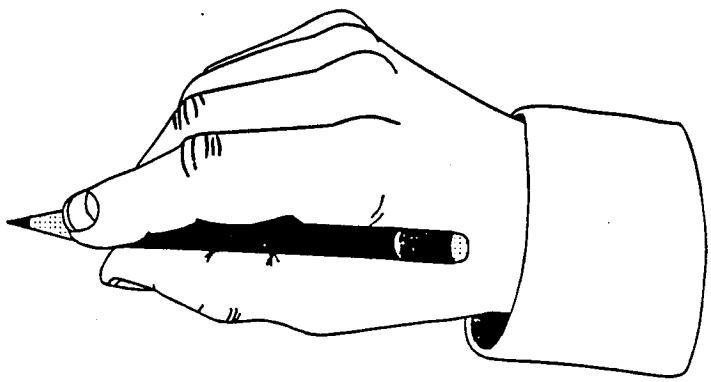
TECHNOLOGY TRANSFER TRAINING PROGRAM

WRITING THE METRIC WAY



Illinois Department of Transportation

Bureau of Local Roads and Streets

INTRODUCTION

The Technology Transfer Center has developed this training workbook to provide anyone who writes, transcribes or types metrics, a working knowledge of the metric units, their proper usage and the editorial rules for using the metric (SI) system. This booklet is intended as a metric reference relative to local highway agency business and not the sole authority for the complete metric system.

This booklet may be used as a class workbook or a home-study workbook. It begins with an explanation of metric units, their proper usage and editorial rules and is followed by a glossary, a conversion table and a brief metric quiz. The quiz is designed to provide the participant with practical examples of metric usage. An answer sheet for the quiz is provided in the back of the book.

OVERVIEW OF SI

The United States is the last industrialized country to convert to the metric system. Burma and Liberia are the only other countries that have not converted to the "SI" metric system. The term "SI" is an abbreviation for International System of Units. It is a modern-day metric system and was established by international agreement in 1960. It now provides a standard international language to describe measurement.

In SI, there are seven base units, many derived units, and two supplementary units which are summarized in table 1.2. There are specific definitions of the base units and supplementary units. This section will provide an overview of the metric system with an emphasis on highway engineering related units of length, mass, time, and temperature.

Table 1.2. Overview of SI.

	Units	*Symbol*
Base units		
length	meter	m
mass	kilogram	kg
time	second	s
temperature*	kelvin	K
electrical current	ampere	A
luminous intensity	candela	cd
amount of material	mole	mol
Derived units	**	
Supplementary units		
angles in the plane	radian	rad
solid angles	steradian	sr

*We will use degrees Celsius (°C), which has a more common usage than kelvin.
** Many derived units exist; several will be discussed in this session.

1. Base Units

The base units uniquely describe a property requiring measurement. The seven base units are length, mass, time, temperature, electrical current, luminous intensity, and amount of material. These units are dimensionally independent.

Length

One of the most common units in civil engineering and other disciplines is length. In SI, the base length unit is the meter. The meter, and a few of its sub-multiples, are presented in figure 1.1.

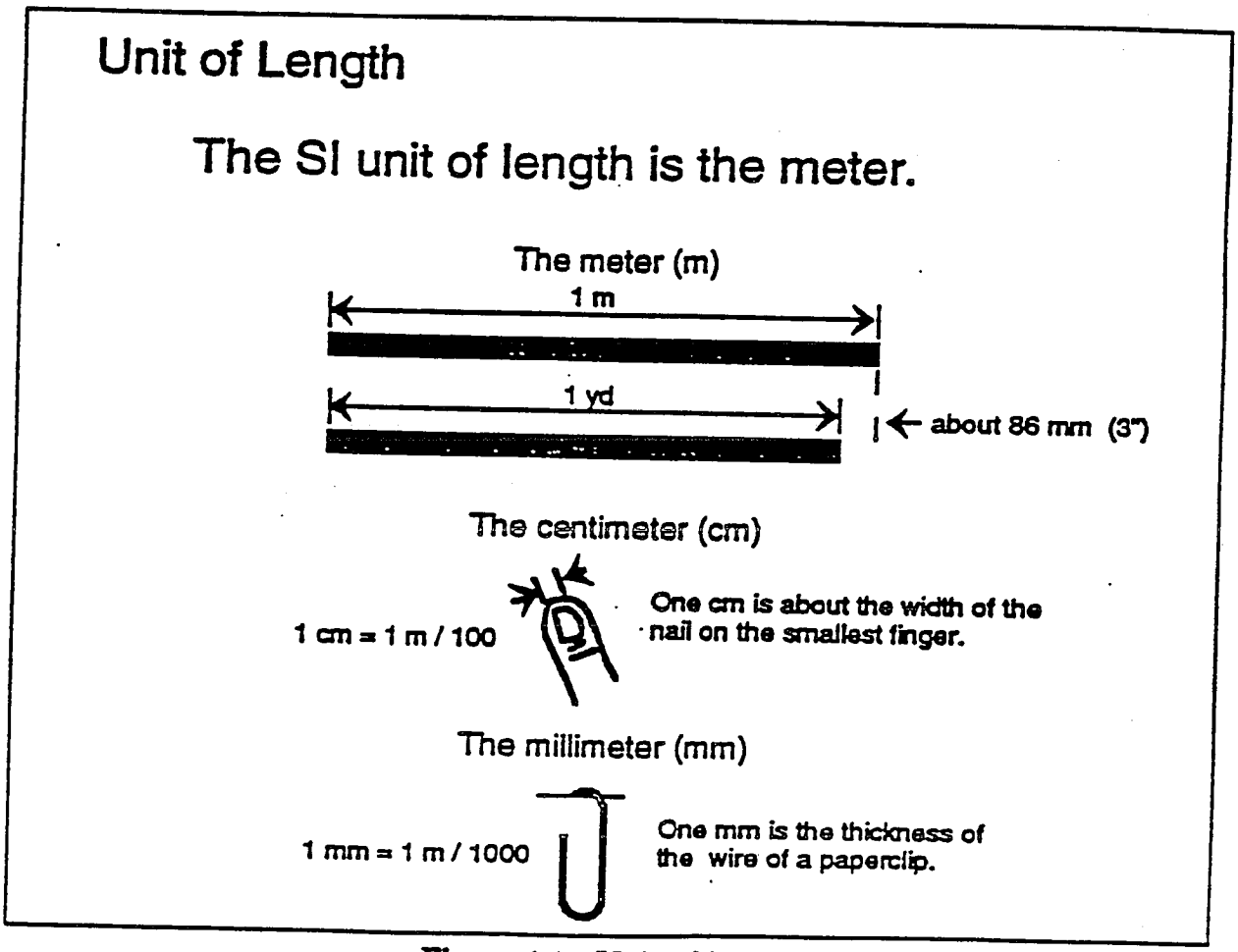


Figure 1.1. Unit of length.

- The meter is slightly longer than a yard.
- Other common units of length with their proper prefix are the centimeter and the millimeter.

- The centimeter is 1/100 of a meter and is about the width of the nail on the smallest finger.

- The millimeter is 1/1000 of a meter and is about the thickness of the wire of a paperclip.

- The centimeter is not a preferred unit on highway plans. The millimeter is the preferred unit.

The kilometer is a particularly important multiple of the meter for highway applications. Figure 1.2 illustrates its magnitude.

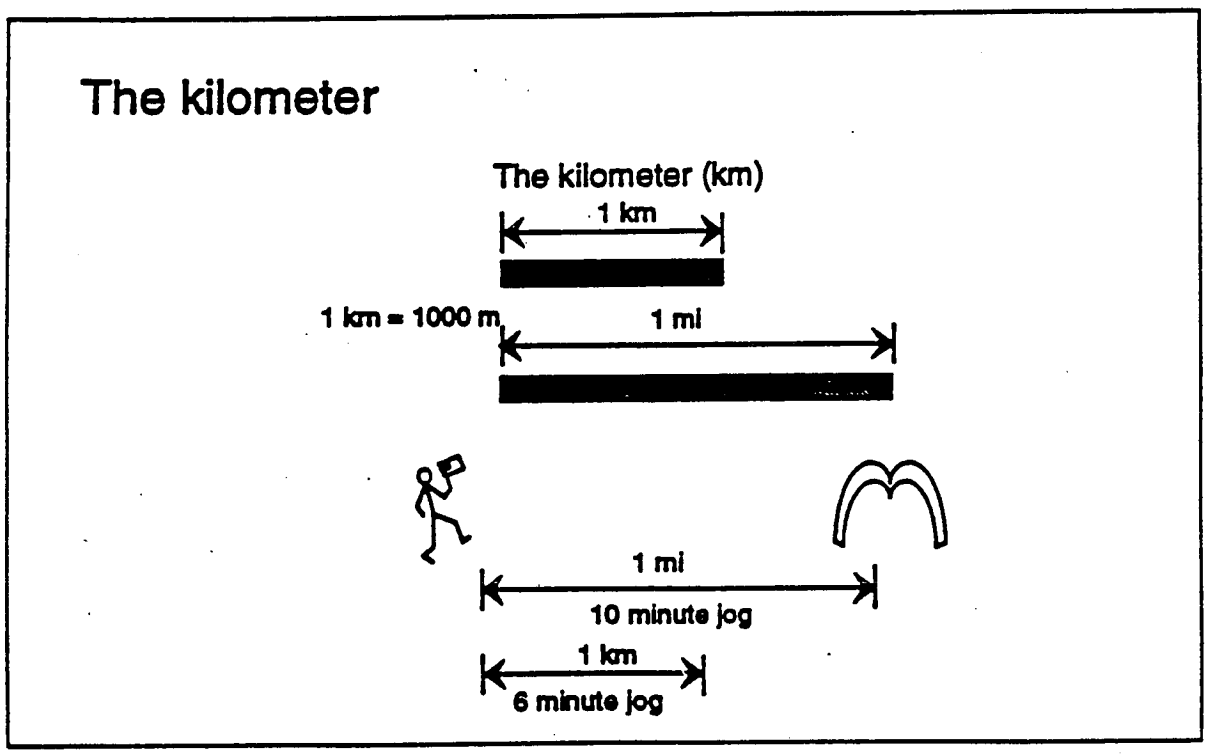


Figure 1.2. The kilometer.

- If it takes President Clinton 10 minutes to jog a mile to McDonalds, then at the same speed, he can go a kilometer in about 6 minutes.

- A speed of 62 mph is equal to a speed of 100 km/hr.

- The proper pronunciation is KILL´-o-meter and not kil-AHM-eter.

METRIC LENGTHS

millimeter (mm)	SI standard
centimeter (cm)	not normally used
decimeter (dm)	not normally used
meter (m)	SI standard
kilometer (km)	SI standard

GIVEN	MULTIPLY BY	TO GET
millimeters (mm)	.001	meters (m)
centimeters (cm)	.01	meters (m)
decimeters (dm)	.1	meters (m)
meters (m)	1	meters (m)
kilometers (km)	1,000	meters (m)

millimeters (mm)	1	millimeters (mm)
centimeters (cm)	10	millimeters (mm)
decimeters (dm)	100	millimeters (mm)
meters (m)	1,000	millimeters (mm)
kilometers (km)	1,000,000	millimeters (mm)

HOW METRIC LENGTHS ARE RELATED

mm 10 **cm** 10 **dm** 10 **m** 1,000 **km**

divide →

← multiply

Notice that when changing lengths within the metric system, all you need to do is move the dicimal point.

Example: Change 10,413 mm to meters.

10,413 mm · 0.001 = 10.413 m

Example: Change 9.86 dm to millimeters.

9.86 dm x 100 = 986.0 mm

Mass

The second base unit relevant to highway applications is the kilogram which is a measure of mass. Mass is the measurement of inertia of an object. It may be thought of as the measure of an object's resistance to acceleration. Mass is illustrated in figure 1.3.

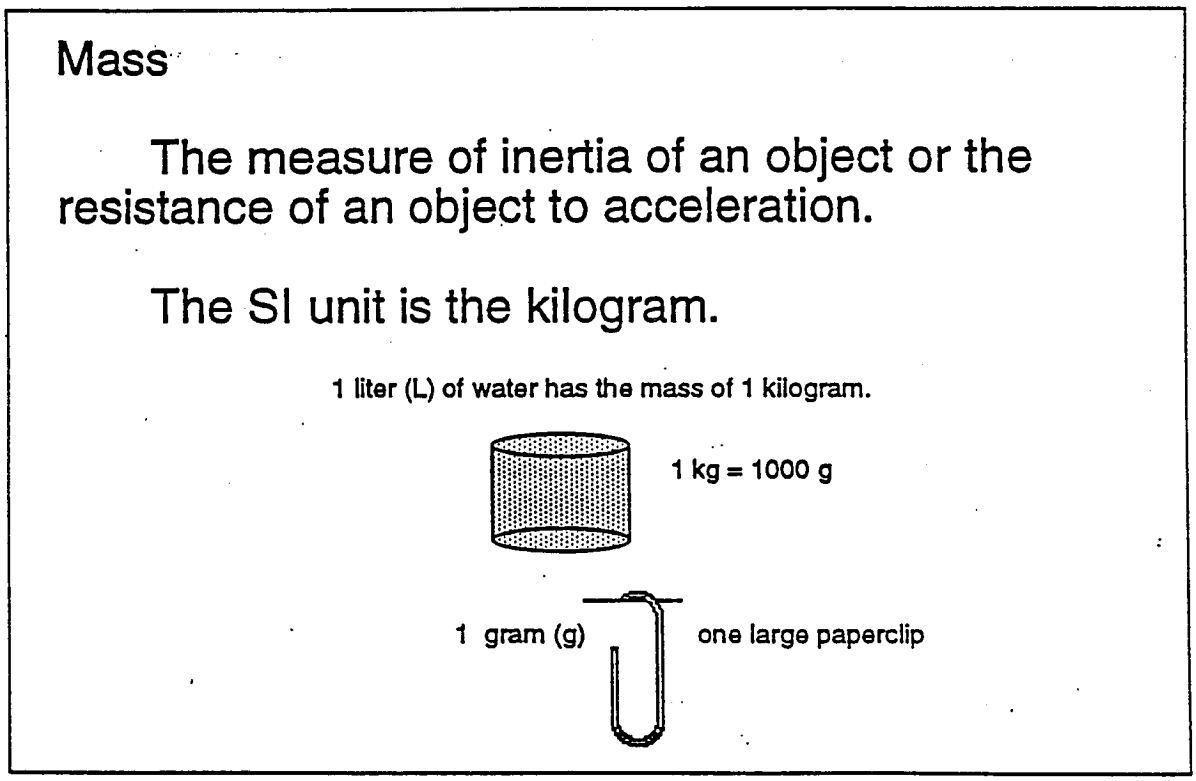


Figure 1.3. Mass.

- A liter of water (slightly more than a quart) has roughly one kilogram of mass.
- There are 1000 grams in a kilogram. There are a million milligrams in a kilogram.
- One milligram per kilogram is referred to as one part per million.

Time

A familiar SI base unit which is relevant to highway, and most other applications, is time. The second is the SI unit of time. It is the same as in the English system. Figure 1.4 illustrates the concept of time.

SI unit of time: second → (s)

This is the same unit as in English system.

Duration of heartbeat on a person at rest
1 s

Use "s" not "sec"

Figure 1.4. Time.

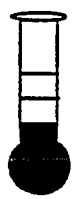
Temperature

Temperature is another base unit with usage in highway applications especially in material testing procedures and construction specifications. Kelvin is the base SI temperature unit with the Celsius scale being closely related, as shown in figure 1.5.

Unit of temperature

Base unit: kelvin
Common unit: degrees Celsius

Celsius	Fahrenheit
100°C (water boils)	212°F
37°C (body temp.)	98.6°F
0°C (water freezes)	32°F
	0°F



Tips for Remembering Celsius

Sauna	Flaming forties
Hot summer day	Thirsty thirties
Mild summer day	Temperate twenties
Fall day	Tingling teens

Celsius	kelvin
100°C	373 K boiling of water
0°C	273 K freezing of water
-273°C	0 K absolute zero

40°C	=	104°F
30°C	=	86°F
20°C	=	68°F
10°C	=	50°F
0°C	=	32°F

Figure 1.5. Temperature.

- The Celsius scale is the metric temperature scale that the public will learn, e.g., through weather reports. It is based on freezing and boiling points of water at atmospheric pressure.

NOTE: The Celcius scale is the selected temperature scale for use by Illinois Department of Transportation.

2. Derived Units

Derived units are formed by combining base units to express other characteristics. Velocity (m/s), slope (m/m), and density (kg/m^3) are derived measures. Many others have their own special unit name. Table 1.3 summarizes many of these units. The relationships between all derived units remain on a decimal basis.

Table 1.3. Derived units with special names.

Quantity	Name	Symbol	Expression
frequency	hertz	Hz	s^{-1} 1/s
force	newton	N	$kg \cdot m/s^2$
pressure, stress	pascal	Pa	N/m^2
energy, work, quantity of heat	joule	J	$N \cdot m$
power, radiant ~~flux~~	watt	W	J/s
electric charge, quantity	coulomb	C	$A \cdot s$
electric potential	volt	V	W/A
capacitance	farad	F	C/V
electric resistance	ohm	Ω	V/A
electric conductance	siemens	S	A/V
magnetic flux	weber	Wb	$V \cdot s$
magnetic flux density	tesla	T	Wb/m^2
inductance	henry	H	Wb/A
luminous flux	lumen	lm	$cd \cdot sr$
illuminance	lux	lx	lm/m^2

Area and volume are common derived units which have many variations. The liter is a special metric unit for volume which is slightly larger than a quart. Some of these are shown in figure 1.6.

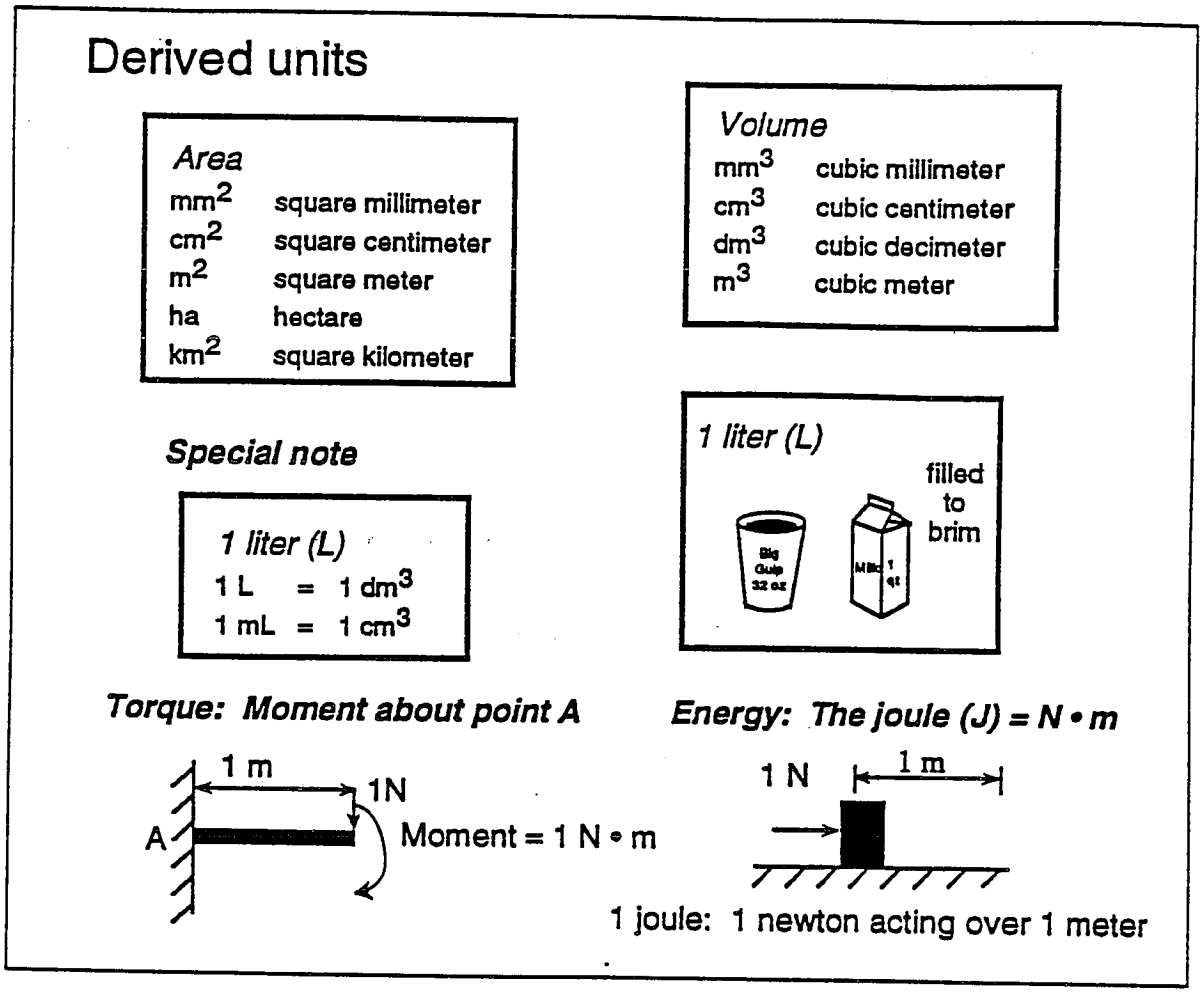


Figure 1.6. Derived units.

3. Supplementary Units

The supplementary units are the radian and steradian. The radian replaces the degree of curvature in the definition of surveying on a horizontal curve. The steradian is used in the definition of light units.

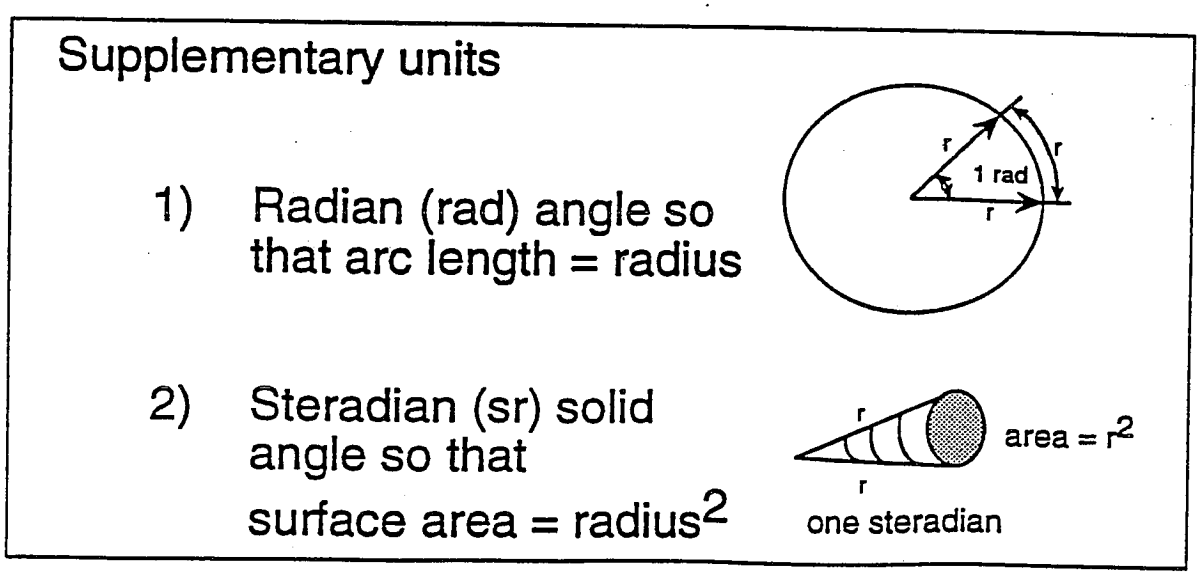


Figure 1.8. Angles.

4. Nomenclature

The metric system includes an organized nomenclature for describing various units and their multiples as well as proper ways of writing metric names and symbols. The logical and consistent method of expressing metric units of measure is part of the system's appeal.

One reason the metric system is preferred is because each unit of measure has two parts: a prefix and a base unit.

- The prefix is the part that gives the relative size. The same prefixes are applied to all unit names, and they are summarized in table 1.4. For example, a millimeter represents 1/1000th of a meter.

- The base unit gives the type of measurement.

Table 1.4. Prefixes.

Submultiples			*Multiples*		
deci	10^{-1}	d	deka	10^{1}	da
centi	10^{-2}	c	hecto	10^{2}	h
milli	10^{-3}	m	kilo	10^{3}	k
micro	10^{-6}	μ	mega	10^{6}	M
nano	10^{-9}	n	giga	10^{9}	G
pica	10^{-12}	p	tera	10^{12}	T
femto	10^{-15}	f	peta	10^{15}	P
atto	10^{-18}	a	exa	10^{18}	E
zepto	10^{-21}	z	zetta	10^{21}	Z
yocto	10^{-24}	y	yotto	10^{24}	Y

The symbols representing prefixes are shortened forms of the prefixes. The symbol for "micro" is the Greek letter μ or "mu" and is used because "m" is already used. "da" is used for "deka" and is the only symbol with two letters for abbreviation. The use of capital letters versus lower case letters does bear a significance. For example, "M" vs. "m" have different meanings; "M" means "mega" and "m" means "milli."

PARTICIPANT'S QUIZ

The following paragraph is a technical description of a proposed project. Make corrections (where necessary) to this paragraph so that the description follows proper metric writing procedure.

The eastbound approach to said project section, located within the City of Rockwood, is a 12.55 meter wide pavement, back-to-back of curb, composed of a one inch bituminous surface course on a 38 1/10 mm binder course on bituminous and concrete base courses (thicknesses unknown) on dirt. Said section is composed of one eastbound and one westbound thru lane each having a lane width of 3.6 ms, with 152 MM curbs. Separate turning lanes exist within said section at each major signalized intersection. The right-of-way thru said section is twenty m. The City of Rockwood has no plans to widen said section to four lanes and has recently resurfaced this section as a two lane roadway. The westbound approach to said project is a 15m wide pavement back-to-back of curb, composed of an eight inch reinforced concrete pavement on a 102 mm. granular subbase. Said project is composed of two eastbound and two westbound thru lanes each having a lane width of 3.3 m. Curb and gutter is Type B-15.60. The right-of-way is 66m wide.

5. Philosophies of conversion

Conversion from the English system of measurement to SI is an important topic for the transition period. It affects standards, specifications, guidelines, numerical regulatory limits, and manufacturing. There are two philosophies of conversion which may be applied in a given circumstance:

1) Soft conversion:
   - Direct mathematical conversion. The physical dimension of a standard or product is unchanged, only the numerical value changes. For products this results only in changing of the label.

   Examples: A 55 mph speed limit becomes 88.51 km/h.
   A 12-foot lane becomes a 3.658 m lane.

2) Hard conversion:
   - converting to an even whole number. Results in changing product size as well as label.

   Examples: A 55 mph speed limit becomes 90 km/h.
   A 12-foot lane becomes a 3.6 m lane.

METRIC EDITORIAL GUIDE

EDITORIAL REFERENCE

This part of the workbook covers editorial rules for using the modern form of the metric system, called "The International System of Units" (abbreviated SI). A limited number of the units outside SI that are acceptable for use with SI also are included.

The text is based on *American National Standard Metric Practice*, ANSI/IEEE Std 268-1982, *Standard for Metric Practice*, ASTM E380-86, International Organization for Standardization ISO 1000-1981, *Metric Editorial Guide*, ANMC 1992, and *Metric Training for Highway Agencies*, NHI course number 12301.

Known metric usage variations between the Illinois Department of Transportation and usage rules listed here have been noted in the text.

CAPITALIZATION

Units: Unit names, including prefixes, are not capitalized except at the beginning of a sentence and in those titles, headings and other instances in which all main words are capitalized. The word Celsius is the only exception.

Examples: Meter is the unit used for Olympic track events.
Force is measured in newtons.

In "degree Celsius," note that "degree" is lowercase and "Celsius" is capitalized. (The "degree centigrade" is now obsolete.)

Symbols: The short forms for metric units are called symbols. The first letter of a symbol is capitalized when the name of the unit is derived from the name of a person. The larger prefix symbols (mega and up) are also capitalized. Other symbols are generally lower case regardless of the surrounding text.

Examples:	**Unit Name**	**Unit Symbol**
	meter	m
	gram	g
	newton	N
	pascal	Pa

"L" and "l" are alternative symbols for liter. Since the symbol "l" can be easily confused with the numeral "1", the symbol "L" is recommended for U.S. use.

SYMBOL TYPE STYLE

Unit symbols are printed in upright letters. Italic letters are reserved for quantity symbols, such as *A* for area, *m* for mass, and *tt* for time. In typewriting or longhand, underlining may be used as a substitute for italics.

Use the correct symbols, never abbreviations.

Example: s (second), not sec ; mm^2, not sq. millimeter

PUNCTUATION AND SPELLING

A period is not used after a symbol, except when the symbol is at the end of the sentence.

Examples: When you add 15 g of salt ...
The length of the field is 350 m.

The spelling and usage of metric symbols are the same in all languages and alphabets. The U.S. government has adopted the Germanic spelling of liter and meter, however.

There are three cases where the final vowel of a prefix is omitted when spelling vowed pairs: megohm, kilohm, and hectare. In all other cases, both vowels are retained and both are pronounced. A space or hyphen should not be used.

Example: milliampere, gigaohm

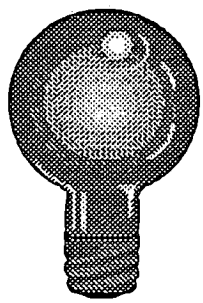
PLURAL USAGE

Names of units follow normal English usage when spelling out plurals. Plurals of unit names are formed by adding an "s," except for hertz, lux, and siemens, which remain unchanged.

Examples: twenty meters, one kilogram, two lux

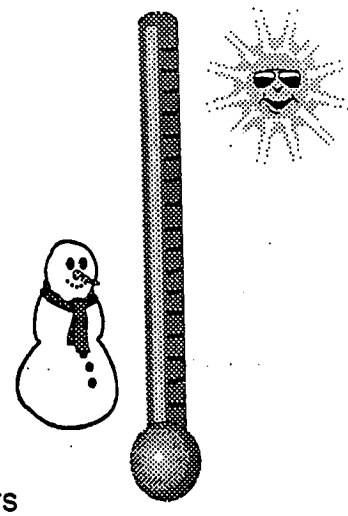
Symbols for units are the same in singular and plural.

Examples: 1 m, 100 m, 1 g, 20 g



sixty watts

SPACING



Use a space between a digit and a symbol.

Examples: 5 mm, 3 L, 70 Pa

For angle measure, do not leave a space between the numeral and the degree symbol.

Example: 30°

The symbol for degree Celsius is °C, an inseparable symbol, with no space between the two parts. Whether or not a space is left between the numeral and the symbol is a matter of editorial preference.

Examples: Either 20°C or 20 °C is correct. (FHWA prefers the former and IDOT prefers the later.)

20° C is not correct.

MIXING SYMBOL, NAMES AND NUMERALS

Use a symbol only with a number for technical writing (the area is 10 m).

Example:
Correct: 5 g, five grams; Incorrect: 5 grams, five g

Numerals may be combined with written unit names in non-technical writing (10 meters).

Do not mix symbols with spelled out names in the same expression.; write out unit names if numerals are not used (carpet is measured in square meters). Do not use symbols alone in text (without a number).

Examples:	Correct	Incorrect
	60 kg/L	60 kilograms/L
	10 m/s²	10 m/second squared
	about a gram	about a g
	about 1 g	

The mixing of prefixes should be avoided unless the difference in size is extreme.

Examples: 40 mm wide and 1500 mm long, not 40 mm wide and 1.5 m long.
1500 meters of 2 mm diameter wire.

Nonmetric units should not be used with metric units, except units for time, plane angle, or rotation.

Examples: Use kg/m², not kg/ft²; g/L, not g/gal.

NUMERAL USAGE

Decimal notation is preferred. Do not use fractions.

Examples: 2.5 g, not 2½ g

The decimal marker will continue to be a dot on the line and the comma will still be used to separate long numbers.
(Many countries use a comma as a decimal marker and a space to separate long numbers.)

Examples: 10.51 m and 2,500 kg

Put a leading zero in front of a decimal point so the point will not be overlooked.

Example: 0.7 mm, not .7 mm

To multiply symbols, use a raised dot (·) but do not pronounce it or spell it out. Do not use a space before or after the product dot. Do not use a product dot between words.

Examples: 15 N·m, not 15 N x m
10 newton meters, not 10 Nm

When writing a *name* of a compound unit that is a product, use a space or a hyphen between the words.

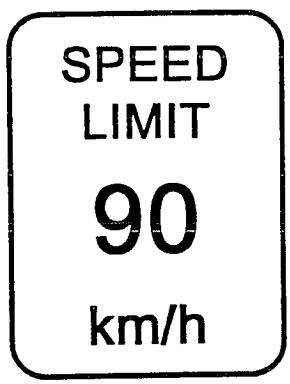
Example: newton meter, newton-meter

To divide symbols, use a horizontal bar, slash, or negative exponent. Use the word *per* when pronouncing or spelling out divided units.

Examples: m/s^2, not $meters/s^2$
$\frac{J}{kg}$, not J-kg
kilometers per hour, not kilometers over hour

Complex division requires that commas or parentheses be inserted to eliminate ambiguity.

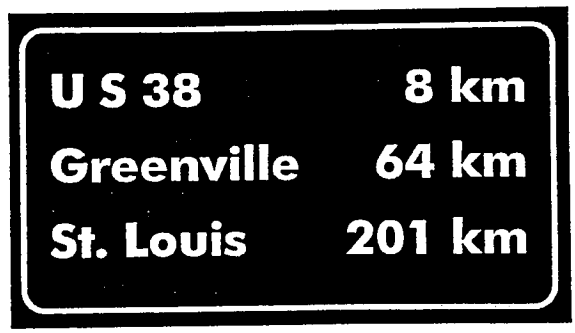
Examples: J/(kg·K), not J/kg/K
meters per second, per second,
not meters per second per second



APPENDIX

PREFIXES AND POWERS OF TEN

Prefixes are used with base units to show the relative size of a type of measurement.



Examples:
One millimeter represents 1/1000th of a meter.
One kilometer represents 1000 meters.

The metric prefix is a power of ten. Care should be taken to avoid mixing prefixes and powers. The expression of powers with base units is preferred. Prefix choices should also be made that are consistent (in charts) or that are easy to read and indicate the appropriate precision.

Examples: 10^2 m, not 10^4 cm; 10^3 kg, not 10^6 g
20 mL, not 0.02 L, 60 kg, not 60,000 g

When raising units to a power, the word squared or cubed follows the unit name. When writing the powers of units for areas or volumes the word square or cubic precedes the unit name.

Example: 2 m/s^2 = two meters per second squared
3 mm^2 = three square millimeters

COMPOUND UNITS

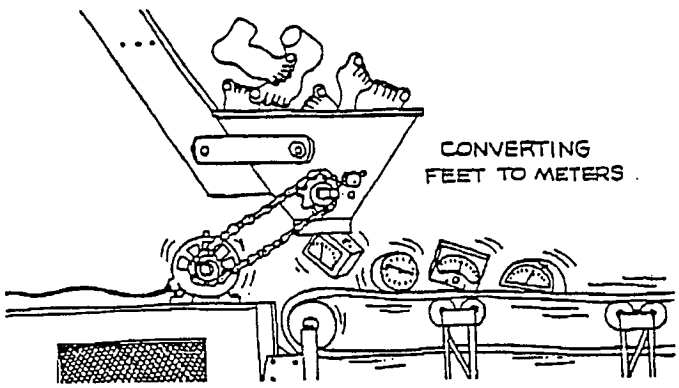
When forming the multiple of a compound unit, it is recommended that, in general, only one prefix be used, usually in the numerator.

Examples: kg/m, not g/mm
km/s, not m/ms

However, since the kilogram is an SI base unit, it is proper to write J/kg, kJ/kg, etc.

It is preferred that a ratio of two values of the same quantity be written as a decimal or as a percentage and not as a fraction.

Example: A slope of 40 mm/m or 40 m/km should be written as a 0.04 m/m slope or could also be expressed as a 4% slope.



Quantity	From English Units	To Metric Units	Multiply by*
Length	mile	km	1.609
	yard	m	0.9144
	foot	m	0.3048
	inch	mm	25.40
Area	square mile	km^2	2.590
	acre	m^2	4047
	acre	hectare (ha)	0.4047
	square yard	m^2	0.8361
	square foot	m^2	0.092 90
	square inch	mm^2	645.2
Volume	acre foot	m^3	1 233
	cubic yard	m^3	0.7646
	cubic foot	m^3	0.028 32
	cubic foot	L (1000 cm^3)	28.32
	100 board feet	m^3	0.2360
	gallon	L (1000 cm^3)	3.785
	cubic inch	cm^3	16.39
Mass	lb	kg	0.4536
	kip (1000 lb)	metric ton (1000 kg)	0.4536
Mass/unit length	plf	kg/m	1.488
Mass/unit area	psf	kg/m^2	4.882
Mass density	pcf	kg/m^3	16.02
Force	lb	N	4.448
	kip	kN	4.448
Force/unit length	plf	N/m	14.59
	klf	kN/m	14.59
Pressure, stress, modulus of elasticity	psf	Pa	47.88
	ksf	kPa	47.88
	psi	kPa	6.895
	ksi	MPa	6.895
Bending moment, torque, moment of force	ft-lb	N • m	1.356
	ft-kip	kN • m	1.356

* 4 significant figures; underline denotes exact conversion.

GLOSSARY

AASHTO	-	American Association of State Highway Transportation Officials.
acceleration	-	The rate of change of velocity with respect to time.
ampere	-	The unit of current in two straight parallel wires of a long length separated by one meter in free space, which produces a magnetic force between the two wires of 2×10^{-7} newtons per meter length.
ANMC	-	American National Metric Council.
ASTM	-	American Society of Testing Materials.
base units	-	Seven SI units which by choice are regarded as dimensionally independent: **meter, kilogram, second, ampere, kelvin, mole,** and **candela.**
candela	-	Unit of luminous intensity in a given direction of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and has a radiant intensity in that direction of 1/683 watt per steradian.
Celsius	-	A temperature scale that registers the freezing point and boiling point of water at atmospheric pressure as 0 and 100 degrees, respectively.
coherent system	-	A system of measurement units mutually related by rules of multiplication and division without any conversion factor, except for unity.
conversion, hard	-	Conversion from one measurement system to another using the numerical conversion factor to calculate quantities in a new system and then rounding to a convenient dimension.
conversion, soft	-	Conversion from one measurement system to another using the numerical conversion factor to calculate quantities in a new system.
derived units	-	Units that can be formed by combining base units according to the algebraic relations linking the corresponding quantities.

DOC	-	Department of Commerce.
FHWA	-	Federal Highway Administration.
force	-	A vector quantity that tends to produce an acceleration of a body in the direction of application.
gram	-	1/1000 of a kilogram.
GSA	-	General Services Administration.
hectare	-	The derived unit of area equal to 10 000 m^2.
ISO	-	International Organization for Standardization.
joule	-	The derived unit of energy equal to one newton meter.
kelvin	-	Unit of temperature that is the fraction 1/273.16 of the thermodynamic triple point of water.
kilogram	-	The mass of a cylinder of platinum-iridium alloy kept by the International Bureau of Weights and Measures near Paris.
liter	-	The unit of volume occupied by a mass of 1 kilogram of pure water at its maximum density and at standard atmospheric pressure. Also 1 dm^3.
mass	-	The measure of inertia that an object has, or the measure of the ability of an object to resist acceleration.
meter	-	The length of path traveled by light in a vacuum during a time interval of 1/299 792 458 of a second.
Metric Conversion Act of 1975	-	Established for voluntary conversion to metric by United States' industries.

mole	-	The unit of the amount of substance of a system that contains as many elementary entities as there are atoms in 0.012 kilograms of carbon-12.
newton	-	The derived unit of force that is equal to one kilogram meter per squared second.
NIST	-	National Institute of Standards and Technology.
Omnibus Trade and Competitiveness Act of 1988	-	Establishes the policy of the United States that metric is preferred system of measurement and each Federal agency use the metric system by a date economically feasible.
pascal	-	The derived unit of pressure equal to one newton per square meter.
plane angle	-	An angle formed by two straight lines.
radian	-	The supplementary unit of plane angle with its vertex at the center of a circle that is subtended by arc equal in length to the radius.
second	-	Duration of 9 192 631 770 periods of the radiation corresponding to the transition between two hyperfine levels of the ground state of the cesium-133 atom.
SI	-	International System of Units.
solid angle	-	An angle subtended at a point by a surface measured in steradians.
standard	-	A criterion or level of performance required to be met.
specification	-	A criterion or measurement found on a design drawing.
steradian	-	The solid angle with its vertex at the center of a sphere such that the surface area is equal to radius of the sphere squared.
supplementary-units		2 SI units that are dimensionless. They are the radian and steradian.

USMA	-	United States Metric Association.
watt	-	The derived SI unit of power equal to one newton · meter per second, or one joule per second.
weight	-	The force of an object due to gravity derived as mass multiplied by gravitational acceleration.

PARTICIPANT'S QUIZ

METRIC USAGE PROBLEMS

Fill in the following blanks by correcting the errors, if present.
Answers from information in the Metric Editorial Guide section.

15) 15 1/2 g _____

16) 23.5 kNs _____

17) 83.4 newton/meter _____

18) 287.8°K _____

19) 38.1° C _____

20) Two degrees celsius _____

21) 23.5 N x m _____

22) 23,354 km _____

23) 57.6mJ _____

24) Four Newtons _____

25) 45 sec _____

26) 30 g. _____

27) 100 ms _____

28) 5mm _____

29) about a m _____

30) 50 mm wide and 1.4 m long _____

31) kilometers/h _____

32) 10^2 cm _____

33) g/mm _____

34) 4/100 slope _____

ANSWERS TO THE PARTICIPANT'S QUIZ

1) T

2) T

3) F

4) T

5) F

6) T

7) T

8) T

9) T

10) F (conversion will result in slight changes)

11) F (unless oil companies try to sneak one in)

12) T

13) T

14) F (the kilogram is the base unit for mass)

Fill in the following blanks by correcting the errors, if present.

15)	15 1/2 g	15.5 g (no fractions)
16)	23.5 kNs	23.5 kN (symbols remain singular)
17)	83.4 newton/meter	83.4 N/m
18)	287.8°K	287.8 K
19)	38.1° C	38.1 °C or 38.1°C
20)	Two degrees celsius	Two degrees Celsius
21)	23.5 N x m	23.5 N·m
22)	23,354 km	OK as shown
23)	57.6mJ	57.6 mJ
24)	Four Newtons	Four newtons

25) 45 sec	45 s
26) 30 g.	30 g
27) 100 ms	100 m
28) 5mm	5 mm
29) about a m	about a meter or about 1 m
30) 50 mm wide and 1.4 m long	50 mm wide and 1400 mm long
31) kilometers/h	kilometers/hour
32) 10^2 cm	1 m
33) g/mm	kg/m
34) 4/100 slope	4% slope or 0.04 slope

ANSWERS TO THE PARTICIPANT'S QUIZ

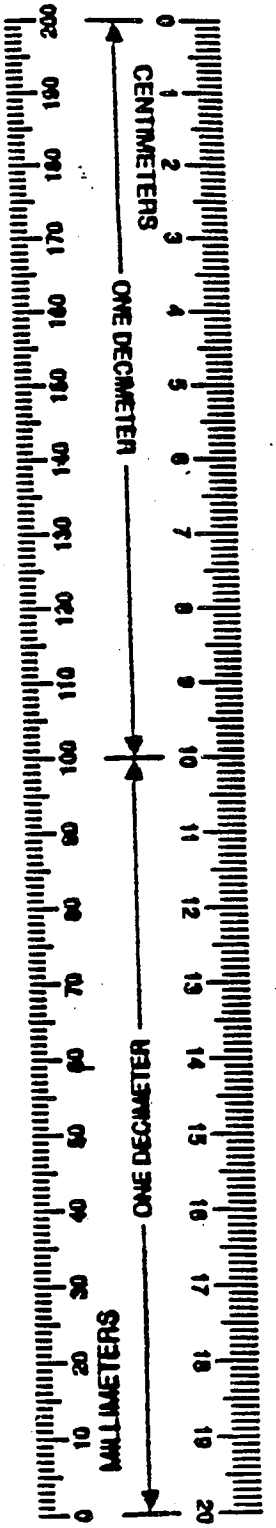
The following paragraph is a technical description of a proposed project. Make corrections (where necessary) to this paragraph so that the description follows proper metric writing procedure.

The eastbound approach to said project section, located within the City of Rockwood, is a 12.55 meter **(12.55 m)** wide pavement, back-to-back of curb, composed of a one inch **(25.4 mm)** bituminous surface course on a 38 1/10 mm **(38.1 mm)** binder course on bituminous and concrete base courses (thicknesses unknown) on dirt. Said section is composed of one eastbound and one westbound thru lane each having a lane width of 3.6 ms **(3.6 m)**, with 152 MM **(152 mm)** curbs. Separate turning lanes exist within said section at each major signalized intersection. The right-of-way thru said section is twenty m **(20 m or twenty meters)**. The City of Rockwood has no plans to widen said section to four lanes and has recently resurfaced this section as a two lane roadway. The westbound approach to said project is a 15m **(15 m)** wide pavement back-to-back of curb, composed of an eight inch **(203 mm)** reinforced concrete pavement on a 102 mm. **(102 mm)** granular subbase. Said project is composed of two eastbound and two westbound thru lanes each having a lane width of 3.3 m. Curb and gutter is Type B-15.60. The right-of-way is 66m **(66 m)** wide.

TECHNOLOGY TRANSFER TRAINING PROGRAM

METRIC (SI) TRAINING FOR LOCAL HIGHWAY AGENCIES

PARTICIPANT'S WORKBOOK



Illinois Department of Transportation
Bureau of Local Roads and Streets

SI "METRIC" TRAINING FOR HIGHWAY AGENCIES

CONTENTS

Page

INTRODUCTION 1

OBJECTIVES 1
SCHEDULE 1

GLOSSARY 2

USEFUL CONVERSION FACTORS 6

SESSION 1. BUILDING BLOCKS FOR CONVERSION TO SI 11

SESSION 2. AN OVERVIEW OF SI IN THE HIGHWAY CONTEXT 43

SESSION 3. PARTICIPANT'S QUIZ 65

ANSWERS TO PARTICIPANT'S QUIZ
AND DESIGN INFORMATION 73

INTRODUCTION

This material and course has been adapted from the NHI training course "SI Training for Highway Agencies" No. 12301. (FHWA-HI-93-066 October 1993). This course has been designed to target local agency engineers, technicians and others with a technical background. The United States is the only remaining industrial nation to convert to the metric system. The Department is now required by Federal Executive Order 12770, July 25, 1991, to convert its operations to the metric system of measurements by September 1996. These seminars and materials are provided by the Bureau of Local Roads and Streets to assist local agencies in the conversion to the metric system to meet this deadline.

OBJECTIVES

Objectives for this course are that upon completion of the course each participant should:

1. Have a working knowledge of the metric units and their proper usage;

2. Be knowledgeable in applying the English/metric conversion factors necessary for highway program development, design, and construction work; and

3. Be able to perform their job with the same or greater degree of efficiency using metric.

The third objective is the primary objective of the course and subsumes the other two objectives listed. In fact, experience has shown that working in dual units and emphasizing conversion between English and SI units diminishes the effectiveness of the conversion and training processes. Hence, conversion (objective 2) will be minimized except where absolutely essential.

GLOSSARY

AASHTO	-	American Association of State Highway Transportation Officials.
acceleration	-	The rate of change of velocity with respect to time.
ampere	-	The unit of current in two straight parallel wires of a long length separated by one meter in free space, which produces a magnetic force between the two wires of 2×10^{-7} newtons per meter length.
ANMC	-	American National Metric Council.
ASTM	-	American Society of Testing Materials.
base units	-	Seven SI units which by choice are regarded as dimensionally independent: **meter, kilogram, second, ampere, kelvin, mole, and candela.**
candela	-	Unit of luminous intensity in a given direction of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and has a radiant intensity in that direction of 1/683 watt per steradian.
Celsius	-	A temperature scale that registers the freezing point and boiling point of water at atmospheric pressure as 0 and 100 degrees, respectively.
coherent system	-	A system of measurement units mutually related by rules of multiplication and division without any conversion factor, except for unity.
conversion, hard	-	Conversion from one measurement system to another using the numerical conversion factor to calculate quantities in a new system and then rounding to a convenient dimension.
conversion, soft	-	Conversion from one measurement system to another using the numerical conversion factor to calculate quantities in a new system.
derived units	-	Units that can be formed by combining base units according to the algebraic relations linking the corresponding quantities.

DOC - Department of Commerce.

FHWA - Federal Highway Administration.

force - A vector quantity that tends to produce an acceleration of a body in the direction of application.

gram - 1/1000 of a kilogram.

GSA - General Services Administration

hectare - The derived unit of area equal to 10 000 m^2. Commonly used when referring to a measurement of land.

ISO - International Organization for Standardization.

joule - The derived unit of energy equal to one newton meter.

kelvin - Unit of temperature that is the fraction 1/273.16 of the thermodynamic triple point of water. The base SI temperature scale. There are no negative values. Celsius temperature plus 273.

kilogram - The mass of a cylinder of platinum-iridium alloy kept by the International Bureau of Weights and Measures near Paris

liter - The unit of volume occupied by a mass of 1 kilogram of pure water at its maximum density and at standard atmospheric pressure. Also 1 dm cubed.

mass - The measure of inertia that an object has, or the measure of the ability of an object to resist acceleration. Not affected by gravitational forces.

meter - The length of path traveled by light in a vacuum during a time interval of 1/299 792 458 of a second. Equivalent to 3.28 feet.

Metric Conversion Act of 1975 - Established for voluntary conversion to metric by United States' industries.

mole	-	The unit of the amount of substance of a system that contains as many elementary entities as there are atoms in 0.012 kilograms of carbon-12.
newton	-	The derived unit of force that is equal to one kilogram meter per squared second.
NIST	-	National Institute of Standards and Technology.
Omnibus Trade and Competitiveness Act of 1988	-	Establishes the policy of the United States that metric is preferred system of measurement and each Federal agency use the metric system by a date economically feasible.
pascal	-	The derived unit of pressure equal to one newton per square meter.
plane angle	-	An angle formed by two straight lines.
radian	-	The supplementary unit of plane angle with its vertex at the center of a circle that is subtended by arc equal in length to the radius.
second	-	Duration of 9 192 631 770 periods of the radiation corresponding to the transition between two hyperfine levels of the ground state of the cesium-133 atom.
SI	-	International System of Units.
solid angle	-	An angle subtended at a point by a surface measured in steradians.
standard	-	Short for "Highway Standard" which is a standardized, detailed, design drawing issued by IDOT and commonly attached to design plans
specification	-	Directions, provisions or requirements which are contained in or supplement contracts. Describes the method or manner of performing and paying for work, the quantities, and the quality of materials to be furnished under the contract.

steradian	-	The solid angle with its vertex at the center of a sphere such that the surface area is equal to radius of the sphere squared.
supplementary-units		2 SI units that are dimensionless. They are the radian and steradian.
USMA	-	United States Metric Association.
watt	-	The derived SI unit of power equal to one newton · meter per second, or one joule per second.
weight	-	The force of an object due to gravity derived as mass multiplied by gravitational acceleration.

Quantity	From English Units	To Metric Units	Multiply by*
Length	mile	km	1.609
	yard	m	0.9144
	foot	m	0.3048
	inch	mm	25.40
Area	square mile	km^2	2.590
	acre	m^2	4047
	acre	hectare	0.4047
	square yard	m^2	0.8361
	square foot	m^2	0.092 90
	square inch	mm^2	645.2
Volume	acre foot	m^3	1 233
	cubic yard	m^3	0.7646
	cubic foot	m^3	0.028 32
	cubic foot	L (1000 cm^3)	28.32
	100 board feet	m^3	0.2360
	gallon	L (1000 cm^3)	3.785
	cubic inch	cm^3	16.39
Mass	lb	kg	0.4536
	kip (1000 lb)	metric ton (1000 kg)	0.4536
Mass/unit length	plf	kg/m	1.488
Mass/unit area	psf	kg/m^2	4.882
Mass density	pcf	kg/m^3	16.02
Force	lb	N	4.448
	kip	kN	4.448
Force/unit length	plf	N/m	14.59
	klf	kN/m	14.59
Pressure, stress, modulus of elasticity	psf	Pa	47.88
	ksf	kPa	47.88
	psi	kPa	6.895
	ksi	MPa	6.895
Bending moment, torque, moment of force	ft-lb	N • m	1.356
	ft-kip	kN • m	1.356

* 4 significant figures; underline denotes exact conversion.

Quantity	From English Units	To Metric Units	Multiply by*
Moment of mass	lb • ft	kg • m	0.1383
Moment of inertia	lb • ft^2	kg • m^2	0.042 14
Second moment of area	in^4	mm^4	416 200
Section modulus	in^3	mm^3	16 390
Power	ton (refrig) Btu/s hp (electric) Btu/h	kW kW W W	3.517 1.054 745.7 0.2931
Volume rate of flow	ft^3/s cfm cfm mgd	m^3/s m^3/s L/s m^3/s	0.028 32 0.000 471 9 0.4719 0.0438
Velocity, speed	ft/s	m/s	<u>0.3048</u>
Acceleration	f/s^2	m/s^2	<u>0.3048</u>
Momentum	lb • ft/sec	kg • m/s	0.1383
Angular momentum	lb • ft^2/s	kg • m^2/s	0.042 14
Plane angle	degree	rad mrad	0.017 45 17.45

* 4 significant figures; underline denotes exact conversion.

Important quantities

	English unit	SI unit
Acceleration of gravity	32.2 ft/s^2	9.81 m/s^2
Density of water (4°C, 39.4°F)	1.94 $slug/ft^3$ = 1.94 $lb \cdot ft^2 s^{-4}$	1,000 kg/m^3 = 1.0 g/cm^3 or 1.0 Mg/m^3
Specific weight of water (15°C, 50°F)	62.4 lb/ft^3	~9810 N/m^3 or 9.81 kN/m^3
Standard sea-level atmosphere	14.7 psia 29.92 in Hg 33.9 ft H_2O	101.32 kN/m^2, abs 760 mm Hg 10.33 m H_2O 1013.2 millibars

THE METRIC SYSTEM

Linear Measure

		1 millimeter	=	0.03937	inch
10 millimeters	=	1 centimeter	=	0.3937	inch
10 centimeters	=	1 decimeter	=	3.937	inches
10 decimeters	=	1 meter	=	39.37	inches or 3.2808 feet
10 meters	=	1 decameter	=	393.7	inches
10 decameters	=	1 hectometer	=	328.08	feet
10 hectometers	=	1 kilometer	=	0.621	mile or 3,280.8 feet
10 kilometers	=	1 myriameter	=	6.21	miles

Square Measure

		1 square millimeter	=	0.00155	square inch
100 square millimeters	=	1 square centimeter	=	0.15499	square inch
100 square centimeters	=	1 square decimeter	=	15.499	square inches
100 square decimeters	=	1 square meter	=	1,549.9	square inches or 1.196 square yards
100 square meters	=	1 square decameter	=	119.6	square yards
100 square decameters	=	1 square hectometer	=	2.471	acres
100 square hectometers	=	1 square kilometer	=	0.386	square mile or 247.1 acres

Land Measure

1 square meter	=	1 centiare	=	1,549.9	square inches
100 centiares	=	1 are	=	119.6	square yards
100 ares	=	1 hectare	=	2.471	acres
100 hectares	=	1 square kilometer	=	0.386	square mile or 247.1 acres

Volume Measure

1,000 cubic millimeters	=	1 cubic centimeter	=	0.06102	cubic inch
1,000 cubic centimeters	=	1 cubic decimeter	=	61.023	cubic inches or 0.0353 cubic foot
1,000 cubic decimeters	=	1 cubic meter	=	35.314	cubic feet or 1.308 cubic yards
1,000 liters	=	1 cubic meter			

Capacity Measure

10 milliliters	=	1 centiliter	=	0.338 fluid ounce
10 centiliters	=	1 deciliter	=	3.38 fluid ounces or 0.1057 liquid quart
10 deciliters	=	1 liter	=	1.0567 liquid quarts or 0.9081 dry quart
10 liters	=	1 decaliter	=	2.64 gallons or 0.284 bushel
10 decaliters	=	1 hectoliter	=	26.418 gallons or 2.838 bushels
10 hectoliters	=	1 kiloliter	=	264.18 gallons or 35.315 cubic feet

Weights

10 milligrams	=	1 centigram	=	0.1543	grain or 0.000353 ounce (avdp.)
10 centigrams	=	1 decigram	=	1.5432	grains
10 decigrams	=	1 gram	=	15.432	grains or 0.035274 ounce (avdp.)
10 grams	=	1 decagram	=	0.3527	ounce
10 decagrams	=	1 hectogram	=	3.5274	ounces
10 hectograms	=	1 kilogram	=	2.2046	pounds
10 kilograms	=	1 myriagram	=	22.046	pounds
10 myriagrams	=	1 quintal	=	220.46	pounds
10 quintals	=	1 metric ton	=	2,204.6	pounds

Area Length, and Volume Conversion Factors

Quanity	From Inch– Pound Units	To Metric Units	Multiply by
Length	mile	km	1.609 344
	yard	m	0.914 4
	foot	m	0.304 8
		mm	304.8
	inch	mm	25.4
Area	square mile	km^2	2.590 00
	acre	m^2	4 046.856
		ha (10 000 m^2)	0.404 685 6
	square yard	m^2	0.836 127 36
	square foot	m^2	0. 092 903 04
	square inch	mm^2	645.16
Volume	acre foot	m^3	1.233.49
	cubic yard	m^3	0.764 555
	cubic foot	m^3	0.028 316.85
	cubic foot	cm^3	28 316. 85
	cubic foot	L (1000cm^3)	28.316 85
	100 board feet	m^3	0.235 974
	gallon	L (1000 cm^3)	3.785 41
	cubic inch	cm^3	16.387 064
	cubic inch	mm^3	16387.064

NOTE: Underline denotes exact number

These conversion factors are carried to a decimal place that would not be required in most situations. Values may be rounded to the desired accuracy. The following conversion factors were used for most of the calculations in this manual.

1 mile = 1.6 Kilometers (km)

1 foot = 0.3 meters

1 inch = 25 mm

SESSION 1: BUILDING BLOCKS FOR CONVERSION TO SI

Learning Objectives:

- Understand the motivation for conversion to SI, the role of the Federal government and FHWA, and the role of State highway agencies;
- Demonstrate how SI measurements are already a part of daily life;
- Learn the organization and usage of the metric system.

Content: This session will open with a slide presentation demonstrating the already painless introduction of SI units into our lives. For example, are we confused when we buy a two-liter bottle of a soft drink or watch a one hundred-meter dash at a high school track meet or participate in a ten kilometer run? After this introduction, a presentation of the motivation for converting to metric is made including the Federal, FHWA, and State roles. Finally, the organization and structure of the metric system, the distinction between hard and soft conversion, and the visualization of SI units is presented. General observations about the importance of public awareness are shared.

SESSION 1
BUILDING BLOCKS FOR CONVERSION TO SI

Page

A. INTRODUCTION TO SESSION 1 15

B. MOTIVATION FOR SI 17

C. GOVERNMENT AND PUBLIC ROLES 19

1. Congress and the President 19
2. Department of Commerce 20
3. Department of Transportation and Federal Highway Administration ... 21
4. State Highway Agencies 22
5. AASHTO 22
6. Public Awareness 23

D. OVERVIEW OF SI 25

1. Base units 26
2. Derived units 31
3. Supplementary units 34
4. Nomenclature 35
5. Coherency 37
6. Philosophies of conversion 38
7. Precision and rounding 39

E. SUPPLEMENTARY SOURCES OF INFORMATION 41

1. General exposition on SI and its use 41
2. SI and construction 41

SESSION 1
BUILDING BLOCKS FOR CONVERSION TO SI

List of Figures

Page

1.1 Unit of length 26
1.2 The kilometer 27
1.3 Mass 28
1.4 Time 29
1.5 Temperature 30
1.6 Derived units 32
1.7 Mass and weight 33
1.8 Angles 34

SESSION 1
BUILDING BLOCKS FOR CONVERSION TO SI

List of Tables

Page

1.1 FHWA conversion plans 21
1.2 Overview of SI 25
1.3 Derived units with special names 31
1.4 Prefixes 36

A. INTRODUCTION TO SESSION 1

Developed at the time of the French Revolution, the metric system rapidly spread throughout Europe during the Napoleonic wars. It was promoted in the United States first by Thomas Jefferson and later by John Quincy Adams, but the Federal Government took no formal action on metric measurement until 1866 when its use as a measurement system was legalized. In 1893, all standard U.S. measures were defined in terms of metric units. In 1902, Congressional legislation requiring the Federal Government to use metric exclusively was defeated by a single vote. Today, the United States is the last industrialized country to convert to the metric system. The term "SI" is an abbreviation for International System of Units. It is a modern-day metric system and was established by international agreement in 1960. It now provides a standard international language to describe measurement.

This session will:

- describe the organization and usage of the metric system (SI).
- explain why the Federal Government is converting to SI and discuss the roles of other levels of government and the public.
- outline productive approaches for learning the metric system (for example, we all have "a feel" for certain units in the English system such as a pound or a mile. We need to visualize the metric units and typical dimensions and avoid the mental conversion process).
- demonstrate the motivations for conversion to SI.
- illustrate the broad familiarity with the metric system we have already acquired through the existence of metric-dimensioned products in our daily lives such as:

  - light bulb (75 watts).
  - cigarettes (100 millimeters).
  - sugar packets (1 gram).
  - nutritional label (5 grams fat).
  - 2-liter bottle.
  - track and field (400 meter dash).
  - engine size (3.2 liters).
  - radio (97.1 megahertz).

- camera lens/film (35 millimeters).
- mechanical pencil (0.7 millimeters).
- skis (215 centimeters).
- clock (45 seconds).
- pills (500 milligrams).
- chemistry flask (500 milliliter).

Notes:

B. MOTIVATION FOR SI

There are several reasons for the United States, in general, and the highway community, specifically, to adopt the metric system:

- International communication

  Fewer and fewer nations are familiar with the current U.S. measurement units and many are unwilling to overcome this hurdle to purchase and use American goods. This puts the United States at an international disadvantage.

- International competitiveness

  Many American firms that have already begun to use metric have experienced an increase in their foreign billings after they converted to metric. However, to satisfy the American market, some have to produce in both units, unnecessarily increasing production costs. The U.S. does export engineering services and road building equipment.

- Increased efficiency

  The fact that Canada has had success in their conversion process to metric is encouraging. Many firms were stubborn to finally convert, but they report an increased overall efficiency mainly because of a decrease in design costs, an increase in construction efficiencies, and improved dimensioning techniques. Examples of a few U.S. firms that report this benefit are IBM, the liquor industry, and Otis Elevator.

- Consolidation and redesign

  In the process of converting to a new unit system, a rethinking of sizes and standards can occur. The metric system uses fewer measurements within a category.

  For example:

Category	English	Metric
length	inches, feet, miles	meters
volume	gallons, cubic feet	liters, cubic meters
weight	pounds, ounces	newtons

- Simplicity

  Metric is base 10 and has fewer units than the English system. This reduces the possibility for errors.

Notes:

Metric Product Changes

- 5 % remanufactured
- 95 % relabeled

C. GOVERNMENT AND PUBLIC ROLES

The process of conversion involves a variety of actions involving all levels of Government, private industry, and the public. The Federal Government is mandated to convert, and this, combined with the growing need of business to work with the Government and to compete in the international market, will result in the conversion of other sectors of the economy.

1. Congress and the President

Congress and the Executive office have been responsible for enactment of statutes and the initiation of executive orders regarding metric conversion.

- 1975 - Metric Conversion Act.
  - Congress established a national policy of coordinating and encouraging the increased use of the metric system.
  - U.S. metric board was established to coordinate *voluntary* conversion to metric. It is an independent board still in existence today. The Board has 17 members, with varying backgrounds, appointed by the President. The members are approved by the Senate.
  - Public reaction was negative after several states posted metric signs along highways.
- 1988 - Congress amends the act as part of the Omnibus Trade and Competitiveness Act (PL100-418) Section 5164 of the 1988 Act.
  - U.S. policy to designate the metric system as preferred for trade and commerce.
  - Federal Government is required to convert operations to the metric system to the extent "economically feasible" by 9/30/92.

- 1991 - President George Bush signs Executive Order 12770 (July 25).
  - Provides guidelines for departments and agencies of the Federal Government to use metric measures to the extent economically feasible by end of FY 1992 or by such other date established in consultation with the Secretary of Commerce.
  - To increase understanding of SI through educational information.
  - In response to the Act and Order, plans vary from agency to agency, but most agencies are planning to complete conversion between 1994 and 1996.

2. Department of Commerce

Implementation of metric conversion is the responsibility of each Federal agency. Coordination of the Federal effort has been delegated to the Department of Commerce (DOC).

- The DOC has the lead to coordinate efforts of the Federal agencies. They provide guidance, definition, and a general policy for conversion to metric.
- The DOC is chair of the Interagency Council on Metric Policy of which Federal Highway Administration (FHWA) is a member. In fact, there is a transportation subcommittee of which the Department of Transportation (DOT) is chair.
- In the "Federal Register," the DOC removed the voluntary aspect of metric conversion on January 2, 1991, for the Federal Government. Federal agencies are required to use metric measures and set up target dates for full implementation.

3. Department of Transportation and Federal Highway Administration

The DOT is responsible for implementation within its structure including the FHWA. The primary roles of the FHWA in metric conversion are listed below:

- Within the FHWA, there is the Metric Work Group, which was formed in December of 1990. This group is responsible for developing agency policy and a conversion plan as shown in table 1.1.

Table 1.1. FHWA conversion plans.

Program Elements/Activities	*Target Date*
Develop FHWA metric conversion plan.	Approved 10-31-91
Initiate revision of pertinent laws and regulations that serve as barriers to metric conversion.	1991
Conversion of FHWA manuals, documents, and publications.	1994
Data collection and reporting.	1995
Federal lands highway and Federal-aid construction contracts.	9-30-96

- The ultimate target date for FHWA is September 1996. After that date, anyone receiving construction authorization from FHWA will be required to perform the work using SI units. This is the key for state highways to convert to SI by the end of September 1996. This conversion will require planning and consistent work at the Federal and state level.
- Each region/division of FHWA has designated metric specialists to cooperate with state and local government and provide support.
- Historical records are converted only when necessary for ongoing operations and future projections. Data collection and reporting is scheduled to be fully SI by 1995.

4. State Highway Agencies

Involvement of State Highway Agencies for non-Federal aid activities is completely voluntary. However, there are incentives for conversion and significant activity is underway.

- Incentives for conversion are provided in the relationship with the Federal Government. FHWA Federal Lands Highway offices will use SI along with the rest of FHWA.
- A metric conversion is a good idea and may include a number of the following activities (not necessarily in this order):

  - demonstration of support for metric by agency leadership.
  - naming a metric coordinator.
  - forming a metric committee or work group.
  - developing a conversion plan and timetable.
  - assigning responsibilities for plan implementation.
  - planning and conducting a public awareness program.
  - revising necessary laws, statutes, and codes.
  - coordinating with other agencies and the private sector.
  - conducting training activities.
  - monitoring and modifying plan implementation.

5. AASHTO

The American Association of State Highway and Transportation Officials (AASHTO) is also playing a leadership role in the transition to SI. These roles are summarized as follows:

- The "Green Book" *A Policy on Geometric Design of Highways and Streets* currently has temporary standards that are in the metric system. They may be used until the complete version is published in 1995.

- AASHTO has a plan for converting each committee and subcommittee to metric by 1996. This timetable is compatible with FHWA's timetable.

- AASHTO has produced a "Guide to Metric Conversion" which includes information on developing conversion plans and such engineering standards as:

  - design speed and running speed.
  - cross-section elements.
  - horizontal curvature.
  - stationing.
  - vertical clearances.
  - map and plan ratios.
  - contour intervals.

- Canada converted to metric in the 70's and had a very similar experience with the process of converting to the metric system. AASHTO has used much of the Canadian criteria.

6. Public Awareness

The public also has a role to play in metric conversion. Although not involved in the technical aspects of conversion, negative public reaction can slow the transition unnecessarily. Some elements of the public role are presented below.

- The U.S. public generally resists conversion to SI.

- In other countries such as England, Canada, and Australia, many did not want to convert to the metric system and believed the experience would be traumatic.

- Even though most FHWA conversion is invisible to the public, they will be exposed to speed limits, distances, and elevations in SI units.

- Contractors, material suppliers, and consulting engineers will be required to transition to the use of metric units once state highway agencies and FHWA require surveying, design, and construction in SI and may convert sooner.

Notes:

D. OVERVIEW OF SI

The SI "metric" system was not the first metric approach. It was preceded by the cgs (centimeter-gram-second) system and the mks (meter-kilogram-second) system.

In SI, there are seven base units, many derived units, and two supplementary units which are summarized in table 1.2. There are specific definitions of the base units and supplemental units. This section will provide an overview of the metric system with an emphasis on highway engineering related units of length, mass, time, and temperature.

Table 1.2. Overview of SI.

	Units	*Symbol*
Base units		
length	meter	m
mass	kilogram	kg
time	second	s
temperature*	kelvin	K
electrical current	ampere	A
luminous intensity	candela	cd
amount of material	mole	mol
Derived units	**	
Supplementary units		
angles in the plane	radian	rad
solid angles	steradian	sr

*We will use degrees Celsius (°C), which has a more common usage than kelvin.
** Many derived units exist; several will be discussed in this session.

1. Base Units

The base units uniquely describe a property requiring measurement. The seven base units are length, mass, time, temperature, electrical current, luminous intensity, and amount of material. These units are dimensionally independent.

Length

One of the most common units in civil engineering and other disciplines is length. In SI, the base length unit is the meter. The meter, and a few of its sub-multiples, are presented in figure 1.1.

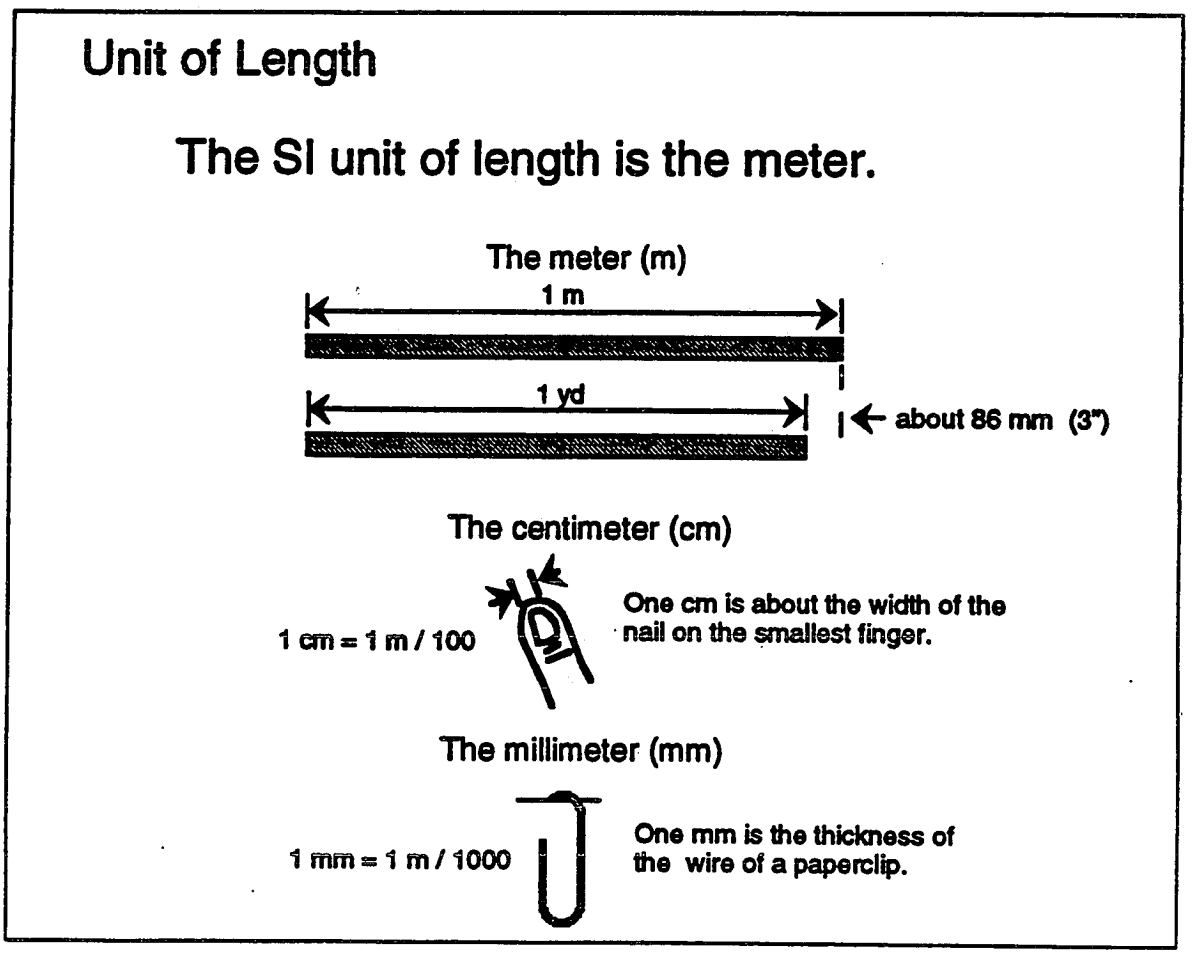


Figure 1.1. Unit of length.

- The meter is slightly longer than a yard.
- Other common units of length with their proper prefix are the centimeter and the millimeter.
  - The centimeter is 1/100 of a meter and is about the width of the nail on the smallest finger.
  - The millimeter is 1/1000 of a meter and is about the thickness of the wire of a paperclip.
  - The centimeter is not a preferred unit on highway plans. The millimeter is the preferred unit.

The kilometer is a particularly important multiple of the meter for highway applications. Figure 1.2 illustrates its magnitude.

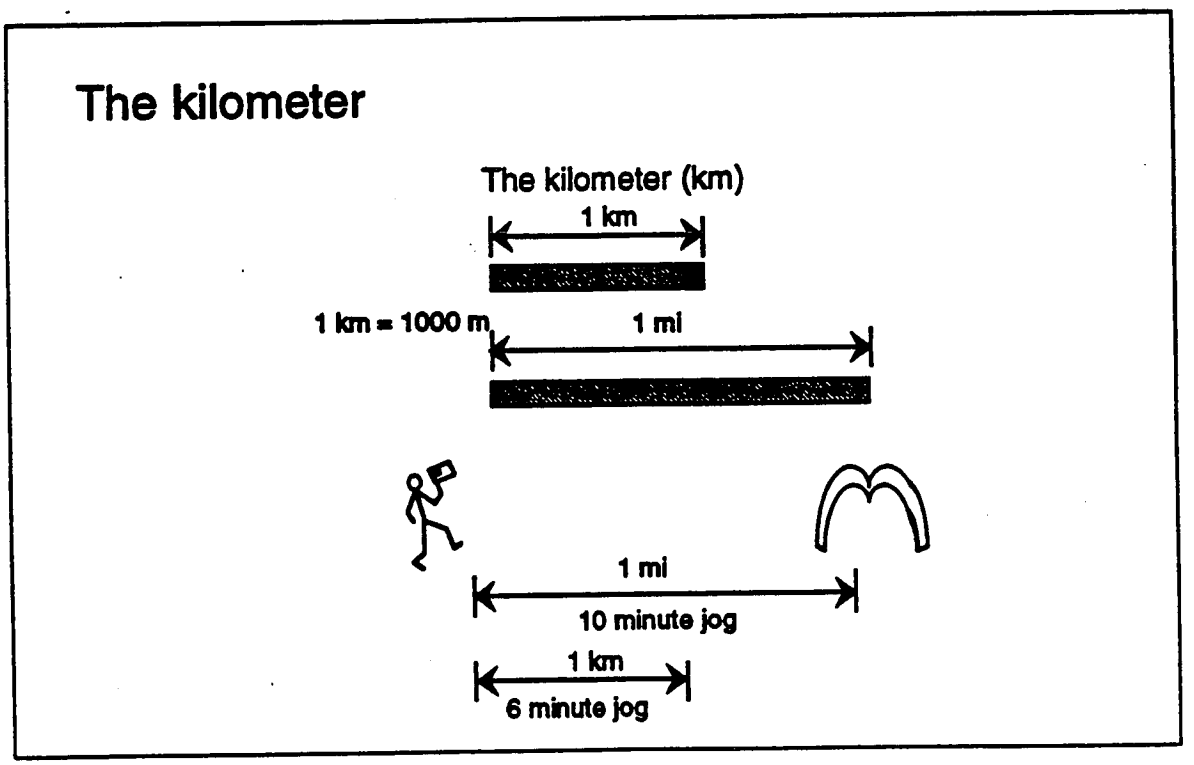


Figure 1.2. The kilometer.

- If it takes President Clinton 10 minutes to jog a mile to McDonalds, then at the same speed, he can go a kilometer in about 6 minutes.
- A speed of 62 mph is equal to a speed of 100 km/hr.
- The proper pronunciation is KILL'-o-meter and not kil-AHM-eter.

Mass

The second base unit relevant to highway applications is the kilogram which is a measure of mass. Mass is the measurement of inertia of an object. It may be thought of as the measure of an object's resistance to acceleration. Mass is illustrated in figure 1.3.

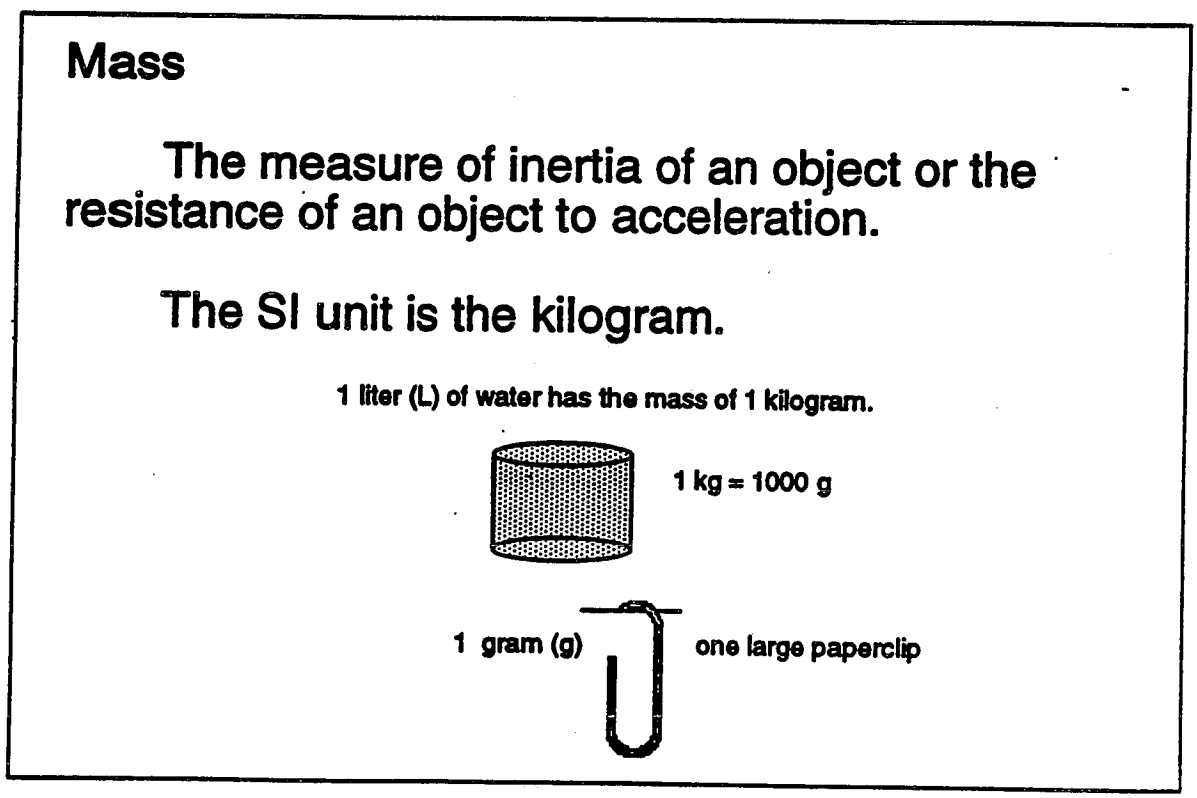


Figure 1.3. Mass.

- A liter of water (slightly more than a quart) has roughly one kilogram of mass.
- There are 1000 grams in a kilogram. There are a million milligrams in a kilogram.
- One milligram per kilogram is referred to as one part per million.

Time

A familiar SI base unit which is relevant to highway, and most other applications, is time. The second is the SI unit of time. It is the same as in the English system. Figure 1.4 illustrates the concept of time.

SI unit of time: second → (s)

This is the same unit as in English system.

Duration of heartbeat on a person at rest
1 s

Use "s" not "sec"

Figure 1.4. Time.

- The second is approximately the duration of a slow heartbeat on a relaxed person. It is also the time it takes an apple to fall 5 m (16 feet) to the ground from the branch of a tree.
- One day is 86.4 ks.
- There have been many attempts at developing a decimal hour and day. None have been adopted. The minute, hour, and day are not SI units, but are acceptable for use with SI units.

Temperature

Temperature is another base unit with usage in highway applications especially in material testing procedures and construction specifications. Kelvin is the base SI temperature unit with the Celsius scale being closely related, as shown in figure 1.5.

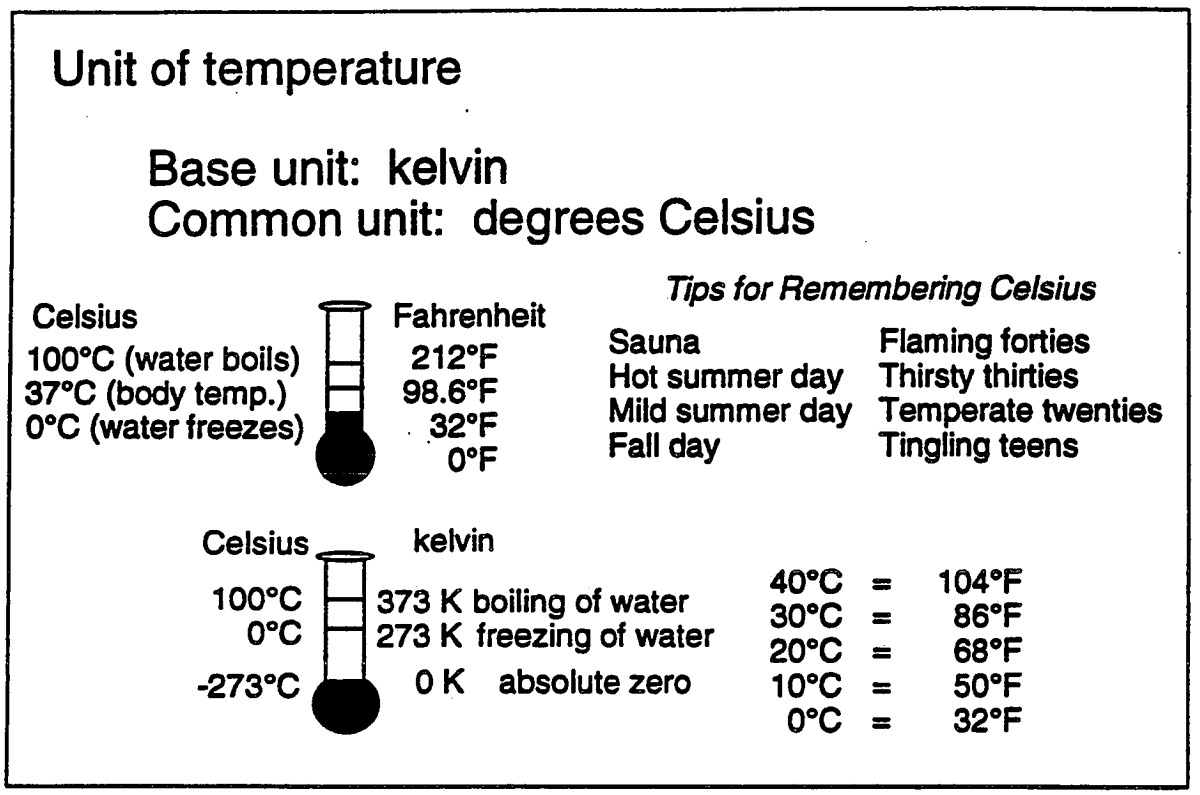


Figure 1.5. Temperature.

- The Celsius scale is the metric temperature scale that the public will learn, e.g., through weather reports. It is based on freezing and boiling points of water at atmospheric pressure.

- The kelvin scale is used in science and engineering, and it is the SI temperature scale. There are no negative values.

2. Derived Units

Derived units are formed by combining base units to express other characteristics. Velocity (m/s), slope (m/m), and density (kg/m^3) are derived measures. Many others have their own special unit name. Table 1.3 summarizes many of these units. The relationships between all derived units remain on a decimal basis.

Table 1.3. Derived units with special names.

Quantity	Name	Symbol	Expression
frequency	hertz	Hz	s^{-1} 1/s
force	newton	N	$kg \cdot m/s^2$
pressure, stress	pascal	Pa	N/m^2
energy, work, quantity of heat	joule	J	$N \cdot m$
power, radiant flux	watt	W	J/s
electric charge, quantity	coulomb	C	$A \cdot s$
electric potential	volt	V	W/A
capacitance	farad	F	C/V
electric resistance	ohm	Ω	V/A
electric conductance	siemens	S	A/V
magnetic flux	weber	Wb	$V \cdot s$
magnetic flux density	tesla	T	Wb/m^2
inductance	henry	H	Wb/A
luminous flux	lumen	lm	$cd \cdot sr$
illuminance	lux	lx	lm/m^2

Area and volume are common derived units which have many variations. The liter is a special metric unit for volume which is slightly larger than a quart. Some of these are shown in figure 1.6.

The use of other derived units depends upon the context. For example, energy and torque are dimensionally equivalent, but represent different concepts. **Energy** is written with units of joule which is a special name for N · m, while **Torque** is always written as N · m rather than as joule. These are also illustrated in figure 1.6.

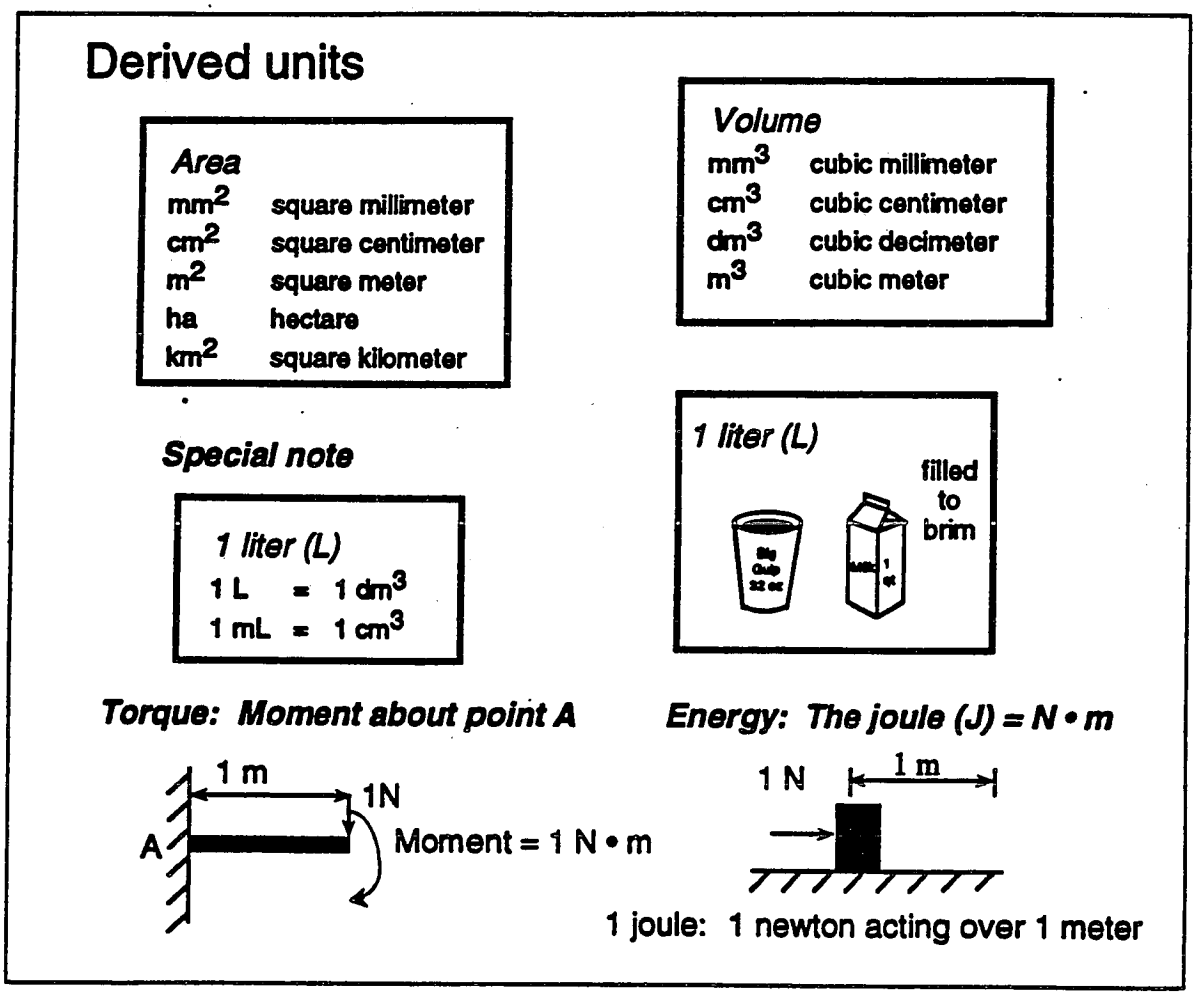


Figure 1.6. Derived units.

A subtle distinction exists between "mass" and "weight": "mass" is a base quantity while "weight" is a derived quantity related to mass and the acceleration due to gravity. Weight is sometimes referred to as the force of gravity. A person's mass does not change when walking on the moon versus the earth, but the person's weight does. The weight of an object is a function of the gravitational pull on the object. Figure 1.7 illustrates this distinction. In English units, one tends to operate in terms of weight (pounds) primarily. If mass is needed, one divides by the acceleration due to gravity (32.2 ft/s^2) to find slugs or pounds-mass. In SI units, mass is the base quantity, and force of gravity is calculated by multiplying by the acceleration due to gravity (9.81 m/s^2). Loosely speaking, it is common to convert pounds to kilograms by dividing by 2.2. This can only be applied on earth (home of most highway projects).

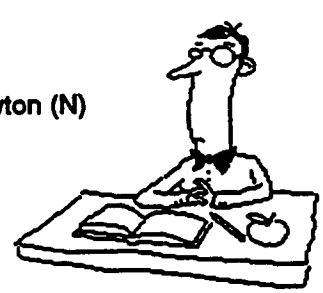
	mass	weight or force of gravity	force
English	slug pound-mass	pound pound-force	pound pound-force
metric	kilogram	newton	newton

Example:

On Earth, the acceleration due to gravity = 9.81 m/s^2.
Therefore, a 1 kg object placed on a structure will impose a force of gravity of 9.81 N. It also weighs 2.2 pounds.

Weight:

The newton (N)



220 lb man on Earth = weighs 981 N

220 lb man on Earth = mass of 100 kg.

Figure 1.7. Mass and weight.

3. Supplementary units

The supplementary units radian and steradian are regarded as dimensionless derived units which express plane and solid angles, respectively. The radian is the plane angle when the arc length of a circle is equal to the radius of the circle. The steradian is the solid angle when the surface area of a portion of a sphere is equal to the radius of the sphere squared. They are illustrated in figure 1.8.

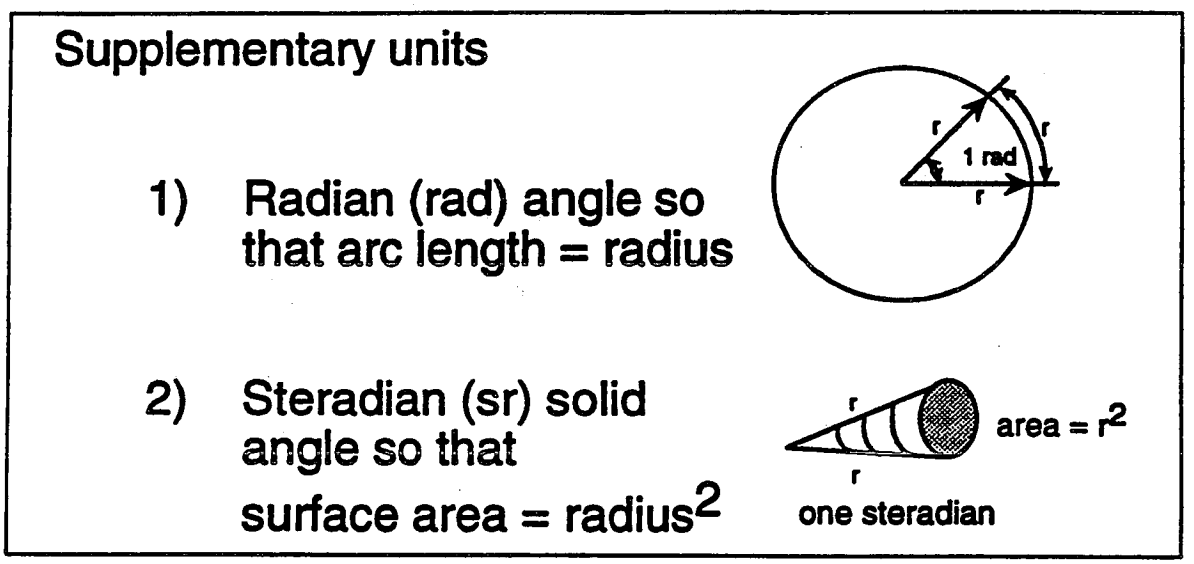


Figure 1.8. Angles.

Supplementary units are dimensionless, but do have a specific purpose.

- 360 degrees = 2π radians
- A sphere has 4π steradians
- circumference = $2\pi r$
- surface area = $4\pi r^2$

The SI unit for plane angle is the radian. Use of the degree, minute, and second is permissible when the radian is not a convenient unit. Use of the minute and second is discouraged except for special fields such as surveying and cartography.

- In surveying, the preferred notation for precise measurement of angles, directions, azimuths or bearings, and geodetic or astronomic positions is the degree, minute, and second.

- Slopes may be represented in radians or degrees. If degrees are used, only decimal degrees may be used rather than minutes and seconds.

4. Nomenclature

The metric system includes an organized nomenclature for describing various units and their multiples as well as proper ways of writing metric names and symbols. The logical and consistent method of expressing metric units of measure is part of the system's appeal.

One reason the metric system is preferred is because each unit of measure has two parts: a prefix and a base unit.

- The prefix is the part that gives the relative size. The same prefixes are applied to all unit names, and they are summarized in table 1.4. For example, a millimeter represents 1/1000th of a meter.

- The base unit gives the type of measurement.

Table 1.4. Prefixes.

Submultiples			*Multiples*		
deci	10^{-1}	d	deka	10^{1}	da
centi	10^{-2}	c	hecto	10^{2}	h
milli	10^{-3}	m	kilo	10^{3}	k
micro	10^{-6}	μ	mega	10^{6}	M
nano	10^{-9}	n	giga	10^{9}	G
pica	10^{-12}	p	tera	10^{12}	T
femto	10^{-15}	f	peta	10^{15}	P
atto	10^{-18}	a	exa	10^{18}	E
zepto	10^{-21}	z	zetta	10^{21}	Z
yocto	10^{-24}	y	yotto	10^{24}	Y

The symbols representing prefixes are shortened forms of the prefixes. The symbol for "micro" is the Greek letter μ or "mu" and is used because "m" is already used. "da" is used for "deka" and is the only symbol with two letters for abbreviation. The use of capital letters versus lower case letters does bear a significance. For example, "M" vs. "m" have different meanings; "M" means "mega" and "m" means "milli."

A few simple rules govern the proper written expression of metric units. It is important to honor the rules to avoid the possibility of miscommunicating information. The rules are as follows:

- Use a space between a digit and a symbol.
  Correct: 5 mm, Incorrect: 5mm
- Use a symbol only with a number.
  Correct: five grams, 5 g; Incorrect: five g, 5 grams
- Do not use fractions.
  Correct: 2.5 g, Incorrect: 2 1/2 g

- The same symbol is used for singular and plural.
  Correct: 5 m, 1 g, Incorrect: 5 ms
- Unit names do not begin with a capital letter when they are spelled out (exception: Celsius).
  Correct: newton, joule, Incorrect: Newton, Joule
- Symbol names do not require a period.
  Correct: 5 kJ, Incorrect: 5 kJ.
- Use spaces instead of a comma to separate long numbers (5 or more digits). This rule may not apply to engineering drawings and financial statements.
  Correct: 23 200 m. Incorrect: 23,200 m
- SI uses a " , " for decimal points, but we will continue to use a " . ".
  Correct: 22.1 ha, Incorrect: 22,1 ha

5. Coherency

SI is a "coherent" system of measurement because all of its units are formed by multiplying or dividing base units using only the factor of one. This is not true of the English system. Therefore, conversion within the metric system from one unit to another is very simple. The only thing that changes is the location of the decimal point.

A measurement system is coherent if:

- All derived and supplementary units are formed by multiplying and/or dividing base units.
- The above multiplication only involves the numeric factor of one (1).

Coherent examples:

Force = mass x acceleration
one newton = one kilogram x one meter / (one second)^2

Examples of incoherency:

1 gallon = 0.137 ft^3
1 acre = 43,560 ft^2

Examples that show that it is easy to convert from unit to unit.

5.21 m (meters) = 52.1 dm = 5210 mm = 0.521 dam
432.5 Pa (pascals) = 4.325 hPa = 0.432 5 kPa = 432 500 mPa
51 300 W (watts) = 51.3 kW = 0.051 3 MW

6. Philosophies of conversion

Conversion from the English system of measurement to SI is an important topic for the transition period. It affects standards, specifications, guidelines, numerical regulatory limits, and manufacturing. There are two philosophies of conversion which may be applied in a given circumstance:

1) Soft conversion:
   - Direct mathematical conversion. The physical dimension of a standard or product is unchanged, only the numerical value changes. For products this results only in changing of the label.

   Examples: A 55 mph speed limit becomes 88.51 km/h.
   A 12-foot lane becomes a 3.658 m lane.

2) Hard conversion:
   - converting to an even whole number. Results in changing product size as well as label.

   Examples: A 55 mph speed limit becomes 90 km/h.
   A 12-foot lane becomes a 3.6 m lane.

For a transition period it will be necessary to convert existing English quantities into the equivalent SI units. The Conversion Factors table on pages 9 and 10 summarizes several conversion factors useful in highway engineering.

7. Precision and rounding

Conversion to SI is a good opportunity to highlight the topics of precision and rounding. However, it must be emphasized that these are not topics unique to SI. Precision of a measurement refers to the degree of mutual agreement between individual measurements such that they are reproducible. Rounding refers to the process of reducing the number of significant digits in a quantity to those appropriate for representing the precision of a quantity. In a unit system such as the English system, we are constantly converting from feet to inches, from horsepower to watts, and others. The rules of precision followed on those occasions should also be followed when converting from English to metric units or from mass (in kilograms) to force of gravity (in newtons). Two rules are available:

Primary rule: Maintain precision of a value. This must always be achieved.

General rule: When implementing the primary rule, it is often effective to round the value to the same number of significant digits. This will approximately give the same implied precision. When maintaining the same number of significant digits provides misleading information on precision, the primary rule overrides the general rule.

Example where general rule applies: 5.2 miles at 1.609 km/mi = 8.369 km = 8.4 km.

Example where primary rule governs: 8.6 miles at 1.609 km/mi = 13.837 km = 13.8 km.

The highway engineer is already familiar with the notion of precision. The engineer reports a value, such as 5.2 miles, and there is an implied level of accuracy or precision. 5.2 miles implies a number between 5.15 and 5.25. When converting to metric, this same precision rule should be followed. Generally speaking, it is a good idea to round the metric value off to the same number of significant digits as the former example shows. The latter example shows that this is not always the case. In order to maintain precision, the result has three significant digits instead of two.

If a quantity is described by more than 1 unit, then convert to the smaller unit before converting to metric. This will also cause the metric value to reflect the accuracy which was implied in the original value. For example, if a measurement is provided as 6 feet 4 1/2 inches, it should be converted to metric in two steps. First, its equivalence in inches must be found as 76.5 inches. Then, it can be converted to metric using the appropriate conversion factor as follows (note only three significant figures are retained):

76.5 inches x 25.4 mm/inch = 1943.1 mm to 3 significant figures = 1940 mm.

The procedures for rounding are generally familiar to most technically trained personnel and are summarized below. The rules presented here are those specified in ASTM E380-92a:

- Round up if the next digit is larger or down if the next digit is less than 0.5.

  Examples:

  43.87 mm → 43.9 mm
  279.4 K → 279 K

- If the number is exactly 0.5, then round up only if it makes the digit an even number.

  Examples:

Round up	77.5 J → 78 J
Round down	76.5 J → 76 J

Notes:

E. SUPPLEMENTARY SOURCES OF INFORMATION

The following materials are readily accessible and may be useful for implementing SI in an organization. Although not necessary for each individual to have a full set of these documents, it is recommended that an organization acquire them as a resource as needed. They are listed below by general category.

1. General exposition on SI and its use

American Society for Testing and Materials, *Standard Practice for Use of the International System of Units (SI) (The Modernized Metric System),* E380-92a, 1992.

National Institute of Standards and Technology, Barry N. Taylor, Editor, *The International System of Units (SI),* U.S. Department of Commerce, NIST Special Publication 330, August 1991.

National Institute of Standards and Technology, Barry N. Taylor, Editor, *Interpretation of the SI for the United States and Metric Conversion Policy for Federal Agencies,* U.S. Department of Commerce, NIST Special Publication 814, October 1991.

2. SI and construction

General Services Administration, *Metric Design Guide,* Office of Design and Construction, Second Edition, April 1992 (draft).

National Institute of Building Sciences, *Metric Guide for Federal Construction,* First Edition, 1991.

Notes:

Notes:

SESSION 2: AN OVERVIEW OF SI IN THE HIGHWAY CONTEXT

Learning Objectives:

- Introduce SI physical constants and specifications/standards currently being developed or developed for use in highway transportation;
- Introduce important SI reference materials, computer programs, tools and equipment.

Content: In this session, the general SI knowledge introduced in session 1 will be enhanced with specific presentation of highway transportation SI issues in planning, right-of-way, roadway/structure design, roadway/structure construction, and material sampling and testing. Relevant physical constants and standards being developed by AASHTO will be presented and examples provided of their use. Information on the availability and use of SI documents, computer programs, tools and equipment useful for daily tasks will be provided.

SESSION 2
AN OVERVIEW OF SI IN THE HIGHWAY CONTEXT

Page

A. INTRODUCTION 47

B. SPECIAL AREAS OF THE HIGHWAY FIELD 49

Planning and Road Design 49
Bridge Design 55

C. SUPPLEMENTARY SOURCES OF INFORMATION 56

1. **SI Tools** 56
2. **SI/English Conversion Programs** 56
3. **Printed Documents** 56

D. EDITORIAL GUIDE 59

SESSION 2
AN OVERVIEW OF SI IN THE HIGHWAY CONTEXT

List of Figures

Figure **Page**

2.1 AASHTO design values for lane widths, shoulders and clear zones 51

2.2 AASHTO design values for stationing, map ratios, and horizontal curvature 51

2.3 AASHTO design values for vertical clearance and bridge length. 49

2.4 Bridge design topic areas 55

SESSION 2
AN OVERVIEW OF SI IN THE HIGHWAY CONTEXT

List of Tables

Table **Page**

2.1 Horizontal curvature 52

2.2 Map ratios 53

A. INTRODUCTION

This session addresses specific areas of highway engineering. The first section is broken down into five areas: Planning and Road Design, Drainage, Bridge Design, Materials, and Quantity/Cost Estimation. This session shows how the metrication process affects each of these areas. For example--physical constants are different when converted to the metric system; engineering standards and specifications are also different in the metric system.

The second section shows that there are already several resources available to aid in the conversion from English to SI such as computer programs and drawing tools. A key to effective conversion to SI is the availability of standards and specifications in SI. The following are key points.

- Support for the highway engineer and technician must be made available in the form of metric standards and specifications. Responsibility for developing such standards belongs to several organizations: 1) AASHTO, 2) FHWA, 3) State DOTs, 4) ASTM, 5) building code groups, and 6) industry associations.

- Some codes are now available such as ASTM E-615M (rebar). Others will not be available for 2 or 3 more years (or longer).

- A source of support for metrication in the construction industry is the National Institute for Building Sciences (NIBS). It is a nonprofit, nongovernmental organization authorized by Congress to serve as an authoritative source on issues of building sciences and technology. The Construction Metrication Council was created by the NIBS to provide industry-wide, public and private sector support for the metrication of Federal construction and to promote the adoption and use of the metric system of measurement as a means of increasing the international competitiveness, productivity, and quality of the U.S. construction industry.

- The transition period from English to SI should be made as short as practicable to minimize conversion activities which may introduce errors and to avoid inefficient use of dual systems.

- The AASHTO guide to metric conversion is a good start for the conversion process.

Notes:

B. SPECIAL AREAS OF THE HIGHWAY FIELD

1. Planning and Road Design

Planning and road design generally are the first activities involved in developing new or rehabilitating old roadways. As such, much activity in SI conversion is focused on this topic area. In particular, AASHTO has produced a guide to metric conversion which discusses many standards and specifications for planning and road design and has also prepared a supplement to the "Green Book."

The following list shows several areas to pay attention to when converting to SI:

- Location.
- Right-of-way.
- Map and plan ratios.
- Contour intervals.
- Design speeds/AADT.
- Speed limits/signing.
- Cut/fill estimates.
- Horizontal and vertical alignment.
- Roadside safety and vertical clearance.
- Stationing.
- Cross section intervals.

Development of standards

Many of the above areas are covered in the AASHTO Green Book. The metric task force within AASHTO has finished establishing metric criteria. Approved January 6, 1993, by AASHTO and adopted by FHWA through regulatory actions, the new metric criteria may be used by states as an interim design criteria on Federal-aid projects. A complete metric version of the Green Book will be published in 1995.

Most of the selected design values are hard conversions. Figure 2.1 describes sample design values for lane widths, shoulders, and limited clear zone information. The 9, 10, 11, and 12 ft lanes are replaced with 2.7, 3.0, 3.3, and 3.6 m lanes, respectively. These are hard conversions because the size of the lane slightly changes. Canadian values for lane widths are slightly different. They are based on 0.25 m increments rather than 0.3 m increments.

Figure 2.2 shows additional design values for stationing and horizontal curvature. The present practice of expressing curvature by degree of curve will be discontinued and the radius definition will be adopted instead. Kilometer stationing has been adopted by the AASHTO geometric design subcommittee after its adoption by the AASHTO construction subcommittee. One hundred meter stationing had also been considered. Cross section spacing will be at intervals of 10 m, 20 m, and/or 50 m depending on the application.

Table 2.1, found in the "AASHTO Guide to Metric Conversion," gives minimum rounded radii in meters for values of super-elevations and design speeds. These serve only as examples.

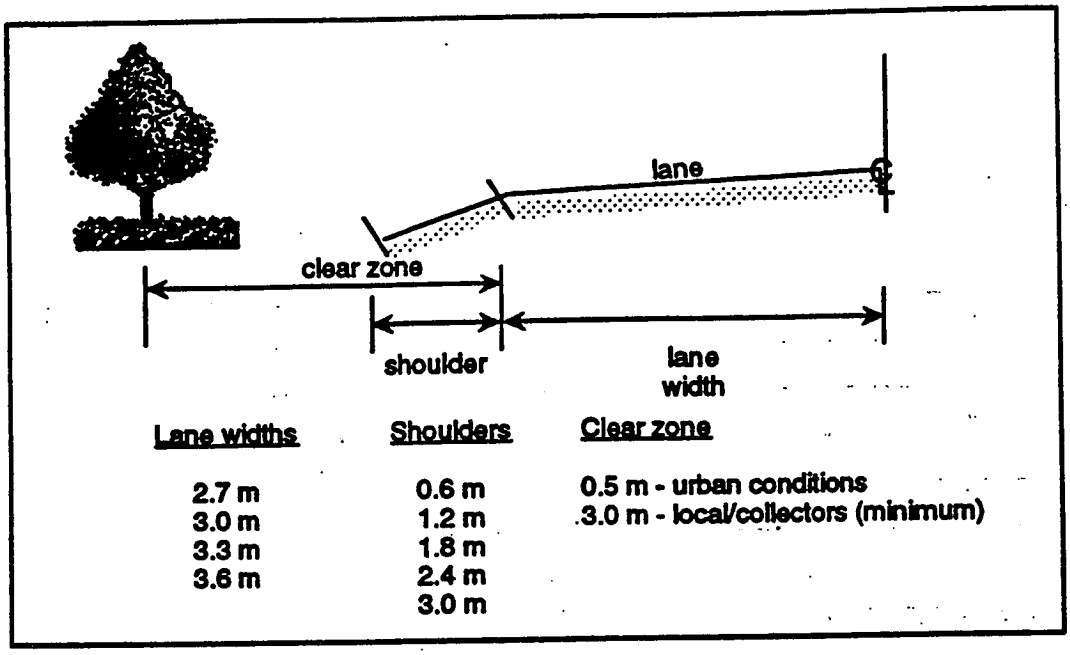


Figure 2.1. AASHTO design values for lane widths, shoulders, and clear zone.

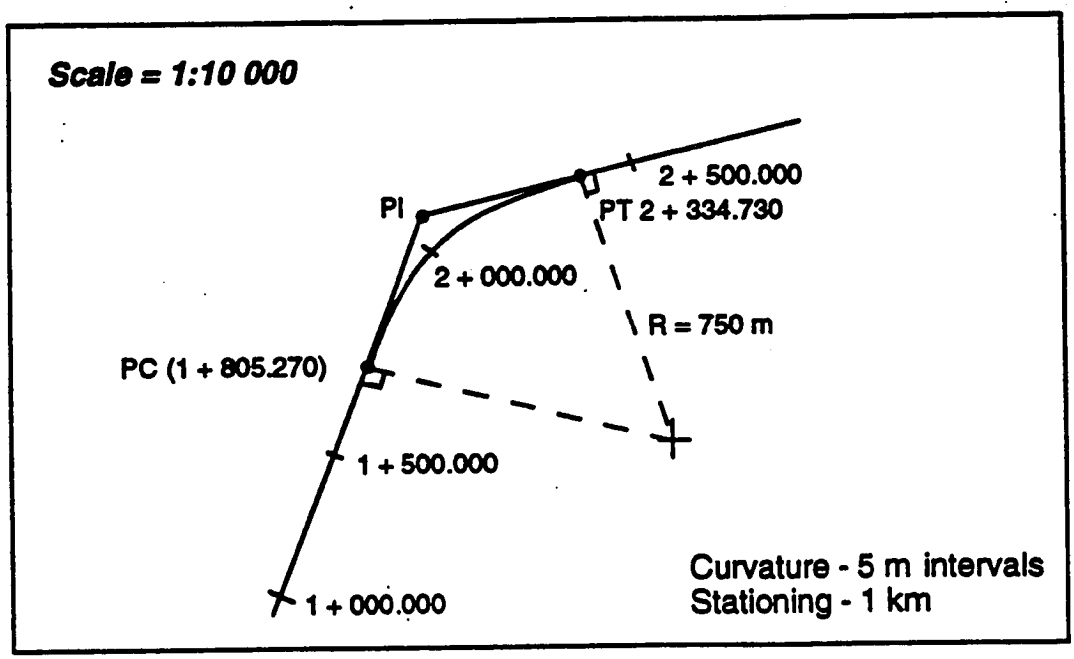


Figure 2.2. AASHTO design values for stationing and horizontal curvature.

Table 2.1. Horizontal curvature.

Design Speed km/h	Minimum rounded radius in meters	
	6% max. superelevation	8% max. superelevation
40	55	50
50	90	80
60	135	125
70	195	175
80	250	230
90	335	305
100	435	395
110	560	500
120	755	665

Source: "AASHTO Guide to Metric Conversion," 1993.

Map scales (or map ratios) will also be affected by conversion to SI. SI scales follow the number series 1-2-5 and 1-2.5-5. Examples are shown in table 2.2 along with English equivalents. Example SI ratios may include 1:200 for urban plan sheets; 1:500 for other plan sheets; and 1:100 for vertical alignment and cross sections. A special note is that land areas are given in three different metric units, depending on what is being measured.

- meters^2 - plats, plans, deeds, etc.
- hectare (ha) - farm land, public land, small watersheds, etc.
- km^2 - watersheds, states, etc.

Contour intervals will also be affected and represented as 0.5, 1, 2, 5, or 10 m unless more accuracy is required. Other government agencies who generate mapping products used by highway engineers are in the process of conversion to SI as well.

Table 2.2. Map ratios (scales).

SI Ratio	Closest English Scales	Equivalent English Ratio
1:100	1" = 10'	1:120
1:200	1" = 25'	1:300
1:500	1" = 50'	1:600
1:1000	1" = 80' 1" = 100'	1:960 1:1200
1:2000	1" = 200'	1:2400
1:5000	1" = 400'	1:4800
1:10 000	1" = 800' 1" = 1000'	1:9600 1:12 000
1:25 000	1" = 2000'	1:24 000
1:50 000	1" = 1 mi.	1:63 360
1:100 000	1" = 2 mi.	1:126 720
1:250 000	1" = 4 mi.	1:253 440
1:500 000	1" = 8 mi.	1:506 880
1:1 000 000	1" = 16 mi.	1:1 013 760

Figure 2.3 schematically represents vertical clearance and bridge length. The recommended values represent hard conversions to reasonable quantities.

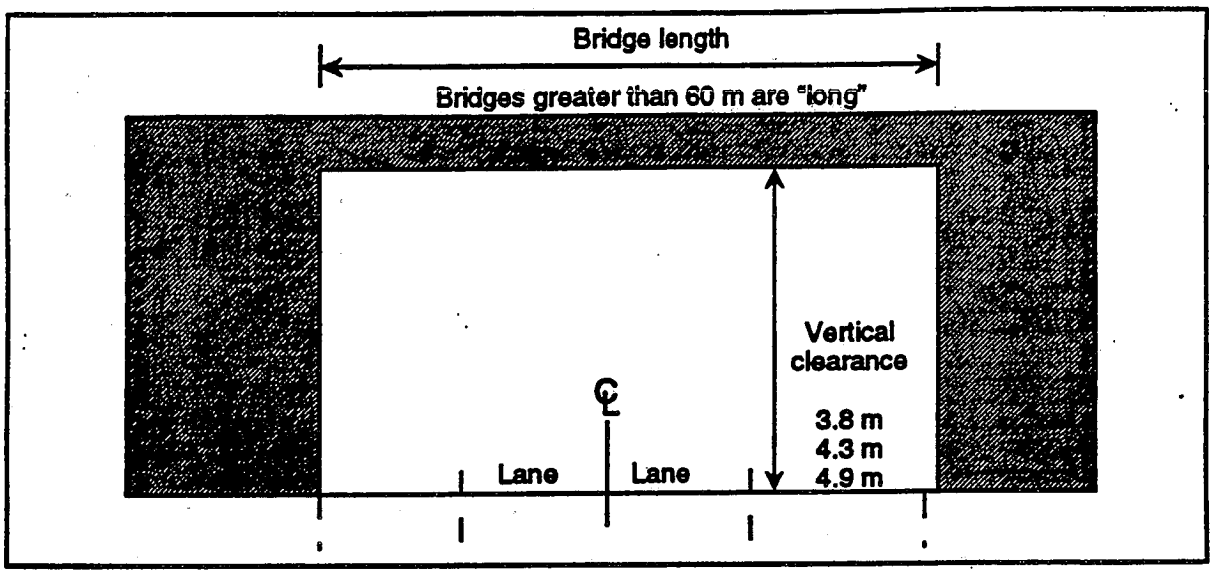


Figure 2.3. AASHTO design values for vertical clearance and bridge length.

The standard vertical clearance of 4.9 m is related to clearance on interstate highways. Other sample specifications are as follows:

- Curbs 150 mm (6 in)
  225 mm (9 in)
- Stopping sight distance eye height - 1070 mm (3.51 ft)
  object height - 150 mm (0.49 ft)
- Cuts and fills → volume measurements in m^3
- Signing → letter sizes will be in millimeters
- Pavement markings (use approximate conversion)
  - inches x 25 = millimeters, ex. 4 in = 100 mm
  - feet x 0.3 = meters

2. Bridge Design

The area of bridge design is very broad and covers a number of subjects, as illustrated in figure 2.4. The analysis of beams and trusses for appropriate loads, pressures, and forces requires an understanding of SI. Beam and truss lengths are dimensioned in meters. Loads are given in either kN or MN instead of pounds or tons. Pressures on a bridge are given in the metric unit of kPa. Forces are given in kN, and distributed loads are given in kN/m. Plan detailing and specifications will also be performed in SI.

Metrication and bridge design

- Beams
- Trusses
- Loads, pressures, and forces
- Plan detailing

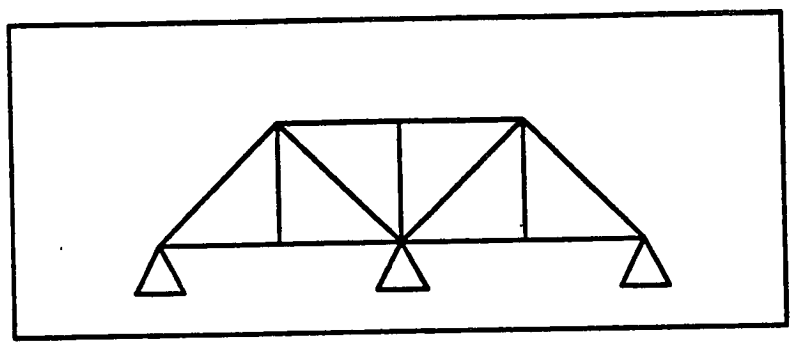


Figure 2.4. Bridge design topic areas.

C. SUPPLEMENTARY SOURCES OF INFORMATION

Although much work remains to be accomplished in converting standards, specifications, computer programs, measuring devices, and equipment, a significant amount of effort has already been expended. Resources available are listed below:

1. SI Tools

- Blackhawk Metric Supply (North American Tool Corp.)
  S. Beloit, IL
  815-389-2850
  (measuring devices, calculators, measuring tapes, etc.)

- "Sample Metric Drawings from Facilities, Sitework and Road Construction." A new drawing package being developed by the General Services Administration. Call Otto Schick (215-656-5822) for more information.

- "Metric Database," from the American Institute of Steel Construction (AISC), containing dimensions and properties of structural shapes in SI units. For diskettes or more information, call AISC at 312-670-5434.

2. SI/English Conversion Programs

- Available on electronic bulletin board - Federal Electronic Bulletin Board System (FEBBS), 202-366-3764 (call 202-366-9022 if problems are encountered).

3. Printed Documents

- General Services Administration, *Metric Design Guide,* Office of Design and Construction, Second Edition, April 1992 (draft).

- *Standard Alphabet for Highway Signs and Pavement Markings*, Metric Edition, 1977.

- American Association of State Highway Transportation Officials, *Standard Specifications for Transportation Materials and Methods of Sampling and Testing,* 15th Edition, 1990, with 1991 and 1992 interim updates. (Note: Many materials evaluations have been performed using metric measures for many years.)

- American Association of State Highway Transportation Officials, *Standard Specifications for Highway Bridges,* 14th Edition, 1989, with 1990 and 1991 interim updates. (Appendix E of this document contains a fairly exhaustive list of the relevant metric formulas and units.)

- American Congress on Surveying and Mapping, *Metric Practice Guide for Surveying and Mapping,* Copyright March 1978, reprinted March 1992.

- Daniel S. Turner and Jay K. Lindly, *AASHTO Guide to Metric Conversion,* 1993.

- National Institute of Building Science, *Metric Guide for Federal Construction,* First Edition, 1991.

- R.S. Means Co., Inc., *Means Building Construction Cost Data, Metric Edition,* Kingston, MA, 1992.

Notes:

PAVEMENTS

METRIC		ENGLISH
3.0 m lane	(9.84 ft.)	10 ft. lane
3.3 m lane	(10.83 ft.)	11 ft. lane
3.6 m lane	(11.81 ft.)	12 ft. lane

SHOULDERS

METRIC		ENGLISH
600 mm	(1.97 ft.)	2 ft.
1.2 m	(3.94 ft.)	4 ft.
1.8 m	(5.91 ft.)	6 ft.
2.4 m	(7.87 ft.)	8 ft.

HIGHWAY DITCHES

METRIC		ENGLISH
600 mm	(1.97 ft.)	2 ft.
1.0 m	(3.28 ft.)	3 ft.
1.2 m	(3.94 ft.)	4 ft.
1.8 m	(5.91 ft.)	6 ft.

HIGHWAY SLOPES

V : H (AASHTO)

METRIC	ENGLISH
1:6	6:1

BRIDGE LOAD RATINGS

METRIC	ENGLISH
MS 18	HS 20
MS 13.6	HS 15
M 13.6	H 15
M 9	H 10

NOTE: A METRIC TON IS EQUAL TO 2204.6 lbs. To convert an English ton to a metric ton, multiply by 0.9072.

METRIC EDITORIAL GUIDE

EDITORIAL REFERENCE

This part of the workbook covers editorial rules for using the modern form of the metric system, called "The International System of Units" (abbreviated SI). A limited number of the units outside SI that are acceptable for use with SI also are included.

The text is based on *American National Standard Metric Practice*, ANSI/IEEE Std 268-1982, *Standard for Metric Practice*, ASTM E380-86, International Organization for Standardization ISO 1000-1981, *Metric Editorial Guide*, ANMC 1992, and *Metric Training for Highway Agencies*, NHI course number 12301.

Known metric usage variations between the Illinois Department of Transportation and usage rules listed here have been noted in the text.

CAPITALIZATION

Units: Unit names, including prefixes, are not capitalized except at the beginning of a sentence and in those titles, headings and other instances in which all main words are capitalized. The word Celsius is the only exception.

Examples: Meter is the unit used for Olympic track events.
Force is measured in newtons.

In "degree Celsius," note that "degree" is lowercase and "Celsius" is capitalized. (The "degree centigrade" is now obsolete.)

Symbols: The short forms for metric units are called symbols. The first letter of a symbol is capitalized when the name of the unit is derived from the name of a person. The larger prefix symbols (mega and up) are also capitalized. Other symbols are generally lower case regardless of the surrounding text.

Examples:

Unit Name	Unit Symbol
meter	m
gram	g
newton	N
pascal	Pa

"L" and "l" are alternative symbols for liter. Since the symbol "l" can be easily confused with the numeral "1", the symbol "L" is recommended for U.S. use.

SYMBOL TYPE STYLE

Unit symbols are printed in upright letters. Italic letters are reserved for quantity symbols, such as *A* for area, *m* for mass, and *tt* for time. In typewriting or longhand, underlining may be used as a substitute for italics.

Use the correct symbols, never abbreviations.

Example: s (second), not sec ; mm^2, not sq. millimeter

PUNCTUATION AND SPELLING

A period is not used after a symbol, except when the symbol is at the end of the sentence.

Examples: When you add 15 g of salt ...
The length of the field is 350 m.

The spelling and usage of metric symbols are the same in all languages and alphabets. The U.S. government has adopted the Germanic spelling of liter and meter, however.

There are three cases where the final vowel of a prefix is omitted when spelling vowed pairs: megohm, kilohm, and hectare. In all other cases, both vowels are retained and both are pronounced. A space or hyphen should not be used.

Example: milliampere, gigaohm

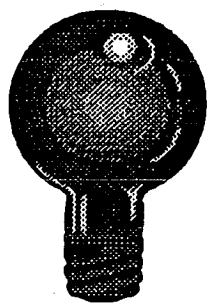
PLURAL USAGE

Names of units follow normal English usage when spelling out plurals. Plurals of unit names are formed by adding an "s," except for hertz, lux, and siemens, which remain unchanged.

Examples: twenty meters, one kilogram, two lux

Symbols for units are the same in singular and plural.

Examples: 1 m, 100 m, 1 g, 20 g



sixty watts

SPACING

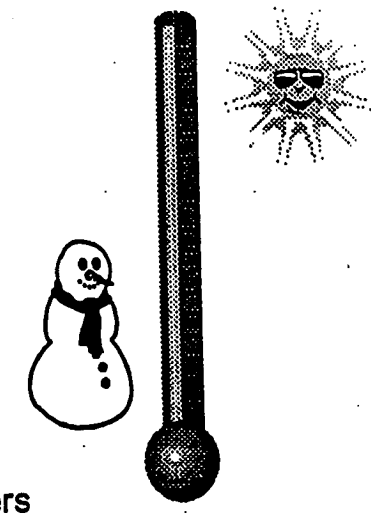
Use a space between a digit and a symbol.

Examples: 5 mm, 3 L, 70 Pa

For angle measure, do not leave a space between the numeral and the degree symbol.

Example: 30°

The symbol for degree Celsius is °C, an inseparable symbol, with no space between the two parts. Whether or not a space is left between the numeral and the symbol is a matter of editorial preference.



Examples: Either 20°C or 20 °C is correct. (FHWA prefers the former and IDOT prefers the later.)

20° C is not correct.

MIXING SYMBOL, NAMES AND NUMERALS

Use a symbol only with a number for technical writing (the area is 10 m).

Example:
Correct: 5 g, five grams; Incorrect: 5 grams, five g

Numerals may be combined with written unit names in non-technical writing (10 meters).

Do not mix symbols with spelled out names in the same expression.; write out unit names if numerals are not used (carpet is measured in square meters). Do not use symbols alone in text (without a number).

Examples:	Correct	Incorrect
	60 kg/L	60 kilograms/L
	10 m/s²	10 m/second squared
	about a gram	about a g
	about 1 g	

The mixing of prefixes should be avoided unless the difference in size is extreme.

Examples: 40 mm wide and 1500 mm long, not 40 mm wide and 1.5 m long.
1500 meters of 2 mm diameter wire

Nonmetric units should not be used with metric units, except units for time, plane angle, or rotation.

Examples: Use kg/m², not kg/ft²; g/L, not g/gal.

NUMERAL USAGE

Decimal notation is preferred. Do not use fractions.

Examples: 2.5 g, not 2½ g

The decimal marker will continue to be a dot on the line and the comma will still be used to separate long numbers.
(Many countries use a comma as a decimal marker and a space to separate long numbers.)

Examples: 10.51 m and 2,500 kg

Put a leading zero in front of a decimal point so the point will not be overlooked.

Example: 0.7 mm, not .7 mm

To multiply symbols, use a raised dot (·) but do not pronounce it or spell it out. Do not use a space before or after the product dot. Do not use a product dot between words.

Examples: 15 N·m, not 15 N x m
10 newton meters, not 10 Nm

When writing a *name* of a compound unit that is a product, use a space or a hyphen between the words.

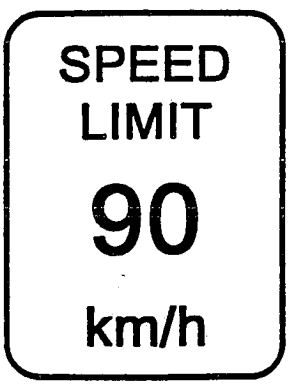
Example: newton meter, newton-meter

To divide symbols, use a horizontal bar, slash, or negative exponent. Use the word *per* when pronouncing or spelling out divided units.

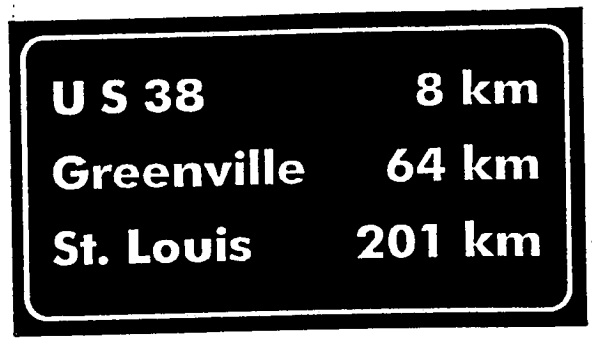
Examples: m/s^2, not $meters/s^2$
$\frac{J}{kg}$, not J-kg
kilometers per hour, not kilometers over hour

Complex division requires that commas or parentheses be inserted to eliminate ambiguity.

Examples: J/(kg·K), not J/kg/K
meters per second, per second,
not meters per second per second



PREFIXES AND POWERS OF TEN



Prefixes are used with base units to show the relative size of a type of measurement.

Examples:
One millimeter represents 1/1000th of a meter.
One kilometer represents 1000 meters.

The metric prefix is a power of ten. Care should be taken to avoid mixing prefixes and powers. The expression of powers with base units is preferred. Prefix choices should also be made that are consistent (in charts) or that are easy to read and indicate the appropriate precision.

Examples: 10^2 m, not 10^4 cm; 10^3 kg, not 10^6 g
20 mL, not 0.02 L, 60 kg, not 60,000 g

When raising units to a power, the word squared or cubed follows the unit name. When writing the powers of units for areas or volumes the word square or cubic precedes the unit name.

Example: 2 m/s^2 = two meters per second squared
3 mm^2 = three square millimeters

COMPOUND UNITS

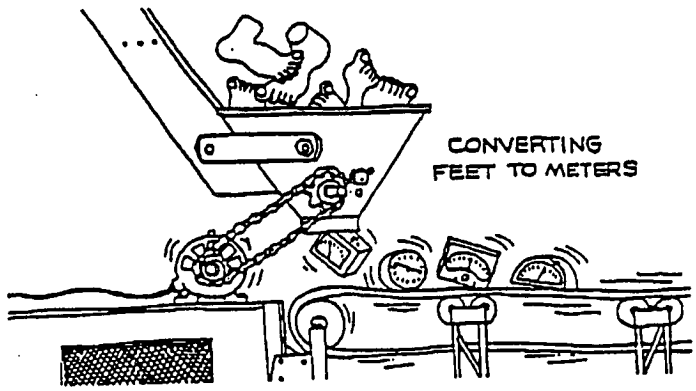
When forming the multiple of a compound unit, it is recommended that, in general, only one prefix be used, usually in the numerator.

Examples: kg/m, not g/mm
km/s, not m/ms

However, since the kilogram is an SI base unit, it is proper to write J/kg, kJ/kg, etc.

It is preferred that a ratio of two values of the same quantity be written as a decimal or as a percentage and not as a fraction.

Example: A slope of 40 mm/m or 40 m/km should be written as a 0.04 m/m slope or could also be expressed as a 4% slope.



SESSION 3: PARTICIPANT'S QUIZ

Learning Objective: Provide an opportunity for participants to test their new knowledge of SI by applying it.

Content: A short "quiz" will be given to allow participants to exercise their introduction to SI and to illustrate issues of precision, rounding, scale, and conversion in a simple highway transportation context. The instructor will go through the quiz with the participants so they can be given timely feedback.

I. This is an open book quiz. Answer the following questions "True" or "False". Answers are provided in the back of this manual (Appendix A).

Answers from information on:		True or False	
p. 25	1)	There are seven base units in SI.	____
p. 25	2)	There are two supplemental units in SI.	____
p. 37	3)	English and SI are both coherent unit systems.	____
p. 33	4)	The weight of an object changes from one planet to the next.	____
p. 33	5)	The mass of an object changes from one planet to the next.	____
p. 15	6)	The metric system is in use in the United States today.	____
p. 32	7)	The liter is a metric unit.	____
p. 25	8)	The liter is an SI unit.	____
p. 32	9)	The liter is slightly larger than a quart.	____
p. 29	10)	The symbol for second is (s).	____
p. 32 then p. 29	11)	One cubic centimeter of water has a mass of approximately 1 g.	____
	12)	Speed limits will increase as a result of metric conversion.	____
	13)	The price of gasoline will decrease as a result of metric conversion.	____
p. 58	14)	A metric tons weighs more than an English ton.	____
p. 37	15)	Metric symbols are not followed by a period except at the end of a sentence.	____
p. 30	16)	Thirty degrees Celsius is warmer than sixty-eight degrees Fahrenheit.	____
p. 25	17)	The gram is one of the seven base units.	____

Check the appropriate answer.

Answers from information on:

p. 8 — 18) How many meters is a 402-ft home run to center field?

a) 122
b) 122.5
c) 123
d) 121.5
e) 121

p. 8 — 19) What force of gravity (newtons) is generated by a 14-pound bowling ball?

a) 62 N
b) 6.4N
c) 60 N
d) 6.0 N
e) 140 N

p. 39 & 40 — 20) If it is 3100 (2 significant figures) miles from Boston to San Francisco, how many kilometers is it?

a) 4990 km
b) 1900 km
c) 1930 km
d) 5000 km
e) 3100 km

p. 38 — 21) Converting a speed from 65 miles per hour to 104.6 kilometers per hour is known as what?

a) hard conversion
b) soft conversion
c) both hard and soft conversion

p. 38 — 22) Converting a speed from 60 miles per hour to 100 kilometers per hour is known as what?

a) hard conversion
b) soft conversion
c) both hard and soft conversion

Answers from information on:

p. 8 23) 6 feet, 4 1/2 inches is equal to how many millimeters?

a) 900 mm
b) 1,943.1 mm
c) 1.94 mm
d) 2000 mm
e) 1900 mm

p. 8 24) What is the mass, in kilograms, of a 14-pound bowling ball on Earth?

a) 6.4 kg
b) 62 kg
c) 60 kg
d) 140 kg
e) 6.0 kg

p. 8 25) What is the hard conversion of the Indianapolis 500 from English (miles) to SI (km)? (Keeping the same significant figures)

a) Indianapolis 310
b) Indianapolis 800
c) Indianapolis 300
d) Indianapolis 805
e) Indianapolis 500

p. 8 26) What is the soft conversion of the Indianapolis 500 from English (miles) to SI (km)?

a) Indianapolis 310
b) Indianapolis 800
c) Indianapolis 300
d) Indianapolis 804
e) Indianapolis 500

p. 8 27) Perform a conversion to SI of the following quantity: nine yards. (To the nearest meter)

a) 9 y
b) 10 m
c) 8 m
d) 8.23 m
e) 9 m

PARTICIPANT'S QUIZ

==========

METRIC USAGE PROBLEMS

Fill in the following blanks by correcting the errors, if present.
Answers from information in the Metric Editorial Guide section.

28) 15 1/2 g _____

29) 23.5 kNs _____

30) 83.4 newton/meter _____

31) 287.8°K _____

32) 38.1° C _____

33) Two degrees celsius _____

34) 23.5 N x m _____

35) 23,354 km _____

36) 57.6mJ _____

37) Four Newtons _____

38) 45 sec _____

39) 30 g. _____

40) 100 ms _____

41) 5mm _____

42) about a m _____

43) 50 mm wide and 1.4 m long _____

44) kilometers/h _____

45) 10^2 cm _____

46) g/mm _____

47) 4/100 slope _____

PARTICIPANT'S QUIZ

==========

Fill in the following blanks with the appropriate answer.

p. 37 48) A system of units is _____ if the division or multiplication factor from unit to unit is 1.

p. 38 49) A _____ conversion is converting from one measurement system to another using the numerical conversion factor to calculate quantities in a new system.

p. 38 50) A _____ conversion is converting from one measurement system to another using the numerical conversion factor to calculate quantities in a new system and then rounding to a convenient dimension.

p. 40 51) When rounding, if the next digit is 5, and there are no more digits after the 5, then round _____ .

p. 40 52) If we want to convert 11 feet, 2 inches to SI, we should first convert everything to _____ and then convert to SI.

p. 39 53) The general rule to maintain precision while converting to metric is to round off to the same number of _____ .

p. 8 54) The SI unit of pressure is the _____ .

Problems:

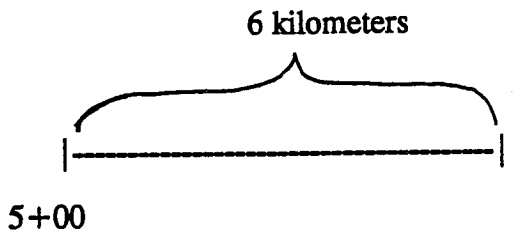
1 The following paragraph is a technical description of a proposed project. Make corrections (where necessary) to this paragraph so that the description follows proper metric writing procedure.

The eastbound approach to said project section, located within the City of Rockwood, is a 12.55 meter wide pavement, back-to-back of curb, composed of a one inch bituminous surface course on a 38 1/10 mm binder course on bituminous and concrete base courses (thicknesses unknown) on dirt. Said section is composed of one eastbound and one westbound thru lane each having a lane width of 3.6 ms, with 152 MM curbs. Separate turning lanes exist within said section at each major signalized intersection. The right-of-way thru said section is twenty m. The City of Rockwood has no plans to widen said section to four lanes and has recently resurfaced this section as a two lane roadway. The westbound approach to said project is a 15m wide pavement back-to-back of curb, composed of an eight inch reinforced concrete pavement on a 102 mm. granular subbase. Said project is composed of two eastbound and two westbound thru lanes each having a lane width of 3.3 m. Curb and gutter is Type B-15.60. The right-of-way is 66m wide.

PARTICIPANT'S QUIZ

==========

2 A highway resurfacing project is being scheduled for the summer. The beginning English station is 5+00. The project is 6 kilometers in length. Convert the beginning station to metric and give the ending metric station.



APPENDIX

ANSWERS TO THE PARTICIPANT'S QUIZ

1. T
2. T
3. F (only SI is coherent)
4. T
5. F
6. T (e.g., soft drink packaging)
7. T
8. F (not all metric units are SI units)
9. T
10. T
11. T
12. F (conversion will result in slight changes)
13. F
14. T
15. T
16. T
17. F (kilogram is the base unit for mass)
18. C (using the general rule for rounding)
19. A
20. D
21. B
22. A
23. B
24. A
25. B
26. D (round even)
27. C
28) 15 1/2 g 15.5 g (no fractions)
29) 23.5 kNs 23.5 kN (symbols remain singular)
30) 83.4 newton/meter 83.4 N/m
31) 287.8°K 287.8 K
32) 38.1° C 38.1 °C or 38.1°C
33) Two degrees celsius Two degrees Celsius
34) 23.5 N x m 23.5 N·m
35) 23,354 km OK as shown
36) 57.6mJ 57.6 mJ
37) Four Newtons Four newtons
38) 45 sec 45 s
39) 30 g. 30 g
40) 100 ms 100 m
41) 5mm 5 mm
42) about a m about 1 m about a meter or
43) 50 mm wide and 1.4 m long 50 mm wide and 1400 mm long
44) kilometers/h kilometers/hour
45) 10^2 cm 1 m
46) g/mm kg/m
47) 4/100 slope 4% slope or 0.04 slope

ANSWERS TO THE PARTICIPANT'S QUIZ

48) coherent

49) soft

50) hard

51) even

52) inches

53) significant figures

54) pascal or Pa

Problem 1

The corrections to the paragraph are in parentheses after each error.

The eastbound approach to said project section, located within the City of Rockwood, is a 12.55 meter **(12.55 m)** wide pavement, back-to-back of curb, composed of a one inch **(25.4 mm)** bituminous surface course on a 38 1/10 mm **(38.1 mm)** binder course on bituminous and concrete base courses (thicknesses unknown) on dirt. Said section is composed of one eastbound and one westbound thru lane each having a lane width of 3.6 ms **(3.6 m)**, with 152 MM **(152 mm)** curbs. Separate turning lanes exist within said section at each major signalized intersection. The right-of-way thru said section is twenty m **(20 m or twenty meters)**. The City of Rockwood has no plans to widen said section to four lanes and has recently resurfaced this section as a two lane roadway. The westbound approach to said project is a 15m **(15 m)** wide pavement back-to-back of curb, composed of an eight inch **(203 mm)** reinforced concrete pavement on a 102 mm. **(102 mm)** granular subbase. Said project is composed of two eastbound and two westbound thru lanes each having a lane width of 3.3 m. Curb and gutter is Type B-15.60. The right-of-way is 66m **(66 m)** wide.

Problem 2

Beginning Station 0+152.400

Ending Station 6+152.400

* From "Criteria for Metric Highway Design"

11. Other Decisions For Metric Design:

- For surveying, the kilometer station will be used. This will require three places after the decimal point.

  The kilometer station is written as: (km) (m) (mm) 1 + 000.000

  with kilometer stationing increasing from south to north and west to east and from left to right on design and right of way plan sheets.

- Tick marks should be shown on the plan centerline at 50 m intervals.

- The standard cross-section interval will be 25 m for rural conditions and 10 m for urban conditions. Additional cross-sections should be taken as needed to obtain accurate quantities.

- In converting existing surveys from English units to metric units, the U.S. Survey Foot definition should be used. One foot = 0.30480061 meters or one meter = 3.28083333 feet.

- Superelevation will be expressed as a percentage on the plans. As an example, 0.06 ft/ft is the same as 0.06 m/m and both can be written as 6%.

- Grades will continue to be expressed in percentages. (i.e., for 100 m of length in the horizontal plane, we would measure the vertical drop or rise, divide the vertical by the horizontal, multiply by 100 and this would be the grade in percent). Grades on plans will be the same whether defined in English or metric units.

- Angles will continue to be expressed in degrees, minutes, and seconds.

- All metric mapping will be plotted at the following scale ratios:
  - Design Mapping - 1:500
  - Location Study Mapping - 1:2500

- Requests for aerial photography or half-tone positives usually should be at the following scale ratios:

1:1000 (Urban Area)	1:5000 (Rural area)
1:2500 (Urban Area)	1:7500 (Rural area)

- Design speeds are now stated in km/h and can not be directly related to design speeds in mph as used in our past highway designs (km/h can be converted to mph by multiplying by 0.62). However, the following will apply: 50 km/h will replace 30 mph, 70 km/h will replace 45 mph, 90 km/h will replace 55 mph, 100 km/h will replace 60 mph, and 110 km/h will replace 70 mph. Refer to revised Tables 2-100A, 2-100B and 2-500, in metric units, for correlation with the new functional classification system and respective design speeds. Also refer to Tables 2-100A, 2-100B and 2-500 in English units (for informational purposes only) as to how the new functional classification system relates to IDOT's previous classification system.

- Considerable information is now available on metric units in the new book of Standard Specifications for Road and Bridge Construction dated July 1, 1994.