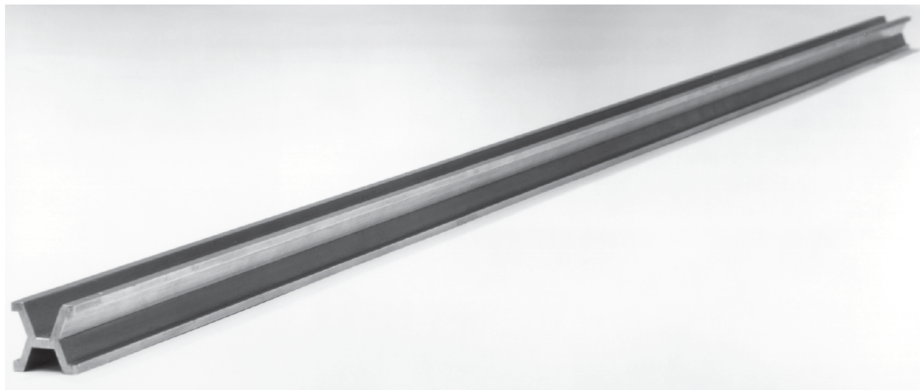
A short story on length

Richard Davis refreshes our memory on the venerable metre.

Since 1983 the speed of light in vacuum c has had the exact numerical value 299,792,458 when expressed in the units metres per second. It follows that the metre is defined as 1 m = c s/299,792,458, which is the distance light travels in vacuum during the specified fraction of one second[1]. (The second has since 1967 been defined by a property of the caesium-133 atom[1].)

Flash back to 1875, when the International Bureau of Weights and Measures (BIPM) was created by the Metre Convention. (The date was 20 May, now World Metrology Day.) The immediate task of the BIPM was to provide calibrated metre bars and kilogram cylinders to be used internationally. By 1889 the metre had been defined as the distance L_2 between two lines engraved on a particular platinum-iridium bar, $\mathfrak{M}$, of the type pictured. Care was taken to ensure that L_2 was the same as L_1, the length between opposite ends of an earlier metre bar introduced in France in 1799. Many copies of $\mathfrak{M}$ were also fabricated and then calibrated against $\mathfrak{M}$. Most were distributed to national laboratories. Of course, L_1 itself had been meant to correspond to L_0, $1/4 \times 10^{-7}$ of the polar circumference of the Earth, as measured from the North Pole to the equator along the Paris meridian[2]. But the length L_1 of the bar conserved at the archives had become the definition of the 'practical' metre, and so it was decided that L_2 should equal L_1 rather than L_0.



Credit: courtesy of the BIPM

Three years after $\mathfrak{M}$ was sanctioned as the defining artefact metre, Albert Michelson brought purpose-built equipment to the BIPM and succeeded in counting the number (over 1.5 million) of cadmium wavelengths in a distance of 1 m as defined by $\mathfrak{M}$. In his 1907 Nobel Lecture[3], Michelson evoked these measurements and, thanks to fortuitous timing, was able to add that Fabry and Perot had just confirmed his cadmium result using a different optical technique. He concluded that whenever the need arose, $\mathfrak{M}$ could be replaced so accurately by reverse engineering from the cadmium wavelength that the replacement bar would be indistinguishable from the original. In 1907, spectroscopists adopted the Fabry–Perot cadmium value to define their own unit of length, the ångström, and took this to be indistinguishable from 10^{-10} m.

When the International System of Units (SI) was first announced in 1960, it included a new definition of the metre, defined by an exact number of wavelengths of a particular emission from a krypton-86 lamp, relegating $\mathfrak{M}$ to history.

For this change in definition to be as seamless as possible, the length of the cadmium line as determined by Fabry and Perot in 1907 was used to establish the krypton wavelength in metres, allowing the ångström unit to be superseded by exactly 0.1 nanometres with no effect on previous measurements. Similarly, measurements traceable to the length of L_2 were unaffected, as Michelson had envisioned.

By 1972 the 'new' definition of the metre based on krypton had already become obsolete. In that year, an experimental value of c was reported[4] with an uncertainty 100 times smaller than any previous measurement. It turned out to be the last measurement of c. The result was based on determinations of the frequency f and wavelength l of a methane-stabilized laser. The value of c followed from $c = lf$, where wavelength was measured in terms of the defining wavelength of krypton and f was measured in terms of the frequency defining the second[1]. The limiting uncertainty was the metre definition, annoyingly based on "some incoherent radiation from a krypton discharge lamp"[5]. The metre needed to be redefined once more, and there were only two reasonable choices: either define a fixed value for the wavelength of light emitted by the most suitable stabilized laser, or adopt a fixed value for the speed of light. The advantage of the latter was plain: "the wavelength of stabilized lasers would be known to the same accuracy with which their frequencies can be measured"[4]. An online database of radiations that can be used to realize the metre[6] illustrates that the 1983 definition continues to serve us well. ❐

Richard Davis

International Bureau of Weights and Measures (BIPM), Sèvres, France.

e-mail: rdavis@bipm.org

Published online: 2 August 2018

https://doi.org/10.1038/s41567-018-0243-4

References

1. The International System of Units (SI) 8th edn (BIPM, 2006).
2. Alder, K. *The Measure of All Things* (Free Press, New York, NY, 2002).
3. Michelson, A. A. in *Nobel Lectures, Physics 1901–1921* 166–178 (Elsevier, Amsterdam, 1967).
4. Evenson, K. M. et al. *Phys. Rev. Lett.* **29**, 1346–1349 (1972).
5. Hall, J. L. *Phys. Today* 68, 44 (May, 2015).
6. Recommended values of standard frequencies, SI Brochure: Appendix 2. *BIPM* https://www.bipm.org/en/publications/mises-en-pratique/standard-frequencies.html (2016).