On May 20, 2019 new values will be implemented for the International System of Units (SI) base units of the kilogram, kelvin, mole and ampere, and the derived units of the volt and ohm. These values are based on redefinitions of the Planck constant, elementary charge, the Boltzmann constant and the Avogadro constant. The changes are based on the evolution of the definition of the kilogram, the SI unit of mass, which has progressed from a physical artifact—held at the International Bureau of Weight and Measures (BIPM) since 1889—to a constant of nature, Planck’s constant, that can be accessed anywhere in the universe.

The new definition of the kilogram benefits the entire world in potentially having better access to realization of the kilogram, and eliminates the risks associated with maintaining a standard that is based on a sole artifact.

As a result of the redefinitions, some measurement reference standards must be adjusted to the new value of the definition. Other measurement reference standards may account for the redefined value by incorporating an additional contributor to their measurement uncertainty evaluations. This application note summarizes the changes being made to SI units and provides guidance on how to implement them.

This is not the first time that an adjustment to the measurement system has been made. For example, in 1990 the volt was defined to be based on the Josephson effect and the ohm on the Quantum Hall effect. At that time, the shift¹ of the volt in the United States was 9.26 x 10⁻⁶ (9.26 parts per million or 0.000926%)¹ which was significant because a large percentage of laboratories owned devices that were capable of this accuracy, such as the Fluke 5700A High Performance Multifunction Calibrator. The 1990 volt definition exceeds the performance specification of this product on the 11 volt and 22 volt ranges, so a Fluke 5700A that was calibrated to the United States representation of the volt in 1989 would be out of tolerance as compared to the 1990 volt. The Fluke 5700A not only was used at many National Metrology Institutes (NMIs), but it was used in primary, secondary, and working level calibration laboratories and in some cases, test laboratories around the world, as the Fluke 5730A is today.

The adjustments to the volt on May 20, 2019 is nearly 100 times less in magnitude than the 1990 adjustment, and as a result a smaller number of organizations will be affected. However, metrologists should be aware of the redefinition and its implications on their calibration laboratory.
Overview of the SI redefinition

In order to transition from the International Prototype kilogram (IPK) to a constant of nature, a series of experiments have been conducted in collaboration with the top NMIs in the world. The experiments involved realizing the kilogram through the Kibble (watt) balance and through means of x-ray-crystal-density. As a result of the experiments, the following constants will be updated on May 20, 2019:

- The Planck constant $h$ is exactly $6.626 \text{,} 070 \text{,} 15 \times 10^{-34}$ joule second
- The elementary charge $e$ is exactly $1.602 \text{,} 176 \text{,} 634 \times 10^{-19}$ coulomb
- The Boltzmann constant $k$ is exactly $1.380 \text{,} 649 \times 10^{-23}$ joule per kelvin
- The Avogadro constant $N_A$ is exactly $6.022 \text{,} 140 \text{,} 76 \times 10^{23}$ mol

The SI will continue to have the same seven base units, but the new definition of the kilogram will now be expressed in terms of the Planck constant; the ampere will be defined in terms of the elementary charge; the kelvin will be defined in terms of the Boltzmann constant; and the mole will be defined in terms of the Avogadro constant.

Measurement system adjustments as a result of constant redefinitions

The Volt

The most significant shift in any of the measurement units is the volt. The updates to the Planck Constant and the Fundamental Electron Charge will cause a shift of $0.107 \times 10^{-6}$ or 0.107 parts per million (ppm). The new value for the Josephson constant $(2e/h)$ is slightly smaller than the 1990 value, so a device that is measured to the 2019 value will be larger than the 1990 value by approximately 0.1 ppm. Calibration laboratories that operate a Quantum Hall based resistance standard (QHR), the value for the Von Klitzing Constant should be updated in the operating system software in the same manner as described for the volt. However, since most calibration laboratories do not operate a QHR, the value of this adjustment is generally insignificant as it is half the calibration uncertainty that NIST provides for a Thomas 1 ohm calibration. The guidance from the CCEM is that no action is required for resistance uncertainties that are larger than 0.05 ppm.

The Kilogram

On May 20, 2019, calibrations that are traceable to the IPK will have an increased expanded uncertainty of 0.02 ppm, which is less than half the uncertainty of a NIST calibration at 1 kg, so this adjustment is insignificant to industrial calibration laboratories.

The Pascal

The fundamental SI unit of pressure, the Pascal is expressed in N/m$^2$ which can be further reduced to kg/m$\cdot$s$^2$. Since the meter and second are not being redefined in 2019, the only change is based on the kilogram, which again is approximately 0.02 ppm. The most accurate calibrations for pressure are on the order of ppm, so again, this adjustment is insignificant.
The Kelvin

Although the definition of the SI unit for thermodynamic temperature, the kelvin, is being redefined in terms of the Boltzmann constant, the definitions of ITS-90 are not changing at this time, so any calibration that is performed in accordance with ITS-90 or PLTS-2000 will not change.

2 Resolution 1 of the 26th CGPM (2018)
3 BIPM “Mise en pratique for the definition of the ampere and other electric units in the SI” Draft Version 1.0 8/12/2017
4 Kletke, Ray “Maintaining 10 VDC at 0.3 PPM or Better in your Laboratory” 1996 NCSL Conference Session 3C
5 CCEM “Guidelines for Implementation of the “Revised SI” Consultative Committee for Electricity and Magnetism, BIPM CCEM/19-04.2_b 08/12/2017 Version 1.0
6 Retrieved from the CMC’s for NIST at www.bipm.org on 21 April 2019
7 BIPM “Mise en pratique for the definition of the kilogram in the SI” Draft version 11.3 20/07/2018
8 The term Parts Per Million (PPM) is no longer an acceptable way to express values of quantities but is used because the audience understands the term well and it improves comprehension of the application note.