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The quantum SI: a focus on electromagnetic units and standards

Luca Callegaro
INRIM - Istituto Nazionale di Ricerca Metrologica, Torino, Italy, http://www.inrim.it

The International System of units (SI) is the basis of everyday measurements. It is the modern incarnation of the metric system, which history traces back to the French Revolution. The SI is maintained by the General Conference on Weights and Measures (Conférence Générale des Poids et Mesures, CGPM) and evolves to sustain the scientific and technological progress.

The SI present name and general structure dates back to 1960 [1]. In the SI en force from 1960 until 2019 the definition of the seven base units (second s, metre m, kilogram kg, ampere A, kelvin K, mole mol, candela cd) were quite different from each other. The kilogram was defined as the mass of a single object, the international prototype—a cylinder of platinum-iridium alloy manufactured in 1889. The prototype is unique, at risk of damaging, nearly inaccessible (measured only about every 40 years) and there is some evidence of a change in its mass. The ampere had a purely mechanical definition in terms of electrodynamic forces on straight conductors; realisations of the ampere were cumbersome and with an uncertainty limited to a few parts in 1×10^6 because of the mechanical measurements needed.

On 16 November 2018 the General Conference of Weights and Measures has approved a major revision of the SI [2], entered en force on 20 May 2019. The seven base units are now defined in terms of fundamental constants of nature, to which an exact value is assigned. The kilogram and the ampere are defined in terms of an exact value of the Planck constant h and of the elementary charge e.

It is possible to realize the SI units everywhere and everytime by physical experiments that link the units to the corresponding fundamental constants. For electromagnetic quantities, the link is given by quantum phenomena in solid-state devices: the Josephson effect, the quantum Hall effect, single-electron devices.

Present electromagnetic metrology research focuses on exploiting the quantum properties of new materials (among them, graphene and topological insulators), and new technologies for device fabrication and for cryogenics and measurement systems. The aim is to realise the new SI units and perform traceable electromagnetic measurements by reducing their cost, operator efforts, system complexity, need for periodic calibrations.

After framing the topic in its historical context, the talk will highlight the recent developments in quantum electromagnetic metrology, and discuss some open issues.

References

[1] Bureau International des Poids et Mesures, “The International System of Units,” May 20 2019, 9th SI Brochure. [Online]. Available: www.bipm.org

[2] 26th General Conference of Weights and Measures (CGPM), “Resolution 1: On the revision of the International system of units (SI),” in *in press.* [Online]. Available: https://www.bipm.org/en/CGPM/db/26/1/