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High school students' misconceptions in electricity and magnetism and some experiments that can help students to reduce them

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Summary. — The Czech Conceptual test from the area of Electricity and Magnetism was prepared at Department of Physics Education, Faculty of Mathematics and Physics, Charles University in Prague. The first part of the paper presents three problematic topics which were identified using this test — charge distribution on an insulators, Coulomb's law and electromagnetic induction. However, to identify misconceptions is not enough. Therefore, the main part of the paper presents some experiments which can help students to overcome their misconceptions and to better understand not only the topics mentioned above. Most of these experiments can be done with very simple tools and materials.

1. – Introduction

Electricity and magnetism is one of topics in the Czech curriculum for high school physics. It is natural to explore how Czech high school students (students of age from 15 to 19) understand Electricity and Magnetism and which misconceptions are typical for them. For this, we prepared the Conceptual test from the area of Electricity and Magnetism. The test, examples of questions and results were presented on ICPE-EPEC 2013 conference and are published in its Proceedings (Koudelkova, Dvorak, 2014). Therefore, only basic information about this test is written in the first part of this paper. Further, in the main part of the paper, we present some experiments, which could help students to overcome their misconceptions. Important information about concrete students' misconceptions are also presented since they are relevant for experiments that should help to overcome them.

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2. – About CCTEM

Czech Conceptual Test from the area of Electricity and Magnetism (CCTEM) is based on CSEM (Maloney, 2001). It has 18 questions, nine of them are used from CSEM (seven of them being slightly modified), other nine correspond to Czech curriculum.

Nearly 200 students were involved in the testing of the final version of CCTEM during school year 2012-2013, more than 150 others were involved during school year 2013-2014. All involved students (aged 16–18) are from general high schools. The pretest was done just before beginning of the lessons from the area of electricity and magnetism, the post-test just after the instruction. Students usually had lessons from the area of electricity and magnetism for about half a school year, two lessons (45 minutes each) a week. (The range partly depends on the school curriculum.)

More detailed information about the test and its developing was written in the paper (Koudelkova, Dvorak, 2014).

3. – Example of results and experiments

Note: Experiments described below were prepared on the basis of results of CCTEM in the school year 2012-2013.

3·1. *Charge distribution on insulators*. – There are two questions in the test focusing on charge distribution — one is about charge distribution on a conductor, the second one concerns charge distribution on an insulator. The assignment is similar in both questions — what will happen with small amount of charge, which we put on one place at a can/PET bottle. Possible answers are the following:

A. All of the charge remains near the point

B. The charge is distributed over the outside surface of the tin/bottle

C. The charge is distributed over the outside and inside surface of the tin/bottle

D. Most of the charge is still near the point, but part of it is distributed over the surface of the tin/bottle

E. There will be no charge left

In the question concerning a can, results were not bad (more than 40% of the students in post-test chose the correct answer). Concerning the charge distribution on a bottle, only 18% of the students in the post-test chose the correct answer. Students seem to be convinced that charge disappears and it seems that this misconception survives after the instruction (almost 80% of the students have this idea before the instruction and still almost 70% after the instruction, see fig. 1).

Czech students have experience with charge distribution on a can — we often use cans for electrostatics experiments. On the other side, they know the charge distribution on an insulator only from a case of plastic rod, so they, in fact, have no experience with charge distribution on an insulator. For a better understanding of charge distribution on an insulator we use a model of a "plastic can" – as a suitable model we found sewage pipe, which looks similar as a can, is non-conducting, is not antistatic and it is big enough (bigger pipe is necessary to show students that it is possible to charge it only at one place).

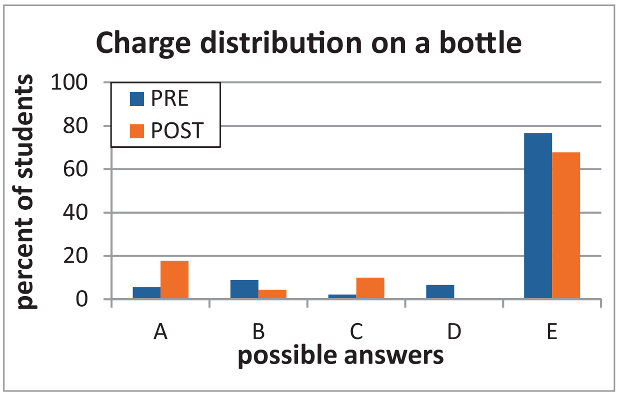

Fig. 1. – Charge distribution on a plastic bottle—students answers.

As a charge indicator we use a piece of aluminium fastened on a piece of wire.

Arrangement of the experiment can be seen in fig. 2.

Using this sewage pipe, students can see differences between behaviour of charge on a conductor and on an insulator:

- Charge on a pipe stays only at the place we charged. If we put charge on several places, it will be on each of them.
- If we discharge one place from those charged before, charge will remain on the other places.
- Charge stays on the tube for more than few minutes, it does not disappear.

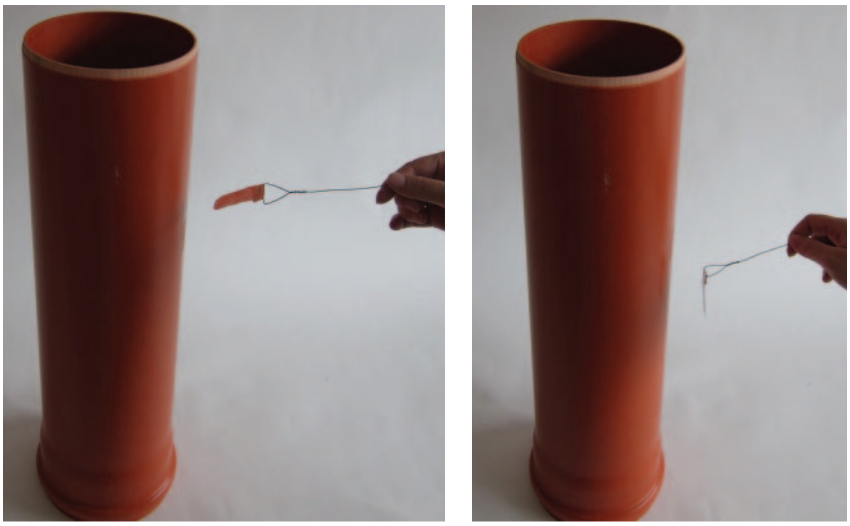

Fig. 2. – Arrangement of the experiment —left: the charge is placed on sewage pipe; right: The charge is not placed on sewage pipe.

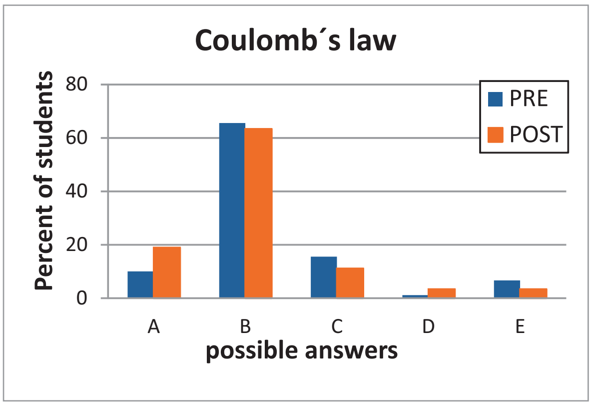

Fig. 3. – Coulomb's law— students answers.

One technical note: Charge stays on the pipe for a long time, so it is problem to discharge it. One suitable method is wiping the pipe by wet cloth and then letting it to dry.

3·2. *Coulomb's law*. – Students learn Coulomb's law for quite a long time and they usually solve many tasks including quantitative tasks. However, it seems they do not understand Coulombs' law as well as one could expect after the time they spent learning it.

In the test, there are two questions which focus on Coulomb's law. In the first of them, we ask students how the electric force acting on a given charge will change when we put charge $3Q$ instead of charge Q to the same distance. Results of this question are good both in pretest and post-test—there are about 75% of correct answers.

In the second question we ask students how the electric force will change when we put one of the two charges two times further.

Students' results can be seen in fig. 3. Possible answers are:

A. $F_{\mathrm{e}}/4$,

B. $F_{\mathrm{e}}\ /2$,

C. F_{e},

D. $4F_{\mathrm{e}}$,

E. another possibility.

It can be seen, that more than 60% of the students (both in pretest and post-test) chose answer B. So, they thought, that the force will be one half.

Reason for this result can be that students know Coulombs' law well, but only quantitatively. So, is it possible to show them the dependence of electric force on distance qualitatively and more illustratively?

We use two experiments which can show students this dependence qualitatively. First of them is used in our Interactive Physics Laboratory (see Šabatka *et al.*, 2014). It uses two ping-pong balls covered by conductive colour as a charges. The force is measured using sensitive scales. Arrangement of this experiment can be seen in fig. 4. Students can use this setup for both qualitative experiments and quantitative measurement.

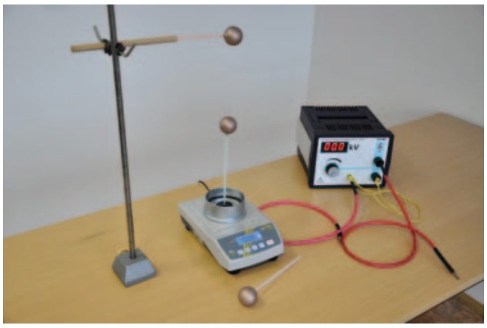

Fig. 4. – Demonstration of Coulomb's law using ping-pong balls (Šabatka *et al.*, 2012).

For the second experiment one needs only very low-cost equipment— a straw, a piece of paper, a skewer and a pin.

The skewer with a pin is used as a stand for the straw. A scale is drawn on a piece of paper. The whole setup is placed on the end of a table (far from any metal parts).

It can be easily seen that the deflection of the straw is proportional to the repelling (Coulomb) force. The deflection can be seen on the upper part of the straw, which is used as a pointer. The lower part of the straw (close to its end) is charged. If we make the distance between the charged rod and the straw twice smaller, we can see that the deflection is approximately four times larger. In the left situation in fig. 5, the distance between charged rod and a lower part of a straw is about 60 cm and the deflection is about one centimetre. On the right-hand part of the figure, the distance is half size (about 30 cm) and the deflection is four centimetres.

It is possible to use this experiment to found proportionality constant in the Coulombs' law, but this measurement is only very approximate.

3˙3. *Electromagnetic induction.* – There is one question in the CCTEM test focused on electromagnetic induction. Students are asked in which mutual movements of a magnet and a loop with ammeter will be any current measured by the ammeter. Students choose different options from these movements: movement of the magnet from the loop; collapsing of the loop (which change the area of the loop); rotation of the loop around its axis; movement of the loop toward to the magnet. All possibilities can be seen in fig. 6.

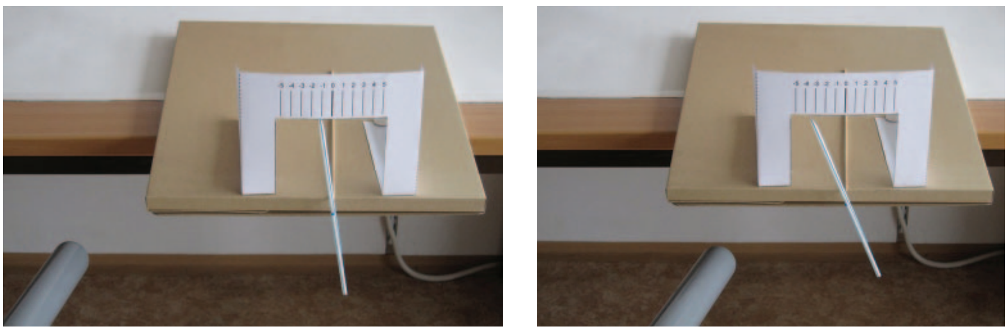

Fig. 5. – Coulombs' law— a simple qualitative experiment.

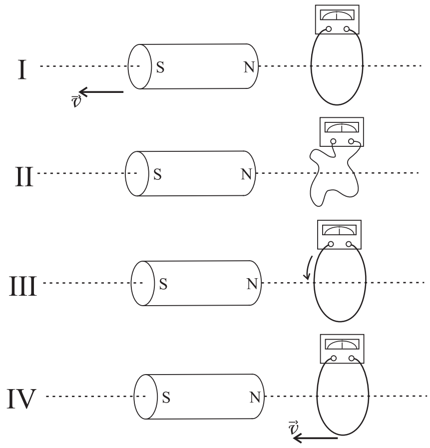

Fig. 6. – Electromagnetic induction—assignment of the task.

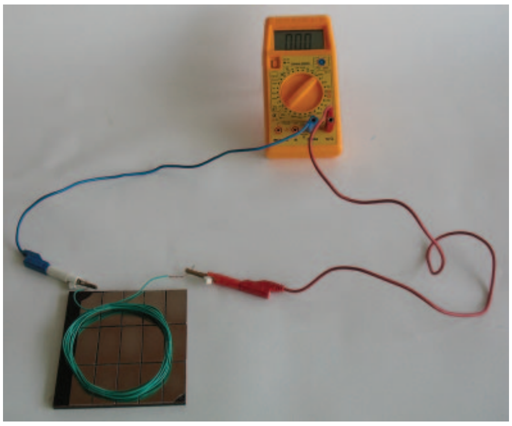

Fig. 7. – A coil in a uniform magnetic field.

This question is based on a similar question from CSEM. Authors of CSEM mentioned, that 72% of the students "[. . .] who choose answers that used the idea that 'motion' from either the loop or the magnet is necessary to create an induced current. Students may not seem the collapsing loop as changing the magnetic flux or the rotating loops as not changing the magnetic flux." (see Maloney *et al.*, 2001, p. S18). It seems that Czech students are more "careful" and chose only possibilities they know for sure. About 35% of the students chose answer which corresponds with movement of the loop toward to the magnet; other nearly 30% of the students chose answer which corresponds with movement of the magnet to the loop or the loop to the magnet. Only about 15% of the students chose correct answer in the post-test (and about 10% in the pretest).

So, students seem to know that the voltage is induced when there is some movement between the magnet and the loop. Some of them maybe know the Faraday's law and know something about change of magnetic flux, but they seem to have problem to understand fully what a "change of magnetic flux" means. Also, they do not see that changing the area of the coil changes the flux.

Now, how to show them what is the area of the coil and what connection is between changes of the area of the coil and induced voltage?

As a "magnet" we use uniform magnetic field of thin neodymium magnets forming a plate, a coil is made from pliable wire and the induced voltage is measured by a voltmeter.

The overall setup can be seen in fig. 7.

Using this equipment, we can show students that the voltage is induced when:

- We deform the coil (which changes the area of the coil)
- We move the coil to or from the magnets (if we are far enough from the magnets where the field is not uniform)
- We move the coil outside the surface of the magnets (which changes the area in which magnetic lines intersects the coil)
- We rotate the coil around its horizontal axis (which changes the angle between the coil and the direction of magnetic field lines).

Also, we can show them in which situation the voltage is *not* induced:

- There is no movement of the coil with respect to the magnet (so, there is some magnetic flux, but it does not change)
- We rotate the coil around its vertical axis (again, there is no change of magnetic flux)
- We deform the coil with the core inside it (nearly all magnetic field is inside the core, so the important "area" is the area of the core and the magnetic flux stays practically constant).

4. – Conclusion

The CCTEM was intended primarily as a diagnostic tool for Czech high school teachers. Therefore, it is only in Czech now. However, if you are interested in it, English version could be provided too.

Experiments we describe above are simple and mostly low-cost. However, they show effects students seem to have problem with, so they can help students to overcome their misconceptions. Verification of the influence of these experiments on students' comprehension of this area is in progress.

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