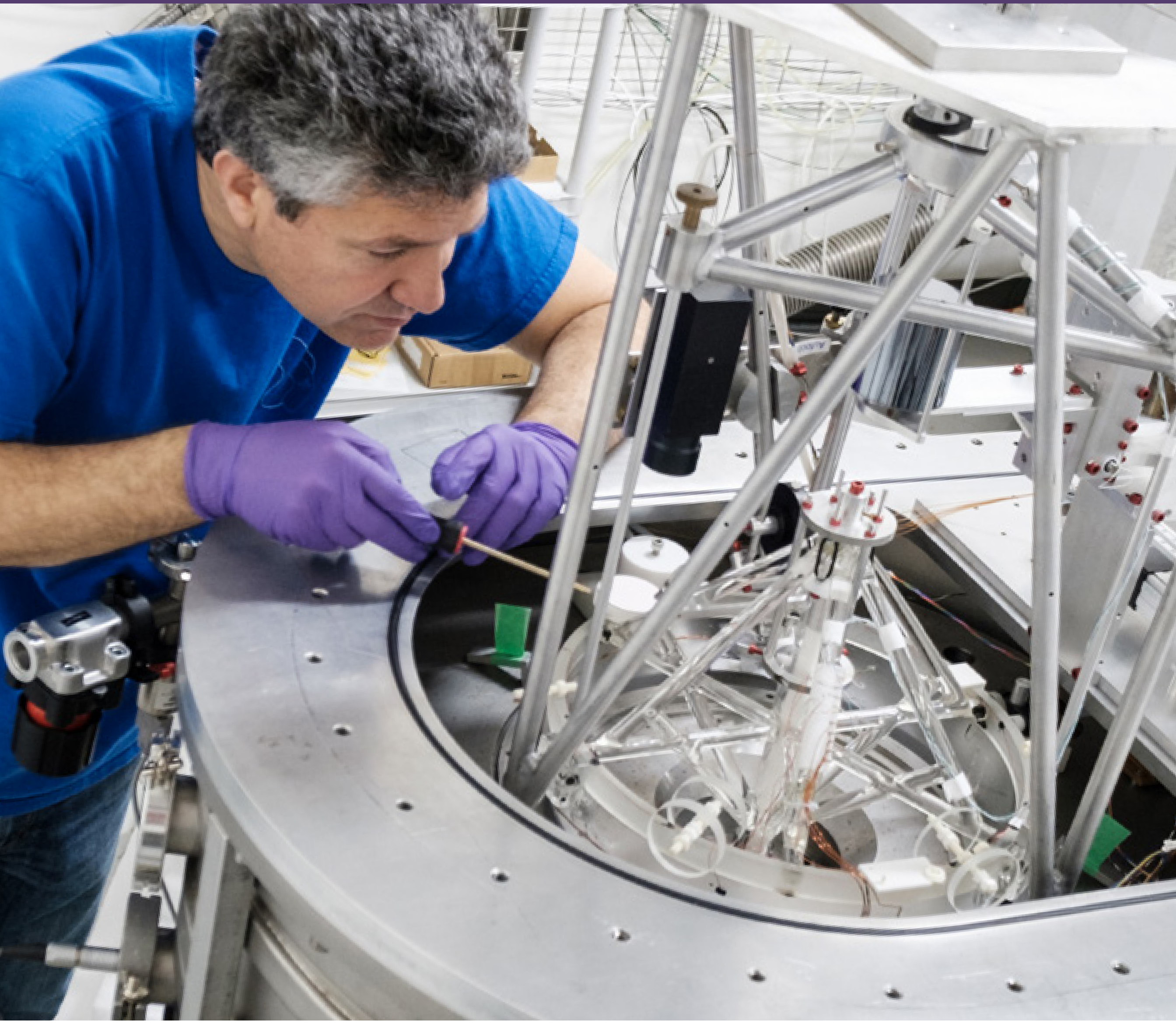
NRC·CNRC

The International System of Units: A shift to fundamental constants



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Innovation in Canada's measurement standards

The International System of Units (SI) is the most widely used system of units with official status in almost every country in the world. It contains seven base units, which are all dependent simply, repeatably and accurately on physical constants, which are always the same and can be measured anywhere.

The Planck constant is a fundamental constant of nature that scales the relationship between the energy and frequency of light. The National Research Council of Canada (NRC) is one of a few national metrology institutes providing leadership in experiments that are essential to determining the unit kilogram from Planck constant.

NRC Kibble balance project

The NRC Kibble balance, housed in an underground and isolated laboratory in Ottawa, Ontario, has played two essential roles in the redefined of the International System of Units (SI). Initially it was used to measure the value of *h*, the Planck constant, in order to support the global effort to redefine the kilogram, where NRC achieved the most accurate measurement in the world. Now, after redefinition of the SI, the NRC Kibble balance has taken on the role of the primary mass standard for Canada, supporting traceability to the SI for the Canadian scientific and industrial community. NRC also continues to play an integral role in ensuring consistency of the kilogram as nations adapt to the new definition, through an international agreement known as the global Consensus Value of the kilogram, to which the NRC Kibble Balance provides important measurements.

In the Kibble balance experiment the gravitational force on a mass is balanced against the electromagnetic force generated by passing a current through a coil suspended in a magnetic field. The current is calibrated using quantum standards of voltage and resistance, providing the link between the Planck constant and mass. Besides the electrical measurements, alignment of the balance is critical and has to be adjusted to very fine tolerances, gravitational forces on the mass must be known precisely, and the motion and position of the coil must be controlled interferometrically within fractions of the wavelength of light. Finally, to disseminate the value of mass out to users, fine corrections are made for changes that occur when moving mass standards between the vacuum in which the Kibble balance operates to air in which the mass standards are used practically. The resolution of the measurements used to make this correction is less than the mass of a single layer of water molecules on the surface of mass standards.

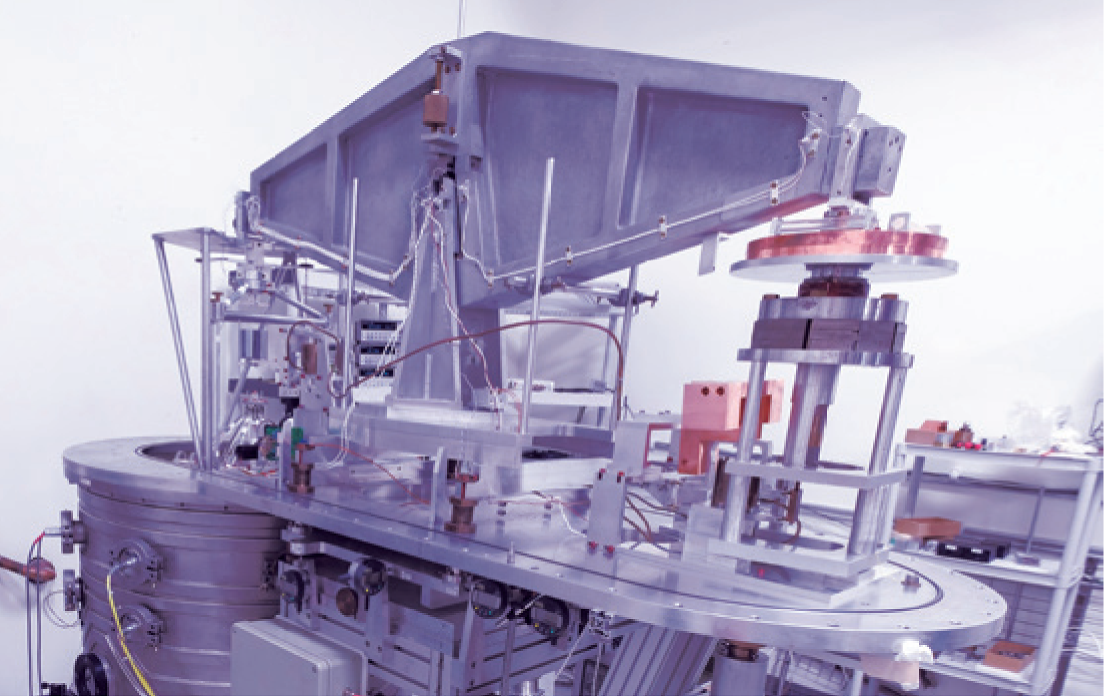
The International System of Units_(SI): past, present and future

A unit of measurement is a standardized quantity of a physical property used as a factor to express quantities of that property

Units of measurement were among the earliest tools invented by humans. Primitive societies needed rudimentary measures for many tasks: constructing dwellings of an appropriate size and shape, fashioning clothing, or bartering food or raw materials. The measuring instruments of many of the earliest systems were based on parts of the body—the length of a foot, the span of the hand stretched out, and things found in the natural surroundings— seeds and gourds. As widespread communities began integrating, it became evident that there was a chaotic abundance of "measures," sometimes decided by the greed of the ruler or rich farmer, and conflicts arose over land, water, forest and capital.

And so it came to be that about 200 years ago, in the midst of the French Revolution, the National Assembly of France requested the French Academy of Sciences to "deduce an invariable standard for all the measures and all the weights." Today, the International System of Units (SI) is the system of measurement used uniformly throughout the world. Universally familiar in science, the SI has become a dominant presence in international commerce and trade. The creation of the decimal Metric System at the time of the French Revolution in 1799 and the subsequent deposition of two platinum standards representing the meter and the kilogram in the Archives de la République in Paris were the first steps in the development of the modern International System of Units. Initially the meter was tied to one forty-millionth of the Paris meridian and the kilogram to the mass of a cubic decimeter of water. This realization of the kilogram standard proved impractical.

Since its initiation in 2009 the NRC Kibble balance project has made surprising advances and continues to boast the lowest uncertainty ever achieved for the determination of Planck's constant.



The Metre Convention of 1875, a landmark in globalization signed by representatives of seventeen nations put the metric system in the hands of the International Bureau of Weights and Measures (BIPM). New internationally sanctioned platinum-iridium prototypes of the meter and kilogram were constructed as the base units of length and mass, and together with the astronomical second as the unit of time these units constituted a three-dimensional mechanical unit system.

Advances in science and technology led to the revision of the Meter Convention in 1921, which extended the scope and responsibilities of the BIPM to other fields in physics, and to the adoption of a four-dimensional system based on the meter, kilogram, second and ampere. In 1954 the ampere, the kelvin and the candela were assigned as the base units respectively for electric current, thermodynamic temperature and luminous intensity.

The name International System of Units (SI) was given to the system in 1960, and in 1971 the present version of the SI was completed by adding the mole as the base unit for amount of substance, bringing the total number of base units to seven. There have been many changes to the system during the years from 1971 to 2010: the definitions of many of the base units have been revised to meet new developments in measurement science and to ensure the coherence of the entire system. This dynamic characteristic of the SI continues. As of September 20, 2019, with the redefinition of the SI, the seven base units are all referenced to fundamental physical constants.

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