

METRIC TERMINOLOGY AND PROCEDURE

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1 The General Conference on Weights and Measures in 1960 generated the International Metric System. International metric is generally known as SI (Le Système International d'Unités). The letters SI will be used to identify this system without further explanation in this section.

2 METRIC UNITS. SI consists of base, supplementary, and derived units, with a series of approved prefixes.

2.1 Base units are the seven units selected to form a basic metric measurement structure, the foundation on which all other units are based. Two other units, called supplementary units (the radian and steradian) complete the basic system. These base and supplementary units are listed in Table 1.

2.2 Derived units are those produced by combining base and supplementary units to provide the necessary names for natural and formulated quantities. Certain selected derived units with special names are listed in Table 2.

2.3 Standard prefixes are used to form multiples and submultiples of base, supplementary, and derived units. These prefixes are shown in Table 5.

3 COHERENCE. The basic advantage of SI over the previous metric systems (cgs and mks) is coherence between units. An objective in the GM approach to metrication is to adhere to SI. This approach will result in minimizing complex calculation processes.

3.1 A system of units is coherent if the product or quotient of any two unit quantities in the system is a single unit of the resulting quantity. For example, in any coherent system, unit area results when unit length is multiplied by unit length, unit velocity when unit length is divided by unit time, and unit force when unit mass is multiplied by unit acceleration. Since SI is coherent, any multiplication or division of base (Table 1 or derived Table 2) units (that is, kilogram or any unprefix SI unit) will 1) produce the numerical answer, 2) establish the proper decimal point placement, 3) provide a coherent unit for the resultant dimension, and 4) eliminate the need for the alteration of dimensionless constants.

3.2 It must be remembered, however, that the kilogram is the only base or derived SI unit with a prefix. This is an unfortunate but necessary inconsistency in SI. All coherent formulae using mass must use kilogram (kg) not grams (g). When expressing measurements of mass in written or spoken communication, any conventional term can be used, e.g., mg, g, kg, Mg, etc. But they must be converted to kilograms when coherent calculations are performed.

3.2.1 Example: Coherency exists all the way from the watt, a derived unit, to base units as long as the kilogram is used.

$$W = J/s = N \cdot m/s = (kg \cdot m/s^2) \cdot (m/s) = kg \cdot m^2/s^3$$

3.2.2 To have used gram as the base unit would have introduced a factor of 1000 into the series of equations, thus spoiling coherency:

$$W = J/s = N \cdot m/s = (1000 \text{ g} \cdot m/s^2) \cdot (m/s) = 1000 \text{ g} \cdot m^2/s^3$$

3.3 The International Organization for Standardization (ISO) has considered introduction of a new name to replace and be equal to the kilogram of mass. If it ever happens, it will be several years away. Meanwhile, everyone is instructed to use the kilogram as the base SI unit for mass.

3.4 The manner in which coherence can be achieved in GM is straightforward. As long as we stick to the units in Tables 1 and 2 coherence will be maintained. Whenever a deviation from these units is justified, a simple decimal conversion to coherent units must be anticipated. This was done in column 3 of Table 7.

3.4.1 The following pronunciation symbols will be used in all tables which follow.

ā = as in day	î = as in tip
a = as in mat	ī = as in side
ä = as in cart	ô = as in bone
ə = same as a in about	ü = as in union
e = as in bed	û = as in pull
ē = as in eel	' = accent is on that syllable

4 ISO COMPUTER SYMBOLS. International Standard, ISO 2955-1974 (E), is titled "Information Processing - Representations of SI and Other Units for Use in Systems with Limited Character Sets." Portions of this standard which will be used in GM have been inserted in the tables. Single case upper representation is used. These symbols and rules are applicable only to computer use.

4.1 The Rules Listed in ISO 2955 Are:

4.1.1 Rule No. 1. In narrative (free text) data, a space character shall be used to separate the numeric value and the unit representation; for example 10 M, 2 M2. In formatted data, as in records, the use of the space character as a separator is optional, since its use or non-use is defined in the format description.

4.1.2 Rule No. 2. To indicate multiplication of units, a full stop (.) between the representations of units (combined with prefix or not) is necessary.

Examples:

- 1) P.A.S to designate pascal second, unit of dynamic viscosity.
- 2) N·M to designate newton-meter, unit of torque.

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TABLE 1 - BASE UNITS

1. Quantity	2. Name of SI Unit	3. Pronunciation	4. Symbol	5. ISO Computer Symbol
length	meter	'mēt-ər	m	M
mass	kilogram	'kil-ə-gram	kg	KG
time	second	'sek-ənd	s	S
electric current	ampere	'am-pi(ə)r	A	A
thermodynamic temperature	kelvin	'kel-vən	K	K
amount of substance	mole	'mōl	mol	MOL
luminous intensity	candela	kan-'del-ə	cd	CD
Supplementary units				
plane angle	radian	'rād-ē-ən	rad	RAD
solid angle	steradian	ste-'rād-ē-ən	sr	SR

The full stop between the two letters also avoids confusion between N·M (newton-meter) and NM (nanometer).

4.1.3 Rule No. 3. To indicate division of units, the numerator and the denominator are separated by a solidus (/); alternatively, the denominator may be expressed with a negative exponent (see Rule No. 5); for example M/S or M·S⁻¹ for meter per second.

4.1.4 Rule No. 4. Positive exponents are indicated by the respective numerals without any further sign, directly after the representation of the unit; for example M2 for m².

4.1.5 Rule No. 5. Negative exponents are indicated by a minus sign followed by the respective numeral, both together directly after the representation of the unit; for example M-3 for m⁻³.

4.1.6 A prefix representation is combined with a unit representation to form a new unit representation which can be raised to a power with positive or negative exponent and which can be combined with other unit representations to form representations or compound units. There is no separator or space between the prefix representation and the unit representation; for example CM2 for cm², KN/M2 or KN·M-2 for kN/m².

NOTES TO USER:

1. A prefix is not allowed to stand alone, without combination with a unit; for example, T alone means tesla but not tera. Compound prefixes should not be used; for example, NM (nanometer) should be used instead of MUM (millimicrometer).

2. In the case of base SI unit kilogram, which contains a prefix in its name, the representations for decimal multiples and submultiples are formed by use of the corresponding prefix representation together with the representation of the unit gram; for example, the representation for 10⁻⁶ kilogram = 10⁻³ gram is denoted by MG and not by UKG.

5 DERIVED UNITS WITH SPECIAL NAMES.

5.1 In SI there is only one unit for each physical quantity—the meter for length, the kilogram (instead of the gram) for mass, second for time, etc. From these base units, units for all other quantities are derived. These derived units are defined by simple equations such as force = mass x acceleration, energy = force x distance, power = work/time. Special names have been given to the most commonly used expressions, such as newton (N) for force, joule (J) for energy, watt (W) for power. The derived units with special names are listed in Table 2.

5.2 Convenience and ease of comprehension were sufficient reasons for developing special names for derived units, rather than to use base units in these instances. For example, a pascal is much easier to use to express pressure than kg/(m·s²). Even more dramatic, an ohm is not as awkward as kg·m²/(A²·s³). These base formulae are abstract (impossible to visualize) and more importantly, they do not correspond to instrumentation and measurement methods, as do the derived units.

5.3 An SI unit for a derived quantity, such as that for energy, is the same regardless of whether the process is thermal, mechanical, electrical, chemical or nuclear. A force of one newton applied for a distance of one meter produces one joule of heat or mechanical energy, which is identically the amount of energy that one watt of electrical power can produce in one second. Likewise, the power requirements or output of all devices and processes are expressed in watts;

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thus an automobile engine, an electric motor, a furnace, a refrigerator, and a heat transfer unit will all be rated in watts.

5.4 Derived units are coherent. They are derived from other coherent or base units as shown in Table 2 column 5. In fact, they can be expressed in base units only, as shown in Table 2 column 6.

5.5 Units in Tables 1 and 2 should be used with the prefixes of Table 5 (see Note). The prefixes are for use in written and spoken language. The multiplication factors are used during calculations.

NOTE: The exception is the kilogram. Apply the prefixes to gram, not kilogram. For example, 1 000 kilograms is a megagram, not a kilogram.

TABLE 2 - DERIVED UNITS WITH SPECIAL NAMES

1. Quantity	2. Name of Derived SI Unit	3. Pronunciation	4. Symbol	5. Derivation from Other SI Units	6. Derivation from Base SI Units	7. ISO Computer Symbol
frequency	hertz	'herts	Hz	$\text{Hz} = \text{s}^{-1}$	$\text{Hz} = \text{s}^{-1}$	HZ
force	newton	'n(y)ut-ən	N	$\text{N} = \text{kg} \cdot \text{m}/\text{s}^2$	$\text{N} = \text{kg} \cdot \text{m}/\text{s}^2$	N
pressure, stress	pascal	'pass-kal	Pa	$\text{Pa} = \text{N}/\text{m}^2$	$\text{Pa} = \text{kg}/(\text{m} \cdot \text{s}^2)$	PA
energy, work or quantity of heat	joule	'jü(ə)l	J	$\text{J} = \text{N} \cdot \text{m}$	$\text{J} = \text{kg} \cdot \text{m}^2/\text{s}^2$	J
power, radiant flux	watt	'wät	W	$\text{W} = \text{J}/\text{s}$	$\text{W} = \text{kg} \cdot \text{m}^2/\text{s}^3$	W
quantity of electricity, electric charge	coulomb	'kü-läm	C	$\text{C} = \text{A} \cdot \text{s}$	$\text{C} = \text{A} \cdot \text{s}$	C
electrical potential, potential difference, tension, electromotive force	volt	'völt	V	$\text{V} = \text{J}/\text{C} = \text{W}/\text{A}$	$\text{V} = \text{kg} \cdot \text{m}^2/(\text{A} \cdot \text{s}^2)$	V
electric capacitance	farad	'far-ad	F	$\text{F} = \text{C}/\text{V}$	$\text{F} = \text{A}^2 \cdot \text{s}^4/(\text{kg} \cdot \text{m}^2)$	F
electric resistance	ohm	'öm	Ω^a	$\Omega = \text{V}/\text{A}$	$\Omega = \text{kg} \cdot \text{m}^2/(\text{A}^2 \cdot \text{s}^2)$	OHM
electric conductance	siemens	'sē-məns	S	$\text{S} = \Omega^{-1} = \text{A}/\text{V}$	$\text{S} = \text{A}^2 \cdot \text{s}^2/(\text{kg} \cdot \text{m}^2)$	SIE
magnetic flux	weber	'web-ər	Wb	$\text{Wb} = \text{V} \cdot \text{s}$	$\text{Wb} = \text{kg} \cdot \text{m}^2/(\text{A} \cdot \text{s}^2)$	WB
magnetic fluxdensity	tesla	'tes-la	T	$\text{T} = \text{Wb}/\text{m}^2$	$\text{T} = \text{kg}/(\text{A} \cdot \text{s}^2)$	T
inductance	henry ^b	'hen-rē	H	$\text{H} = \text{Wb}/\text{A}$	$\text{H} = \text{kg} \cdot \text{m}^2/(\text{A}^2 \cdot \text{s}^2)$	H
luminous flux	lumen	'lü-mən	lm	$\text{lm} = \text{cd} \cdot \text{sr}$	$\text{lm} = \text{cd} \cdot \text{sr}$	LM
illuminance	lux ^c	'ləks	lx	$\text{lx} = \text{lm}/\text{m}^2$	$\text{lx} = \text{cd} \cdot \text{sr}/\text{m}^2$	LX
activity (radioactive)	becquerel	be-'krel	Bq	$\text{Bq} = \text{s}^{-1}$	$\text{Bq} = \text{s}^{-1}$	BQ
absorbed dose	gray	'grā	Gy	$\text{Gy} = \text{J}/\text{kg}$	$\text{Gy} = \text{m}^2/\text{s}^2$	GY

^aIf this symbol is not readily available, the unit name (ohm) should be spelled out.

^bPlural of henry is henries.

^cPlural of lux is lux.

NOTE: The International Committee for Weights and Measures in 1969 recognized the units in Table 6, although they are not part of SI. The units of time and plane angle deviate from coherence in that they bring in 60, 3 600, 86 400, 6.283 19, 1.745 3 $\times 10^{-2}$, 2.909 $\times 10^{-4}$ and 4.848 $\times 10^{-6}$ as

prefixes when converting to seconds and radians. These prefixes are awkward but will undoubtedly persist for awhile due to deep-rooted custom worldwide. Such awkwardness can be avoided altogether if the original measurements are taken in seconds for time and in radians for angles.

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To repeat, we will save time and reduce the possibility of error whenever we choose to use the second as the unit of time in technical matters, rather than minutes, hours or days, and the radian as the measurement of plane angle rather than revolution or degrees. The second of time is obviously more

compatible with past practice. Radians will have greater difficulty gaining general acceptance, except in laboratories and measurements of a highly technical nature. In any event, the above non-SI units must be converted to base or derived units in all coherent calculations.

TABLE 3 - EXAMPLE OF SI DERIVED UNITS EXPRESSED BY MEANS OF BASE UNITS

1. Quantity	2. SI Unit	3. Unit Symbol	4. ISO Computer Symbol
area	square meter	m^2	M2
volume	cubic meter	m^3	M3
speed, velocity	meter per second	m/s	M/S
acceleration	meter per second squared	m/s^2	M/S2
wave number	one per meter	m^{-1}	M-1
density, mass density	kilogram per cubic meter	kg/m^3	KG/M3
current density	ampere per square meter	A/m^2	A/M2
magnetic field strength	ampere per meter	A/m	A/M
concentration (of amount of substance)	mole per cubic meter	mol/m^3	MOL/M3
specific volume	cubic meter per kilogram	m^3/kg	M3/KG
luminance	candela per square meter	cd/m^2	CD/M2

TABLE 4 - EXAMPLES OF SI DERIVED UNITS EXPRESSED BY MEANS OF SPECIAL NAMES

1. Quantity	2. SI Unit	3. Unit Symbol	4. ISO Computer Symbol
dynamic viscosity	pascal-second	Pa·s	P.A.S
moment of force	newton-meter	N·m	N.M
surface tension	newton per meter	N/m	N/M
heat flux density, irradiance	watt per square meter	W/m^2	W/M2
heat capacity, entropy	joule per kelvin	J/K	J/K
specific heat capacity specific entropy	joule per kilogram kelvin	$J/(kg \cdot K)$	J.KG-1.K-1
specific energy	joule per kilogram	J/kg	J/KG
thermal conductivity	watt per meter kelvin	$W/(m \cdot K)$	W.M-1.K-1
energy density	joule per cubic meter	J/m^3	J/M3
electric field strength	volt per meter	V/m	V/M
electric charge density	coulomb per cubic meter	C/m^3	C/M3
electric flux density	coulomb per square meter	C/m^2	C/M2
permittivity	farad per meter	F/m	F/M
permeability	henry per meter	H/m	H/M
molar energy	joule per mole	J/mol	J/MOL
molar entropy, molar heat capacity	joule per mole kelvin	$J/(mol \cdot K)$	J.MOL-1.K-1

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5.6 The quantities listed in Table 8 are ways of expressing data. These units are more nearly a way of speaking than mathematical equations. Whenever an expression will not be used in further calculations requiring coherency, the units may be selected for convenience. Since these types of expressions are so universally useful, a few are listed. Others will be added as they are pointed out. Since these are not

strictly mathematical, some of the rules for style and usage may be disregarded. It is recommended that these expressions be used as words and not be expressed in mathematical symbols. Column 3 lists the symbols to be used when necessary for space or brevity, in the same sense that shorthand is used.

TABLE 5 - PREFIXES

1. Prefix	2. Pronunciation ^a	3. SI Symbol	4. Multiplication Factors	5. ISO Computer Symbol
exa peta	'ex-ə 'pet-ə	E P	1 000 000 000 000 000 000 = 10 ¹⁸ 1 000 000 000 000 000 = 10 ¹⁵	E P
tera giga mega	'ter-ə 'jig-ə 'meg-ə	T G M	1 000 000 000 000 = 10 ¹² 1 000 000 000 = 10 ⁹ 1 000 000 = 10 ⁶	T G MA
kilo hecto ^c deka ^c	'kil-ə 'hek-tə 'dek-ə	k h da	1 000 = 10 ³ 100 = 10 ² 10 = 10 ¹	K H DA
deci ^c centi ^c milli	'des-ə 'sent-ə 'mil-ə	d c m	0.1 = 10 ⁻¹ 0.01 = 10 ⁻² 0.001 = 10 ⁻³	D C M
micro nano pico	'mī-krō 'nan-ō 'pē-kō	μ ^b n p	0.000 001 = 10 ⁻⁶ 0.000 000 001 = 10 ⁻⁹ 0.000 000 000 001 = 10 ⁻¹²	U N P
femto atto	'fem-tō 'at-tō	f a	0.000 000 000 000 001 = 10 ⁻¹⁵ 0.000 000 000 000 000 001 = 10 ⁻¹⁸	F A

^aPronunciation of prefixes remains the same regardless of the unit to which it is attached. Thus, kilo in kilogram, kilowatt and kilometer is pronounced the same in each case. (kil-'am-ət-ər is to be discouraged. 'kil-əmet-ər is correct.) In three cases, the final vowel in the prefix will be elided, namely, kilohm, megohm, and hectare.

^b Where Greek symbol μ is unavailable, type a lower case u and add a tail by hand: μ

^c Avoid where possible except as noted in A3.2

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TABLE 6 - OTHER UNITS FROM ISO 1000

1. Quantity	2. Name of Unit	3. Unit Symbol	4. Conversion to Coherent Unit	5. ISO Computer Symbol
time	minute	min	1 min = 60 s	MIN
time	hour	h	1 h = 60 min = 3 600 s	HR
time	day	d	1 d = 24 h = 86 400 s	D
time	year	a	1 a = 365.242 19 d = 31 556 926 s	ANN
plane angle	revolution	r	1 r = 2π rad = 6.283 19 rad	R ^b
	degree	°	1° = $(\pi/180)$ rad = 1.745 33 x 10 ⁻² rad	DEG
	minute ^a	'	1' = $(1/60)^\circ$ = 2.908 9 x 10 ⁻⁴ rad	MNT
	second ^a	"	1" = $(1/60)'$ = 4.848 1 x 10 ⁻⁶ rad	S
volume	liter	L	1 L = 1 dm ³ = 10 ⁻³ m ³	L
mass	metric ton	t	1 t = 10 ³ kg = 1 Mg	TNE
area	are	a	1 a = 100 m ²	ARE
hydraulics	poise	P	1 P = 100 mPa·s	P
	stokes	St	1 St = 10 ⁻⁴ m ² /s	ST
energy (atomic & nuclear physics)	electronvolt	eV	1 eV = 1.602 19 x 10 ⁻¹⁹ J	EV
Celsius temperature	degree Celsius	°C	1°C = 1 K ^c	CEL
mass of an atom	atomic mass unit (unified)	u	1 u = 1.66053 x 10 ⁻²⁷ kg	U

^a Decimal subdivisions of a degree are recommended in preference to minutes and seconds, except possibly on maps.

^b Not included in ISO 2955 but listed here for completeness.

^c The temperature interval one degree Celsius equals one Kelvin exactly. Celsius temperature (t) is related to thermodynamic temperature (T) by the equation: $t = T - 273.15$.