HANDS ON EXPERIMENTS ON MAGNETISM AND SUPERCONUDCTIVITY

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Introduction

"Supercomet2" is a European Union project within Leonardo da Vinci framework comprising as many as 17 countries. Its aim is to show new teaching methods, on the example of superconductivity – a rather modern problematics, still to be fully understood. A sub-group of this project prepares simple hand-on experiments mainly on superconductivity and magnetism. Typical experiments on magnetism discuss:

- magnetostatics – attractive or repulsive interaction of static magnets
- Oersted's experiment with a magnetic needle
- Faraday's induction law
- electric motors and generators
- eddy currents

Experiments which are proposed in this paper belong essentially to the above categories. However, we group them, showing several similar objects, in order to stress common physical phenomena. In this way, instead of discussing just magnetostatics, we show a few types of obtaining stable levitation of magnets; Faraday law is shown also in several ways. Finally, a set of experiments can be used to show complete Maxwell laws. All experiments prepared within the programme will form a hardware package but will be also available in a virtual form via internet and on a CD-Rom. Some of the ideas were already presented [1], some of them are included into the previous CD-Rom "Physics and Toys" [2] (in Polish).

Choice of experiments

Three classes of experimental set-ups are proposed:

1) complex equipment, owned by university or local education centre and loaned to schools at request after previous training of teachers; an example is the Leybold apparatus for measurements of the transition temperature in superconductors
2) cheap intermediate set-ups to be used in single schools; several examples of magnetic levitation and illustrations of Lenz's principle would form this packet
3) easy experiments which can be constructed at zero cost by individual teachers, like the model of Volta's electrophore made of a polystyrene "glass".

Obviously, majority of proposed experiments is not new and are well known to teachers. On the other hand, extensive catalogues allow to choose professional but usually expensive equipment [3]. Here we show some objects which are available in shops with scientific toys or souvenirs. Showing new aspects, possible funny or unexpected, involves the emotional part of recognition, and in this way creates more inter-branched and durable knowledge.

We choose experiments and objects which are:

- ”at reach” – available on internet or being everyday objects
- cheap – possible to be bought or constructed privately by teachers
- fast in use
- effective from the point of view of didactics
- contain, possibly a reference to historical experiments.

Electricity sources

By "electricity sources" we summarize different ways of generating the current or the voltage, DC or AC. Historically first was tribology, i.e. generating voltage (and little current) by friction. Otto von Guericke at about 1660 used a sulphur ball rubbed by hand. It took many years before the modern version of the electrostatic machine was constructed by J. Wimshurst in the 1880's. But its principle is the same as in the experiment with a silk scarf taken out from a wool coat, fig.1. Quite high voltage can be obtained from a piezoelectric lighter – with the lighter and two Christmas tree balls hanging on thin wires the Coulomb's experiment can be reproduced [4].

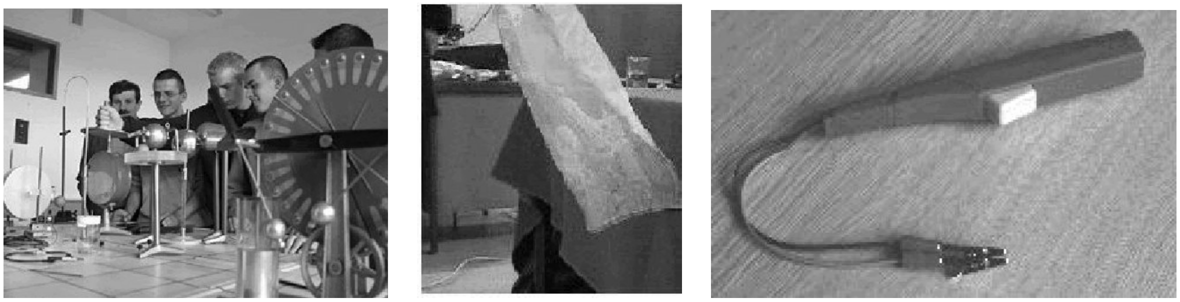

Fig.1. "Voltage" sources: a) Wimshurst's tribological machine, b) Ania's scarf taken from a wool coat does not hang vertically in stiff air, c) piezoelectric gas-lighter produces several keV, be careful!

Volta's pile is still the unique source of electricity (current) for all portable gadgets, like PCs and handy's. Unfortunately, we know how to make Volta's piles but we do not know why they produce the defined voltage and not another. The electrochemical potential is a kind of the ionisation potential, but not of a free molecule but of the solid state, and not in vacuum but in highly polar, liquid medium. Two different metal plates and any liquid (our body) make Volta's pile. But if you call it "IQ meter" and place at the entrance of the university senate all professors will try it. Then you comment: "Oh! Yes! Usually it should be above 1.0 and not negative, but sometimes, when you are tired it can happen..."

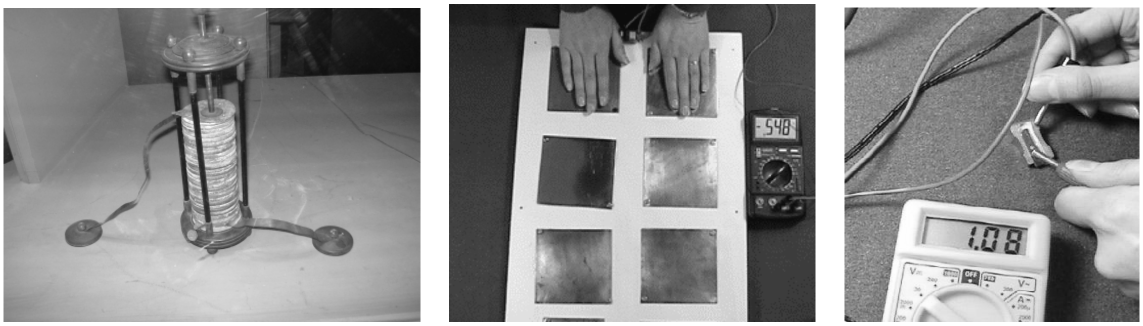

Fig.2. "Current" sources: a) original Volta's piles from Como museum; you can make a similar one using two types coins – every second junction is separated by a wet paper or cloth; b) IQ meter – note the worst ever, negative result in IQ; c) a metal sharpener – a stainless steel knife and the aluminium body separated by a piece of wet paper give as much as 1 V.

Faraday's generators can be shown by school laboratory devices, by a toy-like portable lamp (protected by the USA patent laws but produced in some countries quite cheap) or by a Helmholtz coil – a set of thick wire windings on a rectangular frame. The latter, if a current is supplied, turns slowly in the Earth's magnetic field, becoming the simplest electric motor [5].

Fig. 3. AC current sources, or electric motors: a) a turning coil from the school lab [6], b) Helmholtz's coil - about 100 windings of 0.8 mm diameter wire (the chair and Ania's legs in the background are not necessary) c) hand-shaken lamp – the current is generated moving a magnets incite the coil (made in China).

Levitation (1)

Levitation can be used to show the magnetostatic interactions, but not only. The key point in levitation is the stabilization of the interaction, by constraints, or some feedback. The simplest case in the two-dimensional constraint, in fig. 4a the magnets are simply bi-polar, with poles on upper and lower basis of the donuts. The stick prevents the magnets from sliding aside. In the levitating pen, fig.4b, the mechanical constraint is just in one point. But in this case magnets are two inside the pen – still donuts, but with poles on the external and internal side of the donuts. The same sign poles as on the external side of the donuts are placed in the upper part of the base. This mutual configuration of poles in the base and donuts pushes the pen up and left (on fig. 4b) – the mechanical barrier blocks the pen from going too much to the left. In the magnetic roulette, fig. 4c, all six poles in the basis repulse the ball and the fun consists in the instability of the system.

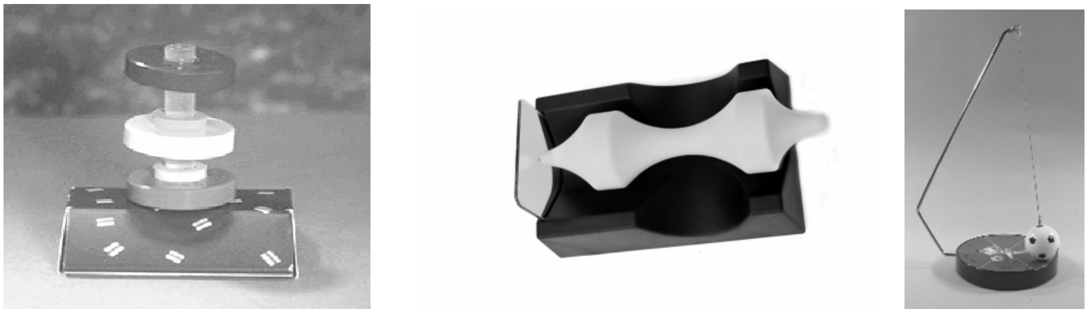

Fig. 4. Magnetostatic interactions: a) donuts, with poles on upper and lower bases are blocked in two directions by the stick; b) in the levitation pen one pole is on the external, lateral side of the donuts inside the pen; the repulsive interaction pushes the pen up (against the gravity) and left, against the barrier; c) in the roulette it is the cord above which prevents the ball from flying apart left and right.

Levitation (2)

In the second case of levitation, see fig. 5, some feedback is present. In a levitron, this is the gyroscopic momentum, keeping the spinning top in the vertical position in fig.5a. Note, however that the range of the dynamic stability (i.e. the initial tilt of the axis, the departure point and the spinning initial velocity) is very narrow [7]. In the levitating globe this is the electronic circuit governing the current of the upper base coil which adjusts dynamically the attracting force. The same dynamic adjustment, via the diamagnetic interaction is present in fig. 5c: an iron cube is levitating, attracted by the magnets above, and repulsively stabilized by the two thick graphite blocks above and below.

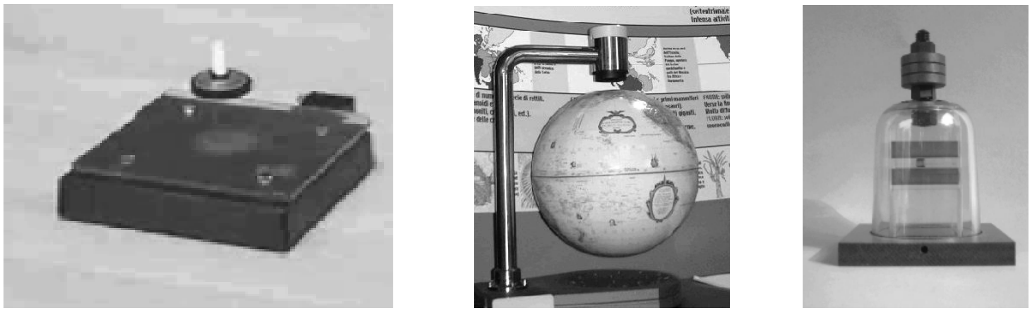

Fig. 5. Levitation stabilized by dynamic interactions: a) a levitron hangs inside the potential well, made of four magnets on the base corners but it is quite difficult to stabilize it [7]; b) the hanging globe is stabilized by an electronic feedback, driving the current in the coil above; c) levitation of an iron cube, stabilized by the diamagnetic interaction with two thick graphite plates above and below: the position of magnets above is to be adjusted before the experiment.

Detectors

To visualize magnetic field one can still use sub-millimetre iron filings, fig. 6a, but this toy does not allow to show details of magnets. These tiny structures are shown in fig.6b, where the traces of two cylindrical magnets are compared: that to the left is a magnet from levitating donuts, these to the right are two magnets used to fix remember-notes on the fridge case. These latter magnets are *multipoles*: on the same face, north and south poles form successive stripes. This second "detector" is a drawing-pad for children – a thin layer of micro fillings, suspended in a paraffin oil between two walls (the front one is transparent). A "cancel" bar is a strip of unipolar magnet, moved below the screen. The space between the two walls is divided into smaller, hexagonal cells, in order to avoid pulling all the micro fillings in one corner of the screen. The fig.6c shows a ferromagnetic fluid, allowing to show 3-D distribution of magnetic fields. Unfortunately the liquid deteriorates quickly.

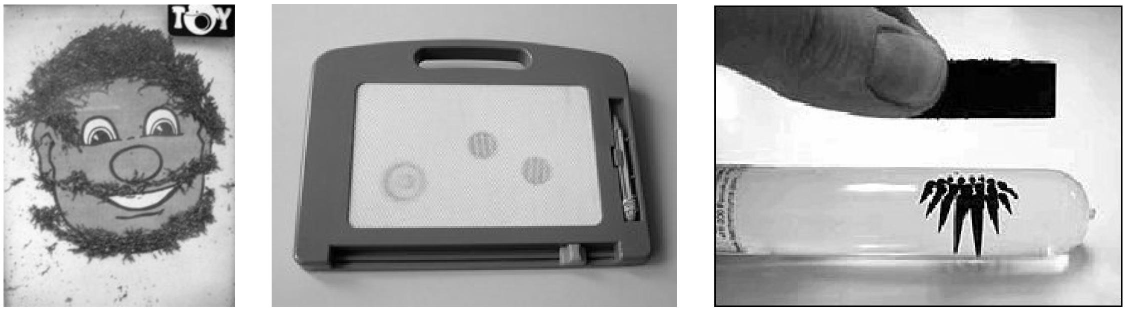

Fig. 6. Three devices to show the magnetic field lines. a) and old play with sub-millimetre iron filings, b) a novel screen for drawing for children, made of micro fillings suspended in paraffin oil; c) Ferro fluid cell [photo – www.teachersource.com]

Shields

Apart from sources, shields are also required. It is rather simple to shield electrostatic fields or electromagnetic waves, see fig. 7a. The shielding is based on so-called Faraday cage – no electrical charges exist inside a (perfectly conducting) metal. All electrical charges concentrate on the external surface of the cage. But it is quite hard to shield magnetic fields, comprised the Earth field. This comes from the same principle as the magnetostatic