Currently there is a great deal of discussion in the United Kingdom about "going metric", or with "metrication". In 1965, in reply to a Parliamentary Question, the President of the Board of Trade stated that "the Government consider it desirable that British industries on a broadening front should adopt metric units, sector by sector, until that system can become in time the primary system of weights and measures for the country as a whole". The system which is to be adopted is the SI system of units. SI stands for Système Internationale d'Unités (International System of Units). The adoption of this set of units will have widespread repercussions in the scientific literature, also amongst makers of scientific apparatus. Already it has impinged upon lecture courses given in various centres for the new syllabus of the Primary FFARCS examination. The overthrow of various traditional units is bound to produce some complications, and this is particularly true, as far as medicine is concerned, in the case of pressures. Physics is traditionally a subject concerned with measurement and has long been associated with anaesthesia. Hence the author felt that at this time a discussion concerning SI units would not be out of place, and would stimulate anaesthetists to think in terms of the new units.

The history of units.
The idea of a decimal system of units was conceived by Simon Stevin (1548–1620) who also developed the concept of decimal fractions. Following the French revolution, the statesman Talleyrand, advised by contemporary scientists, aimed at the establishment of an international decimal system of weights and measures "a tous les temps, a tous les peuples". It was based upon the metre as the unit of length (intended to be one ten-millionth part of the distance from the North Pole to the equator at sea-level through Paris) and the gramme as the quantity of matter (the mass of 1 cm³ of water at 0°C). In 1837, the British Association for the Advancement of Science chose the centimetre and gramme as basic units of length and mass for scientific purposes. The adoption of the second as the unit of time led to the well-known c.g.s. system of units. In about 1900, practical measurements in metric units began to be based upon the metre, kilogramme and second, thus giving the MKS system of units. In 1935 the International Electrotechnical Commission (IEC) accepted the recommendation of Professor Giorgi that the MKS system of mechanical units be linked with the electromagnetic units by the adoption of one of the latter as a fourth base-unit. The IEC adopted the ampere, the unit of electric current, as the fourth base-unit in 1950 to give the MKSA system.

Since 1875 all international matters concerning the metric system have been the responsibility of the Conférence Générale des Poids et Mesures (CGPM); this is also responsible for the Bureau International des Poids et Mesures (BIPM) at Sèvres. The kilogramme is still defined in terms of the international prototype held at Sèvres, but the metre is now defined in terms of a number of wavelengths of a particular wavelength of light. The 10th meeting of the CGPM in 1954 adopted a rationalized and coherent system of units based upon the four MKSA units, the Kelvin as the unit of temperature and the Candela as the unit of luminous intensity. The 11th meeting in 1960 gave it the full title "Système Internationale d'Unités".

Units of mass, force and weight.
The SI unit of mass is the kilogramme and the unit of force is the newton. This is the force required to give a mass of 1 kilogramme an acceleration of 1 metre per second per second. This is an absolute unit of force which is independent of the value of the acceleration due to gravity. Since gravity varies by about 0.5 per cent over the earth's surface, units of force such as...
as the pound-weight which depend upon gravity can only be used for low accuracy work. In the past, pound and pound-weight have been used indiscriminately. The use of an absolute unit of force avoids the confusion of having to write lb and lbf. Similarly the kilogram weight (kilopond) will be superseded.

Units of pressure.
The SI unit of pressure is the newton per square metre and supersedes the pound per square inch (p.s.i.) and the kilopond per square centimetre. Wherever possible the N m$^{-2}$ should be used in the appropriate multiples and sub-multiples. The bar ($10^{5}$ N m$^{-2}$) is allowed as a unit of pressure in conjunction with SI units, as are the hectobar ($10^{7}$ N m$^{-2}$) and the millibar ($10^{3}$ N m$^{-2}$). For high vacuum work with pressures of about 1 N m$^{-2}$ or less, it is recommended that the N m$^{-2}$ with its decimal sub-multiples is used in preference to the torr or mm Hg.

The unit of energy.
The SI unit of energy in all forms is the joule (J). Energy is defined as the capacity for doing work. In effect it represents a certain amount of stored work, so that its dimensions are those of work. Work is done when a force moves its point of application, so that 1 joule of work is done when a force of 1 newton is displaced through a distance of 1 metre in the direction of the force, so that 1 joule is equivalent to 1 newton-metre. It supersedes the various calories, the kilowatt hour, the BTU and the horse-power.

The unit of power.
This is the watt (W). It equals 1 joule per second.

The unit of temperature.
On the SI system temperature is expressed in degrees Celsius. The units of Kelvin and Celsius temperature interval are identical. (The name "degree Kelvin" (symbol °K) was changed to "Kelvin" (symbol K) at the 13th CGPM in 1967.) A temperature expressed in degrees Celsius is equal to the temperature expressed in Kelvin less 273.15. The Centigrade scale is now known as the Celsius scale and supersedes the Fahrenheit scale.

Electrical units.
Many of the common units are unchanged, for example the ampere (A), volt (V), ohm (Ω) and farad (F). The unit of electric charge remains the coulomb (C), whilst the unit of inductance stays as the henry (H). The unit of frequency is now called the hertz (Hz), rather than 1 cycle per second. The hertz is defined as the frequency of a periodic phenomenon of which the periodic time is 1 second. Care must be taken not to apply the hertz to non-periodic phenomena such as an isolated pulse. The unit of magnetic flux called the weber (Wb) is the flux which, linking a circuit of one turn, produces in it an electromotive force of 1 volt as it is reduced to zero at a uniform rate in 1 second. The unit of magnetic flux density is the tesla (T) where 1 T = 1 Wb m$^{-2}$.

Illumination.
The unit of illumination called the lux (lx) is an illumination of 1 lumen per square metre.

Decimal multiples and sub-multiples of SI units.
These are formed by means of the following prefixes:

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<tr>
<th>Factor by which the unit is multiplied</th>
<th>Prefix</th>
<th>Symbol</th>
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Examples: 1 cm$^{3}$ = 10$^{-6}$ m$^{3}$, one microsecond = 10$^{-6}$ s and 1 mm$^{2}$/s = 10$^{-6}$ m$^{2}$/s.

Units to be allowed in conjunction with SI units.
It has been mentioned previously that the bar is allowed as a unit of pressure in conjunction with SI units. Similarly, the litre (l.) is allowed as a unit of volume, the SI unit being the cubic metre. The following table lists the allowable units of interest to anaesthetists.
The common units of time, e.g. minute, hour and year, will persist as will the angular degree. Visible light wavelengths will be expressed in terms of nanometres (1 nanometre = 10 Ångstrom units). Infra-red wavelengths will be expressed in terms of micrometres (1 μm = 1 micron).

Surface tension is expressed in newtons per metre (N m⁻¹); thermal conductivity in watts per metre per degree Celsius (W m⁻¹ °C); heat capacity in joules per kelvin (J K⁻¹) or joules per degree Celsius (J/°C); specific heat capacity in joules per kilogram per kelvin (J/kg K) or joules per kilogram per degree Celsius (J/kg °C); entropy in joules per kelvin (J/K); and latent heat in joules per kilogram (J/kg).

**APPLICATIONS OF SI UNITS TO ANAESTHESIA**

For many of the quantities encountered in measurements of concern to the anaesthetist little inconvenience will be experienced when working in SI units. For example, volume flow rates of gases will still be expressed in litres per minute. The biggest problem will undoubtedly arise in expressions involving pressure and force. Traditionally, the smaller pressures have been expressed in terms of the height of a fluid column which they can support, for example, mm Hg and cm H₂O. The basic SI unit of pressure is the N m⁻², but this is inconveniently large for many medical applications. Since 1 mm Hg = 133.322 N m⁻², a blood pressure of 120/80 mm Hg becomes 15,996/10,664 N m⁻². Similarly, an inflation pressure of 20 cm H₂O becomes 1962 N m⁻² and a full gas cylinder pressure of 1800 p.s.i. is equivalent to 12.42 x 10⁹ N m⁻². The situation is eased by the use of the prefix kilo, so that the blood pressure quoted becomes 15.996/10.664 kN m⁻². The figures in terms of N m⁻² are high, of course, because pressure is defined as force per unit area and a square metre is a large area compared with a square inch or square centimetre. It does seem very unlikely that the mm of Hg will be easily displaced from clinical blood pressure measurements. Gas pressure gauges could be scaled in terms of deka N m⁻² or millibars. Since one millibar = 100 N m⁻² an inflation pressure of 20 cm H₂O is equivalent to 19.6 millibars. In this case little change is involved in the numerical value.

Before leaving the subject of pressure measurements, it would be as well to illustrate some conversions, e.g. 1800 p.s.i. into N m⁻². Taking 1 lb. = 453.6 grams and 1 square inch = 6.45 cm², then 1 lb. per square inch = 453.6/6.45 grams weight per cm² = 453.6 x 981/6.45 dynes/cm². Now, 1 dyne per cm² = 10⁻¹ N m⁻², so that

\[ 453.6 \times 981 \times 10^{-1} = 4.536 \times 10^{5} \text{ N m}^{-2} \]

1 lb. inch⁻² = \( \frac{1}{6.45 \times 10} \) N m⁻² = 6,900 N m⁻² and 1800 p.s.i. = 12.42 x 10⁶ N m⁻².

In the case of a pressure of 100 mm Hg, the equivalent weight per cm² is 10 x 13.6 grams wt., where 13.6 g/c.c. is the density of mercury. In dynes this becomes 10 x 13.6 x 981 which is 13.6 x 981 N m⁻² = 13,332 N m⁻².

The metre-kilopond is a unit which has been used to express the work cost of respiration. This would now be replaced by the joule (newton-metre) where one metre-kilopond equals 9.806 joules. A typical respiratory power consumption is 0.02 metre-kiloponds per second; this becomes 0.196 watts. The total airway resistance of about 1.6 cm H₂O per litre per second becomes 157
Clearly respiratory equations are likely to represent an area involving a substantial amount of changes.

In blood-gas studies, a typical $P_{a CO_2}$ of 40 mm Hg becomes 5.33 kN m$^{-2}$ whilst a typical $P_{a O_2}$ of 100 mm Hg becomes 13.33 kN m$^{-2}$. Standard bicarbonate remains in milliequivalents per litre and pH is still expressed in terms of pH units.

Since pressures are heavily involved, one would expect some substantial changes in the expressions used in hemodynamics. When blood pressures are given in SI units the vascular resistance in terms of SI units becomes kN m$^{-2}$ cm$^{-3}$ s, since basically hydraulic resistance is a mean pressure divided by a volume flow rate. At present vascular resistance is often expressed in terms of centimetre-gram-second units, i.e. in terms of dyne-sec.cm$^{-5}$. Since 1 dyne.cm$^{-2}$$=10^{-4}$ Nm$^{-2}$, a vascular resistance given in dyne-sec.cm$^{-5}$ can be converted to kN m$^{-2}$ cm$^{-3}$ s by multiplying by $10^{-4}$. The units of cardiac output remain unchanged as litres per minute, with the stroke volume in ml. Similarly, cardiac index is still in terms of litres per minute per square metre. For a cardiac output of 10 litres per minute in man, and a mean arterial blood pressure of 100 mm Hg, the vascular resistance is likely to be about 800 dyne-sec.cm$^{-5}$. This is equivalent to 0.08 kN m$^{-2}$ cm$^{-3}$ s. Figure 1 illustrates the interdependence of systemic arterial pressure, carotid sinus pressure and systemic resistance all expressed in SI units. Figure 2 shows the relationship between the heart rate expressed in terms of Hertz rather than beats per minute and carotid sinus pressure.

At present cardiac work is expressed in terms of gram.metres per minute. These units result from expressing the mean blood pressure in grams weight per square centimetre and assuming that this acts over a distance in metres obtained by multiplying the cardiac output in litres per minute by 10. On the SI system, cardiac work is expressed in watts. For a patient in shock, with a mean arterial pressure of 50 mm Hg and a cardiac output of 1.5 litres per minute, the cardiac work is 1068 gram.metres per minute or 1.7 watts. For a mean arterial pressure of 85 mm Hg and cardiac output of 6.64 litres per minute the cardiac work is 7675 gram.metres per minute or 11.4 watts.

The SI unit policy of concentrating on the joule as the unit of energy and the watt as the unit of power leads to a considerable simplification of the present large number of different units. For example, a typical respiratory power consumption of 0.2 watts instead of 0.02 metrekilojoules, and a cardiac power of 11.4 watts.
instead of 7676 gram.metres per minute. These values can be compared with the basic metabolic rate which is the minimal heat output produced by the fasting individual, physically and mentally at rest, at room temperature (approx. 20°C). In the age group 30-40 years, an average basic metabolic rate for men is 39.5 kilo-calories per hour per square metre of body surface area. The average surface area for men is approximately 1.8 square metres. Since 1 calorie equals 4.19 joules, the average basic metabolic rate for men in this age group becomes 83 watts. For a patient on a non-rebreathing circuit with a minute volume of 5 litres, the inspired gas being dry at 20°C and the expired gas being fully saturated with water at 36°C, there will be a heat loss of 12.8 watts due to warming and moistening the inspired gas.

The policy of stating the capacity of gas cylinders in cubic feet or gallons in the case of the condensable gases will cease and will be replaced by volumes in litres: 1 gallon = 4.546 dm³ = 4.546 litres; 1 cubic foot = 0.0283 m³ = 28.32 litres.

Body temperature will be expressed in degrees Celsius, whilst Kelvin temperatures will continue to be used in gas law equations.

CONCLUSIONS

The Government has expressed the view that it hopes by 1975 that the greater part of the country's industry will have changed over to the use of SI units. Clearly the change will take some time to bring about, and the Royal Society of London Conference of Editors recommended in 1968 that all scientific and technical journals should make the change-over to SI units as soon as possible. Manufacturers of anaesthetic equipment will have to agree on standard calibrations and this should remove the variety of current units such as pounds per square inch, kg/cm², kp/cm², gallons and cubic feet. It will also line up with the pharmaceutical industry which has now "gone metric". Finally, the adoption of SI units will help anaesthetists to comprehend equipment and textbooks originating in other countries, and to co-operate with control and other engineers.

REFERENCES


FIFTH INTERNATIONAL CONGRESS ON ANAESTHESIOLOGY

The Congress will take place in Kyoto, Japan, from October 2 to 8, 1972. The Belgian Professional Association of Specialists in Anaesthesia and Reanimation is to organize a three-weeks group tour from Brussels to the Far East, open to all anaesthetists of Western Europe and their families. The journey can thus be accomplished on the most advantageous terms. Booking is done on guaranteed periodical payments in advance.

For further particulars apply to

Dr. Et. Troch, Marcel de Backerstraat 2, Ekeren 2 (Antwerp), Belgium.