Three experiments inspired by secondary school students' misconceptions about electricity and magnetism

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Abstract

The contribution describes three experiments which were inspired by the very frequent secondary school students' misconceptions about electricity and magnetism. The first experiment relates to a charge on an insulator, the second one demonstrates qualitatively Coulomb's law and the third experiment illustrates behaviour of a coil in a homogeneous magnetic field. The misconceptions are described as well as are the results of research that demonstrate a relevant misconception for each experiment respectively.

Introduction

First, we used the well-known Conceptual Survey of Electricity and Magnetism [1] intended for first-year students of high school to test the secondary school students' misconceptions about electricity and magnetism. Unfortunately, the test was far too abstract for Czech students and thus it was not reflective enough. Because of these reasons the test was significantly reduced, the questions have been modified and some other questions have been added, so that the test was more comprehensible for students and also corresponded with physics content at Czech secondary schools. This new Electricity and Magnetism Concept Test (EMCT) was described in more detail in the publication [2]. Misconceptions mentioned in this article are based on the results of the research, which took place in school year 2012-2013. Test was divided into two phases, the first phase took place before the course of electricity and magnetism (hereinafter pre-test) and the second part after students attended the course (hereinafter post-test).

Charge on an insulator

Misconception

Almost 70 % of tested students even after the course of electricity and magnetism seem to be convinced that charge on an insulator disappears. Less than 18 % of students answered correctly the question about what is going to happen to the charge placed on a plastic bottle[1] (see diagram in pic. 1).

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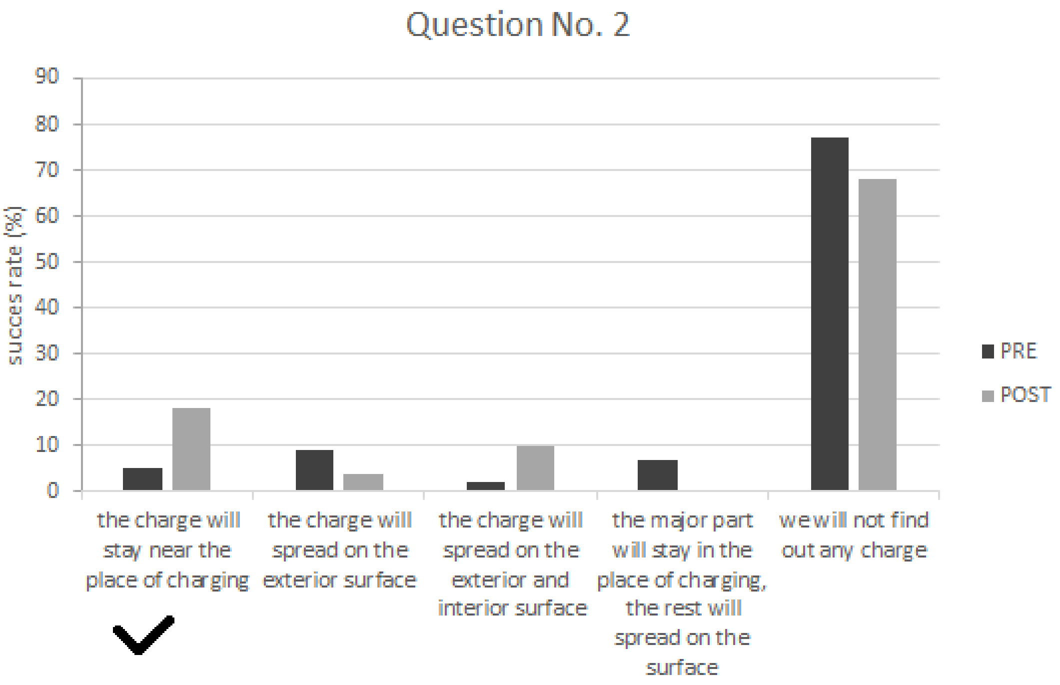
[1] Wordings of the questions in this article were reduced. In the test itself the wordings are longer, more accurate and supplemented with illustrations.

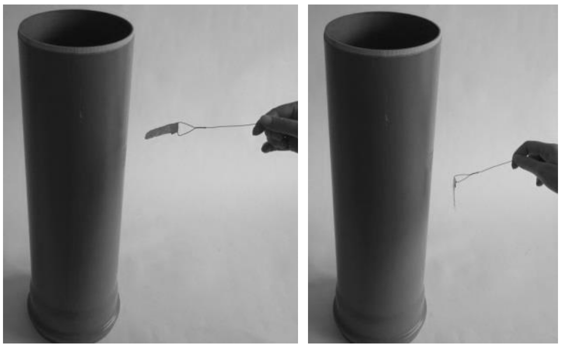


Pic. 1 – Students' answers to the question about what is going to happen to the charge placed on the plastic bottle, which stands on an insulated mat.

Nevertheless, students do not have such a big problem with charge's behaviour on a conductor (more than 40 % of students answered correctly the question in the post-test about what is going to happen to the charge on a tin, another 40 % were convinced that the charge is going to spread on the interior side of the tin too). Authors of the CSEM test ([1]) also mention the problem with understanding charge's behaviour on a conductor or insulator. How can we show, what is going to happen to the charge on a plastic bottle, then?

Experiment – charge on a sewer pipe

Wide sewer pipe has proved to be a suitable model of a plastic bottle. It is big, so it is more advantageous to demonstrate and it can be electrified by friction easier. Charge indicator can be made from a piece of tinfoil (see pic. 2) or we can also use a neon lamp. Charged pipe can be discharged by wiping it with a wet cloth.



Pic. 2 – Charge on a „plastic bottle ". Charged pipe is on the left, discharged pipe is on the right.

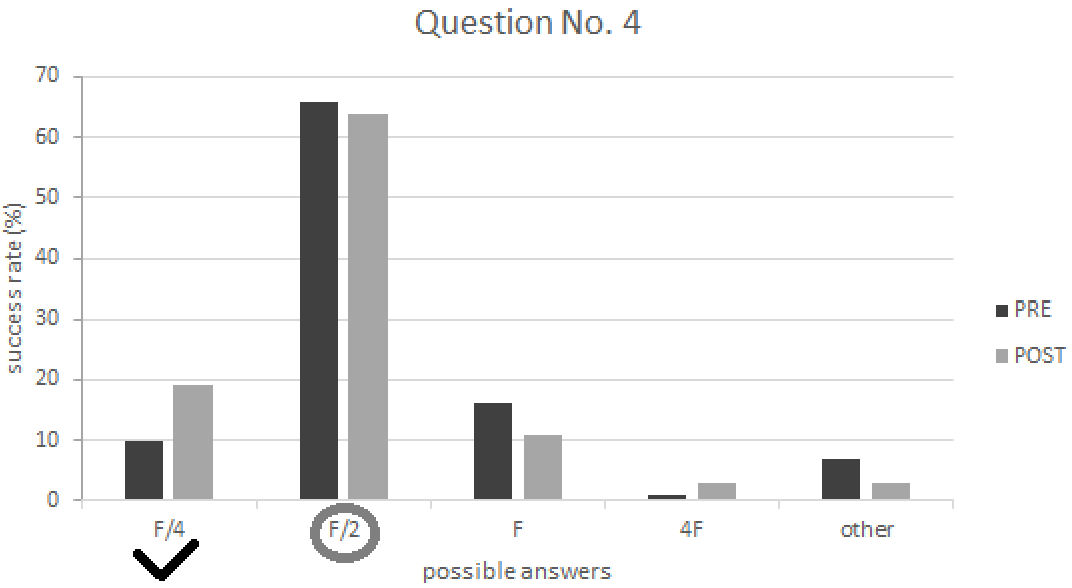
Using the pipe, we can show the difference between the charge's behaviour on a bottle (pipe) made of insulating material and charge's behaviour on a conductive tin:

- Charge on the pipe will stay only in the place at which we have rubbed it. If we rub the pipe in more places, charge will stay in all of them.
- If we discharge one of the rubbed places (by the neon lamp or by touch), charge in the other charged places will stay.

Coulomb's law

Misconception

In spite of the fact that Coulomb's law is given relatively enough attention at secondary school, it seems that students are not able to apply the law to a concrete situation. 63 % of students responded to the question about how will the force between two charged balls change if we increase the distance between them twofold, that the force will decrease by one-half. Only 19 % of students have chosen the correct answer (see the diagram in pic. 3).



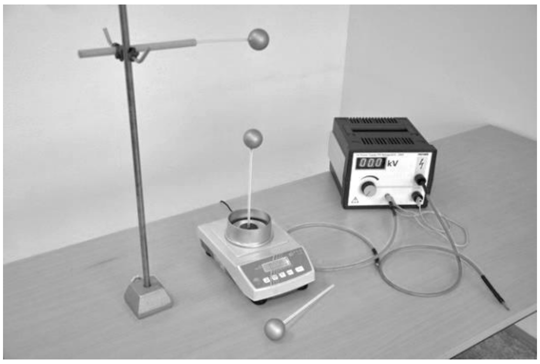
Pic. 3 – Student's answers to the question how will the force between two charged balls change if we increase the distance between them twofold.

From our own teaching experience, we suppose that if the same group of students was given the same problem but with specific numbers, the majority of them would calculate it correctly.

Can we demonstrate the dependence of Coulomb force on the distance without any complicated calculation?

Experiment no. 1 – Measuring the force between two charged balls

Table tennis balls sprayed with conductive paint (or smeared with graphite) can serve as charged marbles and an ordinary straw is a suitable holder for the ball. After charging the balls we can measure the magnitude of electrical force between the charges with sensitive scales (optimal sensitivity up to 1 mg).



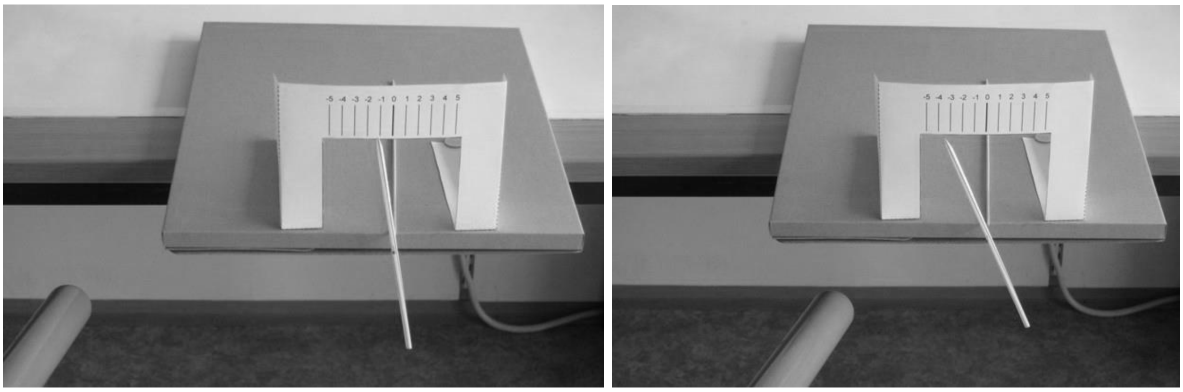
Pic. 4 – Equipment for measuring the force between two charged balls.

This kind of experiment is well-known from foreign literature. Experiment was verified, measured and described for Czech physics teachers some time ago by Zdeněk Šabatka, see chapter 3.2 in the publication [3]. Measuring equipment can be seen in picture 4.

Experiment 2 – Coulomb's law using the indicator from a straw

The fact that the force between two charges decreases with the square of the distance, can be proven with much simpler aids. We just need an ordinary plastic straw, a pin with head, a wooden skewer, a plastic rod that can be electrified by friction and a piece of paper (about one quarter of A4). We puncture the straw with the pin a little from its midpoint. Then we pass the pin through the pinhole and stick it to the end of the skewer. We draw or print a scale on the paper (parallel lines one centimetre apart from each other) and cut out and bend the paper to make the scale, which is shown in pic. 5. (We can weight it down at the back with two coins, so the scale does not fall over, and we can also weight down the skewer with a piece of modelling clay in the similar way.) Finally, we place our instrument on the edge of the table or even better on some board stuck out from the table's edge. It is important that metallic frame of the table is not near the instrument. (Charges induced in the frame could totally distort the result of the experiment.)

We electrify a part of the plastic straw at its lower end by friction, using paper handkerchief for instance. The plastic rod is also electrified by friction. When we bring close to the straw from the side, the bottom end of the straw is repelled from the rod. The upper end of the straw points to the scale. We move the plastic rod closer to the straw such that that the straw's deviation is around 1 cm. (This can occur in the distance of about 60 cm between the rod and the straw.) Then we move the rod from the bottom end of the straw to the middle and we will see that the deviation of the straw is around 4 cm, which means that in case of half the distance the force is four times greater.



Pic. 5 – Simple instrument, which proves that the force between two charges is proportional to $1/r^2$.

It should be noted that the distance of the plastic rod from the straw, at which the above mentioned deviations occur, depends on whether the straw is balanced, in other words, how far from the midpoint it was punctured. Balance can be corrected by cutting off a small part of the straw at its end. Obviously, the deviation also depends on the magnitude of the charges on the straw and on the rod. It is necessary to try this experiment beforehand, because some straws can be electrified by friction easier, some of them could be hardly electrified at all. It depends on the materials, with which we rub the straw and the rod, and on the external conditions as well.

If we have a charge meter, we can even determine the constant of proportionality in Coulomb's law by this experiment, but the measurement will be very rough.

Coil in a magnetic field. Electromagnetic induction

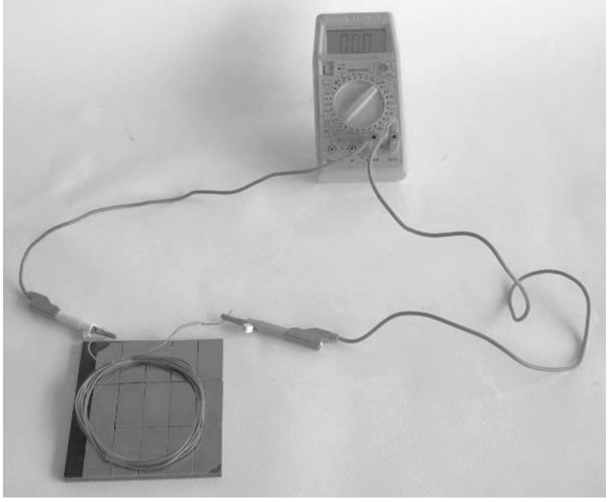
Misconception

Next-to-last question in EMCT test is about electromagnetic induction. Students were asked in which cases of mutual movement of a magnet and a loop there is induced voltage in the loop. Among particular responses there are: moving the magnet from the loop, moving the loop towards the magnet, deformation of the loop (decreasing its area) and rotation of the loop around its own axis. Authors of CSEM test mention that students do not perceive that deforming the loop changes the magnetic flux, but in contrast, they know that rotating loop changes the magnetic flux (see [1]). Czech students seem to be more careful: 35 % of students have chosen as the right answer only moving the loop towards the magnet, another 28 % have chosen moving the loop towards the magnet or moving the magnet from the loop. Change in the magnetic field in case of deformation of the loop is perceived by 15 % of students, in case of the loop's rotation – 18 % of students.

Usually students know that the voltage will be induced if the magnetic flux changes and that the magnetic flux depends on the magnetic induction and surface. Can we somehow simply demonstrate what surface is meant?

Experiment – coil in a homogeneous magnetic field

The apparatus is shown in the pic. 6. Homogeneous magnetic field was created by thin neodymium magnets stuck near each other with the same poles on the top side. Instead of one loop's thread we have used several threads of a soft wire. For measuring induced voltage can be used the "voltage indicator with LED column" (see [4]), or a sensitive voltmeter.

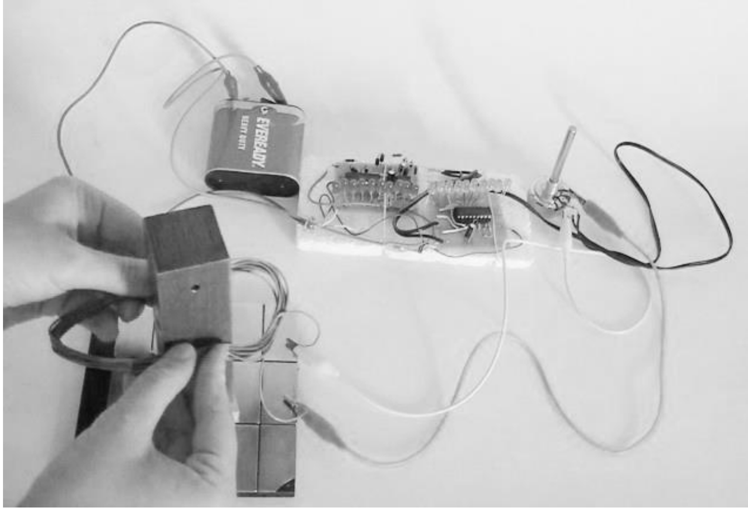


Pic. 6 - Apparatus for measurement when voltage is induced in the coil.

Due to fact that the coil is made of soft wire, we can show students induction of the voltage in case of its deformation as well (and thus in case of its surface's change). Besides the deformation, voltage is also induced in case of:

- moving the loop from and towards the magnets (if it is far from the magnets where the field is not homogeneous anymore)
- moving the loop away from the magnets' area
- rotation of the loop around the horizontal axis (angle between the loop and the magnets changes)

On the contrary, in case of the loop's rotation around the vertical axis voltage will not be induced and the same applies in the case of the loop's deformation if it has core inside (see pic. 7).



Pic. 7 – If there is a core inside the coil, the magnetic flux does not change during the coil's deformation, therefore voltage is not induced in the coil.

Conclusion

If you have some comments or remarks on the experiments, or you want to know more about EMCT test, we will be delighted if you let us know on the e-mail **vera.koudelkova@mff.cuni.cz**.

References

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