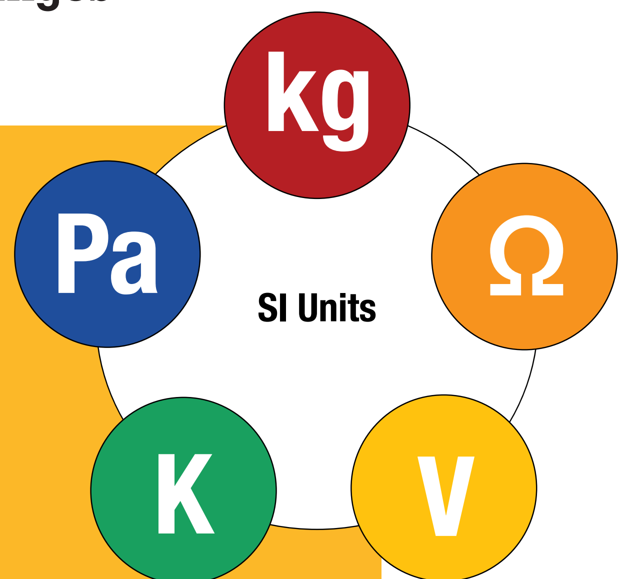
FLUKE

Calibration

APPLICATION NOTE

New definition of the kilogram (the SI unit of mass) and other SI unit redefinitions in 2019

The kilogram and other SI unit changes on Metrology Day, 2019



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 shift[1] 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[2]:

- The Planck constant h is exactly 6.626 070 15 $\times 10^{-34}$ joule second
- The elementary charge e is exactly 1.602 176 634 $\times 10^{-19}$ coulomb
- The Boltzmann constant k is exactly 1.380 649 $\times 10^{-23}$ joule per kelvin
- The Avogadro constant N_A is exactly 6.022 140 76 $\times 10^{23}$ mol^{-1}

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

V

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[3] of 0.107 x 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[8]. Calibration laboratories that operate a Josephson Voltage System (JVS) to directly realize the volt will be required to update the value for the Josephson constant in their system operating software. We advise these laboratories to learn how to update the software before May 20, 2019, but not complete the update until that time. The only other commercial instrument that can observe this adjustment is the Fluke 732 series of Direct Voltage Standards. When a Fluke 732 is calibrated against a JVS, the uncertainty produced for the calibration is typically between 0.06 ppm to 0.1 ppm. While the adjusted value will equal the calibration uncertainty for the 732 series instruments, the specification component of long-term stability is much larger than this, and even when maintaining a control chart that utilizes linear regression, the value associated with this adjustment is absorbed in the linear regression uncertainty[4].

The International Committee of Weights and Measures (CIPM) Consultative Committee on Electromagnetic Quantities (CCEM) has produced a guideline which states that no action is required if your voltage related uncertainties are larger than 0.25 ppm[5]. If your uncertainty for the volt is less than 0.25 ppm and you do not have direct access to a JVS, we recommend that you add the 0.107 ppm adjustment quantity to your uncertainty analysis.

The Ohm

Ω

The adjustment to the ohm is much smaller than the volt, approximately 0.02 ppm[3]. If your laboratory is operating 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[6]. The guidance from the CCEM is that no action is required for resistance uncertainties that are larger than 0.05 ppm.

The Kilogram

kg

On May 20, 2019, calibrations that are traceable to the IPK will have an increased expanded uncertainty of 0.02 ppm[7], 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

Pa

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.

FLUKE ®

Calibration

The Kelvin

K

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.

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[1] John Fluke MFg. Co. Inc. Application Note "Changing to the 1990 Volt and Ohm" 1989

[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] Retreived 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.

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