The International System of Units (SI)—Development and Progress

MARTIN A. PAUL
National Academy of Sciences–National Research Council,
2101 Constitution Ave., N. W., Washington, D. C. 20418

Received January 4, 1971

Since 1960, a coherent system of units known as the SI, bearing the authority of the International Bureau of Weights and Measures, has been in effect and is gaining acceptance among scientists and engineers. It is an extension of the MKSA system, with each physical quantity assigned an SI unit uniquely. Larger and smaller units for a particular physical quantity may be constructed, if considered necessary, by restricted powers of ten designated by an extension of the metric system of prefixes. In the interest of reducing the number of superfluous units and improving communication among scientists in different fields, most units outside the SI are to be progressively discouraged, though some are recognized as continuing to be useful in specialized fields.

The International System of Units (SI)[1] is the most recent phase in the development of a universal, coherent system of measurement designed to facilitate the communication of numerical data. In a "coherent" system, the units are derived from a restricted set of independently defined base units by simple multiplication or division, without introduction of conversion factors. Adopted in its principal features by the 11th General Conference of Weights and Measures (CGPM)[2] in 1960, following a study initiated in 1948, the SI is an extension of the Metric System, modified to take account of improvements in the precision with which the base units can be defined and of increased sophistication in regard to the function of units. Its base units (and their symbols) are: metre (m), kilogram (kg), second (s), ampere (A), kelvin (K), candela (cd), and mole (mol).[3]

The SI is receiving widespread attention in scientific and engineering societies around the world and has been endorsed by major national and international organizations concerned with standardization, including the International Union of Pure and Applied Chemistry (IUPAC),[4] the International Organization for Standardization (ISO),[5] and the Royal Society.[6] A complete description of the SI, with guidelines for its implementation, has recently been published by the International Bureau of Weights and Measures; a translation of the French text has been prepared jointly and published independently by the National Physical Laboratory (UK) and the National Bureau of Standards (USA).[7] My purpose is to explain for prospective users of the SI who have not followed closely its development how the system came into being and why it has been accepted with enthusiasm by scientists and engineers familiar with its background and concerned to reduce needless proliferation of terminology and units. No system of units can be expected to remain static while serving an advancing science. Without doubt, the SI in its present form is not the last word, and it will undergo modification as the need is felt to adapt to continuing improvements in techniques of measurement and to progress in the understanding of natural phenomena. In fact, the SI has already undergone modification in certain of its details since its adoption in 1960.

HISTORICAL BACKGROUND

The Metre and the Kilogram.[5] The Metric System was created by the French Academy of Sciences in response to a proposal introduced in the French National Assembly by Talleyrand in 1790 that a study be undertaken of a universal system of weights and measures, intended for international use, to replace the chaos then prevailing. The Assembly's decree, sanctioned by Louis XVI, called upon the Academy to act in concert with the Royal Society of London to deduce an invariable standard from which all measures and weights could be derived. When English interest was not elicited, a select committee of the French Academy started on the project, which took until 1799 to be carried to completion. A new unit of length, the metre, was proposed from which, in principle, the units for other quantities were to be derived. Larger and smaller units were to be constructed by powers of ten, distinguished by means of a general, ingenious system of prefixes.

After considering, and rejecting, the length of the seconds pendulum as a suggested alternative, the committee elected to base the metre on one ten-millionth the length of a meridian of the earth between the pole and the equator. A survey was actually carried out of a section of the meridian between Dunkirk and Barcelona. It was conducted under conditions of great hardship and personal danger to the surveyors because of the revolutionary upheaval in France. The results were embodied in a length established at the temperature of melting ice between two marks engraved on a platinum bar, the prototype metre.

The new unit of mass (then loosely identified as "weight"), the gram, was intended originally to be based on the metre through a physical property of pure water: it was to be the mass of a cube of water one hundredth metre (one centimetre) on edge at temperature of maximum density. Measurements were undertaken by the committee of the French Academy to prepare a practical realization of this conception in the form of a cylinder of platinum with mass adjusted as precisely as possible to one thousand grams; it was considered not feasible at the time to construct with adequate precision a prototype mass as small as one gram.

These two by then practically independent embodiments of the metre and the kilogram were deposited in 1799 in the Archives of the Republic of France and later came to be known as the prototype metre and prototype kilogram of the Archives. They were adopted by statute of 1799 as the definitive standards for all measures of length and "weight" throughout France, replacing the provisional metre that had been adopted, along with the new metric terminology, by the revolutionary government in 1795. Iron copies of the prototypes were made for distribution as models for the construction of similar standards elsewhere. Copies were brought to the United States in 1805 by Ferdinand R. Hassler, a Swiss-born engineer and metrologist who became Superintendent of the Coast Survey when that office was founded in 1807. During the 19th century, the Metric System gradually spread among the nations of Europe and into Latin America. An act of Congress in 1866 made its use legal in the United States, and redefined our common units, the inch and the pound, in terms of their metric equivalents.

With expanding use of the Metric System in scientific work, particularly in geodetic measurements of increasing precision, the accuracy and reproducibility of the metric standards came into question. On the initiative of the French government, an international conference was convened in 1872 that resolved on the preparation of new prototypes, redefining in themselves the metric units of length and mass independently of any formal connection with the earth's dimensions and the properties of water. By international treaty concluded in Paris in 1875, an agency known as the International Bureau of Weights and Measures (BIPM)[9] was created to carry out the recommendations, serve as a repository for the new standards, and carry on a program of research on metrology. Numbered sets of replica prototype metres and kilograms were constructed of a superior alloy of platinum with 10% of iridium and were exactingly compared with each other and with the prototypes of the Archives. In 1889, a new International Prototype Metre and International Prototype Kilogram were selected from among the copies by the first General Conference of Weights and Measures and have been preserved since in the vaults of the BIPM. Copies were distributed to the adhering nations. The United States received two sets, which are now in the custody of the National Bureau of Standards; one of them was designated to serve as the national reference standards for length and mass and for measurements of other quantities derived from these two.

The International Prototype Kilogram has continued since 1889 to define the metric, and now the SI, base unit of mass:

> *The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.*

The International Prototype Metre, under specified conditions of temperature and support, defined the metric unit of length until 1960. In 1892–93, shortly after this standard was adopted, Albert A. Michelson conducted interferometric studies at the BIPM showing that higher precision and universal reproducibility could be attained in a standard of length based on monochromatic light radiation, for which he chose a red radiation in the spectrum of cadmium. The 7th CGPM in 1927 provisionally adopted as a supplementary standard of length this radiation with wavelength assigned in terms of the metre a defined value, chosen to agree with the then accepted experimental value. The supplementary definition thus did not alter the length of the metre, but offered an alternative standard for its realization. In 1960, the concept was pursued further when the 11th CGPM replaced the International Prototype Metre altogether with a reference standard based on an even more precisely monochromatic radiation, orange-red radiation corresponding to a transition between two states of a particular one of the isotopes of krypton. According to the new definition:

> *The metre is the length equal to* 1 650 763.73 *wavelengths in vacuum of the radiation corresponding to the transition between the levels* $2p_{10}$ *and* $5d_5$ *of the krypton*-86 *atom.*

It is quite possible that this definition will be replaced some time in the future by one based on laser radiation. The change in definition has had no effect on the length of the metre for ordinary purposes, but has been needed as a base for high-precision metrology.

The Second. Until 1960, the internationally accepted unit of time, the second, was defined as $1/86\,400$ of the "mean solar day," whose definition was left to astronomers. In 1960, the 11th CGPM adopted a definition given by the International Astronomical Union that was based on a particular tropical year, a time standard less subject than the previous one to effects of irregularities in the earth's rotation. In recognition of the still more precisely realizable and reproducible standards of time that can now be attained through observations of microwave radiation accompanying transitions between well-defined energy levels of certain atoms and molecules, the 13th CGPM in 1967 adopted the following definition:

> *The second is the duration of* 9 192 631 770 *periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium*-133 *atom.*

The astronomical cycles with which we live do not fit a tidy numerical pattern. Certain time units not decimal multiples of the second and therefore not in the SI, including the minute (min), hour (h), and day (d), which it would be impractical to abandon, continue to be accepted for use with the SI.[7] However, for most scientific purposes, particularly where time measurements enter numerical equations, time can and should be expressed in seconds, or such convenient decimal multiples of the second as are accepted with the SI (see SI prefixes listed in Table V).

The Ampere. The metre, the kilogram, and the second constitute a sufficient base for constructing a coherent system of units (the MKS system) for physical quantities derived from mechanics (such as force, angular momentum, energy), spatial quantities (such as area and volume), and related physical quantities dependent on mass (such as density and moment of inertia). Electric and magnetic units coherent with these base units can be derived through several alternative relationships connecting forces with the magnitudes of electric and magnetic quantities (Coulomb's electrostatic and magnetostatic force laws, Ampère's law). However, the sets of units so derived differ not only among themselves but also from the firmly established system of common units, which includes the coulomb, the ampere, the volt, the watt, and the joule. Therefore, to reduce the confusing multiplicity of units, physicists for some time have favored an extension of the MKS system, the MKSA system,[10] in which the ampere is introduced as a fourth independently defined base unit. The definition of the ampere is that adopted by the 9th CGPM in 1948:

> *The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed 1 metre apart in a vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length.*

This definition (the newton being the SI unit of force, $1\ kg\ m\ s^{-2}$) has been carried over in defining the ampere as one of the SI base units.

The Kelvin. Temperature measurements are utilized in two different kinds of contexts. In one, interest centers in where the temperature stands on a numerical scale indicative of order, but no physical significance is attached to the magnitude of one temperature relative to another. The ordinary Celsius scale, with an arbitrarily assigned zero and one other arbitrarily selected fixed temperature setting the scale (or the unit of temperature difference), serves this purpose. The degree Celsius (°C)[11] in such an expression as: $t = 25°C$, is not a unit in the usual sense that the value of physical quantities is represented by the product of a number and a unit. The temperature 50°C is higher than 25°C, but no physical significance is attached to the fact that the one number is twice as large as the other. In another kind of context, temperature measurements are used in relationships based on the second law of thermodynamics, which ascribes a natural meaning to the magnitude of one temperature relative to another and hence to a unit of absolute or thermodynamic temperature. Until 1954, the Kelvin unit of thermodynamic temperature, the degree Kelvin, was defined as equal to the unit of temperature difference on the centigrade or Celsius scale (i.e., equal to one hundredth the difference between the thermodynamic temperatures of the steam point and the ice point). The 9th CGPM in 1948 gave recognition to the principle, perceived long ago by Kelvin and others, of an absolute thermodynamic scale based on a single fundamental fixed point and accepted the triple point of pure water (the equilibrium temperature of ice, water, and water vapor at their equilibrium pressure) as capable of providing a thermometric reference point more accurately reproducible than the ice point (which is established in the presence of the atmosphere). In 1954, the 10th CGPM followed up this principle by assigning to the triple point of water the thermodynamic temperature 273.16 degrees Kelvin, exactly (a value in agreement with that determined previously by experiment with gas thermometers in terms of the older definition). The 13th CGPM in 1967, recognizing that the unit of thermodynamic temperature and the unit of temperature interval are one and the same, and ought to be designated by a single name and single symbol, decided that this unit be denoted by the name "kelvin" and its symbol by "K" (without the superfluous degree sign). The definition of this SI base unit is accordingly as follows:

> *The kelvin, unit of thermodynamic temperature, is the fraction $^1/_{273.16}$ of the thermodynamic temperature of the triple point of water.*

In adopting the triple point of water as a more accurately reproducible reference temperature than the ice point, the 9th CGPM redefined the zero of the Celsius scale as the temperature 0.010 0 degree below that of the triple point of water. Accordingly, the Celsius temperature (symbol t), not part of the SI but impractical to abandon, is defined in terms of the thermodynamic temperature (symbol T) by the equation: $t = T - T_0$, where $T_0 = 273.15$ K by definition. The Celsius temperature continues to be expressed in degrees Celsius (symbol °C). In expressing temperature differences, the unit, degree Celsius (°C), is equal to the unit, kelvin (K).

The Candela. A sixth SI base unit is the unit of luminous intensity. Earlier units based on flame or incandescent filament standards were replaced in 1948 by action of the 9th CGPM ratifying the establishment of a new unit, the candela. The definition, as amended by the 13th CGPM in 1967, is as follows:

> *The candela is the luminous intensity, in the perpendicular direction, of a surface of 1/600 000 square metre of a blackbody at the temperature of freezing platinum under a pressure of 101 325 newtons per square metre.*

Luminous intensity is a photometric quantity seldom utilized in chemical investigation except in highly specialized areas.

The Mole.[12] In order to introduce SI units for molar physical quantities (such as molar volume, molar mass, molar concentration, standard molar enthalpy of formation), a base unit is needed recognizing the molecular constitution of substances. For many physical quantities the values for different substances bear significant relationships to each other when compared for equal numbers of molecules (or whatever the appropriate constituent entity may be, such as atoms or ions). The physical quantity measuring the amount of a substance in terms of the number of its constituent molecular entities (whether actual molecules or other specified atomic aggregates) has not long been identified by a special name, although a unit, the mole, has long been recognized. The name, "amount of substance" (in French, "quantité de matière"), has been adopted for this quantity by IUPAC,

Table I. SI Base Units

Quantity	Name of Unit	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol

Table II. Examples of SI Derived Units (This list is not exhaustive)

Quantity	Name of Unit	Symbol
Area	square metre	m^2
Volume	cubic metre	m^3
Density	kilogram per cubic metre	$kg\ m^{-3}$
Velocity	metre per second	$m\ s^{-1}$
Acceleration	metre per second squared	$m\ s^{-2}$
Wave number	1 per metre	m^{-1}
Molar concentration	mole per cubic metre	$mol\ m^{-3}$
Molar mass	kilogram per mole	$kg\ mol^{-1}$
Molar volume	cubic metre per mole	$m^3\ mol^{-1}$
Diffusion coefficient	square metre per second	$m^2\ sec^{-1}$
Electric current density	ampere per square metre	$A\ m^{-2}$
Magnetic field strength	ampere per metre	$A\ m^{-1}$

IUPAP, and ISO, and will be proposed to the 14th CGPM in 1971 by the CIPM, with the following definition of the mole as corresponding SI base unit:

The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 *kilogram of carbon*-12.

Note. *When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.*

SI BASE UNITS

The seven[13] SI Base Units, with the definitions given in the preceding section, are summarized in Table I.

The general principle adopted by the 9th CGPM in 1948 governing the writing of symbols for units is as follows:

Roman (upright) type, in general lower case, is used for symbols of units; if however the symbols are derived from proper names, capital roman type is used [for the first letter]. *These symbols are not followed by a full stop (period).*

SI DERIVED UNITS

In the SI, there is one and only one SI Unit for each physical quantity. This is either the appropriate SI Base Unit itself or the appropriate SI Derived Unit, formed from the SI Base Units by the operations of multiplication and division. Examples of derived units for selected physical quantities commonly utilized in chemistry are given in Table II. Several SI Derived Units have been given special names and symbols which may themselves be used to express other derived units in a simpler form than in terms of the base units. Examples are listed in Table III. These special names and symbols have been approved at various sessions of the CGPM for use in the SI.

Table IV presents examples of SI derived units, and their symbols, for other physical quantities in terms of the SI base units and SI derived units with special names.

The product of two or more units may be indicated by a dot between their symbols—for example, $C = A\cdot s$. The dot may be dispensed with, as in the examples cited in Tables II, III, and IV, when there is no risk of confusion with another unit symbol. Also, a solidus (/), a horizontal line, or negative powers (as in Tables II, III, and IV) may be used alternatively to express the symbol for a derived unit formed from two others by division—for example,

$$m/s,\ \frac{m}{s},\ \text{or}\ m\ s^{-1}$$

The solidus should not be repeated on the same line unless ambiguity is avoided by parentheses—for example, $(m^2\ kg/s^2)/mol$ (alternative expression for $J\ mol^{-1}$).

Table III. SI Derived Units with Special Names

Quantity	Name of Unit	Symbol	Definition of Unit
Frequency	hertz	Hz	s^{-1}
Force	newton	N	$m\ kg\ s^{-2}$
Pressure	pascal[a]	Pa	$N\ m^{-2}$
Energy	joule	J	$m^2\ kg\ s^{-2}$
Power	watt	W	$J\ s^{-1}$
Electric charge	coulomb	C	$A\ s$
Electric potential difference	volt	V	$J\ A^{-1}\ s^{-1}$
Electric resistance	ohm	Ω	$V\ A^{-1}$
Electric conductance	siemens[a]	S	Ω^{-1}
Electric capacitance	farad	F	$C\ V^{-1}$
Magnetic flux	weber	Wb	$V\ s$
Magnetic flux density	tesla	T	$Wb\ m^{-2}$
Inductance	henry	H	$Wb\ A^{-1}$
Luminous flux	lumen	lm	$cd\ sr\ m^{-2}$[b]
Illuminance	lux	lx	$cd\ sr\ m^{-2}$[b]

[a] In 1969 the CIPM decided to seek approval of the 14th CGPM for this special name and its symbol. [b] Certain units in the SI have not yet been classified as either base units or derived units. This class of SI Supplementary Units contains the SI unit of plane angle: the radian (rad), and the SI unit of solid angle: the steradian (sr). The latter is treated here as a base unit. For practical reasons, the common units of plane angle: the degree (°), minute (′), and second (″), while not part of he SI, have been retained for general use with the SI (see reference 7).

Table IV. Examples of SI Derived Units for Other Physical Quantities (This list is not exhaustive)

Quantity	Name of Unit	Symbol	Symbol in terms of SI Base Units
Dynamic viscosity	pascal second	Pa s	$m^{-1}\ kg\ s^{-1}$
Heat capacity	joule per kelvin	$J\ K^{-1}$	$m^2\ kg\ s^{-2}$
Thermal conductivity	watt per metre kelvin	$W\ m^{-1}\ K^{-1}$	$m\ kg\ s^{-3}\ K^{-1}$
Electric field strength	volt per metre	$V\ m^{-1}$	$m\ kg\ s^{-3}\ A^{-1}$
Molar energy	joule per mole	$J\ mol^{-1}$	$m^2\ kg\ s^{-2}\ mol^{-1}$
Molar entropy	joule per kelvin mole	$J\ K^{-1}\ mol^{-1}$	$m^2\ kg\ s^{-2}\ K^{-1}\ mol^{-1}$

DECIMAL MULTIPLES AND SUBMULTIPLES OF SI UNITS

To provide systematic nomenclature and symbols for extremely large and extremely small decimal multiples of the SI units, the original list of prefixes defined for the Metric System has been extended by resolutions of the 11th CGPM (1960) and 12th CGPM (1964) for the SI as in Table V.

The following rules recommended by the ISO apply to the use of SI prefixes:

> Prefix symbols are printed in roman (upright) type without spacing between the prefix symbol and the unit symbol (as in cm).
>
> An exponent affixed to a symbol containing a prefix indicates that the multiple or submultiple of the unit is raised to the power expressed by the exponent (for example, $1\ cm^3 = 10^{-6}\ m^3$).
>
> Compound prefixes should be avoided.

Among the base units of the SI, the unit of mass is the only one with a name containing a prefix (for historical reasons). Names of decimal multiples and submultiples of the unit of mass are constructed by attaching the appropriate prefix to the word "gram" and symbol "g" (not to the word "kilogram" and symbol "kg"). The gram, while not *the* SI unit of mass, is thus an accepted submultiple of the SI unit, along with the milligram (mg) and microgram (μg).

UNITS OUTSIDE THE SI

The aim of the International System of Units, with its attendant recommendations, is to secure greater uniformity in the selection of units and, hence, to improve common understanding of their use. Many numerical relationships and computations that include measured physical quantities will assume a particularly simple form, free of conversion factors, when the quantities are expressed throughout in SI units; when recognized decimal multiples or submultiples of SI units are included, conversion factors will consist at most of clearly identified powers of ten. Units not belonging to the SI are to be progressively discouraged. However, it is recognized that in certain specialized fields of science there may be good reasons for using other units, and the time scale envisioned by the work "progressively" need not be the same in all cases.

Table VI, for selected physical quantities used in chemistry, shows units having special names outside the SI and having exact definitions in terms of SI units, that for practical reasons have been accepted for use with the SI for a limited time (see reference 7).

The unit of volume, litre (l), is a special case. This unit, widely used in commerce as well as in scientific investigation, will be retained indefinitely as a special name for the cubic decimetre ($10^{-3}\ m^3$, in terms of the SI unit of volume). The 12th CGPM (1964) which adopted this redefinition of the litre (previously distinguished from the cubic decimetre by representing in principle precisely the volume of a kilogram of water at temperature of maximum density) recommended that the name not be employed to give the results of high-accuracy volume measurements. The common unit of molar concentration, mole per litre (M), possibly merits similar treatment, although no formal recommendation is actually pending before the CGPM.[14] The name and symbol are special for the mole per cubic decimetre ($10^3\ mol\ m^{-3}$, in terms of the SI unit of concentration and should not be employed to give the results of high-accuracy concentration measurements. The word "molarity" is superfluous and should be abandoned. The SI unit, $mol\ kg^{-1}$, is available for molality (amount of solute divided by mass of solvent).

Among other units outside the SI that are recognized as useful in specialized fields of scientific research are several with values obtained by experiment and therefore not known exactly in SI units. Among such units in specialized fields of chemical research are the electron volt (eV), defined as the energy acquired by an electron in passing through a potential difference of 1 volt in vacuum (approximately $1.602\ 19 \times 10^{-19}$ J), and the unified atomic mass unit, defined as equal to $1/12$ the mass of an atom of the nuclide ^{12}C (approximately $1.660\ 53 \times 10^{-27}$ kg).[15]

Table VII lists CGS units that have received special names and are exactly defined in terms of SI units. It is considered preferable not to use these units with the units of the SI. It is expected that in time they will be abandoned.

As regards other units outside the SI, generally the CIPM considers that it is preferable to avoid them and

Table V. SI Prefixes

Factor	Prefix	Symbol	Factor	Prefix	Symbol
10^{12}	tera	T	10^{-1}	deci	d
10^9	giga	G	10^{-2}	centi	c
10^6	mega	M	10^{-3}	milli	m
10^3	kilo	k	10^{-6}	micro	μ
10^2	hecto	h	10^{-9}	nano	n
10^1	deka	da	10^{-12}	pico	p
			10^{-15}	femto	f
			10^{-18}	atto	a

Table VI. Units with Special Names to be Used with the SI for a Limited Time

Quantity	Name of Unit	Symbol	Definition in SI Units
Length	ångström	Å	10^{-10} m (= 0.1 nm)
Area	barn	b	$10^{-28}\ m^2$ (= 100 fm^2)
Pressure	standard atmosphere	atm	101 325 Pa
Pressure	bar	bar	10^5 Pa
Radioactivity	curie	Ci	$3.7 \times 10^{10}\ s^{-1}$

Table VII. CGS Units with Special Names

Name of Unit	Symbol	Value in SI Units
erg	erg	10^{-7} J
dyne	dyn	10^{-5} N
poise	P	10^{-1} Pa s
stokes	St	$10^{-4}\ m^2\ s^{-1}$
gauss	G	corresponds to $10^{-4}\ T^a$
oersted	Oe	corresponds to $(1000/4\pi)\ A\ m^{-1\ a}$
maxwell	Mx	corresponds to $10^{-8}\ Wb^a$

[a] The unit is part of the so-called "electromagnetic" CGS system with three base units (see reference 10) and, strictly speaking, cannot be compared to the corresponding unit of the four-base-unit MKSA and its extension, the SI.

Table VIII. Other Units Generally Deprecated

Name of Unit (and Symbol)	Value in SI Units
conventional millimetre of mercury (mm Hg)	$13.5951 \times 980.665 \times 10^{-2}$ Pa
torr (torr)	(101 325/760) Pa
kilogram-force (kgf)	9.806 65 N
thermochemical calorie (cal)	4.184 J
IT calorie (cal_{IT})	4.1868 J
micron (μ)	10^{-6} m (= 1 μm)
gamma (γ)	10^{-9} kg (= 1 μg)

to use units of the SI instead. Some of these units are listed in Table VIII.

An author feeling the need to use any such units outside the SI should define them in terms of SI units once in each publication in which he uses them. In the interest of keeping communications open, authors should be chary of introducing private names and symbols for units readily expressible in terms of SI units. The use of the International System will become increasingly familiar, and the drawbacks of learning multiple units having only historical significance will become increasingly apparent, as more of the data published in the scientific and technical literature appear in SI units.

REFERENCES

(1) SI is the international abbreviation based on the official name in French, Le Système International d'Unités.

(2) Conférence Générale des Poids et Mesures, governing authority of the International Bureau of Weights and Measures (BIPM), an agency established in 1875 by Treaty (Convention du Mètre) among 18 original signing nations including the U.S.A. The number of adhering nations is now 40. The General Conferences are convened at least every six years; recent General Conferences have been held in 1948, 1954, 1960, 1964, and 1967, the 14th is scheduled in 1971. Agenda are prepared and decisions put into effect by the International Committee on Weights and Measures (CIPM) whose 18 members, each chosen from a different one of the adhering nations, meet annually. The present member from the U.S.A. is Lewis N. Branscomb, Director of the National Bureau of Standards. The BIPM is located in the Pavillion de Breteuil, originally a small royal palace, on the bank of the Seine at Sèvres, between Paris and Versailles. Its Director is Jean Terrien. A recent visit to the BIPM is described by R. Hobart Ellis, Jr., in the December 1969 issue of *Physics Today*, p 57.

(3) The mole was not included among the base units in the 1960 resolutions of the 11th CGPM establishing the SI. Its inclusion as a seventh base unit will be recommended to the 14th CGPM in 1971 by a decision of the CIPM reached in 1969.

(4) "Manual of Symbols and Terminology for Physiocochemical Quantities and Units," M. L. McGlashan, Ed., International Union of Pure and Applied Chemistry, Butterworth & Co., Ltd., London, 1970.

(5) "Rules for the Use of Units of the International System of Units and a Selection of Decimal Multiples and Submultiples of the SI Units," ISO Recommendation R 1000. American National Standards Institute, New York, 1969. The ISO is a nontreaty organization comprised of national standards bodies of some 56 nations. The American National Standards Institute was organized as the American Engineering Standards Committee by five engineering societies in 1918 to act as a clearinghouse for their standardization work; reorganized with several successive changes of name, it is one of the founding members of the ISO and is representative member for the U. S. A.

(6) "Symbols, Signs, and Abbreviations Recommended for British Scientific Publications," The Royal Society, London, 1969.

(7) "The International System of Units (SI)," C. H. Page and P. Vigoureux, Eds., NBS Special Publication **330**, U. S. Government Printing Office, Washington D. C., 1970.

(8) The French spelling, "mètre," has been translated in English as "metre," but American usage favors "meter." The French spelling of the metric unit of mass, "gramme," has been carried over into English, but American usage favors "gram." In the document cited in reference 7, jointly translated by the NPL and the NBS, a compromise was adopted in the hope of providing worldwide uniformity in the spelling of the SI units in English.

(9) See reference 2.

(10) This system is compared with other systems, including the CGS (centimetre-gram-second) and the SI, in a 1965 report of the International Union of Pure and Applied Physics (IUPAP): "Symbols, Units and Nomenclature in Physics," Document **U.I.P. 11** (S.U.N. 65-3).

(11) The centigrade degree is called "degré centésimal" in French. In the interest of promoting a uniform name for the degree represented by the symbol °C, the 9th CGPM in 1948 adopted "degré Celsius" ("degree Celsius" in English translation).

(12) See reference 3.

(13) See reference 3. The description I am presenting is as the SI will be if the 14th CGPM takes action to approve the mole as seventh base unit, as will be recommended to it by action taken by the CIPM.

(14) See reference 3.

(15) The name, "dalton," is widely used for this unit by biochemists and cell biologists (see John T. Edsall, "Definition of Molecular Weight," *Nature*, **228**, 888; 1970) but has not been brought to the official attention of international agencies concerned with standardization of scientific nomenclature.