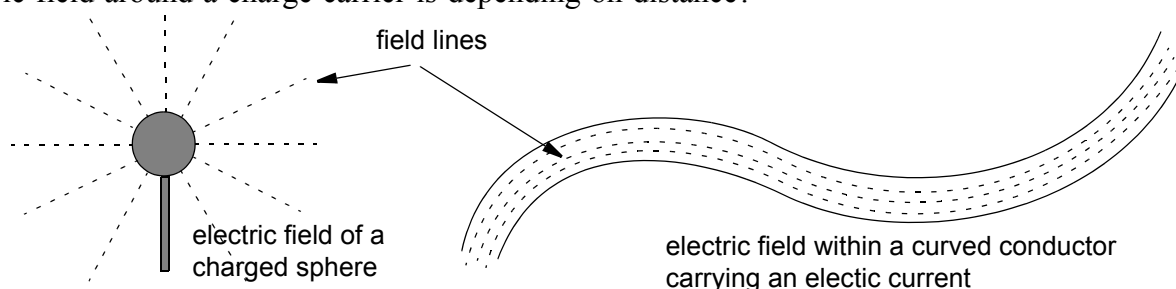


Is there any difference in the physical state of the wires at the cross sections A, B and C, adjoining the branching point from different sides, which can explain the correct splitting of the stream of electrons?

### Item 3

If a uniform curvilinear resistive wire of constant diameter carries an electric current, the electric field within the wire, which is driving the current, is constant and always directed parallel to the axis of the wire, whatever be the curvature of its bending. What is the cause for this fact, which seems to be in contradiction with Coulomb's law, stating that the electric field around a charge carrier is depending on distance?



The answers to these and other similar questions can be found if an electric circuit is not only seen as a system of especially arranged electric currents but also as a capacitor, formed by the surfaces of its conductors. These surfaces will be charged whenever a current is flowing and the resulting surface charge densities - and only these - can explain the effects described above.

A knowledge, based only on the definitions of electric field, energy, potential and potential difference does not supply any hint for an explanation.

Since practically no student had been told about surface charges in relation to electric currents, we found that practically nobody - and even only a few physics teachers - could give any satisfying answer to the items in our test.

The existence of surface charges are mentioned in some text books ([1] as example). However these charge densities are rather small under normal dc and ac conditions and hard to measure. Since they do not intervene with the traditional mathematical treatment, based on energy considerations, they are practically always left aside.

The following questions remain:

Is the exclusion of the underlying causal mechanism and the exclusive treatment of energy considerations sufficient for the majority of our students or is this abstract approach only suited for highly talented students?

Can we improve the learning results for the majority of our students (in the field of electricity) if a substantial part of the teaching time is devoted towards an explicit treatment of surface charges and its distribution among the different parts of an electric circuit.

### New approaches and materials

In the literature quite a few references are found [2-8] where the existence of surface charges is stated as being essential for a full explanation of the electric circuit. Even a full course has been developed by Chaby and Sherwood, where surface charges are treated extensively as causal mechanism to explain „how electric circuits actually work“ [9]. Recently a new book about the existence of surface charges has been published, where the density of sur-

face charges in electric circuits has been treated mathematically for a series of geometrical arrangements. In the appendix of this book a paper of Weber, published in 1852, where a calculation of surface charges on a ring, carrying a steady current.

This early knowledge, however, got lost. The actual situation in respect to electricity courses seems to be hardly effected by these ideas. In practically all modern text books for high school and university physics students - at least in Germany - voltage is still introduced as potential difference with no hint about the underlying causal mechanism, related to surface charges.

Such a conservative attitude could be defended if the reached learning results would be sufficient. Numerous private interviews and the answers of students who were confronted with our test questions, mentioned above, indicate that the concept of voltage remains one of the least understood concepts in the domain of electricity.

To improve this non-satisfying situation, the following hypothesis should be tested.

- 1. The concept of voltage is regarded as a basic one in the field of electricity and this field is regarded as an essential one in classical physics.
- 2. A substantial part of students fail to understand this concept.
- 3. This negative learning experience in respect to such a highly respected topic has a far reaching negative influence on many students in respect to their future attitudes towards physics and interests in physics.
- 4. A new course in the line of the Chabay/Sherwood example, enriched with more visual help in the form of computer generated animations and adequate computer simulations, will result in successful learning experiences for a substantially larger number of students than found today.

Some first examples of such computer based supportive materials and ideas for further developments will be demonstrated and discussed.

## References

- [1] A. Sommerfeld, *Electrodynamics* (Academic press, New York, 1952), 125-130
- [2] A. Marcus, The electric field associated with a steady current in a long cylindrical conductor, *American Journal of Physics*, 9, 225-226 (1941)
- [3] O. Jefimenko, *Amer.J.Phys.*30, 19-21(1962),
- [4] W.G.V. Rosser, What makes an electric current flow, *American Journal of Physics*, 31, 884-885 (1963)
- [5] H. Härtel, The electric voltage: What do students understand? What can be done to help for a better understanding? In: Duit, R. (ed.); Jung, W. (ed.); Rhöneck, C. von (ed.): *Aspects of Understanding Electricity. Proceedings of an International Workshop. IPN-Arbeitsberichte 59.* Kiel: IPN, 353-362, (1985); [http://www.astrophysik.uni-kiel.de/~hhaertel/PUB/voltage\\_IPN.pdf](http://www.astrophysik.uni-kiel.de/~hhaertel/PUB/voltage_IPN.pdf)
- [6] H. Härtel, A Qualitative Approach to Electricity. Palo Alto: IRL, IRL Report. IRL 87-0001, (1987); [http://www.astrophysik.uni-kiel.de/~hhaertel/PUB/voltage\\_IRL.pdf](http://www.astrophysik.uni-kiel.de/~hhaertel/PUB/voltage_IRL.pdf)
- [7] H. Härtel, Spannung als Ladungsunterschied, *Naturwissenschaft im Unterricht Physik/Chemie*, Heft 31, 36-38, (1988)
- [8] W.R. Moreau, Charge distribution on DC circuits and Kirchoff's laws, *European journal of physics* 10, 286-290 (1989)
- [9] R. Chabay, B. Sherwood, *Matter and Interaction, Volume II: Electric & Magnetic Interaction*, John Wiley (2002)
- [10] A. Koch Torres Assis, J. Akashi Hernandez, The Electric Field Outside Resistive Wires Carrying Steady Currents; <http://www.ifi.unicamp.br/~assis/ftp/eout2.pdf>