S.I. units and nomenclature in soil science

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1 atmosphere corresponds to pF 3.014 and similarly
10 atmospheres correspond to pF 4.014 and so on
Thus in S.I. units, pF 3.0 = 101.325 kN m^{-2} and the three commonly used values of tension to determine water retention by soils are

pF 2.014 or 10.132 5 kN m^{-2} (1/10 atmosphere)
pF 2.537 or 33.775 kN m^{-2} (1/3 atmosphere)
pF 4.190 or 1 519.875 kN m^{-2} (15 atmospheres)

To measure pF values from tension recorded in kilonewton the following expression can be calculated.

if tension is T kN m^{-2}, then
$pF = \lg (T \times 10^{1}) - 2$

FOOD
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FOREWORD

This short Bulletin is intended primarily to make all soil scientists in FAO and their counterpart staff aware of the Système International d'Unités - a system of physical units rapidly becoming adopted all over the world - with particular reference to its application to the discipline of soil science.

FAO soil scientists are working in many different countries each of which has its own national units of measurement. However, it is often desirable to convey results obtained from one country to another and for this, a commonly understood system of units and nomenclature is necessary.

Then, as it is essential to adopt an internationally acceptable system of units, it would be logical and sensible to adopt the S.I. which is already legally recognized in a great many, if not most, countries.

Naturally, the adoption of a new system cannot take place instantaneously and it is not expected that the S.I. be strictly adhered to as from this moment. Nevertheless, every effort should be made to familiarize oneself with the system and to use it when feasible. In the early stages of the changeover, it may be advisable to include the better known traditional units in parenthesis for the benefit of the uninitiated.

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Acknowledgements

In order to compile this Soils Bulletin several publications have been consulted but special mention must be made of the monograph by M.L. McGlashan entitled Physico-chemical Quantities and Units and of the various pamphlets issued by the British Institute of Standards.

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1. INTRODUCTION

Primitive units for measuring quantities were essentially of a practical nature. Thus the English unit of length, the foot, came from the length of an average man's foot and the height of horses is still measured in 'hands'.

The various units used in Europe for the quantity of length alone, include mile, foot, yard, metre, inch, chain, fathom and furlong – not to mention rods, poles and perches; and other countries have their own specialized terms such as 'guz' in Pakistan and 'arraa' in Syria.

It is quite obvious that the adoption of one, internationally acceptable unit for each basic quantity is not only desirable, but imperative and this is especially so in the field of science and technology. In soil science, such terms as acre-six-inch, ^{o}F, p.s.i. and so on, although still used, are quite indefensible and in the not too distant future will probably be classified with phlogiston.

The first really rational approach to the problem was the decimal system. The idea of a decimal unit system was conceived by a Frenchman, Stevin, in the late 16th century and the general adoption of a metric system was established in France by Talleyrand after the Revolution. In those early days two main units were defined; these were the gramme as unit of mass and which was defined in terms of one cubic centimetre of water at freezing point and, the metre as unit of length (the metre was defined in the extraordinary manner as being one ten millionth of the distance at sea level between the north pole and the equator, via Paris).

Later, the second, as unit of time was added and thus the c.g.s system came into being. In the early 20th century, the metre was re-introduced for length (having been changed to the centimetre) and the unit of mass was changed to the kilogramme, giving the m.k.s. system. By 1950 the fourth unit, ampere, had been adopted for electrical current giving the m.k.s.a. system. This change, among other things, provided a link between mechanical and electromagnetic concepts and was acceptable to scientists and practical engineers alike.

Since the late 19th century, the Conférence Générale des Poids et Mesures (CGPM) has been the international authority on units. Amongst other actions, the CGPM controls the Bureau International des Poids et Mesures (BIPM) which in its laboratory at Sèvres keeps the standard kilogramme. At one time this laboratory also kept the standard metre (which had been simplified from its original distance calculation) but nowadays the metre is defined in terms of wavelength (see Appendix I).

In 1954 the CGPM agreed upon a system of units based upon the four m.k.s.a. units, and with two additional units, the kelvin for temperature and the candela for luminous intensity. In 1960 this system was formally named the "Systême International d'Unités" now known in all languages as 'S.I. Units'.

With regard to nomenclature, the International Organization for Standarization (ISO) and its technical committee has its headquarters in Copenhagen and is responsible for the comprehensive publication (in several volumes) dealing with physical quantities in the various fields of science and technology. For chemistry, the International Union of Pure and Applied Chemistry (IUPAC) is the responsible body and similar unions exist for other disciplines.

In order to ensure complete uniformity and agreement between these various bodies and national governments, the International Organization for Legal Metrology (OIML) was set up. It is not inconceivable that all these international bodies may be incorporated into the United Nations one day. By 1965 over thirty countries from Korea to Brazil (a notable exception being the USA) had made the system of the CGPM the only legally accepted system.

It should not be assumed that the questions of units and nomenclature are now completely and finally settled. Many matters remain to be decided upon and not all the decisions of the international committees have been internationally accepted. The CGPM itself is still in the throes of debate; some of its subsidiary bodies have unilaterally decided upon certain terms, yet to receive the blessing of the parent body and some independent organizations and individuals are in open revolt.

However, like it or not, the Systême International d'Unités is here to stay and it behoves every scientist and technologist whatsoever his discipline, to at least know about the system. Our children are, willy nilly, learning it at school and most printed works of science (including journals of soil science) are now using it.

Although there is undoubtedly room for improvement and grounds for complaint, the S.I. is definitely a step in the right direction and deserves the support, in principle, of all scientists.

2. S.I. UNITS

2.1 General

The Système International d'Unités is a rationalized, coherent [1] system of metric units which derives all the quantities needed in all technologies from only six basic units.

These six basic units are:

Quantity	Name of unit	Symbol
Length	metre	m
Mass	kilogramme	kg
Time	second	s
Temperature	kelvin	K
Electric current	ampere	A
Luminous intensity	candela	cda

These units can be used as such or in fourteen multiples which are:

Tera	(T)	and which is 10^{12}	Centi	(c)	10^{-2}
Giga	(G)	10^{9}	Milli	(m)	10^{-3}
Mega	(M)	10^{6}	Micro	(μ)	10^{-6}
Kilo	(k)	10^{3}	Nano	(n)	10^{-9}
Hecto	(h)	10^{2}	Pico	(p)	10^{-12}
Deca	(da)	10^{1}	Femto	(f)	10^{-15}
Deci	(d)	10^{-1}	Atto	(a)	10^{-18}

Thus length may be expressed as metre (m) or kilometre (km) or millimetre (mm) or nanometre (nm) and so on.

The unit symbols are printed in upright (Roman) type, are unaltered in the plural and are not followed by a full stop (except at the end of a sentence). For example, we write 3 km and not 3 km. or 3 kms. No space is left between the multiple prefix and the basic unit, e.g. nm and not n m. The first of these expressions, nm, stands for nanometre, 10^{-9}m, whereas the second expression, n m, means n x m which may be something quite different. (Compound prefixes must not be used; i.e. mm is used for 10^{-3} m and not cdm.) A space must be left between two S.I. units written as a multiple; i.e. kg dm^{-3} and not kgdm^{-3}.

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[1] "A system of units is coherent if the product or quotient of any two units is the unit of the resultant quantity". This means, for example, that unit area results when unit length is multiplied by unit length; thus in a coherent system the square foot is the area if the unit length is one foot. The resulting area would not be in the coherent system if expressed in acres, hectare or sq. miles.

This follows from the rule that if a multiple of a basic unit is raised to a power, the power applies to the whole multiple and not to the basic unit alone; thus, $1\ \mathrm{km}^3 = 1\ (\mathrm{km})^3 = \mathrm{k}^3\mathrm{m}^3 = (10^3)^3\ \mathrm{m}^3 = 10^9\mathrm{m}^3$.

Arbitrary names such as micron for micrometre, can no longer be used. It has been recognized however, that some departure from strict purity is acceptable; for example, minutes,hours and days may be used in every-day parlance and the word litre may be used as a verbal reference to the cubic decimetre. In all calculations, formulae and equations however, the basic units only may be used.

The definition of each basic unit is given in Appendix I.

It will be noticed that the system has apparently broken its own rules by postulating what appears to be a decimal multiple as a basic unit. This is the unit of mass, the kilogramme. Logically the basic unit should be the gramme but this cannot be if the m.k.s. system is to be retained. However, multiples of the unit follow conventional practice and we do not, for example, refer to a kilokilogramme (kkg) or to a millikilogramme (mkg) but to a megagramme (Mg) and a gramme (g) respectively. Note that the gramme is not itself an S.I. unit.

The names given to the S.I. basic units and their symbols are mandatory and have been internationally agreed upon.

After the six basic units had been decided, it was found that a unit to define amount of substance was needed, especially in the field of chemistry. Thus a seventh basic unit, the mole (symbol mol), although not yet accepted by the CGPM, is expected to be so and is here considered as such.

The S.I. includes two more units which are dimensionless, the radian (rad) and the steradian (sr) for the quantities plane angle and solid angle respectively.

2.2 Derived units

Each of the basic units has resulted in various derived units; for example area and volume are derived from the basic unit of length and density is derived from length and mass.

All derived units are formed by mathematical manipulation of basic units; that is, by multiplication, division, differentiation or integration. No numerical factors are involved and thus the derived factors remain in the coherent system.

Those derived units relevant to soil science are listed in the following table which also shows some of the units commonly used and which are to be discarded. Certain derived units have been given special names and symbols; these are indicated in the table but it should be noted that not every one has been accepted yet by the CGPM.

SOME DERIVED S.I. UNITS AND CORRESPONDING NON-S.I. UNITS [1]

Quantity	S.I. unit	Special name	Non-S.I. units
Area	m^{2}	–	acre, hectare, sq.in. etc
Volume	m^{3}	–	litre, ml, cc, pint, etc
Velocity	m s^{-1}	–	m.p.h., etc
Angular velocity	rad s^{-1}	–	–
Volume flow	$\text{m}^{3}\ \text{s}^{-1}$	–	cusecs
Density	kg m^{-3}	–	g/cc etc
Surface tension	kg s^{-2} (N m^{-1})	–	dynes/cm
Dynamic viscosity	$\text{kg m}^{-1}\ \text{s}^{-1}$ (N s m^{-2})	–	dynes sec/cm^{2}, centipoise
Kinematic viscosity	$\text{m}^{2}\ \text{s}^{-1}$	–	centistokes
Diffusion coefficient	$\text{m}^{2}\ \text{s}^{-1}$	–	–
Pressure	$\text{kg m}^{-1}\ \text{s}^{-2}$ (N m^{-2})	pascal (Pa)	atmosphere, bar, mmHg, psi, etc
Force	kg m s^{-2}	newton (N)	lbf, etc
Work, Energy	$\text{kg m}^{2}\ \text{s}^{-2}$	joule (J)	ergs
Quantity of electricity	A s	coulomb (C)	–
Electric potential, emf, potential difference	$\text{kg m}^{2}\ \text{s}^{-3}\ \text{A}^{-1}$ $(\text{J s}^{-1}\ \text{A}^{-1})$ $(\text{N m s}^{-1}\ \text{A}^{-1})$	volt (V)	–
Electrical resistance	$\text{kg m}^{2}\ \text{s}^{-3}\ \text{A}^{-2}$ (V A^{-1})	ohm (Ω)	–

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[1] Units in parenthesis are alternative ways of expression using the units with special names.

Quantity	S.I. unit	Special name	Non-S.I. units
Electric conductance	$\mathrm{kg}^{-1}\ \mathrm{m}^{-2}\ \mathrm{s}^{3}\ \mathrm{A}^{2}\ (\Omega^{-1})$	siemens (S)	mho, mmho, etc
Conductivity	$\mathrm{kg}^{-1}\ \mathrm{m}^{-3}\ \mathrm{s}^{3}\ \mathrm{A}^{2}\ (\mathrm{S\ m}^{-1})$	-	mhos/cm, etc
Concentration	$\mathrm{mol\ m}^{-3}$	-	g/l, etc
Specific volume	$\mathrm{m}^{3}\ \mathrm{kg}^{-1}$	-	cc/g, etc
Radio-activity	s^{-1} (Hz)	-	curie (Ci)
Specific radio-activity	$\mathrm{s}^{-1}\ \mathrm{kg}^{-1}$	-	d. $\mathrm{min}^{-1}\ \mathrm{g}^{-1}$
Molality	$\mathrm{mol\ kg}^{-1}$	-	moles/1000 g
Avagadro constant	mol^{-1}	-	atoms/g-atom ions/g-ion
Frequency	s^{-1}	hertz (Hz)	c.p.s.

2.3 Some rules of the "Système International d'Unités"

Certain rules have been (or will be) discussed in other and more relevant parts of the text; this short section summarizes remaining points to be noted.

i. For all calculations, equations etc, basic units must be used and not their multiples; this ensures keeping within the coherent system. Thus whereas an incubation of soil may be talked about in terms of hours or days, any calculations involving the period of incubation must be made in seconds. Similarly, all weights (mass) used in calculations must be expressed in kilogramme - even if they are actually of the order of microgramme or tons.

As an example consider the calculation of calcium carbonate equivalent from the data of a manometric experiment. Using non-S.I. units, the calculation is made using the expression:

$$\% \text{ CaCO}_3 \text{ equiv.} = \frac{\text{cc CO}_2}{\text{wt of sample(g)}} \times \frac{\text{Pressure (mmHg)}}{(^\circ\text{C} + 273)} \times 0.16$$

The same expression using S.I. units becomes:

$$\% \text{ CaCO}_3 \text{ equiv.} = \frac{\text{vol. of CO}_2}{\text{wt of sample}} \times \frac{\text{Pressure}}{\text{Temperature}} \times 1.22$$

where it is understood that volume is expressed in m^3, weight in kg, temperature in kelvin and pressure in kg m^{-1} s^{-2}.

ii. The special names given to some units are not given an initial capital letter. The symbols also are not given capital letter unless they are derived from a person's name. For example, we write one newton as 1 N and two siemens as 2 S but four seconds as 4 s. (Note that the terminal s of siemens is part of the unit name and does not imply a plural, 1 S is one siemens.)

iii. The prefix or its symbol should always be written immediately adjacent to the basic unit; e.g. picosecond or ps. This is particularly important to avoid confusion between m for metre and m for milli.

iv. The accepted spelling of the unit of mass is kilogramme. Hence we write, for example, gramme and not gram or grams for g and its multiples.

v. The word 'specific' now exclusively means 'per unit mass'. For example, specific volume is volume/mass. If the extensive quantity is denoted by a capital letter then the specific quantity can be denoted by the same letter in lower case; e.g. specific volume v, is given by $v = V/m$.

vi. Numbers: the decimal sign for numbers should be a dot on the line; e.g. 1.45. Dots or commas must not be used to separate large numbers into groups as, for example, 24,323,000. Instead a space is left, 24 323 000.

For logarithms, log or $\log_{10}$ is now written lg and $\log_e$ is written ln.

vii. The Solidus: the use of the solidus or stroke, / , is now controlled. When unit symbols are combined as a quotient, e.g. kilogramme per litre, it is recommended that a negative power be used; i.e. kg dm^{-3}. Similarly, metre per second is written m s^{-1} and so on.

The solidus may be used:-

a) if units are written out in full; e.g. metre/second

b) to separate a mathematical quantity and a unit. This is used particularly in table headings and for graph axes; e.g. V/m^3 means volume in cubic metre.

viii. The value of any physical quantity is equal to a numerical value multiplied by a unit and neither the physical quantity nor its symbol should imply a particular unit. For example it is incorrect to say that density ρ, is given by $\rho = m/V$ where m is the mass in kilogramme and V the volume in cubic metre. All that should be said, if anything, is where m is the mass and V the volume.

Similarly it is incorrect to write that density $= \rho$ kg dm^{-3}, as if, say, the density is 15 kg dm^{-3}, then we would be stating that density = 15 kg dm^{-3} kg dm^{-3}.

SOIL CHEMISTRY

The following is an outline of those S.I. units and nomenclature of particular relevance to soil chemistry. Many scientific quantities however, cannot be apportioned categorically to one specific discipline and thus certain of the subjects discussed here, temperature for instance, are also the concern of section (4) - Soil Physics - and vice versa.

Concentration

Although verbal reference may still be made to quantities of volume as litre, millilitre and so on, written units of volume must always be in terms of the cubic metre. Thus ml, cc, l, /ml, /l are written as cm^3, cm^3, dm^3, cm^{-3}, dm^{-3} respectively. Modern graduated glassware is now marked in S.I. units of volume.

It follows that a standard solution of sodium chloride will be written, for example, as 2.314 g dm^{-3} NaCl and not as 2.314g/l NaCl. (Again it is emphasized that if equations or formulae are involved, then all units must be basic and not multiples; i.e. volumes must be in m^3 and mass in kg. Thus our standard solution would have a concentration of 2.314 kg m^{-3}.)

The commonly used term 'parts per million' will now be written not as p.p.m. but as $\mu g\ cm^{-3}$ as far as solutions are concerned and $\mu g\ g^{-1}$ for solids.

The concept of 'normal' solutions and of equivalent weights has been abolished. Instead, use of the basic unit mole has been introduced. The mole is the amount of substance which contains as many elementary units as there are atoms in 0.012 kg of carbon-12. These elementary units must be specified and may be atoms, ions, molecules and so on.[1] For example, 1 mole of sodium chloride has a mass equal to 0.05845 kilogramme and, one mole of carbon dioxide has a mass of 0.044 kg.

The unit mole replaces such terms as gramme-molecule, gramme-atom and gramme-equivalent. Thus we speak of one mole of hydrochloric acid and not one gramme molecule of HCl; and instead of referring to one equivalent of H_2SO_4, we refer to one mole of $\frac{1}{2}\ H_2SO_4$.

Consequently, what used to be referred to as a 0.1 normal (0.1 N or sometimes 0.1 n) solution of KCl is now defined as a solution containing 0.1 mol dm^{-3} KCl. For the sake of convenience (e.g. to label a flask) it is permitted to refer to such a solution as being 0.1M. Similarly, a normal solution of sulphuric acid is referred to as being 0.5M.

Under no circumstances may the term 'molar' be used in place of the symbol M. The word molar exclusively means 'divided by amount of substance'. For example molar volume is volume divided by the amount of substance and is expressed as $Vm = V/n$. It does not necessarily have any connection with the unit mole and can hence lead to confusion. Usually, however, it does mean 'per mole' and in such a case (which must be specified) the molar volume of water is approximately 18 $cm^3\ mol^{-1}$ and the molar volume of a gas at s.t.p. is 0.022 414 $m^3\ mol^{-1}$.

3.2 Ion exchange properties

Loss of the terms 'normal' and 'equivalent' will no doubt confuse the chemist at first but of more importance to soil scientists is the fact that expression of

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[1] See Appendix I.

ion exchange data should presumably no longer be made in milliequivalents. The international committee has not specifically pronounced on this matter but as the equivalent has definitely been abolished in favour of the mole we must assume that exchangeable ions are to be reported in millimole (mmol). Similarly, the convenience of balancing the results of an analysis by the sum of the cations equalling the sum of the anions, has to be reconsidered. No great difficulty arises when referring to ions of the same valency; for example, 1 m.e. of potassium is simply 1 mmol of potassium and 1 m.e. of calcium is 0.5 mmol of calcium. The difficulty arises when attempting to define cation exchange capacity or total exchangeable bases.

It is suggested (and this suggestion of course has not the approval of the CGPM) that the exchange capacity of a soil could be expressed in millimole percentage if it is assumed that monovalent ions are implied; for example, if the C.E.C. is stated as 60, then 60 mmol per 100 g of soil is meant and that 100 g of soil can hold 60 x 1 mmol Na^+, or 60 x $\frac{1}{2}$ mmol Ca^{2+} or 60 x 1/3 mmol Al^{3+} and so on. The exchange capacity could be written as mmol (I) per 100g (instead of m.e. per 100g), the (I) indicating the valency. Similarly, T.E.B. could be expressed as mmol (I) per 100g.

3.3 Conductivity

The electric conductivity of solutions is now expressed as milli (or micro) siemens per centimetre, i.e. mS cm^{-1} or μS cm^{-1}. As 1 mS = 1 mmho, no conversion factors for past results are needed and instruments graduated in multiples of mhos can be read directly in multiples of siemens. However, modern conductivity meters (except possibly those manufactured in America) are graduated in siemens. The symbol for conductivity is either σ or κ ; and the symbol for conductance is G, thus one refers to $\sigma \times 10^3$ rather than EC x 10^3.

3.4 Temperature

The new unit for thermodynamic temperature and for thermodynamic temperature interval is the kelvin with symbol K (not °K or deg. K or k) and temperature is measured in kelvin (not degree kelvin). The kelvin scale of temperature is the absolute scale and thus 0 °C = 273.15 kelvin.

The degree Celsius (°C) is a unit of thermodynamic temperature <u>interval</u> identical with the kelvin.

$$\begin{array}{llll}
\text{Thus,} & T_1 = 393.35\text{ K} & \text{but not } 393.35\ ^\circ\text{C} & (\text{actually } 120.20\ ^\circ\text{C}) \\
 & T_2 = 251.15\text{ K} & \text{but not } 251.15\ ^\circ\text{C} & (\text{actually } \underline{-22.00\ ^\circ\text{C}}) \\
 & (T_1 - T_2) = 142.20\text{ K} & \text{or } 142.20\ ^\circ\text{C} & (\qquad\qquad 142.20\ ^\circ\text{C})
\end{array}$$

It will no doubt take time before the degree Celsius disappears from science although it is now quite redundant, but in all formulae, calculations and so on, the kelvin must be used.

3.5 Colorimetry

Wavelength is now expressed in terms of the metre and usually the multiple nanometre (nm) is used. Thus the optimum wavelength for determining phosphorus with vanadomolybdate is written as 470 nm and not as 470 mμ or 4700 Å. Modern spectrophotometric instruments are calibrated in nanometre and no longer in millimicron.

The ultra-violet range of spectrum is 185 – 400 nm
the visible " " " " 400 – 760 nm
the infra-red " " " " 760 – 15 000 nm.

It may be noted that the abolition of the Ångström as a unit has caused much dissatisfaction, particularly among those dealing with X-ray analysis, for example clay mineralogists.

The terms optical density, extinction and absorbance are now more accurately, decadic absorbance (or sometimes decadic extinction) and its recommended symbol is A.

$A = \lg (1/T)$ where T is the transmittance, defined as $T = I_t/I_o$; I_o being the intensity of incident light and I_t the intensity of transmitted light.

3.6 Elements, Nuclides, Isotopes and Compounds

Fortunately no changes have been made in the symbols for chemical elements; it should, however, be noted that mass numbers should be placed as superscripts on the left-hand side, e.g. ^{15}N and ^{14}C, not N^{15} or C^{14}.

The right-hand superscript position is reserved exclusively for denoting states of ionization, excitation or valency.
Thus,

Cl^- SO_4^{2-} Al^{3+} Ca^{2+} and so on (not SO_4^{--} , Al^{+++})

and $K_4Fe^{II}(CN)_6$.

The recommended symbol for the relative atomic mass of an element (atomic weight) is A_r ; thus A_r (Cl) = 35.453 and similarly the symbol for relative molecular mass of a substance (molecular weight) is M_r ; e.g. M_r (NaCl) = 58.443.

Special names such as cuprous or ferric, to indicate valency differences are no longer used. The written names of compounds containing metals should have the numerical value of the state of oxidation included as Roman numerals in brackets after the name of the metal:

e.g.	Cuprous oxide	is now written	copper (I) oxide
	Cupric oxide	" " "	copper (II) oxide
	Ferrous sulphate	" " "	iron (II) sulphate
	Stannic chloride	" " "	tin (IV) chloride
	Manganese dioxide	" " "	manganese (IV) oxide

and a more complicated example is red lead or triplumbic tetroxide, which is now written as Dilead (II) lead (IV) oxide.

Names of compounds derived from metals (i.e. anions containing metals) should always end in '...ate' and Roman numerals used if necessary:

e.g. $KAlO_2$ is potassium aluminate

$K_4Fe(CN)_6$ formerly called potassium ferrocyanide, is potassium hexacyano ferrate (II).

$K_3Fe(CN)_6$ formerly potassium ferricyanide, is potassium hexacyano ferrate (III).

$SnCl_6^{2-}$ is hexachlorstannate (IV).

In non-metallic compounds the stoichiometric proportions of the elements are denoted by Greek numerical prefixes; thus PCl_5 is called phosphorus pentachloride[1] and NO is nitrogen monoxide, not nitric oxide; similarly NO_2 is nitrogen dioxide (not peroxide) or in the case of pure dimer, dinitrogen tetroxide, and N_2O is dinitrogen oxide.

Salts with ionizable hydrogen are named thus:
$NaHCO_3$ is sodium hydrogen carbonate and not sodium bicarbonate. This means that logically Na_2SO_4 should be called sodium tetraoxosulphate but to date the more familiar names for such compounds are being allowed.

The following is a short list of other chemical compounds, commonly encountered in soil science, which have names different to those we have been accustomed to. The list is by no means exhaustive but rather intended to be representative. Most manufacturers of chemicals are nowadays labelling their products with the new names and so it is essential to be able to recognize them.

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[1] But note that P_2O_5 is Tetraphosphorus decoxide.

Common name	Approved name
Ammonium hydroxide	Ammonia solution
Ammonium persulphate	Ammonium peroxodisulphate
Ammonium metavanadate	Ammonium trioxovanadate (IV)
Ammonium (etc) acetate	Ammonium (etc) ethanoate
Alcoholic potash	Potassium hydroxide (ethanolic)
Aniline	Aminobenzene
Acetic acid	Ethanoic acid
Acetylene	Ethyne
Butyric acid	Butanoic acid
n-Butyl alcohol	Butan-1-ol
sec-Butyl alcohol	Butan-2-ol
Cuprammonium sulphate	Tetrammine copper (II) sulphate
Ethyl bromide	Bromoethane
Ethyl mercaptan	Ethanethiol
Ethylene	Ethene
Ether (Diethyl ether)	Ethoxyethane
Ferric chloride	Iron (III) chloride
Ferrous ammonium sulphate	Iron (II) ammonium sulphate
Formaldehyde	Methanal
Methyl ethyl ketone	Butanone
Potassium bicarbonate	Potassium hydrogen carbonate
Polythene	Polyethene
Polyvinyl chloride	Polychloroethene
Pyruvic acid	3-Oxopropanoic acid
Sodium stearate	Sodium octadecanoate
Succinic acid	Butane-1, 4-dioic acid

3.7 Radioactivity

The unit curie (C or Ci) is no longer used to express radioactivity which is defined with the basic S.I. unit of time, the second.

$$1 \text{ curie} = 3.7 \times 10^{10} \ s^{-1}$$

Thus, for example, instead of speaking of a solution labelled with 60 µCi P^{32}, we now say labelled with $2.22 \times 10^{6} \ s^{-1}$ ^{32}P.

Similarly, the total gramma-radioactivity from the thorium family (for example) at the µg g^{-1} level, is expressed as 21.09 s^{-1} per kg soil, rather than as 57µµC/100g soil.

4. SOIL PHYSICS

As indicated under section (3), many of the subjects discussed under the heading of soil chemistry or of soil physics really belong to both sections and no clear-cut distinction can be made.

4.1 Mechanics

4.1.1 Pressure

Pressure is no longer measured in centimetre of water, millimetre of mercury, bars, atmospheres etc., but in pascal.

A pascal (symbol Pa) is one newton per square metre (1 N m^{-2}) and a newton is defined as the force necessary to give an acceleration of one metre per second squared to a mass of one kilogramme.

Thus in basic S.I. units, pressure is measured in kg m^{-1} s^{-2}.

The relevant conversion factors and inter relationships are:

1 atmosphere = 101 325 Pa = 101 325 N m^{-2} = 101 325 kg m^{-1} s^{-2}
or, as it is more usual in soil science to employ kilonewton,
1 atmosphere = 101.325 kN m^{-2}.

Similarly, 1 p.s.i. (pound per sq. inch) = 6.89 kN m^{-2}
1 cm of water = 0.098 kN m^{-2}
1 mm of mercury = $13.5951 \times 9.806\ 65$ N m^{-2}
1 bar = 10^{5} N m^{-2}

pF values:

As the pF value is the logarithm to base ten of the height (in cm) of a water column equivalent to a given tension, 1 atmosphere corresponds to pF 3.014

and similarly 10 atmospheres correspond to pF 4.014 and so on. Thus in S.I. units, pF 3.0 = 101.325 kN m^{-2} and the three commonly used values of tension to determine water retention by soils are:

pF 2.014	or	10.132 5 kN m^{-2}	(1/10 atmosphere)
pF 2.537	or	33.775 kN m^{-2}	(1/3 atmosphere)
pF 4.190	or	1519.875 kN m^{-2}	(15 atmosphere)

To measure pF values from tension recorded in kilonewton the following expression can be calculated,

If tension is T kN m^{-2} , then

$$pF = \lg (T \times 10^3) - 2$$

4.1.2 Density

Density is measured in kg m^{-3} and its recommended symbol is ρ. Thus the bulk density or particle density of a soil should not be reported in the units g/cc.

On the large scale of soil management, it has been customary to use such expressions as "an acre six inch of soil weighs 10^6 x 2 lb." Strictly speaking one should now say that 680 m^3 of soil weigh 10^6 kg for the same quantity. However, this loses the practical usefulness of the expression and it would surely be admissable to report a hectare (more strictly 10^4 m^2) 15 cm of soil as weighing 2.2 x 10^6 kg. Relative Density, symbol d, (written in italics) has, of course, no units. The term supersedes the name 'specific gravity' which applied only when water was the reference substance. When using the term relative density, both the substance under examination and the reference substance should be specified.

4.1.3 Viscosity

The quantity of viscosity enters into soil physics when considering water movement (intrinsic permeability for example), mechanical analysis (Stoke's Law) and the study of colloids. It is now expressed in kg m^{-1} s^{-1} and not in dyne sec/cm^2.

Consider Stoke's Law for example. This is usually expressed as:

$$v = \frac{2}{9} \frac{(dp - d)\, g\, r^2}{\eta}$$

where v is the velocity in cm/sec of a particle radius r cm and density dp in g/cc, falling through a liquid of density d and viscosity η dynes sec/cm^2.

If we convert all values to basic S.I. units, that is, to m, s, kg and remembering to express η in terms of $\mathrm{kg\ m^{-1}\ s^{-1}}$, we find that exactly the same expression gives the velocity, v, in $\mathrm{m\ s^{-1}}$.

However, it may be that all formulae do not yield the correct result if the units are changed in this manner and it is advisable to make careful calculations so as to finish with a correct formula completely in S.I. basic units and strictly coherent.

4.1.4 Surface tension

Surface tension is now measured in $\mathrm{N\ m^{-1}}$ or, more strictly, in $\mathrm{kg\ s^{-2}}$.

4.2 Thermodynamics

Some facts of thermodynamics (other than straightforward temperature measurement) relevant to soil science can be summarized thus:

i. A calorie 15° C = 4.1855 J
ii. Quantity of heat is measured in joule, where $\mathrm{J = kg\ m^{2}\ s^{-2}}$.
iii. Thermal conductivity is measured in $\mathrm{J\ s^{-1}\ m^{-1}\ K^{-1}}$, or $\mathrm{W\ m^{-1}\ K^{-1}}$ where W is the unit watt and $\mathrm{W = kg\ m^{2}\ s^{-3}}$.
iv. Heat capacity is measured in $\mathrm{J\ K^{-1}}$ (and must on no account be called specific heat).
v. Specific heat capacity (previously called specific heat) is measured in $\mathrm{J\ kg^{-1}\ K^{-1}}$.

   Thus the specific heat capacity of water is 4.185 5 joule per kilogramme per kelvin and that of sand is about 0.8 $\mathrm{J\ kg^{-1}\ K^{-}}$ and that of loam about 1.1 $\mathrm{J\ kg^{-1}\ K^{-1}}$.
vi. Specific latent heat (previously called Latent Heat) is expressed in $\mathrm{J\ kg^{-1}}$.

4.3 Miscellaneous

Hydraulic conductivity	is expressed in	$\mathrm{m\ s^{-1}}$	
Hydraulic head	"	m	
Soil water pressure head	"	m	
Water diffusivity	"	$\mathrm{m^{2}\ s^{-1}}$	
Water flow	"	$\mathrm{m^{3}\ s^{-1}}$	(and not in cusecs or c.f.s.)
Soil water flux	"	$\mathrm{m\ s^{-1}}$	(except in every-day parlance when $\mathrm{m^{3}}$/day is used).

Moisture tension	is expressed in	kg m s^{-2}
Hygroscopicity	"	m^{3}
Moisture potential (ergs/g)	"	m^{2} s^{-2}
Osmotic pressure	"	N m^{-2}
Compressibility	"	m^{2} N^{-1}
Shear modulus	"	N m^{-2}
Rate of reaction	"	mol s^{-1}
Porosity	"	cm^{3} cm^{-3}
Specific surface area	"	m^{2} kg^{-1}
Dispersion coefficient of solute	"	cm^{2} s^{-1}
Gas constant (R)	is 8.314 kg m^{2} s^{-2} K^{-1} mol^{-1}	
Faraday constant (F)	is 9.648 70 x 10^{4} A s mol^{-1}	
Planck constant (h)	is 6.625 6 x 10^{-34} J s	
Rydberg constant (R_{∞})	is 1.097 373 1 x 10^{-7} m^{-1}	

Sieve mesh size is measured in mm and thus we refer to, say, 0.15 mm soil and not to 100-mesh soil (see Appendix III).

APPENDIX I

DEFINITIONS OF BASIC S.I. UNITS

Metre	The metre is the length equal to 1 650 763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels $2p_{10}$ and $5d_5$ of the krypton-86 atom.
Kilogramme	The kilogramme is equal to the mass of the international prototype of the kilogramme. (The prototype is a piece of platinum-irridium kept at the BIPM at Sèvres. It is expected to be replaced by an alternative definition dependent upon an atomic phenomenon.)
Second	The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom.
Ampere	The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed one metre apart in a vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length.
Kelvin	The kelvin is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. (The triple point of water is the temperature at which the three physical forms of water, i.e. liquid, solid and vapour, are co-existant. At 0 °C the vapour pressure of liquid water and ice is about 613 N m^{-2} or 4.6 mm, and so the conditions for the triple point to exist are brought about by lowering the pressure from the normal 101.33 kN m^{-2} or 760 mmHg, to 613 N m^{-2}.)
Candela	The candela is the luminous intensity, in a perpendicular direction, of a surface of 1/600 000 square metre of a black body at the temperature of freezing platinum under a pressure of 101 325 N m^{-2}.

Mole The mole is the amount of substance which contains as many elementary units as there are atoms in 0.012 kilogramme of carbon-12. The elementary unit must be specified and may be an atom, a molecule, an ion, a radical, an electron, a photon, etc., or a specified group of such entities.

(The number of entities per mole involved is $6.022\ 52 \times 10^{23}\ \mathrm{mol}^{-1}$ and is called the Avagadro constant.)

NON-S.I. UNITS OR UNITS WITH NON-S.I. NAMES DEFINED IN TERMS OF THE S.I.

Physical Quantity	Name of unit	Non-S.I. symbol	S.I. definition of unit
Length	ångström	Å	10^{-10} m
	micron	μ	10^{-6} m = μm
	millimicron	μ	10^{-9} m = nm
	mile	m	1 609.344 m = 1.609 344 km
	yard	yd	0.914 4 m = = 91.44 cm
	foot	ft	0.304 8 m = 30.48 cm
	inch	in	0.0254 m = 25.4 mm
Area	hectare	ha	10^4 m^2
	are	a	10^2 m^2
	acre	a	4046.9 m^2
	square mile	m^2	2.589 99 km^2
	square yard	yd^2	0.836 127 m^2
	square foot	ft^2	0.092 903 m^2
	square inch	in^2	645.16 mm^2
Volume	litre	l	10^{-3} m^3
	millilitre	ml	10^{-6} m^3 = cm^3
	cubic inch	in^3	16 387.1 mm^3
	cubic foot	ft^3	0.028 317 m^3
	gallon (UK)	gal	4.546 09 dm^3
	pint	pt	0.568 26 dm^3
Mass	tonne	t	10^3 kg
	ton	t	1016.046 08 kg
	hundredweight	cwt	50.802 304 kg
	pound	lb	0.453 592 kg
	ounce	oz	0.028 350 kg = 28.35 g
	gamma	γ	10^{-9} kg

Physical Quantity	Name of unit	Non-S.I. symbol	S.I. definition of unit
Density	gramme per cc	g/cc	kg dm^{-3}
	pound per cubic inch	lb/in^3	2.767 99 x 10^4 kg m^{-3}
	pound per cubic foot	lb/ft^3	16.018 5 kg m^{-3}
Velocity	foot per second	ft/s	0.3048 m s^{-1}
	miles per hour	m.p.h.	0.447 04 m s^{-1}
	km per hour	km/h	0.277 778 m s^{-1}
Pressure	pound per sq. in	p.s.i.	6.894 76 x 10^3 kg m^{-1} s^{-2} = 6.894 76 kN m^{-2}
	bar	bar	10^5 kg m^{-1} s^{-2} = 10^5 N m^{-2}
	hectobar	hbar	10^7 kg m^{-1} s^{-2}
	millibar	mbar	10^2 kg m^{-1} s^{-2}
	atmosphere	atm	101 325 kg m^{-1} s^{-2} = 101 325 N m^{-2}
	mm of mercury	mmHg	13.5951 x 9.806 65 N m^{-2}
	torr	Torr	101 325/760 N m^{-2}
Force	dyne	dyn	10^{-5} N
	pound foot	lbf	4.448 22 N
Energy	erg	erg	10^{-7} J
	calorie	cal	4.1868 J
	British Thermal Unit	BTU	1.055 06 kJ
	kilowatt hour	kWh	3.6 x 10^6 J
Temperature	degree Rankin	°R)	5/9 K
	degree Fahrenheit	°F)	
Dynamic viscosity	poise	p	10^{-1} kg m^{-1} s^{-1}
	centipoise	cp	10^{-3} N s m^{-2}
Radioactivity	curie	Ci	3.7 x 10^{10} s^{-1}

Physical Quantity	Name of unit	Non-S.I. symbol	S.I. definition of unit
Conductivity	mho/cm	mho/cm	$\mathrm{S\ cm^{-1} = kg^{-1}\ m^{-3}\ s^{-3}\ A^{2}}$
	millimho/cm	mmho/cm	$\mathrm{mS\ cm^{-1}}$

Special quantities used in soil science:

kilogramme per hectare = $\mathrm{kg\ 10^{-4}\ m^{-2}}$

pounds per acre = $\mathrm{0.11\ kg\ 10^{-3}\ m^{-2}}$

hundred weight per acre = $\mathrm{1.26\ kg\ 10^{-2}\ m^{-2}}$

tons per acre = $\mathrm{25.14\ kg\ 10^{-2}\ m^{-2}}$

APPENDIX III

DATA FOR SIEVES SHOWING OPENINGS IN S.I. UNITS COMPARED WITH U.S. STANDARD AND I.M.M. MESH NUMBERS

Openings in mm	Mesh No.	
	U.S.	I.M.M.
2.54	-	5
2.00	10	-
1.06	-	12
1.00	18	-
0.42	40	30
0.25	60	50
0.21	70	60
0.18	80	-
0.16	-	80
0.15	100	-
0.11	140	-
0.10	-	120
0.08	170	150
0.07	200	-
0.06	230	200
0.05	300	-

BIBLIOGRAPHICAL NOTE

The following is a short list of publications that may be consulted for further information on the subjects of S.I. units and physico - chemical nomenclature

1. British Standards Institution publication: BSI Recommendation R. 31. This is, or will be, a comprehensive publication dealing with various fields of science and technology. It is being published in separate volumes.
2. Manual of physico-chemical symbols and terminology. IUPAC. (Butterworths Scientific Publications, London.)
3. Nomenclature of inorganic chenistry. IUPAC.
4. Symbols, units and nomenclature. IUPAC.
5. Physico-chemical quantities and units. M.L. McGlashan. Royal Institute of Chemistry; Monographs for Teachers, No. 15.
6. The Use of S.I. Units. British Standards Institution.