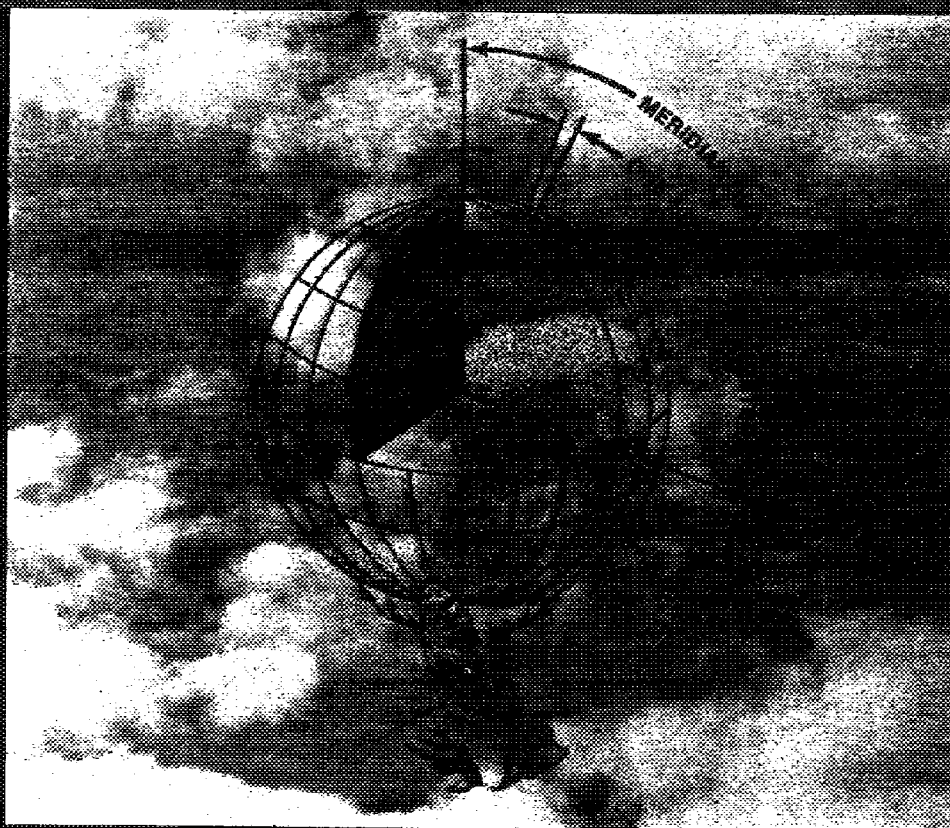


Metric Practice Guide for the Welding Industry



American Welding Society

COVER

The "meter" was the first unit named and defined by the National Assembly of France in 1793. From it the "metric system" evolved.

A provisional value was adopted based on the measurement of the meridian quadrant by Cassini and Lacaille in 1740.

Since then, the meter has been redefined several times and is now based on the velocity of light (see Table 1)

Keywords—Metric practice, SI units, conversions,
round-off rules, preferred numbers

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An American National Standard

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Metric Practice Guide for the Welding Industry

Third Edition

Superseding
AWS A2.3-78 and A1.1-80

Prepared by
AWS Committee on Metric Practice

Under the direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors
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Abstract

This document contains the most widely accepted version of the International System of Units (SI). It includes the base units, supplementary units, derived units, and rules for their use. Also covered are conversion factors and rules for their use in converting customary inch-pound units to SI units.

Recommendations are presented for style and usage in such areas as prefixes, punctuation, number grouping, etc. There are also suggestions to industry for managing the transition.



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Foreword

(This Foreword is not a part of ANSI/AWS A1.1-89, *Metric Practice Guide for the Welding Industry*, but is presented for information purposes only.)

The present AWS Policy on Metrication states, in part, that "The AWS supports a timely transition to the use of SI units. The AWS recognizes that the U.S. customary system of units will eventually be replaced by the SI units. To delay the transition to SI units and to lengthen unnecessarily the transition period results in greater costs and confusion and increases the loss of compatibility with the international market."

At the present time, the U.S. stands alone as the only industrial country that still predominantly uses the inch-pound system of measurement. Since the signing of the Metric Act of 1975 by President Ford and an initial flurry of transition, the voluntary feature of the Act allowed the impetus to stagnate. We now find ourselves at odds not only with other industrial countries, but also, in many cases, with each other.

Many major companies—including General Motors Corporation, Ford Motor Company, Chrysler Corporation and an estimated 70 percent of the Fortune 500—have made the switch in some aspect of their businesses. But smaller firms—typically those with fewer international interactions—have been slower to change.

More recently, the Omnibus Trade and Competitiveness Act, which was signed by President Reagan in August 1988, designated the metric system as the preferred measurement method in trade and commerce. Specifically, this Act requires each Federal Agency to use the metric system in its procurements, grants and other business-related activities by the end of FY 1992.

This standard is intended to facilitate this transition.

Advice and response from readers are solicited. Any comments should be directed to the Secretary, Committee on Metric Practice, American Welding Society, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, Florida 33135.

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Metric Practice Guide for the Welding Industry

1. Scope

This metric practice guide contains the accepted definition of the International System of Units (SI) as contained in the pertinent American National Standards Institute (ANSI) and International Standards Organization (ISO) documents (see reference documents page). It contains the base units, supplementary units, derived SI units, and rules for their use in AWS documents and by the welding industry. It also contains factors and rules for converting from U.S. inch-pound units to SI units and recommendations to industry for managing the transition.

2. Features of SI

SI is a modernized system of measurement. It was formally established in 1960 as the International System of Units and is officially recognized by all industrial nations. It has features that make it superior to the U.S. customary system and to other metric systems. The advantages to be derived from these features, presented below, require familiarity with the SI units to recognize the simplicity of their usage.

2.1 Absolute Base. An absolute system has several advantages, the greatest of which is simplicity of calculation. For example, an absolute base is one in which force is not defined by the action of gravity. In SI units, a force of one newton gives a mass of one kilogram an acceleration of one meter per second squared. In contrast, in European metric practice (cgs units), a force of one kilogram force (gravitational system) accelerates the same mass 9.806 650 meters per second squared; whereas, in U.S. customary units, one pound force accelerates a mass of one slug one foot per second squared. Additional confu-

sion arises in the United States because the pound is used for either force or mass, although, properly, the poundal should be used for force when the pound is used for mass, or the pound should be used for force when the slug is used for mass.

2.2 Coherence. Coherence is the characteristic that relates any derived unit to any other, or to the base units from which it is formed, without the use of conversion factors.

In SI units, a force of one newton applied through a distance of one meter does work equivalent to one joule, which equals the work produced by one watt of power in one second.

In U.S. inch-pound units, a force of one pound applied through a distance of one inch produces energy equivalent to 0.000 107 Btu, which is the same as that produced by one horsepower in 0.000 505 hour. Coherence is a valuable characteristic in engineering calculation and lends itself to simplifying even elementary use of measurement units.

2.3 Unique Units. Another desirable characteristic of SI is its use of only one unit for each physical quantity.

The SI units for force, energy, and power are the same regardless of whether the process is mechanical, electrical, or thermal. Power, whether in engines or air conditioners, is measured in watts. By contrast, the U.S. customary system has nine commonly used units for area, twenty-five units for energy, twenty-six units for length, and so on.

2.4 Decimal System. SI is a decimal system and, thus, easier to use because it is easier to work in multiples of ten and in decimal notation than in the fractions and decimalized fraction equivalents common to the customary system.

The above combination of features makes SI an excellent system, suitable for all kinds of measurements. Though there remain areas that can and no doubt will be improved, SI is practical for universal application and is rapidly becoming the commonly used world measurement system.

3. SI Units and Symbols

SI consists of seven base units, two supplementary units, a series of derived units, and a series of prefixes for the formation of multiples of the various units (See Tables 1, 2, and 3).

3.1 SI Units. SI units and their symbols are the following:

Measure	Unit	Symbol
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
luminous intensity	candela	cd
amount of substance	mole	mol
plane angle ¹	radian	rad
solid angle ¹	steradian	sr

3.2 Derived Units. Any additional quantity can be measured using combinations of the SI units. Some examples are listed in Table 2.

3.3 Prefixes. SI prefixes should be used to indicate orders of magnitude, thus simplifying numeric terms and providing a convenient substitute for writing powers of ten as generally preferred in computation. For example, 16 800 meters or 16.8×10^3 meters becomes 16.8 kilometers. See Table 3 for the list of prefixes and 6.1 for examples of their use.

4. Other Units Used with SI

There are certain units which, although not part of SI, are in widespread use and are acceptable for use with SI. See Table 4 for examples.

1. Supplementary units.

5. Units Pertaining to Welding

Table 5 shows the recommended SI units to be used in welding nomenclature. The selection of these terms was based on use of (1) SI units where practicable, (2) numbers of reasonable size, and (3) accepted units currently in use.

Electrode and fillet sizes are tabulated in Table 6. SI values in columns (A) and (B) are approximate equivalents for conversion on drawings, specifications, and so forth. These values are for conversion only and are not intended for new designs where a more rational series for sizing, such as shown in column (C), may be used.

6. Style and Usage

6.1 Application and Usage of Prefixes

6.1.1 Prefixes should be used with SI units to indicate orders of magnitude. Prefixes provide convenient substitutes for using powers of ten, and they eliminate insignificant digits.

Preferred	Nonpreferred
12.3 km	12 300 m, 12.3×10^3 m

6.1.2 Prefixes in steps of 1000 are recommended. The use of the prefixes hecto, deka, deci, and centi should be avoided.

Preferred	Nonpreferred
mm, m, km	hm, dam, dm, cm

6.1.3 Prefixes should be chosen so that the numerical value lies between 0.1 and 1000.

6.1.3.1 For special situations such as tabular presentations, the same unit, multiple, or submultiple may be used even though the numerical value exceeds the range of 0.1 to 1000.

6.1.4 Multiple and hyphenated prefixes should not be used.

Correct	Incorrect
pF, GF, GW	μ μ F, Mkg, kMW, G-W

Table 1
Definitions of SI Base and Supplementary Units

meter	The meter is the length of the path travelled by light in vacuum during a time interval of $1/299\,792\,458$ of a second.
kilogram	The mass equal to the mass of the international prototype of the kilogram.
second	The duration equal to $9\,192\,631\,770$ periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom.
ampere	That constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed one meter apart in a vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per meter of length.
kelvin	The thermodynamic temperature that is the fraction $1/273.16$ of the thermodynamic temperature of the triple point of water.
candela	The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of $(1/683)$ watt per steradian.
mole	The amount of substance of a system that 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.
radian	The plane angle between two radii of a circle that cuts off on the circumference an arc equal in length to the radius.
steradian	The solid angle which, having its vertex in the center of a sphere, cuts off an area of the surface of the sphere equal to that of a square with sides of length equal to the radius of the sphere.

6.1.5 It is generally desirable to use only base and derived units in the denominator. Prefixes are used with the numerator unit to give numbers of appropriate size (see 6.1.3).

Preferred	Nonpreferred
200 J/kg, 5 Mg/m ³	0.2 J/g, 1 kg/mm

6.1.6 Prefixes are to be attached to the base SI units with the exception of the base unit for mass, the kilogram, which contains a prefix. In this case, the required prefix is attached to gram.

6.1.7 Prefixes should not be mixed unless magnitudes warrant a difference.

Correct	Incorrect
5 mm long $\times$ 10 mm high	5 mm long $\times$ 0.01 m high
Exception	
4 mm diam $\times$ 50 m long	

6.1.8 The pronunciation of the prefixes is always the same, regardless of the accompanying base unit. For example, the accepted pronunciation for kilo is "kill-oh". The slang expression "keelo" for kilogram should never be used.

6.2 Use of Nonpreferred Units

6.2.1 The mixing of units from different systems should be avoided.

Preferred	Nonpreferred
kilogram per cubic meter (kg/m ³)	kilogram per gallon (kg/gal)

6.2.2 The use of non-SI units should be limited to those listed in Table 4.

6.3 Mass, Force, and Weight. The unit of mass is the kilogram. The kilogram-force is non-SI and should not be used. The SI unit of force is the newton (N).

Table 2
Formulas for SI Derived Units

Measure	Unit	Symbol	Formula
acceleration-linear	meter per second squared		m/s^2
-angular	radian per second squared		rad/s^2
area	square meter		m^2
capacitance	farad	F	$\text{A} \cdot \text{s/V}$
conductivity (thermo)	watt per meter kelvin		$\text{W}/(\text{m} \cdot \text{K})$
electric field strength	volt per meter		V/m
electromotive force	volt	V	W/A
electricity (quantity)	coulomb	C	$\text{A} \cdot \text{s}$
energy, work, heat and impact strength	joule	J	$\text{N} \cdot \text{m}$
force	newton	N	$\text{kg} \cdot \text{m/s}^2$
frequency	hertz	Hz	s^{-1}
illumination	lux	lx	lm/m^2
inductance	henry	H	$\text{V} \cdot \text{s/A}$
luminous flux	lumen	lm	$\text{cd} \cdot \text{sr}$
magnetic flux	weber	Wb	$\text{V} \cdot \text{s}$
magnetic flux density, magnetic induction	tesla	T	Wb/m^2
power	watt	W	J/s
pressure, stress	pascal	Pa	N/m^2
resistance	ohm	Ω	V/A
velocity-linear	meter per second		m/s
-angular	radian per second		rad/s
volume	cubic meter		m^3

Correct	Incorrect
N/m^2 or Pa, $\text{N} \cdot \text{m/s}$ or W	kgf/m^2

5.8°
Angular minutes and seconds should be avoided

The common term "weight" should not be used in technical literature.

6.4 Temperature. The SI unit for thermodynamic temperature is the kelvin. The degree Celsius is, however, widely used in engineering work and may be used where considered necessary or desirable for clearer understanding. The degree Celsius was formerly called "degree centigrade". The degree Fahrenheit should not be used.

6.5 Time. The SI unit for time is the second. The use of minute, hour, and day is permissible.

6.6 Angles. The SI unit for plane angle is the radian. The SI unit for solid angle is the steradian. The degree (°) may be used where appropriate or convenient and should be decimalized.

6.7 Stress and Pressure. The SI unit for pressure and stress is the pascal, which is newton per square meter (N/m^2). The unit kPa is appropriate for most pressures and the unit MPa for most stresses. Other pressure and stress terms, such as the following, should not be used.

Incorrect
kilogram-force per square centimeter (kgf/cm^2)
pound-force per square inch (psi)

6.8 Capitalization. SI unit names are capitalized only at the beginning of a sentence (examples: newton, pascal, meter, kelvin, and hertz). In "degree Celsius," degree is lower case and Celsius is always capitalized.

Table 3
SI Prefixes

Exponential Expression	Multiplication Factor	Prefix	Symbol
10 ¹⁸	1 000 000 000 000 000 000	exa	E
10 ¹⁵	1 000 000 000 000 000	peta	P
10 ¹²	1 000 000 000 000	tera	T
10 ⁹	1 000 000 000	giga	G
10 ⁶	1 000 000	mega	M
10 ³	1 000	kilo	k
10 ²	100	hecto*	h
10	10	deka*	da
10 ⁻¹	0.1	deci*	d
10 ⁻²	0.01	centi*	c
10 ⁻³	0.001	milli	m
10 ⁻⁶	0.000 001	micro	μ
10 ⁻⁹	0.000 000 001	nano	n
10 ⁻¹²	0.000 000 000 001	pico	p
10 ⁻¹⁵	0.000 000 000 000 001	femto	f
10 ⁻¹⁸	0.000 000 000 000 000 001	atto	a

* Nonpreferred. Prefixes should be selected in steps of 10³ so that the resultant number before the prefix is between 0.1 and 1000 (see 6.1). These prefixes should not be used for units of linear measurement, but may be used for higher order units. For example, the linear measurement, decimeter, is nonpreferred, but square decimeter is acceptable.

SI unit symbols are not capitalized except for those derived from a proper name. The capital L is the symbol for the unit liter.

A (ampere), K (kelvin), W (watt), N (newton), J (joule), etc.
m (meter), kg (kilogram), etc.

Only five prefix symbols are capitalized, namely, E (exa), P (peta), T (tera), G (giga), and M (mega).

6.9 Plurals. Unit symbols are the same for singular and plural. Unit names form their plurals in the usual manner.

50 newtons (50 N), 25 grams (25 g)

6.10 Punctuation. Periods are not to be used after SI unit symbols except at the end of a sentence.

Periods (not commas) are used as decimal markers.

Periods are not used in unit symbols or in conjunction with prefixes.

Correct	Incorrect
5.7 mm	5.7 m.m.

A raised dot is used to indicate the product of two unit symbols.

meter second (m · s), newton meter (N · m)

A slash or solidus (/) or a negative exponent is used as follows to indicate the quotient of two unit symbols:

(1) Only one solidus should be used in a combination.

(2) A solidus and a negative exponent can be used together, even together with parentheses, for complicated cases.

(3) Numerical values are to be used so that the denominator is unity.

Table 4
Other Units Which May be Used with SI Units

Units	Symbol	Value
minute	min	1 min = 60 s
hour	h	1 h = 60 min = 3600 s
day	d	1 d = 24 h = 1440 min = 86 400 s
degree (angular)	°	1° = (π/180) rad = 0.0175 rad
bar*	bar	1 bar = 0.1 MPa = 10 ⁵ Pa
liter	L	1 L = 0.001 m ³ = 1 dm ³
degree Celsius	°C	1°C = 1 K (interval)
angstrom*	Å	1 Å = 0.1 nm = 10 ⁻¹⁰ m
atmosphere*	atm	1 atm = 101 325 Pa

* In use temporarily

Table 5
Units Pertaining to Welding

Property	Unit	Symbol
area dimensions	square millimeter	mm ²
current density	ampere per square millimeter	A/mm ²
deposition rate	kilogram per hour	kg/h
electrical resistivity	ohm meter	Ω · m
electrode force	newton	N
flow rate (gas and liquid)	liter per minute	L/min
fracture toughness	meganeutron meter ^{-3/2}	MN · m ^{-3/2}
impact strength	joule	J = N · m
linear dimensions	millimeter	mm
power density	watt per square meter	W/m ²
pressure (gas and liquid)	kilopascal	kPa = 1000 N/m ²
pressure (vacuum)	pascal	Pa = N/m ²
tensile strength	megapascal	MPa = 1000 000 N/m ²
thermal conductivity	watt per meter kelvin	W/ (m · K)
travel speed	millimeter per second	mm/s
volume dimensions	cubic millimeter	mm ³
wire feed speed	millimeter per second	mm/s

Correct	Incorrect
m/s, m · s ⁻¹ , 4 m/s m/s ² , m · kg/(s ³ · A)	m/0.1 s, m/s/s, m · kg/s ³ /A, kg/s/m ²

The word "per" is used to indicate the quotient of two unit names.

meter per second squared (m/s²)

An exponent is used with unit symbols to show powers.

m³

The words "square", "squared", and "cubic" are used with unit names to indicate powers.

square meter (m²), cubic meter (m³), second squared (s²)

6.11 Number Grouping

6.11.1 Numbers made up of five or more digits should be written with a space separating each group of three digits counting both to the left and right of the decimal point. With four digit numbers, the spacing is optional.

6.11.2 Spaces (not commas) should be used between the groups of three digits.

Correct	Incorrect
1 420 462.1; 0.045 62 1452 or 1 452	1,420,462.1;0.04562

6.12 Miscellaneous Styling

6.12.1 A space is to be used between the numerical value and the unit symbol.

Correct	Incorrect
4 mm	4mm

6.12.2 Unit symbols and names are never used together in a single expression:

Correct	Incorrect
meter per second (m/s)	meter/s

6.12.3 Numbers are expressed as decimals, not as fractions. The decimal should be preceded by a zero when the number is less than unity.

Table 6
Electrode and Fillet Sizes

(A) Electrode Size (Approx. Equivalents)		(B) Fillet Size (Approx. Equivalents)		(C) Metric Fillet Size (Rational Series)
in.	mm	in.	mm	mm
0.030	0.8	1/8	3	3
0.035	0.9	5/32	4	4
0.040	1.0	3/16	5	5
0.045	1.1	1/4	6	6
1/16	1.6	5/16	8	8
5/64	2.0	3/8	10	10
3/32	2.4	7/16	11	12
1/8	3.2	1/2	13	*
5/32	4.0	5/8	16	16
3/16	4.8	3/4	19	20
1/4	6.4	1	25	25

* No value is required in this interval for rational sizing. See the 10 series in Table 11, and the example given in 9.2.

Correct	Incorrect
0.5 kg, 1.75 m	1/2 kg, .5 kg., 1 ³ / ₄ m

6.12.4 SI unit symbols should be printed in Roman (upright) type rather than *italic* (slanted or script).

6.12.5 Typed rather than hand-drawn prefixes should be used when possible. The spelled word may be used in preference to the use of hand-drawn symbols.

6.12.6 When it is necessary or desirable to use U.S. inch-pound units in an equation or table, SI units should be restated in a separate equation, table, or column in a table. As an alternative, a note may be added to an equation or table giving the factors to be used in converting the calculated result in U.S. inch-pound to preferred SI units. The SI equivalents may follow and be inserted in parentheses.

7. Conversions

General factors for converting from the commonly used U.S. inch-pound units to proper SI units are given in Table 7.

Factors for converting to units recommended for welding are given in Table 8.

7.1 Rules for Converting and Rounding. Converting and rounding are necessary only during a transition period. In manufacturing practice, this occurs most frequently when designing is done in SI units and fabrication must be done in conventional units. The necessity for conversion and rounding disappears when all steps can be done in one system.

Exact conversion from one system to another usually results in numbers that are inconvenient to use. Also, the intended precision is exaggerated when the conversion results in more decimal places than are necessary.

The degree of accuracy of the converted number is based on the intended or necessary precision of the product. The precision must be determined by the designer or user. The guidelines given herein may then be applied to arrive at appropriate numerical equivalents.

7.2 Inch-Millimeter Conversion. Exact conversion from inches to millimeters often results in unnecessarily long decimal numbers. Showing more decimal places than necessary leads to misinterpretation, uses valuable space, and increases the possibility of error. The numbers should be rounded to eliminate insignificant decimal places, consistent with the accuracy required. The rounding of equivalent millimeter dimensions should be handled as described here.

7.2.1 Nominal Dimensions. The closest practical indication of equivalent inch and millimeter values

Table 7
General Conversions

Property	To Convert From	To	Multiply By
acceleration (angular)	revolution per minute squared	rad/s ²	$1.754\ 329 \times 10^{-3}$
acceleration (linear)	in./min ²	m/s ²	$7.055\ 556 \times 10^{-6}$
	ft/min ²	m/s ²	$8.466\ 667 \times 10^{-5}$
	in./min ²	mm/s ²	$7.055\ 556 \times 10^{-3}$
	ft/min ²	mm/s ²	$8.466\ 667 \times 10^{-2}$
	ft/s ²	m/s ²	$3.048\ 000 \times 10^{-1}$
angle, plane	deg	rad	$1.745\ 329 \times 10^{-2}$
	minute	rad	$2.908\ 882 \times 10^{-4}$
	second	rad	$4.848\ 137 \times 10^{-6}$
area	in. ²	m ²	$6.451\ 600 \times 10^{-4}$
	ft ²	m ²	$9.290\ 304 \times 10^{-2}$
	yd ²	m ²	$8.361\ 274 \times 10^{-1}$
	in. ²	mm ²	$6.451\ 600 \times 10^2$
	ft ²	mm ²	$9.290\ 304 \times 10^4$
	acre (U.S. Survey)	m ²	$4.046\ 873 \times 10^3$
density	pound mass per cubic inch	kg/m ³	$2.767\ 990 \times 10^4$
	pound mass per cubic foot	kg/m ³	$1.601\ 846 \times 10$
energy, work, heat and impact energy	foot pound force	J	1.355 818
	foot poundal	J	$4.214\ 011 \times 10^{-2}$
	Btu*	J	$1.054\ 350 \times 10^3$
	calorie*	J	4.184 000
	watt hour	J	$3.600\ 000 \times 10^3$
force	kilogram-force	N	9.806 650
	pound-force	N	4.448 222
impact strength	(see energy)		
length	in.	m	$2.540\ 000 \times 10^{-2}$
	ft	m	$3.048\ 000 \times 10^{-1}$
	yd	m	$9.144\ 000 \times 10^{-1}$
	mile (statute)	m	$1.609\ 300 \times 10^3$
mass	pound mass (avdp)	kg	$4.535\ 924 \times 10^{-1}$
	metric ton	kg	$1.000\ 000 \times 10^3$
	ton (short, 2000 lbm)	kg	$9.071\ 847 \times 10^2$
	slug	kg	$1.459\ 390 \times 10$
power	horsepower (550 ft lbf/s)	W	$7.456\ 999 \times 10^2$
	horsepower (electric)	W	$7.460\ 000 \times 10^2$
	Btu/min*	W	$1.757\ 250 \times 10$
	calorie per minute*	W	$6.973\ 333 \times 10^{-2}$
	foot pound-force per minute	W	$2.259\ 697 \times 10^{-2}$
pressure	pound force per square inch	kPa	6.894 757
	bar	kPa	$1.000\ 000 \times 10^2$
	atmosphere	kPa	$1.013\ 250 \times 10^2$
	kip/in. ²	kPa	$6.894\ 757 \times 10^3$
temperature	degree Celsius, t _C	K	t _K = t _C + 273.15
	degree Fahrenheit, t _F	K	t _K = (t _F + 459.67)/1.8
	degree Rankine, t _R	K	t _K = t _R /1.8
	degree Fahrenheit, t _F	C°	t _C = (t _F - 32)/1.8
	kelvin, t _K	C°	t _C = t _K - 273.15

Table 7 (Continued)

Property	To Convert From	To	Multiply By
tensile strength (stress)	ksi	MPa	6.894 757
torque	inch pound force	N · m	$1.129\,848 \times 10^{-1}$
	foot pound force	N · m	1.355 818
velocity (angular)	revolution per minute	rad/s	$1.047\,198 \times 10^{-1}$
	degree per minute	rad/s	$2.908\,882 \times 10^{-4}$
	revolution per minute	deg/min	$3.600\,000 \times 10^2$
velocity (linear)	in./min	m/s	$4.233\,333 \times 10^{-4}$
	ft/min	m/s	$5.080\,000 \times 10^{-3}$
	in./min	mm/s	$4.233\,333 \times 10^{-1}$
	ft/min	mm/s	5.080 000
	mile/hour	km/h	1.609 344
volume	in. ³	m ³	$1.638\,706 \times 10^{-5}$
	ft ³	m ³	$2.831\,685 \times 10^{-2}$
	yd ³	m ³	$7.645\,549 \times 10^{-1}$
	in. ³	mm ³	$1.638\,706 \times 10^4$
	ft ³	mm ³	$2.831\,685 \times 10^7$
	in. ³	L	$1.638\,706 \times 10^{-2}$
	ft ³	L	$2.831\,685 \times 10$
	gallon	L	3.785 412

* thermochemical

occurs when the millimeter value is shown to one less decimal place than its inch equivalent. For example, 0.365 in. equals 9.27 mm. However, fractional inch conversions may exaggerate the intended precision. For example, the rule may not be applicable when changing $17/8$ in. to 47.63 mm unless the precision of $17/8$ in. was intended to be that of 1.875 inches. Some dimensions must be converted more accurately to ensure interchangeability of parts. The methods described in 7.3 will accomplish this requirement.

7.2.2 Tolerances. The following round-off criteria should be used when it is necessary to ensure the physical and functional interchangeability of parts made and inspected using either system of measurement, and when inch dimensions are converted to millimeter equivalents and shown on dual dimensioned drawings:

(1) Basic and maximum-minimum dimensions. Basic dimensions are inherently precise and should be converted exactly. When the function of a feature requires that the maximum and minimum limits in millimeters be within the inch limits, maximum limits are rounded down and minimum limits are rounded up.

(2) Dimensions without tolerance. Untoleranced dimensions are converted to exact millimeter equivalents

and rounded to equivalent or better precision, depending upon the purpose of the dimension.

(3) Toleranced dimensions. The normal practice for toleranced dimensions is to use Method A as described in 7.2.2.2. However, when the function of a feature requires that the millimeter equivalents must be within the inch dimension tolerance limits in all cases, Method B is used as described in 7.2.2.3.

7.2.2.1 Number of Decimal Places in Tolerances. Table 9 lists the criteria for retaining decimal places in millimeter equivalents to inch tolerances. The number of decimal places is determined by the inch tolerance span.

7.2.2.2 Round-Off Method A. This method produces rounded millimeter tolerances which will not vary from the inch tolerances by more than 5.0 percent. Thus, for a dimension with a tolerance of 0.001 in., the maximum amount that the rounded millimeter can be greater or less than the inch tolerance is 0.000 050 inch.

To determine the millimeter equivalents of inch dimensions by Method A, these steps should be followed:

(1) The maximum and minimum limits in inches should be determined.

Table 8
Conversions for Common Welding Terms*

Property	To Convert From	To	Multiply By
area dimensions (mm ²)	in ² mm ²	mm ² in ²	$6.451\,600 \times 10^2$ $1.550\,003 \times 10^{-3}$
current density (A/mm ²)	A/in ² A/mm ²	A/mm ² A/in ²	$1.550\,003 \times 10^{-3}$ $6.451\,600 \times 10^2$
disposition rate** (kg/h)	lb/h kg/h	kg/h lb/h	0.45** 2.2**
electrical resistivity (Ω · m)	Ω · cm Ω · m	Ω · m Ω · cm	$1.000\,000 \times 10^{-2}$ $1.000\,000 \times 10^2$
electrical force (N)	pound-force kilogram-force N	N N lbf	4.448 222 9.806 650 $2.248\,089 \times 10^{-1}$
flow rate (L/min)	ft ³ /h gallon per hour gallon per minute	L/min L/min L/min	$4.719\,475 \times 10^{-1}$ $6.309\,020 \times 10^{-2}$ 3.785 412
fracture toughness (MN · m ^{-3/2})	ksi · in. ^{1/2} MN · m ^{-3/2}	MN · m ^{-3/2} ksi · in. ^{1/2}	1.098 855 0.910 038
heat input (J/m)	J/in. J/m	J/m J/in.	$3.937\,008 \times 10$ $2.540\,000 \times 10^{-2}$
impact energy	foot pound force	J	1.355 818
linear measurements (mm)	in. ft mm mm	mm mm in. ft	$2.540\,000 \times 10$ $3.048\,000 \times 10^2$ $3.937\,008 \times 10^{-2}$ $3.280\,840 \times 10^{-3}$
power density (W/m ²)	W/in. ² W/m ²	W/m ² W/in. ²	$1.550\,003 \times 10^3$ $6.451\,600 \times 10^{-4}$
pressure (gas and liquid) (kPa)	psi lb/ft ² N/mm ²	kPa kPa kPa	6.894 757 $4.788\,026 \times 10^{-2}$ $1.000\,000 \times 10^3$
pressure (gas and liquid) (kPa)	kPa kPa kPa	psi lb/ft ² N/mm ²	$1.450\,377 \times 10^{-1}$ $2.088\,543 \times 10$ $1.000\,000 \times 10^{-3}$
pressure (vacuum) (Pa)	torr (mm Hg at 0°C) micron (μm Hg at 0°C) Pa Pa bar	Pa Pa torr micron psi	$1.333\,220 \times 10^2$ $1.333\,220 \times 10^{-1}$ $7.500\,640 \times 10^{-3}$ 7.500 640 $1.450\,377 \times 10^1$
tensile strength (MPa)	psi lb/ft ² N/mm ² MPa MPa MPa	MPa MPa MPa psi lb/ft ² N/mm ²	$6.894\,757 \times 10^{-3}$ $4.788\,026 \times 10^{-5}$ 1.000 000 $1.450\,377 \times 10^2$ $2.088\,543 \times 10^4$ 1.000 000
thermal conductivity (W/[m · K])	cal/(cm · s° · C)	W/(m · K)	$4.184\,000 \times 10^2$
travel speed, wire feed speed (mm/s)	in./min mm/s	mm/s in./min	$4.233\,333 \times 10^{-1}$ 2.362 205

* Preferred units are given in parentheses.

** Approximate conversion.

Table 9
Millimeter Value Round-Off Using
Inch Tolerance Span

Inch Tolerance Span		Round Off Millimeter Value to These Decimal Places	
At Least	Less Than		
0.000 04	0.0004	4 places	0.00XX
0.0004	0.004	3 places	0.0XX
0.004	0.04	2 places	0.XX
0.04	0.4	1 place	X.X
0.4 and over		Whole number	XX

Example: The span of a +0.005 to -0.003 in. tolerance is 0.008. Since 0.008 is between 0.004 and 0.04, two decimal places are retained in individually converting 0.005 and 0.003.

(2) The tolerance span in inches should be determined.

(3) The inch limit dimensions should be converted to millimeter values using exact millimeter equivalents.

(4) Based on the tolerance span in inches, the number of decimal places to be retained should be established using Table 9 and the millimeter values rounded according to the rounding rules given in 7.4. See the example in Table 10.

7.2.2.3 Round-Off Method B. This method is used when the resulting millimeter tolerances must be within the inch tolerances. In extreme cases, this

method may result in the lower limit millimeter tolerance being greater than the lower inch tolerance by a maximum of five percent. Similarly, the upper limit millimeter tolerance may be smaller than the upper inch tolerance by a maximum of five percent. Thus, the tolerance span may be reduced by up to ten percent of the original design inch tolerance; however, it is very unlikely that the five percent maximum will occur at both limits simultaneously. To determine the millimeter equivalents of inch dimensions by Method B, these steps should be followed:

(1) The maximum and minimum limits in inches should be determined.

(2) The tolerance span in inches should be determined.

(3) The inch tolerance should be converted to exact millimeter equivalents.

(4) Based on the tolerance span in inches, the number of decimal places to be retained in the millimeter values should be established using Table 9.

(5) If rounding is required, millimeter values should be rounded to fall within the inch tolerance limits; that is, to the next lower value for the upper limit and to the next higher value for the lower limit. See the example in Table 10.

7.3 Other Conversions. To establish meaningful and equivalent converted values, a careful determination must be made of the number of significant digits to be retained so as not to sacrifice or exaggerate the precision of the value. To convert a pressure of 1000

Table 10
Comparison of Round-Off Methods A and B

Inch dimension:	1.934-1.966 in.
Tolerance span:	0.032 in.
Conversion:	1.934 in. = 49.1236 mm (exactly) 1.966 in. = 49.9364 mm (exactly)
From Table 9:	0.032 lies between 0.004 and 0.04; therefore, the millimeter values are to be rounded to two decimal places.
Method A:	Rounding off 49.1236 and 49.9364 to two decimal places via the method shown in 7.2.3 gives 49.12 mm and 49.94 mm, respectively.
	Method A gives a tolerance span of 0.82 mm.
Method B:	Rounding to within the inch tolerance limits requires the 49.1236 mm limit to be rounded up, giving 49.13 mm as the lower limit, and the 49.9364 mm limit to be rounded down, giving 49.93 mm as the upper limit.
	Method B gives a tolerance span of 0.80 mm.

The tolerance span of 0.032 in. equals 0.8128 mm. In this example, Method A would increase the tolerance span by 0.0072 mm (0.88 percent); whereas, Method B would decrease the tolerance span by 0.0128 mm (1.6 percent).

psi to 6.894 757 MPa is not practical because the value does not warrant expressing the conversion using six decimal places.² The intended precision of a value can be established from the specified tolerance or by an understanding of the equipment, process, or accuracy of the measuring device.

7.3.1 Values with a Specified Tolerance. A tolerance on a value provides a good indication of the intended precision. A general rule for determining the intended precision of a toleranced value is to assume that it is one-tenth of the total tolerance. Since the intended precision of the converted value should be no greater than that of the original, the total tolerance is divided by ten and converted. The proper significant digits are retained in both the converted value and the converted tolerance so that the last significant digit retained is in units no larger than one-tenth the converted tolerance. The following examples illustrate this rule:

(1) 200 ± 15 psi pressure converted to Pa. Total tolerance is 30 psi, divided by 10 is 3 psi, which converted is about 20.7 kPa. The units to use equal 10 kPa (rather than 100 kPa or 1 kPa) since 10 kPa is the largest unit smaller than 20.7 kPa, which is one-tenth the converted tolerance.

200 ± 15 psi = 1378.9514 ± 103.421 355 kPa, which rounds to 1380 ± 100 kPa = 1.38 ± 0.10 MPa.

(2) 25 ± 0.1 oz of alcohol converted to liters. Total tolerance is 0.2 oz, divided by 10 is 0.02 oz, converted is about 0.6 mL.

Units to use: 0.1 mL (rather than 10 mL or 1 mL).

25 ± 0.1 oz = 739.34 ± 2.957 mL, which rounds to 739.3 ± 3.0 mL.

7.3.2 Values with No Specified Tolerance. If a value is shown without a tolerance, the intended precision relates to the number of significant digits shown by assuming that the value had been rounded from a greater number of digits. The intended precision is established as being plus or minus one-half unit of the last significant digit in which the value is stated. However, as the last significant digit moves away from the decimal point, the intended precision becomes distorted if this rule is used indiscriminately. In these cases, the intended precision is estimated as being some digit closer to the decimal point based on the nature of the value's use. Since the intended precision

2. Applying the policy of 7.3.4, a practical conversion is 7 MPa.

of the converted value should be no greater than that of the original, the intended precision is established and converted. The proper significant digits are retained in the converted value so that the last significant digit retained is in units no larger than the converted intended precision. The following examples illustrate this policy:

(1) 157 miles (rounded from any value between 156.5 and 157.5 miles) to kilometers. Total intended precision is 1 mile, which is about 1.6 km.

Units to use: 1 km

157 miles = 252.613 km, which rounds to 253 km.

(2) 50 000 psi tensile strength converted to pascals. Total estimated precision is 500 psi (3.4 MPa) from the nature of use and the precision of the measuring equipment.

Units to use: 1 MPa, 50 000 psi = 344.7379 MPa which rounds to 345 MPa.

(See also 7.2.2.4 for less precise conversion.)

(3) An electrical lead 8 ft long, converted to meters. The total intended precision is 1 ft, or about 0.3 m.

Units to use: 0.1 m

8 ft = 2.4384 m, which rounds to 2.4 m.

7.3.3 Temperature. All temperatures expressed in whole numbers of degrees Fahrenheit are converted to the nearest 0.1 kelvin or degree Celsius. Fahrenheit temperatures indicated to be approximate, maximum, or minimum, or to have a tolerance of $\pm 5^\circ\text{F}$ or more, are converted to the nearest whole number in kelvin or degree Celsius. Fahrenheit temperatures having a tolerance of plus or minus 100°F or more are converted to the nearest 10 kelvin or degrees Celsius.

$$100 \pm 5^\circ\text{F} = 38 \pm 3^\circ\text{C} = 311 \pm 3 \text{ K}$$

$$1000 \pm 100^\circ\text{F} = 540 \pm 40^\circ\text{C} = 810 \pm 40 \text{ K}$$

7.3.4 Pressure or Stress Conversion. In most cases, stress values are converted from ksi to the nearest one megapascal. Pressure or stress values having an uncertainty of more than two percent may be converted without rounding by the approximate factors:

$$1 \text{ psi} = 7 \text{ kPa} \quad 1 \text{ ksi} = 7 \text{ MPa}$$

7.4 Round-Off Rules. When the next digit beyond the last digit to be retained is less than five, the last digit retained is not changed.

4.463 25 rounded to three decimal places is 4.463.

7.4.1 When the digits beyond the last digit to be retained amount to more than five followed by zeros, the last digit retained is increased by one.

8.376 52 rounded to three decimal places is 8.377.

7.4.2 When the digit beyond the last digit to be retained is exactly five followed by zeros (expressed or implied), the last digit to be retained, if even, is unchanged; but the last digit to be retained, if odd, is increased by one.

4.365 00 becomes 4.36 when rounded to two decimal places.

4.355 00 also becomes 4.36 when rounded to two decimal places.

7.4.3 The final rounded value is obtained from the precise value to be rounded, not from a series of successive rounding. To maintain precision during conversion, the millimeter equivalent value is carried out to at least one extra decimal place. Generally, it is best to use exact values and round off only the final results.

8. Transition

8.1 Introduction. Almost all segments of U.S. society and industry will feel the impact of the metric conversion. Indeed, many companies are already in various phases of conversion. Some companies, particularly those with foreign interests, have completely converted. Others are maintaining an awareness of the state of metrication in the United States.

This section is a compilation of experiences and recommendations from several sources which are in various stages of transition.

8.2 Considerations

8.2.1 Abrupt Changeover in Engineering and Design from U.S. Customary Units to Metric Units. The goal is to have engineers and designers "thinking metric" as quickly as possible. The experience in Great Britain showed that learning to think metric is important in reducing transition time and costs and in gaining the benefits of the simpler, more rational metric measurement system. This is especially so for engineers and designers who must think in groups of interrelated numbers and who depend on a "feel" for the design significance of these relationships. Changing engineering and design activities to metric abruptly is practical because it is largely a conversion involving relatively low-cost equipment replacement.

8.2.2 Replacement of Fabricating Equipment on a Cyclical Basis Except for Some Inspection Activities. Changing fabrication activities from U.S. customary to metric involves a large capital investment in equipment. The transition time and cost in the shops can be shortened somewhat by converting machine displays. Some machines are used only for nonprecision stock removal and need never be converted. Others, such as the NC machines with digital displays, are electronically convertible. Gages are in a special category. They last so long that cyclical replacement is not a practical way to convert inspection activities. Also, inspection serves as a check on the other fabrication activities, including conversion mistakes. It seems reasonable to convert gages on a high-priority basis.

Cost-benefit considerations in the shop call for more of a cyclical replacement approach with a completion goal consistent with average tool life. This means that the metric unit used by the engineering and design departments must be converted at the machine tool that still operates in inches. Metric-to-inch conversions must occur at some stage of the design-fabrication cycle while there are machines still working in inches.

8.2.3 Dual Dimensioning. A popular way to handle the conversion of measurement is to dual-dimension the drawings: but side-by-side dual dimensioning (using brackets) is a costly transition mechanism. Besides added drawing costs and increased drawing clutter, it allows engineers and designers to avoid learning to think metric because all the old familiar inch numbers are still there to use. Also, it is important for the transition period conversion mechanisms to allow for gradual change as the need for conversion in the shop decreases. Dual dimensioning at the design level can make for a costly transition mechanism until the last machine or vendor that must be dealt with is converted. This is because the purchase-fabricate decision is usually made after design work is complete; the designers do not know where a drawing may go for fabrication and must treat every part as though it will be done by inch machines. One company considered several ideas and decided that the simplest and least costly way to handle the millimeter-inch conversion at the machine was to use a conversion table (see 8.2.4.1). This means there would be a dualism in the shop, decreasing with time, during the transition period. Dualism is less troublesome in shops where, for the most part, an operator is concerned with only one dimension at a time—the one being cut.

8.2.4 Engineering Drawing-to-Shop Practice Conversions. The following techniques may be considered for dimensioning drawings. They are to be used only during a transition period. Ultimately, all dimensions will be in SI units, and all machine tools will have similar displays.

The first method involves the use of a conversion table which accompanies each drawing or is otherwise available to each user of the drawing. The second method involves the inclusion of inch equivalents of millimeter dimensions, in tabular form, on each drawing.

Note that neither method involves side-by-side dual dimensioning.

8.2.4.1 Technique No. 1: The Use of a One-Page Simplified Conversion Table Based on Preferred Dimensions. Supplying a conversion table to the machine operator becomes a more attractive idea if it is combined with a system of preferred dimensions and tolerances that permits a simplified one-page table. Designers are expected to use the preferred numbers for dimensions and tolerances except in unusual cases. Since both designers and fabricators use the same simplified table, the engineer/designer should have confidence in the conversion of the millimeter dimension for fabrication and inspection. The few numbers on a drawing not covered by the table are converted by the designer and placed in a corner of the drawing. The success of this approach is measured by how few numbers on a drawing are not from the preferred list. If too many of the numbers on a drawing are converted on the drawing, it becomes a form of dual dimensioning.

8.2.4.2 Technique No. 2: The Inclusion of a Conversion Chart on Each Drawing. Millimeter-to-inch conversions are included in tabular form on new drawings. Only the dimensions appearing on the drawing are given, usually in order of magnitude. One approach is to use computer-generated conversion charts which are copied onto adhesive-backed Mylar. The charts are then attached to the original drawings for copying. Similar charts can be attached to existing drawing vellums along with a prominent "METRIC" label. The "change" block would reflect the revision, and the drawings would be reissued.

8.2.5 When to Replace Existing U.S. Customary Inventory with Metric Inventory. No attempt should be made to use raw materials and supplies produced with metric units if doing so degrades some design or fabrication factor, including cost. Also, materials

should be called out on metric drawings as they are fabricated and specified, i.e., metric units should be used for "metric" materials, and customary units should be used to define materials fabricated using U.S. customary units. The entire inventory of supplies should be monitored to introduce metric supplies on a timely basis. Also, it is important to know as early as possible the availability of metric materials to prepare for the change in inventory and design.

8.2.6 The Use of a Preferred Number Approach for General Inventory Reduction Prior to the Need to Carry Dual Inventory.³ A possible inventory reduction plan would designate preferred items within the existing inventory to the engineering and design departments. Item usage would then be monitored to see which, if any, of the nonpreferred items should be added to the preferred list. All remaining nonpreferred items would be eliminated from the inventory. It is important that the monitoring procedure be sensitive to the possible use of preferred items at the expense of design integrity. The attractiveness of the preferred list approach to inventory reduction is that design requirements can be tested before anyone has to take a hard position on what will be eliminated from the inventory.

The success of this approach depends upon the extent to which an existing inventory can be pruned without significant loss of fabrication efficiency.

8.2.7 Each Major Group Should Be Taught Only What It Needs to Know. Formal classroom training can provide changeover background information for inspirational purposes and for the basics of SI. Reference material should then be provided for self-teaching. There has been a tendency to overdo the training aspects of metric conversion beyond what is economical. SI is a simple system, and individuals need to learn initially only the part of SI which pertains to their discipline.

8.2.8 Standard Practices Should Be Established and Used. The necessary policy and procedures should be provided by the issuance of a metric engineering standard. This standard will serve to coordinate efforts and assure that common practices are used.

3. See section 9. Preferred Numbers

9. Preferred Numbers

9.1 Definition. Preferred numbers are a series of numbers recommended as an aid to establish sizes, such as sizes of bolts, electrodes, fillet welds, etc., where a range of sizes is desired.⁴

These series are designed according to a geometric progression. Each number in the series has the same proportional relationship to its preceding number. For general purposes of sizing and grading, a geometric series is usually more rational than an arithmetically progressive series.

In an arithmetic series, the unit size increment is constant for any range of sizes. An example of the customary arithmetic progression is fractional drill (or hole) sizes that are in size increments of 1/64 inch. The fineness of the division gets ridiculously small as the nominal diameter increases to 1 in. or more.

9.2 Application of Preferred Numbers. The size of the increments in a geometric series is determined by a multiplying factor which, in the most common series used in the mechanical field (the Renard Series), is a root of 10. The 5, 10, 20, and 40 series are the most commonly used preferred number series. These cover the majority of applications. One series is selected from this group for a given standard, according to the size or number of increments desired.

The basis for the preferred number system is as follows: 1.0 is used as the first number of a series. Each succeeding number is determined by multiplying its preceding number by a constant factor for the series. The product is rounded to measurable values, consistent with the characteristics for which a standard is being established. Constant factors are determined as follows:

For the 5 series $\sqrt[5]{10}$, or 1.5849

For the 10 series $\sqrt[10]{10}$, or 1.2589

For the 20 series $\sqrt[20]{10}$, or 1.1220

For the 40 series $\sqrt[40]{10}$, or 1.0593

In the 5 series, succeeding numbers represent an increase of approximately sixty percent over the pre-

4. The term *size* as used herein should be interpreted broadly. While in many cases it will refer to a dimension of length, area, or volume, it may also refer to a mass, a capacity to perform, a rating, and so forth.

ceding number; in the 10 series, approximately twenty-five percent; in the 20 series, approximately twelve percent; and in the 40 series, approximately six percent. (The 5, 10, 20, and 40 series preferred numbers are shown in Table 11.)

The progressively larger steps within a preferred number series result in fewer sizes within the overall range of a product or material line. This can mean savings in such items as development, tooling, setup time, and stock keeping.

The numbers in Table 11 are approximations of the theoretical values thus obtained, the departure from the theoretical values being no more than 1.3 percent. The theoretical values are not given here because they are of no value in the practical application of the system. A table of the "exact" numbers (five decimals) is given in ANSI document Z17.1, which can be obtained from the American National Standards Institute (see "Reference Organizations").

As an example of the application of the preferred number concept, the preferred number 10-series was used to determine the appropriate rational sizes of fillet welds given in Table 6, column (C). In this case, the series was started at 3 mm (approximately equal to a 1/8 in. fillet). The 3 mm was rounded from the table value of 3.15 as a practical consideration. From there on, the sizes 4, 5, 6, 8, etc., result in approximately twenty-five percent increase per step. Note that the 13 mm size is superfluous and is not used.

9.3 Value of Using Preferred Numbers. The adoption of a series of preferred numbers to be used by all designers tends to unify sizes chosen by different designers, reduces the variety of numbers used, and creates the uniformity and consequent interchangeability that are indispensable to successful standardization work.

For those working toward the development of metric industrial standards and hoping for possible international acceptance, adherence to the concept of preferred numbers is strongly recommended. To get a multiple variety standard in such mechanical fields as welding accepted by the International Organization for Standardization (ISO), the grading suggested should be consistent with the concept of preferred numbers. For example, a major U.S. producer of roller bearings was forced to change the sizes of a new metric line of roller bearings consistent with a preferred number series as part of an effort to make the suggested standard more acceptable to ISO.

Preferred numbers are recommended for use by smaller industrial units or by individuals wishing to establish rational standardization for their own activ-

Table 11
Basic Preferred Numbers, Decimal Series
(1 To 10)

5 Series (60% steps)	10-Series (25% steps)	20-Series (12% steps)	40-Series (6% steps)
1.0	1.0	1.0	1.0
		1.12	1.06
			1.12
	1.25	1.25	1.18
			1.25
		1.4	1.32
			1.4
			1.5
1.6	1.6	1.6	1.6
		1.8	1.7
			1.8
	2.0	2.0	1.9
			2.0
		2.24	2.12
			2.24
			2.36
2.5	2.5	2.5	2.5
		2.8	2.65
			2.8
	3.15	3.15	3.0
			3.15
		3.55	3.35
			3.55
			3.75
4.0	4.0	4.0	4.0
		4.5	4.25
			4.5
	5.0	5.0	4.75
			5.0
		5.6	5.3
			5.6
			6.0
6.3	6.3	6.3	6.3
		7.1	6.7
			7.1
	8.0	8.0	7.5
			8.0
		9.0	8.5
			9.0
			9.5

Note: Percentage steps are approximate averages.

ity in order to have compatibility with eventual national or international standards.

Changing nonconforming standards that are well established and generally satisfactory requires an evaluation of the advantages and disadvantages in each case. Changes made merely for the purpose of conforming to the preferred number system may not be justifiable in the face of economic disadvantage. Appropriate activity in each situation will be determined by the responsible agency or agency's committee. Serious consideration should be given to the use of preferred numbers for any extension of an existing nonconforming standard. Converting to a preferred numbers system over a transition period may be advantageous for some standards. More details of preferred numbers with applications and approximate calculations can be found in ISO Recommendations R3, R17, and R497, which are available from the American National Standards Institute.

Appendix A

(This Appendix is not part of ANSI/AWS A1.1-89, *Metric Practice Guide for the Welding Industry*, but is included for informational purposes only.)

Commonly Used Metric Conversions (Inch-Millimeter Conversion)

1 in. = 25.4 mm exactly

To convert inches to millimeters, multiply
the inch value by 25.4.

To convert millimeters to inches, divide the
millimeter value by 25.4.

Inch and Millimeter Decimal Equivalents of Fractions of an Inch

Inch		Millimeter	Inch		Millimeter
Fraction	Decimal		Fraction	Decimal	
1/64	0.015 625	0.396 875	33/64	0.515 625	13.096 875
1/32	0.031 250	0.793 750	17/32	0.531 250	13.493 750
3/64	0.046 875	1.190 625	35/64	0.546 875	13.890 625
1/16	0.062 500	1.587 500	9/16	0.562 500	14.287 500
5/64	0.078 125	1.984 375	37/64	0.578 125	14.684 375
3/32	0.093 750	2.381 250	19/32	0.593 750	15.081 250
7/64	0.109 375	2.778 125	39/64	0.609 375	15.478 125
1/8	0.125 000	3.175 000	5/8	0.625 000	15.875 000
9/64	0.140 625	3.571 875	41/64	0.640 625	16.271 875
5/32	0.156 250	3.968 750	21/32	0.656 250	16.668 750
11/64	0.171 875	4.365 625	43/64	0.671 875	17.065 625
3/16	0.187 500	4.762 500	11/16	0.687 500	17.462 500
13/64	0.203 125	5.159 375	45/64	0.703 125	17.859 375
7/32	0.218 750	5.556 250	23/32	0.718 750	18.256 250
15/64	0.234 375	5.953 125	47/64	0.734 375	18.653 125
1/4	0.250 000	6.350 000	3/4	0.750 000	19.050 000
17/64	0.265 625	6.746 875	49/64	0.765 625	19.446 875
9/32	0.281 250	7.143 750	25/32	0.781 250	19.843 750
19/64	0.296 875	7.540 625	51/64	0.796 875	20.240 625
5/16	0.312 500	7.937 500	13/16	0.812 500	20.637 500
21/64	0.328 125	8.334 375	53/64	0.828 125	21.034 375
11/32	0.343 750	8.731 250	27/32	0.843 750	21.431 250
23/64	0.359 375	9.128 125	55/64	0.859 375	21.828 125
3/8	0.375 000	9.525 000	7/8	0.875 000	22.225 000
25/64	0.390 625	9.921 875	57/64	0.890 625	22.621 875
13/32	0.406 250	10.318 750	29/32	0.906 250	23.018 750
27/64	0.421 875	10.715 625	59/64	0.921 875	23.415 625
7/16	0.437 500	11.112 500	15/16	0.937 500	23.812 500
29/64	0.453 125	11.509 375	61/64	0.953 125	24.209 375
15/32	0.468 750	11.906 250	31/32	0.968 750	24.606 250
31/64	0.484 375	12.303 125	63/64	0.984 375	25.003 125
1/2	0.500 000	12.700 000	1	1.000 000	25.400 000

Appendix B

(This Appendix is not part of ANSI/AWS A1.1-89, *Metric Practice Guide for the Welding Industry*, but is included for informational purposes only.)

Pressure and Stress Equivalents—Pounds—Force per Square Inch To Kilopascals and Thousand Pounds—Force per Square Inch to Megapascals

$$1 \text{ psi} = 6894.757 \text{ Pa}$$

To convert psi to pascals, multiply the psi value by $6.894\,757 \times 10^3$

To convert pascals to psi, divide the pascal value by $6.894\,757 \times 10^3$

psi or ksi	0	1	2	3	4	5	6	7	8	9
	kPa or MPa									
0	0.0000	6.8948	13.7895	20.6843	27.5790	34.4738	41.3685	48.2633	55.1581	62.0528
10	68.9476	75.8423	82.7371	89.6318	96.5266	103.4214	110.3161	117.2109	124.1056	131.0004
20	137.8951	144.7899	151.6847	158.5794	165.4742	172.3689	179.2637	186.1584	193.0532	199.9480
30	206.8427	213.7375	220.6322	227.5270	234.4217	241.3165	248.2113	255.1060	262.0008	268.8955
40	275.7903	282.6850	289.5798	296.4746	303.3693	310.2641	317.1588	324.0536	330.9483	337.8431
50	344.7379	351.6326	358.5274	365.4221	372.3169	379.2116	386.1064	393.0012	399.8959	406.7907
60	413.6854	420.5802	427.4749	434.3697	441.2645	448.1592	455.0540	461.9487	468.8435	475.7382
70	482.6330	489.5278	496.4225	503.3173	510.2120	517.1068	524.0015	530.8963	537.7911	544.6858
80	551.5806	558.4753	565.3701	572.2648	579.1596	586.0544	592.9491	599.8439	606.7386	613.6334
90	620.5281	627.4229	634.3177	641.2124	648.1072	655.0019	661.8967	668.7914	675.6862	682.5810
100	689.4757									

This table may be used to obtain SI equivalents of values expressed in psi or ksi. SI values are usually expressed in kPa when original value is in psi and in MPa when original value is in ksi.

This table may be extended to values below 1 or above 100 psi (or ksi) by manipulation of the decimal point and addition.

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Appendix C

(This Appendix is not part of ANSI/AWS A1.1-89, *Metric Practice Guide for the Welding Industry*, but is included for informational purposes only.)

Conversions for Fahrenheit—Celsius Temperature Scales

Find the number to be converted in the center (boldface) column. If converting Fahrenheit degrees, read the Celsius equivalent in the column headed "°C". If converting Celsius degrees, read the Fahrenheit equivalent in the column headed "°F".

°C	°F	°C	°F	°C	°F	°C	°F
-273	-459	-40	40	24.4	76	199	390
-268	-450	-34	30	25.6	78	204	400
-262	-440	-29	20	26.7	80	210	410
-257	-430	-23	10	27.8	82	216	420
-251	-420	-17.8	0	28.9	84	221	430
-246	-410	-16.7	2	30.0	86	227	440
-240	-400	-15.6	4	31.1	88	232	450
-234	-390	-14.4	6	32.2	90	238	460
-229	-380	-13.3	8	33.3	92	243	470
-223	-370	-12.2	10	34.4	94	249	480
-218	-360	-11.1	12	35.6	96	254	490
-212	-350	-10.0	14	36.7	98	260	500
-207	-340	-8.9	16	37.8	100	266	510
-201	-330	-7.8	18	38.9	102	271	520
-196	-320	-6.7	20	40.0	104	277	530
-190	-310	-5.6	22	41.1	106	282	540
-184	-300	-4.4	24	42.2	108	288	550
-179	-290	-3.3	26	43.3	110	293	560
-173	-280	-2.2	28	44.4	112	299	570
-168	-270	-1.1	30	45.6	114	304	580
-162	-260	0.0	32	46.7	116	310	590
-157	-250	1.1	34	47.8	118	316	600
-151	-240	2.2	36	48.9	120	321	610
-146	-230	3.3	38	50.0	122	327	620
-140	-220	4.4	40	51.1	124	332	630
-134	-210	5.6	42	52.2	126	338	640
-129	-200	6.7	44	53.3	128	343	650
-123	-190	7.8	46	54.4	130	349	660
-118	-180	8.9	48	55.6	132	354	670
-112	-170	10.0	50	56.7	134	360	680
-107	-160	11.1	52	57.8	136	366	690
-101	-150	12.2	54	58.9	138	371	700
-96	-140	13.3	56	60.0	140	377	710
-90	-130	14.4	58	61.1	142	382	720
-84	-120	15.6	60	62.2	144	388	730
-79	-110	16.7	62	63.3	146	393	740
-73	-100	17.8	64	64.4	148	399	750
-68	-90	18.9	66	65.6	150	404	760
-62	-80	20.0	68	66.7	152	410	770
-57	-70	21.1	70	67.8	154	416	780

Appendix C (Continued)

°C	°F	°C	°F	°C	°F	°C	°F
- 51	- 60	- 76	22.2	72	161.6	188	370
- 46	- 50	- 58	23.3	74	165.2	193	380
432	810	1490	738	1360	2480	1043	1910
438	820	1508	743	1370	2498	1049	1920
443	830	1526	749	1380	2516	1054	1930
449	840	1544	754	1390	2534	1060	1940
454	850	1562	760	1400	2552	1066	1950
460	860	1580	766	1410	2570	1071	1960
466	870	1598	771	1420	2588	1077	1970
471	880	1616	777	1430	2606	1082	1980
477	890	1634	782	1440	2624	1088	1990
482	900	1652	788	1450	2642	1093	2000
488	910	1670	793	1460	2660	1099	2010
493	920	1688	799	1470	2678	1104	2020
499	930	1706	804	1480	2696	1110	2030
504	940	1724	810	1490	2714	1116	2040
510	950	1742	816	1500	2732	1121	2050
516	960	1760	821	1510	2750	1127	2060
521	970	1778	827	1520	2768	1132	2070
527	980	1796	832	1530	2786	1138	2080
532	990	1814	838	1540	2804	1143	2090
538	1000	1832	843	1550	2822	1149	2100
543	1010	1850	849	1560	2840	1154	2110
549	1020	1868	854	1570	2858	1160	2120
554	1030	1886	860	1580	2876	1166	2130
560	1040	1904	866	1590	2894	1171	2140
566	1050	1922	871	1600	2912	1177	2150
571	1060	1940	877	1610	2930	1182	2160
577	1070	1958	882	1620	2948	1188	2170
582	1080	1976	888	1630	2966	1193	2180
588	1090	1994	893	1640	2984	1199	2190
593	1100	2012	899	1650	3002	1204	2200
599	1110	2030	904	1660	3020	1210	2210
604	1120	2048	910	1670	3038	1216	2220
610	1130	2066	916	1680	3056	1221	2230
616	1140	2084	921	1690	3074	1227	2240
621	1150	2102	927	1700	3092	1232	2250
627	1160	2120	932	1710	3110	1238	2260
632	1170	2138	938	1720	3128	1243	2270
638	1180	2156	943	1730	3146	1249	2280
643	1190	2174	949	1740	3164	1254	2290
649	1200	2192	954	1750	3182	1260	2300
654	1210	2210	960	1760	3200	1266	2310
660	1220	2228	966	1770	3218	1271	2320
666	1230	2246	971	1780	3236	1277	2330
671	1240	2264	977	1790	3254	1282	2340
677	1250	2282	982	1800	3272	1288	2350

Appendix C (Continued)

°C		°F	°C		°F	°C		°F	°C		°F
682	1260	2300	988	1810	3290	1293	2360	4280	1599	2910	5270
688	1270	2318	993	1820	3308	1299	2370	4298	1604	2920	5288
693	1280	2336	999	1830	3326	1304	2380	4316	1610	2930	5306
699	1290	2354	1004	1840	3344	1310	2390	4334	1616	2940	5324
704	1300	2372	1010	1850	3362	1316	2400	4352	1621	2950	5342
710	1310	2390	1016	1860	3380	1321	2410	4370	1627	2960	5360
716	1320	2408	1021	1870	3398	1327	2420	4388	1632	2970	5278
721	1330	2426	1027	1880	3416	1332	2430	4406	1638	2980	5396
727	1340	2444	1032	1890	3434	1338	2440	4424	1643	2990	5414
732	1350	2462	1038	1900	3452	1343	2450	4442	1649	3000	5432

$$^{\circ}\text{C} = 5/9 (^{\circ}\text{F} - 32)$$

$$^{\circ}\text{F} = 9/5 (^{\circ}\text{C} + 32)$$

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Reference Organizations

American National Metric Council
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