Hands- and minds-on electricity and magnetism

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Abstract. The paper describes several interesting school physics experiments from the area of electricity and magnetism found in foreign journals. These experiments may serve as an inspiration for development of similar school physics experiments or modified versions of experiments and for quantitative measurements on such experiments (which are often used just as qualitative experiments in our school practice). As an example we created a slightly modified version of an experiment Magnetic pendulum and measured its motion in various conditions. This experiment is described in more details in the article.

Introduction

There are many experiments from the area of electricity and magnetism in student's books for lower or higher secondary schools. But most of these experiments are only qualitative. For example – there is a collection of nice but only qualitative electrostatic experiments with cans.

It might be worthwhile to measure various quantities and parameters of these experiments quantitatively (charge, voltage, etc.). It may be interesting for high secondary school students in special seminars and for university students and it could also help to improve the experiments themselves.

One of main goals of my work is therefore to do quantitative measurements concerning some commonly used qualitative experiments.

The other goal is to find further experiments, to test them (again including quantitative measurements) and to describe them for physics teachers and students.

My work should serve mainly for high's schools students and their teachers and for students of basic physics courses in universities.

Literature search

As a starting point I searched for school experiments from the above mentioned area described in foreign and Czech books and journals. Most of interesting experiments and ideas I found appeared in foreign journals, namely American Journal of Physics, Physics Teacher and Physics Education.

Figure 1 presents the topic areas and the level of 39 articles containing interesting experiments or ideas about teaching electricity and magnetism. Some of these experiments are known in Czech Republic, but I insert them here because the articles present quantitative measurement or new ideas.

To describe all the references presented in Fig. 1 would make this article too long so I would like to comment just a few I found most interesting and inspiring.

First article I'd like to note is named "*"Franklin's Bells" and charge transport as an undergraduate lab*" [1]. Franklin's Bells is commonly used electrostatic experiment (but it isn't known under this name in Czech Republic). The "bell" consists of a ball oscillating between two plates of charged capacitor. Authors of the article describe some quantitative models and measurements of this experiment.

The article named "*Demonstrating diamagnetism*" [2] contains interesting idea how to demonstrate diamagnetism in high school. The author uses sensitive electronic balance, neodymium magnet and a bismuth sample. He puts the bismuth sample on the balance and tares it. When he puts the magnet near the sample, the balance will register positive "mass" of a few centigrams – the balance actually measures the diamagnetic force.

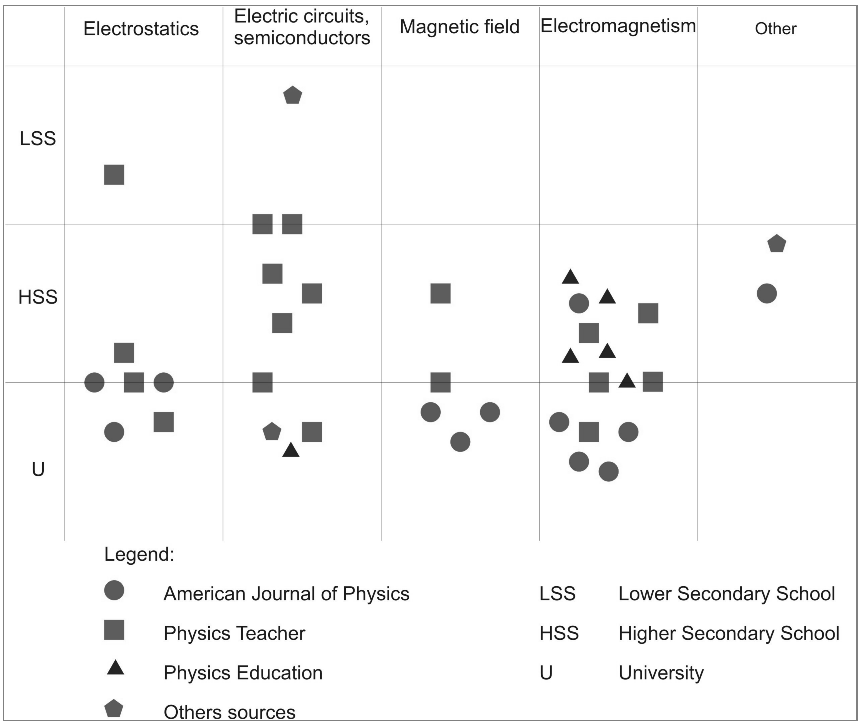

Figure 1 Articles describing with interesting experiments or ideas concerning electricity and magnetism

Article named "*A Cheap Simple Ammeter for Batteries-and-Bulbs Activities*" [3] contains instructions how to made a simple ammeter (Fig.2). I think that such ammeter can be built by students in higher secondary schools in school labs or as homework.

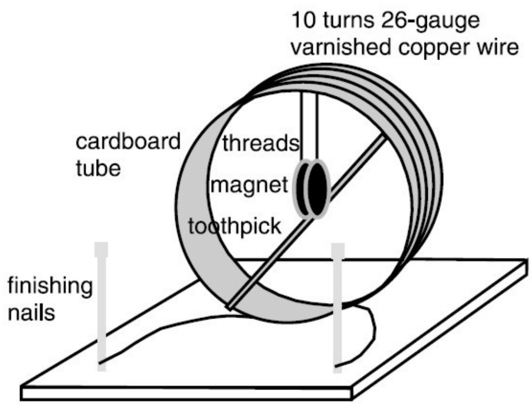

Figure 2 Simple cheap ammeter (figure is adapted from [3])

In the article "*LED's in Physics Demos: A Handful of examples*" [4] there are some ideas how to use LED in physics demonstration experiments. I found interesting the idea of using LED in the topic of Electromagnetic induction. Commonly a voltmeter is used to show two polarities of induced voltage. Author of this article uses red and green LED, which are wired in parallel and in opposite orientation (see Fig. 3).

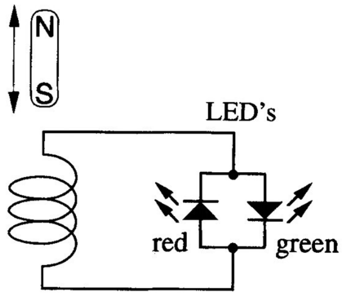

Figure 3 LED's used to study electromagnetic induction (figure is adapted from [4])

There are many articles about a magnet falling through a pipe (e.g. [5-9]). Authors of these articles measure and model this experiment in different ways. Experiment with a magnet falling through a pipe is commonly known in Czech Republic, but again it is used only as a qualitative experiment.

The article "*A magnetic circuit demonstration*" [10] contains very interesting experiment with an electric transformer. In this experiment the transformer with one primary and two secondary windings is used. The experiment demonstrates how primary windings influences secondary windings and how both secondary windings interact.

Example of one interesting experiment: Magnet near a special copper cube

Experiment I found very interesting is described in the article "*Magnetic-pendulum set-up illustrates eddy-current generation and inhibition*" [11]. The original experiment uses a cube made from layers of aluminium and a copy paper. Figure 4 shows the experimental setup. There is neodymium magnet, which swings like a pendulum above the cube. If the cube has one orientation (Fig. 5a) eddy-currents are generated in the aluminium plates and magnet motion is halted very quickly. But if the cube has the orientation shown in Fig.5b the eddy currents generated by a motion of the magnet are much weaker than in first case. Therefore the braking force is small and the magnet swings back and forth for quite a long time.

There is also a short video belonging to this article.

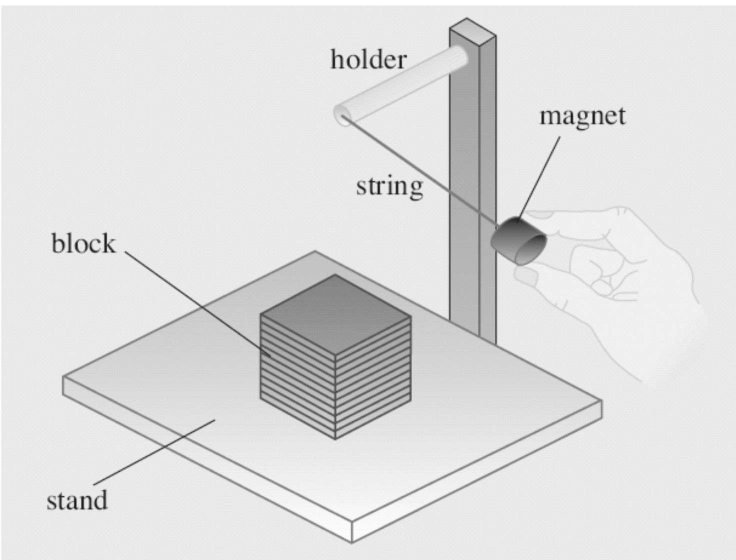

Figure 4 Experimental setup of Magnetic pendulum experiment (figure is adapted from [11])

I decided to repeat the experiment in slightly modified version.

My block is made of copper plates and layers of epoxy, which serve both as glue and an isolation. My block is 6x6x4,5 cm large. I choosed a copper block, because copper has greater conductivity than aluminium, so a braking force is bigger.

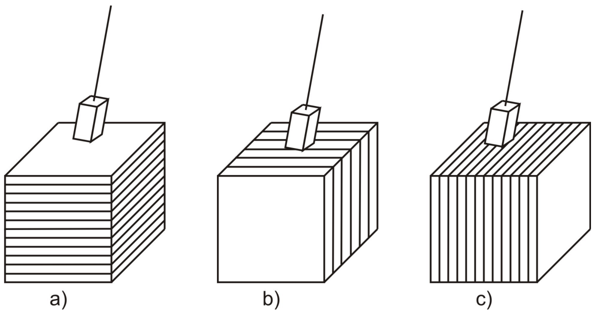

Figure 5 Three orientations of the copper block in the experiment

The copper block enables to do several interesting experiments, both simple and more elaborated. For example we (or students) can try to find the answers to following questions:

- How the magnet moves if the block has the orientation shown in Fig. 5b? The motion of this position of cube was not shown in the video in [11].
- Does the motion of the magnet correspond to damped harmonic oscillations? (So is the braking force proportional to the velocity of the magnet?)
- How large is the damping ratio of this motion?
- What happenes, when the block is orientated so that its layers are at acute angle to the direction of motion of the magnet?
- How does the motion depend on the distance between the block and the magnet in its lowest position?
- And one rather theoretical question: Can we model eddy-currents generated by the motion of the magnet?

Figure 6 shows experimental setup of my experiment. I used very simple method to measure the motion – I recorded it by a digital camera and then processed this video.

Figure 6 The experimental setup of Magnetic pendulum experiment used in measurements described in this article

Results

First interesting thing I noticed is that this experiment can demonstrate all three types of motion of damped harmonic oscillator.

If the magnet is close to the block in the position shown in Fig. 5a the pendulum is over-damped. (We can try to find the distance for which the damping is critical.) When the block is in second position (see fig. 5c), pendulum repeats damped harmonic oscillations with relatively large damping ratio.

Third, when the block is orientated as it is shown at Fig. 5b, the braking force is small.

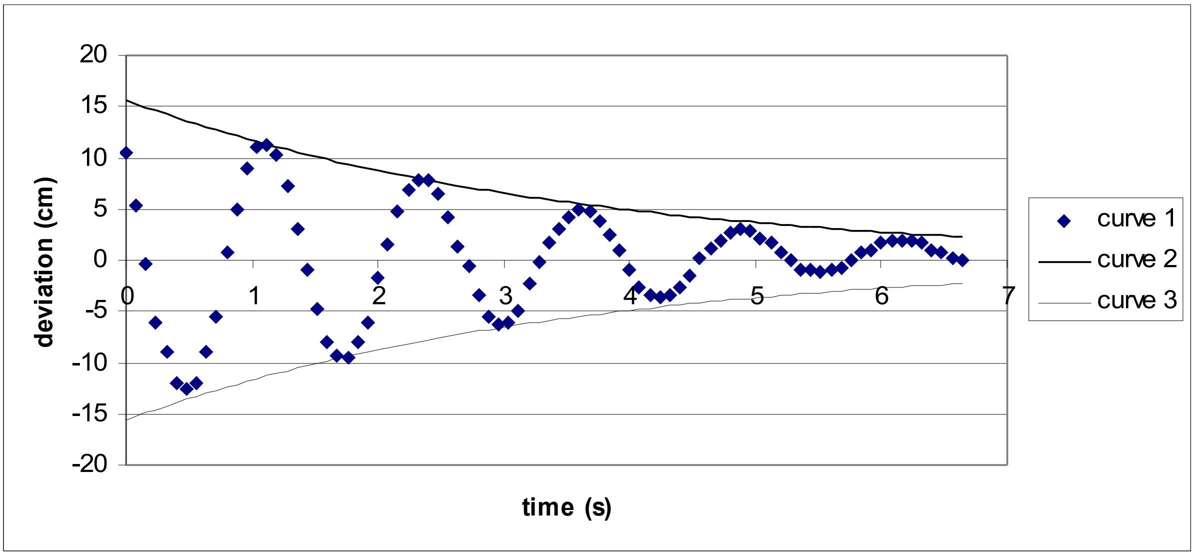

Figure 7 Graph of the motion of the magnet

Figure 7 shows graph of the motion of the magnet, when the block is in the second position. Curve 1 on the graph represents the measured motion of the magnet; curves 2 and 3 are exponential regression functions. Damping of the pendulum is exponential, so we can reasonably assume the braking force is proportional to the velocity of the motion (though, inevitably, there must be some discrepancies due to slightly changing distance of the magnet from the cube, final dimensions of the cube etc.).

An interesting question mentioned above is how the pendulum moves, when the block is orientated so that its layers are at acute angel to the initial direction of motion of the magnet. I found that direction of pendulum motion shifts so that finally it is parallel to the layers. The braking force is larger in the direction perpendicular to the layers, so the velocity component in this direction is damped quickly. In the direction parallel to the layers the braking force is relatively small, so this is the direction in which the motion lasts.

Conclusions

Some interesting experiments and ideas, mainly from foreign journals, were found. We plan to repeat and modified these experiments and to do quantitative measurements on these experiments.

We built a modified version of one experiment – Magnetic pendulum – and did some quantitative measurements, which were not done in the original article.

Acknowledgments.

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