Physics, Mathematics, and the Real World

Physics is a fundamentally human activity. It is a collective expression of the sense of wonder we feel before the rich diversity of the natural universe.

"The most beautiful experience we can have is the mysterious. It is the fundamental emotion that stands at the cradle of true art and true science."

—ALBERT EINSTEIN

Your gut-level "Oh, wow!" response when you witness a spectacular sunset is an expression of wonder. But wonder isn’t just "Oh, wow!" and certainly not "Oh, wow! Now let’s go to dinner." Wonder couples the "Oh, wow!" response with curiosity, with the urge to explore what you’re seeing. In this sense, science and the arts are somewhat alike.

"There is no science without fancy, no art without facts."

—VLADIMIR NABOKOV

But physics, like all true science, goes an important step further by aspiring to collective understanding—not just how I understand something but reaching agreement on how we understand it.

"Art is I. Science is we."

—CLAUDE BERNARD, nineteenth-century physiologist
Reaching agreement is not merely a matter of majority rule. Physicists must exchange ideas and verify one another's observations and reasoning, testing whether behavior implied by the reasoning is borne out by further observations. Thus, they carry on the very human activity of consensus building in careful and refined ways. Physics is a consensual body of knowledge to which many individuals have contributed. Humans are social animals, and physics is very fundamentally the activity of a social species.

1-1 What Is Physics?

The activity of trying to understand is much the same in any area of knowledge. Imagine yourself as a small child, watching an older sibling playing soccer or baseball. Eventually, by careful observation and reasoning, you begin to figure out the rules of the game. In much the same way, we are all observers of the great game of nature, and after much observation we may find that certain rules appear to be followed without exception: the sun always rises in the east and sets in the west, a rock released in midair always falls down, hot and cold objects mixed together always reach a common in-between temperature. Physics is the activity of trying to find the rules by which nature plays.

Underlying physics, therefore, or any science for that matter, is the belief that there are rules, that nature is in some sense orderly. But that doesn't mean that the rules are easy to figure out.

Case 1-1 Inferring the Rules of Baseball from an Obstructed Viewpoint

Imagine yourself always watching baseball from the same overpriced but lousy seat in the ballpark. Your seat has an obstructed view (see Figure 1-1); you can see the batter, but not the catcher, the home plate umpire, or the path by which either takes or leaves the field. You are also too far away to hear what is happening on the field. Even if you start out knowing absolutely nothing about the game, you might quickly infer that there is a catcher from the way the ball keeps coming back from the unseen region. STOP & think

To infer something is to think that it is implied by the evidence. On what basis might you infer the existence of a home plate umpire?

Figuring out the whole conceptual structure of balls and strikes is more difficult, but at length you think you have it worked out. Although you cannot see the scoreboard, you know whether the home crowd reacts positively or negatively after each pitch. You become more confident about your understanding each time a batter walks off the field after a third strike. Then one day a batter swings and misses at a third strike and runs to first base. This is an anomalous event—one that doesn't fit the previously established pattern. Baseball, it turns out, has a dropped third strike rule: If the catcher fails to catch the pitch on a third strike, the batter can attempt to advance to first base, and must be thrown out like any other base runner.

If you have never seen the catcher, though you’ve inferred that one exists, it is more difficult to figure out what is happening. You must build a mental picture of what the catcher is doing that is consistent with what you can see. But that picture is tentative, always subject to revision—literally picturing anew—if it turns out to conflict with some later observation.

Your understanding of the rules governing balls and strikes must also be considered tentative. You can never be sure you have seen all there is to see and that there will not be some unexpected event like a dropped third strike to make you reconsider. When that does happen, it is not the rules of baseball that have changed, only your understanding of what those rules are.
Our view of nature is also obstructed. There are aspects of the game of nature that our senses cannot detect. For example, humans never see ultraviolet radiation or X rays, but we infer from the exposure of photographic film that they exist. The details of the exposure in turn let us draw inferences about the objects that emit them, even objects thousands of light years away.

As we do for the baseball game, we assume that the rules of nature exist and are unchanging. But as in Case 1-1, the activity of reaching an understanding of those rules is endless. Our present understanding must always be viewed as tentative. It is a model, a mental picture in which the pieces of the picture obey the rules we’ve deduced. It is a good model to the extent that the objects in the real world behave as our mental picture would lead us to expect. In other words, we consider a model or theory valid, and potentially useful and productive, if it fits with all the evidence so far.

✦ THE SCOPE OF PHYSICS Because the behaviors we encounter in the natural universe are so overwhelmingly diverse, physics must cover a broad range of topics, though it turns out that underlying much of that diversity are the rules in a few fundamental areas. You will find that the areas listed here overlap and interconnect in surprising ways.

The study of motion and forces encompasses the orbits of planets and the paths of comets, the spin on a curve ball or the hovering of a Frisbee, and the aerodynamics of a supersonic jet or of the prehistoric forerunners of present-day birds (Figure 1-2).

The study of electricity and magnetism provides insight into phenomena as diverse as:

- Atmospheric effects, such as lightning and the aurora borealis, or northern lights.
- The technology underlying television, personal computers, use of solar energy, and a vast array of basic and not-so-basic appliances and instrumentation.
- The details of chemical reactions, including those (collectively called your metabolism) that occur in your body.

Figure 1-2 Flyers old and new. The study of motion and forces can help us understand the aerodynamics of (a) the archaeopteryx, a prehistoric ancestor of today’s birds, or (b) the next-generation supersonic passenger jet as envisioned by NASA.

Models: Although hobbyists, architects, and others may build models out of wood, Plexiglas, and so on, that people can see and hold, physicists build models in their heads. The model is the idea itself; it is a theory.
Properties of new materials, such as high-temperature superconductors.

- The transmission of signals in your own nervous system by means of charged particles moving in electric fields.

- The electrophoresis technique used in genetics and in blood identification in criminal and paternity cases to compare samples of DNA by looking at the different flow rates of its component parts in an electric field.

**Optics**, the study of light and related emissions (from X rays to radio waves), relates to:

- The working of your eyeglasses or microscope.

- The diverse ways in which different living things see (e.g., bees view the world through compound eyes and can see ultraviolet though we cannot; see Figure 1-3).

- Why things look as they do (a rainbow, say, or a blue sky or a red sunset).

- The use of X rays to analyze the submicroscopic structure of crystals and large molecules, a technique that has been of interest to geologists, to solid state or condensed matter physicists, and to biologists trying to determine the structure of DNA.

- The development and use of lasers and holography.

- The identification of substances by the light and related emissions that they give off, and the application of this procedure (called spectroscopy) to emissions from distant stars, quasars, and so on. This has enabled us to develop a considerable understanding, all of it inferred, of the composition of the objects that populate outer space and of the origins of our universe. In the late twentieth century the study of those origins, called cosmology, evolved rapidly from philosophical speculation to hard science.

Studies of heat and temperature apply equally to matters of auto engine efficiency, the risks of hot tubs, home insulation, determining whether dinosaurs were warm- or cold-blooded, the risks to global climate of increasing carbon dioxide and other gases in the atmosphere, or the heat generation processes in the interiors of stars.

Physicists at the cutting edge of physics still need a thorough understanding of these basic areas, called classical physics, whether they are studying the smallest known components of the universe in elementary particle physics or the largest in astrophysics and cosmology. Whether working on one of the world’s largest high-energy particle accelerators (Figure 1-4a), or on the Hubble Space Telescope (Figure 1-4b), they are constantly considering how the basic underlying rules play out in new and unexpected contexts. But they are also asking where our understanding breaks down and where we may have to infer new or revised rules.
1-2 Measurement and Units

“The supreme task of the physicist is to arrive at those universal elementary laws from which the cosmos can be built up by pure deduction. There is no logical path to these laws; only intuition, resting on sympathetic understanding, can lead to them.” —ALBERT EINSTEIN

Before you can figure out the laws or rules things follow, you must first observe them. To develop a “sympathetic understanding,” you need to become familiar with how things behave. Physics necessarily begins with what we detect by means of our senses. But then, to develop a shared understanding, we must be able to agree in detail on what we have observed and we must be able to communicate what we see without risk of being misunderstood. It is too vague, for example, to say that a ball player is large. Which athlete in Figure 1-5 is larger? By what standard? It would be clearer to give each athlete’s height, weight, or shoulder width. We could agree on how the measurements compare, no matter which athlete we call larger.

In physics, therefore, observations are generally quantitative, that is, they are expressed in terms like height and weight that can have numerical values. Something that can have a numerical value is called a quantity. Speed, area, and the price per pound of potatoes are all examples of quantities. For the remainder of this chapter, we will focus on some aspects of how we treat quantities. As we do so, bear in mind Einstein’s emphasis on intuition and a sympathetic understanding of how things behave. Physics is not just mathematics, or even primarily mathematics. Your use of mathematics has to be guided by thinking about how things behave and what rules or physical principles govern their behavior.

Figure 1-5 Comparing the “largeness” of athletes. Who is “larger,” the tall, thin basketball player or the shorter but much broader football player?
Figure 1-6 Balancing a laboratory rat. The three standard 1-kg masses just balance a (very large) 3-kg laboratory rat.

Measurements are quantitative observations made in comparison with a **standard**, which we call a unit of measurement. For many years, the distance between two fine lines engraved on a bar of platinum-iridium alloy kept at the International Bureau of Weight and Measures outside Paris was the internationally recognized standard meter. The standard meter is now defined as the length of the path traveled by light in a vacuum during a time interval of $\frac{1}{299\,792\,458}$ second. When we say a soccer field is 100 meters long, we mean it is 100 times as long as the carefully marked-off unit called a meter.

Likewise, we can establish a unit of mass by choosing a particular block of metal: a cylinder of platinum-iridium alloy serves this purpose at the International Bureau of Weights and Measures. Another mass is equal to this mass if it just balances it on an equal arm balance in a uniform gravitational environment. If we call our standard unit of mass a **kilogram**, a rat will have a mass of 3 kg if it just balances three of these units on a balance scale (Figure 1-6). For now, what we will mean by the mass of an object is the number of standard units that it can counterbalance on an equal arm balance. Physicists call this an operational definition, because we are defining mass by what we do (the “operation” we perform) to measure it.

Crudely speaking, mass measured in this way gives us a feel for “how much stuff” we have. But mass is different from weight. Placed on the moon, the contents of each pan in Figure 1-6 will weigh less, but the rat still counterbalances the three standard kilograms and thus still has a mass of 3 kg.

To measure **time duration**, we must choose the duration of some particular happening as our standard or unit. But we cannot pick something that happens just once, because we could never go back and check it. How would we know if our clock has sped up if the standard is gone? We therefore have to pick a happening that keeps repeating itself, such as the back-and-forth swing of a pendulum. Such occurrences are said to be **cyclical** or **periodic**. Two well-known examples of periodic occurrences or cycles used as standard units of time duration are the duration of a complete rotation of Earth on its axis, which we call a day, and the duration of one complete orbit of Earth about the sun, which we call a year. These and other units are now taken as multiples of the second, which is itself defined as a cycle characteristic of a particular type of radiation emitted by cesium atoms.

The units most commonly used in physics are the units of the Système Internationale (SI units), a current version of the metric system generally agreed on by the international scientific community and in extensive everyday use in nearly every country in the world except the United States. The basic SI units for fundamental quantities, including those we have considered so far, are listed in Table 1-1.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>SI Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>meter (m)</td>
</tr>
<tr>
<td>Mass</td>
<td>kilogram (kg)</td>
</tr>
<tr>
<td>Time duration</td>
<td>second (s)</td>
</tr>
<tr>
<td>Electric current</td>
<td>ampere (A)</td>
</tr>
<tr>
<td>Temperature</td>
<td>kelvin (K)</td>
</tr>
<tr>
<td>Amount of substance</td>
<td>mole (mol)</td>
</tr>
<tr>
<td>Luminous intensity</td>
<td>candela (cd)</td>
</tr>
</tbody>
</table>

SI units are sometimes called **mks** (meter-kilogram-second) units. Other larger or smaller units of these quantities are expressed as multiples of basic units by a system of prefixes. These prefixes, which represent multiplication by different powers, are summarized in Table 1-2. For instance, 1 nanosecond is $1 \times 10^{-9}$ seconds, and 5 kilograms is $5 \times 10^3$ grams. In the latter case, it is the kilogram that we take as basic, not the gram.

By basic units, we mean that units of all other quantities can be defined in terms of these. In contrast to basic units, those are called derived units. For instance, the unit of two-dimensional space or area is a square 1 m by 1 m, called a square meter. A rectangle measuring 3 m by 2 m (Figure 1-7a) thus has an area equal to length $\times$ width $= 3 \, m \times 2 \, m = 6 \, m^2$ because there are three rows of two square-meter squares in this rectangle. When we multiply units as well as numbers, we get $m^2$ as units of area. To make this meaningful, we choose to identify 1 “$m^2$” as a square meter.

We can similarly derive units of three-dimensional space (volume). If we have a block measuring 3 m by 2 m by 4 m (Figure 1-7b), we can picture it as made up of cubes 1 m on a side, which we call cubic meters. As the figure shows,
each layer has three rows of two cubes (six cubes in all), and there are four layers, so in all there are $3 \times 2 \times 4 = 24$ cubic meters. In effect, we have multiplied length by width by height to get volume ($V = lwh$). Multiplying units as well as numbers gives this is meaningful only if we identify $m^3$ as a cubic meter.

To get a volume in meters, length, width, and height must all be in meters. This is always the case: To get a derived quantity in standard units, the quantities you use to calculate it must be in standard units. Some derived units have names that obscure their derivation. It will turn out, for example, that the SI unit of energy is $kg \cdot m^2/s^2$, which is called a joule. In energy calculations, your energy will not come out in joules unless you are working with mass in kilograms, length in meters, and time duration in seconds.

The basic quantities involved in the definition of a derived quantity are called its dimensions. If we represent the basic quantities mass, length, and time duration by the bracketed symbols $[M]$, $[L]$, and $[T]$, then the dimensions of energy are $[MLT]$. Appendix F provides a fuller treatment of dimensions and of a method called dimensional analysis for checking dimensions to see whether there is an error in a mathematical relationship among physical quantities.

**CONVERTING UNITS** When you do a calculation, the available values of quantities are not always in the units you want. In that case, you have to convert units. This is often true outside of physics as well. A change machine, for example, is a device that converts from dollars to quarters. You end up with the same value, but expressed in different units.

To convert units, you first need a conversion relationship, such as “one dollar equals four quarters” or $1 \text{ min} = 60 \text{ s}$. Dividing both sides of the equation by the same thing, you can arrive at either

$$\frac{1 \text{ min}}{60 \text{ s}} = \frac{60 \text{ s}}{60 \text{ s}} = 1 \quad \text{or} \quad 1 = \frac{1 \text{ min}}{1 \text{ min}} = \frac{60 \text{ s}}{1 \text{ min}}.$$

Thus you can write one (1) as either $1 = \frac{1 \text{ min}}{60 \text{ s}}$ or $60 \text{ s} = 1 \text{ min}$. Multiplying by one never changes the value of something. When we convert, we want to change the units in which a value is expressed without changing the value. We can do that by multiplying by one (1) written in suitable form:

To convert 5 min to seconds:

$$5 \text{ min} = 5 \frac{\text{min}}{1 \text{ min}} \times \frac{60 \text{ s}}{1 \text{ min}} = 300 \text{ s}$$

To convert 300 s to min:

$$300 \text{ s} = 300 \frac{\text{s}}{60 \text{ s}} \times \frac{1 \text{ min}}{60 \text{ s}} = 5 \text{ min}$$

**Table 1-2 Prefixes for SI (or Metric) Units**

<table>
<thead>
<tr>
<th>The Prefix...</th>
<th>Is Abbreviated...</th>
<th>And Means...</th>
<th>The Prefix...</th>
<th>Is Abbreviated...</th>
<th>And Means...</th>
</tr>
</thead>
<tbody>
<tr>
<td>yetta-</td>
<td>Y</td>
<td>$10^{24}$</td>
<td>centi-</td>
<td>c</td>
<td>$10^{-2}$</td>
</tr>
<tr>
<td>zetta-</td>
<td>Z</td>
<td>$10^{21}$</td>
<td>milli-</td>
<td>m</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>exa-</td>
<td>E</td>
<td>$10^{18}$</td>
<td>micro-</td>
<td>μ (mu)</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>peta-</td>
<td>P</td>
<td>$10^{15}$</td>
<td>nano-</td>
<td>n</td>
<td>$10^{-9}$</td>
</tr>
<tr>
<td>tera-</td>
<td>T</td>
<td>$10^{12}$</td>
<td>pico- or μμ</td>
<td>p</td>
<td>$10^{-12}$</td>
</tr>
<tr>
<td>giga-</td>
<td>G</td>
<td>$10^{9}$</td>
<td>femto-</td>
<td>f</td>
<td>$10^{-15}$</td>
</tr>
<tr>
<td>mega-</td>
<td>M</td>
<td>$10^{6}$</td>
<td>atto-</td>
<td>a</td>
<td>$10^{-18}$</td>
</tr>
<tr>
<td>kilo-</td>
<td>k</td>
<td>$10^{3}$</td>
<td>zepto-</td>
<td>z</td>
<td>$10^{-21}$</td>
</tr>
<tr>
<td>hecto-</td>
<td>h</td>
<td>$10^{2}$</td>
<td>yocto-</td>
<td>y</td>
<td>$10^{-24}$</td>
</tr>
<tr>
<td>deka-</td>
<td>da</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>deci-</td>
<td>d</td>
<td>$10^{-1}$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 1-7** Units of area and volume.
Like one dollar and four quarters, 300 s is the same value as 5 min, but expressed in different units. In each case, we pick the form of one so that when we multiply, the units we don't want “cancel out,” and we are left with the units we do want.

**PROCEDURE 1-1**

**Converting a Quantity to Different Units**

1. Rewrite your conversion relationship \( x \) first units = \( y \) second units as either
   \[
   \frac{x \text{ first units}}{y \text{ second units}} = 1 \quad \text{or} \quad \frac{y \text{ second units}}{x \text{ first units}} = 1
   \]

2. Multiply the quantity by 1 in whichever of these two forms cancels out the units you don't want and leaves the units you do want in the right place (numerator or denominator).

3. Check to make sure your result makes sense: You should always get more of the smaller unit, fewer of the larger unit.

**Example 1-1 Converting Speed**

For a guided interactive solution, go to Web Example 1-1 at www.wiley.com/college/touger

A bus travels 110 km/h (kilometers per hour) on open highway. What is this speed in standard SI units?

**Brief Solution**

1. Identify the units you want for your answer. In SI, distances are in meters (m) and time durations are in seconds (s).

2. 110 km/h is really a fraction \( \frac{110 \text{ km}}{1 \text{ h}} \) or \( \frac{110 \text{ km}}{1 \text{ h}} \), and means 110 kilometers are traveled in each hour or per hour.

3. Write the conversion relations between the units you start out with and those you want. In this case, it may be easier to convert time in two steps, first from hours to minutes, then from minutes to seconds.

   \[
   1 \text{ km} = 1000 \text{ m} \quad 1 \text{ h} = 60 \text{ min} \quad 1 \text{ min} = 60 \text{ s}
   \]

4. As fractions, these relations become

   \[
   \frac{1 \text{ km}}{1000 \text{ m}} = 1 \quad \frac{1 \text{ h}}{60 \text{ min}} = 1 \quad \frac{1 \text{ min}}{60 \text{ s}} = 1
   \]

5. Multiply by 1 as many times as necessary to get the units you want:

   \[
   \frac{110 \text{ km}}{1 \text{ h}} \times \frac{1000 \text{ m}}{1 \text{ km}} \times \frac{1 \text{ h}}{60 \text{ min}} \times \frac{1 \text{ min}}{60 \text{ s}} = \frac{110 \times 1000 \times 1 \times 1 \text{ m}}{3600 \text{ s}} = 30.6 \text{ m/s}
   \]

**Alternative method.** You can also do unit conversion by substitution. For instance, in Example 1-1 you can substitute 1000 m for 1 km, 60 min for 1 h, and 60 s for 1 min. Thus,

   \[
   110 \text{ km/h} = \frac{110(1000 \text{ m})}{60 \text{ min}} = \frac{110(1000 \text{ m})}{60(60 \text{ s})} = 30.6 \text{ m/s or } 30.6 \text{ m/s}
   \]

◆ Related homework: Problems 1-5, 1-10, 1-11, 1-12, and 1-20.
1-2 Measurement and Units ♦ 9

**Example 1-2  Buying a Carpet**

You want to carpet a 12 ft × 15 ft room. You can readily calculate that the floor area is 180 ft², but carpeting is sold by the square yard (yd²). How many square yards do you need? **STOP & Think** Since 1 yd = 3 ft, should you just divide by 3? ♦

**Solution**
1. We have the conversion relation 1 yd = 3 ft, which we can rewrite as \( \frac{1 \text{ yd}}{3 \text{ ft}} = 1 \) or \( \frac{1 \text{ ft}}{3 \text{ yd}} = 1 \).
2. Remember that 1 ft² = 1 ft × 1 ft. Thus, 180 ft² = 180 ft × ft, and we have to end up with yd² = yd × yd. We therefore have to multiply twice by \( \frac{1 \text{ yd}}{3 \text{ ft}} \):

\[
180 \text{ ft}^2 = 180 \text{ ft} \times \text{ ft} = 180 \text{ ft} \times \text{ ft} \times \frac{1 \text{ yd}}{3 \text{ ft}} \times \frac{1 \text{ yd}}{3 \text{ ft}}
\]

\[
= 20 \text{ yd} \times \text{ yd} = 20 \text{ yd}^2
\]

♦ Related homework: Problems 1-6 and 1-9.

**SIGNIFICANT FIGURES** No measurement is completely precise. You cannot read distances much smaller than 0.001 m (1 mm) on a meter stick, nor can you read more than a certain number of places on any instrument that has a numerical readout, be it an electronic balance calibrated in units of mass or a multimeter that measures electric current and voltage. The number of places that you can legitimately read with your measuring instrument is called the number of significant figures. A numerical value should always be written to show the number of significant figures. Suppose you measure “exactly” two meters on a tape measure that has 0.001 m accuracy. The measured value is not really exact, but it is closer to 2.000 m than to 2.001 m or to 1.999 m. Therefore, you must write 2.000 m, not 2 m, to represent your measurement. If you converted to kilometers (1 m = 10⁻³ km), you would have to write 2.000 × 10⁻³ m, not 2 × 10⁻³ m.

**STOP & Think** Does a mass of 5000 kg represent one significant figure? Two? Three? Four? More? ♦

Ordinary writing of numbers is sometimes ambiguous, but in scientific notation we can distinguish readily the number of significant figures in 5 × 10⁵ kg (one), 5.000 × 10⁵ kg (four), or 5.000000 × 10⁵ kg (seven, that is, more).

When you use your measured values to calculate a result, you **cannot claim greater accuracy (more significant figures) for your result than for the measurements from which it came**. Suppose \( A = 2.000 \text{ m} \) and \( B = 3.000 \text{ m} \) are the measured lengths of the two legs of a right triangle. You wish to calculate the length of the hypotenuse using the Pythagorean theorem: \( A^2 + B^2 = C^2 \). Using your calculator, you obtain the value \( C = 3.605551725 \text{ m} \). The last six places of this calculator readout are meaningless because your measurements could give you only four significant figures. Because your calculator readout is closer to 3.606 than to 3.605, you must write that \( C = 3.606 \text{ m} \).

If the measurements you had were \( A = 2.000 \text{ m} \) and \( B = 3.0 \text{ m} \) because \( B \) was measured by a less precise instrument, you would have to write your result as \( C = 3.6 \text{ m} \). Your result cannot have more significant figures than any of the values you used to find it.

When you estimate, you can sometimes be more flexible, because you are basing your calculations on numbers that you either guess at based on experience or round off for convenience. For example, Mrs. Wang knows she can get carpeting for $8.79 a square yard. She eyeballs her children’s playroom and says,
We have discussed physics as a collective human activity that involves observing diverse phenomena in the natural world and trying to figure out the rules that govern their behavior. In practice, observation generally means measurement. Measurements are always made in comparison to carefully defined standards called units of measurement. Values of physical quantities, things like time duration and mass, which may have numerical values, must be expressed in terms of such units; it matters whether you tell your friend you will meet her in 2 minutes or 2 weeks. In physics, we ordinarily express values in SI units (see Table 1-1), but sometimes we need to convert from other units. See Procedure 1-1 for converting units.

In writing numerical values, you need to be aware of the number of significant figures (e.g., has one, has four). You cannot claim greater accuracy (more significant figures) for your result than for the measurements from which it came.

Is it meaningful to ask which is the larger building? Explain why or why not.

Does the duration of time between sunrise and sunset make a good unit of time? Briefly explain.

The National Institute of Standards and Technology in Gaithersburg, Maryland, declares that the distance between two fine parallel lines on a particular metal rod is a standard unit of length. The rod is then shipped to a research station in Antarctica to be used as a standard for some high-precision measurements. Is there a problem with this? Briefly explain.

The speed limit on many U.S. highways is 55 miles/hr. What is this speed
a. in ft/s?
b. in SI units?

a. How many meters is 20 feet? How many feet is 20 meters?
b. How many square meters is 20 square feet? How many square feet is 20 square meters?
c. How many cubic centimeters are there in 20 ? How many cubic meters are there in 20 ?

Judith Jamison, long the principal dancer of the Alvin Ailey Dance Theater, was a striking presence on the stage in part because she was 5’10”, or 70 inches tall, a height that had traditionally been considered too tall for a ballet dancer.

a. What is Ms. Jamison’s height in cm?
b. What is Ms. Jamison’s height in meters?
c. A mischievous publicist for the dance company decides to report Ms. Jamison’s height in fictional units as 5 pseudometers tall. For this to be correct, how many inches must there be in a pseudometer?
Qualitative and Quantitative Problems

1-9. Using the data in Problem 1-2, find
   a. the total area of office space in the Empire State building in SI units.
   b. the total volume of the Pentagon in SI units.

1-10. A runner has just completed a 4-minute mile. What was his average speed (total distance divided by total time) in m/s?

1-11. A top Major League fastball pitcher can throw a baseball 95 mi/h (miles per hour). What is this speed in m/s?

1-12. A runner is entered in the 5000-meter event. She wishes to know how many miles she is running. Do the conversion for her.

Going Further

The questions and problems in this group are not organized by section heading, so you must determine for yourself which ideas apply. Some of them will be more challenging than the Review and Practice questions and problems (especially those marked with a • or **).

1-13. In 1959, members of an MIT fraternity measured the nearby Massachusetts Avenue Bridge by rolling fellow student Oliver Smoot end over end across it and painting a mark after each length. The paint marks have been kept fresh ever since, and you can still read “364.4 SMOOTS” at the MIT end of the bridge. Assuming a reasonable height for Oliver, estimate the length of the bridge in meters.

1-14. A small sample of water from Sludgeport Harbor contains (0.002 g in each cubic centimeter) of a certain pollutant. How many kilograms of this pollutant are contained in each cubic meter of water from the harbor?

1-15. a. Estimate the speed (total distance divided by total time) in m/s at which your hair grows. State the assumptions on which you base your calculation.

   b. According to our present understanding of continental drift, a continental mass will typically drift a distance of about 3 m in a century. How does the speed at which the continents move compare with the speed at which your hair grows?

1-16. How many hours would it take a person walking at a speed of 1.4 m/s to complete Boston’s 20-mile Walk for Hunger?

1-17. In one reference, you read that the average human brain at birth has a mass of about 0.390 kg. In another reference, you find that the mass of the typical adult human brain is about 1.350 kg. Typically, how many times as massive as a newborn brain is an adult brain?

1-18. Professional basketball player Yao Ming is 7’6” tall. What minimum height in meters must a doorway have for him to be able to go through the doorway barefoot without having to bend at all?

1-19. A liter (L) is equal to 1000 cm³. Allergists are concerned with the volume of air their patients’ lungs can hold. An allergist determines that his patient has a lung capacity of 3.9 L. What is this patient’s lung capacity in cubic meters?

1-20. An American training schooner puts in at a Caribbean port to get some replacement rope. The captain knows that the rope they buy at home weighs 0.13 pounds per foot (lb/ft). In the islands, weights (actually masses) are in kilograms and lengths in meters. What weight per unit length in kg/m should the captain look for?

1-21. When dealing with thin sheet metal, you might be interested in the mass per unit area rather than the mass per unit volume, or density. The units would then be units of mass divided by units of area. Here are four possibilities:

   \[
   \frac{\text{kg}}{\text{m}^2}, \frac{\text{kg}}{\text{cm}^2}, \frac{\text{g}}{\text{m}^2}, \frac{\text{g}}{\text{cm}^2}
   \]

   The numerical value of the mass per unit area for a particular kind of sheet metal would depend on the units in which it was expressed. Rank the four possible units in order of the numerical value the mass per unit area would have when expressed in each of these units. Order them from least to greatest, making sure to indicate any equalities.

1-22. The label on a paint can says that the coverage is 450 square feet per gallon. What would be the SI units for coverage? See Appendix C for conversion factors. Simplify your answer if possible.