Redefinition of SI Units and Its Implications

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Abstract: The presented paper discusses the summary of the special issue consisting of 13 peer-reviewed papers regarding Redefinition of SI Units and Its Implications. The papers discuss state-of-the-art reviews and progress made as of now and ongoing progress regarding the redefinition of SI units at different National Metrology Institutes (NMIs) and academic/research institutes across the globe. Different methodologies adopted while investigating redefinition of SI units have been discussed and summarized by the researchers, which will serve as a pivotal point in guiding the researchers in upcoming time.

Keywords: CGPM; Redefinition; SI unit; Kilogram; XRCd; Kibble balance; Metre; Optical frequency standard

1. Introduction

Metrology is the science of measurements. The weight and length parameters had been prominently used by the earliest human civilizations mainly for agriculture and trade. In earlier eighteenth century with the French revolution to the very recent adoption of newly redefined system of units at 26th General Conference on Weights and Measures (CGPM), simplified and uniform systems of weights and measures were developed for measurements. The International System (SI) of units is undoubtedly paramount for the scientific and industrial development and growth of any economy. There are seven SI base units: second; metre; kilogram; ampere; kelvin; mole; and candela. The SI is the hearth of metrology and acts as a tool for any scientific development in the country. The SI unit of mass is defined based on the fixed value of plank constants. There are two principal routes that have been taken to realize the SI unit of mass. In the first route, the Kibble balance is used and kilogram is defined through the fixed value of Plank constant and second route is X-ray crystal density (XRCd) method, where the fixed numerical value of Avogadro's

number is defined as the kilogram. The newly adopted definition of the kilogram is particularly important because it stamps out the need of any physical artefact. The SI unit of current is defined based on the fixed value of elementary charge. The realization of the SI unit of thermodynamic temperature is defined based on the fixed numerical value of Boltzmann constant. There are various methods, such as dielectric constant gas thermometry; acoustic gas thermometry; Doppler broadening technique and noise thermometry, that have been carried out in various NMIs across the globe for realizing the thermodynamic temperature. The SI unit of luminous intensity is defined based on the fixed numerical value of luminous efficacy. The candela is defined as the luminous intensity in a given direction, which is described as 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 $\text{cd sr kg}^{-1} \cdot \text{m}^{-2} \text{s}^3$, where the kilogram, metre and second are defined in terms of h , c and $\Delta\nu_{Cs}$. The SI unit of amount of substance is defined based on the fixed numerical value of Avogadro constant. The 26th meeting of CGPM acts as the paradigm shift in metrology. The latest redefinition has huge significance in the area of measurements where dependences in artefact-based standard are now changed with fundamental constants of nature.

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2. Summary

The first/feature article is authored by Rab et al. of CSIR-NPL, India. This article addressed the different stages of advancement of the measurement system and SI units in India. This study focused on the significant role of metrology and new SI system in different domains of manufacturing and service sectors so that it can establish a strong traceability chain for augmenting the industrial growth and strengthening the national quality infrastructure of India. From time to time, there have been different changes undergone in the measurement systems. It also briefly described the current status of SI unit system based on quantum metrology and related to fundamental constant [1].

The second article is authored by Kuramoto et al. from National Institute of Advanced Industrial Science and Technology, Tsukuba, Ibaraki, Japan. This study focused on the realization of new definition of Kilogram established on 20 May 2019. This new definition is explored at NMIJ by the XRCd method using ^{28}Si -enriched spheres and experiment reveals that relative standard uncertainty is found to be 2.4×10^{-8} , for the two spheres of approximate 1 kg [2].

The third article is authored by Pramann et al. of Physikalisch-Technische Bundesanstalt (PTB), Bundesallee Braunschweig, Germany. In this article, XRCd method is used for the dissemination of the SI base unit kilogram yielding smallest possible uncertainties associated with the mass m within a few parts in 10^{-8} . This work compares different available and newly developed analytical methods and their results for the determination of the molar mass M of silicon highly enriched in ^{28}Si (M_e) and of silicon (M_x) with an almost natural isotopic distribution [3].

The fourth article is authored by Massa et al. from Istituto Nazionale di Ricerca Metrologica (INRiM), Italy. This study addressed the measurements of the spacing of the silicon planes and describes the most critical features of combined X-ray and optical interferometry. Advancement of combined X-ray and optical interferometry as applied to the metrology of nanostructures and the manipulation of matter on the atomic scale are analysed. The results depict that the numerical and experimental determinations of the surface stress are challenging. Lattice strains and lattice parameter of measurements are underway to work out the problem of phase topography [4].

The fifth article is by authored Acharya et al. of CSIR-NPL, India. This article addressed the detection probe laser beams, geometry of the detection chamber, data acquisition/ processing techniques of the cold atoms in CsF1 primary standard at CSIR-NPL. For data acquisition, two distinctly separated detection channels are used to improve

S/N ratio, resulting in efficient design of detection hardware/software [5].

The sixth article is authored by Sharma et al. of CSIR-NPL, India. This article reported a systematic review of the development of optical atomic clock. These clocks operate at optical frequencies and provide better accuracy/higher stability. This article also discussed the different atomic clocks, optical frequency standards and the recent developments of atomic clocks CSIR-NPL. With the most accuracy, these optical clocks may lead to a possible redefinition of time and frequency SI unit in near future [6].

The seventh article is authored by Nandita et al. of Amrita School of Engineering, India, which discusses the atomic clock Ensemble Algorithm based on the ANN model for a time-scale. This work formulated 3, 4 and 5 clock ensemble models and it used four deviation functions to compute the deviation for the combination of each pair of clocks. The result depicts that ANN model shows the better stability when compared with other model like Kalman filter and multi-scale ensemble formation (METS) algorithm [7].

The eighth article is authored by Monika et al. of CSIR-NPL, India. This article discussed the Rydberg atom-based technique for E-field strength evaluation at microwave frequency. In this study, different situations like impact of power variation of microwave, the detuning of microwave frequency and the distance variation of source antenna are considered to sense the RF electrometry and measure the E-field strength. The Rydberg atoms provide high sensitivity to the microwave radiation, detecting weak field of $12.5 \mu\text{W}$ at 15.09 GHz. From the results obtained, with large frequency range, high sensitivity and self-calibration of Rydberg atoms technique are the best way for new generation E-field probes, which are traceable to SI units [8].

The ninth article is authored by Saha et al. of CSIR-NPL, India. This article reported the evolution of unit of Candela and also describes the requirement of Quantum Candela. Candela is one of the seven base units, which is the only base unit to be related to the human physiology and gives a physical base to the phenomenon of vision. The advancement of semiconductor technology led to the growth of detectors opened the way for detector-based photometry [9].

The tenth article is authored by Sharma et al. of CSIR-NPL, India. This article describes the redefinition of SI unit at CSIR-NPL-India from the period of Vedic civilization to the present system of SI unit of length 'Metre'. This article also describes the evolution of dimensional metrology since 1953, parallel to the realization of SI unit, including the contributions of CSIR-NPL in that field of dimensional metrology and advanced research like Shear interferometer, Jamin interferometer for surface roughness. This study

also discussed the advanced services to be done by length, dimension and nano-metrology at CSIR-NPL [10].

The eleventh article is authored by Ehtesham et al. from of CSIR-NPL, India. In this study, author reviewed the key developments in the evolution of mass standard till now. This article discussed the working principle of Kibble balance to realize of kilogram to its new definition. Presently, NPL UK demonstrated single-mode two-measurement phase Kibble balance. The new concept opens up interesting advances in mass metrology, including various realization methods, realizing the unit (other than 1 kg) and traceability sources [11].

The twelfth article is authored by Thakur et al. of CSIR-NPL, India. This article focused quantum Pascal pressure standards using an optical interferometer manometer. Recently, NIST USA developed a quantum pressure standard in the 1 Pa to 180 kPa pressure range. The study depicts the realization of quantum Pascal with the help of changes in the resonance frequency of EM waves during the light–matter interaction [12].

The thirteenth article is authored by Garg et al. of CSIR-NPL, India. This article focused on the two particular features: measurement methodology and measurement uncertainty in realization and dissemination of unit watt in airborne sound. The dissemination of quantity sound power is usually done with a transfer standard that is commercially available aerodynamic. The traceability chain of sound power level originates with primary sound power source for realization of the unit. The development of a primary sound power standard is the utmost requirement so as to strengthen the traceability chain [13].

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