

Standard Units of Measure

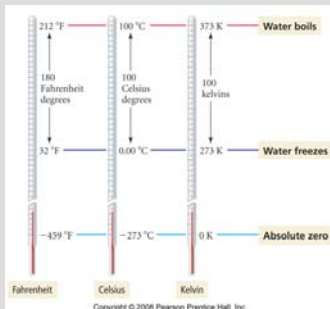
The Standard Units

- Scientists have agreed on a set of international standard units for comparing all our measurements called the SI units
 - *Système International* = International System

Quantity	Unit	Symbol
length	meter	m
mass	kilogram	kg
time	second	s
temperature	kelvin	K

Temperature Scales

- Fahrenheit Scale, °F
 - used in the U.S.
- Celsius Scale, °C
 - used in all other countries
- Kelvin Scale, K
 - absolute scale
 - no negative numbers
 - directly proportional to average amount of kinetic energy
 - 0 K = absolute zero



Fahrenheit vs. Celsius

- a Celsius degree is 1.8 times larger than a Fahrenheit degree
- the standard used for 0° on the Fahrenheit scale is a lower temperature than the standard used for 0° on the Celsius scale

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

Kelvin vs. Celsius

- the size of a “degree” on the Kelvin scale is the same as on the Celsius scale
 - though technically, we don’t call the divisions on the Kelvin scale degrees; we called them kelvins!
 - so 1 kelvin is 1.8 times larger than 1°F
- the 0 standard on the Kelvin scale is a much lower temperature than on the Celsius scale

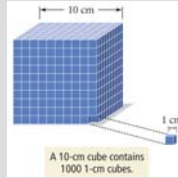
$$\text{K} = ^{\circ}\text{C} + 273.15$$

Common Prefix Multipliers in the SI System

Prefix	Symbol	Decimal Equivalent	Power of 10
mega-	M	1,000,000	Base x 10 ⁶
kilo-	k	1,000	Base x 10 ³
deci-	d	0.1	Base x 10 ⁻¹
centi-	c	0.01	Base x 10 ⁻²
milli-	m	0.001	Base x 10 ⁻³
micro-	μ or mc	0.000 001	Base x 10 ⁻⁶
nano-	n	0.000 000 001	Base x 10 ⁻⁹
pico	p	0.000 000 000 001	Base x 10 ⁻¹²

Volume

- Derived unit
 - any length unit cubed
- Measure of the amount of space occupied
- SI unit = cubic meter (m³)
- Commonly measure solid volume in cubic centimeters (cm³)
- Commonly measure liquid or gas volume in milliliters (mL)
 - 1 mL = 1 cm³



Common Units and Their Equivalents

Mass

- 1 kilogram (kg) = 2.205 pounds (lb)
- 1 pound (lb) = 453.59 grams (g)
- 1 ounce (oz) = 28.35 grams (g)

Volume

- 1 liter (L) = 1000 milliliters (mL)
- 1 liter (L) = 1000 cubic centimeters (cm³)
- 1 liter (L) = 1.057 quarts (qt)
- 1 U.S. gallon (gal) = 3.785 liters (L)

Density

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

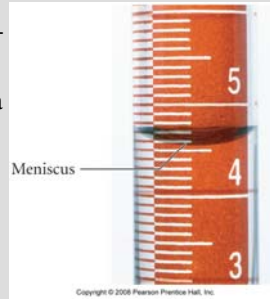
- For equal volumes, denser object has larger mass
- For equal masses, denser object has smaller volume
- Heating an object generally causes it to expand, therefore the density changes with temperature

Substance	Density (g/cm ³)
Charcoal (from oak)	0.57
Ethanol	0.789
Ice	0.917 (at 0 °C)
Water	1.00 (at 4 °C)
Sugar (sucrose)	1.58
Table salt (sodium chloride)	2.16
Glass	2.6
Aluminum	2.70
Titanium	4.51
Iron	7.86
Copper	8.96
Lead	11.4
Mercury	13.55
Gold	19.3
Platinum	21.4

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What Is a Measurement?

- quantitative observation
- comparison to an agreed-upon standard
- every measurement has a number and a unit

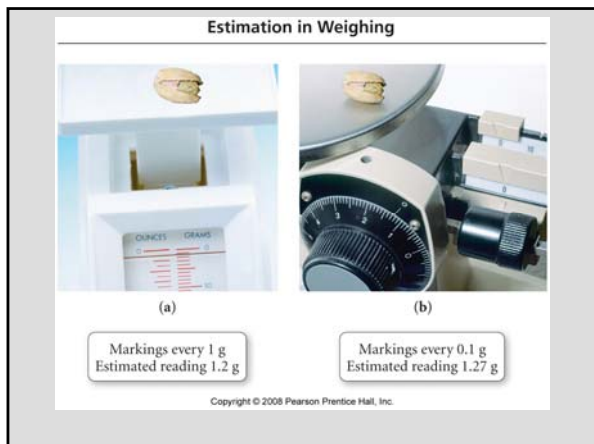


A Measurement

- the unit tells you what standard you are comparing your object to
- the number tells you
 1. what multiple of the standard the object measures
 2. the uncertainty in the measurement
- scientific measurements are reported so that every digit written is certain, except the last one which is estimated

Estimating the Last Digit

- for instruments marked with a scale, you get the last digit by estimating between the marks
 - if possible
- mentally divide the space into 10 equal spaces, then estimate how many spaces over the indicator mark is



Significant Figures

- the non-place-holding digits in a reported measurement are called **significant figures**
 - some zeros in a written number are only there to help you locate the decimal point
- significant figures tell us the range of values to expect for repeated measurements
 - the more significant figures there are in a measurement, the smaller the range of values is

12.3 cm
has **3** sig. figs.
and its range is
12.2 to 12.4 cm

12.30 cm
has **4** sig. figs.
and its range is
12.29 to 12.31 cm

Counting Significant Figures

- 1) All non-zero digits are significant
 - 1.5 has 2 sig. figs.
- 2) Interior zeros are significant
 - 1.05 has 3 sig. figs.
- 3) Leading zeros are **NOT** significant
 - 0.001050 has 4 sig. figs.
 - 1.050 x 10⁻³

Counting Significant Figures

- 4) Trailing zeros may or may not be significant
- 1) Trailing zeros after a decimal point are significant
 - 1.050 has 4 sig. figs.
 - 2) Zeros at the end of a number without a written decimal point are ambiguous and should be avoided by using scientific notation
 - if 150 has 2 sig. figs. then 1.5×10^2
 - but if 150 has 3 sig. figs. then 1.50×10^2

Significant Figures and Exact Numbers

- Exact numbers have an unlimited number of significant figures
 - A number whose value is known with complete certainty is **exact**
 - from counting individual objects
 - from definitions
 - 1 cm is exactly equal to 0.01 m
 - from integer values in equations
 - in the equation for the radius of a circle, the 2 is exact
- radius of a circle = $\frac{\text{diameter of a circle}}{2}$

Example 1.5 Determining the Number of Significant Figures in a Number

How many significant figures are in each of the following?

- 0.04450 m 4 sig. figs., the digits 4 and 5, and the trailing 0
- 5.0003 km 5 sig. figs., the digits 5 and 3, and the interior 0's
- 10 dm = 1 m infinite number of sig. figs., exact numbers
- 1.000×10^5 s 4 sig. figs., the digit 1, and the trailing 0's
- 0.00002 mm 1 sig. fig., the digit 2, not the leading 0's
- 10,000 m Ambiguous, generally assume 1 sig. fig.

Multiplication and Division with Significant Figures

- when multiplying or dividing measurements with significant figures, the result has the same number of significant figures as the measurement with the fewest number of significant figures

$$\begin{array}{ccccccc} 5.02 & \times & 89,665 & \times & 0.10 & = & 45.0118 = 45 \\ 3 \text{ sig. figs.} & & 5 \text{ sig. figs.} & & 2 \text{ sig. figs.} & & 2 \text{ sig. figs.} \\ 5.892 & \div & 6.10 & = & 0.96590 & = & 0.966 \\ 4 \text{ sig. figs.} & & 3 \text{ sig. figs.} & & 5 \text{ sig. figs.} & & 3 \text{ sig. figs.} \end{array}$$

Addition and Subtraction with Significant Figures

- when adding or subtracting measurements with significant figures, the result has the same number of decimal places as the measurement with the fewest number of decimal places

$$\begin{array}{ccccccc} 5.74 & + & 0.823 & + & 2.651 & = & 9.214 = 9.21 \\ 2 \text{ dec. pl.} & & 3 \text{ dec. pl.} & & 3 \text{ dec. pl.} & & 2 \text{ dec. pl.} \\ 4.8 & - & 3.965 & = & 0.835 & = & 0.8 \\ 1 \text{ dec. pl.} & & 3 \text{ dec. pl.} & & 3 \text{ dec. pl.} & & 1 \text{ dec. pl.} \end{array}$$

Rounding

- when rounding to the correct number of significant figures, if the number after the place of the last significant figure is
 - 0 to 4, round down
 - drop all digits after the last sig. fig. and leave the last sig. fig. alone
 - add insignificant zeros to keep the value if necessary
 - 5 to 9, round up
 - drop all digits after the last sig. fig. and increase the last sig. fig. by one
 - add insignificant zeros to keep the value if necessary
- to avoid accumulating extra error from rounding, round only at the end, keeping track of the last sig. fig. for intermediate calculations

Both Multiplication/Division and Addition/Subtraction with Significant Figures

- when doing different kinds of operations with measurements with significant figures, do whatever is in parentheses first, evaluate the significant figures in the intermediate answer, then do the remaining steps

$$3.489 \times (5.67 - 2.3) =$$

$$3.489 \times 3.37 = 12$$

3 sig
2 dp
1 dp
2 sig
2 sig

Example 1.6 Perform the following calculations to the correct number of significant figures

- a) $1.10 \times 0.5120 \times 4.0015 \div 3.4555$
- b)
$$\begin{array}{r} 0.355 \\ +105.1 \\ -100.5820 \\ \hline \end{array}$$
- c) $4.562 \times 3.99870 \div (452.6755 - 452.33)$
- d) $(14.84 \times 0.55) - 8.02$

Example 1.6 Perform the following calculations to the correct number of significant figures

- a) $1.10 \times 0.5120 \times 4.0015 \div 3.4555 = 0.65219 = 0.652$
- b)
$$\begin{array}{r} 0.355 \\ +105.1 \\ -100.5820 \\ \hline 4.8730 = 4.9 \end{array}$$
- c) $4.562 \times 3.99870 \div (452.6755 - 452.33) = 52.79904 = 53$
- d) $(14.84 \times 0.55) - 8.02 = 0.142 = 0.1$

Precision and Accuracy

Uncertainty in Measured Numbers

- uncertainty comes from limitations of the instruments used for comparison, the experimental design, the experimenter, and nature's random behavior
- to understand how reliable a measurement is we need to understand the limitations of the measurement
- **accuracy** is an indication of how close a measurement comes to the **actual** value of the quantity
- **precision** is an indication of how reproducible a measurement is

Accuracy vs. Precision

