

Hands-On Experiments on Magnetism and Superconductivity

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We describe some simple experiments on electricity sources and magnetism. A set of these experiments is under preparation within “Supercomet2” Leonardo da Vinci EU project.

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 example of superconductivity – a rather modern problematics, still not fully understood. The present paper describes the work of a subgroup of this project dealing with simple hand-on experiments mainly on magnetism.

In particular, the “SC2” handbook describes subjects of:

- magnetostatics – attractive or repulsive interaction of static magnets
- Oersted's experiment with a magnetic needle
- Faraday's induction law and electromagnetic generators.

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 permanent magnets; in a similar manner we show different ways of visualising the magnetic field lines. All experiments prepared within the LdV 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 presented before [1], some objects are already described in the multi-language version on internet [2].

Choice of experiments

Three classes of experimental set-ups are discussed within “Supercomet2” project:

1. complex equipment, owned by university or local education centre and loaned to schools on 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 are 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 a more inter-branched and durable knowledge is created. We choose experiments and objects which are:

- "at reach" – available on internet or being everyday objects
- cheap – possible to be bought or constructed on their own by teachers
- fast in use
- effective from the point of view of didactics
- make reference, possibly, to some 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. It is made of two plastic disks with metal paths, the disks rotate in opposite directions and are rubbed by copper brushes. The same principle, of separating charges by rubbing, one finds in the experiment with a silk scarf taken out from a wool coat, fig.1b. If such a scarf is then folded in two and hung in the middle, the two ends will repel each other, like in the electrostatic. Quite a high voltage can be obtained from a piezoelectric lighter – one has to take-off the metallic cup and connect isolated wires to the two electrodes. Coulomb's experiment can be reproduced by using this lighter and two Christmas tree balls made of thin glass and metalised inside, hanging on thin wires, fig. 1c. Depending on the polarizability applied, the two balls will attract or repel each other.



Fig.1: "Voltage" sources: a) Wimshurst's tribological machine (the right part of the photo), b) silk scarf taken from a wool coat doesn't hang vertically, c) piezoelectric gas-lighter used for "Christmas experiment".

Volta's pile is still a 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 a highly polar, liquid medium. Two different metal plates and any liquid (even our body) make Volta's pile. But if you call it "IQ meter" and place at the entrance of the class it will make a lot of fun. You simply comment: "Oh! Yes! Usually it should be above 1.0 and not negative, but sometimes, when you are tired it happens..."

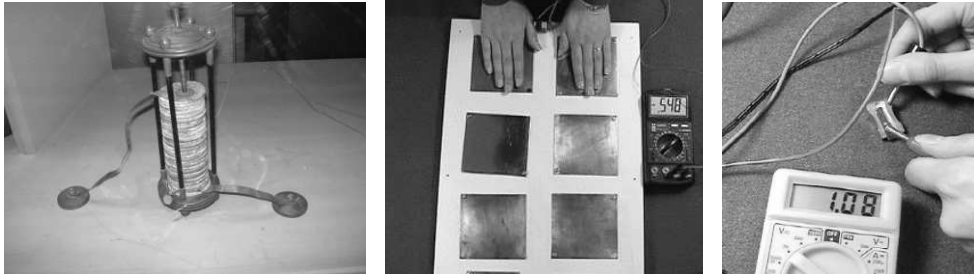


Fig.2: Three examples of electrochemical sources: a) original Volta's piles from Como museum; you can make a similar pile using two types coins – copper and aluminium, for example and putting a piece of wet paper or cloth between every second junction (so the pile is done like this: Al, Cu, wet cloth, Al, Cu, wet cloth, etc); b) “IQ” meter – note the worst ever, negative result in IQ (“IQ meter” consists of two columns of different metals; each metal piece is connected below the wooden plate to the electrical exit, seen here between the two hands); c) electrochemical pile made of a pencil 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 DC current is supplied, turns slowly in the Earth's magnetic field, becoming the simplest electric motor [1].



Fig. 3: AC electromagnetic current source, based on Faraday law, working also as electrical motors: a) a turning coil placed in the field of a permanent magnet [5], b) Helmholtz's coil - about 100 windings of 0.8 mm diameter wire wound on a wooden frame and turned around in the Earth magnetic field will create a few mV voltage; the same coil, supplied with DC current from car battery, turns slowly in the Earth field, c) hand-shaken lamp – the current is generated moving a magnet inside the coil (a toy 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 by some feedback. The simplest case in the two-dimensional constraint. In fig. 4a the magnets are simply bi-polar, with opposite 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 donut. 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, the poles of the same sign are placed in the base and on the external side of donut magnet in 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 from above which prevents the ball from flying apart.

Levitation (2)

In the second case of levitation, see fig. 5, some feedback is present. A levitron consists of four permanent magnets in the corners of the base, the levitating magnet is spinning and its weight must be carefully chosen. In the levitron, this is the gyroscopic momentum, keeping the spinning top in the vertical position in fig.5a. If gyroscope tends aside, the lines of the magnetic field there are not vertical anymore what causes the levitron precession. This precession brings it back to the centre of the plate. 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 [6]. In the levitating globe, fig. 5b, a coil supplied with regulated DC current is placed above the globe. This is the electronic circuit governing the current which adjusts dynamically the attracting force. If the globe is placed initially too close to the upper base, it will stick there; if it is placed too far – it will fall down. A somewhat similar feedback, but based on diamagnetism is present in the levitation set from fig. 5c. A small iron cube visible in the middle is levitating, attracted by three donut magnets above. It is also repelled by two thick graphite blocks above and below. This repulsion is due to the diamagnetic interaction of the static magnet with graphite plates.

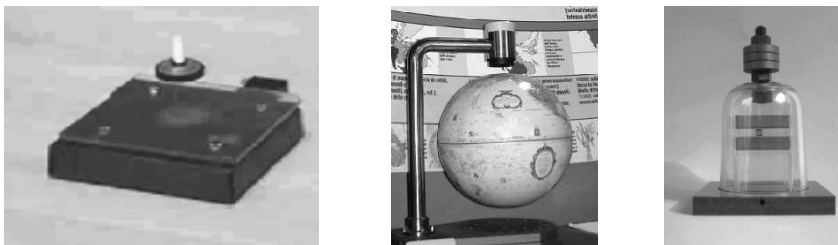


Fig. 5: Levitation stabilized by dynamic interactions: a) a levitron hangs inside the potential well, made of four magnets on the base corners but it is quite difficult to stabilize it [6]; b) the hanging globe is stabilized by an electronic feedback, driving the current in the coil above; c) levitation 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 donut magnet from the levitating pen – one see that the poles inside and outside the donut. The two magnets to the right are traces from magnets used to fix remember-notes on the fridge case. These latter magnets are *multipoles*: on the same face, north and south poles form a series of successive stripes. The "detector" from fig.6b 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 fillings, b) a novel screen for drawing for children, made of micro fillings suspended in paraffin oil, the front screen is transparent; c) Ferro fluid cell [photo – www.teachersource.com]

Shields

Apart from sources, shields are also frequently required, for xample in TV tubes. It is rather easy to shield electrostatic fields or electromagnetic waves, see fig. 7a. This 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. So a handy placed inside the cage wil not work. But it is quite hard to shield magnetic fields. This comes from the same principle as the magnetostatic interaction: two, opposite magnetic poles are always present (no free magnetic "charges" exist). Therefore, the only way of shielding is to subtract the magnetic lines from the neighbourhood, concentrating them inside a material with a high magnetic permeability. A box made of such a material, mu-metal, an alloy of Ni and Co with relative magnetic permeability μ about 40,000, keeps the space inside free of magnetic fields. Geese and marine turtles would get lost during their migrations with the Earth magnetic field switched-off.

In fig. 7c we show a detector of electromagnetic waves – an AC tester for electricians, used to detect wires inside walls. It is enough sensitive to show leakage from a microwave oven and show the health hazard from staying close to the TV screen.

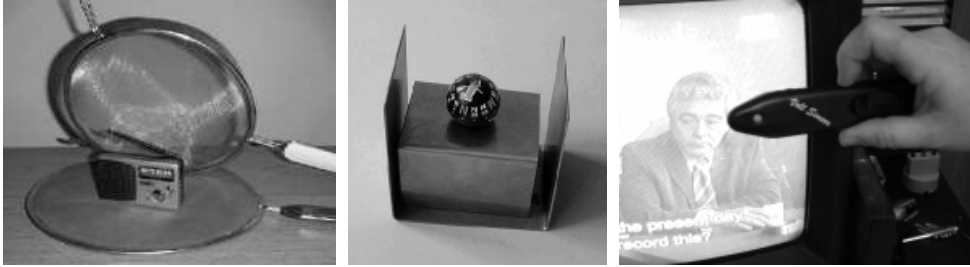


Fig. 7: Shielding and detecting EM fields. a) a sieve is enough to shield FM (in the 100 MHz range) radio waves, but can be not sufficient to shield the GHz fields used in cell phones – some field penetrates though the holes of the sieve; b) magnetic field are shielded by a box made of a high magnetic- permeability metal; c) a detector of AC wires inside walls is enough sensitive to detect also HF electromagnetic fields outside TV screen or near the doors of the microwave oven.

Examples shown here illustrate the general idea of the proposed experiments: seek for the same, similar, or contrary phenomena in different devices. Some more experiments, comprising levitation of YBCO superconductors are shown on our "Supercomet2" internet site [7].

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