

LEARNING KNOTS ON ELECTRICAL CONDUCTION IN METALS

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Abstract

A number of studies related to the conceptual understanding of DC circuits highlighted several difficulties in learning about: the closing of the circuit (Osborne, 1983), differentiation of the concepts of electrical energy, voltage and current (Psillos, 1998), the determination of the equivalent circuit as a descriptor of multiple loop circuit and use of systemic reasoning instead of local reasoning (McDermott & Shaffer, 1992). Others researchers identified the following issues, which are relevant to learning: the phenomenological relationship between electrostatic and electrodynamics (Eylon & Ganiel, 1990; Stocklmayer & Treagust, 1996; Viennot, 2001; Chabay & Sherwood, 2007) and the link between the macroscopic and microscopic level of processes description (Licht, 1991; De Posada, 1997; Thacker, Ganiel & Boys, 1999; Wittmann, Steinberg & Redish, 2002). The dilemma of displaying the microscopic world is still under discussion (Mashhadi & Woolnough, 1999; Seifert & Fischler, 2003): students are confronted every day with colorful pictures of atoms and molecules which are spread both by the media and the textbooks, not in accordance with the actual proportions between the physical properties of the particles (size and speed) and can generate misunderstandings about the microscopic processes. The comprehensive discussion of these issues leads to design learning paths on those specific concepts which favor a parallel approach on macroscopic and microscopic levels of the phenomena.

Introduction

This study is founded on literature survey and presents some research results on teaching/learning of electric conduction in solids. 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 involved concepts (charge, current, field, potential, ...). These aspects 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 any age. From the perspective of physics education it's important to recognize learning knots of the specific context. As concern the electric conduction in metals, there are several knots related to different aspects:

- 1) Electrical circuits,
- 2) Phenomenological relationship between electrostatic and electrodynamics,
- 3) Link between the macroscopic and microscopic level of processes description,
- 4) Use of simulations and analogies.

1. Electrical circuits

The researches developed starting from 1980 (Fredette & Clement, 1981; Osborne, 1983; Shipstone, 1984) have analyzed how children working with batteries, wires and light bulbs to build simple circuits. A number of studies shows that the basic concepts related to the d.c. circuits are

not intuitive and that electrical phenomena are interpreted by young people through persistent and widespread non scientific schemes. These alternative conceptions coexist in parallel with the scientific view and are not integrated into it, even to the end of education path. The transition from the common sense to the scientific view, according to Psillos (1998), is favored by the measurement procedures that allow to identify and recognize the physical quantities voltage and current and their role in explaining the functioning of the circuit.

As in the context of electrostatics, learning difficulties are compounded by the fact that the processes involved in the electrical phenomena are far from direct sensory perception. It is not easy to connect the observable effects to abstract concepts like "electric charge", "current" and "energy". Since the students know that the batteries "are consumed" and you pay for household electricity consumption, they believe that in the circuits "something is consumed" and, for many of them, the most reasonable thing to "consume" is the electricity itself, conceived as energy at times, sometimes as electric current. Some authors find that the concept of conservation of electric charge is intuitive for children and yet coexists with the view that the current is consumed. In addition, the concept of electric potential is already quite difficult to acquire in the context of electrostatics, for most students its relevance and applicability in the case of electrical circuits remains unclear. The main learning knots identified, as regards electrical circuits, are:

- a) need of closing the circuit for the current circulation
- b) topological knot: recognizing the equivalent circuit as describer of many loop circuit (McDermott & Shaffer, 1992)
- c) sequential knot: the current in a series circuit element is independent of its position
- d) construction of formal thinking: representing the circuit with a symbolic scheme
- e) role of the battery: it is not a source of constant current regardless of the connected circuit
- f) use of systemic reasoning in place of local reasoning: the change of a circuit element can generate changes in all other circuit elements
- g) interpretation and differentiation of the concepts of energy, voltage and electric current (Psillos, 1998)
- h) incorrect use of Ohm's law: the absence of current implies absence of voltage

2. Phenomenological relationship between electrostatic and electrodynamics

Many authors (Eylon & Ganiel, 1990, Thacker, Ganiel & Boys, 1999; Tveita, 1997) tend to identify in the missing link between electrostatic and electrodynamics the main reason for incomplete students' conceptual knowledge about electrical circuits. These authors argue that students whose education has focused on the microscopic processes involved in the functioning of electrical circuits develop a better understanding not only of simple macroscopic phenomena, but also more complex phenomena such as transient.

Specifically Chabay & Sherwood (2007) argue that provide students with an explanatory mechanism facilitates the understanding of physical phenomena. They, to teach the electrical

conduction, choose the electric field as conceptual referent and the surface charges as a mechanism. In this way, they also realize the connection between the macroscopic and microscopic description of the processes. Main learning knots of context are:

- a) transient processes occurring in electric circuits with capacitors
- b) electric charge concept and physical properties
- c) differentiation of the voltage propagation in the circuit by the current circulation
- d) voltage concept as engine of the charge transfer
- e) link between macroscopic concept of voltage and microscopic concept of electric potential
- f) needs of surface charges on the wire so that the electric field inside the wire is parallel to the wire longitudinal axis (Chabay & Sherwood, 2007)

3. Link between the macroscopic and microscopic level of processes description

The link between electrostatics and electrodynamics for many authors is integrated with the connection between the macroscopic and microscopic description of the processes of electrical conduction. In contrast, other studies (Benseghir & Closset, 1996, Borges & Gilbert, 1999) show a cautious attitude on the educational value of the microscopic model of learning by identifying nodes as:

- a) overcoming the local model focused on the behaviour of single atom (as in chemistry)
- b) integration of different models: current as a flow of charge carriers, motion of electrons in metals (random motion in the absence of field, drift motion in the presence of field), description of states and processes in the quantum band model
- c) evidences for the existence of the electron and characterization of its physical properties both intrinsic and interaction with the ionic lattice of the material.

4. Use of simulations

A model of conduction in metals based on the free electron gas (Stephens, McRobbie & Lucas, 1999) can be used to explain the observed relation between resistance and section of the wire (Ohm's second law): the resistance decreases by increasing the section not because the conduction electrons have more space available to move (the average number of collisions of an electron per unit time does not change with respect to the thin wire) but because a greater number of electrons through a section of the wire into time. Similar representations are proposed by the simulations of the interior of a wire with flowing current. According Sins & al. (2009), computer simulation tools can be an opportunity to promote the development of scientific thought in the students on issues of particular complexity, such as the relationship between macroscopic and microscopic properties of material.

Simulations can show a phenomenon and/or enable one to make predictions about its trend. Phet Interactive Simulations or Easy Java Simulations provide a microscopic representation of electrical transport in solids. Showing current as moving electron spheres to directly counter the

spontaneous model that current is consumed, but the physical proportions among electrons and lattice ions are not respected. However such simulations can help to show how macroscopic properties emerge from a microscopic model at the level of material individual constituent and their interactions. The use of simulations also involves learning knots among which we highlight the following:

- a) physical proportions among electrons and lattice ions are not respected
- b) free electrons model of metals in Supercomet simulation: the average electric field into a metal is zero, then opposite sign charges don't interact by Coulomb law

5. Analogies

In teaching practice the use of hydraulic analogies is common in teaching of electrical conduction in wires. Under this analogy the wires are likened to pipes and current to a fluid flowing in them, the battery to a pump, etc. These analogies are founded, from the mathematical perspective, on the fact that the transport equations defined by the laws of Fourier, Ohm, Poiseuille have the same form to describe the flow of heat, electricity and a viscous fluid, respectively. Chiu & Lin (2005) argue that "using analogies not only promoted profound understanding of complex scientific concepts (such as electricity), but it also helped students overcome their misconceptions of these concepts". However, we can identify knots in the context:

- a) water is a liquid substance and electric current is not
- b) the current repartition between two parallel bulbs connected to the same battery
- c) the current repartition between two different bulbs in series

6. Implications for physics education

Common reasoning must be taken into account in teaching: they should be considered not only as creating an obstacle to learning physics, but also as resources at the learner's disposal.

The comprehensive discussion of these issues leads to design learning paths on those specific concepts which favor a parallel approach on macroscopic and microscopic levels of the phenomena.

The relative learning process should be planned as an aware and systematic transition between different levels of description and interpretation of phenomena.

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