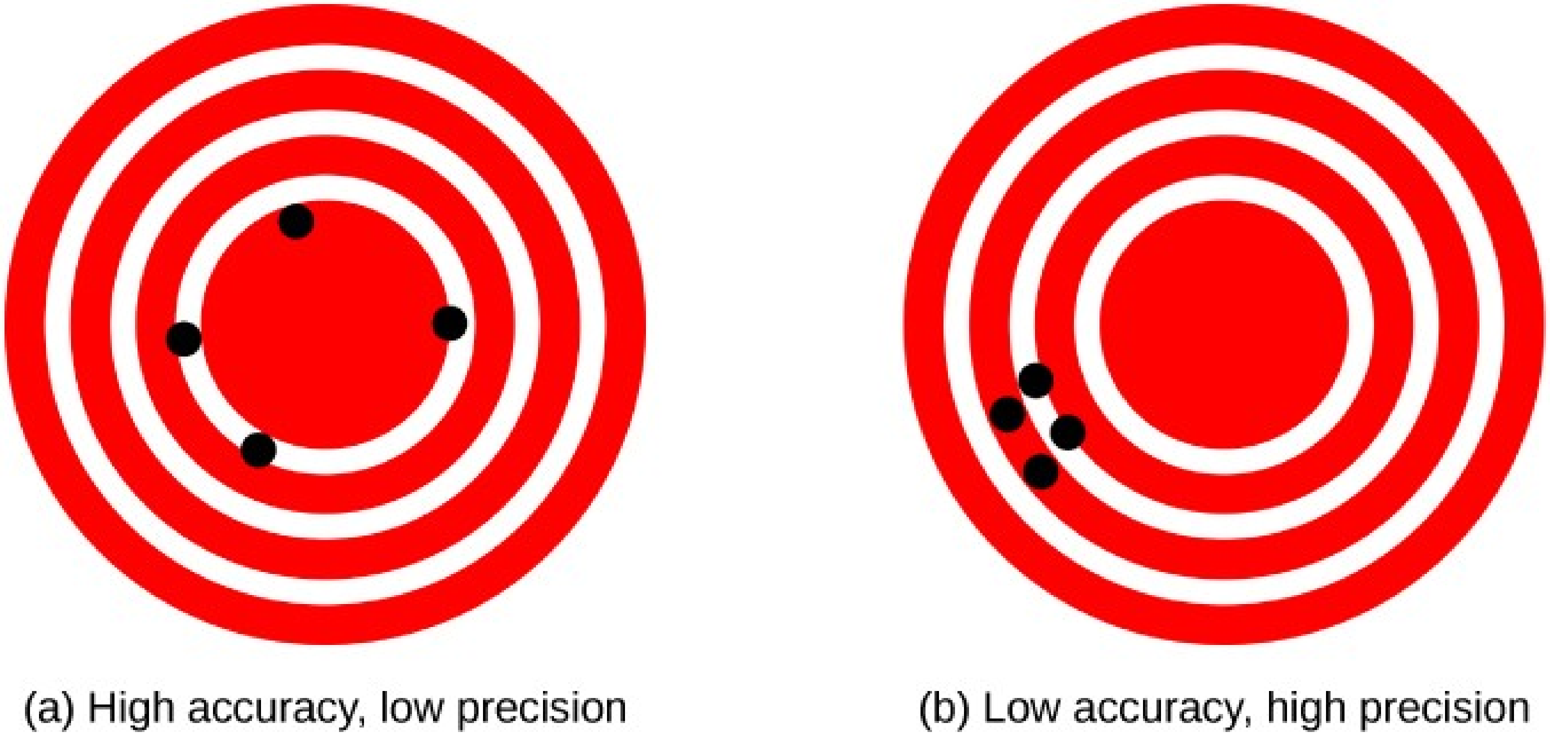
ANNOUNCEMENTS

Homework #1, due Monday, Aug. 27 before class

- Answer conceptual questions 1.4 and 1.8
- Solve problems 1.16 and 1.46

There will be a 5-minute quiz on Monday at beginning of class

ACCURACY AND PRECISION



A GPS attempts to locate a restaurant at the center of the bull's-eye. The black dots represent each attempt to pinpoint the location of the restaurant.

a) The dots are spread out quite far apart from one another, indicating low precision, but they are each rather close to the actual location of the restaurant, indicating high accuracy.

b) The dots are concentrated rather closely to one another, indicating high precision, but they are rather far away from the actual location of the restaurant, indicating low accuracy. (credit a and credit b: modification of works by Dark Evil)

SI UNITS

ISQ Base Quantity	SI Base Unit
Length	meter (m)
Mass	kilogram (kg)
Time	second (s)
Electrical current	ampere (A)
Thermodynamic temperature	kelvin (K)
Amount of substance	mole (mol)
Luminous intensity	candela (cd)

Table 1.1 ISQ Base Quantities and Their SI Units

SI UNITS

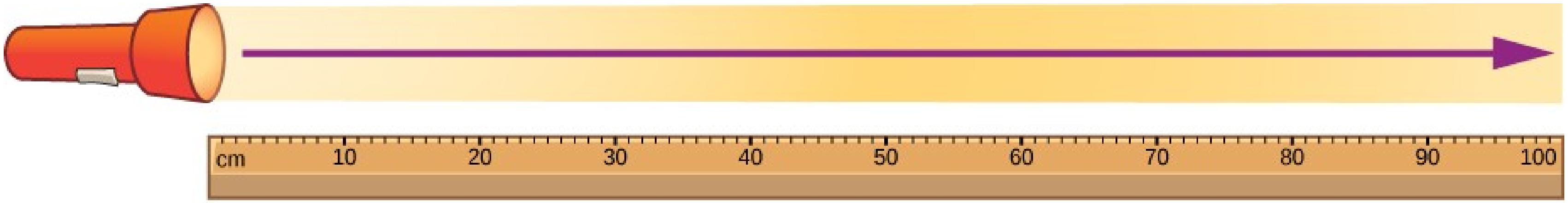
The second

The SI unit for time, the **second** (abbreviated s), has a long history. For many years it was defined as 1/86,400 of a mean solar day. More recently, a new standard was adopted to gain greater accuracy and to define the second in terms of a nonvarying or constant physical phenomenon (because the solar day is getting longer as a result of the very gradual slowing of Earth's rotation). Cesium atoms can be made to vibrate in a very steady way, and these vibrations can be readily observed and counted. In 1967, the second was redefined as the time required for 9,192,631,770 of these vibrations to occur (Figure 1.8). Note that this may seem like more precision than you would ever need, but it isn't—GPSs rely on the precision of atomic clocks to be able to give you turn-by-turn directions on the surface of Earth, far from the satellites broadcasting their location.

SI UNITS

The meter

The SI unit for length is the **meter** (abbreviated m); its definition has also changed over time to become more precise. The meter was first defined in 1791 as 1/10,000,000 of the distance from the equator to the North Pole. This measurement was improved in 1889 by redefining the meter to be the distance between two engraved lines on a platinum–iridium bar now kept near Paris. By 1960, it had become possible to define the meter even more accurately in terms of the wavelength of light, so it was again redefined as 1,650,763.73 wavelengths of orange light emitted by krypton atoms. In 1983, the meter was given its current definition (in part for greater accuracy) as the distance light travels in a vacuum in 1/299,792,458 of a second (Figure 1.9). This change came after knowing the speed of light to be exactly 299,792,458 m/s. The length of the meter will change if the speed of light is someday measured with greater accuracy.



Light travels a distance of 1 meter
in 1/299,792,458 seconds

The meter is defined to be the distance light travels in 1/299,792,458 of a second in a vacuum. Distance traveled is speed multiplied by time.

SI UNITS

The kilogram

The SI unit for mass is the **kilogram** (abbreviated kg); it is defined to be the mass of a platinum–iridium cylinder kept with the old meter standard at the International Bureau of Weights and Measures near Paris. Exact replicas of the standard kilogram are also kept at the U.S. National Institute of Standards and Technology (NIST), located in Gaithersburg, Maryland, outside of Washington, DC, and at other locations around the world. Scientists at NIST are currently investigating two complementary methods of redefining the kilogram (see Figure 1.10). The determination of all other masses can be traced ultimately to a comparison with the standard mass.

METRIC PREFIXES

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

EXAMPLE 1.1

Using Metric Prefixes

Restate the mass $1.93 \times 10^{13}\text{kg}$ using a metric prefix such that the resulting numerical value is bigger than one but less than 1000.

Strategy

Since we are not allowed to “double-up” prefixes, we first need to restate the mass in grams by replacing the prefix symbol k with a factor of 10^3 (see Table 1.2). Then, we should see which two prefixes in Table 1.2 are closest to the resulting power of 10 when the number is written in scientific notation. We use whichever of these two prefixes gives us a number between one and 1000.

Solution

Replacing the k in kilogram with a factor of 10^3, we find that

$$1.93 \times 10^{13}\text{kg} = 1.93 \times 10^{13} \times 10^{3}\text{g} = 1.93 \times 10^{16}\text{g}.$$

From Table 1.2, we see that 10^{16} is between “peta-” (10^{15}) and “exa-” (10^{18}). If we use the “peta-” prefix, then we find that $1.93 \times 10^{16}\text{g} = 1.93 \times 10^{1}\text{Pg}$, since $16 = 1 + 15.$ Alternatively, if we use the “exa-” prefix we find that $1.93 \times 10^{16}\text{g} = 1.93 \times 10^{-2}\text{Eg}$, since $16 = -2 + 18.$ Because the problem asks for the numerical value between one and 1000, we use the “peta-” prefix and the answer is 19.3 Pg.

UNIT CONVERSION AND DIMENSIONAL ANALYSIS

EXAMPLE 1.3

Converting between Metric Units

The density of iron is $7.86\,\text{g/cm}^3$ under standard conditions. Convert this to kg/m^3.

Strategy

We need to convert grams to kilograms and cubic centimeters to cubic meters. The conversion factors we need are $1\,\text{kg} = 10^3\text{g}$ and $1\,\text{cm} = 10^{-2}\text{m}$. However, we are dealing with cubic centimeters $(\text{cm}^3 = \text{cm} \times \text{cm} \times \text{cm})$, so we have to use the second conversion factor three times (that is, we need to cube it). The idea is still to multiply by the conversion factors in such a way that they cancel the units we want to get rid of and introduce the units we want to keep.

Solution

$$7.86\,\frac{\cancel{\text{g}}}{\cancel{\text{cm}}^3} \times \frac{\text{kg}}{10^3\,\cancel{\text{g}}} \times \left(\frac{\cancel{\text{cm}}}{10^{-2}\text{m}}\right)^3 = \frac{7.86}{(10^3)(10^{-6})}\,\text{kg/m}^3 = 7.86 \times 10^3\,\text{kg/m}^3$$

Check your units!

Base Quantity	Symbol for Dimension
Length	L
Mass	M
Time	T
Current	I
Thermodynamic temperature	Θ
Amount of substance	N
Luminous intensity	J

Table 1.3 Base Quantities and Their Dimensions

EXAMPLE 1.5

Checking Equations for Dimensional Consistency

Consider the physical quantities s, v, a, and t with dimensions $[s] = \mathrm{L}$, $[v] = \mathrm{LT}^{-1}$, $[a] = \mathrm{LT}^{-2}$, and $[t] = \mathrm{T}$. Determine whether each of the following equations is dimensionally consistent: (a) $s = vt + 0.5at^2$; (b) $s = vt^2 + 0.5at$; and (c) $v = \sin(at^2/s)$.

Strategy

By the definition of dimensional consistency, we need to check that each term in a given equation has the same dimensions as the other terms in that equation and that the arguments of any standard mathematical functions are dimensionless.

Check dimensional consistency!

EXAMPLE 1.5

Checking Equations for Dimensional Consistency

Consider the physical quantities s, v, a, and t with dimensions $[s] = \mathrm{L}$, $[v] = \mathrm{LT}^{-1}$, $[a] = \mathrm{LT}^{-2}$, and $[t] = \mathrm{T}$. Determine whether each of the following equations is dimensionally consistent: (a) $s = vt + 0.5at^2$; (b) $s = vt^2 + 0.5at$; and (c) $v = \sin(at^2/s)$.

Strategy

By the definition of dimensional consistency, we need to check that each term in a given equation has the same dimensions as the other terms in that equation and that the arguments of any standard mathematical functions are dimensionless.

Solution

a. There are no trigonometric, logarithmic, or exponential functions to worry about in this equation, so we need only look at the dimensions of each term appearing in the equation. There are three terms, one in the left expression and two in the expression on the right, so we look at each in turn:

$$\begin{aligned}
&[s] = \mathrm{L} \\
&[vt] = [v] \cdot [t] = \mathrm{LT}^{-1} \cdot \mathrm{T} = \mathrm{LT}^0 = \mathrm{L} \\
&[0.5at^2] = [a] \cdot [t]^2 = \mathrm{LT}^{-2} \cdot \mathrm{T}^2 = \mathrm{LT}^0 = \mathrm{L}.
\end{aligned}$$

All three terms have the same dimension, so this equation is dimensionally consistent.

EXAMPLE 1.5

Checking Equations for Dimensional Consistency

Consider the physical quantities s, v, a, and t with dimensions $[s] = \mathrm{L}$, $[v] = \mathrm{LT}^{-1}$, $[a] = \mathrm{LT}^{-2}$, and $[t] = \mathrm{T}$. Determine whether each of the following equations is dimensionally consistent: (a) $s = vt + 0.5at^2$; (b) $s = vt^2 + 0.5at$; and (c) $v = \sin(at^2/s)$.

Strategy

By the definition of dimensional consistency, we need to check that each term in a given equation has the same dimensions as the other terms in that equation and that the arguments of any standard mathematical functions are dimensionless.

b. Again, there are no trigonometric, exponential, or logarithmic functions, so we only need to look at the dimensions of each of the three terms appearing in the equation:

$$
\begin{aligned}
[s] &= \mathrm{L} \\
[vt^2] &= [v] \cdot [t]^2 = \mathrm{LT}^{-1} \cdot \mathrm{T}^2 = \mathrm{LT} \\
[at] &= [a] \cdot [t] = \mathrm{LT}^{-2} \cdot \mathrm{T} = \mathrm{LT}^{-1}.
\end{aligned}
$$

None of the three terms has the same dimension as any other, so this is about as far from being dimensionally consistent as you can get. The technical term for an equation like this is *nonsense*.

EXAMPLE 1.5

Checking Equations for Dimensional Consistency

Consider the physical quantities s, v, a, and t with dimensions $[s] = \mathrm{L}$, $[v] = \mathrm{LT}^{-1}$, $[a] = \mathrm{LT}^{-2}$, and $[t] = \mathrm{T}$. Determine whether each of the following equations is dimensionally consistent: (a) $s = vt + 0.5at^2$; (b) $s = vt^2 + 0.5at$; and (c) $v = \sin(at^2/s)$.

Strategy

By the definition of dimensional consistency, we need to check that each term in a given equation has the same dimensions as the other terms in that equation and that the arguments of any standard mathematical functions are dimensionless.

c. This equation has a trigonometric function in it, so first we should check that the argument of the sine function is dimensionless:

$$\left[\frac{at^2}{s}\right] = \frac{[a]\cdot[t]^2}{[s]} = \frac{\mathrm{LT}^{-2}\cdot\mathrm{T}^2}{\mathrm{L}} = \frac{\mathrm{L}}{\mathrm{L}} = 1.$$

The argument is dimensionless. So far, so good. Now we need to check the dimensions of each of the two terms (that is, the left expression and the right expression) in the equation:

$$[v] = \mathrm{LT}^{-1}$$
$$\left[\sin\left(\frac{at^2}{s}\right)\right] = 1.$$

The two terms have different dimensions—meaning, the equation is not dimensionally consistent. This equation is another example of “nonsense.”

UNCERTAINTIES

Percent uncertainty

Another method of expressing uncertainty is as a percent of the measured value. If a measurement A is expressed with uncertainty δA, the **percent uncertainty** is defined as

$$\text{Percent uncertainty} = \frac{\delta A}{A} \times 100\%.$$

EXAMPLE 1.7

Calculating Percent Uncertainty: A Bag of Apples

A grocery store sells 5-lb bags of apples. Let's say we purchase four bags during the course of a month and weigh the bags each time. We obtain the following measurements:

- Week 1 weight: 4.8 lb
- Week 2 weight: 5.3 lb
- Week 3 weight: 4.9 lb
- Week 4 weight: 5.4 lb

We then determine the average weight of the 5-lb bag of apples is 5.1 ± 0.2 lb. What is the percent uncertainty of the bag's weight?

SIGNIFICANT FIGURES

Zeros

Special consideration is given to zeros when counting significant figures. The zeros in 0.053 are not significant because they are placeholders that locate the decimal point. There are two significant figures in 0.053. The zeros in 10.053 are not placeholders; they are significant. This number has five significant figures. The zeros in 1300 may or may not be significant, depending on the style of writing numbers. They could mean the number is known to the last digit or they could be placeholders. So 1300 could have two, three, or four significant figures. To avoid this ambiguity, we should write 1300 in scientific notation as 1.3×10^3, 1.30×10^3, or 1.300×10^3, depending on whether it has two, three, or four significant figures. *Zeros are significant except when they serve only as placeholders*.

Significant figures in calculations

When combining measurements with different degrees of precision, *the number of significant digits in the final answer can be no greater than the number of significant digits in the least-precise measured value*. There are two different rules, one for multiplication and division and the other for addition and subtraction.

1. *For multiplication and division, the result should have the same number of significant figures as the quantity with the least number of significant figures entering into the calculation*. For example, the area of a circle can be calculated from its radius using $A = \pi r^2$. Let's see how many significant figures the area has if the radius has only two—say, $r = 1.2$ m. Using a calculator with an eight-digit output, we would calculate

$$A = \pi r^2 = (3.1415927\ldots) \times (1.2\,\mathrm{m})^2 = 4.5238934\,\mathrm{m}^2.$$