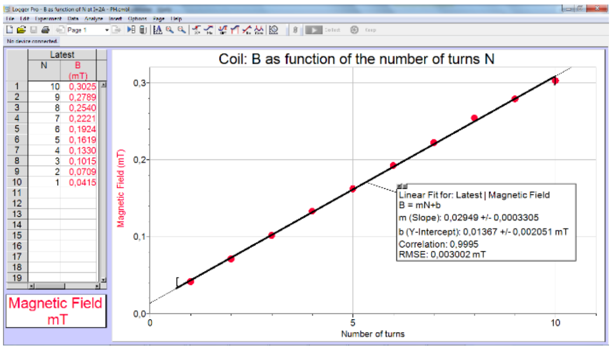
19		

Linear Fit for: Latest | Magnetic Field
B = mI+b
m (Slope): 0,1490 +/- 0,0006066 mT/A
b (Y-Intercept): 0,005911 +/- 0,0006621 mT
Correlation: 0,9999
RMSE: 0,001410 mT



	Latest	
	N	B (mT)
1	10	0,3025
2	9	0,2789
3	8	0,2540
4	7	0,2221
5	6	0,1924
6	5	0,1619
7	4	0,1330
8	3	0,1015
9	2	0,0709
10	1	0,0415
11		
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Linear Fit for: Latest | Magnetic Field
B = mN+b
m (Slope): 0,02949 +/- 0,0003305
b (Y-Intercept): 0,01367 +/- 0,002051 mT
Correlation: 0,9995
RMSE: 0,003002 mT

Both results are in good agreement with the formula for the magnetic field in a coil with the radius R

$$B = \mu_0 \cdot \frac{NI}{2R}$$

The third relationship, the magnetic field in the center of a coil being inversely proportional to the radius of the coil, can be shown by making coils with 10 turns on each of the 4 PVC tubes. Of course, you can use the relationships to find μ_0.

The experimental work in physics

The DIY kit and the possibilities of different methods of teaching and learning were presented in courses for Danish high school teachers 2012-2014.
The DIY kit is also included in a newly published report on "The experimental work in physics" (1). The DIY kit is used as an example of an open problem in which the students have to plan and carry out the experimental study on their own.

The Danish students finish their physics course with an oral examination, in which they also have to make experiments. The curriculum states that "Students should be able to organize, describe and perform physical experiments for the study of an open problem." Hence it is important that everyday teaching gives the students the opportunity to work in this way. The curriculum also states that the students should be able to verify or falsify simple hypotheses. The DIY kit supports this in a very simple manner.

The report on "The experimental work in physics" has gained some of its ideas from “Understanding Science - how science really works” (2). “Understanding Science” describes the very traditional way of experimental work in science teaching, as well as a modern way, including the process of scientific inquiry.

Traditional (linear, too simple)

1. Ask a question
2. Formulate a hypothesis.
3. Perform experiment.
4. Collect data.
5. Draw conclusion.

http://clipart-library.com/clipart/BiaE8BLMT.htm

It looks like a recipe in a cookbook!

In the cookbook-like experimental setups, the students only have to perform the experiment, collect data and draw conclusions. This is the way most students perform their first experiments.

Despite the numbering, scientific understanding is not a linear process. You often have to go back, change your hypothesis, the experimental setup, or redo the experiments with new equipment. The collected data might even falsify your hypothesis, forcing you to modify your hypothesis or redo the experiment in another way.

“Understanding Science - how science really works” has a better model for scientific work, “The *real* process of science” (3). Formulating the experiment as an open problem forces the students to do much more on their own. Questions like these could be taken into account:

1. Ask a question
2. Formulate a hypothesis.
3. Which types of equipment can be used?
4. How do I make the experimental setup?
5. Perform experiment and collect data.
6. What can I do with my data?
7. Draw conclusion.

Considering the points mentioned as “stepping stones”, you will often decide the steps 1-4, only leaving the steps 5-7 (measuring, data processing, drawing conclusions) to the students. As the students become more proficient, you can leave more and more for themselves to decide.

With the DIY kit is step 3 is decided, but the students have to plan and carry out the the rest of other parts of the experimental study on their own.

Closing remarks

The concept is developed as part of the reintroduction of electric and magnetic fields in the Danish curriculum. The experiments and the teaching method are developed for 17-18 years old students on A-level, but the experiments can be used on lower levels, too.

(1) "Det eksperimentelle arbejde I fysik", www.emu.dk/sites/default/files/det-eksperimentelle-arbejde-i-fysik.pdf. (in Danish only, sorry!)

(2) “Understanding Science - how science really works”. University of California Museum of Paleontology, https://undsci.berkeley.edu

(3) “The *real* process of science”. 2015. University of California Museum of Paleontology, https://undsci.berkeley.edu/article/0_0_0/howscienceworks_02

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