OR-OSHA TECHNICAL MANUAL OR-OSHA TECHNICAL MANUAL OR-OSHA TECHNICAL MANUAL

Section IX

GENERAL

CHAPTER 1: METRIC SYSTEM CONVERSION

SECTION IX: CHAPTER 1

METRIC SYSTEM CONVERSION

A. INTRODUCTION

Use of metric measurement standards in the United States has been authorized by law since 1866. In 1988, Congress enacted legislation (Public Law 100-418) to establish the metric system as the preferred system of weights and measures for all domestic trade and commerce. This legislation also required the use of metric measurement standards in all Federal activities. On July 25, 1991, the President issued Executive Order 12770, which reiterated the order to implement the metric system "as the preferred system of weights and measures for United States trade and commerce." This executive order directed all Federal agencies to implement "metrification" to the extent economically feasible by September 30, 1992.

In 1988, when Congress enacted metrification legi-slation, the U.S. was the only major industrial nation not using the metric system. As a result, domestic industries were often at a competitive disadvantage and were sometimes even excluded from the international marketplace. In its deliberations, Congress also found that the inherent simplicity of the metric system could lead to major cost savings, further enhance our international competitive position, and provide substantial advantage to the Federal Government in its own operations.

Commercially, metric measure is sometimes used as a *household* measure in the U.S., e.g. two-liter soft drinks. Most food labels list both metric and English measure. Metric measure labeling has opened markets for business products in areas which use metric measure daily.

OSHA's safety compliance operations and industrial hygiene efforts have an advantage in metrification because the biological, chemical, and physical sciences have long used the metric system. Students of these subjects have been using metric weights and measures along with daily use of the "English" system of measures for decades. Time-weighted averages (TWA), permissible exposure limits (PEL), and sampling and reporting forms all make use of the metric system. For example, the industrial hygiene *Air Sampling Report*, OSHA-91(S) (Rev. 1/84) requires data as metric measures and weights. Also examine OSHA reference Table Z-1-A (29 CFR 1910 Subpart Z).

B. THE METRIC SYSTEM

Originally, there were only two basic reference points, the ***meter*** for length and the ***gram*** for weight. The list of reference points has been expanded for the International System (SI) to include the ***kilogram*** (instead of the gram) for mass, the ***second*** for time, the ***ampere*** for electric current, the ***degree Kelvin*** for temperature, and the ***candela*** for light intensity (see Table IX:1-1).

The reference objects for these International standards units are maintained for comparisons and checked periodically against other international references by the National Institute for Standards and Technology (NIST).

The base units used in the metric system are:

TABLE IX:1-1. METRIC BASE UNITS

Measurement	*Unit name*	*Unit symbol*
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	Kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

The ***metric system*** entails the use of multiples or powers of ten to describe magnitudes greater or less than the basic units of meter, gram, ampere, and so forth. The prefixes for the multiples and submultiples of basic units are presented in Table IX:1-2. For example, mass or weight can be presented as:

- the ***kilogram*** is 1000 grams and
- the ***milli****gram is 1/1000 gram.*

TABLE IX:1-2. PREFIXES AND SYMBOLS FOR DECIMAL MULTIPLES AND SUBMULTIPLES OF UNITS[1]

Power of 10	*Prefix*	*Symbol*
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10^{1}	deca*	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	F
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

* Also "deka."

1 Conférence générale des Poids et Mesures, *Comtes rendus de séances de la 11e Conférence générale des Poids et Mesures,* Paris 1960, Gauthier-Villars, Paris 1961, page 87; Conférence générale des Poids et Mesures, *Comtes rendus des séances de la 12e Conférence générale des Poids et Mesures,* Paris 1964, Gauthier-Villars, Paris, 1964, page 94.

There are:

- 100 ***centi****meters* to one ***meter*** and
- 1000 ***meters*** to one ***kilo****meter.*

Also, volume can be presented as:

- 10 ***deci****liters* in one ***liter***,
- 10 ***liters*** in one ***deca****liter*, and
- 10 ***deca****liters* in one ***hecto****liter.*

Area and volume in both inch-pound and the metric system are calculated similarly. Area is length times width with the measure of each side in the same units for both length and width for square **feet ($feet^2$)** or square **meters (m^2).** Volume is likewise length times width times height: **cubic yards ($yard^3$)** or **cubic meters (m^3)**.

The metric measure of a liter is defined as a volume of 1000 cubic centimeters (cc) or a volume of 10 cm by 10 cm by 10 cm.

In physics, some measurements are defined by several metric units. These derived units are named, generally, for the scientists who first defined the measurement. The metric expression as a combination of metric units is presented in Table IX:1-3.

TABLE IX:1-3. DERIVED SI UNITS WITH SPECIAL NAMES

	Unit Name	*Symbol*	*Formula*	*Expressions as metric base units*
Frequency	hertz	Hz	1/s or s^{-1}	s^{-1}
Force	newton	N	m · kg · s-2	$m \cdot kg \cdot s^{-2}$
Energy, Work	joule	J	N · m	$m^2 \cdot kg \cdot s^{-2}$
Power	watt	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
Electric charge	coulomb	C	A · s	A · s
Electric potential	volt	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
Electric resistance	ohm	W	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
Electric capacitance	farad	F	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
Magnetic flux	weber	Wb	V · s	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
Pressure, Stress	pascal	Pa	N/m^2	$m^{-1} \cdot kg \cdot s^{-2}$
Conductance	siemens	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
Magnetic flux	density tesla	T	Wb/m^2	$kg \cdot s^{-2} \cdot A^{-1}$
Inductance	henry	H	Wb/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
Luminous flux	lumen	lm	cd · sr	cd · sr
Illuminance	lux	lx	lm/m^2	$m^{-2} \cdot cd \cdot sr$

C. THE CONVERSION PROCESS

The conversion equivalent for an *inch* is 1 inch equals 2.54 centimeters or 25.4 millimeters. The measure and units to be converted are multiplied by the conversion factor to yield the new measure and units. Do include the units in the conversion calculation and *cancel* the units as part of the calculation process (Table IX:1-4).

Each conversion factor has the metric units per inch-pound units and should be included in the calculation converting inch-pound units to metric units until the use of the conversion factor is ingrained in the user. During a calculation, ***like*** units divided by ***like*** units equal ***one*** and cancel themselves, as shown in Table IX:1-4.

Because of the number of conversion factors presented in *Federal Standard 376A* (May 5, 1983), include with the numeric conversion factor both metric and inch-pound unit labels during the calculations. Cancel like units during the calculation. Then only the new measurement unit labels will remain (see Table IX:1-4).

TABLE X:1-4. AN EXAMPLE OF AN INCH-POUND TO SI METRIC CONVERSION

Original inch-pound measure	*Conversion*	*Calculated metric measure*
1 inch	2.54 cm/inch	
	1 inch @ 2.54 cm/inch	
	1 ~~inch~~ @ 2.54 cm/~~inch~~	
		2.54 cm (or 25.4 mm)

D. CONVERSION PRECISION

Some conversion factors have been developed to seven significant digits, e.g., Federal Standard 376A includes the conversion factor for the foot (survey) as used in the U.S. as:

1 ft (survey) = 0.3048006 m

When using a conversion factor, round resulting calculations to the number of significant digits of the original inch-pound measurement or to fewer significant decimal positions.

Precision is not increased by converting from inch-pound to metric by a multiple digit conversion factor.

Calculations or conversion of a measurement from inch-pound to metric measure requires the application of three ***rules of calculation,*** often done by habit.

SIGNIFICANT NUMBER OF DIGITS

A distance shown as **61** miles has two significant digits, implying measurement accuracy to a whole number of miles. A distance written as **61.6** miles is three significant digits, two plus one decimal digit and implies accuracy to one tenth of a mile.

The number of digits presented usually reflects the accuracy of the actual measurement. The figures in **61** miles or **61.2** miles may represent an automobile's odometer measurement. A surveyor's measurement may be represented as **61.243** miles from measurement stake point to stake point: five significant digits including three decimals.

NUMBER OF CARRIED DIGITS

If the conversion number will result in a larger number, 1.609 km/mi, carry only the total number of first number digits, e.g.:

- **61** mi x 1.609 km/mi calculates to **98.**149 km but is presented as **98** km.

- **61.2** mi x 1.609 km/mi calculates to **98.**4708 km but is presented as **98.5** km.

- **61.243** mi x 1.609 km/mi calculates to **98.539**987 km but is presented as **98.540** km.

If the conversion number will result in a ***smaller number,*** carry only the total number of first number digits *plus one extra digit,* e.g.:

- 4 lb x 0.453 lb/kg calculates to **1.8**12 kg but is presented as **1.8** kg (for measurement by a household scale).

- **4.3** lb x 0.453 lb/kg calculates to **1.94**79 kg but is rounded up and is presented as **1.95** kg (for measurement by a postal scale).

- **4.33** lb x 0.453 lb/kg calculates to **1.961**49 kg is presented with no rounding as **1.961** kg (for measurement by a laboratory scale).

"ROUNDING" OF NUMBERS

To "round off" calculated numbers to a minimum number of significant digits, follow these rules:

- When a number such as **13.34** is to be rounded to **13.3+**, the digit 4 is less than 5 so the number is rounded to an unchanged **13.3**.

- When a number as **13.37** is to be rounded to **13.3+**, the digit 7 is equal to or greater than 5 so the number is rounded or increased to a changed **13.4**.

E. CONVERSION EQUIVALENTS

The document to be used as a primary reference for inch-pound to metric conversions is Federal Standard 376A, ***Preferred Metric Units for General Use by the Federal Government,*** May 5, 1983. A selected number of conversion factors are presented in Tables IX:1-5 through IX:1-15.

The basic units of the measurement system are by definition to man-made reference standards for mass or weight (the kilogram) and length (the meter). Some units of measure are mathematically derived, as plane and solid angle measures (from geometry), or derived from astronomical phenomena, time, or are not related to either mass or length measurement references. The units for these measures have not changed. A measure of frequency, cycles per second (cps), has been renamed ***Hertz*** to honor the German physicist H. R. Hertz.

Measures of light were defined in physics originally in terms of the metric system and have not changed. If the measure of light was converted to the inch-pound system, and include inch-pound area measures as part of its definition, a conversion to metric equivalents is necessary. These exceptions to light measurements are presented in the appropriate table.

TEMPERATURE

Metrification or establishment of the measure system as a base of ten is extended to temperature measures.

G. D. Fahrenheit, the German physicist, defined a scale of measure for his alcohol thermometer in 1709 and used the same scale again in 1714 for his mercury thermometer. On this scale, water freezes at 32E and boils at 212E. The base of ten temperature scale definition of Anders Celsius, the Swedish astronomer, is used in the metric system for temperature measures. The point at which water freezes or becomes a solid is 0E Celsius and the point of transition of water from a liquid to a gas is at 100E Celsius.

[These definitions assume that the atmospheric pressure is at a standard of 760 mm of mercury pressure.]

The relationship between the arbitrary Fahrenheit scale and the Celsius scale used within the metric system is:

$$\frac{(\textbf{degrees}\ \textit{Fahrenheit - 32})}{9} \times 5 = \textbf{degrees}\ \textit{Celsius}$$

The equation must be applied for the conversion. For every nine-degree interval on the Fahrenheit temperature scale (EF), the Celsius temperature scale (EC) changes only five units. Please note that at the freezing point for water, the Celsius scale is at zero but the Fahrenheit scale is at 32E. It is convenient to remember that only at -40E are both scales equivalent:

-40EC = -40EF

TABLE IX:1-5. LENGTH

1.609347 kilometers (km)	1 mile (mi) [*statute*]
1.609344 kilometers (km)	1 mile (mi) [*international*]
1.828 meters (m)	1 fathom (fm)
0.9144 meter (m)	1 yard (yd)
0.3048006 meter (m)	1 foot (ft) [*survey*]
0.3048 meter (m)	1 foot (ft) [*international*]
2.54 centimeters (cm)	1 inch (in)
25.4 millimeters (Fm)	1 inch (in)
25.4 Fm	1 mil
1 Fm	1 micron
0.0254 Fm	1 Fin
0.1 nm	1 angstrom (Å)

TABLE IX:1-6. AREA

2.589998 square kilometers (km^2)	1 square mile (m^2)
0.4046873 hectare (ha)	1 acre
4046.873 square meters (m^2)	1 acre
0.8361274 square meter (m^2)	1 square yard (yd^2)
0.09290304 square meter (m^2)	1 square foot (ft^2)
6.4516 square centimeters (cm^2)	1 square inch (in^2)
645.16 square millimeters (cm^2)	1 square inch (in^2)

TABLE IX:1-7. VELOCITY

0.3048 meter/second (m/s)
1 foot/second (ft/s)

1.609347 kilometers/hour (km/h)
1 mile/hour (mi/h)

TABLE IX:1-8. VOLUME

1233.489 cubic meters (m^3)
1 acre foot (acre ft)

0.7645549 cubic meter (m^3)
1 cubic yard (yd^3)

0.1589873 cubic meter (m^3)
1 barrel (bbl) [*42 gallons*]

0.02831685 cubit meter (m^3)
1 cubic foot (ft3)

28.31685 liters (l)
1 cubic foot (ft^3)

0.002359737 cubic meter (m^3)
1 board foot (bd ft)

35.23907 liters (l)
1 bushel (bu)

3.785412 liters (l)
1 gallon (gal) [*liquid*]

0.9463529 liter (l)
1 quart (qt) [*liquid*]

0.4731765 liter (l)
1 pint (pt) [*liquid*]

29.57353 milliliters (ml **or** cc)
1 fluid ounce (fl oz)

16.38706 cm^3
1 in^3

TABLE X:1-9. MASS (WEIGHT)

1.016047 metric tons (t)
1 long ton
where 1 t = 1000 kg

0.90718474 metric ton (t)
1 short ton
where 1 short ton = 2000 pounds

0.45359237 kilogram (kg)
1 pound (lb avdp)

31.10348 grams (g)
1 ounce (oz troy)

28.34952 grams (g)
1 ounce (oz avdp)

64.79891 milligrams (mg)
1 grain (gr)

TABLE IX:1-10. DENSITY

1.186553 metric ton/m^3
1 short ton/yd^3

16.01846 kg/m^3
1 lb/ft^3

119.8264 g/^{l}
1 lb/gal

7.489152 g/^{l}
1 oz/gal

TABLE IX:1-11. PRESSURE

101.325 kPa	1 atmosphere (atm) *[standard]*
100 kPa	1 bar
6.894757 kPa	1 lbf/in^2 *[formerly psi]*
3.38638 kPa	1 inch Hg *[at 32EF]*
2.98898 kPa	1 foot H_2O *[at 39.2EF]*
0.24884 kPa	1 inch H_2O *[at 60EF]*
0.133322 kPa	1 mm Hg *[at 0EC]*
0.1 kPa	1 millibar

TABLE X:1-12. STRESS

6.894757 MPa	1 kip/in^2 (formerly **ksi**)
0.006894757 MPa	1 lbf/in2 (formerly **psi**)
6.894757 kPa	1 lbf/in2 (formerly **psi**)
0.04788026 kPa	1 lbf/ft^2

TABLE X:1-13. WORK

3.6 MJ	1 kWh
4.184 J	1 cal th
1.055056 kJ	1 Btu
1.355818 J	1 ft · lbf
105.4808 MJ	1 therm (U.S.)

TABLE X:1-14. POWER

3.516800 kW	1 ton (refrigeration)
1.055056 kW	1 Btu/s
0.7456999 kW	1 hp (550 lbf/s)
0.746 kW	1 hp (electric)
0.2930711 W	1 Btu/h

TABLE X:1-15. MISCELLANEOUS

Heat flow rate	1.055056 kW / 1 Btu/s
Heat capacity	1.899108 kJ/EC / 1 Btu/EF
Magnetic field strength	79.57747 A/m / 1 oersted (Oe)
Conductivity	100 S/m / 1 mho/cm
Wavelength	0.1 nm / 1 angstrom (Å)
Luminance	0.3183099 cd/cm^2 / 1 lambert (L)
	0.1550003 cd/cm^2 / 1 cd/in^2
	3.426259 cd/cm^2 / 1 foot-lambert (ft-L)
	10.76391 lx / 1 foot-candle (fc)

F. REFERENCE

General Services Administration. Federal Standard 376A, *Preferred Metric Units for General Use by the Federal Government,* May 5, 1983.