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Conservation of charge to understand potential using on line charge measurements

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Summary. — Electric potential turns out to be one of the most difficult concepts in students' learning: its role is not recognized either in electrokinetics or in electrostatics. In this area the transfer of charge between conductors is explained according to Coulomb's law and looking at the same amount of an entity on them as a balancing factor. Moreover, students' ideas often imply a lack of awareness about the conservation of charge. The inclusion of the idea of potential as a magnitude running the transfer of charge was planned in a vertical path on electrostatics using a strategy based on simple experiments. The need for repeated quantitative measurements, with good sensitivity, makes the on-line measure a determining factor.

PACS 01.50.-i – Educational aids.
PACS 01.50.F- – Audio and visual aids.

1. – Introduction

Electricity is one of the most important topics in physics, both looking at the wide contexts of everyday life where it is applied both for the relevant role of the concepts involved (charge, current, field potential. . .) as concerns the subject. These characteristics make electricity a subject for teaching in every level of instruction. It is also one of the most investigated fields as regards the learning difficulties of students of whatever age, particularly about circuits (Mc Dermott 1992). Some researches (Eylon 1990, Benseghir 1996) have suggested as origin of the students' difficulties in electrokinetics a missing link with the magnitudes of electrostatics underling the interpretation of phenomena related to circuits This view spurred investigations about learning in the field of electrostatics too.

2. – Students' difficulties in learning electrostatics

Research on learning about electrostatics led to the identification of difficulties experienced by students in high school and university when interpreting the basic phenomena (Furió 2004), such as electrification and induction. According to these researches students use in their interpretations four models of electricity, so that it 1) is created when a body is rubbed, 2) makes an electric atmosphere that attracts the bodies nearby, 3) is a fluid, 4) is a group of entities - charge - which acts at a distance. In the most commonly used model electricity as a fluid goes on dielectrics by rubbing and on metals by contact. Investigations carried out at various levels show that one of the concepts reported as very difficult for students in electrokinetics, the electric potential is not used for the interpretation of processes of charge transfer. High school and University students foresee a transfer of charge between conductors (identical) only if both and oppositely charged, until one of them becomes neutral. The concept of force between charges is used to justify a certain configuration of charge, but without taking into account all the charges on both conductors (Guruswamy 1997). The answers of the students imply that in many cases the conservation of charge is not taken into account in determining the configuration of charge of the bodies after the contact. For prospective primary teachers the reason of moving of the free electrons in a conductor connecting two differently charged metal spheres is the difference in the number of electrons on them (from the sphere that has more charge to the other, up to an equal number of charges on both) while 25% of the sample interchanges the potential difference with the difference in charge, concept of more real meaning that the previous one (Barbas 1997). University students explain the phenomena of charging mainly by the transfer of charge from one body to another, from the greater amount of charge to the lesser; there is an identification of charge and potential (they grow in the same way), and the latter is considered an indicator of the amount of charge that a body can hold. Electrical capacity is defined as the amount of charge that can be stored in a body and then this magnitude does not make sense for neutral bodies (Guisasola 2008). Emerges as students do not have a scientific explanation of the concept of potential and fail to establish a significant relationship between potential, charge and capacitance. There is also a convergence compared to other studies (Viennot 1999) in the use of formal operational definitions in incorrect causal terms.

3. – Educational proposal

Research on learning difficulties in electrostatics was the starting point for an educational proposal aiming to significant learning in this area, bearing in mind the need to tackle the learning difficulties from a phenomenological point of view, to build in childhood the interpretative grounding of the phenomenology. Since elementary school pupils can be faced with phenomenology to bring out their ideas on the phenomena and to compare them to build a scientific knowledge replacing their spontaneous ideas.

The proposal, in the theoretical framework of the Model of Educational Reconstruction (Duit 2006), focuses on the macroscopic properties of the electrical interactions to build the first level of interpretation of electrostatic phenomena. It is organized in hands-on activities with stimulus exploratory cards (Martongelli 2001, Michelini 2004) and a strategy based on conceptual micro steps based on SPEA (Situation, Prevision, Experiment, Analysis) cycles. One activity concerns the study of the transfer of charge for a measure about the charge conservation and for the introduction of the concept of electric potential.

The educational objectives of the experiment, divided into phases, are a) a review of the conservation of charge as a constant outcome of all the observed phenomena, b) a stimulus for the expression by the students of their ideas about the charge transfer between objects, metallic or not, charged or not c) an observation of the conditions under which the charge transfer occurs, also in contrast to the students' mental models d) the identification of a new quantity —the potential— that drives the phenomenon e) the

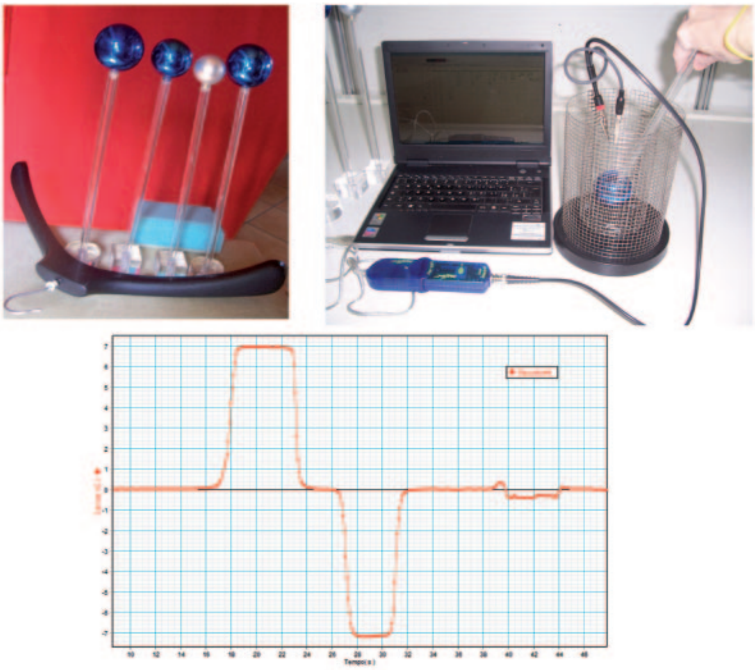

Fig. 1. – From left, top to bottom: materials of the transfer by contact experiment, example of measure and outcome.

acquisition of a way of looking at the system under study in a comprehensive manner by identifying the characteristics influencing the phenomenon.

4. – Experiment

The experiment requires measurements of the charge on the involved objects. This measure was designed as a measure with an on-line apparatus and displayed in graphical mode (charge versus time). The advantages of this set up are: a) technical: the need for quantitative measurements, with good sensitivity, repeated in a short time, without loss of charge on the measured systems makes the on-line measure (made with a PASCO charge sensor and a Faraday ice pail) a determining factor of the experiment, b) educational: the graphic view of the outcomes allows pupils both to take advantage from the functional reduction which facilitates the interpretation of the phenomena with real-time measurements, and to transduce charge measures in length measurements (of charge peaks) that can be compared and summed (algebraically, since the peak versus represents the charge sign), even at elementary school levels.

The measurement procedure (based on the measure of the potential induced on a Faraday cage) may be justified by a previous discussion of the concept of charge including induction: in this case, we did not notice difficulty by middle/junior high school students to accept that what you get is a measure of the charge on the object inserted into the cage.

The activity uses easily available and inexpensive materials, as Christmas tree ornaments (fig. 1).

In the first part of the experience a measure of the charge on two little plates, before and after they have been rubbed against each other, is performed. A graph with two

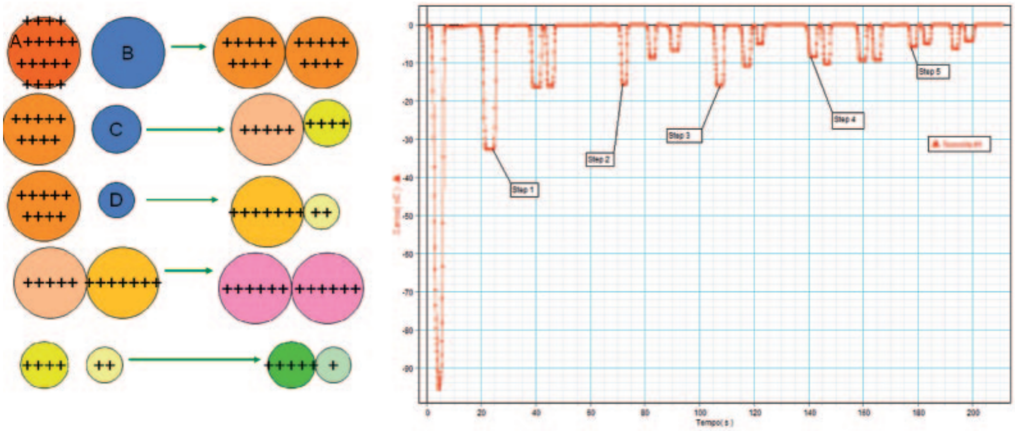

Fig. 2. – Diagram of the experience of charge transfer and example of measure outcome.

opposite peaks of charge, of equal value and different signs can be seen on the computer screen as the experiment goes on (fig. 1).

The second part of the experience is carried out measuring the charge on a rubbed insulator and on spheres of various sizes, before and after contacts made in a sequence addressing some of the main learning difficulties reported in the literature; the experimental results are used to introduce a quantity (potential) which drives the charge transfer after observing the conditions triggering and stopping it. The sequence of 5 steps (contacts between spheres) is summarized as follows (fig. 2):

- One charged sphere (A) touches an identical uncharged sphere (B): half charges transfer, State(A) = State(B); the condition of the charged spheres can be marked by charge: S = S(Q).

- The charges on two couples of spheres (A-C, B-D), each couple composed by one charged sphere (having both the same charge and size) and one smaller uncharged sphere (of different sizes), are measured after their touching: S(A) = S(C), S(B) = S(D), but Q(A) < Q(B), then S(A) < S(B) (A and B are identical), then S(C) < S(D) because S(A) = S(C) and S(B) = S(D): S = S(sizes).

- Two identical spheres, A e B, initially with a different amount of like charge on them, have the same amount of charge after a contact: S(A) = S(B), ΔQ becomes zero.

- Two different spheres, C and D, with a different amount of charge on them, show a ΔQ increased after a contact. Charge passed from the place with a lesser amount of charge to the one with the greater (fig. 3).

After each step pupils can see and measure that the total amounts of charge on the spheres involved are the same before and after their contact, that is, charge is conserved.

5. – Conclusions

The simple charge measures proposed are easy to carry out and to read, so are suitable to be used since the lower school levels. The possibility offered by on-line measures

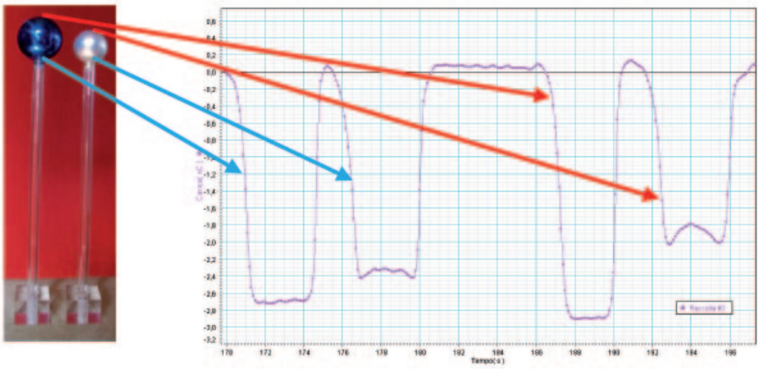

Fig. 3. – (Colour on-line) Step 5: Measure of charge on two spheres before (left, blue) and after (right, red) their contact.

to make repeated measurements in a short time, allow both to repeat the proposed measurements, and to carry out other explorations suggested by students (for example, controlling the time dependence of the transfer of charge). The exploration of the phenomenology is so well supported by data acquisition systems such as those described, which become essential tools for introducing students to a scientific interpretation of the phenomenology.

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