METRICATION WITHOUT TEARS

BY

E. W. J. SATCHELL, M.I.E.E., AND D. H. CAMERON, M.I.MECH.E., M.I.MAR.E.
(*Ship Department, M.O.D.(N), Bath.*)

A revolution has started in Britain! This has nothing to do with protest marchers or militant LSE students but nevertheless will affect to a greater or lesser extent every man, woman and child in the United Kingdom.

The introduction of decimal coinage is the beginning of a process which will sweep away our long cherished Imperial system of units with its quaintly haphazard, incremental ratios and substitute an efficient new system, based upon the metric 'rule of ten'.

The first known exponent of the decimal system of units was Simon Stevin in about 1600 AD. However, the first such system to be adopted was the metric system at the time of the French Revolution. The units chosen as basic to the system were those of mass, length and time; the gramme, the metre and the second. In practice, the actual unit of mass deposited as a standard at Sevres in France was the kilogramme (1,000 grammes). World-wide recognition of the metric system was achieved in 1875 by the signing of an International

Metric Convention (ratified in 1878). This Conference set up an international body to regulate matters concerning the metric system, the CGPM (Conference Generale des Poids et Mesures). A variant of the metric system using the gramme, the centimetre and the second (the cgs system) was adopted by the British Association for the advancement of science in 1873 and has been used throughout the world for scientific work.

During the 19th Century, the basic laws of electricity were established and naturally enough the units employed in measuring electrical quantities were those of the cgs system. In practice it proved impossible to define electrical units solely in terms of mass, length and time, as the magnitudes of two of the fundamental electrical properties of space could not be measured separately, nor could their dimensions be determined. The product of these two quantities was, however, known to be $1/c^2$, c being the velocity of light. A cgs electromagnetic system of units was developed by assigning an arbitrary non-dimensional number to one of these properties, thus fixing the value and dimensions of the other. Practical electrical units such as the ampere and the volt were established by raising these fundamental units by suitable powers of 10 to give convenient sized units for everyday use. Since there is only one arbitrary constant in the series of practical electrical units and in all other respects they are related to the metric system by powers of 10, it will be appreciated that the electrical units can be integrated into the metric system by the simple expedient of fixing upon one of the electrical quantities as a fundamental standard and adding this to the three initial standards for mass, length and time.

This fact was first pointed out by Professor Giorgi in 1902, by which time practical measurements in the metric system had come to be based on the metre, kilogramme and second. He also pointed out that this usage of the kilogramme as the unit of mass had the further advantage that the electrical units would fall naturally into place as coherent units (i.e., derived on a 1 : 1 basis). In 1935 the International Electro-Technical Commission adopted this recommendation of Professor Giorgi and in 1950 they decided on the ampere as the fourth base unit, giving the MKSA or Giorgi system of units.

In 1954 the CGPM adopted and extended the MKSA system by adding kelvin as the unit of temperature and the candela as the unit of luminous intensity. In 1960, the world body concerned with weights and measures recommended the adoption of this new system which was given the title 'Systeme International d'Unites' (S.I.), and it is this system, already accepted by some 25 metric countries which the United Kingdom has decided to adopt.

The S.I. system is based on six fundamental units:

Length	— the metre (m)
Mass	— the kilogramme (kg)
Time	— the second (s)
Electric Current	— the ampere (A)
Luminous Intensity	— the candela (cd)
Temperature	— the kelvin (K)

From these six basic units, all the other units are derived on a 1 : 1 basis (coherently). For example:

Velocity	— the metre/second (m/s)
Area	— the square metre (m^2)

Some of these derived units are given specific names, for example the unit of force ($kg.m/s^2$) is called the newton (N) and the unit of mechanical work is called the joule (N.m).

The S.I. system of units lays down preferred multiples and sub-multiples of the basic units. These preferred multiples and sub-multiples are in steps of 10^3. Hence the preferred units of length are the metre, the kilometre, the megametre (10^6 metres), etc., together with the sub-multiples millimetre, micrometre (10^{-6} metres), etc. In forming multiples and sub-multiples of such units as velocity, kilometres/second or millimetres/second should be used, i.e., the prefix should be attached to the numerator not the denominator. However, a difficulty arises here. Since the kilogramme, the fundamental unit of mass, already contains its multiple prefix, it cannot be associated with other multiples or sub-multiples to indicate magnitude. This is a serious inconsistency and the case was argued at great length for the adoption of another name for the unit of mass identical in magnitude with the kilogramme. Details of the approved multiples and sub-multiples are given in BSI Publication PD5686 (January, 1969).

The S.I. system recognizes that some of the preferred units will be unwieldy or otherwise unsuitable for practical purposes and permits a second preference of multiples provided that the relationship between these non-preferred units and the first preference units is clearly understood. For example, draught marks for ships are most conveniently expressed in decimetres (10^{-1}m). Also some commonly used units are not part of the rational S.I. system but will continue in everyday use: e.g., everyday temperatures will be expressed in degrees Celsius (degrees C) not degrees kelvin (K). The minute (60 seconds) and the hour (3,600 seconds) will also continue.

There are two particular areas of the new S.I. system which might lead to initial difficulty, although, in fact, the new concepts are basically simpler than previous ones. These are the areas of power, work and energy, and of mass, weight and force.

Power, Work and Energy

Heat energy, electrical energy and mechanical energy are all manifestations of the same basic phenomenon although this tends to be forgotten in the Imperial system because different units are used, e.g., the Btu, the kilowatt hour, and the foot pound. This anomaly gives rise to conversion factors, e.g.

1 HP = 746 watts
= 550 ft lb/second
1 Btu = 778 ft lb

The S.I. system uses only one energy unit analogous to the ft lb (force x distance), the newton metre (Nm). This unit is also called the joule (J). The corresponding unit of power is the Nm/second or joule/second which is the watt. The effect of this single unit for work with the related unit for power is to produce a drastic simplification in calculation. A few examples are given below:

(*a*) Hydraulic power = pressure × area × distance ÷ time

$$= \frac{N}{m^2} \times m_2 \times m \div s$$

$$= \frac{Nm}{s} = \text{watts}$$

(*b*) If the calorific value of a fuel is X joules/kg and a boiler burns Y kg/second then the input to the boiler is XY watts, and if the steam is used to drive a generator of output Z watts, the overall efficiency is Z/XY.

Mass, Weight and Force

The preceding paragraphs illustrate very clearly the simplicity of calculation which results when the newton (N) is used as the unit of force. the newton is a coherent unit derived from the formula:

$$\text{Force} = \text{mass} \times \text{acceleration}$$

$$1\text{N} = 1\text{ kg} \times \frac{1\text{ m}}{1\text{s}^2}$$

The concept of coherent force units is not a new one. There are similar units in the imperial system and the cgs system viz:

$$1\text{ poundal} = \frac{1\text{ lb} \times 1\text{ ft}}{1\text{s}^2}$$

$$1\text{ dyne} = \frac{1\text{ gm} \times 1\text{ cm}}{1\text{s}^2}$$

The newton as a force unit already forms part of the MKS system which has been taught in our Universities and Technical Colleges for the past ten years.

However, the coherent force unit has other advantages when dealing with problems concerned with dymanics. For example, since the newton (N) is the force producing unit acceleration (1 metre/s^2) on unit mass (1 kg), it follows that the force acting on a mass of 1 kg under the influence of gravity (9·81 metres/s^2) is gN or 9·81N. Thus wherever gravity is involved, g appears in the equation. When gravity is not involved, g does not appear. This is logical and avoids any possible confusion. As an example, the hydraulic power calculation above is independent of gravity and would be equally correct for a system in outer space. However, had the calculation employed lb force or kilogram force units it would have been necessary to introduce gravitational acceleration into the equation. This operation is so alien to common sense that it is not surprising that g is often forgotten in such circumstances.

The use of the newton has given rise to much argument and ill-founded criticism. Coherent force units are not a new concept as exemplified by the poundal, which, however, has not been universally accepted in the Imperial system. The great advantage of the newton is not only that it is a coherent force unit, but also that it is simply related to the heat and electrical energy units the joule and watt second. The only real difficulty in using the newton is related to the concept of weight. Weight is, in fact, a special case of force, being that force acting on a mass in a gravitational field; as we move into the space age the fact that weight is a special case becomes more obvious. A housewife living on the moon in the year 2,000 will want the same sack of potatoes to last a week as she does on earth. It is clearly the mass she is interested in and not the weight. The easy solution for engineers is to forget the concept of weight leaving the man in the street to call his sack of potatoes 'weight' if he finds this easier. The engineer must learn to think of force and mass. If he does this then he should have no difficulty with the newton.

The introduction of the S.I. system has already started and the process is gathering momentum daily. By 1975 the revolution will be complete and Industry, both technological and domestic will have switched to the new units. Will you be ready?