LEARNING OBJECTIVES:

1.02.01 Identify the commonly used unit systems of measurement and the base units for mass, length, and time in each system.

1.02.02 Identify the values and abbreviations for SI prefixes.

1.02.03 Given a measurement and the appropriate conversion factor(s) or conversion factor table, convert the measurement to the specified units.

1.02.04 Using the formula provided, convert a given temperature measurement to specified units.

INTRODUCTION

A knowledge of the unit analysis and conversion process is a necessity for the Radiological Control Technician. It is useful for air and water sample activity calculations, contamination calculations, and many other applications. This lesson will introduce the different unit systems, the fundamental units in each system, and the unit analysis and conversion process. Many calculations accomplished in radiological control are actually unit conversions, not complex calculations to be memorized.

UNITS AND MEASUREMENTS

Units are used in expressing physical quantities or *measurements*, i.e., length, mass, etc. All measurements are actually relative in the sense that they are comparisons with some standard unit of measurement. Two items are necessary to express these physical quantities: a number which expresses the magnitude and a unit which expresses the dimension. A number and a unit must both be present to define a measurement. Measurements are algebraic quantities and as such may be mathematically manipulated subject to algebraic rules.

Fundamental Quantities

All measurements or physical quantities can be expressed in terms of three fundamental quantities. They are called fundamental quantities because they are dimensionally independent. They are:

- *Length* (L)
- *Mass* (M) (not the same as weight)
- *Time* (T)

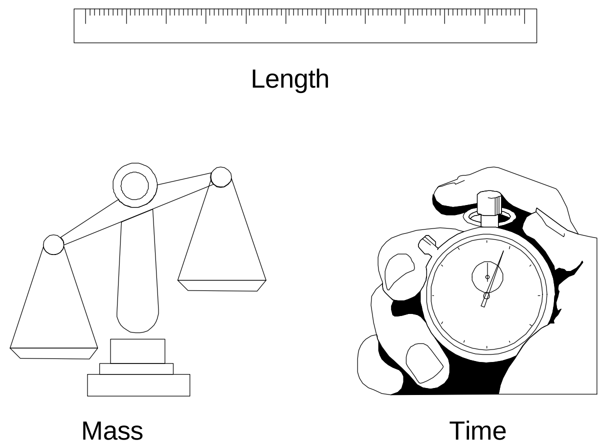

Figure 1. Fundamental Units

Derived Quantities

Other quantities are derived from the fundamental quantities. Derived quantities are formed by multiplication and/or division of fundamental quantities. For example:

- Area is the product of *length* times *length* (width), which is $L \times L$ or L^2
- Volume is area times length, which is *length* times *length* times *length*, or L^3
- Velocity is expressed in *length* per unit *time*, or L/T
- Density is expressed in *mass* per unit volume, or M/L^3

1.02.01 Identify the commonly used unit systems of measurement and the base units for mass, length, and time in each system.

SYSTEMS OF UNITS

The units by which physical quantities are measured are established in accordance with an agreed standard. Measurements made are thereby based on the original standard which the unit represents. The various units that are established, then, form a *system* by which all measurements can be made.

English System

The system that has historically been used in the United States is the English System, sometimes called the English Engineering System (EES). Though no longer used in England, many of the units in this system have been used for centuries and were originally based on common objects or human body parts, such as the foot or yard. Though practical then, the standards for these units were variable as the standard varied from object to object or from person to person.

Even though fixed standards have since been established for these antiquated units, no uniform correlation exists between units established for the same quantity. For example, in measuring relatively small lengths there are inches, feet and yards. There are twelve inches in a foot, and yet there are only three feet in a yard. This lack of uniformity makes conversion from one unit to another confusing as well as cumbersome. However, in the U.S., this system is still the primary system used in business and commerce.

Table 1. English System Base Units

Physical Quantity	Unit	Abbr.
Length:	foot	ft.
Mass:	pound	lb.
Time:	second	sec.

International System of Units (SI)

Since the exchange of scientific information is world-wide today, international committees have been set up to standardize the names and symbols for physical quantities. In 1960, the **International System of Units** (abbreviated SI from the French name Le **S**ystème **I**nternationale d'Unites) was adopted by the 11th General Conference of Weights and Measures (CGPM). The SI or modernized **metric system**, is based on the decimal (base 10) numbering system. First devised in France around the time of the French Revolution, the metric system has since been refined and expanded so as to establish a practical system of units of measurement suitable for adoption by all countries. The SI system consists of a set of specifically defined units and prefixes that serve as an internationally accepted system of measurement. Nearly all countries in the world use metric or SI units for business and commerce as well as for scientific applications.

1.02.02 Identify the values and abbreviations for SI prefixes.

SI Prefixes

The SI (or modernized) system is completely decimalized and uses prefixes for the base units of *meter* (m) and *gram* (g) as well as for derived units, such as the *liter* (l) which equals 1000 cm^3.

SI prefixes are used with units for various magnitudes associated with the measurement being made. Units with a prefix whose value is a positive power of ten are called *multiples*. Units with a prefix whose value is a negative power of ten are called *submultiples*.

For example, as a point of reference, the meter is a little longer than a yard. Try using a yard stick to measure the size of a frame on film for a camera. Instead you would use inches, because it is a more suitable unit. With the metric system, in order to measure tiny lengths, such as film size, the prefix *milli*- can be attached to the meter to make a millimeter, or 1/1000 of a meter. A millimeter is much smaller and is ideal in this situation. On the other hand, we would use a prefix like *kilo*- for measuring distances traveled in a car. A *kilometer* would be more suited for these large distances than the meter.

Table 2. SI Prefixes

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

Prior to the adoption of the SI system, two groups of units were commonly used for the quantities length, mass and time: **MKS** and **CGS**. The units for these subsystems are given below.

Table 3. Metric Subsystems

Physical Quantity	**CGS**	**MKS**
Length:	centimeter	meter
Mass:	gram	kilogram
Time:	second	second

SI Units

In the SI system there are seven fundamental physical quantities. These are length, mass, time, temperature, electric charge, luminous intensity, and molecular quantity (or amount of substance). In the SI system there is one-and only one-SI unit for each physical quantity. The SI system base units are those in the metric MKS system. Table 4 lists these seven fundamental quantities and their associated SI unit. The units for these seven fundamental quantities provide the base from which the units for other physical quantities are derived.

For most applications the RCT will only be concerned with the first four quantities as well as the quantities derived from them.

Radiological Units

In the SI system, there are derived units for quantities used for radiological control. These are the becquerel, the gray and the sievert. The SI unit of activity is the becquerel, which is the activity of a radionuclide decaying at the rate of one spontaneous nuclear transition per second. The gray is the unit of absorbed dose, which is the energy per unit mass imparted to matter by ionizing radiation, with the units of one joule per kilogram. The unit for dose equivalent is the sievert, which is the absorbed dose of ionizing radiation multiplied by the dimensionless factors and other multiplying factors with the units of joule per kilogram. These quantities and their applications will be discussed in detail in Lesson 1.06.

Other units

There are several other SI derived units that are not listed in table 4. It should be noted that the SI system is evolving and that there will be changes from time to time. The standards for some fundamental units have changed in recent years and may change again as technology improves our ability to measure even more accurately.

Table 4. International System (SI) Units

Physical Quantity	Unit	Symbol	Dimensions
	Base units		
Length:	meter	m	m
Mass:	kilogram	kg	kg
Time:	second	s or sec.	s
Temperature:	kelvin	K	K or °K
Electric current:	ampere	A or amp	A or (C/s)
Luminous intensity:	candela	cd	cd
Molecular quantity:	mole	mol	mol
	Selected derived units		
Volume:	cubic meter	m^3	m^3
Force:	newton	N	$kg{\cdot}m/s^2$
Work/Energy:	joule	J	N·m
Power:	watt	W	J/s
Pressure:	pascal	Pa	N/m^2
Electric charge:	coulomb	C	A·s
Electric potential:	volt	V	J/C
Electric resistance:	ohm	Ω	V/A
Frequency:	hertz	Hz	s^{-1}
Activity:	becquerel	Bq	disintegration/s
Absorbed dose:	gray	Gy	J/kg
Dose equivalence:	sievert	Sv	Gy·Q·N

1.02.03 Given a measurement and the appropriate conversion factor(s) or conversion factor table, convert the measurement to the specified units.

UNIT ANALYSIS AND CONVERSION PROCESS

Units and the Rules of Algebra

Remember that a measurement consists of a number and a unit. When working problems with measurements, it should be noted that the units follow the same rules as the values. Some examples are provided below.

$$(cm) \times (cm) = cm^2$$

$$\frac{ft^3}{ft} = ft^2$$

$$\frac{1}{yr} = yr^{-1}$$

As mentioned above, measurements are subject to algebraic laws of operation and can therefore be multiplied, divided, etc., in order to convert to a different system of units. Obviously, in order to do this, the units must be the same. For example, a square measures one foot in length and 18 inches in width. To find the area of the square in square inches we must multiply the length by the width. However, the measurements are in different units, and cannot be multiplied.

We can convert feet to inches. We know that there are 12 inches in one foot. We can use this ratio to convert 1 foot to 12 inches. We can then calculate the area as 12 inches × 18 inches, which equals 216 in^2, which is a valid measurement.

Steps for Unit Analysis and Conversion

1) Determine given units and desired units.

2) Build (or obtain) conversion factor(s) -- see Conversion Tables at end of lesson

A conversion factor is a ratio of two equivalent physical quantities expressed in different units. *When expressed as a fraction, the value of all conversion factors is 1*. Because it equals 1, it does not matter which value is placed in the numerator or denominator of the fraction.

Examples of conversion factors are:

$$\frac{365\ days}{1\ year} \qquad \frac{12\ inches}{1\ foot} \qquad \frac{1\ foot^3}{2.832E4\ cm^3}$$

Building conversion factors involving the metric prefixes for the same unit can be tricky. This involves the conversion of a base unit to or from a subunit or superunit.

To do this, use the following steps:

Example: 1 gram to milligrams

a) Place the base unit in the numerator and the subunit/ superunit in the denominator (or vice versa).

$$\frac{g}{mg}$$

b) Place a 1 in front of the subunit/superunit.

$$\frac{g}{1\ mg}$$

c) Place the value of the prefix on the subunit/ superunit in front of the base unit.

m (*milli*-) = 10^{-3} or 1E-3

$$\frac{1E-3\ g}{1\ mg}$$

Also remember that algebraic manipulation can be used when working with metric prefixes and bases. For example, 1 centimeter = 10^{-2} meters. This means that 1 meter = $1/10^{-2}$ centimeters, or 100 cm. Therefore, the two conversion factors below are equal:

$$\frac{1E-2\ m}{1\ cm} \qquad \frac{1\ m}{100\ cm}$$

3) Set up an equation by multiplying the given units by the conversion factor(s) to obtain desired units.

When a measurement is multiplied by a conversion factor, the units (and probably the magnitude) will change; however, the actual measurement itself does not change. For example, 1 ft and 12 inches are still the same length; only different units are used to express the measurement.

By using a "ladder" or "train tracks," a series of conversions can be accomplished in order to get to the desired units. By properly arranging the numerator and denominator of the conversion factors, given and intermediate units will cancel out by multiplication or division, leaving the desired units. Some examples of the unit analysis and conversion process follow.

EXAMPLE 1.

Convert 3 years to seconds.

Step 1 - Determine given and desired units

Given units: years
Desired units: seconds.

Step 2 - Build/obtain conversion factor(s)

We can use multiple conversion factors to accomplish this problem:

1 year = 365.25 days
1 day = 24 hours
1 hour = 60 minutes
1 minute = 60 seconds

Step 3 - Analyze and cancel given and intermediate units. Perform multiplication and division of numbers.

$$\left(\frac{3\ \text{years}}{}\right)\left(\frac{365.25\ \text{days}}{1\ \text{year}}\right)\left(\frac{24\ \text{hours}}{1\ \text{day}}\right)\left(\frac{60\ \text{minutes}}{1\ \text{hour}}\right)\left(\frac{60\ \text{seconds}}{1\ \text{minute}}\right) = 94{,}672{,}800$$

EXAMPLE 2.

What is the activity of a solution in $\frac{\mu Ci}{ml}$ if it has 2000 $\frac{dpm}{gallon}$?

Step 1 - Determine given and desired units.

Given units: $\frac{dpm}{gallon}$

Desired units: $\frac{\mu Ci}{ml}$

Step 2 - Build conversion factor(s).

1 liter = 0.26418 gallons
1 dpm = 4.5 E-07 µCi
1 liter = 1000 ml

Step 3 - Analyze and cancel given and intermediate units. Perform multiplication and division of numbers.

$$\left(\frac{2000\ \not{d}\not{p}\not{m}}{\not{g}\not{a}\not{l}}\right)\left(\frac{4.5E-7\ \mu Ci}{1\ \not{d}\not{p}\not{m}}\right)\left(\frac{0.26418\ \not{g}\not{a}\not{l}}{1\ \not{\ell}}\right)\left(\frac{1\ \not{\ell}}{1{,}000\ ml}\right) = 2.38E-7\ \frac{\mu Ci}{ml}$$

Practical exercises and their solutions are provided at the end of this lesson.

1.02.04 Using the formula provided, convert a given temperature measurement to specified units.

TEMPERATURE MEASUREMENTS AND CONVERSIONS

Temperature measurements are made to determine the amount of heat flow in an environment. To measure temperature it is necessary to establish relative scales of comparison. Three temperature scales are in common use today. The general temperature measurements we use on a day-to-day basis in the United States are based on the **Fahrenheit** scale. In science, the **Celsius** scale and the **Kelvin** scale are used. Figure 2 shows a comparison of the three scales.

The Fahrenheit scale, named for its developer, was devised in the early 1700's. This scale was originally based on the temperatures of human blood and salt-water, and later on the freezing and boiling points of water. Today, the Fahrenheit scale is a secondary scale defined with reference to the other two scientific scales. The symbol °F is used to represent a degree on the Fahrenheit scale.

About thirty years after Fahrenheit scale, Anders Celsius, a Swedish astronomer suggested that it would be simpler to use a temperature scale divided into one hundred degrees between the freezing and boiling points of water. For many years his scale was called the **centigrade** scale. In 1948 an international conference of scientists named it the Celsius in honor of its inventor. The Celsius degree, °C, was defined as 1/100 of the temperature difference between the freezing point and boiling point of water.

In the 19th century, an English scientist, Lord Kelvin, established a more fundamental temperature scale that used the lowest possible temperature as a reference point for the beginning of the scale. The lowest possible temperature, sometimes called *absolute zero*, was established as 0 K (zero Kelvin). This temperature is 273.15°C below zero, or -273.15°C. Accordingly, the Kelvin degree, K, was chosen to be the same as a Celsius degree so that there would be a simple relationship between the two scales.

Note that the degree sign (°) is not used when stating a temperature on the Kelvin scale. Temperature is stated simply as kelvins (K). The kelvin was adopted by the 10th Conference of Weights and Measures in 1954 and is the SI unit of thermodynamic temperature. Note that the degree Celsius (°C) is the SI unit for expressing Celsius temperature and temperature intervals. The temperature interval one degree Celsius equals one kelvin exactly. Thus, 0°C = 273.15 K by definition.

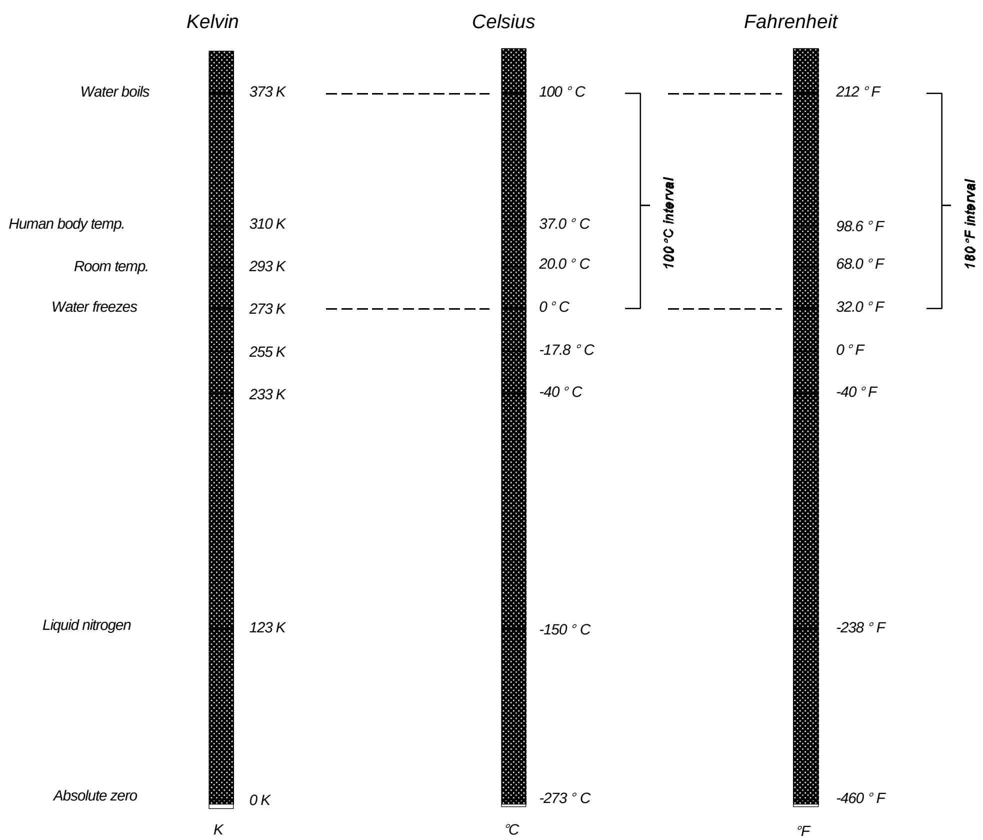

Figure 2. Comparison of Kelvin, Celsius and Fahrenheit scales.

To convert from one unit system to another, the following formulas are used:

Table 5. Equations for Temperature Conversions

°F to °C	$^\circ C = \frac{(^\circ F - 32)}{1.8}$	or	$^\circ C = (^\circ F - 32)\left(\frac{5}{9}\right)$
°C to °F	$^\circ F = 1.8(^\circ C) + 32$	or	$^\circ F = \left(\frac{9}{5}\right)(^\circ C) +$
°C to K	$K = {}^\circ C + 273.15$		

EXAMPLE 3.

Convert 65° Fahrenheit to Celsius.

$$^\circ C = \frac{(65^\circ F - 32)}{1.8}$$

$$^\circ C = \frac{33}{1.8}$$

$$^\circ C = 18.3^\circ C$$

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PRACTICAL EXERCISES:

Convert the following measurements:

1. 67 mm to feet

2. 1843 ounces to kg

3. 3500 microsieverts (μSv) to millirem (mrem)

4. 0.007 years to minutes

5. 5000 disintegrations per minute (dpm) to millicuries (mCi)

6. 2350 micrometer (μm) to inches

7. 2.5E-4 ergs to keV

8. 205 °F to °K

9. 2E-3 rad to milligray (mGy)

10. −25 °C to °F

Use unit analysis and conversion to solve the following problems.

11. Light travels at 186,000 miles per second. How many feet will light travel in one minute?

12. A worker earns a monthly salary of $2500. If the worker gets paid every two weeks and works no overtime, what will be the gross amount for a given pay period?

13. An air sampler has run for 18 hours, 15 minutes at 60 liters per minute. When collected an analyzed the sample reads 7685 disintegrations per minute (dpm). What is the concentration of the sample in micocuries/cm^3?

PRACTICAL EXERCISE SOLUTIONS:

1. 67 mm to feet:

$$\left(\frac{67\ mm}{1}\right)\left(\frac{1\ m}{1E3\ mm}\right)\left(\frac{3.2808\ ft}{1\ m}\right) = 0.22\ ft$$

2. 1843 ounces to kg

$$\left(\frac{1843\ oz}{1}\right)\left(\frac{28.35\ g}{1\ oz}\right)\left(\frac{1\ kg}{1E3\ g}\right) = 52.25\ kg$$

3. 3500 microsieverts (µSv) to millirem (mrem)

$$\left(\frac{3.5E3\ \mu Sv}{1}\right)\left(\frac{1\ Sv}{1E6\ \mu Sv}\right)\left(\frac{1E2\ rem}{1\ Sv}\right)\left(\frac{1E3\ mrem}{1\ rem}\right) = 3.5E2\ mrem = 350\ mrem$$

4. 0.007 years to minutes

$$\left(\frac{0.007\ year}{1}\right)\left(\frac{365.25\ days}{1\ year}\right)\left(\frac{24\ hours}{1\ day}\right)\left(\frac{60\ minutes}{1\ hour}\right) = 3681.72\ minutes$$

5. 5000 dis./min. to millicuries (mCi)

$$\left(\frac{5E3\ dis}{\min}\right)\left(\frac{1\ Ci}{2.22E12\ \frac{dis}{\min}}\right)\left(\frac{1E3\ mCi}{1\ ci}\right) = 2.25E-6\ mCi$$

6. 2350 micrometer (µm) to inches

$$\left(\frac{2350\ \mu}{1}\right)\left(\frac{3.937E{-}5\ inches}{1\ \mu}\right) = 0.0925\ inches = 9.25E{-}2\ inches$$

7. 2.5E-4 ergs to keV

$$\left(\frac{2.5E{-}4\ ergs}{1}\right)\left(\frac{6.2148E11\ ev}{1\ erg}\right)\left(\frac{1\ keV}{1E3\ eV}\right) = 1.55E5\ keV$$

8. 205 °F to K

$$^{\circ}C = \frac{(205\ ^{\circ}F - 32)}{1.8} = 96.1\ ^{\circ}C$$

$$^{\circ}K = 96.1\ ^{\circ}C + 273.16 = 369.27\ ^{\circ}K$$

9. 2E-3 rad to milligray (mGy)

$$\left(\frac{2E{-}3\ rad}{1}\right)\left(\frac{0.01\ Gy}{1\ rad}\right)\left(\frac{1E3\ mGys}{1\ Gy}\right) = 2E{-}2\ mGy = 0.02\ mGy$$

10. −25 °C to °F

$$^{\circ}F = (-25\ ^{\circ}C)1.8 + 32 = -13\ ^{\circ}F$$

Use unit analysis and conversion to solve the following:

11. Light travels at 186,000 miles per second. How many feet will light travel in one minute?

$$\left(\frac{186{,}000\ miles}{\text{sec}}\right)\left(\frac{5280\ ft}{1\ mile}\right)\left(\frac{60\ \text{sec}}{1\ minute}\right) = 5.89E10\ \frac{ft}{\text{min}}$$

12. A worker earns a monthly salary of $2500. If the worker gets paid every two weeks and works no overtime, what will be the gross amount for a given pay period?

$$\left(\frac{2500\ dollars}{month}\right)\left(\frac{12\ months}{1\ year}\right)\left(\frac{1\ year}{52\ weeks}\right)\left(\frac{2\ weeks}{pay\ period}\right) = 1153.85\ \frac{dollars}{pay\ period}$$

13. An air sampler has run for 18 hours, 15 minutes at 60 liters per minute. When collected an analyzed the sample reads 7685 dis./min. What is the concentration of the sample in micocuries/cm^3?

$$\left(\frac{15\ minutes}{1}\right)\left(\frac{1\ hour}{60\ minutes}\right) = 0.25\ hour$$

$$18\ hours + 0.25\ hours = 18.25\ hours$$

$$\left(\frac{18.25\ hours}{1}\right)\left(\frac{60\ minutes}{1\ hour}\right)\left(\frac{60\ l}{1\ minute}\right) = 65{,}700\ l$$

$$\left(\frac{7685\ dpm}{6.57E4\ l}\right)\left(\frac{1\ Ci}{2.22E12\ dpm}\right)\left(\frac{1E6\ \mu Ci}{1\ Ci}\right)\left(\frac{1l}{1E3\ ml}\right)\left(\frac{0.99997\ ml}{1\ cc}\right) = 5.26E{-11}\ \frac{\mu Ci}{cc}$$

INSTRUCTIONS FOR USING CONVERSION FACTORS TABLES

The tables that follow include conversion factors that are useful to the RCT. They are useful in making a single conversion from one unit to another by using the guide arrows at the top of the page in accordance with the direction of the conversion. However, when using the tables to develop equivalent fractions for use in unit analysis equations, a better understanding of how to read the conversion factors given in the table is required.

The conversions in the table have been arranged by section in the order of fundamental units, followed by derived units:

Length
Mass
Time
Area
Volume
Density
Radiological
Energy
Fission
Miscellaneous (Temperature, etc.)

The easiest way to read a conversion from the table is done as follows. Reading *left to right,* "one (1) of the units in the left column is equal to the number in the center column of the unit in the right column." For example, look at the first conversion listed under **Length**. This conversion would be read from left to right as "1 angstrom is equal to E-8 centimeters," or

$$1\text{Å} = 10^{-8}\ centimeters \Rightarrow \frac{1\ \text{Å}}{10^{-8}\ centimeters}$$

Another conversion would be read from left to right as "1 millimeter (mm) is equal to 1E-1 centimeters," or *1 mm = 0.1 cm*. This method can be applied to any of the conversions listed in these tables when reading *left to right*.

If reading *right to left* the conversion should be read as "one (1) of the unit in the right column is equal to the inverse of (1 over) the number in the center column of the unit in the left column." For example, using the conversion shown previously, the conversion reading right to left would be "1 inch is equal to the inverse of 3.937E-5 (1/3.937E-5) micrometers," or

$$1\ inch = \frac{1}{3.937E{-}5\ \mu m} = 2.54E4\ \mu m$$

Multiply # of	→→→→→	**by**	→→→→→	**to obtain # of**
to obtain # of	←←←←←	**by**	←←←←←	**Divide # of**

Length

angstroms (Å)	10^{-8}	cm
Å	10^{-10}	m
micrometer (µm)	10^{-3}	mm
µm	10^{-4}	cm
µm	10^{-6}	m
µm	3.937×10^{-5}	in.
mm	10^{-1}	cm
cm	0.3937	in.
cm	3.2808×10^{-2}	ft
cm	10^{-2}	m
m	39.370	in.
m	3.2808	ft
m	1.0936	yd
m	10^{-3}	km
m	6.2137×10^{-4}	miles
km	0.62137	miles
mils	10^{-3}	in.
mils	2.540×10^{-3}	cm
in.	10^{3}	mils
in.	2.5400	cm
ft	30.480	cm
rods	5.500	yd
miles	5280	ft
miles	1760	yd
miles	1.6094	km

Multiply # of	→→→→→	by	→→→→→	to obtain # of
to obtain # of	←←←←←	**by**	←←←←←	**Divide # of**
		Mass		
mg		10^{-3}		g
mg		3.527×10^{-5}		oz avdp
mg		1.543×10^{-2}		grains
g		3.527×10^{-2}		oz avdp
g		10^{-3}		kg
g		980.7		dynes
g		2.205×10^{-3}		lb
kg		2.205		lb
kg		0.0685		slugs
kg		9.807×10^{5}		dynes
lb		4.448×10^{5}		dynes
lb		453.592		g
lb		0.4536		kg
lb		16		oz avdp
lb		0.0311		slugs
dynes		1.020×10^{-3}		g
dynes		2.248×10^{-6}		lb
u (unified--^{12}C scale)		1.66043×10^{-27}		kg
amu (physical--^{16}0 scale)		1.65980×10^{-27}		kg
oz		28.35		g
oz		6.25×10^{-2}		lb

NOTE: Mass to energy conversions under miscellaneous.

Multiply # of	→→→→→	**by**	→→→→→	**to obtain # of**
to obtain # of	←←←←←	**by**	←←←←←	**Divide # of**
		<u>Time</u>		
days		86,400		sec
days		1440		min
days		24		hours
years		3.15576×10^{7}		sec
years		525,960		min
years		8766		hr
years		365.25		days
		<u>Area</u>		
barns		10^{-24}		cm^2
circular mils		7.854×10^{-7}		$in.^2$
cm^2		10^{24}		barns
cm^2		0.1550		$in.^2$
cm^2		1.076×10^{-3}		ft^2
cm^2		10^{-4}		m^2
ft^2		929.0		cm^2
ft^2		144		in^2
ft^2		9.290×10^{-2}		m^2
$in.^2$		6.452		cm^2
$in.^2$		6.944×10^{-3}		ft^2
$in.^2$		6.452×10^{-4}		m^2
m^2		1550		$in.^2$
m^2		10.76		ft^2
m^2		1.196		yd^2
m^2		3.861×10^{-7}		sq mi

Multiply # of	→→→→→	**by**	→→→→→	**to obtain # of**
to obtain # of	←←←←←	**by**	←←←←←	**Divide # of**

Volume

cm^3 (cc)	0.99997	ml
cm^3	6.1023×10^{-2}	$in.^3$
cm^3	10^{-6}	m^3
cm^3	9.9997×10^{-4}	liters
cm^3	3.5314×10^{-5}	ft^3
m^3	35.314	ft^3
m^3	2.642×10^{2}	gal
m^3	9.9997×10^{2}	liters
$in.^3$	16.387	cm^3
$in.^3$	5.787×10^{-4}	ft^3
$in.^3$	1.639×10^{-2}	liters
$in.^3$	4.329×10^{-3}	gal
ft^3	2.832×10^{-2}	m^3
ft^3	7.481	gal
ft^3	28.32	liters
ft^3	1728	$in.^3$
gal (U.S.)	231.0	$in.^3$
gal	0.13368	ft^3
liters	33.8147	fluid oz
liters	1.05671	quarts
liters	0.26418	gal
gm moles (gas)	22.4	liters (s.t.p.)

Multiply # of	→→→→→	by	→→→→→	to obtain # of
to obtain # of	←←←←←	**by**	←←←←←	**Divide # of**
		Density		
cm^3/g		1.602×10^{-2}		ft^3/lb
ft^3/lb		62.43		cm^3/g
g/cm^3		62.43		lb/ft^3
lb/ft^3		1.602×10^{-2}		g/cm^3
$lb/in.^3$		27.68		g/cm^3
lb/gal		0.1198		g/cm^3
		Radiological Units		
becquerel		2.703×10^{-11}		curies
curies		3.700×10^{10}		dis/sec
curies		2.220×10^{12}		dis/min
curies		10^3		millicuries
curies		10^6		microcuries
curies		10^{12}		picocuries
curies		10^{-3}		kilocuries
curies		3.700×10^{10}		becquerel
dis/min		4.505×10^{-10}		millicuries
dis/min		4.505×10^{-7}		microcuries
dis/sec		2.703×10^{-8}		millicuries
dis/sec		2.703×10^{-5}		microcuries
kilocuries		10^3		curies
microcuries		3.700×10^4		dis/sec
microcuries		2.220×10^6		dis/min
millicuries		3.700×10^7		dis/sec
millicuries		2.220×10^9		dis/min

Multiply # of	→→→→→	**by**	→→→→→	**to obtain # of**
to obtain # of	←←←←←	**by**	←←←←←	**Divide # of**
		Radiological Units		
becquerel		2.703×10^{-11}		curies
curies		3.700×10^{10}		dis/sec
		Radiological Units (continued)		
R		2.58×10^{-4}		C/kg of air
R		1		esu/cm^3 of air (s.t.p.)
R		2.082×10^{9}		ion prs/cm^3 of air (s.t.p.)
R		1.610×10^{12}		ion prs/g of air
R (33.7 eV/ion pr.)		7.02×10^{4}		MeV/cm^3 of air (s.t.p.)
R (33.7 eV/ion pr.)		5.43×10^{7}		MeV/g of air
R (33.7 eV/ion pr.)		86.9		ergs/g of air
R (33.7 eV/ion pr.)		2.08×10^{-6}		g-cal/g of air
R (33.7 eV/ion pr.)		≈98		ergs/g of soft tissue
rads		0.01		gray
rads		0.01		J/kg
rads		100		ergs/g
rads		8.071×10^{4}		MeV/cm^3 or air (s.t.p.)
rads		6.242×10^{7}		MeV/g
rads		10^{-5}		watt-sec/g
rads (33.7 eV/ion pr.)		2.39×10^{9}		ion prs/cm^3 of air (s.t.p.)
gray		100		rad
rem		0.01		sievert
sievert		100		rem

Multiply # of	→→→→→	**by**	→→→→→	**to obtain # of**
to obtain # of	←←←←←	**by**	←←←←←	**Divide # of**

Radiological Units

becquerel	2.703×10^{-11}	curies
curies	3.700×10^{10}	dis/sec

Radiological Units (continued)

µCi/^{3} (µCi/ml)	2.22×10^{12}	dpm/m^{3}
µCi/cm^{3}	2.22×10^{9}	dpm/liter
dpm/m^{3}	0.4505	pCi/m^{3}

Energy

Btu	1.0548×10^{3}	joules (absolute)
Btu	0.25198	kg-cal
Btu	1.0548×10^{10}	ergs
Btu	2.930×10^{-4}	kW-hr
Btu/lb	0.556	g-cal/g
eV	1.6021×10^{-12}	ergs
eV	1.6021×10^{-19}	joules (abs)
eV	10^{-3}	keV
eV	10^{-6}	MeV
ergs	10^{-7}	joules (abs)
ergs	6.2418×10^{5}	MeV
ergs	6.2418×10^{11}	eV
ergs	1.0	dyne-cm
ergs	9.480×10^{-11}	Btu
ergs	7.375×10^{-8}	ft-lb
ergs	2.390×10^{-8}	g-cal

Multiply # of	→→→→→	by	→→→→→	to obtain # of
to obtain # of	←←←←←	**by**	←←←←←	**Divide # of**
		Energy		
Btu		1.0548×10^{3}		joules (absolute)
Btu		0.25198		kg-cal
		Energy (continued)		
ergs		1.020×10^{-3}		g-cm
gm-calories		3.968×10^{-3}		Btu
gm-calories		4.186×10^{7}		ergs
joules (abs)		10^{7}		ergs
joules (abs)		0.7376		ft-lb
joules (abs)		9.480×10^{-4}		Btu
g-cal/g		1.8		Btu/lb
kg-cal		3.968		Btu
kg-cal		3.087×10^{3}		ft-lb
ft-lb		1.356		joules (abs)
ft-lb		3.239×10^{-4}		kg-cal
kW-hr		2.247×10^{19}		MeV
kW-hr		3.60×10^{13}		ergs
MeV		1.6021×10^{-6}		ergs

NOTE: Energy to mass conversion under miscellaneous

Multiply # of	→→→→→	**by**	→→→→→	**to obtain # of**
to obtain # of	←←←←←	**by**	←←←←←	**Divide # of**
		Fission		
Btu		1.28×10^{-8}		grams ^{235}U fissioned[b]
Btu		1.53×10^{-8}		grams ^{235}U destroyed[b,c]
Btu		3.29×10^{13}		fissions
fission of 1 g ^{235}U		1		megawatt-days
fissions		8.9058×10^{-18}		kilowatt-hours
fissions[b]		3.204×10^{-4}		ergs
kilowatt-hours		2.7865×10^{17}		^{235}U fission neutrons
kilowatts per kilogram ^{235}U		2.43×10^{10}		average thermal neutron flu× in fuel[b,d]
megawatt-days per ton U		1.174×10^{-4}		% U atoms fissioned[e]
megawatts per ton U		$2.68 \times 10^{10}/E^{f}$		average thermal neutron flu× in fuel[b]
neutrons per kilobarn		1×10^{21}		neutrons/cm^2
watts		3.121×10^{10}		fissions/sec

[b] At 200 MeV/fission.
[c] Thermal neutron spectrum (α = 0.193).
[d] õ(fission = 500 barns).
[e] At 200 MeV fission, in ^{235}U-^{238}U mi×ture of low ^{235}U content.
[f] E = enrichment in grams ^{235}U/gram total. No other fissionable isotope present.

Multiply # of	→→→→→	**by**	→→→→→	**to obtain # of**
to obtain # of	←←←←←	**by**	←←←←←	**Divide # of**

Miscellaneous

radians	57.296	degrees
eV	1.78258×10^{-33}	grams
eV	1.07356×10^{-9}	u
erg	1.11265×10^{-21}	grams
proton masses	938.256	MeV
neutron masses	939.550	MeV
electron masses	511.006	keV
u (amu on ^{12}C scale)	931.478	MeV

Temperature

$$^\circ C = \frac{(^\circ F - 32)}{1.8} \qquad ^\circ C = (^\circ F - 32)\left(\frac{5}{9}\right)$$

$$^\circ F = 1.8(^\circ C) + 32 \qquad ^\circ F = \left(\frac{9}{5}\right)(^\circ C) + 32$$

$$^\circ K = {}^\circ C + 273.16$$

Wavelength to Energy Conversion

keV = 12.40/Å
eV = 1.240×10^{-6}/m