2 The Language of Science

KEY IDEA

Mathematics is the universal language of science.

PHYSICS AROUND US . . . Math in the Kitchen

Have you ever baked a loaf of bread from scratch? There's something special about the taste and smell of bread fresh from the oven. It does take some effort, however, and you have to follow the directions carefully.

In one popular recipe, you start by combining yeast and a tablespoon of sugar (at 75°F) with $\frac{1}{2}$ cup of water (at 85°F)—a mixture that activates the yeast. After 10 minutes, you add other ingredients: 1 beaten egg, 8 cups of flour, and so forth, to make the dough. After kneading and shaping the dough, you place it into a preheated oven (400°F) for 15 minutes, reduce the temperature to 375°F, and then bake for an additional 25 minutes.

Even the simplest recipe for bread involves dozens of numbers—times, temperatures, weights, and volumes—all of which are essential to the task. Without these exact quantitative instructions, baking bread would be a messy, frustrating business.

In science, as in cooking and countless other aspects of our lives, mathematics is the essential language for communicating ideas with accuracy and precision.

QUANTIFYING NATURE

Take a stroll outside and look carefully at a favorite tree. Think about how you might describe the tree in as much detail as possible so that a distant friend could envision exactly what you see and distinguish that tree from all others.

A cursory description would note the rough brown bark, branching limbs, and canopy of green leaves, but that description would do little to distinguish your tree from most others. You might use adjectives such as "lofty," "graceful," or "stately" to convey an overall impression of the tree. Better yet, you could identify the exact kind of tree and specify its stage of growth—a sugar maple at the peak of autumn color, for example. However, even then your friend would have relatively little to go on.

There are many ways to describe a tree, from focusing on its shape to a discussion of the complex chemistry that goes on in its leaves.

Giving exact dimensions of the tree—its height, the distance spanned by its branches, or the diameter of the trunk—would enhance your description. You could document the shape and size of leaves, the texture of the bark, the angles and spacing of the branching limbs, and the tree's approximate age. You could even estimate the number of board feet of lumber the tree could produce.

To provide more detail, you might examine the tree for moss and insects living on the trunk and for evidence of disease on the leaves. The more detailed your description, the more varied the vocabulary you would need to command and the more precise your measurements of the tree's many parts would have to be. Photographs and other illustrations might be included to supplement your written report. Ultimately, you might even probe the tree at the microscopic level, examining the cells and molecules that give the tree its unique characteristics.

For each different kind of description of the tree, there is an appropriate language. For some uses, words might be sufficient. For example, if you were doing a census of a particular group of trees, a simple "oak tree" might be enough to get the job done. For other uses, such as including an image of the tree in a decorating scheme, you might want a picture or a geometrical shape. For still others, such as a quantitative description of the tree's energy balance or its economic value as lumber, you would need to use numbers. All of these are useful descriptions of the tree, but each is appropriate for answering a different question about the tree.

Scientists constantly grapple with the challenge of describing our world. Their solution to the problem invariably involves developing a complex vocabulary, coupled with appropriate mathematical expressions. In the words of Galileo Galilei, "The book [of science] is written in the mathematical language . . . without whose help it is humanly impossible to comprehend a single word of it, and without which one wanders in vain through a dark labyrinth."

Language and Physics

What makes a language useful? First and foremost, a language must be able to communicate a wide range of expression without ambiguity or confusion. In most day-to-day activities, two or three thousand words suffice for basic communication. However, as soon as you deal with a complex system, such as an automobile, the vocabulary increases dramatically. Think about the last time you had to have your car repaired, for example. The repair shop first had to know which of the hundreds of makes, models, years, and engine types you own. The mechanic then had to identify which of the thousand or so automobile parts was defective. Just to describe the problem, the mechanic has to master thousands of words—the specialized vocabulary of automobiles.

A catalog of parts, alone, however, is insufficient to describe your automobile and how it works. Other statements are needed to describe the car's operation. An engine must idle at a prescribed speed, for example, and the tires must be inflated to a safe pressure. All of these conditions and hundreds more are measured by various gauges and sensors, which are critical to the operation of your car. Numbers, not words, best describe these quantities. Indeed, almost everything to do with the mechanics of driving—speed, acceleration, distance, time—is expressed by numbers.

To be an automobile mechanic, you have to learn a specialized vocabulary that you don't need just to run a car.

The same situation applies to many other things we do in everyday life. To prepare your meals you must know the complex vocabulary of food, including numerous varieties of fruits and vegetables, dozens of cuts of meat and types of seafood, shelves of herbs and spices, and so on. But any cook needs numbers—quantifiable information—as well, to communicate the details of a recipe: how much, how hot, and how long? Similarly, virtually all sports have evolved specialized vocabularies, and they often employ sophisticated mathematical scales to measure performance: earned run average (baseball), third down efficiency (football), serving percentage (tennis), and a host of other parameters that enliven sports reporting.

Communication in science poses special challenges because, like your automobile, natural systems are complex in design and they operate according to strict quantitative guidelines. And, like cooking and sports, science involves complex procedures that must be documented with precision so that others can try the activity for themselves.

Learning the Language of Science

Memorizing complex vocabulary is an integral part of learning *to do* science. Doctors and medical researchers, for example, must be able to refer to thousands of different bones, muscles, nerves, and other anatomical features. Chemists must have command of the names of more than a hundred elements and countless chemical compounds. And physicists must master the intricate vocabulary of mechanics, electromagnetism, thermodynamics, and particle physics. Without this detailed vocabulary, communication between specialists would be all but impossible.

Specialized vocabulary is primarily for the experts. You don't have to learn all the mechanic's jargon to know if your car is running properly; however, if you decide to become a mechanic yourself, you'll need a lot of specialized training, which includes the vocabulary. Similarly, you don't have to be a master chef to enjoy good food or be a star athlete to appreciate sports. The same is true of science—you can appreciate science without having to become a scientist and mastering its specialized vocabulary.

DESCRIBING THE PHYSICAL WORLD

The challenge of describing the vast and complex universe may be divided roughly into two tasks. First, scientists must describe all kinds of physical objects, from atoms to stars. Then they must document how these objects interact and change over time. Both of these jobs rely, in large measure, on mathematics.

Describing an Object: What Is It?

We can't understand how the universe works unless we know its components. For hundreds of years, astronomers plotted the position of every visible star, while geographers mapped the features of our globe. Naturalists traveled to the ends of the Earth collecting every possible rock, shell, flower, and other curio for their museum collections. In our own century, discoveries of vast numbers of galaxies, disease-causing viruses, and a complex zoo of subatomic particles have transformed our understanding of the universe.

Describing new objects requires the ability to identify enough features that distinguish one object from all others. To a certain extent, these descriptions rely on words, which is why the vocabulary of science has become so complex. For example, you might describe a rock as rose-pink, fine-grained, silica-rich, and intrusive. However, eventually such a description has to incorporate numbers for added precision. What is the average size of the grains? How much silica is contained in the rock? What are the light-absorbing properties that give the rock a pink color?

Scalars and Vectors

All of the descriptions we've discussed so far can be expressed as a single number—you buy one gallon of paint, or you drive 10 miles to work. Any quantity that can be expressed as a single number is called a **scalar.** Scalars are crucial to the description of the physical world. As a consumer you are surrounded by scalars: the wattage of a light bulb, the octane rating of gasoline, the efficiency of appliances, and the voltage of your car's battery. You pay for coffee by the pound, fabric by the yard, milk by the gallon, and electricity by the kilowatt-hour. In science we measure the size of microbes, the mass of stars, the density of crystals, and the temperature of our bodies. We will even find that the colors of light may be represented as a scalar quantity (see Chapter 19).

However, sometimes you can't give a description in terms of a single number. If you were giving a friend instructions to your favorite restaurant, for example, you might say something like, "Go north 3 miles on Main Street." Here you have to give a scalar (3 miles) and some additional information (in this case, the direction north). Similarly, physicists describe the velocity of an object in terms of both its speed *and* direction. When a mathematical quantity, such as velocity, requires two numbers in its definition—both a magnitude and a direction—it is called a **vector.**

Vector Addition

Physicists often have to calculate the sum of two or more vectors to analyze real-world problems. The easiest situation to analyze occurs when two vectors lie along the same line. For example, a rower trying to move against a current will find his actual velocity (speed and direction) determined by the sum of two vectors. One of these vectors is the velocity the rower would achieve if he were rowing on still water; the other is the velocity of the current. The sum of the two vectors in this case is just the difference between the two velocities. If, for example, the rower could achieve 10 km/h in still water and the current is against him at 2 km/h, then his net velocity is $(10 - 2) = 8$ km/h.

LOOKING DEEPER

Vectors and the Crash of the *Stardust*

On August 2, 1947, a British South American Airways flight, the *Stardust,* from Buenos Aires, Argentina, to Santiago, Chile, crashed into the high Andes Mountains, killing six passengers and three crew. They had encountered heavy cloud cover, but the experienced crew had made the routine flight many times before—fly at 18,000 feet for 3 hours, ascend to 26,000 feet to avoid the treacherous spine of the Andes, and then descend to Santiago near the Pacific Coast. But on this flight they flew straight into the mountains. What happened?

Fifty years after the mysterious accident, a team of scientists visited the crash site and discovered its cause: the ill-fated passengers and crew were victims of unusually high winds. On that fateful day the *Stardust,* a Lancaster Mark III aircraft, flew west at 300 miles per hour—a speed that made it easy to calculate a flight path. But the crew didn't realize that they were flying straight into an unusually strong jet stream—a 100-mile-per-hour wind blowing to the east.

A plane's net speed (its ground speed) is the sum of two separate speeds. The first is the speed of the plane in still air, while the second is the wind speed. If the wind blows in the same direction as the plane's flight, it adds to the plane's speed in still air. But if the wind is opposite to the direction of the plane, it lessens the plane's speed. The *Stardust's* actual ground speed was the combination of two vectors: 300 miles per hour west *plus* 100 miles per hour east. The vector sum is only 200 miles per hour west—much slower than the crew thought. Thus the plane had not traveled as far west as the crew thought it had, and they descended too soon.

Today, meteorologists constantly monitor the shifting jet streams of Earth's upper atmosphere, and vector addition of wind velocity and plane velocity is a critical part of every flight plan.

Develop Your Intuition: Going with the Flow

What if the rower on page 26 is moving with the current instead of against it? In this case, the rower's velocity is in the same direction as the current. The current increases the rower's speed, so he moves at a speed of (10 + 2) = 12 km/h. When we add two vectors along the same line, the result is the sum of their magnitudes if they are in the same direction and the difference between their magnitudes if they are in the opposite direction.

A more complicated situation arises when the two vectors do not lie along the same line. In this case, the easiest way to add vectors is to use a graph (Figure 2-1). Each vector can be represented as an arrow on an *x-y* plot. For example, a plane flying west 300 miles per hour would appear as an arrow pointing to the left with its tail at the origin (0,0) and a length of 300. If there is a crosswind of 300 miles per hour, we would find the actual velocity of the airplane by connecting the tail of the vector representing the crosswind to the head of the vector representing the airplane's velocity in still air. The sum of the two vectors is a new arrow that extends from the origin point to the head of the second vector, as shown in Figure 2-1.

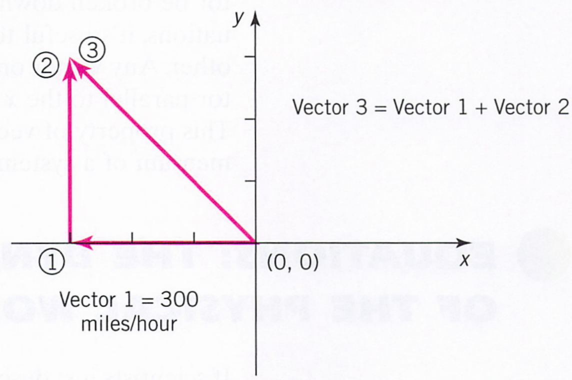


FIGURE 2-1. Vector graph of the velocity of a plane; addition of two vectors.

Vector addition is a lot like giving directions to a friend. "Go three blocks north on Main Street, turn right on Maple, and it's the fourth house on the left." Do you recognize the three vectors described by these instructions?

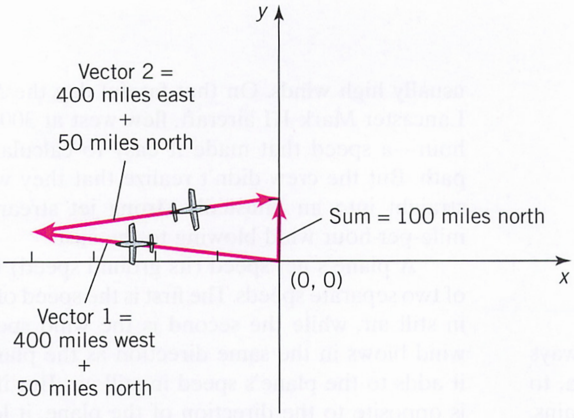


FIGURE 2-2. Vector addition for the path of a plane in a cross wind.

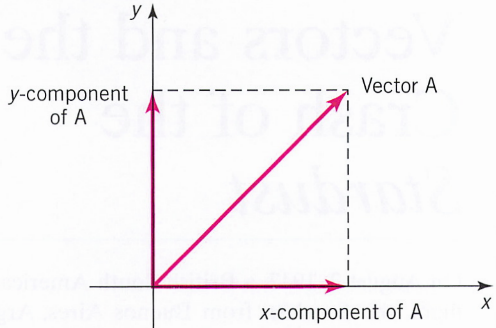


FIGURE 2-3. Any vector can be decomposed into two perpendicular vectors.

Adding Vectors

EXAMPLE 2-1

A plane flies due west at 400 miles per hour for 1 hour, and then flies back due east at the same speed for another hour. Meanwhile, a steady 50-mile-per-hour wind blows from the south. Where does the plane end up relative to its starting position?

SOLUTION: Intuitively, we know that a wind blowing from the south will push the plane toward the north. Since the plane's flight plan is straight east and west, with no intentional veering off to the north or south, we expect the plane will wind up somewhere north of its intended flight path.

To work out the solution exactly, we consider this as a problem of vector addition involving three vectors. During the plane's 2-hour flight, the west leg of 400 miles exactly cancels the east leg of 400 miles. But the steady 50-mile-per-hour southerly wind acts for 2 hours, shifting the plane's position 100 miles to the north. Therefore, as shown in Figure 2-2, the plane winds up 100 miles due north of its starting position. ●

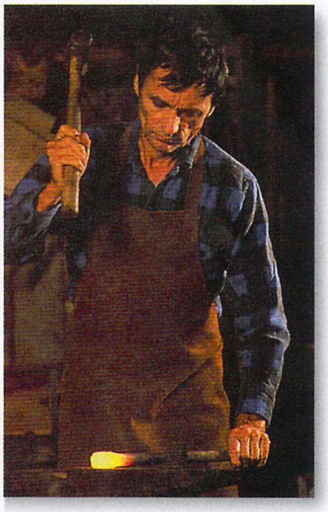
Vector Decomposition Just as vectors can be added together, so too can one vector be broken down into two or more component vectors. In many physical situations, it's useful to decompose a vector into two parts at right angles to each other. Any vector on an x-y graph, for example, can be decomposed into one vector parallel to the x axis plus a second vector parallel to the y axis (Figure 2-3). This property of vectors will become especially useful when we analyze the momentum of a system (Chapter 6).

EQUATIONS: THE DYNAMICS OF THE PHYSICAL WORLD

If scientists just described objects in the universe, science would seem pretty boring. What makes science fascinating and useful is that systems change. Science is a search to understand and predict these changes—the dynamics of our physical world.

Change can be described in words, in tables of numbers, or visually through the use of graphs. Of special importance are **equations,** which define a precise mathematical relationship among two or more measurements. Let's look at an example to see how the same physical behavior can be described in these different ways.

As you will see in Chapter 11, a bar of iron expands when heated. A researcher might carefully measure the length of a 1-meter iron bar at a series of temperatures and prepare a table like Table 2-1. We see a systematic trend in these data; both temperature and length increase. These data can be described in several ways.



Blacksmith with a hot iron bar.

1. We can describe what happens to the iron bar in words:

   When we heat a 1-meter iron bar, it gets longer.

2. We can express this idea as an equation with words:

   The length of the bar equals the original 1-meter length plus a constant times the change in temperature.

3. We can express this idea as an equation in symbols and numbers (approximately):

   $$L = 1 + (0.00006 \times \Delta T)$$

   where L is the length and ΔT is the change in temperature. (Note that Δ, the capital Greek letter delta, is often used in physics to denote a change in some quantity. It is not used by itself, but always with the symbol for that changing quantity. So ΔT denotes a change in temperature, ΔL is a change in length, and so on. Note also that the number 0.00006 comes from dividing the increase in length given in Table 2-1 by the corresponding change in temperature; this is the change in length per 1-degree change in temperature.)

4. Finally, the data might be displayed in graphical form, as a plot of temperature versus length (Figure 2-4).

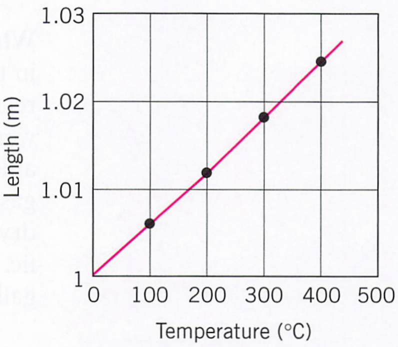


FIGURE 2-4. A graph of temperature versus the length of an iron bar illustrates how two scalar properties are related.

Similar relationships are found in all scientific literature. Researchers graphically document changes in the volume of a gas with pressure, changes in the distance objects fall with time, changes in the growth rate of bacteria with concentration of nutrients, and countless other trends.

The example of the expanding iron bar illustrates why scientists use the language of mathematics. Table 2-1 certainly represents the data, though in a modern experiment that list of numbers could easily run to thousands or even millions

TABLE 2-1 Thermal Expansion of an Iron Bar

Temperature (°C)	Length (meters)
0	1.0000
100	1.0060
200	1.0125
300	1.0183
400	1.0240

of entries. All of that information can be packaged into a one-line equation. Thus, the use of mathematics allows us to express the results of experiments in a highly compressed and convenient form.

As we shall see later, equations have the added advantage of providing us with the best way to make predictions about the behavior of our surroundings. In addition, they transcend national barriers in that they have exactly the same meaning all over the world.

Develop Your Intuition: Fuel Efficiency

How would you describe the gas efficiency of your automobile? A colloquial answer might be, "I get pretty good mileage, especially on interstate highways." Most people would accept that answer, but it wouldn't be very useful in trying to compare two different cars.

To give a more accurate answer, you could keep exact records of your car's mileage and the amount of gas purchased each time you fill up the tank. By dividing the total miles driven by the number of gallons purchased, you could calculate:

$$\text{Miles per gallon} = \frac{\text{Total miles driven}}{\text{Gallons of gas purchased}}$$

Then, you could reply with a scalar quantity, "I get about 30 miles per gallon."

Your answer could be even more precise if you record additional notes. What was the brand and grade of fuel? Was the driving between each fill-up in the city or on high-speed roads? Did you use the air conditioner? Did you recently have an oil change? Were the tires properly inflated? What were the weather and road conditions? With sufficiently detailed records you might be able to say, "My car, when properly serviced and fueled with regular unleaded gas, averages 33.7 miles per gallon when traveling 55 miles per hour on level, dry interstate highways, and approximately 25.5 miles per gallon in city traffic. The use of the air conditioner reduces these values by about 2.5 miles per gallon."

Automobile manufacturers, who must document the fuel efficiency of their vehicles, carry this process a step further by running carefully controlled mileage experiments on dozens of cars in special laboratories. There, engineers develop graphs and equations that relate fuel consumption to numerous other variables. Many of these tests are now mandated by the Environmental Protection Agency to provide consumers with an accurate measure of each brand's fuel efficiency.

Modeling the World

Scientists have devised many ways to describe the natural world. As shown in the previous example of the expanding iron bar, the behavior of a physical system may be documented in words, tables of numbers, or graphs. But no description is more compact and efficient than an equation. A brief survey will help you to visualize the everyday reality underlying four common types of equations used in this book: direct, inverse, power law, and inverse square. These equations may be used to describe all manner of natural phenomena.

(*a*) (*b*)

FIGURE 2-5. (*a*) A graph of a direct relationship between price of fruit and its weight. (*b*) The price per pound can be treated as a constant of proportionality between weight and cost.

1. **Direct Relationships** The simplest equations consist of a *direct relationship* between two variables, A and B, in the form:

$$A = k \times B$$

where k is called a "constant of proportionality." You use a direct relationship every time you buy gas by the gallon or food by the pound:

$$\text{Cost} = \text{Price per pound} \times \text{Weight}$$

In this case, two variables, the weight and the cost, are related by a constant of proportionality called the price per pound.

In a direct relationship the two variables change together: if weight doubles, so must the cost; if weight triples, so does the cost. We say that the cost is *proportional* to the weight. The graph of such a relationship is a straight line (Figure 2-5). In subsequent chapters we will find many direct relationships between pairs of variables, including:

Acceleration is proportional to force (Chapter 4).

Electric power is proportional to electric current (Chapter 18).

Wave frequency is proportional to wave velocity (Chapter 14).

2. **Inverse Relationships** In many everyday situations, one variable increases as another decreases, a situation called an *inverse relationship:*

$$A = \frac{k}{B}$$

where k is a constant. For example, consider an assembly line at which workers who work at different speeds produce automobile parts. The shorter the time, t, it takes for a worker to produce one part, the greater the number, N,

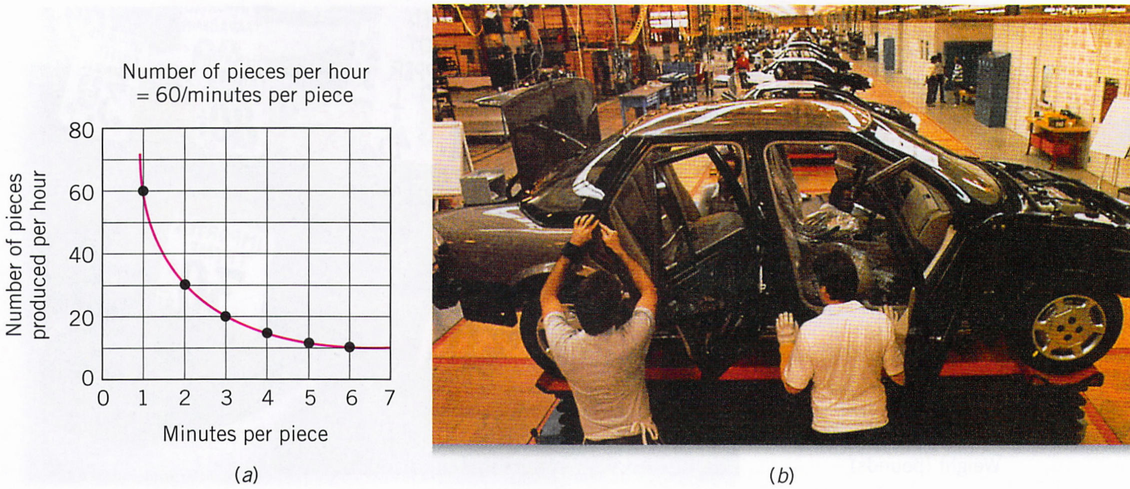


FIGURE 2-6. (*a*) A graph of an inverse relationship between the time it takes a worker to assemble an item and the worker's hourly output. The shorter the assembly time per item, the greater the hourly output. (*b*) An auto assembly line.

of cars produced per hour (Figure 2-6). We say that the number of cars produced in a given time period is *inversely proportional* to the production time:

$$\text{Output of cars} = \frac{\text{Constant}}{\text{Production time per car}}$$

or

$$N = \frac{k}{t}$$

Think about the behavior of the two variables, production time and output in this case. If you make an automobile part in half the time of a fellow worker, you will produce twice as many parts in any given time period. If you produce a part in a third of the time, you'll produce three times as many, and so forth. Inverse relationships thus lead to the distinctive kind of curving graph illustrated in Figure 2-6. We will encounter many examples of such inverse relationships, such as:

For a given force, acceleration is inversely proportional to the mass being accelerated (Chapter 4).

The wavelength of light is inversely proportional to the frequency of light (Chapter 19).

3. Power Law Relationships You may recall from a geometry class the equation that defines the area of a square, A, in terms of the edge length, L:

$$A = L \times L$$

which can be rewritten as:

$$A = L^2$$

Area is said to be equal to length *squared* (Figure 2-7*a* and *b*). Squared relationships are common in our daily lives. For example, in Chapter 3 we see that a dropped object falls a distance that is proportional to the time of fall squared.

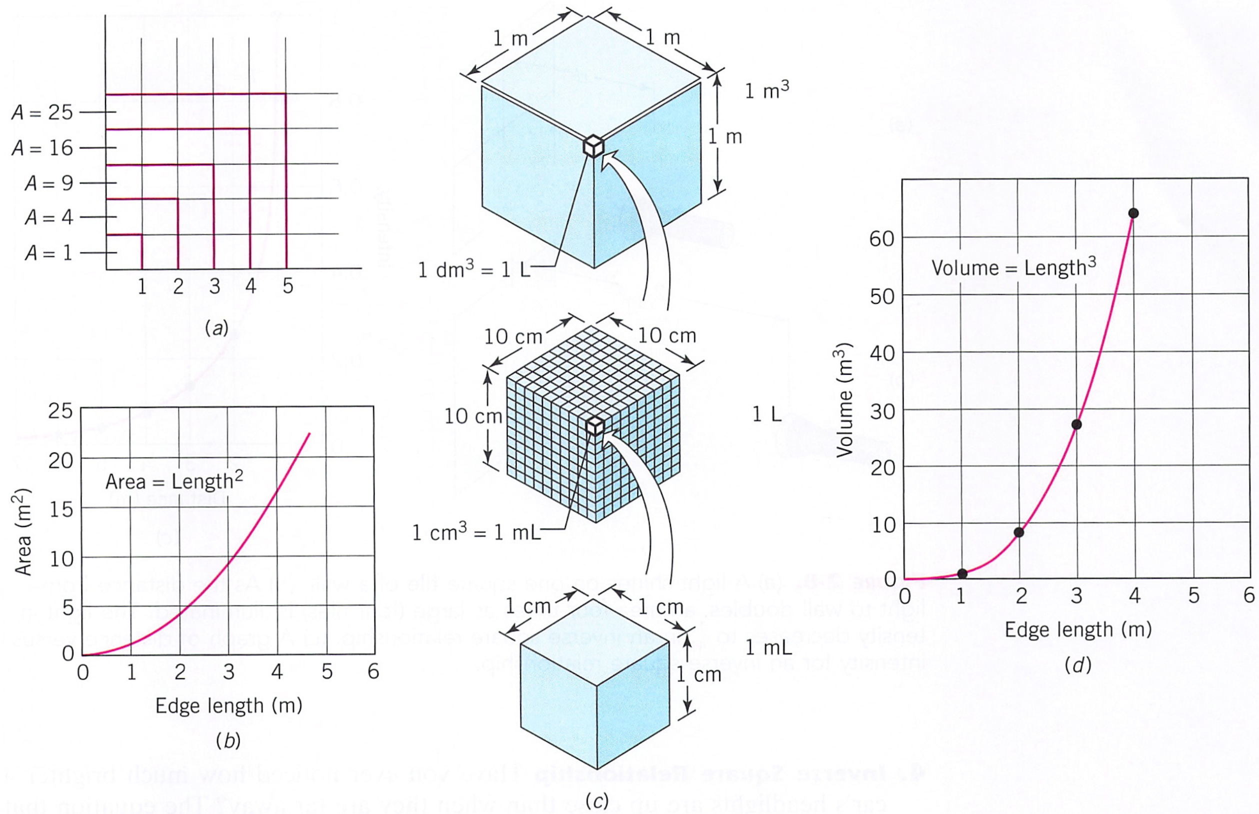


FIGURE 2-7. (*a*) Diagram of a square grid; (*b*) graph of the squared relationship between the area and edge length of a square. (*c*) Diagram of stacked cubes; (*d*) graph of the cubed relationship of volume. An object 10 cm on a side holds $10 \times 10 \times 10 = 1000\ \text{cm}^3$ or 1 liter, while an object 1 meter on a side holds 1000 liters.

A similar kind of relationship is found between the *volume* of a cube, V, and its edge length, L:

$$V = L \times L \times L$$

or, in mathematical notation:

$$V = L^3$$

Note that volume, which is the amount of space an object occupies, is measured in units of distance *cubed,* such as cubic meters (Figure 2-7*c* and *d*). Many systems of measurement adopt special volume units, such as liters or gallons.

Squared-type and cubed-type equations are special cases of a more general class, called "power law equations." These common equations have the form:

$$A = k \times B^n$$

where n is any number and k is a constant. A general feature of these relationships is that one variable changes much more quickly than another. Double the edge of a cube, for example, and the volume increases eightfold; triple the edge length and the volume becomes 27 times larger. The result is a steeply rising graph, as shown in the examples in Figure 2-7.

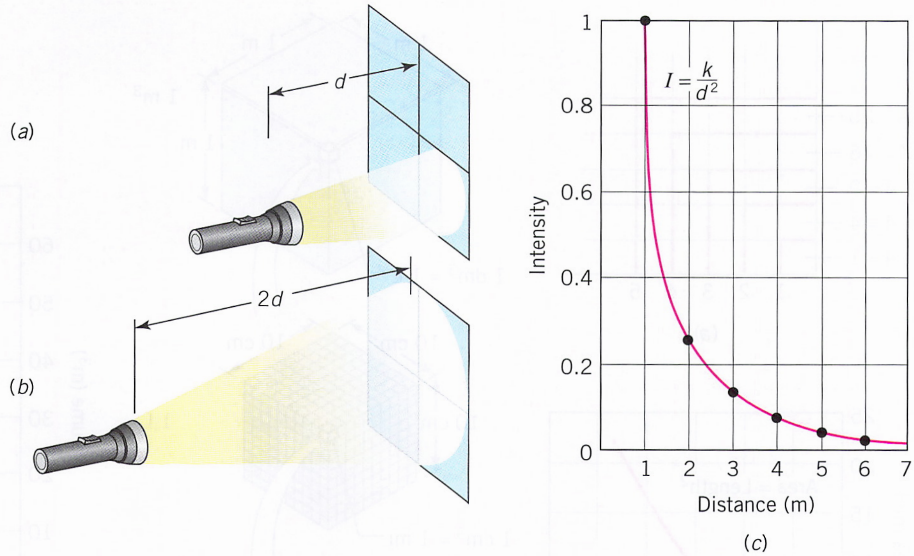


FIGURE 2-8. (*a*) A light shines on one square tile of a wall. (*b*) As the distance from light to wall doubles, an area four times as large (four tiles) is illuminated. The light intensity decreases to $\frac{1}{4}$, in an inverse square relationship. (*c*) A graph of distance versus intensity for an inverse square relationship.

4. Inverse Square Relationship Have you ever noticed how much brighter a car's headlights are up close than when they are far away? The equation that describes this distinctive relationship between brightness and distance (and lots of other natural phenomena, as well) is called the *inverse square relationship.*

Imagine shining a flashlight on a wall with a regular array of square tiles (Figure 2-8*a*). First, you hold the flashlight close to the wall so that all the light falls onto just one square. If you measured that brightness with a photographic light meter, it might register 100 on the meter's scale.

If you move the flashlight twice that distance from the wall (Figure 2-8*b*), then the light illuminates an area twice as high and twice as wide. The light is spread out over an area four times as large as before. Consequently, the light meter reads a brightness of about 25—only $\frac{1}{4}$ as strong as before. This inverse square relationship between light intensity, *I*, and distance, *d*, is

$$I = \frac{k}{d^2}$$

where k is a constant. The general inverse square relationship is

$$A = \frac{k}{B^2}$$

A graph of an inverse square relationship (Figure 2-8*c*) reveals the sharp fall-off of one variable as the other changes gradually. We find in later chapters that inverse square relationships are common in nature; for example, inverse square relationships describe the change of magnitude of everyday electrostatic and gravitational forces as a function of the distance between two objects (see Chapters 5 and 16).

Develop Your Intuition: Flashbulbs and Baseball

You'll often see hundreds of flashbulbs go off at a stadium when a famous baseball player comes up to bat during a night game. Based on what you know about the inverse square relationship, do these flashes help the would-be photographers?

The intensity of light drops off as the inverse square of the distance, so flashbulbs are ineffective at distances greater than a few dozen feet. All the popping flashbulbs make a great sight, but they don't help photographs taken over the great distances of a stadium.

UNITS AND MEASURES

As soon as we begin using numbers to describe any physical system, we have to deal with the issue of units. Walk into any hardware store in the United States and you will notice immediately that the things for sale are measured in many different ways. You can buy paint by the gallon, insulation in terms of how many BTU will leak through it, and grass seed by the pound. In some cases, the units are strange indeed—nails, for example, are measured in an archaic unit called the penny (abbreviated "d" for denarius, a small Roman coin). A 16d nail is a fairly substantial thing, perfect for holding the framework of a house together, while a 6d nail might find use tacking up a wall shelf.

No matter what the material, there is a unit to measure how much is being sold. In the same way, in all areas of science, systems of units have been developed to measure how much of a given quantity there is. We will encounter many of these units in this book—the newton as a measure of force, for example, and the degree as a measure of temperature. Every quantity used in the sciences has an appropriate unit or combination of units associated with it.

We customarily use certain kinds of units together, in what is called a **system of units.** In a given system, units are assigned to fundamental quantities such as mass (or weight), length, time, and temperature. Someone using that system uses only those units and ignores the units associated with other systems.

The International System

In the United States, two systems of units are in common use. The one encountered most often in daily life is the *English system.* This traditional system of units has roots that go back to the Middle Ages. The basic unit of length is the *foot* (which was actually defined in terms of the average length of men's shoes outside a certain church on a certain day), and the basic unit of weight is the *pound.*

Throughout this book, and throughout most of the world outside of the United States, the metric system or, more correctly, the **International System** (abbreviated **SI** for the French Système International) is preferred. In this system, the unit of length is the *meter* and the unit of mass is the *kilogram.* In both the SI and the English system, the basic unit of time is the *second.*

In all probability, the unit from the metric system with which you are most familiar is the *liter,* a measure of volume. A liter is the volume enclosed by a cube 10 centimeters on a side or 1000 cubes 1 centimeter on a side. Soft drinks and other liquids are routinely sold in 1- and 2-liter bottles in the United States. The cubic meter—the volume contained in a cube 1 meter on a side—is also often used as a volume measure in the metric system. The measure of volume in the English system is the cubic foot, but liquids are commonly measured in gallons (3.79 liters), quarts ($\frac{1}{4}$ gallon), and pints ($\frac{1}{8}$ gallon).

Within the SI, units are based on multiples of 10. Thus, the centimeter is one-hundredth the length of a meter, the millimeter is one-thousandth of a meter, and so on. In the same way, a kilometer is 1000 meters, a kilogram is 1000 grams, and so on. This systematic organization differs from the English system, in which 12 inches equals 1 foot, 3 feet makes 1 yard, and 1760 yards makes 1 mile. A list of metric prefixes follows.

METRIC PREFIXES

If the prefix is:	**Multiply the basic unit by:**	**Example with abbreviation**
giga-	billion (thousand million)	gigameter, Gm
mega-	million	megagram, Mg
kilo-	thousand	kilometer, km
hecto-	hundred	hectogram, hg
deka-	ten	dekameter, dam
If the prefix is:	**Divide the basic unit by:**	**Example with abbreviation**
deci-	ten	decigram, dg
centi-	hundred	centimeter, cm
milli-	thousand	milligram, mg
micro-	million	micrometer, μm
nano-	billion	nanogram, ng

Physics in the Making

A Brief History of Units

Ever since humans started engaging in commerce, there has been a need for agreements on weights and measures. Merchants needed to be assured that they were buying and selling the same quantity of goods, that the buyer was getting what he paid for and the seller was receiving full value for her wares. This meant that someone (often a government) had to set up and maintain a system of standard weights and lengths.

King John grants the Magna Carta (Great Charter) to his barons in England. The charter required the establishment of common standards for weights and lengths throughout the kingdom.

The oldest weight standard we know about is the Babylonian "mina," which weighed between 1 and 2 pounds. Archaeologists have found standard stone weights carved in the shapes of ducks (5 mina) and swans (10 mina). In medieval Europe, almost every town maintained its own system of weights and measures, and the only institutions pushing for universal standards were the great trade fairs. The keeper of the fair in Champagne, France, for example, kept an iron bar against which all bolts of cloth sold at the fair had to be measured. The Magna Carta, signed by King John of England in 1215 and generally reckoned to be one of the key documents in the history of democracy, required that "There shall be standard measures of wine, ale, and corn throughout the kingdom." The English system of units eventually evolved from the welter of medieval systems.

The metric system, on the other hand, was a product of the French Revolution at the end of the eighteenth century. In 1799, the French Academy recommended that the length standard be the meter, then defined to be 1/10,000,000 of the distance between the equator and the North Pole at the longitude of Paris and that the gram be defined to be the mass of a cubic centimeter of water at 4°C. In the Connection section in this chapter, we discuss the modern definitions of these quantities.

Conversion Factors

All systems of units help us describe physical objects and events. Confusion may arise, however, when switching back and forth between two different systems. **Conversion factors,** which are used to shift from one system of units to another, are thus vital in both science and commerce. If you have ever visited a foreign country, you have had direct experience with this process; you had to use conversion factors all the time when converting dollars to some other currency.

Hundreds of conversion factors apply to the physical world. One person may give temperature in degrees Fahrenheit, another in degrees Celsius. Distance may be recorded in centimeters or in inches. Some important conversion factors are tabulated in Appendix A.

Driving in North America

EXAMPLE 2-2

Suppose you are driving in Canada. The odometer on your car reads 20,580 miles. You see a sign that reads, "Toronto 87 kilometers." What will your odometer read when you get to that city?

REASONING: Since the odometer reads in miles, the first thing to do is convert 87 kilometers to miles by using the conversion tables in Appendix A. We then add that mileage to the current reading to get our answer.

SOLUTION: From Appendix A, the conversion factor from kilometers to miles is 0.6214. When you see the sign, then, the distance to Toronto is:

$$87 \text{ kilometers} \times 0.6214 \text{ mile/kilometer} = 54 \text{ miles}$$

When you have traveled this far the odometer will read:

$$20{,}580 + 54 = 20{,}634 \text{ miles}$$

LOOKING DEEPER

Powers of Ten

Very large or very small numbers may be written conveniently in a compact way—a way that doesn't involve writing down a lot of zeroes. The system called "powers of ten" notation (also called "exponential notation") accomplishes this goal. The basic rules for the notation are:

1. Every number is written as a number between 1 and 10 followed by 10 raised to a power, or an exponent.
2. If the power of 10 is positive, it means "move the decimal point this many places to the right."
3. If the power of 10 is negative, it means "move the decimal point this many places to the left."

Following these rules, 3.56×10^3 is equivalent to 3560, and 7.87×10^{-4} equals 0.000787.

Multiplying or dividing numbers in powers of ten notation requires special care. If you are multiplying two numbers, such as 2.5×10^3 and 4.3×10^5, you multiply 2.5 and 4.3, but you add the two exponents:

$$\begin{aligned}(2.5 \times 10^3) \times (4.3 \times 10^5) &= (2.5 \times 4.3) \times 10^{3+5}\\ &= 10.75 \times 10^8\\ &= 1.075 \times 10^9\end{aligned}$$

When dividing two numbers, such as 4.3×10^5 divided by 2.5×10^3, you divide 4.3 by 2.5, but you subtract the denominator exponent from the numerator exponent:

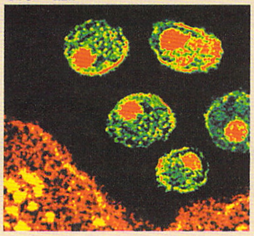
$$\begin{aligned}(4.3 \times 10^5)/(2.5 \times 10^3) &= (4.3/2.5) \times 10^{5-3}\\ &= 1.72 \times 10^2\\ &= 172\end{aligned}$$

For more examples of powers of ten notation, see Looking at Length (p. 38).

Looking at Length

You are about 100 million times larger than a virus, but the Earth is about 10 million times larger than you. That sounds pretty big, but the Sun's diameter is about 100 times larger than that of the Earth; the Earth is only the size of a sunspot. And the Sun is only a tiny dot in the Milky Way galaxy, which contains a hundred billion stars just like it.

10^{-7} m



Virus = 0.0000001 meter

10^{0} m

Child =1 meter (about 3 feet)

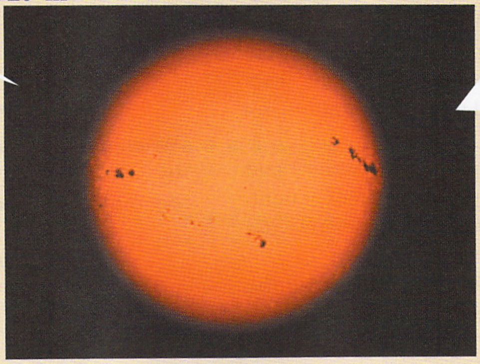
10^{21} m

Galaxy = 100,000 light years across (~10^{18} kilometers)

10^{7} m

Earth = 13,000 kilometers (about 7800 miles) in diameter

10^{9} m



Sun = 1,400,000 kilometers (850,000 miles) in diameter

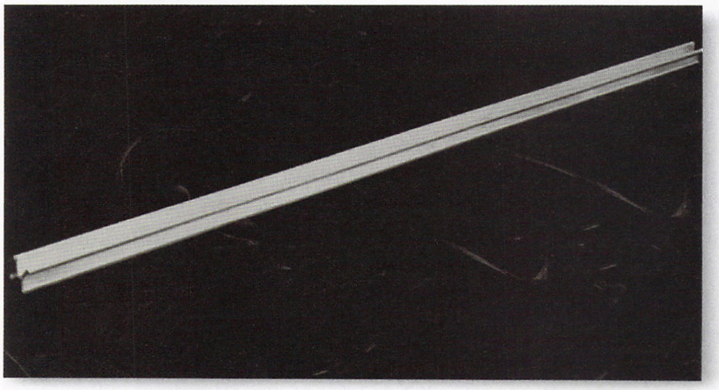
Connection

Maintaining Standards

Systems of units are one place where governments become intimately involved with science, since the maintenance of standards has traditionally been the task of governments. When you buy a pound of meat in a supermarket, for example, you know that you are getting full weight for your money because the scale is certified by a state agency, which relies, ultimately, on international standards of weight maintained by a treaty among all nations.

Originally, the standards were kept in sealed vaults at the International Bureau of Weights and Measures near Paris, with secondary copies kept at places such as the National Institutes of Standards and Technology (formerly National Bureau of Standards) in the United States. For instance, the meter was defined as the distance between two marks on a particular bar of metal, and the kilogram was defined as the mass of a particular block of iridium-platinum alloy. The second was defined as a certain fraction of the length of the year.

Today, however, only the kilogram is still defined in this way. Since 1967, the second has been defined as the time it takes for 9,192,631,770 crests of a light wave (see Chapter 19) of a certain type of light emitted by a cesium atom to pass by a given point. In 1960, the meter was defined as the length of 1,650,763.73 wavelengths of the radiation from a krypton atom, and in 1983 it was redefined to be the distance light travels in 1/299,792,458 seconds. In both these cases, the old standards have been replaced by numbers relating to atoms—standards that any reasonably equipped laboratory can maintain for itself. Atomic standards have the additional advantage of being truly universal—every cesium atom in the universe is equivalent to any other. Only mass is still defined in the old way, in relation to a specific block of material kept in a vault, and scientists are working hard to replace that standard by one based on the mass of individual atoms. ●



(a)

(b)

(a) The old standard meter. (b) The standard kilogram. The meter, which used to be defined in terms of the distance between marks on a bar like this, is now defined in terms of measurements on atoms.

Units You Use in Your Life

The metric and English systems each give a comprehensive set of units that could, in principle, be used to measure everything we encounter in our lives. In point of fact, for various historical and technical reasons, we often use units that don't fit easily into either system all the time. How many of the following units do you recognize?

acre—used to measure land area in the United States (43,560 square feet, or $\frac{1}{640}$th of a square mile)

barrel—international unit for oil production (42 gallons; although many different specialized definitions of barrel exist for other commodities, including wine, spirits, and cranberries)

bushel—used to measure production of grains in the United States (1.24 cubic feet)

caliber—used to measure diameter of bullets and gun barrels (0.01 inches)

carat—used to measure size of gemstones (0.2 grams)

fathom—used to measure depth of navigable water (6 feet)

knot—used to measure speed of ships (1.85 kilometers per hour)

ounce—used to measure the weight of produce ($\frac{1}{16}$ pound)

Troy ounce—used to measure precious metals ($\frac{1}{12}$ pound)

THINKING MORE ABOUT

Units: Conversion to Metric Units

Why does the United States still use English units long after most of the rest of the world has converted to SI units? It may have to do with nonscientific factors such as the geographical isolation of the country, the size of our economy (the world's largest), and, perhaps most important, the expense of making the conversion. (For example, think of the cost to change all the road signs from miles to kilometers on the entire interstate highway system.)

To understand the debate over conversion, you have to realize one important point about units. There is no such thing as a "right" or "scientific" system of units. Units can only be convenient or inconvenient. Thus, U.S. manufacturers who sell significant quantities of goods in foreign markets long ago converted to metric standards to make those sales easier. Builders, on the other hand, whose market is largely restricted to the United States, have not.

By the same token, very few scientists actually use the SI exclusively in their work. Almost every discipline, including physics, chemistry, geology, biology, and astronomy, has its own preferred non-SI units for some measurements. Astronomers, for example, often measure distance in light years or in parsecs; geologists usually measure pressure in kilobars; and many physicists prefer to record energy in electron volts. In the United States, engineers use English units almost exclusively—indeed, when the federal government was considering a tax on energy use in 1993, it was referred to as a BTU tax (the BTU, or British thermal unit, is the unit for energy in the English system). Medical professionals use the cgs system, in which the unit of length is the centimeter, the unit of mass is the gram, and the unit of time is the second. Next time you have blood drawn, take a look at the syringe. It will be calibrated in cubic centimeters (cc).

Sometimes the use of different systems of units on the same scientific or engineering project can lead to trouble. A notable example occurred in fall 1999 when a spacecraft costing $125 million crashed into the planet Mars instead of orbiting it as planned. It turned out that the company that built the rocket for slowing down the spacecraft as it got close to Mars reported its thrust as pounds per square foot, but the flight engineers assumed the number was in metric units. The difference was enough to throw the spacecraft off course by a few hundred miles, leading to the crash.

Given the wide range of units actually in use, how much emphasis should the U.S. government give to metric conversion? How much should the government be willing to spend on the conversion process—how many new signs as opposed to how many repaired potholes on the roads?

Summary

Language allows people to communicate information and ideas. In their efforts to describe the physical world with accuracy and efficiency, scientists have created many new words to distinguish the many different kinds of objects in the universe.

These descriptive terms are amplified by mathematics, which allows scientists to quantify their observations. **Scalars** are numbers that indicate a quantity—mass, length, temperature, and time are familiar scalar quantities. Other quantities, such as velocity and change in position, must be described with a **vector,** which combines information on both magnitude (a scalar) and direction.

Many scientists work to find mathematical relationships between two or more properties—temperature and the length of a metal bar, for example. Such relationships may be presented in the form of an **equation** or a graph.

Scientific measurements rely on a **system of units,** particularly the metric system or **International System (SI). Conversion factors** are used to change from one unit to another.

Key Terms

conversion factor Established mathematical quantity used to shift from one system of units to another. (p. 37)

equation The definition of a precise mathematical relationship among two or more measurements. (p. 29)

International System or SI (Système International) An internally consistent system of units within the metric system; also known as the metric system. (p. 35)

scalar Any quantity that can be expressed as a single number and without a direction. (p. 26)

system of units Units assigned to fundamental quantities such as mass (or weight), length, time, and temperature. (p. 35)

vector A quantity that requires two numbers in its definition—a magnitude and a direction. (p. 26)

Review

1. Why do physicists and other scientists require a specialized vocabulary?
2. Why is scientific vocabulary still growing?
3. What is a scalar quantity? Give an everyday example.
4. What is a vector quantity? Give an everyday example.
5. What is the role of equations in science?
6. What is a direct relationship? Give an example.
7. What is an inverse relationship? Give an example.
8. What is a power law relationship? Give an example.
9. What is an inverse square relationship? Give an example.
10. Describe the ways a scientist might present quantitative data.
11. Why do we need standards of units and measures?
12. What is a system of units? What system do most scientists use?
13. Discuss the relative advantages of the English system and SI of units and measurements.
14. What are the units of length, mass, and volume in the English system of units?

15. What are the units of length, mass, and volume in the metric system of units?

16. What is a conversion factor?

17. Why do scientists often use powers of ten notation?

18. Identify three units of measurement that you might encounter at a grocery store.

19. Which branch of the U.S. government regulates standard weights and measures?

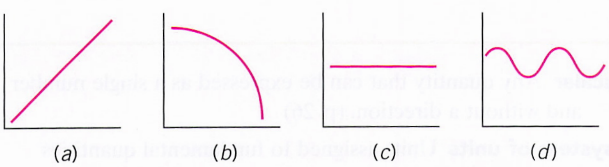
Questions

1. Categorize the following terms as either a scalar or vector quantity. Explain your reasoning for each choice.

a. a 100-yard dash
b. 20,000 leagues under the sea
c. a $75.00 dress
d. 4 days
e. 100 degrees Celsius
f. 1996 A.D.
g. 1 mile northeast
h. the lower 40 acres
i. 12:45 P.M.
j. a cubic yard of cement
k. a force of 20 newtons
l. 40 m/s west
m. 20 kg
n. 30 revolutions per minute

2. What is the principal difference between a vector and a scalar quantity, and why is that important in science?

The following graphs are for Questions 3–5.



3. You have entered a pie-eating contest to eat as many pieces of pie in the shortest amount of time until you can't eat another bite. Your physics instructor watches you during the contest and makes a graph of the number of pieces of pie eaten per minute (vertical axis) versus the time elapsed (horizontal axis). Which of the graphs most likely represents your instructor's data? Express this trend in words.

4. To maximize your chances of winning the lottery, you have decided to buy multiple lottery tickets. Which graph best represents the chance to win the lottery (vertical axis) versus the number of tickets bought (horizontal axis)? Explain this trend in words.

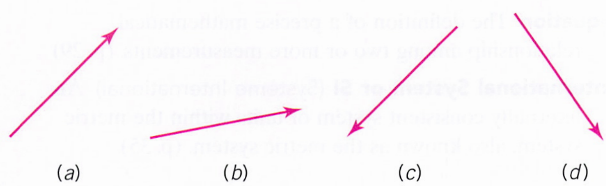
5. The water in the oceans rises and falls with the rotation of the Earth. These cycles are called tides. Which graph best represents the height of the ocean (vertical axis) versus the time of day (horizontal axis)? Explain the trend in words.

6. As discussed in the chapter, scientists at places such as the National Institutes of Standards and Technology near Washington, D.C., take great pains to protect the standard kilogram, encasing it in a vault filled with nitrogen. Why do you suppose this has to be done, while no one seems to want to do the same for the meter and the second?

7. A woman can paddle her kayak at a speed of 3 kilometers per hour through still water. She is paddling upstream in a river that has a flow speed of 2 kilometers per hour. Draw an arrow that represents the velocity of the kayak through the water and another arrow that represents the velocity of the water. Draw a third arrow that represents the actual velocity of the kayak.

8. Suppose a jet airplane travels at 500 miles per hour in still air. On a recent flight the plane was pointed east and was encountering a 100-mile-per-hour side wind, blowing toward the north. Draw an arrow that represents the velocity of the plane without the wind. Draw another arrow that represents the velocity of the wind. Draw a third arrow that represents the velocity of the plane in the presence of the side wind.

9. Decompose the following vectors into a horizontal component and a vertical component. (Draw a horizontal vector and a vertical vector whose sum equals the vector shown.)



10. As a person grows taller, he or she usually gets heavier, too. Is the relationship between the weight of a person and a person's height a *direct relationship*? Why or why not? Give examples to support your conclusion.

11. Consider the relationship between a person's body fat percentage and their top running speed. Is this more likely to be a *direct relationship* or an *inverse relationship*? Explain.

12. You have been hired to paint circles of various diameters as a decorative feature on a new building. Consider the relationship between the amount of paint needed to paint a circle and the diameter of that circle. Is this a *direct, inverse,* or *power law relationship*?

13. Assuming the price of musical CDs has remained fairly constant over the past two years, characterize the relationship between the amount of money a person has spent on CDs and the number of CDs they've bought in the last two years. Is it a *direct, inverse,* or *power law* relationship?

14. Would you rather be given 10 kilo-cents or 1,000,000 nano-dollars? Explain.

15. About how many seconds are there in a year: 30 mega-seconds, 30 kilo-seconds, or 30 milli-seconds?

Problem-Solving Examples

EXAMPLE 2-3 Vectors on the Water

An inexperienced canoeist sets out straight across a 1-mile-wide river, paddling at 5 miles per hour. The average current of the river is 6 miles per hour. Where does she land on the opposite side of the river?

SOLUTION: This problem involves two vectors. The first vector is 1 mile long in a direction perpendicular to the flow of the river (Figure 2-9). The second vector, in a direction parallel to the river's flow, is due to the 6-mile-per-hour current acting on the canoe while it's in the water. In order to calculate the length of this second vector, we have to determine how long the canoe is in the water:

$$\text{Time} = \frac{\text{Distance}}{\text{Velocity}} = \frac{1 \text{ mile}}{5 \text{ miles/hour}} = 0.2 \text{ hour}$$

So the length of the second vector is:

$$\text{Distance} = \text{Velocity} \times \text{Time} = 6 \text{ miles/hour} \times 0.2 \text{ hour} = 1.2 \text{ miles}$$

The canoeist winds up more than a mile downstream from where she left.

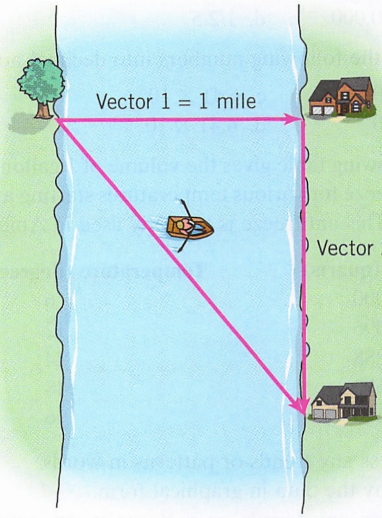


FIGURE 2-9. A person in a rowboat crossing a river is also carried downstream by the current.

EXAMPLE 2-4 Running the Dash

American athletes used to run an event called the 100-yard dash. If an athlete could run the 100-yard dash in 10 seconds, what time would you expect her to have in the 100-meter dash?

REASONING AND SOLUTION: The first step is to use the conversion factor in Appendix A to convert 100 meters to a distance in feet. From Appendix A, the conversion factor for meters to feet is 3.281. Consequently, 100 meters is:

$$100 \text{ meters} \times 3.281 \text{ feet/meter} = 328.1 \text{ feet}$$

We then have to divide the number of feet by 3 to convert to yards:

$$\frac{328.1 \text{ feet}}{3 \text{ feet/yard}} = 109.4 \text{ yards}$$

If we assume that the runner travels at the same speed in the two races, the 100-meter race (equal to a 109.4-yard race) will take longer than the 100-yard race. The time of the 100-meter race is proportional to the distances of the two races multiplied by 10 seconds:

$$\text{Time} = 10 \text{ seconds} \times \frac{109.4 \text{ yards}}{100 \text{ yards}} = 10.94 \text{ seconds}$$

(The women's world record for the 100-meter dash is 10.49 seconds, set in 1988 by American Florence Griffith Joyner. At the same speed, would she have run 100 yards in more or less than 10.0 seconds?)

Problems

1. In Canada a speed limit sign says 70 kilometers per hour. What is the legal speed in miles per hour?
2. How many liters are in a half-gallon container of milk?
3. A runner consistently completes a 1-mile race in 4 minutes. What is his expected time in a 1500-meter race?
4. Write the following numbers in powers of ten notation:

   a. 1,000,000 c. 2.5
   b. 1/1,000,000 d. 1/2.5

5. Convert the following numbers into decimal notation.

   a. 7×10^4 c. 6.41×10^6
   b. 7×10^{-4} d. 6.41×10^{-6}

6. The following table gives the volume of 1 gallon (4 quarts) of antifreeze for various temperatures starting at 6 degrees Celsius. This antifreeze is typically used in American cars.

Volume (quarts)	Temperature (degrees Celsius)
4.0000	6
4.0096	12
4.0288	24
4.0672	48
4.1440	96

   a. Express any trends or patterns in words.
   b. Display the data in graphical form.
   c. Express any trends or patterns in an equation with words.
   d. Express any trends or patterns in an equation with symbols.

7. Veronica was doing a laboratory assignment in which she was investigating the time of descent, final speed, acceleration, and incline angle of a marble rolling down an inclined track and how each was related to the other. Her data are given next.

Incline Angle (degrees)	Time of Descent (s)	Final Speed (m/s)	Acceleration [(m/s)/s]
5	3.75	3.2	0.85
10	2.65	4.5	1.70
15	2.17	5.5	2.54
20	1.89	6.3	3.40
30	1.56	7.6	5.08

A. Consider only the incline angle and the acceleration.

   a. Express any trends or patterns in words.
   b. Display the data in graphical form.
   c. Express any trends or patterns in an equation with words.

B. Consider only the incline angle and the time of descent.

   a. Express any trends or patterns in words.
   b. Display the data in graphical form.
   c. Express any trends or patterns in an equation with words.

C. Consider only the incline angle and the final speed.

   a. Express any trends or patterns in words.
   b. Display the data in graphical form.
   c. Express any trends or patterns in an equation with words.

8. An industrious student decided that she wanted to prove certain laws about gases and the relationships among pressure, volume, and temperature. In Sarah's science laboratory, she collected the following data.

Temperature (kelvins)	Volume (liters)	Pressure (atmospheres)
100	1000	1.0
100	500	2.0
100	250	4.0
100	125	8.0
200	2000	1.0
200	1000	2.0
200	500	4.0
300	750	4.0
600	1500	4.0

   a. Show by using a graph, an equation, or a written statement that the volume is directly proportional to the temperature if the pressure is held constant.
   b. Use these data to show Boyle's law, which states that at a constant temperature the pressure and volume vary inversely.

9. The brightness of a lightbulb can be measured by a light meter in a unit named lumens. Jeremy decided to investigate how the brightness of a certain lightbulb changes with the distance from the lightbulb. Jeremy recorded the following data.

Distance from bulb (feet)	Brightness (lumens)
1	1600
2	400
3	178
4	100
5	64
10	16
20	4

   a. Express any trends or patterns in words.
   b. Display the data in graphical form.
   c. Express any trends or patterns in an equation with words.
   d. Express any trends or patterns in an equation with symbols.

10. Ron used 6980 kW-h (kilowatt-hours) of electricity last year and Jennifer used 5235 kW-h in only 10 months.

a. Who used, on the average, the most electricity per month?
b. What, on the average, were Ron and Jennifer's daily uses of electricity? (Assume a 30-day month.)
c. If Ron paid 8 cents per kW-h and Jennifer paid 10 cents per kW-h, who paid more for electricity last year?

11. P.J. maintains the following exercise schedule. Every Sunday she runs for 30 minutes using 12 calories per minute. On Monday, Wednesday, and Friday, P.J. takes brisk walks for 1 hour each day (4 calories per minute), and every Tuesday and Thursday P.J. plays volleyball for 1.5 hours (5.5 calories per minute). On Saturday she does not exercise.

a. Calculate the total amount of calories P.J. expends during the week.
b. On average, how many calories per day (include Saturday) does P.J. expend?

12. The G-7 countries (the United States, Canada, Japan, Germany, the United Kingdom, France, and Italy) are the leading industrialized countries in the world. Their populations, total energy use, total wilderness areas, and total solid waste disposed for 1991 are given in the following table.

Country	Population (millions)	Annual energy use (10^9 BTU)	Wilderness area (square miles)	Annual solid waste (10^6 tons)
United States	249.2	76,355	379,698	230.1
Canada	26.5	10,309	2,473,308	18.1
Japan	123.5	15,707	9,276	53.2
Germany	77.5	13,881	19,128	21.0
United Kingdom	57.2	8,575	17,912	22.0
France	56.1	8,355	18,454	30.2
Italy	57.1	6,579	5,021	19.1

a. Which country uses the most energy per person? The least energy per person?
b. Which country has the most wilderness area per person? The least wilderness area per person?
c. Which country disposes of the most solid waste per person? The least solid waste per person?
d. If you combined the four European countries into one country, would your answers to a, b, and c change?

13. Express the following quantities in powers of ten notation.

a. 150 gigadollars
b. 43 hectofeet
c. 23 micrometers
d. 92 nanoseconds
e. 74 milligrams
f. 617 kilobucks
g. 43 microbreweries

14. Multiply the following.

a. $(4.3 \times 10^6) \times (7.4 \times 10^{-7})$
b. $(1.2 \times 10^{-8}) \times (3.4 \times 10^{-5})$
c. $(5.5 \times 10^3) \times (6.7 \times 10^7)$
d. $(6.6 \times 10^2) \times 120$
e. $(2.3 \times 10^{12}) \times (4.9 \times 10^8)$

15. Divide the following.

a. $\dfrac{3.3 \times 10^{12}}{3.0 \times 10^{-4}}$
b. $\dfrac{7.6 \times 10^{-6}}{8.2 \times 10^{8}}$
c. $\dfrac{1.5 \times 10^{2}}{5.0 \times 10^{7}}$
d. $\dfrac{2.2 \times 10^{11}}{4.5 \times 10^{8}}$

16. Convert the given quantities to the units shown in parentheses.

a. 40 acres (square miles)
b. 23,000 bushels (cubic yards)
c. 50 barrels (liters)
d. 125 bushels (cubic meters)
e. 50 caliber (millimeters)
f. 50,000 carats (grams)
g. 20 fathoms (meters)
h. 600 knots (kilometers per second)
i. 540 knots (meters per second)

Investigations

1. Identify 20 specialized terms that relate to your favorite sport. What statistics are commonly recorded, and how are they calculated?

2. Investigate the history of temperature scales. Why are two different scales, Celsius and Fahrenheit, still in use?

3. Are scientists the only people who have devised specialized vocabulary? What other fields have their own jargon?

4. Describe your favorite tree so that another student can identify it.

5. Read a history of the French Revolution. Why did this political movement lead to a new system of weights and measures?

6. Investigate the history of systems of units used in a well-established profession, such as surveying, agriculture, cooking, or maritime commerce. Which of these specialized units are still used today?

7. The computer age has led to a wide variety of new units of measurement (e.g., "gigabyte" or "megaflop"). Identify some of these units and investigate their history. When were they introduced, by whom, and why?

8. Both common temperature scales, the Fahrenheit and the Celsius, use the freezing and boiling points of water for their reference points. Since the choice of units is largely a matter of convenience, what sort of temperature scale do you suppose a beer manufacturer, who works with alcohol, might use? A jewelry maker working in gold? A beekeeper who has to prepare honey for bottling? (*Hint:* Honey flows easiest when it is warm but starts to change chemically at temperatures around 160°F.)

WWW Resources

See the *Physics Matters* home page at **www.wiley.com/college/trefil** for valuable web links.

1. **powersof10.com** This interactive web site is based on a famous film by Charles and Ray Eames. You can guide yourself through the metric system of prefixes.
2. **helios.physics.uoguelph.ca/tutorials/vectors/vectors.html** The vectors tutorial at the Department of Physics, University of Guelph.
3. **www.pa.uky.edu/~phy211/VecArith/** Another vector tutorial—this one is an interactive graphical Java applet.
4. **www.nrlm.go.jp/keiryou-e.html** The official scientific standards website of Japan, with a nice set of descriptions of how the basic standards are established.
5. **www.velocity.net/~trebor/prelude.html** A published essay, *A Prelude to the Study of Physics,* discussing the role of models and problem-solving in physics.