Time, the SI and the Metre Convention

This article has been downloaded from IOPscience. Please scroll down to see the full text article.

2011 Metrologia 48 S121
(http://iopscience.iop.org/0026-1394/48/4/S01)

View the table of contents for this issue, or go to the journal homepage for more

Download details:
IP Address: 193.2.92.136
The article was downloaded on 30/09/2011 at 13:28

Please note that terms and conditions apply.
Time, the SI and the Metre Convention

Terry Quinn
Emeritus Director, BIPM, 92 rue Brancas, 92310 Sèvres, France

Received 1 June 2011, in final form 9 June 2011
Published 20 July 2011
Online at stacks.iop.org/Met/48/S121

Abstract
Since 1954 when the definition of the second first came under the authority of the intergovernmental organization of the Metre Convention, the range and complexity of time metrology have increased far beyond anything envisaged in those days. Today, the essential international coordination of this domain of metrology is through the organs of the Convention with the exception of the definition of Coordinated Universal Time, UTC. In this short article I suggest that this also should now come under the authority of the Metre Convention.

In the year 2010 we celebrated the fiftieth anniversary of the formal adoption of the International System of Units (SI) by the 11th General Conference on Weights and Measures (CGPM) in 1960. The six base units of the SI were then the metre, kilogram, second, ampere, kelvin and candela. The mole came later, adopted by the 13th CGPM in 1971 after strong representations from the International Unions of Pure and Applied Chemistry (IUPAC) and Physics (IUPAP) as well as ISO (International Organization for Standardization). In 1960 the second still had an astronomical definition, although it was a new one having only recently been changed from one based on the period of rotation of the Earth to one based on the tropical year, the period of the Earth’s orbit around the Sun. The decision to change the definition in 1956 to the second of ephemeris time had been made by the International Committee for Weights and Measures (CIPM) on the authority given to it by the 10th CGPM in 1954. Both the CGPM in 1954 and the CIPM in 1956 acted on the advice of the International Astronomical Union (IAU) to define a unit of time that would be more stable than that based on the period of rotation of the Earth, whose irregularities had by then become well established. The definition of 1956 was ratified by the 11th CGPM in 1960.

At this same Conference the definition of the metre was changed from that based on the length of the international prototype of the metre kept at the International Bureau of Weights and Measures (BIPM) at Sèvres to one based on the wavelength of a certain radiation of the atom of krypton. This was the first step towards the transformation of our system of units from one based on artefacts, in the broadest sense, to one based on the unvarying constants of nature, as had been foreseen by James Clark Maxwell in 1870 when he wrote:

‘Yet, after all, the dimensions of our earth and its time of rotation, though, relatively to our present means of comparison, very permanent, are not so by physical necessity. The earth might contract by cooling, or it might be enlarged by a layer of meteorites falling on it, or its rate of revolution might slowly slacken, and yet it would continue to be as much a planet as before.

But a molecule, say of hydrogen, if either its mass or its time of vibration were to be altered in the least, would no longer be a molecule of hydrogen.

If, then, we wish to obtain standards of length, time, and mass which shall be absolutely permanent, we must seek them not in the dimensions, or the motion, or the mass of our planet, but in the wavelength, the period of vibration, and the absolute mass of these imperishable and unalterable and perfectly similar molecules’

At the time, science and technology were not sufficiently advanced for Maxwell’s precepts to be implemented. However, at the beginning of the 21st century they are, and we are on the brink of implementing Maxwell’s precepts for a system of units based not simply on the properties of ‘these imperishable and unalterable and perfectly similar molecules’ but on what we call these days the fundamental constants of physics (see draft Resolution A for the 24th CGPM October 20111), but that is another story!

Before 1956, there had been no formal definition of the second by the CGPM. It had simply been 1/86400 of the length of the day. In 1955, however, the first atomic clock had been operated by Essen and Parry at the National Physical Laboratory (NPL). This marked the beginning of the inexorable move of the unit of time from the domain of astronomy and the movements of the heavenly bodies to

1 For this and other matters related to the Metre Convention see the BIPM website www.bipm.org.
that of the much faster movement of atoms in the laboratory. One cannot but have some sympathy with the feelings of astronomers of those days who saw their absolutely reliable and regular time references being replaced by laboratory instruments whose lifespan could be measured in years or at best tens of years whereas theirs was in millions of centuries.

The definitive move to the laboratory had to wait until the 13th CGPM in 1967/68 adopted the present definition of the second based on the atom of caesium 133. The atomic definition of the unit, however, was not all that was required. It was necessary to establish means for setting the hands of the atomic clock, in other words a time scale. It needs hardly to be said but the rapid improvement in precision of the successive realizations of the caesium clock and more recently the even more precise clocks based on atoms other than caesium and at frequencies much higher than those specified in the present definition of the second have led to an enormous increase in the complexity of time scales. These now must be established not only for a Newtonian space-time framework, but also within that of general relativity, which with satellite time navigation is only for a Newtonian space-time framework, but also within the 13th CGPM in 1967/68 adopted the present definition of the second have led to an enormous increase in the complexity of time scales. These new must be established not only for a Newtonian space-time framework, but also within that of general relativity, which with satellite time navigation systems has entered into everyday engineering practice. The papers that follow in this special issue of *Metrologia* give a comprehensive account of how this was done from the beginning and how it continues to be done now.

The purpose of this short introductory paper is to outline how the CGPM, the CIPM and the BIPM under the Metre Convention have become increasingly involved in the unit of time and time scales since 1954, where responsibilities for such matters now lie and to suggest how this might change in the future.

The CIPM first became aware officially of the need for it to become involved in matters related to time and time scales at its meeting in 1954. André Danjon, an astronomer and President of the International Committee, brought a proposal for a new definition of the second from the 1952 IAU General Assembly in Rome. This stemmed from the conclusions of a meeting on Fundamental Astronomical Constants held in Paris in 1950. Danjon said it was necessary for the CGPM formally to adopt the new definition of the second so that it could be seen to be official. He expressed to the Committee the fear that if this did not happen, physicists and astronomers would each adopt different definitions, more or less well defined. While he was right in wanting to make the definition of the second official through the CGPM he was wrong in insisting on adopting an ephemeris second for the reasons he gave. It would have been better to wait and move directly to an atomic second.

However, coming only a few years before it defined the SI, it was perfectly appropriate that the CGPM as an official organ of the Metre Convention should include the unit of time within its purview. It would have been bizarre if in 1960 the SI had included the second whereas the responsibility for its definition belonged, for example, to the IAU. In the same way in 1971, the new definition of the mole, while proposed by IUPAC, IUPAP and ISO, had to be officially adopted by the CGPM for it to enter properly into the SI.

The Metre Convention, originally signed in 1875, took on its present form after modifications in 1921. These transformed it from a Convention dealing almost exclusively with the BIPM to one in which the International Committee was given much wider authority to act on behalf of Member States in matters pertaining to metrological work. The Member States decide to carry out in common (Article 12 of the Regulations 1921, see footnote 1). Since then, the work of the Committee and the BIPM has been greatly enlarged without there being any need to further modify the Convention. The question was raised in the 1950s as to whether or not the Convention needed to be further changed in order to enable a wider range of work to be undertaken at the BIPM but at the 11th CGPM in 1960 it became clear that there was no need. It has in fact become an enabling Treaty for all matters related to metrology.

The operational structure under the Metre Convention can be found on the BIPM website, but in outline it is the following: the overall governing body is the CGPM which meets every four years and is constituted by the delegations of Member States. Under the CGPM is the CIPM made up of 18 individuals, each of a different nationality, elected by the CGPM. The CIPM has exclusive responsibility for the oversight and direction of the BIPM. The CIPM has created a number of Consultative Committees to advise it on specific matters, the first being the Consultative Committee for Electricity created in 1927. There are now ten such Consultative Committee, one of which is the Consultative Committee for Time and Frequency (CCTF). Originally created in 1956 as the Consultative Committee for the Definition of the Second (CCDS), its task is now to advise the CIPM on all matters related to units of time and frequency. Members of the CCTF are from the national metrology institutes and a wide range of observatories and organizations themselves having activities in the field, namely

- Centro Nacional de Metrología [CENAM], Querétaro, Qro, (Mexico)
- Federal Office of Metrology METAS [METAS], Bern-Wabern
- Institute for Physical-Technical and Radiotechnical Measurements, Rostekhregulirovaniye of Russia [VNIIFTRI], Moscow
- International Astronomical Union [IAU], Paris
- International GNSS Service [IGS], Pasadena, CA
- International Telecommunication Union, Radiocommunication Bureau [ITU-R], Geneva
- International Union of Geodesy and Geophysics [IUGG], Boulder
- International Union of Radio Science [URSI], Gent
- Istituto Nazionale di Ricerca Metrologica [I.N.RI.M], Turin
- Korea Research Institute of Standards and Science [KRISS], Daejeon
- National Institute of Information and Communications Technology [NICT], Tokyo
- National Institute of Metrology [NIM], Beijing
- National Institute of Standards and Technology [NIST], Gaithersburg
- National Measurement Institute, Australia [NMIA], Lindfield
techniques and algorithms for time scales. Improved data from BIPM is thus very much involved in studies of time-transfer at present (2011) S121–S124 S123 to account for the slowly changing difference in it differs only by the addition of an integral number of seconds, Time (UTC). The latter is nothing other than TAI from which International Atomic Time (TAI) and Coordinated Universal by the CCTF is the continuous production by the BIPM of definition of the SI second and its work reflects the enormous that the CCTF deals with matters much wider than the range of its membership and its Working Groups shows In addition, the CCTF has set up a number of working groups:

- Working Group on Strategic Planning.
- Advanced Time and Frequency Transfer Techniques, Working Group on Coordination of the Development of Length on Frequency Standards,
- Working Group on Primary Frequency Standards, Frequency Transfer,
- Working Group on Two-Way Satellite Time and

The range of its membership and its Working Groups shows that the CCTF deals with matters much wider than the definition of the SI second and its work reflects the enormous range of activities that now must be included in the provision of accurate time references for the world.

Of course, the principal activity that must be overseen by the CCTF is the continuous production by the BIPM of International Atomic Time (TAI) and Coordinated Universal Time (UTC). The latter is nothing other than TAI from which it differs only by the addition of an integral number of seconds, at present 34, to account for the slowly changing difference in rate between the rotation of the Earth and TAI. These integral seconds are the famous ‘leap seconds’ (see below). The BIPM is thus very much involved in studies of time-transfer techniques and algorithms for time scales. Improved data from commercial clocks, and the prospect of much more accurate primary standards using trapped or cooled atoms or ions, are leading the BIPM to determine how future versions of TAI can be made even more accurate. These studies will lead to new algorithms for computing the scale, optimization of the use of data from novel primary standards, and increased accuracy in the application of Einstein’s theory of general relativity. Other studies may lead to a way of interpreting data from millisecond pulsars so as to provide a time scale with outstanding stability in the very long term. In addition, members of the BIPM scientific staff collaborate with the International Earth Rotation and Reference Systems Service (IERS) and the IAU in the fields of space/time reference frames and are in the appropriate Working party of the International Telecommunication Union dealing with time.

Time laboratories submitting data to the BIPM keep local representations of UTC. The computed differences between UTC and each local representation are available on the Publications page of the BIPM Time Department’s FTP Server. For each time laboratory ‘lab’ a separate file UTC-lab is provided; it contains the values of the differences \([UTC − UTC(\text{lab})]\) in nanoseconds, for the standard dates, starting on 1 January 1998.

It is evident that the CCTF together with the BIPM bring together the highest expertise in all aspects of time metrology.

Now, as regards leap seconds: the need for leap seconds stems from the decision in 1956 to define the second in terms of ephemeris time for the tropical year 1900. The magnitude of the ephemeris second for the year 1900 was the average of some three hundred years of astronomical observations of the rotation of the Earth having a mean date of about 1820. But the length of the day is increasing by about 1.7 ms per century so that in 1956 it was already 2.3 ms longer than it was in 1820 and thus the change introduced a step change in magnitude of the second of some ~3 parts in 10^9. The result was a systematic offset amounting to nearly one second per year with respect to Universal Time, UT1, in 1956. Neither the step change in the magnitude of the second nor its long-term consequences were mentioned at the time. In addition to this systematic offset resulting from the 1956 definition of the second, unpredictable fluctuations of about the same order occur over a small number of years so the need for a leap second cannot be accurately predicted. UTC was created in 1972 to provide a time scale having the stability of the atomic time scale but linked to the rotation of the Earth so as to keep the Sun, on average, over the Greenwich meridian at noon to within 1 s, i.e. 1 s of UT1. When astronomical observations indicate that the mean Sun will depart by more than 0.9 s, a leap second is added. Today, the decision to include a leap second, which is implemented by the BIPM, is taken by the IERS. Established as the International Earth Rotation Service in 1987 by the International Astronomical Union and the International Union of Geodesy and Geophysics, it began operation on 1 January 1988. The IERS took its current name, International Earth Rotation and Reference Systems Service, in 2003.

For modern high accuracy time metrology, the leap second is inconvenient and a number of articles in this issue deal with the question of what to do about it, i.e. whether to suppress it...
altogether, to change it to an interval rather longer or leave it as it is. The decision as to what to do is the responsibility of the ITU. The origin of the ITU’s involvement in this apparently metrological matter is explained in the following article by Ronald Beard. I would, however, make the following comment: the ITU is a UN body the purposes of which are clearly laid out in Article 1 of its constitution, which begins with the following statement of the purpose of the ITU:

‘to maintain and extend international cooperation among its Member States for the improvement and rational use of telecommunications of all kinds.’

This statement is then amplified by a considerable number of sub-paragraphs in which the detailed operation of the Union is exposed. In none of these, of course, is it stated that the ITU should have responsibility for the world’s time scale. A closer examination of the content of these sub-paragraphs makes it clear that the responsibilities of the ITU, although very wide, do not include matters related to the definition of time scales. It is for historical reasons, related to the early diffusion of time signals by radio, that the ITU found itself responsible for the definition of UTC. These days, time is disseminated by many other means, notably by satellite navigation systems and the internet but also by optical fibres, coaxial cable as well as by many systems related to satellite communications.

While I well understand the historical reasons for the ITU having responsibility for the definition of UTC, I suggest that this is now an anomaly and the time has come for it to be transferred to the organization of the Metre Convention. It would be more appropriate for the CGPM, the body under the Metre Convention responsible for defining the SI second and the establishment of TAI and UTC and under which the expertise on units of time and time scales now resides, also to be responsible for defining UTC.