THE CHANGE TO THE METRIC SYSTEM

BY

P. M. NEWMAN, M.SC.

(*Deputy Director of Standardization, M.O.D.(Central)*)

When this issue of the *Journal* is published, a year will have passed since the National Press reported, slightly inaccurately, that Britain was to switch over to the metric system of weights and measures. Inaccurately, because weight is not included in the metric system. But this is looking for trouble too early! Engineers and other technicians will easily become accustomed to mass in technical writings, but it will be a long time before it replaces weight for everyday use. Perhaps it never will. Who would care to enquire of a lady what is her mass? But to pass on to weightier matters.

Since the Government announcement was made, work in preparation for the change has been going on apace. It is clearly the intention that the change should be made as rapidly as possible, even though the process must inevitably be a gradual one, and industries will vary in their ability and eagerness to change. While the Board of Trade expressed the view that for the country as a whole it may take twenty years for the present imperial system of units to be superseded, the hope is expressed that most industries will have changed over within ten years. The rate of change of sectors of the engineering industry is clearly of the first importance to the Navy Department. In the forefront of industries eager to make the change, and already in the process of doing so before the announcement was made, is the electrical industry. As sectors of industry become ready for the change, Government departments are required to encourage it by calling for tenders to be in metric units.

The British Standards Institution is pressing forward vigorously with the new standards needed. They are concentrating first on the fundamental material specifications such as those for the dimensions of metal sheet, plate, bar, etc. and on specifications most needed for the engineering and export trades. A handbook giving working information on many engineering metric standards, in advance of the detailed completion of the British Standards themselves, is expected to be published in about March, 1966. As time goes on, standards in imperial units will in general not be maintained or brought up to date, though many will need to be kept in existence for a very considerable time.

For most people and most purposes, changing to the metric system means working in metres and kilogrammes (the original units of the metric system) instead of in the feet, inches and pounds of the imperial system. Far the greatest impact is in the change of linear measurement, as this is the foundation of the design and manufacture of almost everything that has a predetermined shape or size. An entirely fresh approach has to be adopted. It cannot be overemphasized that the adoption of metric units involves designing to metric dimensions, not merely converting imperial dimensions into metric ones. Metric standards and metric components must be used. For example, it is not a matter of calling a bolt 25·4 mm instead of one inch but of designing to use a bolt from a standard metric range in which the appropriate '1st choice' size will be either 24 or 30 mm. This is a fundamental change.

Although linear dimensions are the medium through which engineering design is given effect, derived units such as force, stress, torque, power, thermal capacity and many others may be involved in developing the design. As these introduce a whole range of unfamiliar units, the nature of the metric system which this country is adopting must be described.

The System Described

Since the metric system was introduced in France at the beginning of the 19th century, it has gone through various changes. These have not altered the magnitudes of the units themselves—though there have been changes and refinements in their definitions—but have aimed at bringing about more satisfactory relationships between the various units.

Mainly in the scientific use of the metric system, complex or derived quantities used to be based on the centimetre, the gramme and the second. In this (the CGS) system the unit of force is the dyne and the unit of energy or work is the erg. Early in this century practical units of measurement began to be based on the metre, the kilogramme and the second, as being more convenient in magnitude, and in 1950 the units of mechanics and electro-magnetics were linked by the adoption of the ampere as the fourth basic unit. This gave the MKSA (or Giorgi) system. Since then the CGPM*, the body responsible for all international matters concerning the metric system, has added two more basic units, those of temperature and of luminous intensity, and there has been further rationalizing of the system. The result is the Système International d'Unités (SI) which is now in process of coming into international use. This is the system which the United Kingdom is to adopt.

The SI has six basic units from which all others are derived. They are the units of

length	metre (m)
mass	kilogramme (kg)
time	second (s)
electric current	ampere (A)
thermodynamic temperature	degree Kelvin (°K)
luminous intensity	candela (cd)

The SI is described, and these units together with some of the derived units are defined, in British Standard 3763:1964. In December, 1965, the British Standards Institution published a booklet, PD 5686, giving a fuller and less formal explanation of the system and some guidance on its use. In the same month the National Physical Laboratory published a somewhat similar booklet entitled 'Changing to the Metric System', which contains a wide range of conversion factors between SI and British units, well set out for easy reference. Both these booklets are recommended to those who wish to familiarize themselves with the system beyond the simple units of length, mass and capacity. Details of these and some other publications are given in the Appendix to this article.

Nothing more need be said at this point about the basic units of the SI, except perhaps the unit of temperature. The units of Kelvin and Celsius temperature interval are identical. A temperature expressed in degress Celsius is equal to the temperature expressed in degrees Kelvin less 273·15. The use of the term centigrade persists in this country, but internationally it was abandoned in 1948 and was replaced by the term Celsius, by which the scale was already widely known in some metric-using countries. (One reason for the change was that in France a 'grade' is $\frac{1}{100}$ right angle, and 1 'centigrade' therefore means $\frac{1}{10\,000}$ right angle). The term Celsius will be appearing more and more in technical literature. Conveniently, the abbreviation (°C) remains unchanged.

An important feature of the SI is that, in addition to its fundamentally decimal nature, it is a coherent system. This means that the product or quotient of any two unit quantities is the unit of the resultant quantity. Thus in a coherent system in which the unit of length is the yard, the unit of area must be the square yard, not the square foot or the acre. Other examples of units which are not coherent are the horsepower and the British thermal unit—in fact the quality of coherence is almost entirely lacking from the traditional British units of measurement, which scarcely deserve to be called a system at all.

Mass and Force

Until quite recently very little distinction was made, for practical purposes, between weight and mass, and the same units were used (and commonly still are) for weight and force, namely the pound or the kilogramme. As engineers

*Conférence Générale des Poids et Mesures.

well know, the weight of a body is not an inherent characteristic of the body itself, but is a particular force acting in a particular direction due to the action of gravity. Over the earth's surface, gravity varies by about 0·5 per cent. So, therefore, does weight, and in spacecraft it may disappear altogether. It is the mass of a body which is its characteristic, and the pound and the kilogramme are essentially units of mass.

Force is proportional to mass multiplied by acceleration (which is one way of stating Newton's second law of motion). Under conditions of free fall, the gravitational force acting on a body—its weight—produces an acceleration commonly taken to be 32·2 feet per second per second. Because of the variations in gravity, and the need to have precise units of force, an international standard value for gravity ('standard acceleration') was agreed as 9·806 65 m/s^2. The force which imparts this acceleration to a mass of 1 kg is named 1 kilogramme-force (kgf) and is the unit of force in the current system of metric technical units. The standard pound-force (lbf) is exactly defined on this basis.

In the SI, the unit of force is the newton (symbol N). It is that force which, when applied to a body having a mass of 1 kilogramme, gives it an acceleration of 1 metre per second per second. Therefore

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

It is evident that the relation between the newton and the kilogramme-force is

$$1 \text{ kgf} = 9{\cdot}806\ 65 \text{ N}$$

The use of the newton as the unit of force does away with the constant necessity for introducing into formulæ and calculations the conversion factor for gravity, and greatly simplifies the system of units. It is the most significant advantage of the SI over the present system of metric technical units.

A Few Derived Units

The newton is itself a derived unit. Many others are derived from it. The SI unit of *energy* is the joule (J = Nm). This supersedes all other units of energy and work whether electrical, mechanical, or quantity of heat. So goodbye to the horsepower-hour and to the British thermal unit (1 Btu = 1·055 06 kJ). Presumably, too, the electrical world will not remain untouched, and the familiar unit the kWh will be ousted in time to come by the megajoule (1 kWh = 3·6 MJ).

The SI unit of *power* is the watt (W = J/s). Engineers may find it strange to rate the output of a ship's propulsion turbines in kW, though perhaps no more strange than getting accustomed to the use of the newton from which the unit is derived. The SI brings about a complete interdependence of mechanical and electrical units.

The SI unit of *pressure and stress* is the newton per square metre (N/m^2). At present this unit has no SI name. In France it is called a pascal (Pa). The prospects of this term being accepted internationally are not known.

As 1 lbf/in^2 = 6894·76 N/m^2, it will be seen that the SI unit is inconveniently small, and multiples of it will commonly need to be used. A tyre pressure of 24 lbf/in^2 will best be expressed as 165 kN/m^2, while a steel stress of 50 $tonf/in^2$ will become 772 MN/m^2.

There is no need to give further examples of the new units. Extensive information is already available in the publications listed in the Appendix, and no doubt much more will be appearing as metrication* proceeds and as remaining uncertainties about practical units to be used are cleared up.

*This word, introduced by the Ministry of Technology, means the process of 'going metric'. It is a convenient and well-sounding word, which is acceptable to the Editor of the Concise Oxford Dictionary, and we may as well help it into currency.

Practical Units to be Used

There are indeed still many uncertainties. The SI is a very recent evolution, and is only now coming into international use. Countries which already have the traditional metric system have a set of units which they can continue to use until it is convenient for them to go over fully to the SI. But the United Kingdom must go straight to the SI now, otherwise a further change would soon have to follow. Consequently much work is going on to ascertain what many of the practical units will be, and these may have to be used, for example in British Standards, in anticipation of their formal international acceptance.

In order to maintain the coherent nature of the system, the practical units must be multiples or sub-multiples of the complete SI units. Thus the stress referred to above as 772 MN/m^2 is in fact 772 $M(N/m^2)$—or 772 megapascals, if that name were to be adopted. The same magnitude of stress could be written as 772 N/mm^2, but this would be an abuse of the system, detracting from its advantages and inviting errors in calculation. This requirement to keep the SI units intact differs from practice under the traditional metric system, where for example steel stresses are commonly shown in kgf/mm^2 while steam pressures are shown in kgf/cm^2.

A multiple of the kg (mass) at present used in metric countries is the tonne, or metric ton, equal to 1000 kg. This is an unfortunate unit as it could so easily be confused with the British ton, from which it differs by being about 35 lb smaller. It is to be hoped that in the SI, this unit will be known as the megagramme (Mg).

For a long time, until the SI units have really come into general use both in this and other countries, it will be common practice for metric quantities to be expressed in both SI units and the traditional metric units. This will be done in future British Standards. The marking of such things as steam pressure gauges will have to be decided.

The Litre

Before passing on from the units themselves, something should be said about the litre. Most people who have a working acquaintance with simple metric measures think that a litre is another name for a cubic decimetre. This is not strictly correct.

When the metric system was first devised, the litre was the volume of a cube of 1 dm side, and the kilogramme was the weight of a litre of water under specified conditions. The standard kilogramme was then established in the form of an iridio-platinum weight.

Because of the difficulty of measuring volumes directly to any close degree of accuracy, the CGPM in 1901 re-defined the litre in terms of the volume occupied by 1 kg of pure water under specified conditions, thus reversing the original dependence between weight and volume. In 1927 it was established that the litre, defined in this way, was equal to 1·000 028 dm^3.

For practical purposes where an order of accuracy not higher than 1 part in 10 000 is required, the litre and the dm^3 can be equated. There is a strong move towards re-defining the litre in terms of the dm^3, and this is likely to come about fairly soon. There are legal difficulties to be overcome first, partly because the Weights and Measures Act 1963 unfortunately inter-related the definition of the gallon to that of the litre. It seems safe to anticipate this piece of rationalization and to go straight for litres. Nobody wants to talk of a cubic decimetre of oil—or any other liquid.

It is unfortunate that the unit symbol for the litre, its initial letter, is so often indistinguishable in print or typescript from the digit 'one'. After which warning, 1 gal = 4·546 l. One litre cannot safely be printed in short.

Conversion Factors are Short Term

The multitudes of conversion factors relating the units of the British and international systems look formidable indeed. Fortunately most people will need only a small selection of them. During the process of metrication there is bound to be much working across from one set of units to the other, and conversion factors cannot be avoided. But as the SI really becomes established the need for them will diminish, and once the designer, the suppliers of materials and parts, the manufacturer and the user are all thinking and working in SI units, there will be no need for any conversion at all. Then the complete simplicity of the SI will have come into its own.

It will take many years for this to be achieved, and to the present generation it may not seem true that conversion factors are short term. The term will be shortened if everyone makes a conscious effort towards metrication. Familiarity with the new units, and a mental sizing of them, will come quickly to most people once they really practise using the units.

It is again stressed that the full adoption of the SI means using metric standards and choosing metric dimensions. Literal translation from one language to another leads to absurdities; the grammar and idiom of the other language must be used. It is so with systems of measurement.

Impact of Metrication on the Navy Department

The practical impact of the change, as it will affect the Navy Department, must now be considered. The actual task of changing the design and manufacturing processes to work in metric units will fall mainly on industry, and for naval machinery and equipment it will usually be worked in with the particular manufacturer's general metrication. This is not to suggest that none of this burden will fall on the Navy Department, but possibly the greater part of the problems, tasks and costs falling to the Department will be consequential ones.

The making of a change may depend solely on industry's readiness for it. But it may also have to be related to associated machinery or equipment. Whether serious difficulties would arise from a mixture of units will have to be considered on many occasions. The making of a change may need to be phased to maintain compatibility between equipments which have to inter-operate either within a ship or perhaps between two Services.

Because of the long time required for design and manufacture of naval equipment, the construction period and subsequent operational life of a naval ship, design decisions, once taken, may have to stand for thirty years or more. So the sooner metrication really becomes effective, the better. It is obvious that inevitably current designs of machinery and equipment in inch units will continue to exist along with newer designs in metric units for a long time to come—and both will need their supporting facilities. Spare parts for metric equipment will normally differ from those for inch equipment. For many years both will have to be stocked, and carried aboard ship. There will thus be a tendency to increase both the variety and numbers of spare parts required, acting against the current efforts to reduce them.

Test and inspection processes and facilities may need to be extended or changed. Maintenance and repair facilities may need to be extended to cater for metric working in addition to the current system. This will affect workshop equipment, machine tools, etc., both in dockyards and in ships. There will need to be a duplication of gauges, taps and dies, spanners, etc. Further training of maintenance personnel may be necessary.

The change of other units besides those of length and mass will at the right time have to be considered so that the consequences are not indefinitely postponed. There will ultimately have to be very extensive replacement or rescaling of instruments and measuring devices showing temperature, pressure, flow, etc. Instruction manuals may need to be amended or re-written. New text books and teaching will have to be introduced in schools and training establishments.

Although the change will be spread over a long period, it may well be that after an apparently slow start the main onset comes with a sudden rush. Provided that the implications have been foreseen, and that plans and preparations to meet them are made in time, there should be very few real difficulties or disturbances.

Valediction

It is right we should look forward and work towards a new age without seeking to cling to the encumbrances of the past. But the old system deserves just a little expression of respect and affection as we begin to pension it off. The eccentricities of old age can be very tiresome, but they may have been quite reasonable in days gone by, and should not be too harshly derided. Occasionally a seeming eccentricity may have more good sense in it than the derider realizes. There is surely little justification for the scathing attack in the leading article in one of the responsible daily papers which, after stating that the influence of many of our own civil and military authorities is an obstacle to British people going metric, continues:

> 'Aviation, for instance, both military and civil, persists in using the knot as a measure of speed and the nautical mile as a measure of distance—the most irrational and absurd choice in the whole lunatic assembly of mad measures. The hydrographic department of the Ministry of Defence in what are still called the "Admiralty" Tide Tables is not much more sane, for it uses the inexcusable decimalized foot, which it adopted in 1920, and, in its atlas of tidal streams, the utterly idiotic decimalized knot. A knot is a nautical mile per hour. It takes a truly delinquent mind to divide knots and feet and inches into tenths when a ready-made, coherent decimalized system of units is available.'

Aviators have to navigate, so why not use the nautical mile? Conscious of his rashness in referring at all, in a naval journal, to this unit of navigation, the author supposes that its convenience to navigators the world over is such that they will want to continue its use indefinitely. Being a one-minute arc of a great circle of the earth, its magnitude is fixed for us. Though it has to be defined in terms of the metre or the foot (which is itself defined in terms of the metre), the nautical mile is itself the practical unit, and it seems much more sensible to divide it decimally than in any other way. The same applies to the knot. If this is best for navigators, why should anyone else pour scorn on it?

The magnitude of the nautical mile is fixed for us so long as angles are expressed in degrees and minutes. Perhaps the time will come when the right angle is internationally decimalized, as it already is in some European countries. Then the degrees and minutes may be replaced by the grades and centigrades of which mention has already been made. Since the metre was originally determined as 10^{-7} of a quadrant of a great circle, an arc of 1 centigrade is 1 km* in length. The navigator's measure would then be the same as the landsman's.

While on the subject of the nautical mile, it seems odd that though the international nautical mile is 1852 m exactly (6 076 ft approx), the United Kingdom nautical mile is 6 080 ft. Is there so much disagreement between the experts on the earth's measurements?

No doubt tide heights will in time be stated in metric measure, but while the foot is the unit for them why is it so inexcusable to subdivide it into tenths? This will result directly from the tidal calculations, and may well be the form in which the heights are most easily used by those who need to know them accurately.

*Actually 1.000 08 km, on the basis of the international nautical mile.

The peculiar land measures which we are to give up were once much more sensible than they appear now and their origins are full of interest. Areas were related to what a man might be expected to plough in a day, and the furlong (furrow-long) was the length of his piece of land. The field, nominally square, was divided into ten strips each of 1 acre, the width of each strip being 1 chain.

The rod, pole or perch causes amusement at its name and jeers at its length of 5½ yards. 'Perch' comes from the Latin for rod or pole—there was a 'pertica' land measure in Roman times—and as for the length, this is not really 5½ yards at all but ¼ chain, which is much more sensible.

The old English foot, which in all probability was introduced by the Belgic invasions in the late Iron Age and is traceable back through Europe to Greece and Asia Minor, was longer than our foot, being equivalent to 13·22 present inches. (The author has not probed into its sub-divisions). This was the commonest building foot up to the 15th century. The fathom was, as it still is, 6 feet, and above that there were decimal relationships. Moreover the chain was sub-divided decimally. The old English system of land measure was therefore as follows, the figures in brackets being the equivalents in our inches:—

yard	2 = fathom,	10 = chain,	10 = furlong,	10 = mile
(39·66)	(79·32)	(793)	(7932)	(79320)

1 chain = 100 links
(7·93)
= 4 rods

Our chain is 792 inches long. So the chain and the furlong have remained substantially unchanged for well over 1 000 years.

It is remarkable how closely the old English system corresponded with metric linear measure. Had it been retained it could have been brought into line with the metre by reducing the yard by only 0·73 per cent; and the half-mile would have become a kilometre. But by statute of 1439 the long yard was suppressed in favour of the present foot which had been legally enforced as early as 950, and presumably the chain was then increased to the odd value of 22 yards in order to retain its length. The mile was changed from 10 to 8 furlongs. A good system was deteriorating.

Many trades and occupations have for centuries had their own measures of volume and capacity. This probably did not trouble anybody as each trade was self-contained, but in these days of interdependence such oddities as the hogshead (52½ gallons) must surely go—with a passing thought that it must have been a very big hog.

What is the future of the pint? The litre will come in for all technical purposes and motorists will think nothing of asking for a half litre of oil, but what is to become of the tankard? Instead of the 'pint pot' and the 'half pint', shall we have half and quarter-litre mugs, or 0·6 and 0·3 litre mugs? The first alternative would reduce our drinks by 12 per cent with an unpredictable effect on sales, while the second would increase them by 5½ per cent with an effect on sales which is fairly easily predictable. But in either case what would we ask for? Probably just 'a large' or 'a small'. Is there really any need to make a change at all, unless it is forced by a future Masses and Measures Act? After all, the actual amount the mug holds has no relation to anything else at all except thirst. The author hopes that here tradition, on which we thrive as does the foreign tourist trade, will win over what may be good sense and that we shall be able to go on asking for and getting a 'half pint, please', with which to drink to the memory of the departed British system and the success of the SI.