REPORT OF THE ROYAL SOCIETY'S BRITISH NATIONAL COMMITTEE FOR NUTRITIONAL SCIENCES

METRIC UNITS, CONVERSION FACTORS AND NOMENCLATURE IN NUTRITIONAL AND FOOD SCIENCES

Report of the Subcommittee on Metrication* of the British National Committee for Nutritional Sciences†

INTRODUCTION

1. *Terms of Reference*

(1) To consider the effects which the change to the metric system in the United Kingdom will have on the application of nutritional sciences and food science to problems of human and animal feeding.

(2) To make recommendations to the British National Committee for Nutritional Sciences on the conversion factors, nomenclature and units to be adopted for general use in making the change to the metric system.

2. *Method of working*

We have considered a series of problems related to the adoption of new units of measure in nutritional sciences and in food science and technology. We have done so taking into account the European Economic Community draft Directive 'regarding the harmonization of member countries' legislation relating to measuring units' (European Economic Community, 1971). We have been represented at a meeting convened by the Metrication Board to discuss physicochemical data in SI units and have corresponded with other interested bodies. The subcommittee has met three times.

3. *General conclusions*

From our considerations we conclude generally that in making any change to metric measure in those technologies in the UK, which relate to nutritional sciences, the International System of units (SI) should be adopted with but minor exceptions.

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In addition, with respect to the nomenclature of accessory food factors (vitamins) we recommend that the British National Committee seeks through the International Union of Nutritional Sciences (IUNS) international recognition of certain tentative definitions of equivalent quantities.

4. *Form of the Report*

(*A*) *Matters related to the adoption of metric measure*; *in particular :*

(1) Those related to simple changes in the expression of quantities from imperial or other measure to metric measure.

(2) Those related to the adoption of unfamiliar units of measure, notably the joule.

(*B*) *Matters related to the nomenclature of nutritional entities and to methods of expressing the biological activity of accessory food factors* (*vitamins*) *; in particular :*

(1) Problems related to terminology in energy metabolism.

(2) Definition of equivalence values for accessory food factors including those which are:

(*a*) based on international agreement;

(*b*) as yet not so agreed.

METRIC MEASUREMENT

5. *Simple changes from imperial to metric measure*

We recommend that the conversion factors to be adopted should follow the recommendations of the International Bureau of Weights and Measures (Ministry of Technology, 1970). The conversion factors for the base SI units of relevance are:

Physical quantity	SI unit	Imperial unit	Metric equivalent
length	metre (m)	yard	0·9144 m
mass	kilogram (kg)	pound	0·453 592 37 kg

The Appendix lists conversion factors for the common imperial measures expressed to four significant figures.

6. *Legal definitions*

There are some anomalies in the present legal definition of British weights and measures which could create difficulty. Indeed, the statement at the foot of the Appendix, warning of possible dangers of using the conversion factors for the purposes of trading within the meaning of the Weights and Measures Act of 1963 (Public General Acts, 1963), is included not only because of legal problems associated with rounding but because of these anomalies.

Outstanding is the situation which has arisen in the new definition of the litre under SI as 1 dm^3 or 10^{-3} m^3 and the metric equivalent of the gallon.

The imperial gallon is defined as the volume occupied by 10 lb water at 62°F, the mass of the water being determined with brass weights. The pound was defined

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before standardization of gravitational acceleration was adopted for the determination of mass but any error introduced from this cause is minor.

The litre as it was defined in 1901 is the volume occupied by 1000 g water at the temperature of its maximal density, 3·98°C. This volume is $1000{\cdot}028 \times 10^{-6}$ m^3.

Accordingly, the definitions of the metric equivalent of the gallon are:

on the basis of the 1901 definition of the litre

1 gallon=4·545963 litre (former);

on the basis of the new definition of the litre

1 gallon=4·546092 10^{-3} m^3 or 4·546092 litre (SI).

The discrepancy is 27 parts/10^6. We have been informed that new legal definitions of equivalent measure will be made shortly. The rounding to four significant figures in the Appendix does not remove the legal problem.

7. *Problems of rounding in making conversions*

We have identified several problems related to the rounding of the values obtained after multiplication of a value expressed in imperial measure by a precisely defined conversion factor. These all relate to problems of imparting spurious precision to the derived values.

Simple conversion of a precisely expressed imperial measure to metric measure does not cause difficulty since the derived value should not have more significant figures than the original. Where, however, it is not clear from the original statement of imperial measure the precision to be accorded it – as for example the statement '1 lb' rather than '1·0 lb' – then it seems reasonable to express the derived measure to two significant figures.

Conversions to metric measure of expressions in imperial measure which have already been rounded can cause difficulty, and it is desirable wherever possible to retain more significant figures than is necessary in any calculation in imperial measure, to make the final rounding in the derived metric measure.

Finally, we have found cases in which data originally determined in the c.g.s. system have been converted to imperial measure using rounded factors (e.g. 1 ounce =28 g) and the result then rounded. Back conversion of this 'secondary imperial' measure to SI using the precise conversion factor could lead to considerable error. Here appeal to the original data is essential.

We recommend that editors of journals which cater for those subjects in which imperial measure is still used should have these problems of rounding drawn to their attention. We expect these problems to be quite transitory.

8. *The expression of concentration*

We have discussed the ways in which the composition of foods and diets with respect to the elements and major and minor nutrients should be expressed, taking into consideration the views of those concerned with the compilation of food tables. We believe that no great difficulty would be caused by adhering to the principles of SI. We are however concerned, as indeed are most scientists, with the definition of the unit of mass as a kilo unit. We accordingly recommend:

(1) That compositions expressed as mass per unit mass, commonly referred to as weight per unit weight (w/w) should have as denominator the unit of mass, the kilogram. Values would thus be expressed as nanograms, micrograms, milligrams or grams per kilogram.

(2) That the same principle as (1) above should be adopted to deal with concentrations expressed as mass per unit volume, commonly referred to as weight per unit volume (w/v). The denominator should be the litre.

(3) Concentrations or composition should not be expressed on a percentage basis.

For the common ratios used in nutritional studies, such as digestibility, biological value, net protein utilization, efficiency of utilization of energy, we recommend that these are expressed as decimals rather than as percentages, so that amounts of available nutrients can be obtained from analytical data by direct multiplication.

In support of the last recommendation ((3) above) we adduce the fact that there is a growing tendency in biochemistry to avoid expression of compositional data on a percentage basis.

In addition, we recommend that all amounts of vitamins should be expressed in terms of their mass rather than in terms of international units. This recommendation involves consideration of equivalent quantities and is dealt with in paragraph 14.

ADOPTION OF THE JOULE AS THE UNIT OF ENERGY

9. *Conversion factors and methods of expression*

We agree with the conclusions of the Working Party of the British National Committee set up to consider the adoption of the joule as the unit of energy in nutritional sciences in February 1969. We here restate two of their conclusions, and comment.

(1) '*To convert existing tabulations of energy measurements expressed in terms of calories to joules the factor to be used is* 4·184 J = 1 *calorie*'.

This expresses what we believe to be true, that the calorie used by nutritionists is to be identified with the thermochemical calorie. This conversion is exact. We further state that the approximation given by the IUNS of 4·19 J = 1 calorie is incorrect, is unnecessary, and that the IUNS should be so informed. The correct conversion is 4·184 J = 1 cal_{th}.

(2) '*Rates of heat flow should be defined in terms of joules/unit time*'.

We realize that this could be interpreted as a departure from SI, for the physical quantity of power should under SI be expressed in terms of the approved derived unit, the watt (J/s). However, the second is too small a unit of time for most nutritional work, and would create difficulty in the day-to-day calculations of dietary allowances which dietitians and nutritionists make. These involve dividing energy requirements expressed as MJ/day by the specific energy of diets expressed as MJ/kg to arrive at masses of diets to be given each day or comparing the sum of the specific energies of foods consumed each day with daily energy requirement to assess the adequacy of energy intake. This does not preclude the use of the watt.

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10. *Factors limiting the adoption of the joule as the unit of energy*

We have noted that in current biochemical and nutritional journals papers are appearing in which the joule is being used rather than the calorie as the unit of energy. We have also noted that the Department of Health and Social Security (1969) has in a recent publication expressed human requirements of energy in terms of both calories and joules. We have been informed that the Ministry of Agriculture, Fisheries and Food is currently compiling the National Food Survey estimates of energy value in both kilocalories and megajoules, that the new edition of McCance & Widdowson's (1967) tables of food composition will also be in terms of calories and joules, and that the Food and Agriculture Organization Expert Committee on Energy and Protein has taken steps to implement the IUNS decision about replacement of the calorie. These steps are to be welcomed.

We realize, however, that there are a number of factors which will delay adoption of the joule. Many of these relate at a scientific level to the lack of primary tabulations of thermochemical and calorimetric data in joules and that those factors in common use in nutritional work for estimating the specific energy of foods or the heat production of animals and man are also expressed in calories. Other factors that will cause delay relate to an understandable conservatism on the part of those who have close concern with the lay public. The argument is familiar. It has taken long to make the public 'calorie conscious' and change to a new unit may well cause confusion. We comment later on this problem (paragraph 13).

11. *Thermochemical tables*

We recommend that as a matter of some urgency tabulations should be prepared for international use of the enthalpies, entropies and free energies of combustion of organic compounds (including those of nutritional relevance) in terms of kilojoules/mole. It is suggested that such compilations should be made as a result of consideration of the primary experimental data and the work should involve not only the IUNS but also the International Union of Pure and Applied Chemistry (IUPAC) and the International Union of Biochemistry (IUB).

12. *Secondary factors to be used which involve the joule*

In human and animal metabolism studies it is usual to estimate heat production from the respiratory exchange and urinary nitrogen excretion. Following Weir (1949) and Brouwer (1965) we recommend the following expressions for calculating heat production from the respiratory exchange:

$$H = 16{\cdot}18O + 5{\cdot}02C - 2{\cdot}17M - 5{\cdot}99N$$

where H represents the heat (in kJ) produced, O the volume (in dm^3*) of oxygen at s.t.p. consumed by the animal, C the volume (in dm^3*) of carbon dioxide at s.t.p. produced, M the volume (in dm^3*) of methane at s.t.p. produced, and N the mass (in g) of nitrogen simultaneously produced in the urine.

Alternatively, and more conveniently, heat production can be estimated from measurements of the volume of air expired and its composition by the following equation:

$$F = 4{\cdot}38 - 20{\cdot}9P,$$

*dm^3 = litre (see paragraph 6 for the new definition of the litre).

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where F represents the heat equivalent of expired air at s.t.p. (kJ/l) and P represents the proportion of oxygen in expired air.

In experiments in which oxygen consumption only is determined, heat production can be estimated with sufficient accuracy on the assumption that the heat equivalent of oxygen is 20 kJ/l. This heat equivalent implies that the respiratory quotient is 0·75 on the Brouwer (1965) scale. The value for heat equivalent, when the respiratory quotient is 0·81, is 20.24 and we think that in view of the assumptions involved in the indirect method of estimating heat, rounding to 20 is admissible.

We have examined the factors for computing the metabolizable energies of foods from their chemical composition to conclude that their intrinsic accuracy is low. We recommend that the (UK) National Committee encourages new work to enable better estimates to be made for the factors to be used for estimation of the specific energy of foods from their chemical composition. As an interim measure, however, we recommend the following factors:

protein	17 kJ/g
fat	37 kJ/g
carbohydrate (as monosaccharide)	16 kJ/g
ethyl alcohol (ethanol)	29 kJ/g

TERMINOLOGY AND MATTERS OF DEFINITION

13. *Terminology in energy metabolism*

The word 'energy' has several meanings besides that which it has in science. Some of these meanings are somewhat archaic but certainly 'energy' is currently used in the sense 'vitality' or 'vigour'.

The word 'calorie' does not have such a multiplicity of meaning. Lavoisier's use of the adjective 'caloric' to describe an elastic fluid now being archaic.

We recommend that editors of journals should not allow the use of the word 'calorie' and list below some obvious alternatives:

calorie intake	energy intake
calorie requirement	energy requirement
calorie value, calorific value, calorie density	specific energy, specific enthalpy of combustion, energy value
calorie balance	energy balance
calorigenesis	heat production
calorie demand (of environment)	thermal demand
protein-calorie malnutrition	protein-energy malnutrition
protein calories per cent	protein:energy ratio
net dietary protein calories per cent	net dietary protein:energy ratio
isocaloric	of equal energy value, isoenergetic

We are very much aware of the problems that arise because as a result of 30 years of education the public has an awareness of the term 'calorie'. We cannot see any easy solution to the problem of substituting the concept that man has a requirement for the energy-yielding constituents derived from food, and this is measured in joules,

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for the concept that he has a calorie requirement and that this is met by eating calories contained in food. We imagine that the popular use of terms involving the word calorie will persist long after the term has disappeared from the nutritional and dietetic literature. However, we hope that popular terms will evolve consonant with the above-mentioned scientific terms, for instance 'low calorie diet' might become 'controlled energy diet'.

14. *Generic descriptors for the vitamins and equivalent quantities*

The IUNS Committee on Nomenclature Report 'Tentative rules for generic descriptors and trivial names for vitamins and related compounds' (IUNS, 1970) states that summations of the contributions to the dietary intake of different forms of the same vitamin is a practical necessity and tentatively identifies that member of a family in terms of which the summation might be made. The IUNS suggested the following summations:

vitamin A	retinol equivalent
vitamin D	cholecalciferol equivalent
vitamin E	α-tocopherol equivalent
vitamin K	phytylmenaquinone equivalent
niacin	nicotinamide equivalent
vitamin B_{12}	cyanocobalamin equivalent
folacin	folic acid equivalent

We have considered questions of the factors to be used to arrive at summations in terms of equivalents and distinguish two divisions:

(a) Those vitamins for which there is already international agreement, namely vitamin A and niacin.

(b) Those which have not yet found universal acceptance through ratification by the IUNS, but which have been adopted by national bodies (see (USA) National Research Council, 1968).

We recommend that in the UK not only is division (a) adopted but that pending international agreement division (b) is also adopted.

15. *Internationally agreed equivalent quantities for vitamin A*

For vitamin A and its provitamins the summation should be made in terms of mass of retinol equivalent using the following factors. Attention is drawn to the relevant paragraph in the IUNS (1970) Report with respect to summation of the provitamins:

$$
\begin{aligned}
1\ \mu g \text{ retinol equivalent} &= 1\ \mu g \text{ retinol} \\
&= 1{\cdot}147\ \mu g \text{ retinyl acetate (International Standard)} \\
&= 6\ \mu g\ \beta\text{-carotene} \\
&= 12\ \mu g \text{ other active carotenoids} \\
&= 3{\cdot}33 \text{ i.u. retinol} \\
&= 10 \text{ i.u. } \beta\text{-carotene}
\end{aligned}
$$

(1 i.u. retinol = 0·3 μg retinol = 0·344 μg retinyl acetate (used for International Standard))

16. *Internationally agreed equivalent quantities for niacin*

For niacin the summation is to be made in terms of nicotinamide equivalent using the following factors:

1 mg nicotinamide equivalent	=	1 mg nicotinic amide
	=	1 mg nicotinic acid
	=	60 mg L- or DL-tryptophan

17. *Tentative equivalent quantities for vitamin D*

The IUNS suggest for vitamin D summation in terms of cholecalciferol, and the following factors are suggested for man:

1 μg cholecalciferol equivalent (man)	=	1 μg cholecalciferol
	=	1 μg ergocalciferol
	=	0·714 μg 25-hydroxycholecalciferol
	=	40 i.u.

18. *Tentative equivalent quantities for vitamin E*

The IUNS suggest for vitamin E summation in terms of tocopherol equivalents and the following factors are suggested:

1 mg α-tocopherol equivalent	=	1 mg D-α-tocopherol
	=	1·1 mg D-α-tocopheryl acetate
	=	1·36 mg DL-α-tocopherol
	=	1·49 mg DL-α-tocopheryl acetate
	=	1·49 i.u.

For practical purposes, the tocopherols other than α (e.g. β, γ and δ), because of their relatively lower potency than the α-form, are disregarded in dietary calculations and evaluations. One international unit of vitamin E is 1 mg of DL-α-tocopheryl acetate. The natural form D-α-tocopheryl acetate, has a potency of 1·36 i.u./mg. The free alcohol, DL-α-tocopherol, has 1·1 i.u./mg and D-α-tocopherol has 1·49 i.u./mg.

19. *Tentative equivalent quantities for 'folacin' (or folic acid)*

In the folic acid group of vitamins, the IUNS (1970) recommend 'folacin' as the generic descriptor, while the IUPAC (1970) use the generic descriptor 'folic acid' (IUPAC–IUB, 1960, 1967). Without predicting what will be the eventual conclusion about nomenclature of the generic descriptor, the factors to derive equivalent quantities can be stated to be:

1 μg folacin equivalent = 1 μg 'free folate'

Free folate is defined as the amount of folic acid activity measured by *Lactobacillus casei* assay without conjugase treatment. The higher conjugates are for the time being not included in view of the uncertainty of the extent to which they are absorbed (see WHO, 1970).

20. *Equivalent quantities of other vitamins*

We have no recommendations to make with respect to vitamin B_{12} or vitamin K or other accessory food factors.

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APPENDIX. CONVERSION FACTORS

Rounded to four significant figures, except where the exact relation contains four figures or less

Length	1 inch	*25·4 mm
	1 foot	*0·3048 m
	1 yard	*0·9144 m
	1 mile	1·609 km
Area	1 square inch (in^2)	645·2 mm^2
	1 square foot (ft^2)	0·092 90 m^2
	1 square yard (yd^2)	0·8361 m^2
	1 acre	4047 m^2 (0·4047 ha)
Volume	1 cubic inch (in^3)	16·39 cm^3
	1 cubic foot (ft^3)	0·028 32 m^3 (28·32 dm^3)
	1 cubic yard (yd^3)	0·7646 m^3
Capacity	1 fluid ounce	28·41 cm^3 (0·028 l)
	1 pint	0·5683 dm^3 (0·568 l)
	1 gallon	4·546 dm^3 (4·546 l)
Mass	1 ounce	28·35 g
	1 pound	0·4536 kg
	1 stone	6·350 kg
	1 hundredweight	50·80 kg
	1 ton	1016 kg (1·016 tonne)
Energy	1 thermochemical calorie	*4·184 J
	1 British thermal unit	1·055 kJ

*Denotes exact relation.

Note. These conversion factors have been rounded up or down in accordance with the normal arithmetical rules. They will not in all cases be suitable for trading purposes, as defined in the Weights and Measures Act 1963. Where conversion factors are so used, it is always necessary for them either to be exact or to be rounded in the customer's favour.

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