Feature

Measurement Standards and How They

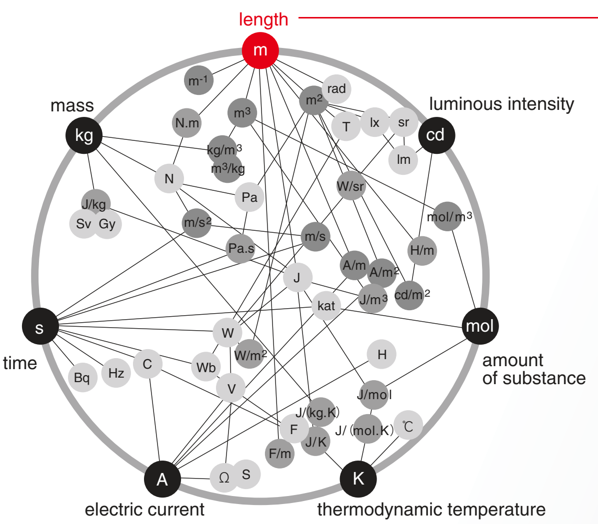
Akira ONO, Research Coordinator

Whenever we buy, sell or exchange any kind of item, we use a remarkably broad array of units. Each of these units is determined according to a standard gradation, or measurement standard. Thanks to the existence of these measurement standards, we can carry out an infinite array of activities and transactions with the confidence that we know exactly how much of each item we are dealing in.

For today's advanced technologies, such as nanotechnology and biotechnology, ever more precise measurement standards are required. The importance of such precise measurement is growing constantly.

How are these measurement standards defined? How are they established and propagated for general use?

The World of the International System of Units (SI)

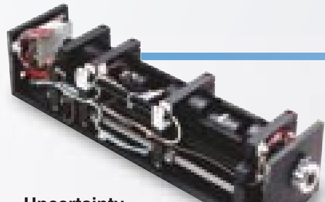


All SI units are derived from of the seven basic units. These units are mutually interconnected. For example, the unit of time (s) is necessary to define length.

National Standards for Length

Iodine-stabilized He-Ne laser

Iodine-stabilized He-Ne lasers provide an extremely stable light source at a wavelength of 633 nm. These lasers can realize an accurate "ruler" with a scale division of half the wavelength, using an interferometer. They are also used as a secondary measurement standard.



Uncertainty

10^{-11}

(precision to 0.1 mm when measuring 10,000 km)

Practical Standards

Gauge blocks account for approximately 80% of the practical length standards presently in use. A gauge block is one of the end standards in a block shape. The distance between its two ends is used directly as a length standard. Because of that, there are over a hundred of them that are different in size. Their shapes are maintained by precision polishing and their absolute length can be realized with better than 0.05 μm precision.

10^{-7}

(precision to 1 m when measuring 10,000 km)

Measuring devices for general use

Various kinds of measuring devices used for manufacturing, such as slide calipers, micrometers and dial gauges, are included in this category.

slide caliper

10^{-5}

(precision to 100 m when measuring 10,000 km)

dial gauge

* nm (nanometer; 1 nm = 1/100 millionth of a meter)

The Role of Measurement Standards Units and Measures

Hirokazu MATSUMOTO,
Deputy Director, Metrology Institute of Japan

Units and Measures

The exchange of materials is an indispensable part of our everyday lives. Yet the greater the quantity and variety of material exchanged, the more difficult it becomes to exchange items directly. Precise information about those items is needed in order to exchange them. For this purpose, a wide range of units is employed.

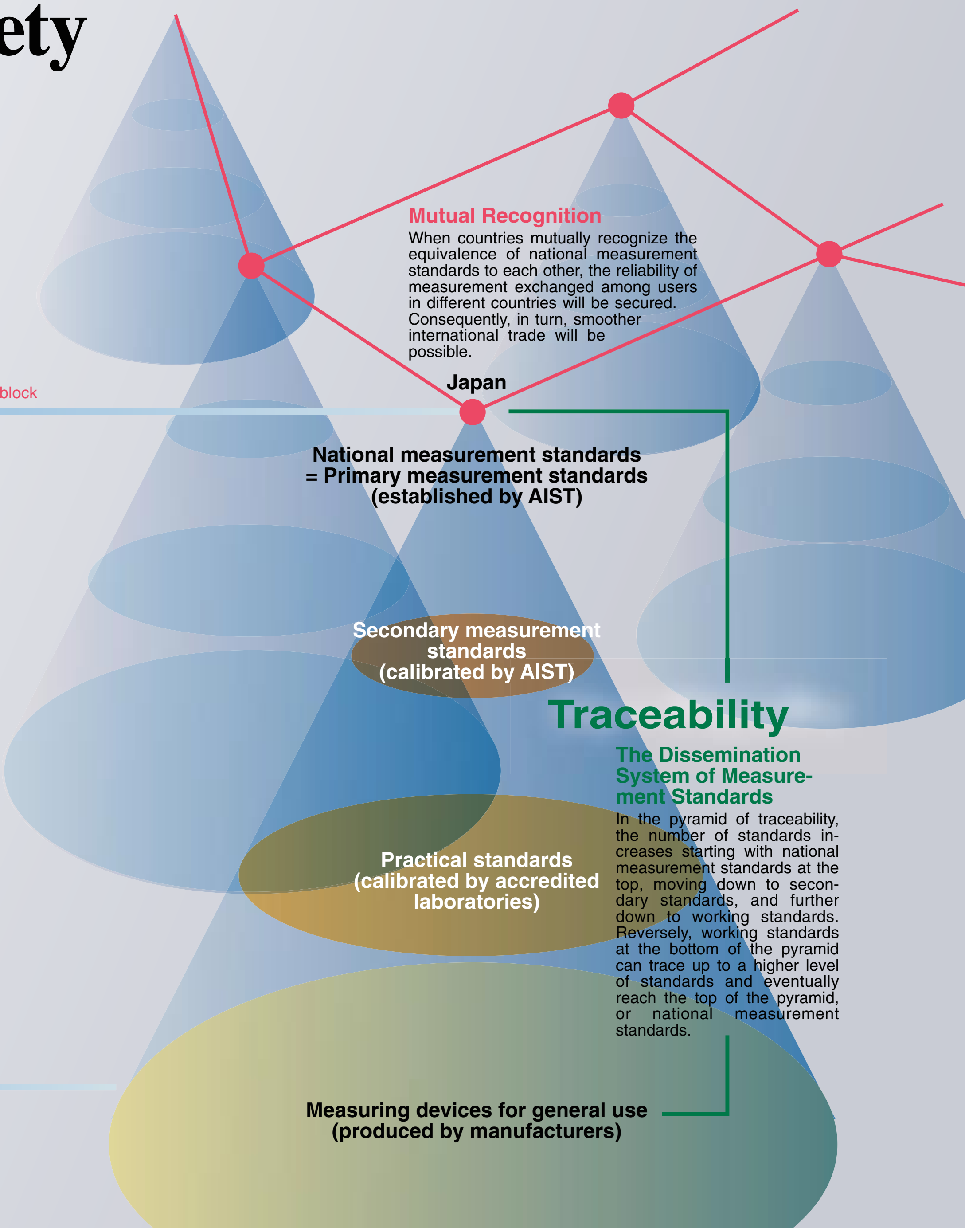
To use these units, a sufficiently large community of users must accept the use of a common set of measures in their everyday lives. If the gradations in these measures – the units – differ among the people conveying information about a given item or transaction and those receiving it, or if the people involved lack confidence in them, it becomes impossible to conduct transactions with confidence, For this reason, measures represent a keystone supporting our modern society.

Measurement Standards for Better Safety and Security

Allowing lab-test results to be used anywhere in the world

In lab tests, blood and urine samples are used to measure levels of cholesterol, gamma-GTP, urinary proteins and the like, to ensure that patients' levels of these substances are normal. These values must be identical (within a reasonable range) at any hospital in the world. If they are not, great confusion and danger may result. Incidentally, no measurement standards for cholesterol have yet been established. AIST is currently working to develop measurement standards for cholesterol and other key blood components.

Support Society



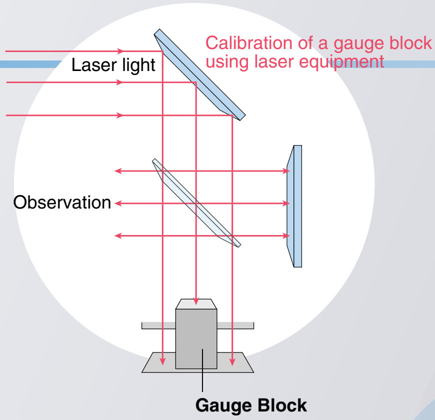
Mutual Recognition

When countries mutually recognize the equivalence of national measurement standards to each other, the reliability of measurement exchanged among users in different countries will be secured. Consequently, in turn, smoother international trade will be possible.

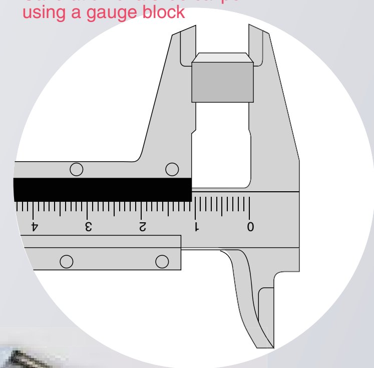
Traceability

The Dissemination System of Measurement Standards

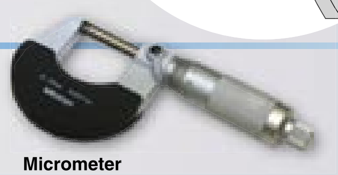
In the pyramid of traceability, the number of standards increases starting with national measurement standards at the top, moving down to secondary standards, and further down to working standards. Reversely, working standards at the bottom of the pyramid can trace up to a higher level of standards and eventually reach the top of the pyramid, or national measurement standards.



Calibration of a gauge block using laser equipment



Calibration of a slide caliper using a gauge block

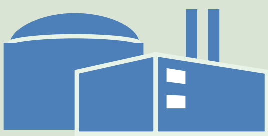


Micrometer

Toshihide IHARA, Manager, Metrology Planning Office, Metrology Management Center

Measuring Critical Water-Supply Flowrate in Nuclear Reactors

Nuclear power plants work by splitting atoms to heat water. The resultant steam drives a turbine, which turns an electrical generator. After passing through the turbine, the water vapor (which is uncontaminated by radiation) is cooled and returned to the water supply, where it is once more sent to the nuclear reactor. Because this flow volume is used to control the amount of heat generated by the nuclear reactor, obtaining an accurate assessment of the water flow is crucially important for the safety and generating efficiency of the power plant. At AIST, we are hard at work developing highly precise technologies for measuring water-supply flow volumes in nuclear reactors.



Monitoring Electromagnetic Environments

Mobile telephones generate redio waves. To prevent such emissions from interfering with pacemakers and other medical devices, mobile phone use is prohibited in hospitals and on trains. Production of electronic devices, such as PCs, is governed by international standards regarding unnecessary generation of radio waves. In Japan, such devices are thus requlated to ensure product safety. AIST prepares the measurement standards needed to monitor and control these high-frequency electromagnetic environments.

Traceability in Measurement Standards

Measurement standards are the means by which standard gradations are stipulated to establish various units. In Japan, the National Measurement Institute of Japan (NMIJ), a center within the National Institute of Advanced Industrial Science and Technology (AIST), determines the national standards upon which measurement standards are based. NMIJ develops and supplies standards that are trusted not only throughout Japan, but in many countries overseas as well.

To make national standards available throughout society, a system of *traceability* must be established. Traceability is provided by a verifiable system for assuring that the units of measurement applied in a given environment are identical with a higher national or international standard for that unit. This article examines how traceability works, using units of length as an example. The standard for length, the measure that stands at the apex of any traceability system, an elaborately constructed physical model representing one meter of length. For 70 years, this physical model of the meter served as the national standard for length in Japan. The problem with the use of physical models, of course, is that the loss of the physical model on which the system is based would result in chaos. For this reason, efforts were made to develop a scientific method of defining the meter. Eventually, in 1960, wavelengths of light came to be used to determine gradation, and “one meter” was defined as 1,650,763.73 times the wavelength of the light emitted by an atom of krypton.

This innovation allowed length to be established using contactless techniques. It reduced uncertainty regarding the accuracy of the measurement value by two orders of magnitude, thereby greatly improving the technological basis upon which modern industry is founded. (“Uncertainty” is a measure of precision; it is the range in which the true value is sure to be found.) A further advance occurred in 1983, when the speed of light was used to redefine “one meter” as the distance that light propagates in a vacuum in 1/299,792,548 of one second. The national standard for “one meter” is thus obtained from a stabilized wavelength produced by an iodine-stabilized helium-neon (He-Ne) laser.

However, the instruments we use on a daily basis were not produced with direct comparison with this national standard. Rather, the standard is transferred from a designated standard device representing the national standard to a secondary standard device. The gradations on the secondary standard device are compared with those on the designated standard device, to “calibrate” the device, or verify its precision. This check can only be performed by an accredited calibration laboratory. Using a technology called wavelength interference, laser wavelengths can be used to accurately calibrate the gradations on a wide range of standard devices. The wavelengths of He-Ne lasers are then used on the secondary standard device as well. By this process, capable private-sector calibration laboratories can calibrate a practical standard device (a gauge block or other simple device that can be used as a standard device by any end user). In the next phase, the gradations on this practical standard device are transferred to the calipers, micrometers, and other devices used by the end user. Here again, this work must be performed by an accredited laboratory.

Japan’s private-sector calibration laboratories boast an exceptionally high level of technology. Today, some 35 accredited laboratories use the designated secondary standard devices in their possession to perform calibration. Standing at the top of the calibration pyramid, these certified operators play an extremely vital role in modern industry: the number of practical standard devices each laboratory has calibrated runs to the hundreds of thousands; and the number of types of general instruments to which the calibrations on those practical standard devices are transferred number in the tens of millions for each accredited laboratory. Because the traceability system forms a pyramid, calibration is remarkably cost-effective in Japan, conveying national standards to the nation’s users with enviably low levels of uncertainty.

International Mutual Recognition

As industrial technology and business operations become increasingly global in nature, the importance of interaction with other countries is rising dramatically. These interactions depend on the ability to trust the measurement standards used by each country; one country’s units must be interchangeable with all others’. For this reason, the international community has been grappling with the need to establish mechanisms to preserve the equivalence of various countries’ measurement standards and provide society with measurement standards that each country can recognize, so that the inspection and test data of each country are interchangeable. This interchangeability is called the “international mutual recognition” of measurement standards. Today 57 signatory countries and regions are members of the International Bureau of Weights and Measures (BIPM), the international standards body established by the Meter Convention.

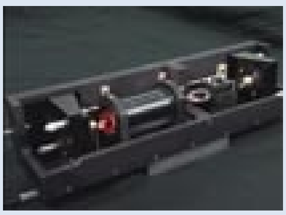
Countries signatory to the international mutual recognition process are required to prepare quality manuals, conduct

Optical Comb: A leading-edge technology for optical frequency measurement

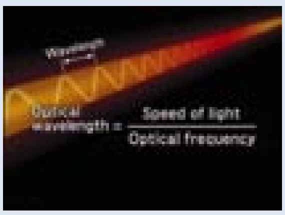
Hajime INABA, Wavelength Standards Section, Time and Frequency Division, Metrology Institute of Japan

The unit of length, the meter, is determined using red light from an iodine-stabilized He-Ne laser (ISHN laser) as a ruler (1). A laser is a wave; its cycle length is called the wavelength. How do we determine the laser wavelength? An optical wavelength is calculated from the optical frequency (2). In the case of an ISHN laser, the optical frequency is approximately 474 THz (1THz =1 terahertz = 10^{12} Hz). Therefore, the wavelength is approximately 633 nm because the speed of light is defined as 299,792.458 km/s.

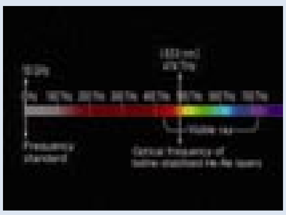
We now come to the question of how the optical frequency of the laser is measured. We must measure an optical frequency using the frequency standard, which is approximately 10 GHz microwave generated from a cesium atomic clock. However, the optical frequency of an iodine-stabilized He-Ne laser is approximately 474 THz, which is more than ten thousand times higher than the cesium frequency (3). Therefore, measuring an



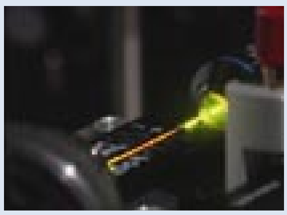
(1) Iodine stabilized He-Ne laser



(2) Relationship between optical wavelength and frequency



(3) Frequency gap between the frequency standard and the laser



(4) Photonic crystal fiber

fully transparent international comparisons, and submit to peer reviews by specialists from other countries. Standards that pass this rigorous process are registered in the BIPM database. Officially in operation from 2004 onward, this system will soon allow measurements gathered in other countries to be accepted “as is” in one’s own country, contributing significantly to smooth trade operations and economic growth.

Legally Designated Measurements That Protect the Security of Our Everyday Lives

Takeshi ITO, Metrology Planning Office, Metrology Management Center

Measuring instruments for commercial transactions and certifications that have a remarkably pervasive influence on private consumers are under strict legal control. For instance, they must pass mandatory verification before they enter the market. They are called "specified measuring instruments".

Today, there are 25 categories of legal measuring instruments in Japan. Meters for water, gas and electricity, for example, are requisite in daily life. Aside from these, in the real world, weighing instruments to weigh foods in retail shops, alcohol hydrometers to determine the alcoholicity in liquors, fuel dispensers at gas stations, and taximeters in taxis are helping people without always being noticed. Sphygmomanometers and clinical thermometers used for health management at home are similarly required to pass verification.

For environmental measurement, sound level meters and vibration level meters are examples of specified measuring instruments. Concerning the contamination of air, soil and water, measuring instruments to determine minute quantities of pollutant such as dioxin, which have drawn public attention, are also subject to verification.

The period of validity of verification is limited. Specified measuring instruments must be subjected to regular inspections to guarantee their accuracy.

Conventional mechanical instruments have adopted more and more advanced electronics, such as CPUs. In this trend, new-generation measuring instruments have been introduced. They can be applied to, for example, centralized screening systems using LANs and the Internet, energy supply management and its distribution system with consolidated databases of measuring results. In addition, they are able to interact with mobile devices such as mobile phones and may allow the popularization of electronic money with IC chips. Those innovations have brought drastic changes in the practices of transactions and logistic systems. Specified measuring instruments are playing valuable roles in this society. They have become more and more important as they incorporate increasingly advanced technology.

On the other hand, these remarkable advances also pose a problem. To ensure the measurement accuracy, legal regulation has mainly dealt with hardware, which has been sufficient so far. However, it has been expanded to installed software today, because the development of information technology has increased the risk of illicit interference and falsification. To meet the emerging needs of software protection, AIST is engaged in the research of this field.

Taxi meter

Noise meter

Gas meter

Water meter

Commercial weighing scale

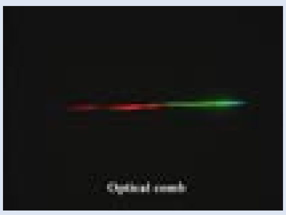
optical frequency using the cesium frequency as a standard was extremely difficult.

At AIST, the investigation of optical frequency measurement has proceeded. As a result, we have developed a special light optical frequency comb, which is a bridge between the microwave frequency region and the optical frequency region. An optical frequency comb can be generated using a femto-second mode-locked laser and a photonic crystal fiber (4).

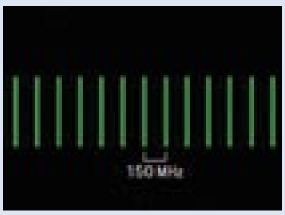
As shown in the photo (5), this optical frequency comb involves various color components, similarly to a rainbow. However, its micro-structure is not continuous like a rainbow but discrete like a comb (6).

The frequency intervals of a comb are uniform. If the intervals are locked to an atomic clock, these comb frequencies are also determined accurately (7). A locked optical comb appears as though a million stabilized lasers form a line at uniform intervals (8).

Various laser frequencies can be measured over 1000 times more accurately than conventional techniques by using an optical comb as an optical frequency ruler. These accurate lasers will improve semiconductor processing precision, for example. Furthermore, using this technique, contributions to the optical communications are expected.



(5) Optical comb



(6) Magnified optical comb (Conceptual figure)

(7) Frequency counter

(8) Frequency measurement of a laser using an optical comb as a frequency ruler