Single-electron Transport and the New Standard for Electrical Current

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Abstract - The present definition of the ampere in the international system of units (SI) is based on electromechanical force exerted between current-carrying wires under idealised conditions. The difficulty in the practical realisation of this definition led to the situation that, since the beginning of the 1990s, in metrology institutes worldwide the ampere is not realised anymore by experiments based on the SI definition. Instead, indirect ways of reproducing the ampere via the electrical units volt and ohm are used, exploiting the superior reproducibility of standards based on the Josephson and quantum Hall effects. Besides practical advantages, this brought the dilemma of using electrical units that strictly were no more realised in the SI system.
The envisaged redefinition of the SI units will base the definition of the ampere on a fixed, exact value of the elementary charge e. The most elegant and direct way of realising the ampere based on this definition is given by the use of single-electron transport (SET) current sources, called SET pumps. Typically operated at cryogenic temperatures (below 1 K), these devices are able to generate currents I by transferring an exact number of electrons per transport cycle, i.e. according to $I = e \cdot f$, with f being the repetition frequency of the transport cycle.

Driven by intensive research efforts in metrology institutes and in academia, there has been significant (almost three orders of magnitude) improvement to the accuracy of SET pumps during the last decade. The highest accuracy achieved so far corresponds to 2 parts in 10^7 at a current of about 90 pA. This result was achieved recently by deploying a new, superior type of electrometer for direct current measurement.

However, future metrological applications require an uncertainty of 1 part in 10^7 or below, at currents of about 100 pA or higher. SET pumps are inherently susceptible to single-electron transfer errors that typically occur statistically during operation. Therefore, significant further improvement in accuracy can be provided by using 'self-referenced' SET pumps, i.e., devices that allow counting and accounting transfer errors on the scale of single electrons.

Together with an overview on the topic, the presentation highlights the recent progress and main results from the field and gives references to corresponding literature for further reading.

Keywords (Index Terms) – Single-electron devices, elementary charge, current, amplifiers, metrology, international system of units.