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Beyond the Metre (Part I)

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BEYOND THE METRE (Part I)*

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Introduction

This article is the first in a series discussing the wide spectrum of metric units. Metric education programs typically avoid measuring force, energy, and other physical quantities. Specialized units like the joule and pascal, however, will be appearing more and more frequently. How many Americans can confidently interpret a label rating a light bulb in lumens? This series of articles for the general reader will review the history of the metric units, the rationales behind their definitions and the fine points of their usage. Examples and exercises will relate the special units to every day experiences. This initial article will deal with the foundations of the metric system, the metre, the second, and their simple extensions.

The International System of Units

In 1870, the International Commission of the Metre set up the machinery to regulate the modern metric system, which is symbolized "SI" in all languages (to stand for the French title meaning "International System of Units"). The acceptability of SI units and the rules for their use are determined by the General Conference of Weights and Measures (CGPM). Its delegates, accredited by the governments which signed the Convention of the Metre, meet periodically to consider changes in the catalog of units or the manner in which they are officially defined.

The SI catalog does not include most units of our customary British system. Even the millimetre of mercury, familiar to those warily monitoring blood pressures and which certainly looks metric, is excluded in order to preserve an important simplicity of the system. Each physical quantity is measured by only one SI unit and its decimal multiples or submultiples. Our customary system employs more than a dozen units of length alone.

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Some countries, such as France, legally exclude all units of measurement except SI. French astronomers determining the distance to a star in light years technically need to post a lookout for the *gendarmerie*. The U.S. and British antimetric opposition have warned that, should metric units prevail, tavern patrons may be carted off in paddy wagons still clutching their pints of beer. The image belongs more to rhetoric than reality. History has shown that exclusive legal systems of measurement exert little compulsion beyond the confiscation of offending butchers' scales and other equipment already subject to government regulation.[1] Old-style tankards, even though habitual offenders against metric laws, remain in use until tavern turnover takes its toll.

The first official U.S. measurement standard was a reference metre procured in 1805 by the official directing coastal surveys[2]. Congress legalized the metric system in an 1866 law passed largely through the efforts of Iowa's Representative John A. Kasson.[3] No such footing exists for our *customary* units, which owe their present standardization to an early nineteenth century secretary of the treasury's directive to all U.S. Customs Houses.[4] The *customary* system is indeed well named. In 1893, all customary units were defined in terms of metric standards. They remain so to this day.

The International System of Units is sometimes called the MKS system from the initials of its foundation units: the metre, kilogram and second. Additional units needed for the study of moving bodies can be built up from combinations of these fundamental units using the laws of physics. Speeds, for example, are expressed in metres per second.

Other foundations are possible for measurement systems. One form of our customary system is grounded on the foot, pound, and second. Physicists zealously cling to the CGS system, which is older than SI and derived from the centimetre, gram and second. For 42 years, the French legal system of measures was a monstrosity based on the metre, *tonne* and second.[5]

The Metre (m)

In 1799, a French law changed the original definition of a metre (one ten-millionth of the distance from the earth's equator to the north pole) in favor of a standard platinum bar designed to match the former length within the limits of manufacturing accuracy available at that time. Henceforth, the bar officially defined the unit. It would be unlikely that two surveying teams would ever agree exactly upon the metre's length by the former definition. The standard bar, on the other hand, was unique and much easier to measure. A limited number of duplicates could be distributed worldwide. Reproducible standards are crucial for a usable measurement system.

In order to reduce thermal variation, a new platinum-iridium bar was used as the standard after 1889. As demand increased there was no way to provide exact copies in the necessary quantities. The CGPM returned to a natural standard in 1960, choosing one which any reasonably equipped laboratory could reproduce. The metre was defined to equal 1,650,763.73 wave lengths of the orange light emitted by krypton-86 atoms.[6] This definition is inherently uncertain by only one billionth of a metre. Meterologists vow to someday set a standard reproducible to within the diameter of a molecule.

Longer distances are expressed in terms of metre multiples using prefixes. Following a suggestion by the nineteenth century physicist James Clerk Maxwell, the symbol "m" represents the metre in much the same way a chemical element is symbolized. Just as the chemical symbols are not abbriviations and require no periods, neither do SI symbols. Symbols for the prefixes combine with the symbols for units in specific ways. The prefix for a factor of a thousand is "kilo-", symbolized "k" in SI. Thus, the symbol for a thousand metres, the kilometre, is written "km" with no period. The symbol is always singular. A distance of ten kilometres would be represented as "10 km", *not* "10 kms".

The Square Metre (m^2)

SI defines its unit of area, the square metre (symbolized "m^2"), to equal the area of a square which is one metre on a side. Multiplying one length measurement in metres by another to find the area of a rectangle yields a result in square metres. This property, called *coherence*, is a general characteristic of SI units. Scientists use metric units largely because of this simplicity. Our customary system does not measure up as well. Surveyors who find a lot to be 600 ft. long by 800 ft. wide cannot simply multiply the results to find its area in acres. They would also need to know that an acre equals 43,560 sq. ft. Unfortunately, a surveyor's foot differs slightly from a regular U.S. foot to further complicate things. The word for the customary system is *incoherent.*

Practical use has generated additional metric area units which are more convenient for particular purposes. Land in metric countries may be measured in *ares* (parcels 10 metres by 10 metres) or, more commonly, in *hectares* (parcels 100 metres by 100 metres). Nuclear physicists fire subatomic particles at targets measured in terms of the *barn,* the area of a square one hundred-trillionth of a metre on a side. A barn is actually too large to describe a target, and scientists often resort to the millibarn in their reports. The phrase "as big as a barn" assumes new significance for these sharpshooters!

The hectare and the barn are not official SI units, although it will be permissible to use them with the International System for a limited time. To incorporate them officially would destroy the square metre's uniqueness and render SI less coherent.

Other definitions of area measure could have been adopted, such as units based on circular areas of one metre radius.

The Cubic Metre (m^3)

Volumes may be expressed in SI using the cubic meter. This unit is far too big for convenient everyday usage. A unit only one-thousandth as large is more practical but impossible to express clearly using a submultiple prefix. No one supports the use of a "millicubic metre" and the "cubic millimetre" is something entirely different. Recognizing this problem, the governors of SI have approved the term "litre" to designate a unit equal to the volume of a cube 0.1 m on a side. While permitting its use by itself, they did not officially adopt the litre into the system. Its incorporation into compound units is discouraged. One can measure the capacity of a gas tank in litres if one wishes, but a river's flow rate should be expressed in cubic metres per second.

The Second (s)

Time, the bane of athletes and philosophers and the most mysterious physical property, is measured by the most accurately defined unit — the second. Today, time is kept to the phenomenal accuracy of one part in ten billion, a tribute to mankind's ingenuity and stubborness.

One critic has gleefully labeled the metric system fraudulent for marking time by sixties instead of tens.[7] The French government's attempt at decimalizing the clock and calendar in 1793 failed because the movement lacked motivation. Unlike the old French weights and measures, time had already been well standardized over the country. Greater simplicity alone could not induce people to change. Time is standardized worldwide today. Any attempt to decimalize it would meet tremendous opposition.

Astronomers have recently passed their age-old responsibility for timekeeping to the atomic physicists. Clocks based on the internal vibrations of atoms can accurately detect miniscule changes in the earth's rotation and the length of the year. In 1978, the CGPM redefined the second to be the time taken for 9,192,630,770 cycles of the radiation making up a spectral line of the cesium-133 atom.[8]

Like the litre, the minute and hour are not part of the International System. The decimal nature of SI is preserved in this way, although the longer time units may still be used by themselves. We can decimalize our own day by thinking of time by the kilosecond, a little more than a quarter of an hour.

The official symbol for the second is "s". One should never abbreviate the unit into "sec." as is often done in textbooks. This may seem to be a fine point, but as Danlous-Dumesnils laments, "It is a strange fact that many a man who would justifiably complain about a misspelling or an unattached participle in a letter attaches no importance to the correct method of writing numbers and measurements."

Summary

This article has reviewed the history and application of the metre and second which are basic units of the International System of Units. The next article in this series will discuss the kilogram, why it already has a prefix in its name, and how it is combined with the metre and the second to create more complex units.

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William Coffman
Director of the Univ. of Iowa Testing Program