Hand- and minds-on electricity and magnetism II.

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Abstract. The paper consists of two parts – experiments for students and experiments for teachers. First part contains two experiments, which were found in literature or internet, verified and quantitatively measured. The second part concerns about two workshops for physics teachers.

Introduction

There are many experiments from the area of electricity and magnetism, but quite often these experiments are presented only qualitatively. Following on my article in WDS last year ([4]), I'd measured some of experiments I described last year. Results of my measurements are in first part of the article named “Experiments for students”. One of goals of my work is experiments for teachers and experiments, which they can do with their students. So, the second part of the article named “experiments for teachers“ consists of information about two workshops for physics teachers.

Experiments for students

Demonstrating diamagnetism

The original experiment is described in the article “Demonstrating diamagnetism” [1]. It shows how to demonstrate diamagnetic force between bismuth sample and a magnet.

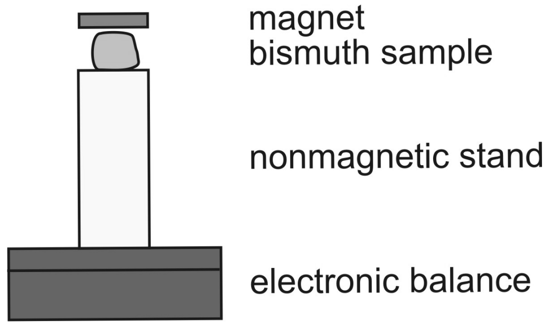

Figure 1. The arrangement of the experiment “Demonstrating diamagnetism”

The experimental setup is shown at fig. 1. It contains sensitive electronic balance, nonmagnetic stand, bismuth sample and neodymium magnet. When the magnet is near the bismuth sample, the electronic balance registers positive “mass” – the diamagnetic force.

In our arrangement the electronic balance was sensitive to a centigrams, the stand was from plastic cup and paper roll (it must be at least 25 cm high). We have bismuth in the form of small scales in a plastic box. The weight of our bismuth sample was about 100 grams. The distance between the bismuth and the magnet is about few millimetres.

In our arrangement the “mass” was about few centigrams, corresponding to diamagnetic force about few tenths of milinewtons.

This experiment may be useful in schools, where sensitive electronic balance are available. Instead of bismuth it is possible to use diamagnetic carbon.

How big is the force between a tin and a straw?

Motivation of this experiment comes from videos on YouTube. There are many videos with tins rolled on a table and powered by charged poles (see for example [2]). These experiments are only qualitative. But a natural question may arise, which can give the motivation for example for a student project: How big is the force between the tin and the charged straw (or the pole).

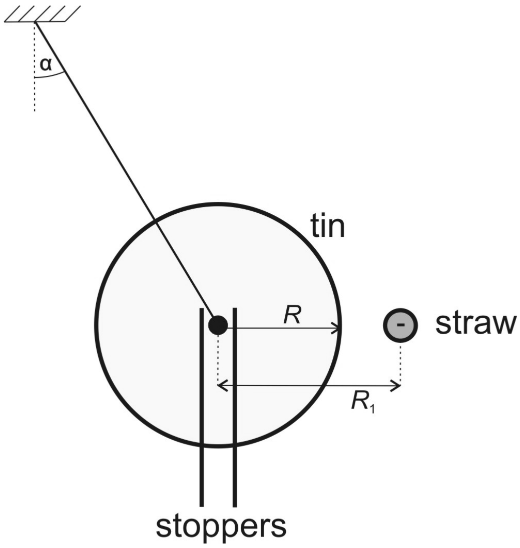

Figure 2. Arrangement of the experiment (viewed from the side)

The force is too small to be measured by a school dynamometer or other similar instrument. But it can be measured by a simple experiment. Figure 2 shows experimental setup of our experiment. There is a “tin” which is put on a skewer and hanged on long threads. Two stoppers on both sides delimit the movement of the tin. When we put a charged straw near the tin, we can measure the distance R_1, where the projected weight of the tin balances the electrostatic force between the tin and the straw. This distance was measured for different angles α.

The electrostatic force is small – and so should be also the projected weight of the tin. If we do not want to be limited only to extremely small angles α, we need very light “tin”. Therefore we used a very light metal cylinder made from aluminium foil on a paper roll. To have it isolated we closed it by Styrofoam cover at both sides. A skewer was used as an axe. Its motion was limited by the wooden stoppers so the axes (and the cylinder) could move for just about one millimetre.

The theoretical value of the electrostatic force was calculated in the idealized case of infinitely long tin and straw. The electrostatic force was calculated by imagine charge method. The resulting linear density of force (i.e. the force per unit length of the tin):

$$\frac{F}{L} = \frac{\tau^2}{4\pi\varepsilon_0 (R_1 - R)} \cdot \frac{2}{\left(\frac{R_1}{R}\right)\left(1 + \frac{R_1}{R}\right)}, \qquad (1)$$

where τ is linear density of charge, R_1 is the distance between axis of the tin and the straw and R is the radius of the tin (see fig. 2).

It can seen that for small distance R_1 the force falls as $1/(R_1 - \mathrm{R})$ and for big R_1 as $1/(R_1)^3$.

The projected weight was calculated from the formula:

$$F_{\rightarrow} = mg \cdot \sin\alpha, \qquad (2)$$

where m is the weight of the apparatus and α is the angle between threads and vertical (see fig. 2).

In our arrangement the values of parameters were:

Length of threads d .... 1.99 m
Length of the tin L.. 10 cm
Radius of the tin R.. 3 cm
Weight of the tin m .... 15.3 g
Charge of the straw .... 40 nC
The angles α we measured were approximately between 0° and 5.7° (sin α range from 0 to 0.1).

The results of our measurement are shown in figure 3. It can be seen from the graph that the experimental results agree with the theory. In fact, the agreement seems to be surprisingly good, taken into account the simplicity of the experimental setup and the idealization in theoretical derivation (In fact, planning the experiment, we expected just the order of magnitude agreement.)

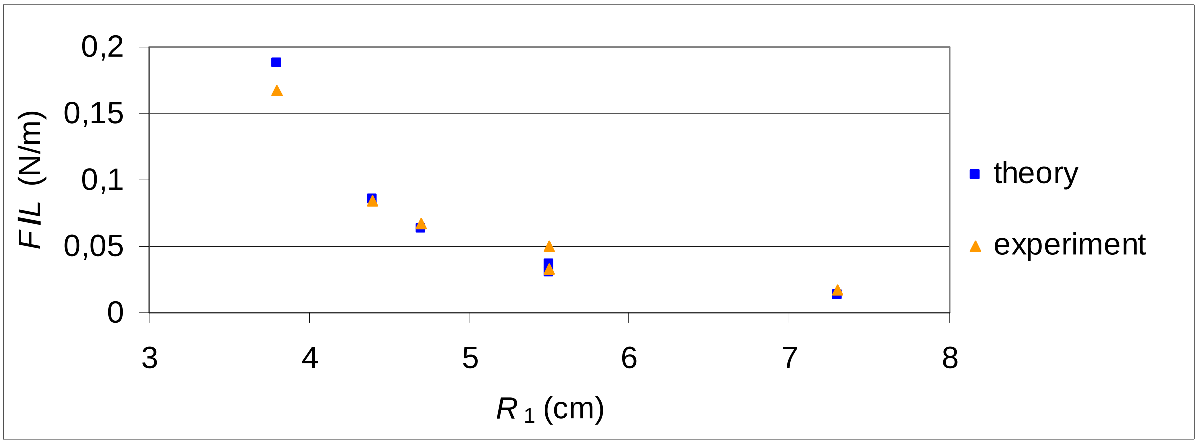

Figure 3. Results of the measurement "How big is the force between a tin and a straw". There is dependence between linear density of force and distance between the tin and the straw.

Experiments for teachers

Transform. Transform? Transform!

The workshop with a provocative name "Transform. Transform? Transform!" I lead in the conference Heureka Workshops 2008 (annual conference of the project Heureka, see [5]), in September 2008 in Náchod. There were about 30 teachers participating in the workshop.

The workshop contained nine experiments with electric transformer. In the following some of those experiments are shortly described:

Where the magnetic flux flows? – This is the name of set of experiments, where participants studied, how the size of inducted voltage depends on distance between one secondary turn and a primary coil, size of the secondary turn etc.

Electric transformer powered by "direct current" – The electric transformer is connected to a direct current power supply, but in the primary circuit there is a rheostat. The task for participants is to shine the LED diodes in the secondary circuit. The scheme of this task is shown in figure 4.

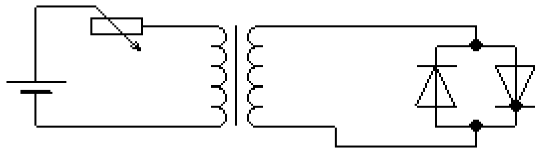

Figure 4. Scheme belongs of the task named "Electric transformer powered by direct current"

Turns of a coil – The participants know primary and secondary voltage and the number of turns of the primary coil. Their task is to calculate the number of turns of the secondary coil, and then to wind it, arrange the transformer and verify their result. But, the assigned numbers are chosen such a way that the number of turns of the secondary coil is four and half. So, the participants discuss, how to wind 4.5 turns, why they didn't measure assigned voltage and, how to made assigned voltage. Figure 5 shows result of one group of teachers – how to make assigned voltage. They use a fact, that magnetic flux doesn't flow only throw the core and use leakage magnetic flux to induce assigned voltage. This result is of course true but not usual. The often result of this task is to open the core and to increase losses in the transformer or add a bulb in the secondary circuit (and load the secondary coil).

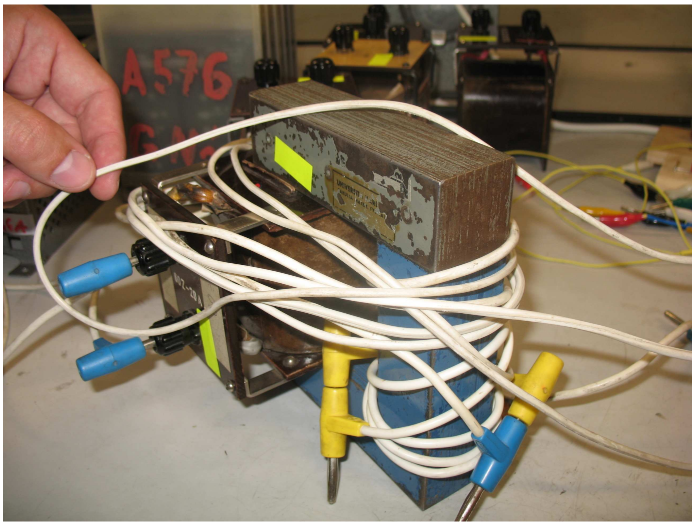

Figure 5. The result of an experiment how to make assigned voltage in the secondary coil of electric transformer (voltage, which would require non-integer number of turns in the secondary coil)

Experiments with electric transformer

The workshop named "Experiments with electric transformer" was held at the meeting "World of Energy Club" organized by ČEZ, a.s. in Plzeň, in May 2009. There were about 40 participants – physics teachers and members of the Club. The workshop was prepared on the base of book "Plays with electric transformer" [3].

There were about six experiments for small groups of teachers and about five demonstrating experiments in the workshop. For example:

Open-circuit transformer – Participants arrange a transformer with transformational ratio equal to one (the primary and secondary coils having the same number of turns) and a bulb in the secondary circuit. They saw the bulb is shining. Then, they move the bulb from the secondary circuit to the primary circuit. The task is, why the bulb isn't shining, when is in the primary circuit (there is the same voltage, isn't it?). Second question is how to make the primary bulb shining. This experiment shows that in the open-circuit transformer (transformer, where is nothing on the secondary side) flow only open-circuit current, which is too small to shine the bulb. The result is to increase the open-circuit current, for example by opening the core or loading the secondary coil.

Transformer's ratio "inside out" – A formula for transformational ratio of currents in primary and secondary coil is presented in many Czech physics textbooks. Bu, is this formula true for usual transformers? Participants´ task is to arrange transformer with some combinations of primary and secondary coils and to verify the formula. The formula is valid only for ideal short-circuit transformer. So, the participants discovered that the formula they teach isn't valid.

"Clever coil" – The motivational question for this experiment is "How the primary coil knows, how big current takes the secondary one?" The scheme of arrangement of this experiment is at a figure 6. Participants arrange a transformer with coils of the same numbers of turns. In the primary circuit there was an indicative bulb (or ammeter); in the secondary circuit there were an ammeter and a bulb. The participants observe shine of primary and secondary bulb (or read currents on ammeters), when they add other bulbs in parallel in the secondary circuit, so when the secondary coil takes bigger current. The question for participants was to explain what happened in the transformer, when they add further bulbs in secondary circuit.

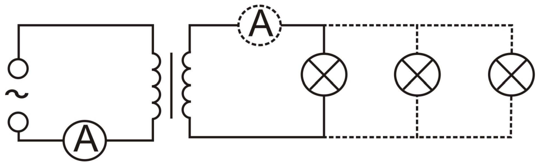

Figure 6. Scheme of the experiment "Clever coil"

Levitating ring – one of demonstrating experiments. The secondary coil of a transformer consists only of one aluminium ring. When the transformer is switched on, the aluminium ring takes off the ground. Figure 7 shows the levitating ring. The question for participants is why the ring levitates and why the second ring (which is cut) doesn't levitate.

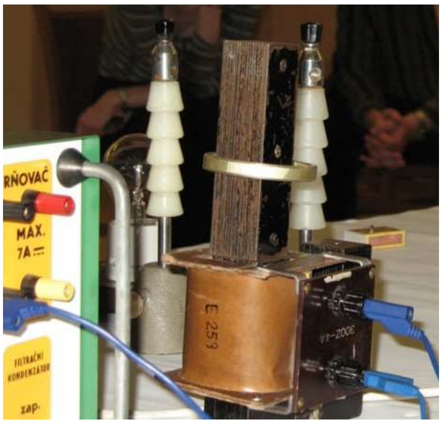

Figure 7. Levitating ring

Conclusion

Some of qualitative experiments we can do quantitative too. The quantitative measurements can by used in students project or in prepared "Interactive physics laboratory" (see [6]).

The workshops for teachers had positive responses. The teachers appreciated new information about function and principle of an electric transformer, interactivity of workshops and applicability of experiments for their students.

Acknowledgments. I wish to thank doc. Leos Dvorak for help with measurement the force between the straw and the tin.

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