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BASIC STANDARDS AND ADOPTION OF SI UNITS [1]

by

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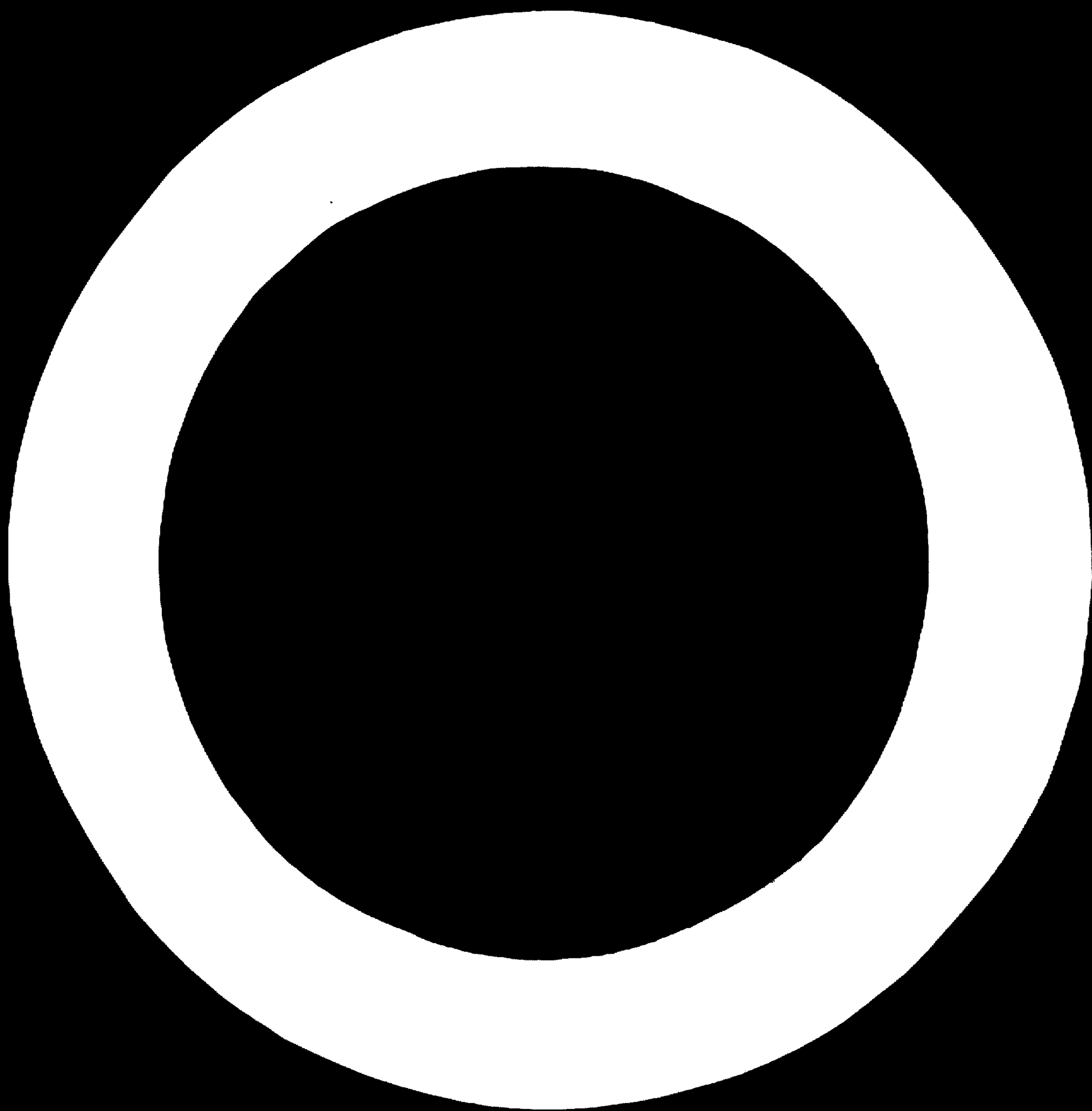

BASIC STANDARDS AND ADOPTION OF SI UNITS

1. Historical background

1.1 The idea of a system of measurements dates back to the very early stage of human civilization. Man has been adopting a variety of things which could serve as standards for measurements. The word "standard" is somewhat overworked and will need definition. In the sense it is employed here it will mean "an agreed reference quantity" or "a document specifying an agreement", the latter being very often referred to as "standard specification". There is little risk of confusing the meaning of the word "standard" as it is used in this paper.

In the early days, parts of the human body were used as standards of length. These were very convenient because they were readily available and easily portable. They are still used for rough and quick length measurements. Since these length standards varied not only from country to country but even from one city to another, it became evident that some standardization was necessary. The same confused situation existed with another standard used very much in commerce, the standard of weights. It was England who had established for a long time standards of weights and measures that have remained nearly unchanged up to the present day. The yard and pound standards established several centuries ago differ very little from those used in the present day. The British system of weights and measures was adopted by all the British colonies and by the United States of America and was for a long time the most widely used weights and measures in the world.

No uniformity of weights and measures existed on the European Continent. The lack of uniformity of weights and measures showed its adverse effects in commerce. These considerations led the National Assembly of France, in 1790, to enact a decree calling upon the French Academy of Sciences to co-operate with the Royal Society of London to "deduce an invariable standard for all measures and weights". The English were not very interested in the French undertaking because they already had an adequate system. Thus, the French proceeded with this work alone. The result of this undertaking is what is known as the "metric system".

1.2 The word "metre" was derived from the Greek word "metron" meaning "to measure" and was used for the first time by the French Academy of Science. The metric system was based on the metre as the unit of length which was intended to be one ten-millionth part of the distance from the North Pole to the equator at sea level through Paris. Subsequent geodetic measurements revealed that there was an error in the definition of the metre.

The unit of mass, the gram, was decided as the mass of one cubic centimetre of water at its temperature of maximum density. This quantity was too small to be measured with the desired precision, so the determination was made on one cubic decimetre of water. Subsequent investigation revealed that this determination was also associated with a small error. Based on those measurements of two prototype physical standards, a metre and a kilogram standard in platinum were constructed and deposited in the Archives of the French Republic in 1799.

Thus, the first basic standards were constructed as forerunners to the present ones. The cubic decimetre was selected as the unit of fluid capacity and the square having its sides ten metres as unit for land area. The unit for time was not included in the system. Interest was aroused in the new system in most European countries. By 1865, almost all of Europe and much of South America were using the French system. There arose a general feeling that an international approach to collective action was called for. In 1870, the French Government invited the representatives of several countries to meet in Paris. Twenty-four countries responded to this invitation but only 15 could send their delegates because of the outbreak of the Franco-Prussian War. The delegates continued the work of the Commission Internationale du Metre, but could not make any decisions. The Commission was resumed in 1872 with participation of delegates from 30 countries. About 40 resolutions were passed dealing with the preparation of new prototypes of kilogram, metre and related matters. The creation of an International Bureau of Weights and Measures was also recommended. The members of the international commission were all scientists and had no authority to commit their governments. In 1875, another conference was again held in Paris, this time attended by representatives of the governments. It was called "Conférence Diplomatique du Metre". On 20 May 1875, the Convention du Metre was signed by 18 states. In this Convention, the signatory states bound themselves to set up and maintain at common expense a permanent scientific body of weights and measures in Paris. This was the foundation of the Bureau International des Poids et Mesures (BIPM).

1.3 The governing authority of the Bureau is the Conference Generale des Poids et Mesures (CGPM) which meets every six years and is made up of delegates from all the member countries. The duties of the CGPM can be briefly defined thus:

(1) To discuss and adopt necessary measures for the propagation and improvement of the metric system.

(2) To study and adopt the results of new fundamental metrological determinations and various scientific resolutions of international importance.

(3) To take important decisions concerning the organisation and the development of the BIPM.

The CGPM also appoints members of the implementing body, called Comité International de Poids et Measures (CIPM), which meets every two years or more frequently and is composed of a maximum of 18 specialists chosen from the signatory countries. The CIPM follows up the decision of the CGPM and looks after the operation and m nagement of BIPM. The CIPM also appoints its own specialists consultative committees. At present there are seven such committees. These are dealing with definitions of the metre, the time unit, electricity, photometry, ionising radiation and the basic units of the Systeme International d'Unités (SI).

1.4 Although the metric system was primarily devised as a system of weights and measures to benefit industry and commerce, scientists soon realized its advantages and it was adopted in scientific and technical circles. Measurement of other quantities called for a basic unit of time and the adoption of the second for this purpose gave the centimetre-gramme-second (CGS) system. This system became widely used by science. About 1900, the need for more practical units became apparent and there developed the idea of the metre, the kilogramme and the second as basic units - the MKS system. The complex relationship among quantities and the multiplicity of units for the same quantity led Prof. Giorgi to propose in 1901 a simplified and rational system, the MKSA system by adopting the "ampere" as the unit of electrical current with the view to linking the electrical and mechanical quantities. In 1935, the International Electrotechnical Commission (IEC) accepted the recommendations of Prof. Giorgi.

1.5 The tenth CGPM held in 1954, adopted as "basic units" of its "Practical System of Units" the quantities length, mass, time, electric current and added to it the thermodynamic temperature and luminous intensity. The eleventh CGPM held in 1960, adopted the name "Système International d'Unités - International System - with the abbreviation "SI". At this occasion, the SI system was to be formed of six basic units, two supplementary units (the plane angle - radian, and the solid angle - steradian) and derived units. The prefixes of multiples and sub-multiples were also adopted. At the same time, the definition of the metre, which was based until then upon the prototype international platinum-iridium metre bar, was changed and based on "1 650 763,73 wavelengths in vacuo of the radiation corresponding to the transition between energy levels 2 p_{10} and 5 d_5 of krypton -86 atom".

The unit of mass, the kilogramme, was defined as "the mass of the international prototype which is in the custody of the BIPM at Sèvres near Paris". (Resolution of the 3rd CGPM, 1901).

The unit of time, the second, was defined "as the duration of 9 192 631 770 periods of radiation corresponding to the transition between two hyperfine levels of the fundamental state of the cesium atom 133". (Resolution of the 13th CGPM, 1967).

The unit of electric current, the ampere, was defined "as that constant current which, if maintained in two parallel rectilinear conductors of infinite length, of negligible circular cross section, and placed at a distance of one metre apart, in a vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre length". (Resolution of the 9th CGPM, 1948).

The unit of thermodynamic temperature, the kelvin, "is the degree interval of the thermodynamic scale on which the temperature of the triple point of water is 273,16 degrees exactly". (Resolution of the 10th CGPM, 1954).

The candela was defined "as that luminous intensity which emanates from the surface of a black body of 1/600,000 metre squared in area at the temperature of solidification of platinum under a pressure of 101 325 newtons per square metre". (Resolution of the 13th CGPM, 1967).

The CIPM decided in 1969 to propose to the 14th CGPM, to be held in 1971 an additional basic unit, "amount of substance", the mole. The mole is to be defined "as that amount of substance of a system which contains so many elemental particles as there are atoms in 0,012 kilogramme of carbon 12.

Table 1 gives the basic units of SI system.

TABLE 1

BASIC UNITS OF THE SI SYSTEM

Quantity	Name of Unit	Unit Symbol
length	metre	m
mass	kilogramme	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
luminous intensity	candela	cd
amount of substance	mole	mol

The supplementary units are given in Table 2.

TABLE 2

SUPPLEMENTARY UNITS

plane angle	radian	rad
solid angle	steradian	sr

Some derived SI units having special names are given in Table 3. For other derived SI units the reader should consult the references given at the end of this paper.

TABLE 3

SOME DERIVED SI UNITS HAVING SPECIAL NAMES

Quantity	Name of Unit	Unit Symbol
force	newton	$N = kg\ m/s^2$
work, energy	joule	$J = N\ m$
power	watt	$W = J/s$
electric charge	coulomb	$C = A\ s$
electrical potential	volt	$V = W/A$
electric capacitance	farad	$F = A\ s/V$
frequency	hertz	$Hz = s^{-1}$
magnetic flux	weber	$Wb = V\ s$
inductance	henry	$H = V\ s/A$
luminous flux	lumen	$lm = cd\ sr$

The orderly array of the basic SI units forms the basis for the measurement of practically every manifestation of energy known to man. Thus, mechanical energy can be measured with the basic SI units of length, mass and time and their derived units. Electrical energy can be measured by adding to the basic SI units of length, mass and time the unit of electric current, the ampere. For the energies of heat and light, the previously mentioned units are used together with the units of thermodynamic temperature and luminous intensity and their derived SI units. This can be seen by inspection of Table 3.

By using the basic units of the SI system, any physical quantity required in science or technology can be derived from first principles.

2. Advantages of the SI system of units

In the sense that it employs existing metric units as basic units of the SI system, the SI system is not new. What is new about it is the concept that from the basic SI unit alone, units for any and every other quantity can be derived from first principles of science. The system is a rationalised version of the current metric system. A very worthwhile exercise in variety reduction has been carried out. This will ensure that all like physical quantities will be measured in terms of the same unit. The mind of the scientist and technologist will require to retain only the first principles and they will cease to be cluttered with a multiplicity of arbitrary units and respective conversion factors. An example will illustrate this point. Before the introduction of the

SI system a unit was created for each situation without regard for other units for the same property. Thus for pressure, for example, there were and still are used the following units: Atmosphere, bar, cm of Hg, cm of water, dyne/cm^2, kg/cm^2, torr, etc. The SI unit of pressure has been designated "newton per square metre" - N/m^2. Other examples of variety reduction could be given.

2.2 The features which make the SI system a superior system of measurement are summarized below:

a) For any quantity there is one and only one SI unit, e.g. the unit of energy is the joule whether derived from mechanical, electrical, chemical or thermal sources of energy.

b) For each quantity there is a unique unit differing from the units of other quantities e.g. kilogramme is used only as a unit of mass and the newton is the only unit of force.

c) The factors for obtaining the derived units from the basic and other derived units are always unity e.g. the physical quantity "force", the newton is 1 N = kg m/s^2 = 1 kg . 1 m/1 s^2.

d) A unique set of unit symbols and abbreviations is used for the names of the units.

e) The Arabic system of numbering to the base 10 is used exclusively so that multiples and sub-multiples have decimal relationship to the unit.

f) To facilitate working with magnitudes smaller or larger than the respective SI unit, a prefix before the unit can be used which has also standardized symbols for the abbreviation of the prefix.

g) All the basic units, except the kilogram, are defined in terms of physical experiments that can be made in an adequately equipped laboratory without reference to the prototype standard.

h) It is a coherent system of units, that is one in which the product or quotient of any two unit quantities gives rise to the unit of the resultant quantity. This is very useful e.g. 1 m x 1 m = 1 m^2 (unit of area).

i) Non-decimal coefficients such as exist in the foot-pound-second system are avoided e.g. 1 foot = 12 inches.

j) In contrast with the CGS system, it has relatively large main units like the "kilogramme" and not the "gramme" for mass and the "newton" and not the "dyne" for force. This makes the system more convenient.

k) The SI system is closely related to the CGS system, the relation being mostly by powers of 10, which will enable scientists, who have been using the CGS system for a long time, to accept it and thus facilitate collaboration with the technologists. This collaboration is at present very important in all modern fields of measurement and measuring science (metrology) which apply in science, technology and industry.

l) The introduction of one energy unit for mechanics as well as heat, namely the "joule" and one power unit, namely the "watt" will eliminate the use of the units "calorie" and "horse-power".

2.3 From the above summary of advantages of the SI system, scientists and technologists are encouraged to use where possible the SI system. Because of the widespread use of the CGS system, the changeover to the SI system has been greatly facilitated especially in the sciences. In technology, some units are so deeply rooted that it will take a considerable time to switch over completely. Some former units are tolerated side-by-side with SI system as an interim measure. It will take considerable time and education to introduce fully the SI system into industrial measurements. Many national standards bureaus foster the introduction of the SI system and the International Organization for Standardization (ISO) has issued a very comprehensive international recommendation R 1000 "Rules for the Use of Units of the International System of Units and a Selection of the Decimal Multiples and Sub-Multiples of the SI Units". ISO Recommendation 1000 has been elaborated in co-operation with BIPM and was the result of much concentrated work of ISO Technical Committee TC 12 over some considerable time. Nearly 85% of the world population uses the metric system which is closely related to the SI system. A number of other countries are officially commited to changeover to the metric system and other countries are in the process of changeover. The largest non-metric country, the United States of America, is making a comprehensive study of the question whether the USA should switch over to the metric system. Considerable interest exists in favor of such changeover. In those countries where the metric system is in use, the changeover from the metric to SI system will have comparatively little effect on commerce and trade. The units most used in commerce are those of length and mass and they are identical, except for sub-multiples, in the metric as well as in the SI system New standard specifications for commercial transactions will have to be drafted where goods or services are measured in other than SI units.

2.4 Many countries have made the SI system of units the only legally accepted system and many other countries are in the process of doing so. Non-metric countries accepted the SI system side-by-side with the existing one. There were no particulars at hand on the stage of acceptance of the SI system by Latin American countries. The situation in Brazil, with respect to the use of SI system of units, was legalized by Decree No. 63 233 of 12 September 1968. The following suggestions can be made concerning the smooth adoption of the SI system of units:

a) The weights and measures administration and any organisation which is custodian of national measurement standards should closely co-operate with the national standards bureau in establishing the SI system of units.

b) The officials of these organizations should be given proper training in the principles and use of the SI system in science, technology, industry, commerce and in all measurements required in the interest of the public.

c) The general public should be educated in the use of the system by available publicity media.

d) The weights and measures legislation should be kept under constant review so that the SI system can be applied as soon as possible.

e) Sufficient attention should be devoted to the field of general and technical education and the SI system of units should be introduced as soon as possible.

f) Standard specifications for commodities and products should be examined and amended as soon as practicable to have all units of measurements converted to SI system. These specifications should, as far as possible, be prepared to conform to the recommendations published by the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC) and the International Organization for Legal Metrology (OIML). In the case of America, mutual co-operation can also be assured within the Pan American Standards Commission (COPANT).

3. Applied and legal metrology

3.1 Metrology is defined as "the science of all measurement". From the purpose which metrology serves it can be classified into: "legal metrology" as used in trade, commerce and under certain legislation in the interest of public health and safety; "applied metrology" as used in industrial and technological measurements, in testing of materials and of function of products and in many measurements executed for conformity with standard specifications; and "scientific metrology" used for maintaining and improving primary or fundamental standards of basic and derived units of the SI or other systems and for keeping the national reference standards.

3.2 The terminology of standards of measurements has not been standardised and for the present purpose the hierarchy of standards can be designated by four grades of precision by confining this example to the standard length. The four grades of precision are:

1) Reference grade standard
2) Calibration grade standard
3) Inspection grade standard
4) Working grade standard

The reference grade is the most precise one. It is usually derived directly from the primary standard or from the fundamental law of physics. It is the function of the National Standards Laboratory (or of the Bureau of Standards of the country) to calibrate and verify from reference standards its calibration standards. Applied metrology laboratories and the weights and measures administration can be linked and tied up to the National Standards Laboratory by having their inspection grade standards verified and calibrated against calibration standards, held by the National Standards Laboratory. The inspection standards of applied metrology laboratories and of the weights and measures administration can be dispersed over the national territory and serve to calibrate and verify working standards in industry and in other establishments needing such a service. In this manner, the basis for accuracy in scientific and industrial measurements can be given and this is an essential step in the formulation of specifications and standards. A clearly defined standard of measurement serves two essential requirements in a standard specification. These are a clear and complete communication expressed in a unit of measurement and a criterion for acceptance or rejection of a product, material or component. The units of measurement can be any one specified from the basic or deri-units of the SI system. Since standards of measurement are a primary matter of public interest their use is made mandatory by the Government.

3.3 The National Standards Laboratory, or the Bureau of Standards, co-operates closely with the applied metrology laboratories and the weights and measures administration as well as with the National Standards Bureau. In some countries all the three mentioned organizations are carried out by one authority, in others they may form separate organizations. The National Standards Laboratory has its standards of measurement linked to those of the BIPM. It also represents the country at any of the BIPM meetings. In developing countries, the National Standards Laboratories may not be established, or it may be in the process of being established as part of the weights and measures administration. In any case, developing countries can obtain the various grades of standards of measurement from some of the well established National Standards Laboratories and the basic reference standards through the BIPM.

3.4 The rapid progress of science, technology and industry needed a corresponding rapid development of standardization which in turn created the necessity of organization of legal metrology and organizations for the enforcement of mandatory standards covering trade, commerce, industry, public health and safety. For the purpose of drafting recommendations to be followed by member countries, the Organisation International de Métrologie Légale (OIML) was created. Latin American countries, with one exception, do not belong to this organization. The OILM co-operates with ISO, IEC and BIPM in order to clarify any matters of standard specifications related to legal metrology.

The OIML has published recommendations on the design and details of weights and measures used in commerce and for other purposes. They also issued recommendations concerning inspection and certification of metrological equipment and concerning pattern approval of weighing and measuring instruments used for trade. In this way, the best practices in legal metrology are made available to those who may need them. Pattern approval requires the testing of functional suitability of weighing and measuring instruments before these are used by the public. In this way, the public is protected against unsuitable weighing and measuring instruments.

The OIML has published recommendations for initial and periodic examination of a large number of weighing and measuring instruments and any of their recommendations can form the basis for national standardisation on a mandatory and voluntary basis.

4. Conclusion

4.1 Developing countries may find it difficult to establish National Standards Laboratories or Bureaus of Standards which control the system of weights and measures and act as custodian of standards of measurements. They will need the services of these laboratories so that their metrology, used in their industries, is based on modern technology.

4.2 Standardisation in practically all activities cannot be carried out without some reference to a system of measurement, to a system of standards of measurement. Applied and legal metrology are part of the infrastructure of standardisation. It may be possible to arrange that standards laboratories are established on a regional or subregional basis. The manufacture of interchangeable components includes today not only measurement of length, but the measurement of quantities of the whole system of SI units or other units. Quality control and inspection is needed to put standardisation to work. Quality control and inspection required standards of measurement to a certain degree of accuracy. The accuracy requirement should conform to the functional requirement.

4.3 Accuracy may be defined as the closeness of approach of a measured quantity to the true value of that quantity. The true value of a measured quantity would be that value which could be determined without error. Thus, in standard specifications relating to measurements, a tolerance should be specified which is consistent with the functional requirement of the measured part. In a measurement there appear five elements which constitute the measuring system. These are: the standard of measurement; the workpiece or part to be measured; the measuring instrument; the person who performs the measurement and the environment in which the measurement is carried out. In standard specifications the accuracy, the tolerances a d the procedures for the five elements of the measuring system should be specified.

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