Team paves the way for the redefinition of the ampere

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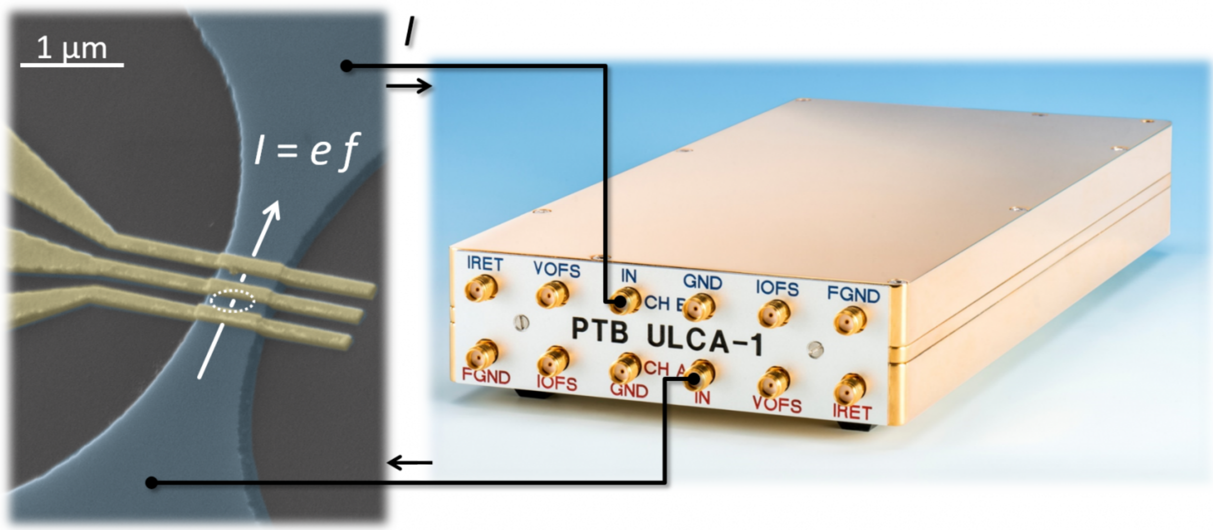

Semiconductor single-electron current source ("single-electron pump", left), connected to the high-precision current/voltage converter ("ultrastable low-noise current amplifier" (ULCA), right). Credit: Source: PTB

By 2018, scientists want all physical base units to be based on solid, unchangeable fundamental constants. The units "meter" and "second" are well ahead of schedule; the kelvin, the kilogram, the mole and the ampere are next in line. Scientists from Physikalisch-Technische Bundesanstalt have now succeeded in measuring the extremely small currents of a single-electron pump with unprecedented accuracy. This is a milestone toward the revision of the International System of Units (SI).

The current definition of the ampere is anything but convenient. It is based on a hypothetical test setup that includes two conductors of infinite length. In this setup, an ampere would generate a precisely fixed force. This definition is thus closely related to mass, which has given physicists serious headaches for a long time due to the instability of the international prototype of the kilogram. The current definition of the kilogram sharply limits the precision with which the ampere can be realized. Physicists have therefore decided that the kilogram prototype has become obsolete and will have to "retire" in 2018, and that the fundaments of the SI should, at the same time, be thoroughly revised.

In order to help the ampere take the leap into the realm of fundamental constants, physicists are counting the electrons flowing over a given time period through a conducting track that is only a few nanometers wide. This presupposes that they are able to manipulate the electron flow, which they have achieved by means of a single-electron pump. It pumps single electrons through what can be imagined as a mountain chain from one valley to the next. In this way, it is possible to count the electrons arriving in the "valley," and thus to determine the elementary charge.

Single-electron pumps present two main challenges: First, the pumps only supply very small currents, which are difficult to measure. Second, statistical errors occur during electron transport, for instance, when an electron falls back into the "valley" where it came from or when two electrons are pumped into the same valley. This is detrimental to precision. A solution has already been developed to solve the pumping errors and has been demonstrated with very slow pumps. The physicists connect several pumps in series and between the pumps, special detectors indicate whether too many or too few electrons pass through the valley. It is thus possible to correct errors while the pumps are active.

Now, scientists at PTB have successfully developed a technique to meet the measurement challenge. Thanks to a novel amplifier, researchers are able to amplify the small current produced by the pumps by a factor of approximately 1000. Combined with two other quantum standards, it is now possible to measure small currents with an unprecedented level of precision.

In their work, PTB's physicists have shown that controlled single-electron pumps provide a considerably more precise realization of the ampere than the conventional ampere definition allows. "For the time being, the single-electron pump is operated without correction. However, the measurement showed that the errors are, indeed, so small that the correction method should also work with these fast pumps. This is a real milestone towards the new SI," explains Franz Ahlers, head of the Electrical Quantum Metrology Department of PTB. There seem to be no remaining obstacles to the redefinition of the ampere, which is planned for 2018. Since the redefinition will only cause very small changes in the electrical units, the revision of the SI will not be noticeable for most consumers. However, things look slightly different in fields such as micro- and nano-electronics or in medical and environmental metrology. In areas such as these, the new ampere will enable a much more accurate calibration of measuring instruments.

More information: H. Scherer, U. Siegner. Elektronen zählen, um Strom zu messen. PTB-Mitteilungen 126, 2 (2016), S. 53-61. www.ptb.de/cms/fileadmin/inter … ngen_2016_Heft_2.pdf

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