S. I. Units: Another View

J. G. Lines

We are frequently reminded that the clinical chemist has to be a man of many parts—scientist, chemical pathologist, administrator, and politician, to name the four principal roles. With the arrival of the Système Internationale des Unités another role has been highlighted—that of obstetrician. In the introduction of any new system—whether it be in the laboratory or elsewhere—there comes a time when the scientific arguments and political pressures are no longer likely to alter the course of events in the immediate future, because there are so many other pressures that make the introduction of the new system virtually inevitable. At that point, the Head of the Department must take on the administrator’s role of ensuring that the transition is as smooth as possible. However, when the local introduction of S.I. units becomes inevitable, the clinical chemist has more than just an administrator’s role to play. An analogy to obstetrics becomes close: not only has the intra-uterine phase been subject to protraction—including possibilities of threatened abortion on several occasions—but delivery requires considerable skill and there are very real possibilities of postpartum haemorrhage or other complications.

As a first step in this obstetric role, when the time for action arrived locally, I determined that a good clinical history should be obtained.

Where shall I begin? Should it be perhaps with the ancient empires of Babylon, Egypt, Greece, or Rome; or should it be in the 17th and 18th centuries when metrization became a concept and a practicality; or should it be with the more recent chronicle of international and national legislation? In reality, all of them are involved, but to make the story flow most easily, it is best to start in 753 B.C. when the brothers Romulus and Remus fought over who should establish a city within a group of seven hills in the northwest of Italy: Romulus won and Rome was founded. The influence and rule of Rome gradually expanded, so that by 300 B.C. Italy had been annexed, and then in the following 500 years it expanded at an ever-increasing rate such that to the south and east virtually all the Mediterranean coastline came under its rule, and to the north and west so did much of Europe. But you are probably asking what does this Empire have to do with S.I. units. The answer is taxation: the link points being land, rent, and taxes.

It is here that the earlier civilizations of the eastern and southern Mediterranean should be drawn into the picture. Romans were not inventors, they merely adopted what was the best from the lands and peoples that they conquered. This was particularly so in measures. The cubit had been used as the measure of length in Persia, Asia Minor, Egypt, and Babylon for many centuries before the Roman conquest of the Mediterranean area. The cubit was 2 feet (about 60 cm or 24 inches) in length, with 1 foot being defined in those days as being equal to 3 palms and 1 palm being equal to 3 thumbs: a thumb was the length of 3 barley corns laid end to end. Equally importantly, the Egyptians appreciated the need for standards: the royal master cubit was a block of black granite against which all the cubit sticks used throughout Egypt were measured regularly. The Romans took on an awareness of this importance of standards, keeping their ultimate standards in the temple of Jupiter on the capitol in Rome. However, instead of using the measure of the natural foot (as defined above), they preferred the northern foot, namely 1 palm added to one natural foot; it became so widely used in northern Europe that the Emperor Nero Claudius Drusus adopted it as the official measure, so that the whole empire had this one measure, the Drusian Foot.

We know something of the extent of taxation in the Roman Empire from the verse in the Bible (Luke, ii, 1) in which it says:

. . . it came to pass in those days that there went out a decree from Caesar Augustus that all the world should be taxed.

This taxation took one of two forms; either taxation according to the size of the building or land measured by the foot measure, or taxation in kind (e.g., farmers would have to provide corn to the Roman armies). The Romans were fair in their dealings, such that rather than just commandeer what corn they needed, they purchased it from the farmer but with taxation being levied at an effective level of about 9½%; although the Romans paid for the corn, the measure into which the corn was placed was a 17½ sextarii wooden measure (1 sextarius is about 36 litres) but the volume stated on the outside of the vessel was 16 sextarii, the difference of 1½ sextarii being the effective tax. A rather similar system was used by William III of England in 1707 when he declared that the gallon measure of wine should be smaller (3.785 L compared to 4.536 L) than that for water, although his taxation level was somewhat higher (20%).

Although the same system of taxation, applied Empire-wide by the Romans, made for harmony throughout the Empire, the great advantage of having just a single system of weights and measures was the increased ease with which merchants could engage in trade. This became particularly clear when the Roman Empire collapsed after the Goths had entered Rome in 476 A.D. and the Dark Ages emerged. During this period, each feudal lord was a complete law unto himself; to demonstrate his authority, he would set his own measures, both for the land as well as that portion of its products which

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1 Dept. of Clinical Biochemistry, Addenbrooke's Hospital, Cambridge, CB2 2QR, U.K.

he extracted from the tenant as tax in kind, and he established his own currency. The many differences in units made it virtually impossible to carry on trade by sale and purchase between different estates, and all trade had to be done by barter. This continued in Europe for the next 250–300 years, until the Frankish Empire began to emerge.

But what was happening in Arabia during the time of the Dark Ages in Europe? The considerable contributions of Arabian scholars to mathematics, science, astronomy, and instrument making, which are well known, enabled them to undertake long voyages by sea because accurate navigation was now possible. A key purpose in making voyages was for trade, particularly in silks, cloth, and spices. The most famous of the caliphs of Bagdad, Harun al Rashid, in his efforts to promote this trade, brought the silks and other items to the court of King Charlemagne, the great Frankish leader. At the same time, he made gifts to Charlemagne of the two standard Arab measures: a Hashimi cubit as the measure of length and an Arabic gold dinar as the measure of weight. Charlemagne recognized the importance of re-introducing a single weights-and-measures system, and so by the *Capitulaire de l'Aix-la-Chapelle* in 789 A.D., he decreed the Livre and the Foot (the *Poid de Marc de Charlemagne* and the *Pied du Roi*) as the official weights and measure. However, there was not much progress in other countries; e.g., it was not until some 600 years later that England recognized the need for legislation. A statute for measuring land was decreed by Edward I in 1305 that read, "It is ordained that 9 grains of barley dry make an inch, twelve inches make a foot, three foot make an Ulna, five ulnas make a rod, forty rods in length and 4 in breadth make one acre." He had an iron Ulna made and declared it to be the standard. As an historical aside, it is of interest to note that the Ulna gradually changed its name to the Elne and then to the Ell, which was used until about 200 years ago as a measure for cloth (about 115 cm). Then in 1497, Henry VII introduced the Troy weight measures in England for weighing of precious metals and gems (avoiding any weights were used for common items) and nearly 100 years later, in 1593, Elizabeth I introduced the rather larger measures of length—the mile and the furlong—when she declared that 8 furlongs make 1 mile. There was therefore some improvement over earlier times, but there was no uniformity, even in France where the situation had actually deteriorated since Charlemagne's visionary reign.

We should move on in our story to the first scientists during the late 16th, 17th, and 18th centuries. The importance of the development of science received acclamation in France and in England by the setting up of the Académie Française, in Paris, and the Royal Society, in London, by people such as Newton, Boyle, and Lavoisier. These scientists needed much more accurate measures than were generally available. They particularly needed an accurate measure of length. The debate was whether the reference measure should be based on the length of a pendulum swinging once each second. The pendulum length was favoured, not just in Europe but also in the United States, where it also received support from President Thomas Jefferson. It seemed very likely that this unit would be approved when it was agreed that John Miller would present an Act to the Houses of Parliament in England at the same time that Talleyrand presented it in the French Constituent Assembly. However, the English eventually felt unable to finalize the agreement, despite its having been approved by Parliament, because war broke out with Spain and, as Spain was considered to be an ally of France, there could be no liaison between England and France on any formal matter, particularly an exact or agreed definition.

France subsequently revised its views and took up the concept of using the size of the earth, declaring that one ten-millionth part of ¼ of the earth's circumference was equal to one metre. It is important though to recognize at this point what was happening in France. This was the time of the Revolution: all successful revolutions end in reform, and so not only was a new official measure of length (the *Mètre*) approved in 1791, but by 1799 units of weight, volume, and money (*gram*, *litre*, and *Franc*) had been decreed as official measures, and decimalization as suggested by their countryman—the Abbé Mouton—had been incorporated. In 1670, Mouton had proposed that the size of the earth in terms of ½⁰ part of 1° latitude should be divided into units of ½° and ½0°, or in multiples of 10 or 100. But was this really the first conception of decimalization? No! For example, in 1620 an Englishman, Edward Gunter, had proposed that it would be simpler for surveying purposes if the chain which was their standard unit of measure (about 20 metres) should be subdivided into 100 links. In the U.S.A., decimalization of currency took place in 1790, nine years ahead of the French adoption of the Franc, which did not actually become legally required until 1840.

The considerable logicality of metrification and decimalization contrasted with the situation in England, where at that time there were still such units as the slug, the nail, and the pottle (about 14.6 kg, 2 cm, and 2.3 L, respectively). The imprecision associated with such units is well illustrated by the means of obtaining the standard agricultural measure of length, the rod. The definition was to "stop sixteen good men and true on a Sunday morning as they leave church and make them put their right foot one after another in a row"; this would then define the measure of a rod for that village. For us as scientists though, perhaps the best commentary on variation in agricultural measures was provided by the great French chemist Lavoisier, who was also the *fermier général* (tax collector) for the Peronne district, when he complained that in that comparatively small area there were 17 different *journal*, *a journal* being defined as that area of land that a farm labourer could plough in one day. ²To further illustrate the complexity of agricultural units and to provide an alternative prospect for the payment of taxes and other dues, in the records of my own village at the village meeting on the 5th November 1856, when the letting of allotments was being discussed, the Minutes read:

At a meeting held this day at the Fox Inn it was agreed that the land known as the Poor Land containing one acre and three rods be let on the following conditions:

That the land be let in allotments of 20 poles each at a rent of 5s.6d. . . . and to ensure prompt payment of the rent . . . each tenant be allowed one quart of beer out of his expective rent if paid at the time specified.

But to return to the scientist, who required not just an accurate measure of length, but also of weight and time: In 1832, Gauss, the great physicist, put forward the requirement for "Absolute Units." He proposed that these should be the centimetre, gram, and second (the second had by then a fixed unit for several centuries, on account of its use in navigation). This CGS system was adopted by the *Conférence Générale des Poids et Mesures* in 1881, when some 23 countries were signatories to the agreement, which of course inherently also contained agreement to go over to the metric system. However, there was considerable difficulty, particularly in relation of technological developments in industry, in utilizing the relatively small units of the CGS system. Thus by the year 1900, the MKS or *mètre, kilogram, second* system replaced the CGS system. Shortly after this, the world moved into the electrical era, and Giorgi pointed out that it was necessary to include some form of electrical unit and the "ampere" was

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added to the MKS system. Later it became necessary to add a unit for light and the "candela" was included; similarly a unit of thermodynamic temperature, the "Kelvin," and a unit for amount in relation to chemistry, the "mole." These absolute units were ratified together as the basis of the Système International des Unités in 1960. But only now, late in the 1970's are we at the point of actually adopting the S.I. system.

What does it mean in medicine? It means that height and weight should be measured by the metre and the kilogram; body temperature in degrees celsius [degrees kelvin is the SI unit—Ed.]; gas pressure should be measured in kilopascals; and in particular for us in clinical chemistry the unit of quantity in relation to volume—i.e., concentration—should be moles per litre. These units do actually have some advantages. For example, we can now calculate the osmolarity of plasma by simple addition of the individual constituents, expressed in millimoles per litre, in addition to assessing more readily other related bio-functions, and we can readily assess gas pressure from the knowledge of the composition of the gas mixture so (e.g.) 5% CO₂ has a partial pressure of 5 kPa, 28% oxygen = 28 kPa, etc.

The next generation of clinical workers will have grown up with the S.I. system, and their children will probably grow up knowing only metrification, decimalisation, and S.I. units. Our problem is to change. It is of some interest to think that this S.I. unit system, which we already use or will shortly be using, comes about not only on account of the needs of the scientific community, but also because of the multiplicity of quaint old units that used to be in existence, the development of Empires, and the subsequent need to exert the governmental burden of taxation.

Perhaps we should not be so antagonistic!

References
Encyclopedia Brittanica. Article on “Weights and measures.”