

## DISCOVERING ELECTROMAGNETIC INDUCTION: INTERACTIVE MULTIMEDIA PATH

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### Abstract

We show that teaching of the electromagnetic induction can be enthusiastic to pupils, once we abstract from a classical approach, i.e. trying to indicate the direction of the current generated. One should rather concentrate on the richness of phenomena which can be explained by the Faraday- Lenz- von Neumann law. The experimental set developed in the framework of a wide international collaboration, which comprises Udine and Torun universities offers a wide choice of experiments, on different levels.

### 1. Scholastic teaching

Typical educational paths on electromagnetic induction go thoroughly through step-by-step explanations: "-What happens if we insert the north pole into the solenoid? – And what if we insert the south pole?". This path is correct but induces students to reasoning that physics is a kind of artificial word, with old instruments and specially isolated situations.

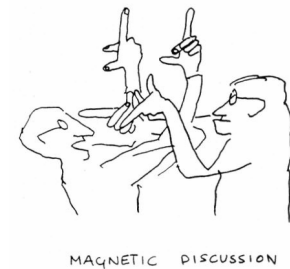
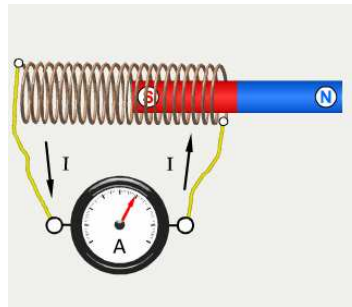
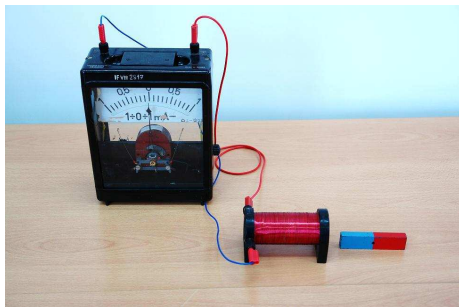


Fig. 1. A [classical experiment](#) on the electromagnetic induction: a special volt-meter, a special coil and a two-colour magnet are (apparently) needed.

Fig.2. Incorrectly constructed multimedia [1] are difficult to be understood.

Fig. 3. "Magnetic discussion" - a drawing by Bruno Touschek

Using multimedia can be even more boring: students find difficult the visualisation of the coil windings directions and the current, at the same time, on a 2-D representation [1], see fig.2.

The crucial question, on the direction of the current induced, is not the "right" or "left" hand rule (as, by the way, it was already discussed in a funny form by Italian excellent nuclear physicist Bruno Touschek, see fig. 3), but the energy-conservation law. This is the very basic law, and the principle of Faraday-Lenz von Neumann is the direct consequence.

### 2. An interactive path

To bring students to this observation we organize an interactive path using elements of Torun-Udine collaboration in international projects [2]. The "hook", i.e. the attention-catching experiment is the ["drunken magnet"](#) which draws a snake-like trajectory on the inclined copper plane. The attention in this experiment is caught by the unexpected behaviour of the magnet: pupils expect that it will fall, or that it will slide slower (due to "fantomatic" Foucault currents) but a force bringing back the magnet to the center of the copper plane seems somewhat mysterious. Any friction (and the Foucault currents seem to be friction-like) tends to hinder the movement, and not to re-direct it.

In the next step we show a well-known experiment with a magnet falling inside a [copper tube](#) [3] but we do not fix the attention on the time of falling but on the observation of the magnet inside. We

insist on the verbalisation of the experiment by pupils. "-What is the best expression for the movement of the magnet inside the tube?". "It is slowed down", "-Really?", "It does not touch the walls", "-Really?", "It *levitates*", "-Yes! This is the best expression!"

The verbalization, bringing the specific experiment to a broader class of phenomena facilitates the further reasoning. In the case of "levitation" it is obvious that the gravitational force must be equilibrated by some opposite force. We change the person who is asked and re-formulate the problem.

"- What is the reason for the *levitation*?" "A repulsive force".

"- So you understand that sometimes the copper plane attracts the moving magnet, sometimes it repels. We call it the Faraday – Lenz – von Neumann principle".

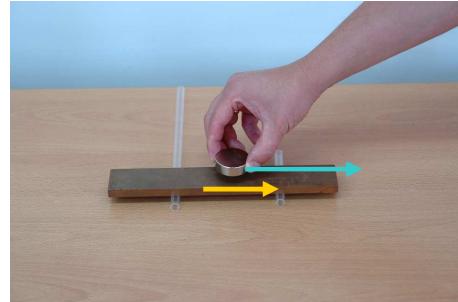
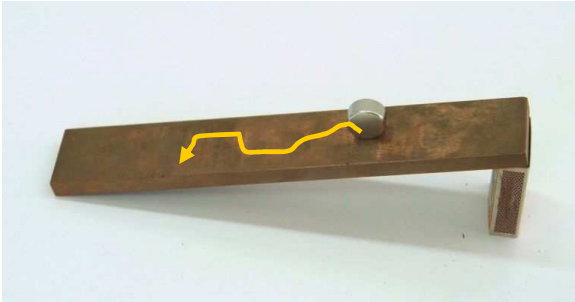


Fig.4. A "drunken magnet" – showing that Lenz-von Neumann principle leads not only to "friction-like" Foucault currents but to visibly "active" deviation of the magnet movement.

Fig.5. The copper plate placed on the rolling bars follows the movement of the magnet: if the magnet is approaching the plate it is repelled, if the magnet is leaving the plate, it is attracted.

A complete statement is needed before next steps: "The change (1) in the magnetic flux induces an extra field (or electric currents (2), if circuits are present) that is opposite to the direction of the initial change." The second series of experiments aim to illustrate single parts (1-3) of the FLvN law. This series may comprise now the classical experiment from fig.1 and all possible experiments of interacting windings and magnets, all from the set of experiments [4] developed recently in the framework of the collaboration.

(3) The "opposite" action can be shown by two more experiments with the set from fig. 4. In the first experiment we make fall (rapidly) the [magnet on the copper plate](#). The magnet does not crash on the plate but descends in a braked mode. But opposite, if we try to extract the magnet from the vicinity of the plate, than the copper [plate is attracted](#), see fig. 5.

(2) A change in the magnetic flux generates an electric current – this is the best to be shown by a ready Pasco (or similar) apparatus, in which the transformer bring the flux to a narrow, vertical rod (this experiment is usually known as "[a jumping ring](#)"). The change of the flux (which can be obtained either by applying an AC current or an interrupted DC current) causes an electric [bulb flash](#), see fig. 6.

(1) Finally we show that only the *net* change in the magnetic flux concatenated induces the current. To verify this we use a plastic tube with a single-layer coil wound around it. The two ends of the coil are attached to the input of an ADC device (Coach system, microphone input of the PC etc.). We check that the voltage spikes appear only when the magnet enters (or exits) the beginning (or end) of the coil, see fig. 7. Inside the coil, the flux growing on the lower face of the magnet is equivalent to the flux diminishing on the upper face of the magnet, so the net flux change is null.

Obviously, the same phenomenon can be explained saying that the voltage generated *below* the magnet is opposite to the voltage generated *above* the magnet, but from a didactical point of view this is redundant, and deviates pupils' attention from the very FLvN principle.

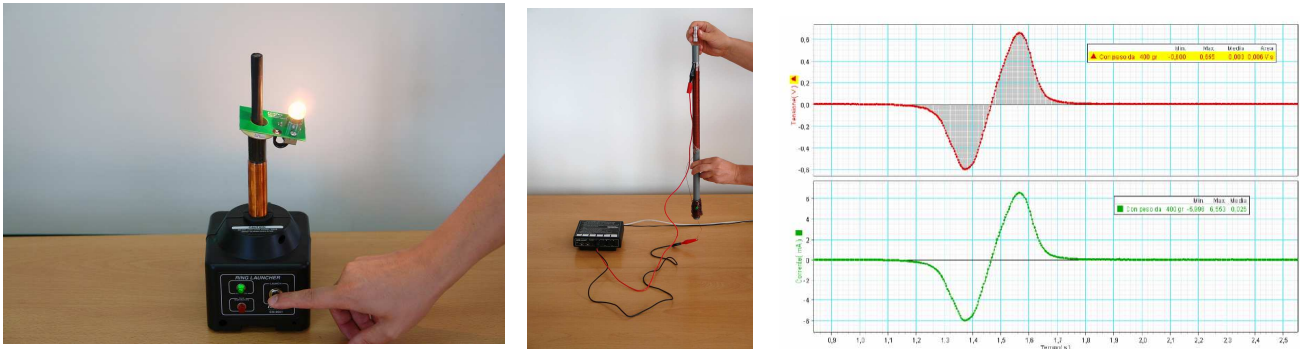


Fig.5. A small bulb attached to windings around the iron rod flashes when the magnetic flux changes.  
 Fig.6. The same flashes can be shown by a LED attached to the winding around a plastic tube when a magnet is falling. By the choice of the LED (red, green) we can actually measure the voltage generated.  
 Fig.7. Distributed windings are wrapped around the same tube. The voltage is generated only when the magnet enters or leaves the windings. The two fluxes integrated over the time are equal [5].

If no ADC system is available, one can simply wind a thick coil around the tube, close the circuit with a LED and observe this latter flash. As the LED requires a minimum voltage to flash, if it flashes this minimum voltage has been obtained in the current spike, see also fig. 7.

Resuming, the very direction of the current generated seems, in the modern, in-hurry word, somewhat less important to be taught. We should rather concentrate on different aspects of the FLvN law, to show that it is present in many aspects. Then, the phenomenon of diamagnetism (also available in the experimental set [4]) and the Meissner effect for superconductors become also less mysterious.

Forty-four experiments in the experimental set [4] allow to try many didactical variations and conjugate the phenomenology with some more general principles, like the energy conservations showing up in the FLvN principle.

## References

[1] <http://online.supercomet.no>, Electromagnetic induction, 4/21 and 5/21.  
 [2] <http://dydaktyka.fizyka.umk.pl/TPSS/>  
 [3] M. Michelini, SUPERCOMET 2, [Teacher guide](#), p. 62.  
 [4] <http://dydaktyka.fizyka.umk.pl/TPSS/zestaw/index.html>  
 [5] M. Gervasio, Saggio finale, SSIS Udine, 2008