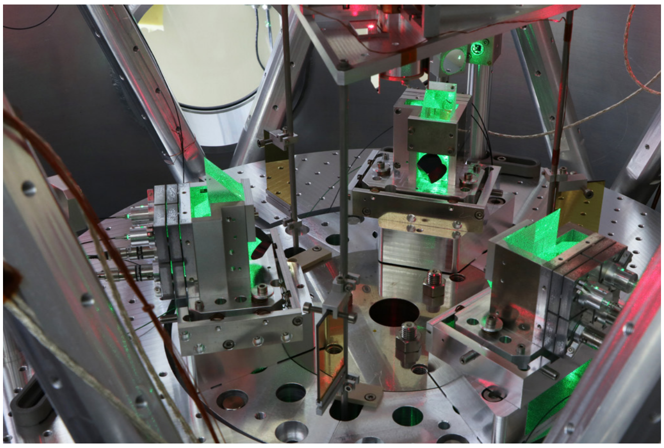
Physical Metrology

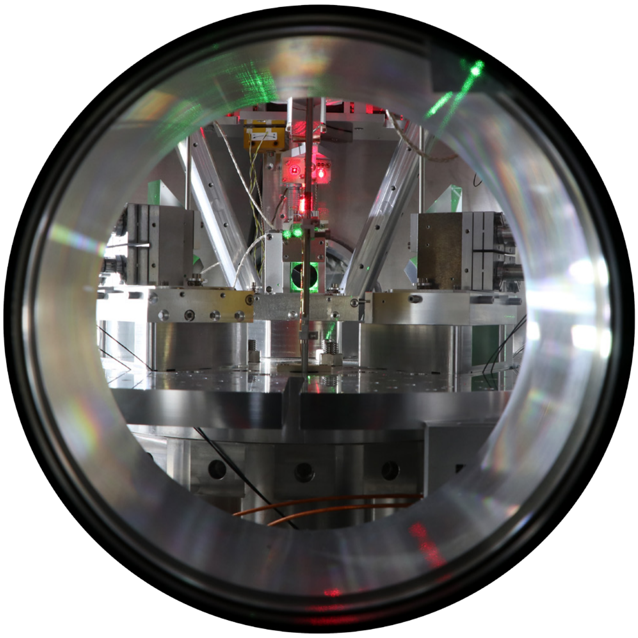
Calibration of mass standards

Following the official launch of the revised SI, the BIPM will continue to provide calibrations of mass standards for NMIs of Member States. At present, traceability to the new definition is achieved via the known relationship between the mass of the IPK and the Planck constant[1]. During 2019, eight calibration certificates were issued for Pt-Ir prototypes and eighteen for stainless steel standards belonging to 13 NMIs. A new 1 kg Pt-Ir mass prototype, n° 112, was delivered to the Republic of Indonesia.



BIPM Kibble balance

Crucial steps towards the completion of the BIPM Kibble balance for realizing the new kilogram definition were achieved in 2019. The type B uncertainty due to misalignment was significantly reduced after the integration of a new interferometer which is firmly mounted on the magnetic circuit. The electrical grounding of the whole apparatus has been improved, the measurement sequence optimized, and the apparatus control and data processing software refined. As a consequence, the relative standard uncertainty has been reduced to about 5×10^{-8}. This will allow the BIPM to participate in the first key comparison of kilogram realizations. A large number of measurements in vacuum of a 1 kg Pt-Ir mass standard were carried out during three one-month periods. During these periods, the apparatus was re-aligned in air several times. The average masses deduced from each period were in good agreement, demonstrating the effective repeatability and reproducibility of the apparatus. The next step will be to develop a new mechanical system for generating the vertical coil displacement and to perform force measurement with the objective of achieving a target uncertainty of 2×10^{-8}.



Official launch of the revised SI

A major event in the field of mass metrology was the official launch of the revised SI on 20 May 2019. The definition of the kilogram is now based on the fixed numerical value of the Planck constant, and no longer relies on the mass of the International Prototype of the Kilogram (IPK)[2]. The BIPM has issued a note[3] explaining the impact of this change on mass calibration uncertainties that were stated on BIPM calibration certificates issued before 20 May 2019. The dissemination process after the redefinition is described in a note issued by the Consultative Committee for Mass and Related Quantities (CCM)[4]. Initially the dissemination will be internationally coordinated to guarantee world-wide uniformity. Later, NMIs operating a method to realize the definition of the kilogram will be allowed to disseminate directly from their own realizations.

The BIPM is the pilot laboratory for the first key comparison of realizations of the kilogram, CCM.M-K8.2019. Seven institutes, including the BIPM, will participate with realizations based on Kibble balances, while two institutes will use the X-ray-crystal-density-technique. The first travelling standards arrived at the BIPM in October 2019 and weighings under vacuum started in November 2019. A Draft A report for this comparison is expected in 2020. The outcome of this comparison will become the basis for the calculation of the “consensus value”, which in turn will become the basis for the temporary international coordination of the dissemination of the kilogram.

On-site QHR resistance standard comparisons

In the field of electricity, the BIPM series of on-site comparisons of quantum Hall resistance standards (BIPM.EM-K12) continued with visits to the NMC, A*STAR (Singapore), NIM (China) and KRISS (Republic of Korea). Altogether, nine comparisons have been performed since this programme resumed in 2013. This series of on-site comparisons allows NMIs to validate their implementation of the quantum Hall effect for dc resistance traceability. Each comparison consists of an on-site comparison of the BIPM quantum Hall resistance (QHR) to that of the visited NMI by measuring a 100 Ω transfer standard, supplemented by the measurement of two resistance ratios. This allows the comparison of the ratio bridges used to scale the 100 Ω up to 10 kΩ and down to 1 Ω. During the comparisons carried out in 2019, a new set of temperature-controlled resistors built at the BIPM, and specifically designed for this task were used.

Four terminal-pair ac-resistance bridge

The characterization of the renovated four terminal-pair ac-resistance bridge, which was started in 2018 by a secondee to the BIPM from NMIJ (Japan), has been finalized. This work led, in particular, to a complete frequency characterization of the ac-resistors used in the quadrature bridge for linking the BIPM 10 pF capacitance reference to the dc quantized Hall resistance[5]. The BIPM built two Haddad type resistors for the LNE (France) of nominal value 1000 Ω and 1290.6 Ω during 2019. An additional 1290.6 Ω Haddad resistor was fabricated for the BIPM. Its negligible frequency dependence was verified using the renewed four terminal pair ac-resistance bridge.

Implementation of the ac-QHR

The study for the implementation of the ac-QHR at the BIPM started in 2019. Following fruitful exchanges between the PTB (Germany) and the BIPM in 2018, it was decided to implement the double-shielding approach developed at the PTB. The GaAs quantum Hall device will be of type LEP 513 or LEP 514 (the device usually used at the BIPM) and its holder will be very similar to that developed during Euromet project 540. The cryo-probe has been assembled and the first measurements are planned to start in early 2020. The final aim is to build a new quadrature bridge incorporating two ac-QHRs.

Josephson voltage standards

In the field of voltage, an on-site comparison of dc Josephson voltage standards has been carried out with MIKES (Finland). The BIPM is making progress with the development of a new protocol to extend its on-site comparison of Josephson standards from dc to ac voltages for frequencies below 1 kHz. A pilot study was carried out at the PTB in collaboration with the KRISS (Republic of Korea), the NMIA (Australia) and the VNIIM (Russian Federation). The aim was to gain experience of the differential sampling technique for ac voltages and to understand the impact of critical parameters that could affect the final result and its uncertainty. The influence of filters (developed at the NMIA) at the output of the ac voltage sources, used as transfer standards, was investigated. In order to monitor the drift of the transfer standard output voltage, dedicated software (developed at the VNIIM) provided a continuous rms value, based on a full sampling technique, from a DVM connected in parallel to the output of the source. The result of these measurements was compared to the result given by the differential sampling technique, which computes the rms value from a reconstruction of the sinewave. Finally, the influence of the type of samplers and the arrangement of the measurement setup were investigated. Further investigations of these parameters are needed to derive a comparison protocol that offers the best benefit for the NMIs.

In addition to the two on-site comparison programmes, a number of bilateral comparisons using travelling standards were carried out in 2019[6-8]: for resistance (BIPM.EM-K13) with NMC, A*STAR and NIM and for voltage (BIPM.EM-K11) with BIM (Bulgaria). A capacitance comparison (BIPM.EM-K14) with SASO (Saudi Arabia) is under way. A total of 76 calibrations have been provided by the electricity laboratories to NMIs in the fields of resistance, capacitance and voltage.