This booklet provides a reference to the quantities, units, and their symbols which are used in physical science. It is a revision of a 1969 report and takes account of the progress which has been made in obtaining international agreement on the definitions, names, and symbols for units and on the rules for the expression of relations involving numbers between physical quantities and units. The report is divided into ten parts: (1) Physical Quantities, Units, and Numerical Values; (2) Recommended Mathematical Symbols; (3) Chemical Elements, Nuclides, and Particles; (4) Quantum States; (5) Nuclear Physics; (6) Thermodynamic Results; (7) Galvanic Cells; (8) Abbreviations of Common Words and Phrases; (9) Recommended Values of Physical Constants; and (10) Bibliography. (Author/TS)
QUANTITIES, UNITS, AND SYMBOLS

A REPORT BY
THE SYMBOLS COMMITTEE OF
THE ROYAL SOCIETY

REPRESENTING
THE ROYAL SOCIETY
THE CHEMICAL SOCIETY
THE FARADAY SOCIETY
THE INSTITUTE OF PHYSICS

1971

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CONTENTS

PREFACE

PART I: PHYSICAL QUANTITIES, UNITS, AND NUMERICAL VALUES

I.1. INTRODUCTION

I.2. PHYSICAL QUANTITIES AND SYMBOLS FOR PHYSICAL QUANTITIES

   I.2.1. Physical quantities
   I.2.2. Symbols for physical quantities
   I.2.3. Printing of symbols for physical quantities
   I.2.4. Choice of symbols for physical quantities
   I.2.5. Modifying signs
   I.2.6. Printing of subscripts and superscripts
   I.2.7. Use of the words 'specific' and 'molar'
   I.2.8. Partial molar quantities
   I.2.9. List of recommended subscripts and superscripts and other modifying signs to be used with the symbols for physical quantities
      (a) Subscripts
      (b) Superscripts
   I.2.10. List of recommended symbols for physical quantities
      (a) Space and time
      (b) Periodic and related phenomena
      (c) Mechanics
      (d) Thermodynamics
      (e) Electricity and magnetism
      (f) Light and related electromagnetic radiation
      (g) Acoustics
      (h) Physical chemistry
      (i) Molecular physics
      (j) Atomic and nuclear physics
      (k) Nuclear reactions and ionizing radiations
      (l) Quantum mechanics
      (m) Solid state physics
      (n) Molecular spectroscopy
   I.2.11. Mathematical operations on physical quantities

page 5

6

8

9

10

11

12

13

14

15

16

17

18

19

20
I.3. **Units and Symbols for Units**

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.3.1. The International System of Units (SI)</td>
<td>21</td>
</tr>
<tr>
<td>1.3.2. Definitions of the SI base units</td>
<td>22</td>
</tr>
<tr>
<td>1.3.3. Names and symbols for SI base units</td>
<td>23</td>
</tr>
<tr>
<td>1.3.4. Names and symbols for SI supplementary units</td>
<td>23</td>
</tr>
<tr>
<td>1.3.5. Special names and symbols for SI derived units</td>
<td>23</td>
</tr>
<tr>
<td>1.3.6. Examples of SI derived units and unit symbols for other quantities</td>
<td>24</td>
</tr>
<tr>
<td>1.3.7. SI prefixes</td>
<td>24</td>
</tr>
<tr>
<td>1.3.8. Decimal multiples of SI units having special names</td>
<td>25</td>
</tr>
<tr>
<td>1.3.9. Other units now exactly defined in terms of SI units</td>
<td>26</td>
</tr>
<tr>
<td>1.3.10. Units defined in terms of certain physical constants</td>
<td>27</td>
</tr>
<tr>
<td>1.3.11. 'International' electric units</td>
<td>27</td>
</tr>
<tr>
<td>1.3.12. Electric and magnetic units belonging to unit-systems other than the SI</td>
<td>28</td>
</tr>
<tr>
<td>1.3.13. Printing of symbols for units</td>
<td>28</td>
</tr>
<tr>
<td>1.3.14. Multiplication and division of units</td>
<td>28</td>
</tr>
</tbody>
</table>

I.4. **Numbers**

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4.1. Printing of numbers</td>
<td>29</td>
</tr>
<tr>
<td>1.4.2. Multiplication and division of numbers</td>
<td>29</td>
</tr>
</tbody>
</table>

PART II: **Recommended Mathematical Symbols**

PART III: **Chemical Elements, Nuclides, and Particles**

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>III.1. Definitions</td>
<td>33</td>
</tr>
<tr>
<td>III.2. Symbols for elements and nuclides</td>
<td>33</td>
</tr>
<tr>
<td>III.3. Symbols for particles and quanta</td>
<td>33</td>
</tr>
<tr>
<td>III.4. Notation for nuclear reactions</td>
<td>34</td>
</tr>
</tbody>
</table>

PART IV: **Quantum States**

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV.1. General rules</td>
<td>35</td>
</tr>
<tr>
<td>IV.2. Atomic spectroscopy</td>
<td>35</td>
</tr>
<tr>
<td>IV.3. Molecular spectroscopy</td>
<td>35</td>
</tr>
<tr>
<td>IV.4. Nuclear spectroscopy</td>
<td>36</td>
</tr>
<tr>
<td>IV.5. Spectroscopic transitions</td>
<td>36</td>
</tr>
</tbody>
</table>
PREFACE

The 1969 Report of the Symbols Committee of the Royal Society entitled 'Symbols, signs, and abbreviations' is now out of print; it was widely read and was clearly of considerable value. The Symbols Committee has therefore been charged with the preparation of a new report, which inter alia takes account of the progress which has been made in obtaining further international agreement on the definitions, names, and symbols for units and on the rules for the expression of relations involving numbers between physical quantities and units. The Committee feels that the new report is more properly entitled Quantities, units, and symbols.

The Committee has again accepted the recommendations of the following international bodies, on each of which the U.K. is represented:

- The General Conference of Weights and Measures
- The International Organization for Standardization
- The International Union of Pure and Applied Physics
- The International Union of Pure and Applied Chemistry
- The International Electrotechnical Commission

The Committee has maintained close contact with the British Standards Institution which is pursuing a common aim towards the adoption of internationally recognized units and symbols, as shown in BS 3763, BS 1991, and in several other British Standards.

It is emphasized that the Symbols Committee recommends only those procedures and symbols which have been internationally agreed.
I.1. Introduction

The value of a physical quantity is equal to the product of a numerical value and a unit

\[ \text{physical quantity} = \text{numerical value} \times \text{unit} \]

Neither any physical quantity, nor the symbol used to denote it, should imply a particular choice of unit.

Operations on equations involving physical quantities, units, and numerical values, should follow the ordinary rules of algebra.

Thus the physical quantity called the wavelength \( \lambda \) of one of the yellow sodium lines has the value

\[ \lambda = 5.896 \times 10^{-7} \text{m} \]

where \( \text{m} \) is the symbol for the unit of length called the metre (see §I.3). This may equally well be written in the form

\[ \lambda / \text{m} = 5.896 \times 10^{-7} \]

or in any of the other ways of expressing the equality of \( \lambda \) and \( 5.896 \times 10^{-7} \) multiplied by \( \text{m} \). By definition (see §I.3)

\[ \text{Å} = 10^{-10} \text{m} \]

and

\[ \text{in} = 2.54 \times 10^{-2} \text{m} \]

where Å and in are the symbols for the units of length called respectively the ångström and the inch; it follows that

\[ \lambda / \text{Å} = (\lambda / \text{m}) \times (\text{m} / \text{Å}) = 5896 \]

and

\[ \lambda / \text{in} = (\lambda / \text{m}) \times (\text{m} / \text{in}) = 5.896 \times 10^{-7} / (2.54 \times 10^{-2}) \approx 2.321 \times 10^{-5} \]

Thus \( \lambda \) may be equated to \( 5.896 \times 10^{-7} \text{m} \), or to \( 5896 \text{Å} \), or to \( 2.321 \times 10^{-5} \text{in} \), but may not be equated to \( 5.896 \times 10^{-7} \) or to any other number.

It follows from the above discussion that the expression which is placed at the head of a column of numerical values of a physical quantity in a table should be a pure number, such as the quotient of the symbol for the physical quantity and the symbol for the unit used.
Example:

<table>
<thead>
<tr>
<th>$\theta_0/\degree{C}$</th>
<th>$T/K$</th>
<th>$10^3 K/T$</th>
<th>$p/\text{MPa}$</th>
<th>$\ln(p/\text{MPa})$</th>
<th>$V_n^g/\text{cm}^3\text{mol}^{-1}$</th>
<th>$p V_n^g/RT$</th>
</tr>
</thead>
<tbody>
<tr>
<td>-56.60</td>
<td>216.55</td>
<td>4.6179</td>
<td>0.5180</td>
<td>-0.6578</td>
<td>3177.6</td>
<td>0.9142</td>
</tr>
<tr>
<td>0.00</td>
<td>273.15</td>
<td>3.6610</td>
<td>3.4853</td>
<td>1.2486</td>
<td>466.97</td>
<td>0.7013</td>
</tr>
<tr>
<td>31.04</td>
<td>304.19</td>
<td>3.2874</td>
<td>7.3815</td>
<td>1.9990</td>
<td>94.060</td>
<td>0.2745</td>
</tr>
</tbody>
</table>

In this table $T$ denotes thermodynamic temperature and $K$ the unit of thermodynamic temperature called the kelvin. Expressions such as ‘$T(K)$’ or ‘$T, K$’ do not denote $T$ divided by $K$ and should be abandoned in favour of $T/K$.

Similarly, the expression used to define the numerical values of a physical quantity plotted on a graph should be a pure number, such as the quotient of the symbol for the physical quantity and the symbol for the unit used.

Example:

![Graph](image)

Algebraically equivalent forms such as $kK/T$ or $(10^{-3} T/K)^{-1}$ may of course be used in place of $10^3 K/T$.

A clear distinction should be drawn between physical quantities and units, and between the symbols for physical quantities and the symbols for units.

Symbols for physical quantities should be printed in italic (sloping) type. Symbols for units should be printed in roman (upright) type. In typescript the distinction should be made by underlining symbols for physical quantities in accord with standard printers’ practice (see the Bibliography, §X.2.1 or §X.3.5).

Physical quantities and the symbols for physical quantities are dealt with in §1.2. The symbols for physical quantities specified there are recommendations.

Units and symbols for units are dealt with in §1.3. The symbols for units specified there are mandatory.

Numbers are dealt with in §1.4.
I.2. Physical quantities and symbols for physical quantities

I.2.1. Physical quantities

A physical quantity is defined by a complete specification of the operations used to measure the ratio (a pure number) of two particular values of that physical quantity.

Each physical quantity is given a name and a symbol which is an abbreviation for that name.

By international convention, seven physical quantities are chosen for use as dimensionally independent base quantities:

<table>
<thead>
<tr>
<th>Physical quantity</th>
<th>Symbol for quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>length</td>
<td>l</td>
</tr>
<tr>
<td>mass</td>
<td>m</td>
</tr>
<tr>
<td>time</td>
<td>t</td>
</tr>
<tr>
<td>electric current</td>
<td>I</td>
</tr>
<tr>
<td>thermodynamic temperature</td>
<td>T</td>
</tr>
<tr>
<td>luminous intensity</td>
<td>I_v</td>
</tr>
<tr>
<td>amount of substance</td>
<td>n</td>
</tr>
</tbody>
</table>

All other physical quantities are regarded as being derived from the base quantities. Plane angle and solid angle are sometimes regarded as base quantities.

I.2.2. Symbols for physical quantities

The symbol for a physical quantity should be a single letter of the latin or the greek alphabet.

An exception to this rule has been made for certain dimensionless quantities used in the study of transport processes, for which the internationally agreed symbols consist of two letters, the first a capital and the second lower case. Such two-letter symbols should be enclosed in parentheses. Example: Reynolds number: (Re).

When necessary the symbol for a physical quantity may be modified by attaching to it subscripts and/or superscripts and/or other modifying signs having specified meanings.

I.2.3. Printing of symbols for physical quantities

When letters of the latin alphabet are used as symbols for physical quantities they should be printed in italic type. When letters of the greek alphabet are used as symbols for physical quantities they should whenever possible be printed in sloping (‘italic’) rather than upright (‘roman’) type.

The symbols for vector quantities should be printed in bold faced italic type. Examples: force: \( \mathbf{F} \), electric field strength: \( \mathbf{E} \). (When the directional character of such quantities is not to be emphasized, the use of ordinary italic type remains as an alternative. However, the use of bold faced italic type will often remain convenient in order to allow the use of the same letters for other quantities.)

The symbols for tensors of the second rank should be printed in bold faced sans serif type which whenever possible should be italic (sloping) rather than roman (upright). Examples: \( \mathbf{S} \), \( \mathbf{T} \).
Abbreviations, i.e. shortened forms of names such as p.f. for partition function, should not be used in mathematical equations. When used in text they should be printed in roman (upright) type. (See also Part VIII.)

I.2.4. Choice of symbols for physical quantities

A list of recommended symbols for physical quantities is given in §1.2.10. Whenever possible the symbol used for a physical quantity should be that (or one of those) recommended there.

Even with the use of both capital and lower case letters, and of bold faced as well as ordinary italic (sloping) type as specified in §1.2.3, the available distinctive letter symbols are insufficient to enable each symbol to be allotted to a single quantity. Some alternatives are therefore given in the list in §1.2.10 where a need for them is most likely to arise or, occasionally, where alternative usages are firmly established and unobjectionable. In some instances a preference is expressed (see heading of §1.2.10) and the preferred symbol should then be used whenever possible; in others no preference is expressed.

Where it is necessary to choose from alternative symbols for a quantity, or to adopt a symbol for a quantity not listed in §1.2.10, consideration should be given to current practice by authorities in the field and to the desirability that symbols for quantities constituting a well defined class should as far as possible belong to the same alphabet, fount, and case.

In order to obtain additional flexibility, capital letters may be used as variants for lower case letters, and vice versa, if no ambiguity is likely to arise. For example, instead of $d_i$ and $d_e$ for internal and external diameter, $d$ and $D$ may be used. The recommended symbol for length is $l$ and for inductance $L$, but $l$ and $L$ may also be used for two lengths or two inductances; if length and inductance appear together, however, $l$ should be used only for length and $L$ for inductance, and necessary distinctions between different lengths or between different inductances should be made by means of subscripts or other modifying signs.

I.2.5. Modifying signs

Letter symbols, numbers, or other signs, may be placed as subscripts or superscripts immediately after the symbol for a physical quantity in order to modify its meaning. A list of recommended symbols for some of the most commonly needed subscripts and superscripts is given in §1.2.9. For the use of other subscripts and superscripts, and of other modifying signs, no rigid rules are laid down but a satisfactory notation should fulfil the following requirements:

(i) it should be unambiguous;
(ii) it should be simple, systematic, and easy to remember;
(iii) it should not use more letters than necessary;
(iv) it should not be too expensive or difficult to print.
Modifying signs such as dots, bars, or tildes (\(\sim\)) may be placed above (or exceptionally below) the symbol for a physical quantity. Such signs, however, should be used sparingly and should never be letters of the alphabet or numbers.

Brackets, including parentheses (\(\)), braces \(\{}\), square brackets \([\)]\), and angle brackets \(\langle\rangle\), should not be used around the symbol for a quantity in order to make it represent any other quantity, unless such use is consistently adopted for a whole class of quantities as in crystallography. In particular, the use of square brackets around a chemical formula to denote the concentration of the substance is recommended.

I.2.6. Printing of subscripts and superscripts

Subscripts or superscripts which are themselves symbols for physical quantities should be printed in italic (sloping) type. All other letter symbols used as subscripts or superscripts should be printed in roman (upright) type.

Example: \(C_p\) for heat capacity at constant pressure, but \(C_B\) for heat capacity of substance B.

When two or more subscripts, or two or more superscripts, having separate meanings are attached to the same symbol they should be separated by commas.

Example: \(C_{p,B}\) for heat capacity at constant pressure of substance B.

Second-order superscripts or subscripts should be avoided as far as possible. Thus \(e^{x^2}\) may be printed as \(\exp x^2\). Also \(A_{\text{NO}_3}\) may be printed as \(A(\text{NO}_3^-)\) and \(\rho_{20 \, ^\circ\text{C}}\) as \(\rho(20^\circ\text{C})\).

I.2.7. Use of the words 'specific' and 'molar'

The word 'specific' before the name of an extensive physical quantity is restricted to the meaning 'divided by mass'. For example, specific volume is the volume divided by the mass. When the extensive quantity is represented by a capital letter, the corresponding specific quantity may be represented by the corresponding lower case letter.

Examples: volume: \(V\) specific volume: \(v = V/m\)
heat capacity: \(C_p\) specific heat capacity: \(c_p = C_p/m\).

The numerical value of a specific physical quantity depends on the units selected for the physical quantity and for the mass.

The word 'molar' before the name of an extensive quantity is restricted to the meaning 'divided by amount of substance'. For example, molar volume is the volume divided by the amount of substance. The subscript \(m\) attached to the symbol for the extensive quantity denotes the corresponding molar quantity.

Examples: volume: \(V\) molar volume: \(V_m = V/n\)
Gibbs function: \(G\) molar Gibbs function: \(G_m = G/n\).

The subscript \(m\) may be omitted where there is no risk of ambiguity.
The numerical value of a molar physical quantity depends on the units selected for the physical quantity and for the amount of substance. The most commonly used unit for amount of substance is the mole (see §1.3.2).

1.2.8. Partial molar quantities

The symbol $X_B$, where $X$ denotes an extensive quantity and $B$ is the chemical symbol for a substance, denotes the partial molar quantity for the substance $B$ defined by the relation:

$$X_B = \frac{\partial X}{\partial n_B} \mid_{T,p,n_0}.$$

The partial molar quantity $X_B$ for a pure substance $B$, which is identical with the molar quantity $X_m$ for the pure substance $B$, may be denoted by $X_B^*$, where the superscript * denotes 'pure', so as to distinguish it from the partial molar quantity $X_B$ for the substance $B$ in a mixture.

1.2.9. List of recommended subscripts and superscripts and other modifying signs to be used with the symbols for physical quantities

(a) Subscripts

1, II...
1, 2...
A, B...
\(i\)
\(u\)
p, V, T, S
p, m, c, a
g, l, s, c
f, e, s, t, d
c
C, D, F
\(\pm\), \(\mp\), \(\infty\)

Especially with symbols for thermodynamic functions, referring to different systems or different states of a system

referring to molecular species $A$, $B$...

referring to a typical ionic species $i$

referring to an undissociated molecule

indicating constant pressure, volume, temperature, entropy

with symbol for an equilibrium constant, indicating that it is expressed in terms of pressure, molality, concentration, or relative activity

referring to gas, liquid, solid, and crystalline states respectively

referring to fusion, evaporation, sublimation, transition, and dissolution or dilution respectively

referring to the critical state or indicating a critical value

with symbols for optical properties, referring to particular wavelengths.

referring to a positive or negative ion, or to a positive or negative electrode indicating limiting value at infinite dilution.

Some of the above subscripts may sometimes be more conveniently used as superscripts.

(b) Superscripts

\(\theta\)

standard in general

* indicating a pure substance

id ideal

E excess
I.2.10. List of recommended symbols for physical quantities

It is recognized that according to context some departures from the recommended symbols will be necessary. Where two or more symbols separated by commas are given for a quantity, these symbols are regarded as alternatives for which no preference is expressed; where they are separated by a dotted line, the first is preferred.

[Note: A, B denotes no preference; A...B denotes A preferred]

(a) Space and time

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>angle (plane angle)</td>
<td>$\alpha, \beta, \gamma, \theta, \phi$, etc.</td>
</tr>
<tr>
<td>solid angle</td>
<td>$\Omega, \omega$</td>
</tr>
<tr>
<td>length</td>
<td>$l$</td>
</tr>
<tr>
<td>breadth</td>
<td>$b$</td>
</tr>
<tr>
<td>height</td>
<td>$h$</td>
</tr>
<tr>
<td>thickness</td>
<td>$d, \delta$</td>
</tr>
<tr>
<td>radius</td>
<td>$r$</td>
</tr>
<tr>
<td>diameter: $2r$</td>
<td>$d$</td>
</tr>
<tr>
<td>distance along path</td>
<td>$s, L$</td>
</tr>
<tr>
<td>generalized coordinate</td>
<td>$q$</td>
</tr>
<tr>
<td>rectangular coordinates</td>
<td>$x, y, z$</td>
</tr>
<tr>
<td>cylindrical coordinates</td>
<td>$r, \phi, z$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>spherical coordinates</td>
<td>$r, \theta, \phi$</td>
</tr>
<tr>
<td>position vector; radius vector</td>
<td>$r$</td>
</tr>
<tr>
<td>area</td>
<td>$A...S$</td>
</tr>
<tr>
<td>volume</td>
<td>$V...v$</td>
</tr>
<tr>
<td>time</td>
<td>$t$</td>
</tr>
<tr>
<td>angular velocity: $d\theta/dt$</td>
<td>$\omega$</td>
</tr>
<tr>
<td>angular acceleration: $d\omega/dt$</td>
<td>$\alpha$</td>
</tr>
<tr>
<td>velocity: $ds/dt$</td>
<td>$u, v, w$</td>
</tr>
<tr>
<td>acceleration: $du/dt$</td>
<td>$\alpha$</td>
</tr>
<tr>
<td>speed of light in a vacuum</td>
<td>$c$</td>
</tr>
<tr>
<td>Mach number</td>
<td>$(Ma)$</td>
</tr>
</tbody>
</table>

(b) Periodic and related phenomena

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>period</td>
<td>$T$</td>
</tr>
<tr>
<td>relaxation time</td>
<td>$\tau$</td>
</tr>
<tr>
<td>frequency: $1/T$</td>
<td>$\nu, f$</td>
</tr>
<tr>
<td>rotational frequency</td>
<td>$\omega$</td>
</tr>
<tr>
<td>angular frequency</td>
<td>$\omega$</td>
</tr>
<tr>
<td>wavelength</td>
<td>$\lambda$</td>
</tr>
<tr>
<td>wavenumber : $1/\lambda$</td>
<td>$\sigma, \ldots, \varphi$</td>
</tr>
<tr>
<td>wavevector</td>
<td>$\sigma$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>circular wavenumber: $2\pi\sigma$</td>
<td>$k$</td>
</tr>
<tr>
<td>circular wavevector</td>
<td>$k$</td>
</tr>
<tr>
<td>damping coefficient</td>
<td>$\delta$</td>
</tr>
<tr>
<td>logarithmic decrement</td>
<td>$\Lambda$</td>
</tr>
<tr>
<td>attenuation coefficient</td>
<td>$\alpha$</td>
</tr>
<tr>
<td>phase coefficient</td>
<td>$\beta$</td>
</tr>
<tr>
<td>propagation coefficient</td>
<td>$\gamma$</td>
</tr>
</tbody>
</table>

(1) When $F$ is a function of time $t$ given by $F(t) = A + B \exp(-t/\tau)$; $\tau$ is also called time constant.
(2) Also called pulsatance.
(3) When $F$ is a function of time $t$ given by $F(t) = A \exp(-\delta t) \sin(2\pi\nu(t-t_0))$.
(4) When $F$ is a function of distance $x$ given by $F(x) = A \exp(-\alpha x) \cos(\beta(x-x_0))$. 
(c) Mechanics

- Mass: \( m \)
- Density (mass density): \( m/V \)
- Relative density: \( \rho_2/\rho_1 \)
- Specific volume: \( V/m \)
- Reduced mass: \( m_1 m_2/(m_1 + m_2) \)
- Momentum: \( mu \)
- Angular momentum: \( b, p_\theta \)
- Angular momentum (vector): \( r \times p \)
- Moment of inertia (vector): \( I \)
- Force: \( F \)
- Weight
- Bending moment: \( M \)
- Moment of force (vector): \( r \times F \)
- Torque; moment of a couple: \( T \)
- Pressure: \( p \)
- Normal stress: \( \sigma \)
- Shear stress: \( \tau \)
- Linear strain: \( \Delta l/l_0 \)
- Shear strain; shear angle: \( \Delta \theta/\theta_0 \)
- Volume strain: \( V/V_0 \)
- Young modulus: \( \sigma/e \)

\( I = \int (x^2 + y^2) \, dm \)

(d) Thermodynamics

- Thermodynamic temperature: \( T, \theta \)
- Common temperature: \( t, \theta \)
- Linear expansivity: \( l^{-1} \, dl/dT \)
- Cubic expansivity: \( V^{-1} \, dV/dT \)
- Heat; quantity of heat: \( q, Q \)
- Work; quantity of work: \( w, W \)
- Heat flow rate: \( \Phi \)
- Thermal conductivity: \( \lambda \)
- Heat capacity: \( C \)
- Specific heat capacity: \( G/m \)
- Specific heat capacity at constant pressure: \( c_p \)
- Specific heat capacity at constant volume: \( c_V \)
- Ratio \( c_p/c_V \)
- Thermal diffusivity: \( \lambda/\rho c_p \)
- Entropy: \( S \)
- Internal energy: \( U \)
- Enthalpy: \( U + pV \)
- Helmholtz function: \( U - TS \)
- Gibbs function: \( U + pV - TS \)
- Massieu function: \( AIT \)
- Planck function: \( -A/T \)
- Specific entropy: \( S/m \)

\( T = \int x^2 \, dx \, dy \)

13
specific enthalpy \( H/m \)
specific Helmholtz function: \( A/m \)
specific Gibbs function: \( G/m \)
Joule–Thomson coefficient: \( (\partial T/\partial P)_H \)
isothermal compressibility: \( -V^{-1}(\partial V/\partial p)_T \)

isentropic compressibility: \( \kappa, \kappa_T \)

- Joule–Thomson coefficient: \( (aT/ap)_H \)
- Isothermal compressibility: \( V^{-1}(\partial V/\partial p)_T \)
- Isentropic compressibility: \( v_i(\partial v/\partial p)_s \)
- Isochoric expansivity: \( 1/V(1/aT)_p \)
- Isothermal expansivity: \( 1/V(1/aT)_T \)
- Thermal diffusion ratio: \( k_T \)
- Thermal diffusion factor: \( \alpha_T \)
- Thermal diffusion coefficient: \( D_T \)

(e) Electricity and magnetism

Electric charge; quantity of electricity
Electric current: \( dQ/dt \)
Charge density: \( Q/V \)
Surface charge density: \( Q/A \)
Electric field strength
Electric potential
Electric potential difference
Electromotive force
Electric displacement
Electric flux
Capacitance
Permittivity: \( D = \varepsilon E \)
Electric constant; permittivity of a vacuum
Relative permittivity: \( \varepsilon_r \)
Electric susceptibility: \( \varepsilon_r - 1 \)
Electric polarization: \( D - \varepsilon_0 E \)
Electric dipole moment
Electric current density
Magnetic field strength
Magnetic potential difference
Magnetomotive force: \( \phi H_s ds \)
Magnetic flux density:
Magnetic induction
Magnetic flux
Magnetic vector potential
Self inductance
Mutual inductance

- Permeability: \( \mu = \mu_0 \mu_r \)
- Relative permeability: \( \mu_r \)
- Magnetic susceptibility: \( \chi_m \)
- Magnetic moment: \( \chi_m B \)
- Magnetization: \( \chi_m H \)
- Magnetic polarization: \( B - \mu_0 H \)
- Electromagnetic energy density
- Poynting vector: \( E \times H \)
- Speed of propagation of electromagnetic waves in vacuum
- Resistivity: \( \rho L \)
- Conductivity: \( 1/\rho \)
- Resistivity: \( \rho \)
- Conductivity: \( 1/\sigma \)
- Permeance: \( 1/B_m \)
- Number of turns
- Number of phases
- Number of pairs of poles
- Loss angle
- Phase displacement
- Impedance: \( R + iX \)
- Reactance: \( X \)
- Resistance: \( R \)
- Quality factor: \( Q \)

\( [\text{Note: } A, B \text{ denotes no preference; } A...B \text{ denotes } A \text{ preferred}] \)

(1) For the specific enthalpy change resulting from phase transitions the term specific latent heat is still used.
(2) Correspondences between certain quantities in this table and certain other quantities that arise when non-rationalized three-quantity systems of electric and magnetic equations are used can be found in the references given in the Bibliography, §X.1.2, Part V: 1965, or §X.1.5.
(3) Also called dielectric constant, \( D \), when it is independent of \( E \).
admittance: $1/Z$

susceptance: $\text{Im } Y$

conductance: $\text{Re } Y$

$Y$ | power, active $P$
$B$ | power, reactive $Q$
$G$ | power, apparent $S$

(f) **Light and related electromagnetic radiation**

The same symbol is often used for a pair of corresponding radiant and luminous quantities. Subscripts $e$ for radiant and $v$ for luminous may be used when necessary to distinguish these quantities.

velocity of electromagnetic waves in vacuum $c$

radiant energy $Q, Q_e$

radiant flux; radiant power $\Phi, \Phi_e...P$

radiant intensity $I, I_e$

radiance $L, L_e$

radiant exitance $M, M_e$

irradiance $E, E_e$

emissivity $\epsilon$

quantity of light $Q, Q_v$

luminous flux $\Phi, \Phi_v$

luminous intensity $I, I_v$

luminance $L, L_v$

luminous exitance $M, M_v$

illuminance; illumination $E, E_v$

light exposure: $\int E \, dt$ $H$

luminous efficacy: $\Phi_v/\Phi_e$ $K$

absorption factor; $\alpha$

reflexion factor; $\tau$

reflectance: $\Phi_r/\Phi_0$ $\rho$

transmission factor; $\tau$

transmittance: $\Phi_{tr}/\Phi_0$ $\tau$

linear extinction coefficient $\mu$

linear absorption coefficient $a$

refractive index $n$

angle of optical rotation $\alpha$

(g) **Acoustics**

velocity of sound $c$

velocity of longitudinal waves $c_1$

velocity of transverse waves $c_t$

group velocity $c_g$

sound energy flux $P$

sound intensity $I, J$

reflexion coefficient: $P_{r}/P_0$ $\rho$

acoustic absorption $\alpha$

coefficient: $1 - \rho$

transmission coefficient: $P_{tr}/P_0$ $\tau$

dissipation coefficient: $\alpha_a - \tau$ $\delta$

For a more complete list of symbols for acoustic quantities see the Bibliography, §X.1.2, Part VII: 1965.

(h) **Physical chemistry**

relative atomic mass of an element (‘atomic weight’) $(1)$ $A_r$

relative molecular mass of a substance (‘molecular weight’) $(1)$ $M_r$

$(1)$ The ratio of the average mass per atom (molecule) of the natural isotopic composition of an element (the elements) to $1/12$ of the mass of an atom of the nuclide $^{12}\text{C}$.

Examples: $A_r(\text{K}) = 39.102$ $A_r(\text{Cl}) = 35.453$ $M_r(\text{KCl}) = 74.555$

The concept of relative atomic or molecular mass may be extended to other specified isotopic compositions, but the natural isotopic composition is assumed unless some other composition is specified.
amount of substance \( n \)
molar mass: \( m/n \)
molar volume: \( V/n \)
molar internal energy: \( U/n \)
molar enthalpy: \( H/n \)
molar heat capacity: \( C/n \)
at constant pressure: \( C_p/n \)
at constant volume: \( C_v/n \)
molar entropy: \( S/n \)
molar Helmholtz function: \( A/n \)
molar Gibbs function: \( G/n \)
(molar) gas constant \( R \)
compression factor: \( p V_m/RT \)
mole fraction of substance \( \text{I} \): \( x_B \)
mass fraction of substance \( \text{B} \): \( w_B \)
volume fraction of substance \( \text{B} \): \( \phi_B \)
molality of solute \( \text{B} \):
\((n_B \text{ divided by mass of solvent})\)
concentration (‘molarity’) of solute \( \text{B} \):
\((n_B \text{ divided by volume})\)
chemical potential of
substance \( \text{B} \):
\((\partial G/\partial n_B)_{T,p,n_B} \ldots \mu_B \)
absolute activity of
substance \( \text{B} \):
\(\exp (\mu_B/RT) \lambda_B \)
partial pressure of substance \( \text{B} \)
in a gas mixture:
\(x_B^p p \)
fugacity of substance \( \text{B} \) in a gas mixture:
\(\lambda_B \lim_{p \to 0} (x_B^p p / \lambda_B) \)
relative activity of \( \mu \text{substance B} \)
activity coefficient (mole fraction basis) \( f_B \)
activity coefficient (molality basis) \( \gamma_B \)
activity coefficient (concentration basis) \( y_B \)
osmotic coefficient \( \phi_B \ldots g \)
osmotic pressure \( \Pi_B \)
surface concentration \( \Gamma_B \)
electromotive force \( E_B \)

Faraday constant \( F \)
charge number of ion \( i \) \( z_i \)
ionic strength: \( \frac{1}{2} \sum_m m_i z_i^2 \) \( I \)
velocity of ion \( i \) \( v_i \)
electric mobility of ion \( i \):
\( v_i = u_i E \) \( u_i \)
electrolytic conductivity \((\text{la})\):
\( J = \kappa E \) \( \kappa \)
molar conductance of electrolyte:
\( \kappa/c \)
transport number of ion \( i \) \( t_i \)
molar conductance of ion \( i \):
\( t_i A \lambda_i \)
overpotential \( \eta \)
exchange current density \( j_0 \)
electrokinetic potential \( \zeta \)
intensity of light \( I \)
transmittance: \( I/I_0 \) \( T \)
absorbance \((\text{la})\):
\(-\log T \) \( A \)
(linear) absorption coefficient:
\( A/\lambda \) \( a \)
molar (linear) absorption coefficient:
\( A/\omega_B \) \( \epsilon \)
angle of optical rotation \( \alpha \)
specific optical rotatory power:
\( \alpha\lambda/m \) \( \alpha_m \)
molar optical rotatory power:
\( \alpha/\omega_B \) \( \alpha_n \)
molar refractive:
\( (n^2 - 1)V_m/(n^2 + 2) \) \( R_m \)
stoichiometric coefficient of
molecules \( \text{B} \) (negative for
reactants, positive for
products)
\( \nu_B \)
general equation for a chemical reaction:
\( 0 = \sum_B \nu_B B \)
affinity of a reaction:
\( -\sum_B \nu_B \mu_B \) \( A \ldots a \)
equilibrium constant \( K \)
degree of dissociation \( \alpha \)
extent of reaction:
\( d\xi = dn_B/\nu_B \) \( \xi \)
rate of reaction:
\( d\xi/dt \) \( \xi, J \)
rate constant of a reaction \( \kappa \)
activation energy of a reaction \( E \)

\( ^{(1)} \) Formerly called specific conductance.

\( ^{(2)} \) Formerly called optical density.
### (i) Molecular physics

<table>
<thead>
<tr>
<th>Molecular Physics</th>
<th>Mathematical Representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avogadro constant</td>
<td>$L, N_A$</td>
</tr>
<tr>
<td>number of molecules</td>
<td>$N$</td>
</tr>
<tr>
<td>number density of molecules: $N/V$</td>
<td>$n$</td>
</tr>
<tr>
<td>molecular mass</td>
<td>$m$</td>
</tr>
<tr>
<td>molecular velocity</td>
<td>$c(c_x, c_y, c_z)_i, u(u_x, u_y, u_z)_i$</td>
</tr>
<tr>
<td>molecular position</td>
<td>$r(x, y, z)$</td>
</tr>
<tr>
<td>molecular momentum</td>
<td>$p(p_x, p_y, p_z)_i$</td>
</tr>
<tr>
<td>average velocity</td>
<td>$\langle c \rangle, \langle u \rangle, c_0, u_0$</td>
</tr>
<tr>
<td>average speed</td>
<td>$\bar{c}, \bar{u}$</td>
</tr>
<tr>
<td>most probable speed</td>
<td>$l, \lambda$</td>
</tr>
<tr>
<td>mean free path</td>
<td>$e$</td>
</tr>
<tr>
<td>molecular attraction energy</td>
<td>$\phi_{11}, \psi_{11}$</td>
</tr>
<tr>
<td>interaction energy between molecules i and j</td>
<td>$N/V = \int fdc_x dc_y dc_z$</td>
</tr>
<tr>
<td>velocity distribution function</td>
<td>$f(c)$</td>
</tr>
<tr>
<td>Boltzmann function</td>
<td>$H$</td>
</tr>
<tr>
<td>generalized coordinate</td>
<td>$q$</td>
</tr>
<tr>
<td>generalized momentum</td>
<td>$p$</td>
</tr>
<tr>
<td>volume in phase space</td>
<td>$\Omega$</td>
</tr>
<tr>
<td>Boltzmann constant</td>
<td>$k$</td>
</tr>
</tbody>
</table>

### (j) Atomic and nuclear physics

<table>
<thead>
<tr>
<th>Atomic and Nuclear Physics</th>
<th>Mathematical Representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>nucleon number; mass number</td>
<td>$A$</td>
</tr>
<tr>
<td>atomic number; proton number</td>
<td>$Z$</td>
</tr>
<tr>
<td>neutron number; $A - Z$</td>
<td>$N$</td>
</tr>
<tr>
<td>(rest) mass of atom</td>
<td>$m_0$</td>
</tr>
<tr>
<td>unified atomic mass constant</td>
<td>$m_a(12C)/12$</td>
</tr>
<tr>
<td>(rest) mass of electron</td>
<td>$m_e$</td>
</tr>
<tr>
<td>(rest) mass of proton</td>
<td>$m_p$</td>
</tr>
<tr>
<td>(rest) mass of neutron</td>
<td>$m_n$</td>
</tr>
<tr>
<td>elementary charge (of proton)</td>
<td>$e$</td>
</tr>
<tr>
<td>Planck constant</td>
<td>$h$</td>
</tr>
<tr>
<td>Planck constant divided by $2\pi$</td>
<td>$\hbar$</td>
</tr>
<tr>
<td>Bohr radius: $h^2/\mu_0 c^2 m_e e^2$</td>
<td>$a_0$</td>
</tr>
<tr>
<td>nuclear angular precession</td>
<td>$eB/2m_e$</td>
</tr>
<tr>
<td>frequency: $geB/2m_e = \gamma B$</td>
<td>$\omega_N$</td>
</tr>
<tr>
<td>cyclootron angular frequency</td>
<td>$\epsilon$</td>
</tr>
<tr>
<td>Planck constant divided by $2\pi$</td>
<td>$\hbar$</td>
</tr>
<tr>
<td>magnetic moment of particle</td>
<td>$\mu$</td>
</tr>
</tbody>
</table>

(1) See also page 45.

(2) No internationally agreed symbol has yet been recommended, but $p \ldots n$ are in use.
[Note: A, B denotes no preference; A...B denotes A preferred]

| spin angular momentum quantum number | mass excess: \( m_a - A m_u \) | \( \Delta \) |
| total angular momentum quantum number | packing fraction: \( \Delta / A m_u \) | \( \gamma \) |
| nuclear spin quantum number | level width: \( \hbar / 2 \pi \tau \) | \( \Gamma \) |
| hyperfine structure quantum number | activity: \(-dN/dt\) | \( \lambda \) |
| principal quantum number | specific activity: \( A / m \) | \( \alpha \) |
| magnetic quantum number | disintegration energy | \( Q \) |
| fine structure constant: \( \mu_0 e^2 c / 2 \hbar \) | spin-lattice relaxation time | \( T_{1\lambda} \) |
| electron radius: \( \mu_0 e^2 / 4 \pi m_e \) | spin-spin relaxation time | \( T_{2\lambda} \) |
| Compton wavelength: \( \hbar / mc \) | indirect spin-spin coupling | \( J \) |

### (k) Nuclear reactions and ionizing radiations

| reaction energy | atomic attenuation coefficient | \( \mu \) |
| cross section | mass attenuation coefficient | \( \mu_m \) |
| macroscopic cross section | linear stopping power | \( S, S_1 \) |
| impact parameter | atomic stopping power | \( S_a \) |
| scattering angle | linear range | \( R, R_1 \) |
| internal conversion coefficient | recombination coefficient | \( \alpha \) |
| linear attenuation coefficient | \( \mu, \mu_1 \) |

### (l) Quantum mechanics

| complex conjugate of \( \Psi \) | anticommutator of \( A \) and \( B \): \( [A, B]_+ \) |
| probability density: \( \Psi^* \Psi \) | \( A B + B A \) |
| probability current density: \( (\hbar / 2 \pi m) (\Psi^* \nabla \Psi - \Psi \nabla \Psi^* \) | matrix element: \( \int \phi_i^* (A \phi_j) \, d\tau \) |
| charge density of electrons: \(-eP\) | Hermitian conjugate of operator \( A \) |
| electric current density of electrons: \(-eS\) | \( A^\dagger \) |
| expectation value of \( A \) | momentum operator in coordinate representation |
| commutator of \( A \) and \( B \): \( AB - BA \) | \(+ (\hbar / 2 \pi i) \nabla\) |
| \( \langle A \rangle, \bar{A} \) | annihilation operators \( a, b, \alpha, \beta \) |
| \( [A, B], [A, B]_\pm \) | creation operators \( a^\dagger, b^\dagger, \alpha^\dagger, \beta^\dagger \) |
(m) Solid state physics

fundamental translations \{ a, b, c; a_1, a_2, a_3 \}

for lattice Miller indices plane in lattice (1)
direction in lattice (0)
fundamental translations in reciprocal lattice vector in crystal lattice distance between successive lattice planes Bragg angle order of reflexion short range order parameter long range order parameter Burgers vector circular wavevector; propagation vector (of phonons)
circular wavevector; propagation vector (of particles)
effective mass of electron Fermi energy Fermi circular wavevector work function differential thermoelectric power Peltier coefficient Thomson coefficient piezoelectric coefficient characteristic (Weiss) temperature Curie temperature Néel temperature Hall coefficient  

(n) Molecular spectroscopy (2)

quantum number of component of electronic orbital angular momentum vector along symmetry axis of component of electronic spin along symmetry axis of total electronic angular momentum vector along symmetry axis of electronic spin of nuclear spin of vibrational mode of vibrational angular momentum (linear molecules) of total angular momentum (excluding nuclear spin) of component of \( J \) in direction of external field of component of \( S \) in direction of external field of total angular momentum (including nuclear spin: \( F = J + I \)) of component of \( F \) in direction of external field of component of \( I \) in direction of external field

\( A, \lambda_1 \)
\( \Sigma, \sigma_1 \)
\( \Omega, \omega_1 \)
\( S \)
\( I \)
\( v \)
\( l \)
\( J \)
\( M, M_J \)
\( M_S \)
\( F \)
\( M_F \)
\( M_I \)

(1) Braces \{ \} and angle brackets \( \langle \rangle \) are used to enclose symmetry-related sets (forms) of planes and directions respectively. Further details regarding crystallographic notation can be found in the tables listed in the Bibliography, §X.2.2.
(2) Further details can be found in the report listed in the Bibliography, §X.2.3.
quantum number (cont.)

of component of angular momentum along axis (linear and symmetric top molecules; excluding electron- and nuclear spin; for linear molecules $K = |A + l|$)

of total angular momentum (linear and symmetric top molecules; excluding electron- and nuclear spin: $J = N + S$)

of component of angular momentum along symmetry axis (linear and symmetric top molecules; excluding nuclear spin; for linear molecules: $P = |K + \Sigma|$)

degeneracy of vibrational mode

electronic term: $E_e/hc$  

vibrational term: $E_{vib}/hc$

coefficients in expression for vibrational term for diatomic molecule:

$$G = \sigma_e(v + \frac{1}{2}) - x\sigma_e(v + \frac{1}{2})^2$$

coefficients in expression for vibrational term for polyatomic molecule:

$$G = \sum_j \sigma_j(v_j + \frac{1}{2}d_j) + \frac{1}{2}\sum_k \sum_l x_{jk}(v_l + \frac{1}{2}d_k)(v_k + \frac{1}{2}d_k)$$

rotational term: $E_{rot}/hc$

moment of inertia of diatomic molecule

rotational constant of diatomic molecule: $\hbar/8\pi^2cI$

principal moments of inertia of polyatomic molecule ($I_A \leq I_B \leq I_C$)

rotational constants of polyatomic molecule: $A = \hbar/8\pi^2cI_A$, etc.

total term: $T_e + G + F$

I.2.11. Mathematical operations on physical quantities

Addition and subtraction of two physical quantities are indicated by

$$a + b \quad \text{and} \quad a - b.$$

Multiplication of two (scalar) physical quantities may be indicated in one of the following ways:

$$ab \quad ab \quad a \cdot b \quad a \times b.$$

Division of one quantity by another quantity may be indicated in one of the following ways:

$$\frac{a}{b} \quad a/b \quad ab^{-1},$$

or in any of the other ways of writing the product of $a$ and $b^{-1}$.

These procedures can be extended to cases where one of the quantities or both are themselves products, quotients, sums, or differences of other quantities.

Brackets should be used in accordance with the rules of mathematics. If the solidus is used to separate the numerator from the denominator and if there is any doubt where the numerator starts or where the denominator ends, brackets should be used.

a) System of loosely coupled electrons.  
b) System of tightly coupled electrons.  
c) All energies are taken here with respect to the ground state as reference level.  
d) For vector quantities see p. 32.
Examples:

Expressions with a horizontal rule

$$\frac{a}{bcd} \quad a/bcd$$

$$\frac{2}{3} \sin kx, \frac{1}{2} RT \quad (2/9) \sin kx, RT/2$$

$$\frac{a}{b} - c \quad a/b - c$$

$$\frac{a}{b-c} \quad a/(b-c)$$

$$\frac{a-b}{c-d} \quad (a-b)/(c-d)$$

$$\frac{a-b}{c-d} \quad a/c - b/d$$

Remark. It is recommended that in expressions like:

$$\sin \{2\pi(x-x_0)/\lambda\} \quad \exp\{(r-r_0)/\sigma\}$$

$$\exp\{-V(r)/kT\} \quad \sqrt{\text{e}/c^2}$$

the argument should always be placed between brackets, except when the argument is a simple product, for example: $\sin kx$, $\sin 2\pi vt$.

A list of recommended symbols for mathematical operators and mathematical constants will be found in Part II.

I.3. Units and symbols for units

I.3.1. The International System of Units (SI)

The International System of Units (SI) comprises the SI units and the SI prefixes.

The SI units are of three kinds: base, supplementary, and derived. There are seven base units (see §§I.3.2 and I.3.3), one for each of the seven physical quantities: length, mass, time, electric current, thermodynamic temperature, luminous intensity, and amount of substance, which are regarded as dimensionally independent. There are two supplementary units (see §I.3.4): one for plane angle and one for solid angle. The derived unit for any other physical quantity is that obtained by the dimensionally appropriate multiplication and division of the base units (see §I.3.6). Fifteen of the derived units have special names and symbols (see §I.3.5).

There is one and only one SI unit for each physical quantity. Decimal multiples of these units may, however, be constructed by use of the fourteen SI prefixes (see §I.3.7).
I.3.2. Definitions of the SI base 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 2p₁₀ and 5d₅ of the krypton-86 atom.

**kilogram**: The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.

**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 1 metre apart in vacuum, would produce between these conductors a force equal to $2 \times 10^{-7}$ newton per metre of length.

**kelvin**: The kelvin, unit of thermodynamic temperature, is the fraction $1/273.16$ of the thermodynamic temperature of the triple point of water.

**candela**: The candela is the luminous intensity, in the 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 $101\,325$ newtons per square metre.

**mole**: The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in $0.012$ kilogram of carbon $12$.

*Note*. When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

**Examples**:

1 mole of HgCl has a mass equal to $0.236\,04$ kilogram.
1 mole of Hg₂Cl₂ has a mass equal to $0.472\,08$ kilogram.
1 mole of e⁻ has a mass equal to $5.4860 \times 10^{-7}$ kilogram.
1 mole of a mixture containing $\frac{2}{3}$ mole of H₂ and $\frac{1}{3}$ mole of O₂ has a mass equal to $0.012\,010\,2$ kilogram.
### I.3.3. Names and symbols for SI base units

<table>
<thead>
<tr>
<th>Physical quantity</th>
<th>Name of SI unit</th>
<th>Symbol for SI unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>length</td>
<td>metre</td>
<td>m</td>
</tr>
<tr>
<td>mass</td>
<td>kilogram</td>
<td>kg</td>
</tr>
<tr>
<td>time</td>
<td>second</td>
<td>s</td>
</tr>
<tr>
<td>electric current</td>
<td>ampere</td>
<td>A</td>
</tr>
<tr>
<td>thermodynamic temperature</td>
<td>kelvin</td>
<td>K</td>
</tr>
<tr>
<td>luminous intensity</td>
<td>candela</td>
<td>cd</td>
</tr>
<tr>
<td>amount of substance</td>
<td>mole</td>
<td>mol</td>
</tr>
</tbody>
</table>

### I.3.4. Names and symbols for SI supplementary units

<table>
<thead>
<tr>
<th>Physical quantity</th>
<th>Name of SI unit</th>
<th>Symbol for SI unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>plane angle</td>
<td>radian</td>
<td>rad</td>
</tr>
<tr>
<td>solid angle</td>
<td>steradian</td>
<td>sr</td>
</tr>
</tbody>
</table>

### I.3.5. Special names and symbols for SI derived units

<table>
<thead>
<tr>
<th>Physical quantity</th>
<th>Name of SI unit</th>
<th>Symbol for SI unit</th>
<th>Definition of SI unit</th>
<th>Equivalent form(s) of SI unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>energy</td>
<td>joule</td>
<td>J</td>
<td>m² kg s⁻²</td>
<td>N m</td>
</tr>
<tr>
<td>force</td>
<td>newton</td>
<td>N</td>
<td>m kg s⁻²</td>
<td>J m⁻¹</td>
</tr>
<tr>
<td>pressure</td>
<td>pascal</td>
<td>Pa</td>
<td>m⁻¹ kg s⁻²</td>
<td>N m⁻², J m⁻³</td>
</tr>
<tr>
<td>power</td>
<td>watt</td>
<td>W</td>
<td>m² kg s⁻³</td>
<td>J s⁻¹</td>
</tr>
<tr>
<td>electric charge</td>
<td>coulomb</td>
<td>C</td>
<td>s A</td>
<td>A s</td>
</tr>
<tr>
<td>electric potential</td>
<td>volt</td>
<td>V</td>
<td>m² kg s⁻³ A⁻¹</td>
<td>J A⁻¹ s⁻¹, J C⁻¹</td>
</tr>
<tr>
<td>electric conductance</td>
<td>ohm</td>
<td>Ω</td>
<td>m² kg s⁻³ A⁻²</td>
<td>V A⁻¹</td>
</tr>
<tr>
<td>electric capacitance</td>
<td>siemens</td>
<td>S</td>
<td>m⁻² kg⁻¹ s³ A²</td>
<td>Ω⁻¹, A V⁻¹</td>
</tr>
<tr>
<td>magnetic flux</td>
<td>farad</td>
<td>F</td>
<td>m⁻² kg⁻¹ s⁴ A²</td>
<td>A s V⁻¹, C V⁻¹</td>
</tr>
<tr>
<td>magnetic flux density</td>
<td>weber</td>
<td>Wb</td>
<td>m² kg s⁻² A⁻¹</td>
<td>V s</td>
</tr>
<tr>
<td>inductance</td>
<td>henry</td>
<td>H</td>
<td>m² kg s⁻² A⁻²</td>
<td>V A⁻¹ s</td>
</tr>
<tr>
<td>luminous flux density</td>
<td>lumen(1)</td>
<td>lm</td>
<td>cd sr</td>
<td></td>
</tr>
<tr>
<td>illumination</td>
<td>lux(1)</td>
<td>lx</td>
<td>m⁻² cd sr</td>
<td></td>
</tr>
<tr>
<td>frequency</td>
<td>hertz</td>
<td>Hz</td>
<td>s⁻¹</td>
<td></td>
</tr>
</tbody>
</table>

(1) In the definition given here for these units, the steradian (sr) is treated as a base unit.
I.3.6. Examples of SI derived units and unit symbols for other quantities

(This list is merely illustrative)

<table>
<thead>
<tr>
<th>Physical quantity</th>
<th>SI unit</th>
<th>A symbol for SI unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>area</td>
<td>square metre</td>
<td>m²</td>
</tr>
<tr>
<td>volume</td>
<td>cubic metre</td>
<td>m³</td>
</tr>
<tr>
<td>wavenumber</td>
<td>1 per metre</td>
<td>m⁻¹</td>
</tr>
<tr>
<td>radioactivity</td>
<td>1 per second</td>
<td>s⁻¹</td>
</tr>
<tr>
<td>density</td>
<td>kilogram per cubic metre</td>
<td>kg m⁻³</td>
</tr>
<tr>
<td>speed; velocity</td>
<td>metre per second</td>
<td>m s⁻¹</td>
</tr>
<tr>
<td>angular velocity</td>
<td>radian per second</td>
<td>m s⁻²</td>
</tr>
<tr>
<td>acceleration</td>
<td>metre per second squared</td>
<td>m² s⁻¹</td>
</tr>
<tr>
<td>kinematic viscosity</td>
<td>square metre per second</td>
<td>m³ s⁻¹</td>
</tr>
<tr>
<td>concentration (of amount of substance)</td>
<td>mole per cubic metre</td>
<td>mol m⁻³</td>
</tr>
<tr>
<td>specific volume</td>
<td>cubic metre per kilogram</td>
<td>m³ kg⁻¹</td>
</tr>
<tr>
<td>molar volume</td>
<td>cubic metre per mole</td>
<td>m³ mol⁻¹</td>
</tr>
<tr>
<td>dynamic viscosity</td>
<td>pascal second</td>
<td>Pa s</td>
</tr>
<tr>
<td>moment of force</td>
<td>metre newton</td>
<td>N m</td>
</tr>
<tr>
<td>surface tension</td>
<td>newton per metre</td>
<td>N m⁻¹</td>
</tr>
<tr>
<td>heat flux density</td>
<td>watt per square metre</td>
<td>W m⁻²</td>
</tr>
<tr>
<td>heat capacity</td>
<td>joule per kelvin</td>
<td>J K⁻¹</td>
</tr>
<tr>
<td>thermal conductivity</td>
<td>watt per metre kelvin</td>
<td>W m⁻¹ K⁻¹</td>
</tr>
<tr>
<td>energy density</td>
<td>joule per cubic metre</td>
<td>J m⁻³</td>
</tr>
<tr>
<td>molar heat capacity</td>
<td>joule per kelvin mole</td>
<td>J K⁻¹ mol⁻¹</td>
</tr>
<tr>
<td>electric field strength</td>
<td>volt per metre</td>
<td>V m⁻¹</td>
</tr>
<tr>
<td>magnetic field strength</td>
<td>ampere per metre</td>
<td>A m⁻¹</td>
</tr>
<tr>
<td>electric charge density</td>
<td>coulomb per cubic metre</td>
<td>C m⁻³</td>
</tr>
<tr>
<td>permittivity</td>
<td>farad per metre</td>
<td>F m⁻¹</td>
</tr>
<tr>
<td>current density</td>
<td>ampere per square metre</td>
<td>A m⁻²</td>
</tr>
<tr>
<td>permeability</td>
<td>henry per metre</td>
<td>H m⁻¹</td>
</tr>
<tr>
<td>luminance</td>
<td>candela per square metre</td>
<td>cd m⁻²</td>
</tr>
</tbody>
</table>

I.3.7. SI prefixes

The following prefixes may be used to construct decimal multiples of units.

<table>
<thead>
<tr>
<th>Multiple</th>
<th>Prefix</th>
<th>Symbol</th>
<th>Multiple</th>
<th>Prefix</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>10⁻¹</td>
<td>deci</td>
<td>d</td>
<td>10</td>
<td>deca</td>
<td>da</td>
</tr>
<tr>
<td>10⁻²</td>
<td>centi</td>
<td>c</td>
<td>10²</td>
<td>hecto</td>
<td>h</td>
</tr>
<tr>
<td>10⁻³</td>
<td>milli</td>
<td>m</td>
<td>10³</td>
<td>kilo</td>
<td>k</td>
</tr>
<tr>
<td>10⁻⁶</td>
<td>micro</td>
<td>µ</td>
<td>10⁶</td>
<td>mega</td>
<td>M</td>
</tr>
<tr>
<td>10⁻⁹</td>
<td>nano</td>
<td>n</td>
<td>10⁹</td>
<td>giga</td>
<td>G</td>
</tr>
<tr>
<td>10⁻¹²</td>
<td>pico</td>
<td>p</td>
<td>10¹²</td>
<td>tera</td>
<td>T</td>
</tr>
<tr>
<td>10⁻¹⁵</td>
<td>femto</td>
<td>f</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10⁻¹⁸</td>
<td>atto</td>
<td>a</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Decimal multiples of the kilogram, kg, should be formed by attaching an SI prefix not to kg but to g, in spite of the kilogram and not the gram being the SI base unit.

**Examples:**
- mg not µkg for \( 10^{-6} \text{ kg} \)
- Mg not kkg for \( 10^{3} \text{ kg} \)

A symbol for an SI prefix may be attached to the symbol for an SI base unit (§I.3.3), or for an SI supplementary unit (§I.3.4), or for an SI derived unit having a special name and symbol (§I.3.5).

**Examples:** cm ns µA mK µmol µrad MHz daN kPa GV MΩ

An SI prefix is also sometimes attached to the symbol for a non-SI unit (see §§I.3.8 to I.3.10).

**Examples:** ml hbar kG kcal MeV

Compound prefixes should not be used.

**Example:** nm but not mum for \( 10^{-9} \text{ m} \)

A combination of prefix and symbol for a unit is regarded as a single symbol which may be raised to a power without the use of brackets.

**Example:** cm² always means \((0.01 \text{ m})^{2}\) and never \(0.01 \text{ m}^{2}\)

### I.3.8. Decimal multiples of SI units having special names

These names are not part of the SI. It is recognized that their use may be continued for some time but it is recommended that except in special circumstances they should be progressively abandoned in scientific publications. The following list is not exhaustive.

<table>
<thead>
<tr>
<th>Physical quantity</th>
<th>Name of unit</th>
<th>Symbol for</th>
<th>Definition of unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>length</td>
<td>Ångström</td>
<td>Å</td>
<td>(10^{-10} \text{ m} = 10^{-1} \text{ nm})</td>
</tr>
<tr>
<td>length</td>
<td>micron</td>
<td>µm</td>
<td>(10^{-6} \text{ m})</td>
</tr>
<tr>
<td>area</td>
<td>barn</td>
<td>b</td>
<td>(10^{-28} \text{ m}^{2})</td>
</tr>
<tr>
<td>volume</td>
<td>litre</td>
<td>l</td>
<td>(10^{-3} \text{ m}^{3} = \text{ dm}^{3})</td>
</tr>
<tr>
<td>mass</td>
<td>tonne</td>
<td>t</td>
<td>(10^{3} \text{ kg} = \text{ Mg})</td>
</tr>
<tr>
<td>force</td>
<td>dyne</td>
<td>dyn</td>
<td>(10^{-5} \text{ N})</td>
</tr>
<tr>
<td>pressure</td>
<td>bar</td>
<td>bar</td>
<td>(10^{5} \text{ Pa})</td>
</tr>
</tbody>
</table>

(1) The symbols µ and µµ, still unfortunately used by some spectroscopists and biologists, should give place to µm (micrometre) and nm (nanometre) respectively.

(2) By decision of the twelfth General Conference of Weights and Measures in October 1964 the old definition of the litre (leading to the value 0.000028 dm³) was rescinded and the word litre reinstated as a special name for the cubic decimetre. Neither the word litre nor its symbol l should be used to express results of high precision.
### Physical quantity and Units

<table>
<thead>
<tr>
<th>Physical quantity</th>
<th>Name of unit</th>
<th>Symbol for unit</th>
<th>Definition of unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>energy</td>
<td>erg</td>
<td>erg</td>
<td>$10^{-7}$ J</td>
</tr>
<tr>
<td>kinematic viscosity</td>
<td>stokes</td>
<td>St</td>
<td>$10^{-4}$ m$^2$s$^{-1}$</td>
</tr>
<tr>
<td>dynamic viscosity</td>
<td>poise</td>
<td>P</td>
<td>$10^{-3}$ Pa s</td>
</tr>
<tr>
<td>magnetic flux</td>
<td>maxwell</td>
<td>Mx</td>
<td>$10^{-8}$ Wb</td>
</tr>
<tr>
<td>magnetic flux density (1)</td>
<td>gauss</td>
<td>G</td>
<td>$10^{-4}$ T</td>
</tr>
</tbody>
</table>

### Other units now exactly defined in terms of the SI units

These units are not part of the SI. It is recognized that their use may be continued for some time but it is recommended that except in special circumstances they should be progressively abandoned in scientific publications. Most of these units should not be used to form compound units. The following list is by no means exhaustive. Each of the definitions given in the fourth column is exact.

#### Symbol for

<table>
<thead>
<tr>
<th>Physical quantity</th>
<th>Name of unit</th>
<th>Symbol for unit</th>
<th>Definition of unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>length</td>
<td>inch</td>
<td>in</td>
<td>$2.54 \times 10^{-2}$ m</td>
</tr>
<tr>
<td>mass</td>
<td>pound (avoirdupois)</td>
<td>lb</td>
<td>0.453 592 37 kg</td>
</tr>
<tr>
<td>time</td>
<td>minute</td>
<td>min</td>
<td>60 s</td>
</tr>
<tr>
<td></td>
<td>hour</td>
<td>h</td>
<td>60 min = 3 600 s</td>
</tr>
<tr>
<td></td>
<td>day</td>
<td>d</td>
<td>24 h = 86 400 s</td>
</tr>
<tr>
<td>force</td>
<td>kilogram-force</td>
<td>kgf</td>
<td>9.806 65 N</td>
</tr>
<tr>
<td>pressure</td>
<td>atmosphere</td>
<td>atm</td>
<td>101 325 Pa</td>
</tr>
</tbody>
</table>
| pressure         | torr         | Torr            | (101 325/760) Pa   [
|                  |              |                 | $\approx 133.322 368$ Pa] |
| pressure         | conventional | mmHg            | $13.5951 \times 980.665$ |
|                  |              |                 | $\times 10^{-2}$ Pa |
|                  |              |                 | $[\approx 133.322 387$ Pa] |
| energy           | thermochemical calorie | cal$_{th}$ | 4.184 J |
| energy           | I.T. calorie  | cal$_{IT}$      | 4.1868 J          |
| thermodynamic temperature ($T$) | degree Rankine$^{-\circ}$ | °R $^{(2)}$ | $(5/9)$ K |
| Celsius temperature ($t_c$) $^{(3)}$ | degree Celsius | °C $^{(2)}$ | K |

---

1. The unit of magnetic flux density formerly called gamma, symbol γ, is equal to 1 nT.
2. The ° sign and the letter following form one symbol and there should be no space between them. Example: 25 °C not 25° C.
3. The Celsius temperature is the excess of the thermodynamic temperature over 273.15 K.
### Units defined in terms of certain physical constants

These units are not part of the SI. The factors for conversion of these units to SI units are subject to change in the light of new experimental measurements of the constants involved. Their use outside the restricted contexts to which they are appropriate should be discouraged. The following list is not exhaustive.

<table>
<thead>
<tr>
<th>Physical quantity</th>
<th>Name of unit</th>
<th>Symbol for</th>
<th>Conversion factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>length</td>
<td>astronomical unit</td>
<td>AU</td>
<td>AU ≈ 149 600 × 10^6 m</td>
</tr>
<tr>
<td></td>
<td>parsec</td>
<td>pc</td>
<td>pc ≈ 30 857 × 10^12 m</td>
</tr>
<tr>
<td>mass</td>
<td>unified atomic mass unit</td>
<td>u</td>
<td>u ≈ 1.660 531 × 10^-27 kg</td>
</tr>
<tr>
<td>energy</td>
<td>electronvolt</td>
<td>eV</td>
<td>eV ≈ 1.602 191 7 × 10^-19 J</td>
</tr>
</tbody>
</table>

### 'International' electric units

These units are obsolete, having been replaced by the 'absolute' (SI) units in 1948. The conversion factors which should be used with electric measurements quoted in 'international' units depend on where and when the instruments used to make the measurements were calibrated. The following two sets of conversion factors refer respectively to the 'mean international' units estimated by the ninth General Conference of Weights and Measures in 1948, and to the 'U.S. international' units estimated by the U.S. National Bureau of Standards as applying to instruments calibrated by them before 1948.

1 'mean international ohm' = 1.00049 Ω
1 'mean international volt' = 1.00034 V
1 'U.S. international ohm' = 1.000 495 Ω
1 'U.S. international volt' = 1.000 330 V

---

(1) The Fahrenheit temperature is the excess of the thermodynamic temperature over 459.67 °R.
(2) The ° sign and the letter following form one symbol and there should be no space between them. Example: 25 °F not 25° F.
(3) A special unit which takes account of the relative potentials for damage by different radiations and other factors is the rem (acronym for radiation equivalent man).
(4) Whenever confusion with the symbol for the radian (angular measure) appears possible the symbol rd may be used.
I.3.12. Electric and magnetic units belonging to unit-systems other than the SI

Definitions of units used in the 'electrostatic CGS' and 'electromagnetic CGS' unit-systems can be found in either of two documents listed in the Bibliography, §X.1.2, Part V: 1965, or §X.1.5.

It appears that for many years to come a knowledge of the 'electromagnetic CGS' unit system will be a necessity for workers in magnetism, but for practical purposes it is usually sufficient to note that 1 gauss (G) corresponds to $10^{-4}$ T and that 1 oersted (Oe) corresponds to $10^3 (4\pi)^{-1} \text{Am}^{-1} \approx 79.5775 \text{Am}^{-1}$.

I.3.13. Printing of symbols for units

The symbol for a unit should be printed in roman (upright) type, should remain unaltered in the plural, and should not be followed by a full stop except when it occurs at the end of a sentence.

Example: 5 cm but not 5 cms. and not 5 cm. and not 5 cms

The symbol for a unit derived from a proper name should begin with a capital roman (upright) letter.

Examples: J for joule and Hz for hertz

Any other symbol for a unit should be printed in lower case roman (upright) type.

Symbols for prefixes for units should be printed in roman (upright) type with no space between the prefix and the unit.

I.3.14. Multiplication and division of units

A product of two units may be represented in any of the ways:

$$\text{N m or N} \cdot \text{m or N} \times \text{m}$$

The representation Nm is not recommended.

A quotient of two units may be represented in any of the ways:

$$\text{m s}^{-1} \text{ or } \frac{\text{m}}{\text{s}}$$

or in any of the other ways of writing the product of m and s$^{-1}$, but not ms$^{-1}$.

These rules may be extended to more complex groupings but more than one solidus (/) should not be used in the same expression unless parentheses are used to eliminate ambiguity.

Examples: J K$^{-1}$mol$^{-1}$ or $J/(K \text{ mol})$ but not $J/K/\text{mol}$

$$\text{cm}^2\text{V}^{-1}\text{s}^{-1} \text{ or } \left(\frac{\text{cm/s}}{\text{V/cm}}\right)$$

but not cm/s/V/cm.
I.4. Numbers

I.4.1. **Printing of numbers**

Numbers should be printed in upright type. The decimal sign between digits in a number should be a point (.) or a comma (,). To facilitate the reading of long numbers the digits may be grouped in threes about the decimal sign but no point or comma should ever be used except for the decimal sign.

*Example:* 2 573.421 736 but not 2,573.421,736

When the decimal sign is placed before the first digit of a number a zero should always be placed before the decimal sign.

*Example:* 0.2573 × 10⁴ but not .2573 × 10⁴

It is often convenient to print numbers with just one digit before the decimal sign. 
*Example:* 2.573 × 10³

I.4.2. **Multiplication and division of numbers**

The multiplication sign between numbers should be a cross (×).

*Example:* 2.3 × 3.4

Division of one number by another may be indicated in any of the ways:

\[
\frac{136}{273} \text{ or } 136/273 \text{ or } 136 \times (273)^{-1}
\]

These rules may be extended to more complex groupings, but more than one solidus (/) should never be used in the same expression unless parentheses are used to eliminate ambiguity.

*Example:* (136/273)/2.303 or 136/(273 × 2.303) but never 136/273/2.303
PART II
RECOMMENDED MATHEMATICAL SYMBOLS

[Note: A, B denotes no preference; A...B denotes A preferred]

equal to
not equal to
identically equal to
corresponds to
approximately equal to
approaches
asymptotically equal to
proportional to
infinity

equal to
smaller than
larger than
smaller than or equal to
larger than or equal to
much smaller than
much larger than
plus
minus
plus or minus
minus or plus

ab, a · b, a × b
a/b, \(\frac{a}{b}\), ab⁻¹
|a|
\(a^n\)
\(a^\frac{1}{n}\), \(\sqrt[n]{a}\)
\(a^{1/n}, a^{\frac{1}{n}}, \sqrt[n]{a}\)
\(\langle a \rangle, \bar{a}\)
p!
\(^nC_p\)

When letters of the alphabet are used to form mathematical operators (Examples: d, Δ, ln, exp) or as mathematical constants (Examples: e, π) they should be printed in roman (upright) type so as to distinguish them from the symbols for physical quantities which should be printed in italic (sloping) type

\[
\sum
\]
\[
\Pi
\]
\[
f(x), f(x)
\]
\[
\lim_{x \to a} f(x)
\]

(1) See also §1.2.11.
(2) \(p! = 1 \times 2 \times 3 \times \ldots \times (p-1) \times p\) where \(p\) is a positive integer.
(3) \(^nC_p = \frac{n!}{(n-p)! p!}\) where \(n\) and \(p\) are positive integers and \(n \geq p\) and where \(0! = 1\).
finite increment of $x$ \quad \Delta x

differential coefficient of $f(x)$ with respect to $x$ \quad \frac{df}{dx}, df/dx, f'(x)

differential coefficient of order $n$ of $f(x)$ \quad \frac{d^n f}{dx^n}, d^n f/dx^n, f^{(n)}(x)

partial differential coefficient of $f(x, y, ...)$ with respect to $x$
when $y, ...$ are held constant \quad \frac{\partial f(x, y, ...)}{\partial x}, \left(\frac{\partial f}{\partial x}\right)_y, \left(\frac{\partial f}{\partial x}\right)_y

operator $\frac{\partial}{\partial x}$ or with single variable $\frac{d}{dx}$

the total differential of $f$ \quad df

inddefinite integral of $f(x)$ with respect to $x$ \quad \int f(x) \, dx

definite integral of $f(x)$ from $x = a$ to $x = b$ \quad \int_a^b f(x) \, dx

integral of $f(x)$ with respect to $x$ round a closed contour \quad \int_{C} f(x) \, dx

exponential of $x$ \quad e^x

base of natural logarithms \quad e

logarithm to the base $a$ of $x$ \quad \log_a x

natural logarithm of $x$ \quad \ln x, \log_e x

common logarithm of $x$ \quad \log x

binary logarithm of $x$ \quad \log_2 x

ratio of circumference to diameter of a circle \quad \pi

sine of $x$ \quad \sin x

cosine of $x$ \quad \cos x

tangent of $x$ \quad \tan x

cotangent of $x$ \quad \cot x

secant of $x$ \quad \sec x

cosecant of $x$ \quad \cosec x

inverse sine of $x$ \quad \sin^{-1} x

inverse cosine of $x$ \quad \cos^{-1} x

inverse tangent of $x$ \quad \tan^{-1} x

inverse cotangent of $x$ \quad \cot^{-1} x

inverse secant of $x$ \quad \sec^{-1} x

inverse cosecant of $x$ \quad \cosec^{-1} x

hyperbolic sine of $x$ \quad \sinh x

hyperbolic cosine of $x$ \quad \cosh x

hyperbolic tangent of $x$ \quad \tanh x

hyperbolic cotangent of $x$ \quad \coth x

hyperbolic secant of $x$ \quad \sech x

hyperbolic cosecant of $x$ \quad \cosech x
[Note: $A, B$ denotes no preference; $A \ldots B$ denotes $A$ preferred]

inverse hyperbolic sine of $x$
inverse hyperbolic cosine of $x$
inverse hyperbolic tangent of $x$
inverse hyperbolic cotangent of $x$
inverse hyperbolic secant of $x$
inverse hyperbolic cosecant of $x$

arsinh $x$ ... sinh$^{-1}$ $x$
arcosh $x$ ... cosh$^{-1}$ $x$
artanh $x$ ... tanh$^{-1}$ $x$
arcoth $x$ ... coth$^{-1}$ $x$
arsech $x$ ... sech$^{-1}$ $x$
arccosech $x$ ... cosech$^{-1}$ $x$

complex operator: $i^2 + 1 = 0$
real part of $z$
imaginary part of $z$
modulus of $z$
argument of $z$
complex conjugate of $z$

$i, j$
$Re z$
$Im z$
$|z|$
$\text{arg } z$
$z^*$

transpose of matrix $A$
complex conjugate matrix of matrix $A$
Hermitian conjugate matrix of matrix $A$

$\hat{A}, A^T$
$A^*$
$A^\dagger$

vector
magnitude of vector $A$
scalar product of vectors $A$ and $B$
vector product of vectors $A$ and $B$
dyadic product of vectors $A$ and $B$
differential vector operator

$A \ldots \hat{A}$
$|A|, A$
$A \cdot B$
$A \times B, A \wedge B$
$AB$
$\nabla, \frac{\partial}{\partial r}$
$\nabla \phi, \nabla^2 \phi$
$\nabla \cdot A, \text{div } A$
$\nabla \times A, \nabla \wedge A, \text{curl } A, \text{rot } A$
$\Box \phi$

scalar product of tensors $S$ and $T$
tensor product of tensors $S$ and $T$
product of tensor $S$ and vector $A$

$S : T$
$S \cdot T$
$S \cdot A$
PART III
CHEMICAL ELEMENTS, NUCLIDES, AND PARTICLES

III.1. Definitions

A nuclide is a species of atoms identical as regards atomic number (proton number) and mass number (nucleon number). Two or more nuclides having the same atomic number but different mass numbers are called isotopes or isotopic nuclides. Two or more nuclides having the same mass number are called isobars or isobaric nuclides.

III.2. Symbols for elements and nuclides

Symbols for chemical elements should be written in roman type. The symbol is not followed by a full stop.

Examples: Ca, C, H, He

The attached numerals specifying a nuclide are as follows:

\[
\text{mass number } ^{14}\text{N}_2 \text{ atoms/molecule}
\]

The atomic number may be placed in the left subscript position.

The right superscript position should be used, when required, to indicate ionic charge, state of excitation, or oxidation number.

Examples:

ionic charge: Cl\(^-\), SO\(_4^{2-}\), Ca\(^{2+}\), PO\(_4^{3-}\)

electronic excited states: He\(^*\), NO\(^*\)
nuclear excited states: \(^{110}\text{Ag}^*, \(^{110}\text{Ag}^m\)
oxidation number: K\(_6\text{M}^{11}\text{V}\text{Mo}_9\text{O}_{32}\)

III.3. Symbols for particles and quanta

<table>
<thead>
<tr>
<th>Particle</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>neutron</td>
<td>n</td>
</tr>
<tr>
<td>proton</td>
<td>p</td>
</tr>
<tr>
<td>deuteron</td>
<td>d</td>
</tr>
<tr>
<td>triton</td>
<td>t</td>
</tr>
<tr>
<td>α-particle</td>
<td>α</td>
</tr>
<tr>
<td>pion</td>
<td>π</td>
</tr>
<tr>
<td>muon</td>
<td>μ</td>
</tr>
<tr>
<td>electron</td>
<td>e</td>
</tr>
<tr>
<td>neutrino</td>
<td>ν</td>
</tr>
<tr>
<td>photon</td>
<td>γ</td>
</tr>
</tbody>
</table>

It is recommended that the following notation should be used:

Hyperons: Upright capital greek letters to indicate specific particles, e.g. Λ, Σ.

Nucleons: Upright lower case n and p to indicate neutron and proton respectively.
Mesons: Upright lower case greek letters to indicate specific particles, e.g. \( \pi, \mu, \tau \).

Leptons: L-particles; e.g. e, \( \nu \).

It is recommended that the charge of particles be indicated by adding the superscript +, −, or 0.

Examples:

\[ \pi^+, \pi^-, \pi^0; \quad p^+, p^-; e^+, e^- \]

If with the symbols \( p \) and \( e \) no sign is shown then the symbols should refer to the positive proton and the negative electron respectively.

The symbol \( \sim \) above the symbol of a particle should indicate the corresponding antiparticle (e.g. \( \bar{\nu} \) for anti-neutrino).

III.4. Notation for nuclear reactions

The meaning of the symbolic expression indicating a nuclear reaction should be the following:

\[ \text{initial nuclide} \quad \text{(incoming particle(s), or quanta)} \quad \text{outgoing particle(s)} \quad \text{final nuclide} \quad \text{(or quanta)} \]

Examples:

\[ \text{\( ^{14}\text{N}(\alpha, p)^{17}\text{O} \)} \quad \text{\( ^{59}\text{Co}(n, \gamma)^{60}\text{Co} \)} \]

\[ \text{\( ^{23}\text{Na}(\gamma, 3n)^{20}\text{Na} \)} \quad \text{\( ^{31}\text{P}(\gamma, pn)^{30}\text{Si} \)} \]
PART IV
QUANTUM STATES

IV.1. General rules
A letter symbol indicating the quantum state of a system should be printed in capital upright type. A letter symbol indicating the quantum state of a single electron should be printed in lower case upright type.

IV.2. Atomic spectroscopy
The letter symbols indicating quantum states are:

- \( L, l = 0: S, s \)
- \( = 1: P, p \)
- \( = 2: D, d \)
- \( = 3: F, f \)
- \( L, l = 4: G, g \)
- \( = 5: H, h \)
- \( = 6: I, i \)
- \( = 7: J, j \)
- \( L, l = 8: L, l \)
- \( = 9: M, m \)
- \( = 10: N, n \)
- \( = 11: O, o \)

A right hand subscript indicates the total angular momentum quantum number \( J \) or \( j \). A left hand superscript indicates the spin multiplicity \( 2S + 1 \).

Examples:
- \(^2P_{3/2}\) - state \((J = \frac{3}{2}, \text{multiplicity } 2)\)
- \(p_{3/2}\) - electron \((j = \frac{3}{2})\)

An atomic electron configuration is indicated symbolically by:

\((nl)^k (n'l')^{k'} \ldots\)

The quantum symbols \( s, p, d, f, \ldots \) are used instead of \( l = 0, 1, 2, 3, \ldots \).

Example: the atomic configuration: \((1s)^2 (2s)^2 (2p)^3\)

IV.3. Molecular spectroscopy
The letter symbols indicating molecular electronic quantum states are for linear molecules:

- \( A, \lambda = 0: \Sigma, \sigma \)
- \( = 1: \Pi, \pi \)
- \( = 2: \Delta, \delta \)

and for non-linear molecules:

- \( A, a; \ B, b; \ E, e; \) etc.

A left hand superscript indicates the spin multiplicity. For molecules having a symmetry centre the parity symbol \( g \) or \( u \), indicating respectively symmetric or
antisymmetric behaviour on inversion, is attached as a right hand subscript. A + or — sign attached as a right hand superscript indicates the symmetry as regards reflexion in any plane through the symmetry axis of the molecules.

Examples: $\Sigma^\pm_2$, $\Pi_u$, $2\Sigma$, $3\Pi$, etc.

The letter symbols indicating the vibrational angular moment states in the case of linear molecules are:

- $l = 0$: $\Sigma$
- $l = 1$: $\Pi$
- $l = 2$: $\Delta$

IV.4. Nuclear spectroscopy

The spin and parity assignment of a nuclear state is $J^\pi$ where the parity symbol $\pi$ is + for even and — for odd parity.

Examples:

- $3^+$, $2^-$, etc.

A shell model configuration is indicated symbolically by:

$$(nlj)^\pi (n'l'j')^\kappa$$

where the first bracket refers to the proton shell and the second to the neutron shell. Negative values of $\kappa$ or $\kappa'$ indicate holes in a completed shell. Instead of $l = 0, 1, 2, 3, \ldots$ the quantum state symbols $s, p, d, f, \ldots$ are used.

Example:

The nuclear configuration $(1d\frac{3}{2})^3(1f\frac{5}{2})^2$.

IV.5. Spectroscopic transitions

The upper level and the lower level are indicated by ′ and ″ respectively.

Examples:

- $h\nu = E' - E''$  $\sigma = T' - T''$

A spectroscopic transition should be indicated by writing the upper state first and the lower state second, connected by a dash in between.

Examples:

- $^2P_\frac{1}{2} \rightarrow ^2S_\frac{1}{2}$ for an electronic transition
- $(J', K') \rightarrow (J'', K'')$ for a rotational transition
- $v' \rightarrow v''$ for a vibrational transition

Absorption transition and emission transition may be indicated respectively by arrows $\leftarrow$ and $\rightarrow$. 36
Examples:

\((J', K') \leftrightarrow (J'', K'')\) absorption from \((J'', K'')\) to \((J', K')\)

\(2\text{P}_{\frac{3}{2}} \rightarrow 2\text{S}_{\frac{1}{2}}\) emission from \(2\text{P}_{\frac{3}{2}}\) to \(2\text{S}_{\frac{1}{2}}\)

The difference \(\Delta\) between two quantum numbers should be that of the upper state minus that of the lower state.

Example:

\[\Delta J = J' - J''\]

The indications of the branches of the rotation band should be as follows:

\[\Delta J = J' - J'' = -2: \text{O-branch}\]
\[= -1: \text{P-branch}\]
\[= 0: \text{Q-branch}\]
\[= +1: \text{R-branch}\]
\[= +2: \text{S-branch}\]
V.1. Notation for covariant character of coupling

\begin{align*}
S & \quad \text{scalar coupling} \\
A & \quad \text{axial vector coupling} \\
V & \quad \text{vector coupling} \\
P & \quad \text{pseudoscalar coupling} \\
T & \quad \text{tensor coupling}
\end{align*}

V.2. Character of transitions

\textit{Multipolarity of transition:}

\begin{align*}
\text{monopole} & \quad E_0 \text{ or } M_0 \\
\text{dipole} & \quad E_1 \text{ or } M_1 \\
\text{electric or magnetic} & \quad E_2 \text{ or } M_2 \\
\text{quadrupole} & \quad E_3 \text{ or } M_3 \\
\text{octupole} & \quad E_4 \text{ or } M_4 \\
\text{2^n-pole} & \quad E_n \text{ or } M_n
\end{align*}

\textit{parity change in transition:}

- transition \textit{with} parity change: yes
- transition \textit{without} parity change: no

V.3. Sign of polarization vector (Basel convention)

In nuclear interactions the positive polarization of particles with spin $\frac{1}{2}$ is taken in the direction of the vector product

$$k_1 \times k_0,$$

where $k_1$ and $k_0$ are the circular wavevectors of the incoming and outgoing particles respectively.
Thermodynamic results for chemical or physical processes should be expressed by quoting the equation for the process (with such specification of the physical states of the participating substances as may be necessary) followed by the value of the change in the appropriate thermodynamic function.

*Examples:*

\[
\begin{align*}
    H_2(g) + \frac{1}{2}O_2(g) &= H_2O(l); \\
    2H_2(g) + O_2(g) &= 2H_2O(l); \\
    H_2O(l) &= H_2O(g);
\end{align*}
\]

\[
\begin{align*}
    \Delta H(298.15 \text{K}) &= -285.83 \text{kJ mol}^{-1} \\
    \Delta H(298.15 \text{K}) &= -571.66 \text{kJ mol}^{-1} \\
    \Delta H(298.15 \text{K}) &= +44.01 \text{kJ mol}^{-1}
\end{align*}
\]

The following symbols should be used to specify physical states. They should be printed in roman type and should be placed in parentheses after the formula of the substance as in the examples given above.

- \text{g} \quad \text{gaseous}
- \text{l} \quad \text{liquid}
- \text{s} \quad \text{solid}
- \text{c} \quad \text{crystalline}
- \text{aq} \quad \text{dissolved at effectively infinite dilution in water.}
PART VII
GALVANIC CELLS

VII.1. The electromotive force of a cell

The cell should be represented by a diagram, e.g.

\[ \text{Zn} \mid \text{Zn}^{2+} \mid \text{Cu}^{2+} \mid \text{Cu}. \]

The electromotive force is equal in sign and magnitude to the electrical potential of the metallic conducting lead on the right when that of the similar lead on the left is taken as zero, the circuit being open.

When the reaction of the cell is written as

\[ \frac{1}{2}\text{Zn} + \frac{3}{4}\text{Cu}^{2+} \rightarrow \frac{1}{4}\text{Zn}^{2+} + \frac{3}{4}\text{Cu}, \]

this implies a diagram so drawn that this reaction takes place when positive electricity flows through the cell from left to right. If this is the direction of the current when the cell is short-circuited, as in the present example, the electromotive force is positive.

If, however, the reaction is written as

\[ \frac{1}{2}\text{Cu} + \frac{1}{2}\text{Zn}^{2+} \rightarrow \frac{1}{4}\text{Cu}^{2+} + \frac{1}{2}\text{Zn} \]

this implies the diagram

\[ \text{Cu} \mid \text{Cu}^{2+} \mid \text{Zn}^{2+} \mid \text{Zn} \]

and the electromotive force of the cell so specified is negative.

VII.2. The electromotive force of a half cell and the so-called 'electrode potential'

The term 'electromotive force of a half cell' as applied to half cells written as follows:

\[ \text{Zn}^{2+} \mid \text{Zn} \]
\[ \text{Cl}^{-} \mid \text{Cl}, \text{Pt} \]
\[ \text{Cl}^{-} \mid \text{AgCl}, \text{Ag} \]
\[ \text{Fe}^{2+}, \text{Fe}^{3+} \mid \text{Pt} \]

means the electromotive forces of the cells:

\[ \text{Pt, H}_2 \mid \text{H}^{+} \mid \text{Zn}^{2+} \mid \text{Zn} \]
\[ \text{Pt, H}_2 \mid \text{H}^{+} \mid \text{Cl}^{-} \mid \text{Cl}, \text{Pt}, \text{Pt} \]
\[ \text{Pt, H}_2 \mid \text{H}^{+} \mid \text{Cl}^{-} \mid \text{AgCl}, \text{Ag} \]
\[ \text{Pt, H}_2 \mid \text{H}^{+} \mid \text{Fe}^{2+}, \text{Fe}^{3+} \mid \text{Pt} \]

implying the reaction

\[ \frac{1}{2}\text{H}_2 + \frac{1}{2}\text{Zn}^{2+} \rightarrow \text{H}^{+} + \frac{1}{2}\text{Zn} \]
\[ \frac{1}{2}\text{H}_2 + \frac{1}{2}\text{Cl}_2 \rightarrow \text{H}^{+} + \text{Cl}^{-} \]
\[ \frac{1}{2}\text{H}_2 + \text{AgCl} \rightarrow \text{H}^{+} + \text{Cl}^{-} + \text{Ag} \]
\[ \frac{1}{2}\text{H}_2 + \text{Fe}^{3+} \rightarrow \text{H}^{+} + \text{Fe}^{2+} \]

where the electrode on the left is a standard hydrogen electrode.
These electromotive forces may also be called *relative electrode potentials* or, in brief, *electrode potentials*.

On the other hand, the term ‘electromotive force of a half cell’ as applied to half cells written as follows:

\[
\begin{align*}
\text{Zn}|\text{Zn}^{2+} \\
\text{Pt, Cl}_2|\text{Cl}^- \\
\text{Ag, AgCl}|\text{Cl}^- \\
\text{Pt}|\text{Fe}^{2+}, \text{Fe}^{3+}
\end{align*}
\]

means the electromotive forces of the cells:

\[
\begin{align*}
\text{Zn}|\text{Zn}^{2+}|\text{H}^+|\text{H}_2, \text{Pt} & \quad \text{implying} \quad \frac{1}{2}\text{Zn} + \text{H}^+ \rightarrow \frac{1}{2}\text{Zn}^{2+} + \frac{1}{2}\text{H}_2 \\
\text{Pt, Cl}_2|\text{Cl}^-|\text{H}^+|\text{H}_2, \text{Pt} & \quad \text{the} \quad \text{Cl}^- + \text{H}^+ \rightarrow \frac{1}{2}\text{Cl}_2 + \frac{1}{2}\text{H}_2 \\
\text{Ag, AgCl}|\text{Cl}^-|\text{H}^+|\text{H}_2, \text{Pt} & \quad \text{reaction} \quad \text{Ag} + \text{Cl}^- + \text{H}^+ \rightarrow \text{AgCl} + \frac{1}{2}\text{H}_2 \\
\text{Pt}|\text{Fe}^{2+}, \text{Fe}^{3+}|\text{H}^+|\text{H}_2, \text{Pt} & \quad \text{Fe}^{2+} + \text{H}^+ \rightarrow \text{Fe}^{3+} + \frac{1}{2}\text{H}_2
\end{align*}
\]

where the electrode on the right is a *standard hydrogen electrode*.

These electromotive forces should not be called electrode potentials.
### PART VIII

**ABBREVIATIONS OF COMMON WORDS AND PHRASES**

This list is not intended to be exhaustive. The words in this list will often be given in full in the text, but where abbreviations are used the following forms are recommended. Such abbreviations should be printed in roman type (except for *ca.*).

<table>
<thead>
<tr>
<th>Word</th>
<th>Abbreviation</th>
<th>Definition</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>absolute</td>
<td>abs.</td>
<td>Greenwich mean time</td>
<td>G.M.T.</td>
</tr>
<tr>
<td>alternating current</td>
<td>a.c.</td>
<td>infrared</td>
<td></td>
</tr>
<tr>
<td>anhydrous</td>
<td>anhyd.</td>
<td>insoluble</td>
<td></td>
</tr>
<tr>
<td>approximate(-ly)</td>
<td>approx., <em>ca.</em></td>
<td>liquid</td>
<td></td>
</tr>
<tr>
<td>aqueous</td>
<td>aq.</td>
<td>magnetomotive force</td>
<td>m.m.f.</td>
</tr>
<tr>
<td>average</td>
<td>av.</td>
<td>maximum</td>
<td></td>
</tr>
<tr>
<td>boiling point</td>
<td>b.p.</td>
<td>melting point</td>
<td></td>
</tr>
<tr>
<td>calculated</td>
<td>calc.</td>
<td>minimum</td>
<td></td>
</tr>
<tr>
<td>centre of gravity</td>
<td>c.g.</td>
<td>nuclear magnetic resonance</td>
<td>n.m.r.</td>
</tr>
<tr>
<td>coefficient</td>
<td>coeff.</td>
<td>observed</td>
<td></td>
</tr>
<tr>
<td>compound</td>
<td>cpd</td>
<td>per cent</td>
<td></td>
</tr>
<tr>
<td>concentrated</td>
<td>conc.</td>
<td>potential difference</td>
<td>p.d.</td>
</tr>
<tr>
<td>constant</td>
<td>const.</td>
<td>precipitate</td>
<td>ppt.</td>
</tr>
<tr>
<td>corrected</td>
<td>corr.</td>
<td>preparation</td>
<td></td>
</tr>
<tr>
<td>critical</td>
<td>crit.</td>
<td>radio frequency</td>
<td>r.f.</td>
</tr>
<tr>
<td>crystalline</td>
<td>cryst.</td>
<td>recrystallized</td>
<td>recryst.</td>
</tr>
<tr>
<td>current density</td>
<td>c.d.</td>
<td>relative humidity</td>
<td>r.h.</td>
</tr>
<tr>
<td>decomposition</td>
<td>decomp.</td>
<td>root mean square</td>
<td>r.m.s.</td>
</tr>
<tr>
<td>diameter, inside</td>
<td>i.d.</td>
<td>section, paragraph</td>
<td></td>
</tr>
<tr>
<td>diameter, outside</td>
<td>o.d.</td>
<td>soluble</td>
<td>sol.</td>
</tr>
<tr>
<td>dilute</td>
<td>dil.</td>
<td>solution</td>
<td>soln</td>
</tr>
<tr>
<td>direct current</td>
<td>d.c.</td>
<td>standard temperature and pressure</td>
<td></td>
</tr>
<tr>
<td>distilled</td>
<td>dist.</td>
<td>temperature</td>
<td>temp.</td>
</tr>
<tr>
<td>electromagnetic unit</td>
<td>e.m.u.</td>
<td>temperature</td>
<td></td>
</tr>
<tr>
<td>electromotive force</td>
<td>e.m.f.</td>
<td>ultraviolet</td>
<td>u.v.</td>
</tr>
<tr>
<td>electron spin resonance</td>
<td>e.s.r.</td>
<td>universal time</td>
<td>U.T.</td>
</tr>
<tr>
<td>electrostatic unit</td>
<td>e.s.u.</td>
<td>vacuum</td>
<td>vac.</td>
</tr>
<tr>
<td>equation</td>
<td>equ.</td>
<td>vapour density</td>
<td>v.d.</td>
</tr>
<tr>
<td>experiment</td>
<td>expt</td>
<td>vapour pressure</td>
<td>v.p.</td>
</tr>
<tr>
<td>experimental</td>
<td>expit</td>
<td>volume</td>
<td>vol.</td>
</tr>
<tr>
<td>freezing point</td>
<td>f.p.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
PART IX
RECOMMENDED VALUES OF PHYSICAL CONSTANTS

The following values have been recommended by the CODATA Committee (20 August 1970). The standard-deviation uncertainty is given below each value. Details concerning the development of this self-consistent set of values and their uncertainties are given by Taylor, Parker & Langenberg (1969); see the Bibliography, §X.2.4.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Value and standard-deviation uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>speed of light in a vacuum</td>
<td>$c$</td>
<td>$2.997 925 0 \times 10^8$ m s$^{-1}$</td>
</tr>
<tr>
<td>magnetic constant, permeability of a vacuum</td>
<td>$\mu_0 = \frac{1}{4\pi} \times 10^7$ H m$^{-1}$</td>
<td>(exact)</td>
</tr>
<tr>
<td>electric constant, permittivity of a vacuum</td>
<td>$\varepsilon_0 = \mu_0^{-1} c^{-2}$</td>
<td>$8.854 185 3 \times 10^{-12}$ F m$^{-1}$</td>
</tr>
<tr>
<td>fine structure constant</td>
<td>$\alpha = \mu_0 e^2 / 2 \hbar$</td>
<td>$7.297 351 \times 10^{-3}$</td>
</tr>
<tr>
<td>charge of a proton</td>
<td>$e$</td>
<td>$1.602 191 7 \times 10^{-19}$ C</td>
</tr>
<tr>
<td>Planck constant</td>
<td>$\hbar = h / 2\pi$</td>
<td>$6.626 196 \times 10^{-34}$ J s</td>
</tr>
<tr>
<td></td>
<td>$\hbar = h / 2\pi$</td>
<td>$6.626 196 \times 10^{-34}$ J s</td>
</tr>
<tr>
<td></td>
<td>$\hbar / 2e$</td>
<td>$2.067 853 8 \times 10^{-18}$ J s C$^{-1}$</td>
</tr>
<tr>
<td>Avogadro constant</td>
<td>$L, N_A$</td>
<td>$6.022 169 \times 10^{23}$ mol$^{-1}$</td>
</tr>
<tr>
<td>unified atomic mass constant</td>
<td>$m_u$</td>
<td>$1.660 531 \times 10^{-27}$ kg</td>
</tr>
<tr>
<td>rest mass:</td>
<td>$m_e$</td>
<td>$9.109 558 \times 10^{-31}$ kg</td>
</tr>
<tr>
<td></td>
<td>$m_e / m_u$</td>
<td>$5.485 930 \times 10^{-4}$</td>
</tr>
<tr>
<td></td>
<td>$m_p$</td>
<td>$1.672 614 \times 10^{-27}$ kg</td>
</tr>
<tr>
<td></td>
<td>$m_p / m_u$</td>
<td>$1.007 276 61$</td>
</tr>
<tr>
<td>Quantity (cont.)</td>
<td>Symbol</td>
<td>Value and standard-deviation uncertainty</td>
</tr>
<tr>
<td>-----------------</td>
<td>--------</td>
<td>------------------------------------------</td>
</tr>
<tr>
<td>rest mass of proton</td>
<td>$m_p/m_e$</td>
<td>1.836 109 11</td>
</tr>
<tr>
<td>rest mass of neutron</td>
<td>$m_n$</td>
<td>$1.674920 \times 10^{-27}$ kg 11</td>
</tr>
<tr>
<td>rest mass of proton/ neutron</td>
<td>$m_n/m_u$</td>
<td>1.008 665 20 10</td>
</tr>
<tr>
<td>Faraday constant</td>
<td>$F$</td>
<td>$9.648670 \times 10^4$ C mol$^{-1}$ 54</td>
</tr>
<tr>
<td>Rydberg constant</td>
<td>$R_\infty = \mu_0^2 m_e c^5/8h^3$</td>
<td>$1.097373 12 \times 10^7$ m$^{-1}$ 11</td>
</tr>
<tr>
<td>Bohr radius</td>
<td>$a_0 = h^2/\pi \mu_0 e^2 m_e$</td>
<td>$5.291771 5 \times 10^{-11}$ m 81</td>
</tr>
<tr>
<td>electron radius</td>
<td>$r_e = \mu_0 e^2/4\pi m_e$</td>
<td>$2.817939 \times 10^{-15}$ m 13</td>
</tr>
<tr>
<td>Bohr magneton</td>
<td>$\mu_B = e\hbar/4\pi m_e$</td>
<td>$9.274096 \times 10^{-24}$ J T$^{-1}$ 65</td>
</tr>
<tr>
<td>magnetic moment:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>of electron</td>
<td>$\mu_e$</td>
<td>$9.284851 \times 10^{-24}$ J T$^{-1}$ 65</td>
</tr>
<tr>
<td></td>
<td>$\mu_e/\mu_B$</td>
<td>1.001 159 639 1 51</td>
</tr>
<tr>
<td>of proton</td>
<td>$\mu_p$</td>
<td>$1.410 620 3 \times 10^{-28}$ J T$^{-1}$ 99</td>
</tr>
<tr>
<td></td>
<td>$\mu_p/\mu_B$</td>
<td>$1.521 632 64 \times 10^{-3}$ 46</td>
</tr>
<tr>
<td>gyromagnetic ratio of protons in H$_2$O</td>
<td>$\gamma_p'$</td>
<td>$2.675 127 0 \times 10^8$ s$^{-1}$ T$^{-1}$ 82</td>
</tr>
<tr>
<td></td>
<td>$\gamma_p'/2\pi$</td>
<td>$4.257 597 \times 10^7$ s$^{-1}$ T$^{-1}$ 13</td>
</tr>
<tr>
<td>$\gamma_p'$ corrected for diamagnetism of H$_2$O</td>
<td>$\gamma_p$</td>
<td>$2.675 196 5 \times 10^8$ s$^{-1}$ T$^{-1}$ 82</td>
</tr>
<tr>
<td></td>
<td>$\gamma_p'/2\pi$</td>
<td>$4.257 707 \times 10^7$ s$^{-1}$ T$^{-1}$ 13</td>
</tr>
<tr>
<td>nuclear magneton</td>
<td>$\mu_N = (m_e/m_p)\mu_B$</td>
<td>$5.050 951 \times 10^{-27}$ J T$^{-1}$ 50</td>
</tr>
<tr>
<td>magnetic moment of protons in H$_2$O ($\mu_p'$)</td>
<td>$\mu_p'/\mu_B$</td>
<td>$1.520 993 12 \times 10^{-3}$ 10</td>
</tr>
<tr>
<td></td>
<td>$\mu_p'/\mu_N$</td>
<td>2.792 709 17</td>
</tr>
<tr>
<td>$\mu_p'$ corrected for diamagnetism of H$_2$O ($\mu_p$)</td>
<td>$\mu_p/\mu_N$</td>
<td>2.792 782 17</td>
</tr>
<tr>
<td>Quantity</td>
<td>Symbol</td>
<td>Value and standard-deviation uncertainty</td>
</tr>
<tr>
<td>----------</td>
<td>--------</td>
<td>------------------------------------------</td>
</tr>
<tr>
<td>Compton wavelength: of electron</td>
<td>λ_C = h/m_e c</td>
<td>2.426 309 6 x 10^{-12} m</td>
</tr>
<tr>
<td>of proton</td>
<td>λ_C, P = h/m_p c</td>
<td>1.321 440 9 x 10^{-15} m</td>
</tr>
<tr>
<td>of neutron</td>
<td>λ_C, n = h/m_n c</td>
<td>1.319 621 7 x 10^{-15} m</td>
</tr>
<tr>
<td>gas constant</td>
<td>R</td>
<td>8.314 34 J K^{-1} mol^{-1}</td>
</tr>
<tr>
<td>Boltzmann constant</td>
<td>k = R/L</td>
<td>1.380 625 x 10^{-23} J K^{-1}</td>
</tr>
<tr>
<td>Stefan–Boltzmann constant</td>
<td>σ = 2π^2 k^4/15h^3c^2</td>
<td>5.669 61 x 10^{-8} W m^{-2} K^{-4}</td>
</tr>
<tr>
<td>first radiation constant</td>
<td>c_1 = 2πhc^2</td>
<td>3.741 844 x 10^{-16} J m^2 s^{-1}</td>
</tr>
<tr>
<td></td>
<td>8πhc</td>
<td>4.992 579 x 10^{-24} J m</td>
</tr>
<tr>
<td>second radiation constant</td>
<td>c_2 = hc/k</td>
<td>1.438 833 x 10^{-2} m K</td>
</tr>
<tr>
<td>gravitational constant</td>
<td>G</td>
<td>6.673 2 x 10^{-11} N m^3 kg^{-2}</td>
</tr>
</tbody>
</table>

(1) The spectral radiant exitance (formerly called spectral radiant emittance and sometimes emissive power), M_A, is given by

\[ M_A = \frac{2\pi h c^2}{\lambda^5} \left\{ \exp \left( \frac{h c}{k T \lambda} \right) - 1 \right\}; \]

the spectral radiant energy density, w_A, is given by

\[ w_A = \frac{8\pi h c}{\lambda^5} \left\{ \exp \left( \frac{h c}{k T \lambda} \right) - 1 \right\}; \]

unfortunately there is no accepted name or symbol for the constant 8πhc.
PART X
BIBLIOGRAPHY

X.1. General sources

X.1.1. The publications of the bodies of the Metre Convention

The proceedings of the General Conference, the International Committee, the Consultative Committees, and the International Bureau are published under the auspices of the Bureau in the following series:

*Comptes rendus des séances de la Conférence Générale des Poids et Mesures; Procès-Verbaux des séances du Comité International des Poids et Mesures; Sessions des Comités Consultatifs;*

*Recueil de Travaux du Bureau International des Poids et Mesures* (this compilation brings together articles published in scientific and technical journals and books, as well as certain work published in the form of duplicated reports.)

The collection of the *Travaux et Mémoires du Bureau International des Poids et Mesures* (22 volumes published between 1881 and 1966) ceased in 1966 by a decision of the International Committee.

From time to time the International Bureau publishes a report on the development of the Metric System throughout the world, entitled *Les récents progrès du Système Métrique.*

Since 1965 the international journal *Metrologia,* edited under the auspices of the International Committee of Weights and Measures, has published articles on the principal work on scientific metrology carried out throughout the world and on the improvement in measuring methods and standards, units, etc., as well as reports concerning the activities, decisions, and recommendations of the various bodies created under the Metre Convention.

X.1.2. The publications of the work of Technical Committee no. 12 of the International Organization for Standardization (ISO/TC 12)

ISO Recommendation R 31. An ISO Recommendation on quantities, units, symbols and conversion factors issued in various parts, seven of which have been published. Six other parts still in draft form remain to be completed. In all the parts dealing specifically with units, the SI units are listed first, but many other units in common international use are also listed, with conversion factors in terms of SI.

The published parts are:

Part I: 1955 Basic quantities and units of the SI and quantities and units of space and time.

Part II: 1958 Quantities and units of periodic and related phenomena.

Part III: 1960 Quantities and units of mechanics.

Part IV: 1960 Quantities and units of heat.
Part V: 1965 Quantities and units of electricity and magnetism.
Part VII: 1965 Quantities and units of acoustics.

In the United Kingdom these can be purchased from the British Standards Institution (see note 3 below for the address).

The parts in preparation are:

DIR 839 Quantities and units of nuclear reactions and ionizing radiation.
DIR 838 Quantities and units of atomic and nuclear physics.
DIR 1777 Quantities and units of physical chemistry and molecular physics.
DIR 1778 Quantities and units of light and related electromagnetic radiations.
DIR 2188 Dimensionless parameters.
DIR 2180 General principles concerning quantities, units and symbols.

X.1.3

X.1.4

X.1.5

X.1.6

X.2. Special sources

X.2.1
BS 1219 1958 Recommendations for proof correction and copy preparation.

X.2.2

X.2.3
X.2.4

X.3. Supplementary literature

X.3.1
BS 3763 1970 The International System of Units.

X.3.2
McGlashan, M. L. 1971 Physicochemical quantities and units (the grammar and spelling of physical chemistry) (2nd ed.). London: The Royal Institute of Chemistry.

X.3.3
BS 350 Conversion factors and tables:
1959 Part 1: Basis of tables, conversion factors.

X.3.4
BS 1991 Letter symbols, signs and abbreviations:
1961 Part 2: Chemical engineering, nuclear science and applied chemistry.
1961 Part 4: Structures, materials and soil mechanics.

X.3.5

X.3.6

Notes
1. The foregoing Bibliography is inevitably selective rather than comprehensive.
2. Many of the items listed (especially those under the heading Supplementary literature) are subject to repeated revision; all such titles should be consulted in their latest edition.
3. The publications labelled with the prefix BS are issued by the British Standards Institution, 2 Park Street, London W1A 2BS.

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