The SI redefinition to come into force from 20 May 2019

The 19th Meeting of the Directors of National Metrology Institutes (NMIs) and Member State Representatives of the International Bureau for Weights and Measures (*Bureau international des poids et mesures,* BIPM) was held at its office at Sèvres, France during 18 and 19 October 2017. Before we discuss the major outcome of this meeting, it is worth understanding the International Convention on SI and derived units and formation of National Metrology Institutes (NMIs), which is schematically shown in Figure 1. On 20 May 1875, 20 industrially developed nations met for the 'Convention of the Metre' and signed the 'Treaty of the Metre' under which three bodies were set up to take custody of the international prototype kilogram and metre, and to regulate comparisons with national prototypes.

(i) CGPM (General Conference on Weights and Measures/*Conférence générale des poids et mesures*): The CGPM meeting takes place every four years and consists of delegates of the nations who have signed the metre convention. The Government of India, through the National Physical Laboratory (NPL), New Delhi as its NMI, signed the metre convention in 1957. Currently, CGPM has 58 Member States and 41 Associate States and Economies. CGPM ensures the propagation and improvement of the International System of Units and endorses the results of new fundamental metrological determinations.

(ii) CIPM (International Committee for Weights and Measures/*Comité international des poids et mesures*): The CIPM has 18 members and meets annually. It has the responsibility to advise the CGPM. The CIPM has several sub-committees and each of them has a responsibility of a particular area of interest. One of the sub-committees, i.e. Consultative Committee for Units (CCUs), advises the CIPM on matters concerning units of measurement.

(iii) BIPM (International Bureau for Weights and Measures/*Bureau international des poids et mesures*): This is an intergovernmental organization through which Member States act together on matters related to measurement science and measurement standards. BIPM provides safe-keeping of the international prototype kilogram and metre and provides laboratory facilities for regular comparisons of the national prototypes with the international prototype. It is also the secretariat for the CIPM and the CGPM.

On the first day, current issues related to the BIPM and CIPM were discussed, which included advanced information about plans for the 26th CGPM to be held during 16–18 November 2018. Barry Inglis (President, CIPM) delivered the welcome address and provided updates on the CIPM activities. Martin Milton (Director, BIPM) presented highlights from the work of the BIPM. E. de Mirandés (CCU Executive Secretary, BIPM) made a detailed presentation on the revised formal definitions of the SI base units that have been examined by the CIPM and will be put up to the 26th CGPM on 16 November 2018 for a final vote. It is expected that the revised SI units will come into force on 20 May 2019 (20 May each year is celebrated as World Metrology Day).

The SI system was originally conceived as one of seven base units (second, metre, kilogram, ampere, kelvin, mole and candela) derivable from nature. However, technical limitations necessitated the use of artifacts such as the 'prototype metre' (bar made of 90% platinum–10% iridium alloy) and 'International prototype kilogram, IPK' (lump made of 90% platinum–10% iridium alloy with a mass equal to the mass of 1 dm^3 of water at its maximum density, i.e. at approximately 4°C. India has a copy of IPK-57 at NPL, New Delhi). In 1960, the metre was redefined in terms of the wavelength of light from krypton-86 radiation, making it derivable from nature, leaving the kilogram as the only unit still defined by an artefact. If the CIPM proposed redefinition is accepted by the CGPM, the SI will, for the first time, be wholly derivable from fundamental constants.

The CIPM proposal is summarized as follows: 'There will still be the same seven base units (second, metre, kilogram, ampere, kelvin, mole and candela). Of these, the kilogram, ampere, kelvin and mole will be redefined by choosing exact numerical values for the Planck constant (h), the elementary electric charge (e), the Boltzmann constant (k), and the Avogadro constant (N_A) respectively. The second, metre and candela are already defined by physical constants, i.e. speed of light (c), hyperfine splitting frequency of the caesium-133 atom, $(\Delta v(^{133}\text{Cs})_{\text{hfs}})$, and the luminous efficacy (K_{cd}) respectively. The new definitions will improve the SI units without changing the size of any of them, thus ensuring continuity with the present measurements. This will mean, amongst other things, that the prototype kilogram will cease to be used as the definitive replica of the kilogram.

The numerical values associated with various constants of nature proposed by the CIPM are as follows:
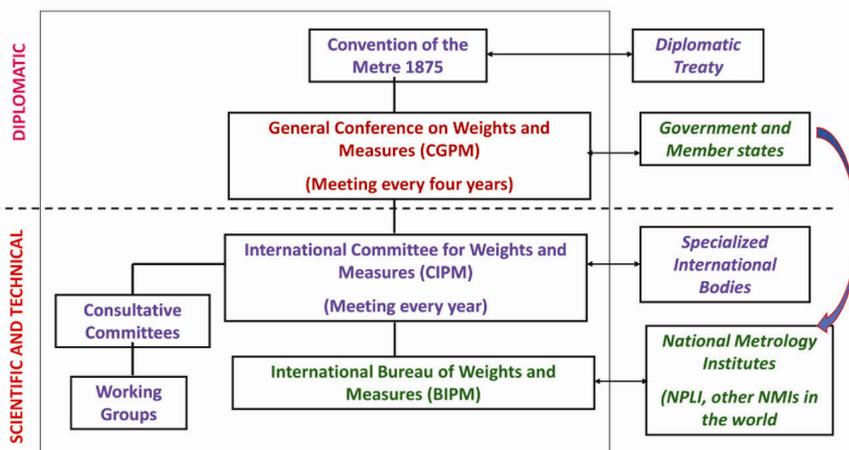
Figure 1. International Convention on SI and derived units and formation of National Metrology Institutes.

(i) The Planck constant h is exactly $6.626070040 \times 10^{-34}$ joule-second (J s).

(ii) The elementary charge e is exactly $1.6021766208 \times 10^{-19}$ coulomb (C).

(iii) The Boltzmann constant k is exactly $1.38064852 \times 10^{-23}$ joule per kelvin (J K^{-1}).

(iv) The Avogadro constant N_A is exactly $6.022140857 \times 10^{23}$ reciprocal mole (mol^{-1}).

(v) The speed of light c is exactly 299792458 metres per second (m s^{-1}).

(vi) The ground-state hyperfine splitting frequency of the caesium-133 atom $\Delta v(^{133}\text{Cs})_{\text{hfs}}$ is exactly 9192631770 hertz (Hz).

(viii) The luminous efficacy K_{cd} of monochromatic radiation of frequency 540×10^{12} Hz is exactly 683 lumen per watt (lm W^{-1}).

In addition, the CIPM has proposed that the international prototype kilogram be retired and that the current definition of the kilogram, ampere, kelvin and mole to be abrogated.

The new proposed definitions of SI units are as follows:

• The second, s, is defined by taking the fixed numerical value of the caesium frequency Δv_{Cs}, the unperturbed ground-state hyperfine transition frequency of caesium-133 atom, to be 9,192,631,770 when expressed in the unit Hz, which is equal to s^{-1}.

• The metre, m, is defined by taking the fixed numerical value of the speed of light in vacuum c to be 299,792,458 when expressed in the unit m s^{-1}, where the second is defined in terms of the caesium frequency Δv_{Cs}.

• The kilogram, kg, is defined by taking the fixed numerical value of the Planck constant h to be $6.626070040 \times 10^{-34}$ when expressed in the unit J s, which is equal to kg m^2 s^{-1}, where the metre and the second are defined in terms of c and Δv_{Cs}. One consequence of this change is that the new definition makes the definition of the kilogram dependent on those of the second and the metre. It may be noted that a Kibble or watt balance is used to measure the Planck constant.

• The ampere, A, is defined by taking the fixed numerical value of the elementary charge, e, to be $1.6021766208 \times 10^{-19}$ when expressed in the unit C, which is equal to A s, where the second is defined in terms of Δv_{Cs}.

• The kelvin, K, is defined by taking the fixed numerical value of the Boltzmann constant k to be $1.38064852 \times 10^{-23}$ when expressed in the unit J K^{-1}, which is equal to kg m^2 s^{-2} K^{-1}, where the kilogram, metre and second are defined in terms of h, c and Δv_{Cs} respectively.

• The mole, mol, is the amount of substance of a specified elementary entity, which may be an atom, molecule, ion, electron any other particle or a specified group of such particles. It is defined by taking the fixed numerical value of the Avogadro constant N_A to be $6.022140857 \times 10^{23}$ when expressed in the unit mol^{-1}.

• The candela, cd, is defined by taking the fixed numerical value of the luminous efficacy of monochromatic radiation of frequency 540×10^{12} Hz, K_{cd}, to be 683 when expressed in the unit lm W^{-1}, which is equal to cd sr W^{-1}, or cd sr kg^{-1} m^{-2} s^3, where the kilogram, metre and second are defined in terms of h, c and Δv_{Cs}.

The redefinition of the SI units may not affect everyday measurements in our daily lives; however, it will be useful to scientists working at the highest level of precision without losing accuracy.

The second day focused on topics pertaining to the NMIs for their futuristic growth. The session was chaired by Alan Steele (NRC). The first session was on 'Talking to Governments: new approaches to impact analysis'. The key questions raised in this session were: (i) What do government reviews and requests for information to NMIs look like across nations? (ii) Would a collaborative 'internationalized' approach to understanding the impact of metrology support national agendas and help individual NMIs explain/justify the role to governments? Mike King (NPL, UK) made a presentation on 'The impact of public support for innovation on firm outcomes' and pointed out that metrology support to the industry leads to enhance their brad values, and allows to create more jobs. The panel discussion on this topic also had views from Mohamed Amer (NIS), D. K. Aswal (NPL, New Delhi), Sergey Golubev (Rosstandart, Russia), Thomas Grenon (LNE), and Claudia Santo (LATU). It was pointed out by Aswal that in the country like India having a population of 1.3 billion, the dissemination of metrology to various government, strategic and private sectors can assist various missions launched by the present government to uplift the life of the poor people. He also stressed upon the requirement of Certified Reference Materials for the quality and safety of life. The second session focused on 'Advanced manufacturing, digitization, and the internet of things'. Joern Stenger (PTB) highlighted that these big themes and novel approaches to innovation are discussed widely by various governments. He emphasized that NMIs should work on the role of measurement science in bringing it into practice in our various economies. The final session of the meeting was on 'Digitalization and Industry 4.0' and the panellists included Takashi Usuda (NMIJ), Hector Laiz (INTI) and Bob Hanisch (NIST). It was mentioned that the First Industrial Revolution used water/steam power to mechanize production; the second used electric power for mass production; the third used electronics and information technology to automate production; the fourth and current one belongs to digitalization that is characterized by a fusion of technologies belonging to physical, chemical, biological and digital spheres. Hanisch made a presentation on the Internet Metrology Resource Registry created by the BIPM.

The BIPM is also developing a 'Strategy to 2025', which will be the basis for discussion at the 26th CGPM in 2018.

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