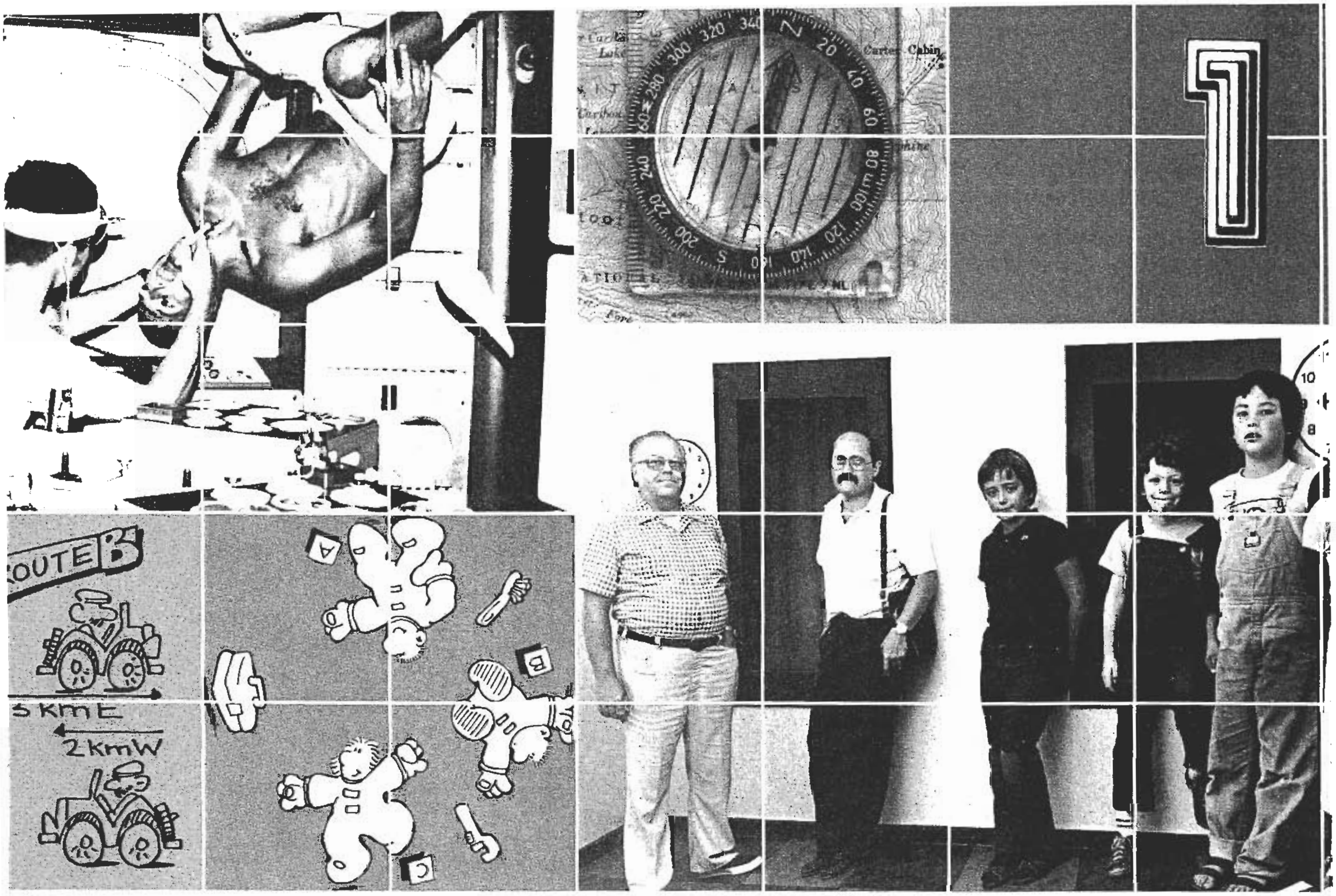


Position and Change

The question of different points of view is a very basic one. Some people like modern art; others call it scribbling. Some like the latest movie; others find it mediocre. When we deal with opinions, it is rare that we ever share completely another's point of view. When we describe position, however, we can agree. All the Wizard (Figure 1-1) had to do to avoid confusion was turn around and face the two baskets in the same direction as the unfortunate citizen. Scientists consciously choose concepts that enable them to share points of view—to agree upon what they observe.

We begin studying motion by defining position and change in position. This chapter will show how *reference objects* combined with *reference directions* provide us with a *reference frame* with which to agree upon the position of an object. In order to be more precise, we will introduce *coordinate systems,* which incorporate the process of measurement into reference frames. *Distance* and *displacement* describe the change in position of a moving object. These last two concepts are the foundation for our later descriptions of motion.

THE WIZARD OF ID

Figure 1-1

DESCRIBING POSITION

Every day we describe the position of many objects. It's on the table. She's at the office. Seaton Hall is north of the Student Union. All these statements describe the location of one object using another object and some reference direction.

Reference Objects and Reference Directions

To convince yourself of the need to describe one object's position in terms of another object, try a short exercise. Figure 1-2 shows a black dot inside a square. Without referring to any other object, try to describe the position of the dot. You probably find the task impossible. You might say that the dot is in the upper center of the square, but then you have used the square itself. If you now try the same exercise using objects inside the square, the task is much easier! You might say that the dot is directly above the person.

The exercise using Figure 1-2 shows that we need other objects to describe an object's location. A **reference object** is anything used to describe

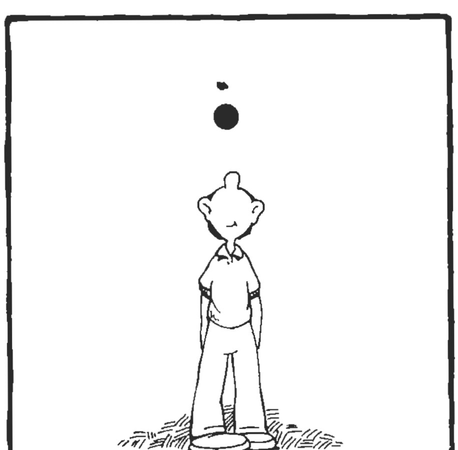


Figure 1-2
We use the person as a reference object to describe the position of the dot.

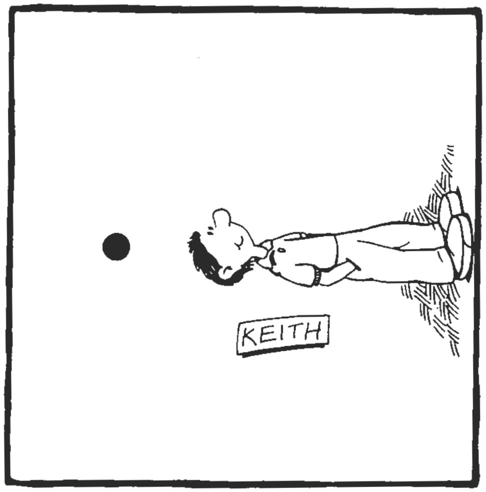


Figure 1-3
Descriptions depend on the orientation of the reference object.

the location of another person or thing. When you say that the dot is directly above the person, you are using the person as the reference object. If you tell a friend that the library is next to the Fine Arts Building, you are using the Fine Arts Building as your reference object. Whenever you use reference objects, you describe another object's position *relative to* the reference object. You describe the position of the dot relative to the person and the position of the Fine Arts Building relative to the library.

When two people choose the same reference object, they still may not agree in their description of the location of another object. You can readily see this if you consider Figure 1-3. First describe the location of the dot using Keith as the reference object. Then describe the dot's location as Keith would describe it using himself as the reference object.

You: The dot is to the left of Keith.

Keith: The dot is above me.

In both cases Keith was the reference object, yet the descriptions of the dot's location were different. Here the differences arise from the terms *above, below, left,* and *right.* Keith used himself to establish *above* and *below.* You used yourself to establish *left* and *right.* You and Keith each used Keith as the reference object but your own bodies to establish the **reference directions.** If you turn the book so that Keith is right side up, your use of reference directions will agree with Keith's. Then, both of you will report that the dot is above Keith.

In real life, as in Figure 1-3, we use our own bodies to establish the reference directions *right* and *left.* The confusion this causes is apparent in the Wizard of Id cartoon (Figure 1-1). In contrast to the subjectivity of right and left, the reference directions *up* and *down* seem more objective. Gravity defines our sense of up and down, so that the terms mean essentially the same to everyone. Down is the direction things fall. Up is the direction opposite to down. Thus, the situation in Figure 1-3 was rather contrived. Normally, one person's *up* and *down* would be the same as another's.

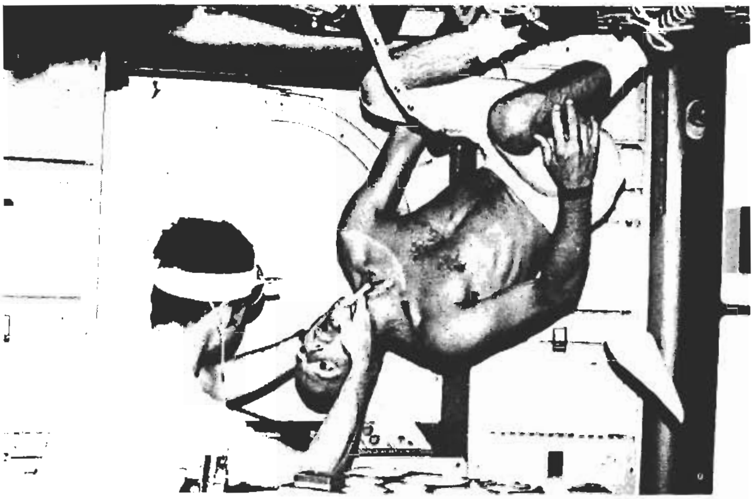


Figure 1-4

The space program has given us an opportunity to explore our sense of up and down in a weightless, or gravity-free, environment. The photograph of the Skylab astronauts (Figure 1-4) looks strange because the things in Skylab are not being pulled toward the earth. Thus we have no clues to establish "right side up." When asked about his sense of orientation in space, Astronaut Joseph Kerwin responded:

> *You do have a sense of up and down, and you can change it in two seconds, whenever it's convenient for you. If you go from one module to the next and you're upside down, you say to your brain "I want that way to be up" and your brain says "OK then that way is up." It's strictly eyeballs and brain.*

Once the physical sensation of gravity is removed, up and down are as subjective as left and right.

Reference Frames

Since we must be able to describe the positions of objects in weightless space as well as here on earth, we need to rely upon more than "eyeballs and brain." In order to agree upon the location of an object, we have to establish a common reference frame. A **reference frame** consists of the reference object and the reference directions used in our description. When we say that Seaton Hall is north of the Student Union, the reference frame consists of Seaton Hall and the compass direction north. Once we define our reference frame, others should be able to place themselves in that same reference frame and agree upon the location of Seaton Hall.

While the strict definition of a reference frame requires both a reference object and a set of reference directions, ordinarily we just mention the reference object. "It's on the table" and "she's at the office" both identify reference objects—the table and the office. The terms *on* and *at,* however, imply a set of commonly agreed-upon reference directions. This works fine as long as we are all in the same earth-based reference frame; but, as illustrated by the Wizard of Id cartoon, assumed reference directions can cause problems.

When we describe an object's location differently from someone else, we usually do so because we have chosen different reference frames. There is no end to the number of reference frames we can invent. Given the standard set of reference directions implicit in our vocabulary, we can invent as many reference frames as there are reference objects. "John is standing five meters west of the tree" and "John is standing two meters north of the house" could both be describing the location of the same person, but from two different reference frames. In the first, the tree defines the reference frame; in the second, the house defines the reference frame. Similarly, statements like "Ed is standing five meters west of the tree and Mary is standing two meters north of the house" tell us nothing about where Ed is relative to Mary. Each description uses a different reference frame.

Ordinarily we can resolve these differences by agreeing on one of the reference frames or by inventing a new reference frame common to the two descriptions. We might both describe John's location relative to the tree, agreeing to use the same reference frame. Or we might describe where the tree is relative to the house, allowing us to invent a common reference frame in which to describe John's location. Either solution would enable us to agree on our descriptions. The important characteristic of reference frames is that they allow people to describe position and change from a common point of view.

SELF-CHECK 1A

For each statement below, identify the reference frame used and whether the reference directions are stated or implied. Is the same reference frame used for each pair of statements?

a. The book is lying on the nightstand.
The book is next to the window.

b. Venus is 20° north of the western horizon.
The moon is about 25° north of the western horizon.

c. The Student Union is north of the Library.
The Fine Arts Building is north of the Student Union.

COORDINATE SYSTEMS

Even with a common reference frame, our descriptions of position may still be imprecise. Suppose I tell you that the flowers are a little to the right of and slightly higher than the book. Missing here is a precise description of distance. How far to the right is *a little?* How much higher is *slightly?* Coordinate systems, which define distance as well as direction, allow us to be more precise.

Adding Measurement

Let's return to the dot, this time without the square. Figure 1-5 shows the dot amidst a series of lines. Use the lines to describe the location of the dot.

Using the convention of left and right and up and down while facing the page, you could say that the dot is at the intersection of the third line from the left and the fourth line from the bottom. Someone else might describe it as the intersection of the third line from the right and the third line from the top. Using the numbers associated with the lines allows us to establish immediately a common reference frame. Now we can say that the dot is at the intersection of the vertical line marked 3 meters and the horizontal line marked 4 meters.

The numbered lines combined with the reference directions vertical and horizontal provide a reference frame called a coordinate system. A **coordinate system** is a reference frame that shows units of measurement for each of the directions, or **dimensions.** Each number, or **coordinate,** describes the location of an object along one dimension. The reference object for the entire system is the point from which all others are measured, at the intersection of the lines marked 0. This point is known as the **origin** of the coordinate system.

A variety of coordinate systems can be invented. Typically each system is named by the number of dimensions it includes and the orientation among those dimensions. Because two coordinates, one for the vertical dimension and one for the horizontal dimension, are required to describe a position, this particular coordinate system is two-dimensional. Since the lines in Figure 1-5 form small rectangles, it is called a *rectangular coordinate system*. The complete name of our reference frame is a two-dimensional rectangular coordinate system.

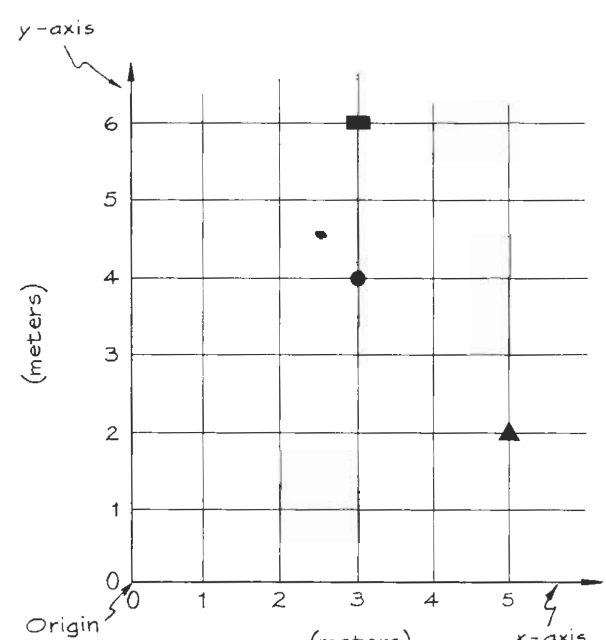


Figure 1-5

Numbered lines provide a more precise description of the dot's location. Distances along the coordinate axes are measured relative to the origin.

Coordinate systems are not restricted to two dimensions nor to lines at right angles to one another. Football players care only about the distance to the goal line. Their coordinate system is one-dimensional. Hikers, however, need to know whether their trail goes over or around the mountain. Topographical maps add contour lines to give us a three-dimensional map of the terrain. A magnetic compass describes orientation about a reference circle. Its coordinates are expressed in degrees. Figure 1-6 shows a few of the many coordinate systems we invent to help us agree on the location of objects.

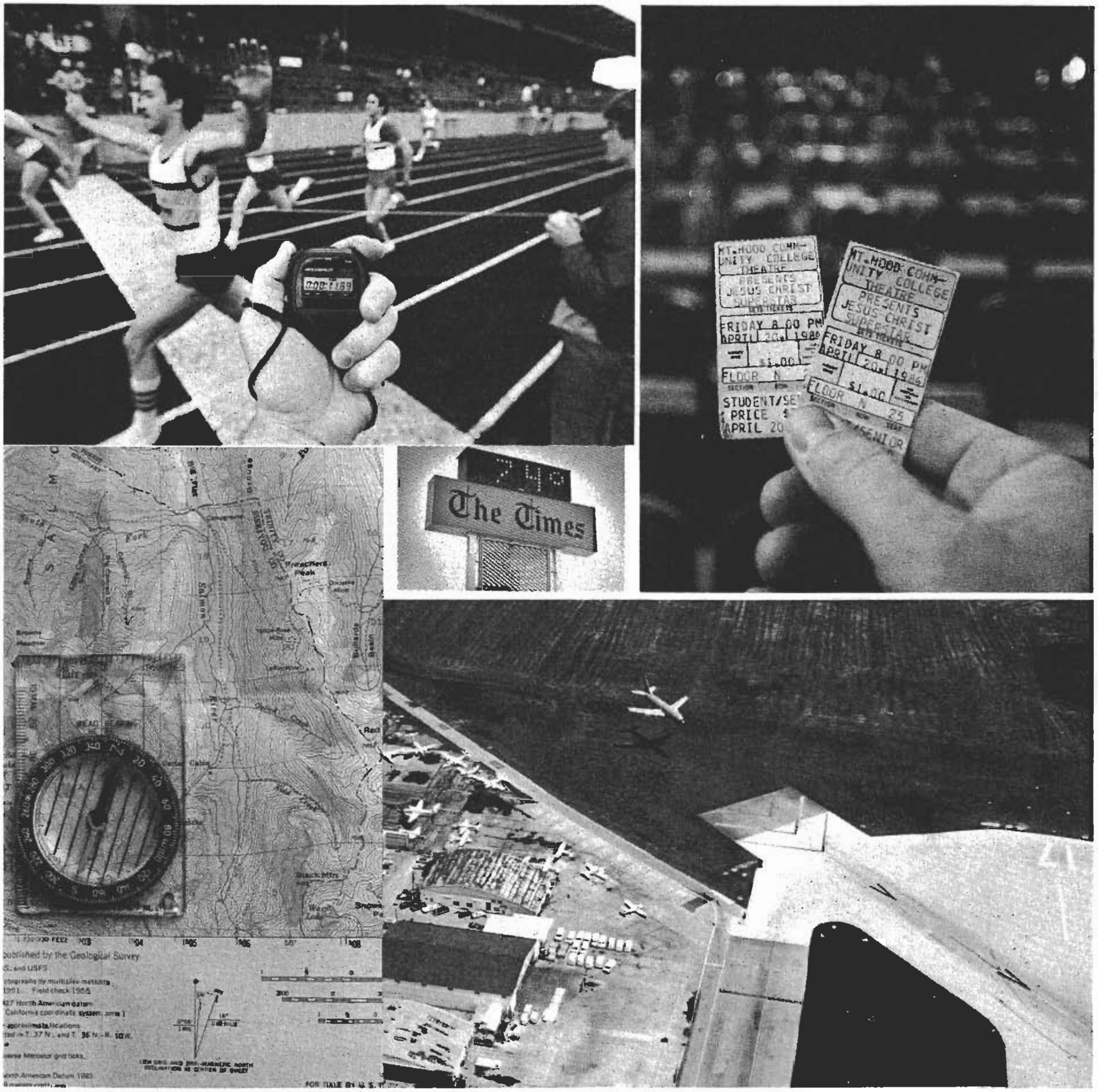


Figure 1-6
Everyday uses of coordinate systems.

Using Rectangular Coordinate Systems

Physicists frequently use a two-dimensional rectangular coordinate system similar to that shown in Figure 1-5. The two lines that define the reference directions of the coordinate system and intersect at the origin are called the **coordinate axes.** Each coordinate axis has a scale along which distances from the origin can be measured. Scales are chosen for convenience and need not be the same for both axes. The orientation of coordinate systems can be chosen at will, but we generally use ourselves as the guide. If you hold a coordinate system so it faces you, up on the system is the same as up for you; right and left mean the same as your right and left. By convention, the horizontal and vertical dimensions are frequently called the *x*- and *y*-dimensions.

In using this coordinate system, we adopt a shorthand notation to describe position. The location of an object is given by two numbers with the appropriate units, separated by a comma: (10 meters, 5 meters) (meters are abbreviated m). The first number and unit gives the distance along the horizontal, or *x*-axis; the second gives the distance along the vertical, or *y*-axis. In Figure 1-5, the square is located at (3 m, 6 m).

The process of establishing a coordinate system with an origin as the reference object, coordinate axes to define reference directions, and measured distances to add precision is the physicists' way of defining the position of an object. To turn the statement around, the **position** of an object is defined by the *x*- and *y*-coordinates of the object in a coordinate system in which the origin and the orientation of the coordinate axes have been specified. Admittedly longer than a definition like "on my right," such a description is clearer because it allows different observers to agree upon the position of any object.

SELF-CHECK 1B

Use the shorthand notation to describe the position of the triangle in Figure 1-5.

BEETLE BAILEY

Figure 1-7
What is Zero's coordinate system?

DESCRIBING CHANGES IN POSITION

If their purpose were only to describe fixed positions, coordinate systems would be useful to mapmakers and geographers but of comparatively little value to physicists and astronomers, who deal with things in motion. But motion involves a change in position, and coordinate systems help us describe these changes.

Consider an everyday example: moving about a city. Figure 1-8 shows a map of the northern section of Salt Lake City. Suppose you ride from P Street, First Avenue to H Street, Fifth Avenue along the route sketched. One way to describe your change in position would be to describe the route. "I started at First and P, rode to First and N, then to Fifth and N, and finally to Fifth and H." Another might be to describe the total distance you traveled along the route, 1.6 kilometers (km). A third way would be to describe the distance from P Street, First Avenue to H Street, Fifth Avenue "as the crow flies." As shown in Figure 1-8, this straight-line distance is 1.2 km. All three descriptions provide information about your motion, but the types of information are quite different. We will discuss the last two descriptions—distance and displacement—in more detail.

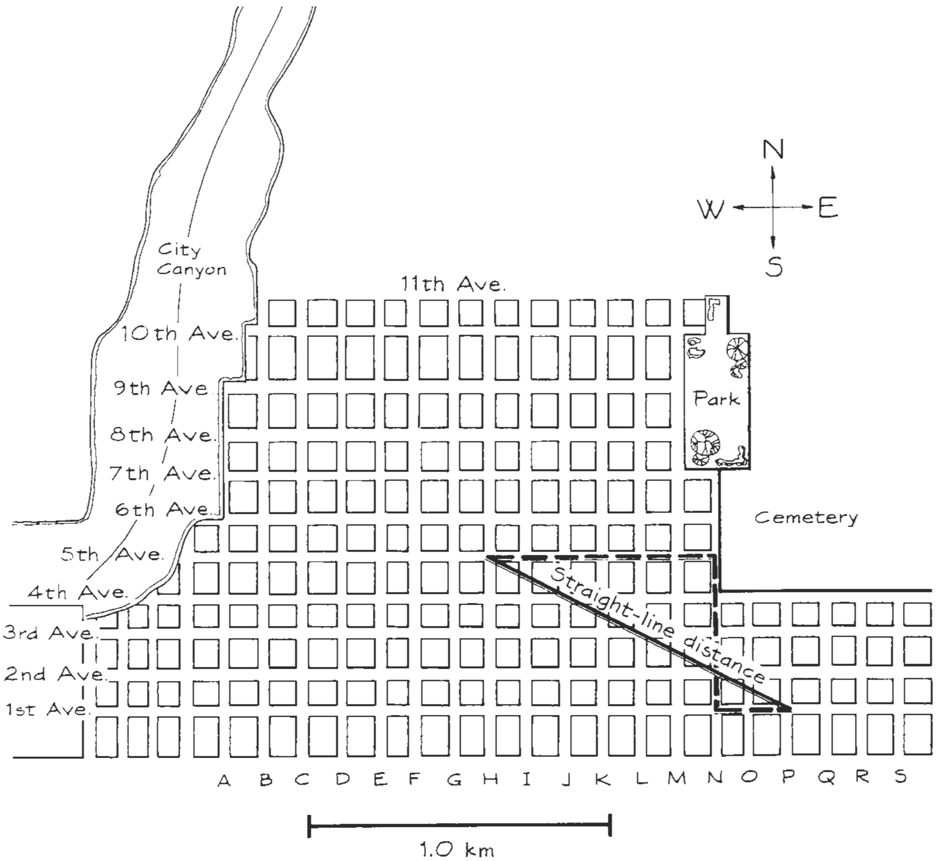


Figure 1-8
A route followed in traveling from P Street, First Avenue to H Street, Fifth Avenue in northern Salt Lake City.

Distance

We use the concept of distance to describe the length of the route you followed, 1.6 km. **Distance** is defined as the *length of path* traveled when an object changes position. We can measure distance in one of two ways. When traveling by car, we can use the beginning and ending odometer readings. The difference between these two numbers is the distance we have traveled. However, using the rectangular coordinate system provided by the streets and avenues, we can also measure the distance along your route by counting the number of blocks you traveled and multiplying this number by the length of each block. The first method involves continuous measurement of the path and does not depend on knowing where you started or stopped. The second involves calculating the length of the path from your known starting and stopping positions.

In a conventional rectangular coordinate system, distance is usually calculated from the coordinates that define your route. Figure 1-9 shows a route followed by a student in moving from *A* to *B* in a library. A coordinate system is superimposed on the route to allow us to measure distances. The student

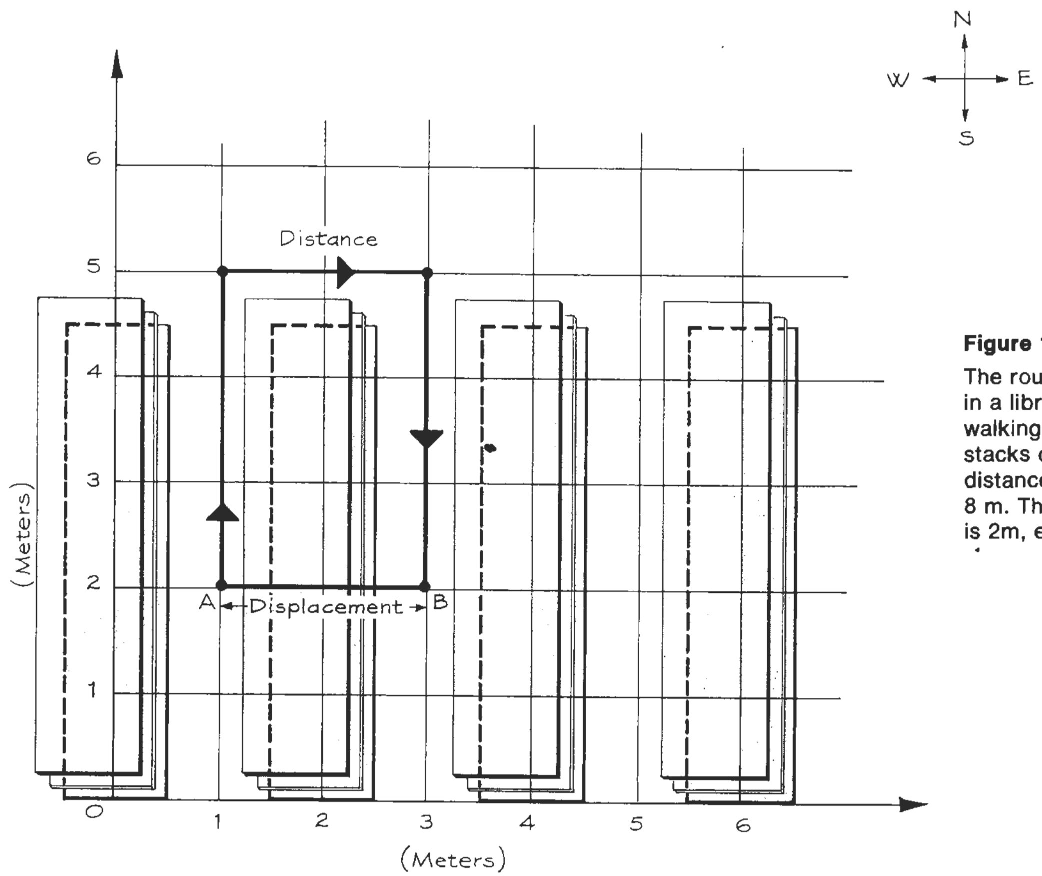


Figure 1-9
The route from *A* to *B* in a library requires walking around the stacks of books. The distance traveled is 8 m. The displacement is 2m, east.

moved from (1 m, 2 m) to (1 m, 5 m) to (3 m, 5 m) and finally to (3 m, 2 m). We can find the distance traveled by adding the distance of each leg of the trip. The distance traveled in the first leg is 5 m minus 2 m, which equals 3 m. Similarly, the distance traveled in the second leg is 3 m minus 1 m, which equals 2 m. For the third leg, it is 5 m minus 2 m, which equals 3 m. The distance traveled over the entire route is 3 m + 2 m + 3 m, which equals 8 m. We can calculate the distance traveled in this manner as long as the route is along the lines of a rectangular coordinate system.

Displacement

You are walking down the street when someone asks where the nearest post office is. "Oh, that's easy," you reply. "It's about three kilometers." If you walk on at this point, the stranger will probably ask someone else. "Three kilometers" is not very useful. "Three kilometers east" would have been much more helpful.

We use the concept of displacement to describe both the distance traveled as the crow flies and the direction in which the motion occurred. The **displacement** of an object is the distance and direction along the straight-line path from its initial position to its final position. A statement of displacement includes a straight-line distance and a direction, written as: straight-line distance, direction. In Figure 1-8, the displacement is 1.2 km, northwest. Quantities such as 30 km, north and 4 m, to your left are displacements. Thirty kilometers is not a displacement; neither is south.

The distinction between distance and displacement can be made clearer by returning to the library example in Figure 1-9. The straight-line distance between *A* and *B* is 2 m. When you arrive at *B*, you are 2 m east of *A*. The displacement is 2 m, east, even though you traveled a distance of 8 m to get there.

One way to distinguish between the terms *distance* and *displacement* is to think about the old stereotype of the expectant father. While his child is being born, he paces back and forth in the waiting room. He moves from one position to another and back again. With each change of position, he travels a distance of a few meters. Then he goes right back to where he started. By the time the baby is born, the father may have moved through a distance of several thousand meters. But his displacement is zero because he always comes back to where he began.

SELF-CHECK 1C

A car drove 3 km east and then 2 km in a different direction. Two possible routes are illustrated in Figure 1-10. Calculate the distance and displacement for each route.

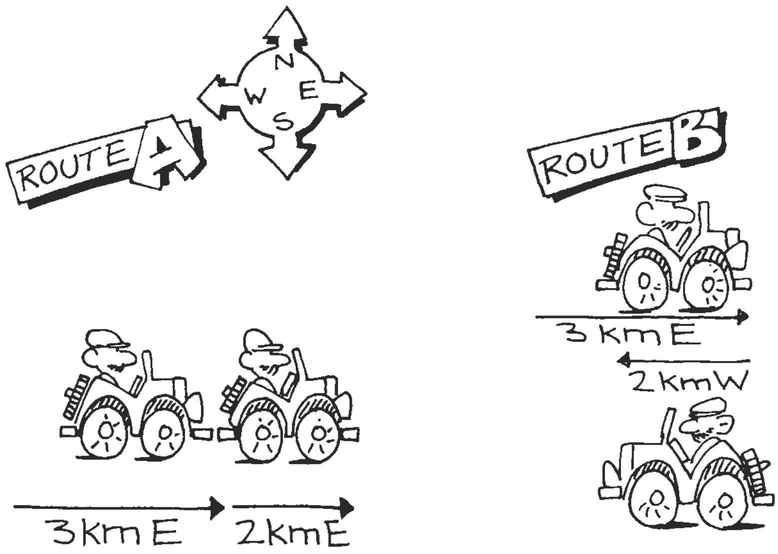


Figure 1-10

Vectors and Scalars

Distance and displacement are related concepts, but they have an important difference: direction. Distance is specified by a number with units, such as 30 km. Displacement requires a number, a unit and a direction, such as 30 km, east. This distinction occurs so frequently in physics that we define terms to distinguish the two types of quantities. A **scalar** is any quantity which can be completely described by a number and a unit. Distance is a scalar. A **vector** is any quantity which can be completely described by a number, a unit, and a direction. Displacement is a vector. The number and unit are often referred to as the **magnitude** of the vector. The magnitude of a displacement of 50 km, north, is 50 km. Quantities like speed, time, and temperature are scalars. Force and momentum, two quantities we will examine in more detail in later chapters, are both vectors. To help you recognize vector and scalar quantities in equations, we designate vectors by boldface type (such as **d** for displacement) and scalars by regular type (such as *l* for distance).

The addition of direction does more than simply change a scalar into a vector. Distance and displacement both describe a change in position. But, as illustrated by the stereotype of the expectant father who paces back and forth but never goes anywhere, these descriptions provide different types of information. Displacement uniquely locates the position of an object but tells us little about the path it took in reaching that position. A displacement of 30 km, north, means simply that the object is 30 km north of its starting location. By contrast, distance provides us information about the length of path followed but no unambiguous information about the object's final location. "The car traveled 30 km" tells us nothing about where to find the car, although we do know how far the car actually traveled. Vectors and scalars are clearly two different types of quantities.

A STEP FURTHER—MATH

WHAT TO DO WHEN THE CAR TURNS A CORNER

The two examples in Self-Check 1C are relatively simple since the car either continued in the same direction or turned around. But cars do turn corners. In the route shown in the figure, the driver traveled 3 km east and then 2 km north. Here the displacement is the straight-line distance from the tail of vector **A** to the tip of vector **B.** Since east and north are at right angles to one another, the displacement is actually the hypotenuse of a right triangle whose other two sides are 3 km, east, and 2 km, north. (The **hypotenuse** is the side of a right triangle that is opposite the 90° angle.) A bit of mathematics enables us to determine the length of the hypotenuse from the other two sides—the net displacement from the two legs of the trip.

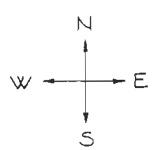
As you may remember, the Pythagorean theorem describes the relationship among the three sides of a right triangle. The square of the hypotenuse is equal to the sum of the square of each of the other two sides. Applying this to the route shown:

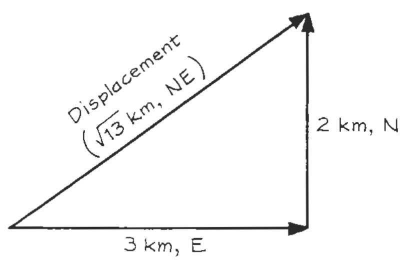
$$(\text{Length of hypotenuse})^2 = (\text{length of side } X)^2 + (\text{length of side } Y)^2$$

$$\begin{aligned}\text{Length of hypotenuse} &= \sqrt{(3\text{ km})^2 + (2\text{ km})^2}\\ &= \sqrt{(9\text{ km}^2 + 4\text{ km}^2)}\\ &= \sqrt{13}\text{ km}\\ &= 3.6\text{ km}\end{aligned}$$

The displacement is 3.6 km, northeast.

While this procedure works for one corner, think about what would happen if we drove 3 km east, 2 km north, and then 2 km west—turning two corners instead of just one. Even a single corner can cause problems if it is not at a right angle. Determining the displacements in these situations becomes a little more complex. In the next section we will present a graphical technique for estimating displacements when the car turns lots of corners or moves along curves. If you find some of these discussions tough going, don't feel dismayed. While turning corners and going around curves is a daily occurrence, calculating displacements is not. What is important is that you realize what displacement describes and that there are mathematical techniques for calculating it.





Working with Vectors

Since vectors have a direction associated with them, arithmetic operations like adding, subtracting, multiplying, and dividing are a little different. Three of these, adding vectors, subtracting vectors, and multiplying a vector by a scalar, crop up several times in later chapters. Let's illustrate the procedure we use with a few examples involving displacement.

In the process of adding vectors, we must keep track of the direction associated with each. A displacement of 1 km, east, added to a displacement of 2 km, west, does not lead to a total displacement whose magnitude is 3 km. The simplest way to add vectors is the **tail-to-tip method,** shown in Figure 1-11(a). In our example, an arrow is drawn to scale to represent each of the two displacements. Since the magnitude of vector **B** is twice as great as the magnitude of vector **A,** vector **B** is twice as long. The point at which each arrow begins is called the vector's **tail.** The point at which each arrow ends is called the vector's **tip.** To add the vectors, place them tail to tip so that the tail of vector **B** lies at the tip of vector **A.** The sum of the two vectors, called the **net displacement,** is a vector that goes from the tail of vector **A** to the tip of vector **B.**

Some situations in which we need to add vectors are relatively simple. When the two vectors are in the same direction, you can simply add the

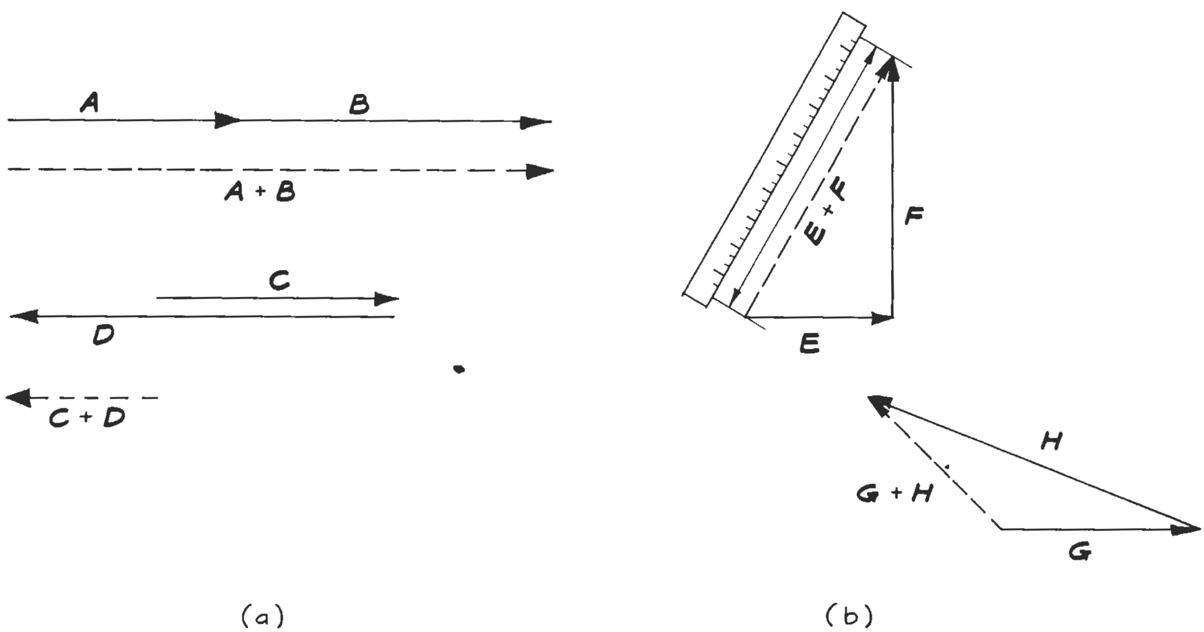
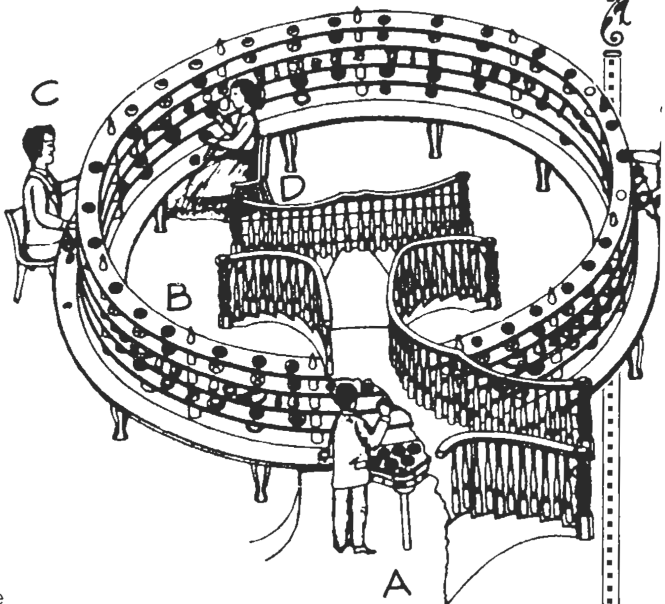


Figure 1-11 **(a)** The tail of vector **B** is placed at the tip of vector **A**. The sum of the two vectors is **A** + **B**, the vector that goes from the tail of vector **A** to the tip of vector **B**. **(b)** Vector **E** + **F** is the vector that goes from the tail of vector **E** to the tip of vector **F**. Vector **G** + **H** describes the sum of vectors **G** and **H**.

SAVING A FEW STEPS?

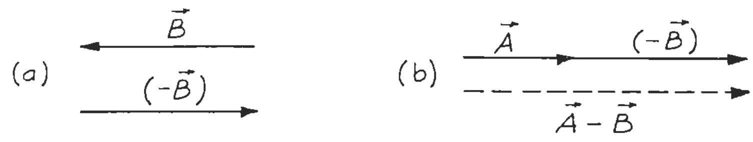


Waiters and waitresses are very much aware of the difference between distance and displacement. They travel long distances but always end up at the same place that they started—back in the kitchen. So, while they may be very tired at the end of their working day, their displacement is zero. During the nineteenth century, William Lance thought of a way to decrease the distance traveled by the waiters and waitresses. His self-waiting table utilized a large mechanized circle of shelves. The servers (A) placed the food on shelves (B) which traveled past the diners (C, D, and E). When the customers saw something appealing, they picked it off the moving shelf. When finished, they placed their dirty dishes on the next empty shelf. The dishes returned to the server (A), who sent them back to the kitchen. Thus, the distance traveled by the dishes was huge, but the distance traveled by the servers was small. Needless to say, the waiters and waitresses were delighted!

magnitudes of the two vectors. A displacement of 1 km, east, added to a displacement of 4 km, east, leads to a net displacement of 5 km, east. When the two vectors are in opposite directions, like **C** and **D,** you could get the result by subtracting the two magnitudes. When the vectors are at right angles to one another, the Pythagorean theorem (page 14) offers an algebraic way of determining the sum of the two vectors. At other angles, however, the tail-to-tip method offers the easiest way to determine the sum of the two vectors. The magnitude of the net displacement can be determined by measuring the length of its arrow to scale (Figure 1-11(b)).

Subtracting vectors takes advantage of the fact that subtraction is the reverse of addition. Suppose we need to subtract two displacements, 1 km, east, and 2 km, west. Vector **A** − vector **B** is the same as vector **A** + (−vector **B**). Consequently, we can subtract vector **B** from vector **A** by adding the negative of vector **B** to vector **A.** Figure 1-12(a) shows vector **B** and its negative, −**B.** To find the difference between the two vectors, we add vector **A** to the negative of vector **B** according to the tail-to-tip method. The resultant displacement is 3 km, east (Figure 1-12(b)).

Multiplying and dividing vectors by scalars is much simpler. Suppose your displacement is 2 km, east, and someone asks you to double your displacement. Doubling the displacement would affect the magnitude of the dis-



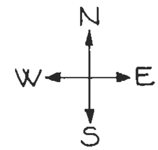


Figure 1-12 To subtract two vectors, you add the negative of the second vector to the first vector. **(a)** The negative of vector **B**, called −**B**, is a vector of the same length but in the opposite direction.
(b) **A** − **B** is the same as **A** + (−**B**). Here **A** and (−**B**) are added using the tail-to-tip method.

placement but not the direction. There is no such thing as "twice as east." A displacement that is twice as great is 4 km, east. A displacement that is half as great is 1 km, east. Multiplying or dividing a vector by a scalar affects only the magnitude of the vector. The direction remains the same.

Reference frames, coordinate systems, distance, and displacement define our concepts of position and change in position. In familiar examples, these concepts seem almost commonsense. In complete definitions, they may seem needlessly complex. As objects start moving, however, we find it increasingly difficult to establish common reference frames, or common points of view. The definitions become increasingly important to us.

CHAPTER SUMMARY

The position of an object must be described in terms of other objects, called *reference objects*. Reference objects and reference directions make up a *reference frame*. In order for two people to agree on the location of an object, they must describe the object's location in terms of the same reference frame.

Coordinate systems are standard reference frames. Rectangular coordinate systems are constructed from lines at right angles to one another. The location of an object in a rectangular coordinate system is specified in terms of distances from a single point, called the *origin*. By convention, we use a shorthand notation in which the position is given by two numbers and units separated by a comma. The first number and unit specifies the distance along the horizontal axis; the second specifies the distance along the vertical axis.

The change in position of an object (its motion) can be described in terms of distance or displacement. *Distance* is the length of the path traveled by an object in moving from its initial to its final position. *Displacement* is the straight-line distance traveled by the object in moving from its initial to its final position and the direction the object travels along that straight-line path. A *scalar* is defined by a number and a unit; a *vector* is characterized by a number, a unit, and a direction. The *magnitude* of a vector is its number and unit. Distance is a scalar quantity; displacement is a vector quantity. Vectors can be added using the *tail-to-tip method*. To subtract two vectors, we add the negative of the second vector to the first vector. Multiplying or dividing vectors by a scalar affects the magnitude of the vector but not its direction.

ANSWERS TO SELF-CHECKS

1A. a. Two different reference frames are used—one defined by the nightstand and the second by the window. Both descriptions are based on implied reference directions.
b. The two statements use the same reference frame—the western horizon. The reference directions have been stated.
c. Two different reference frames are used—one defined by the Library and the second by the Student Union. The reference directions have been stated.

1B. The triangle is located at (5 m, 2 m).

1C. Route A: Distance is 5 km. Displacement is 5 km, east.
Route B: Distance is 5 km. Displacement is 1 km, east.

PROBLEMS AND QUESTIONS

A. Review of Chapter Material

A1. Define the terms listed below:
Reference object
Reference direction
Reference frame
Coordinate system
Rectangular coordinate system
Scalar
Origin
Position
Distance
Displacement
Vector
Tail-to-tip method

A2. How do scientists avoid the "different point of view" problem illustrated in the Wizard of Id cartoon?

A3. In outer space astronauts do not feel the effects of gravity. Which of our common terms for directions lose their meanings in outer space?

A4. How do coordinate systems improve our ability to describe the location of an object?

A5. List three ways you could use to describe the change of position of an object.

A6. How are displacement and distance similar? How do they differ?

A7. How do scalars and vectors differ? Give an example of each.

A8. Why do we add vectors differently than we add scalars?

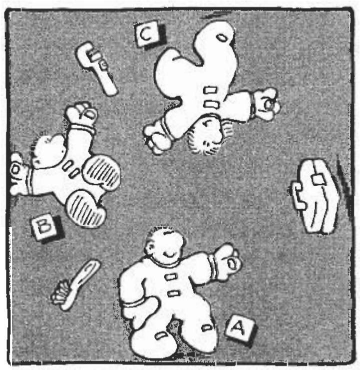
B. Using the Chapter Material

B1. In each sentence below, identify the reference object(s) used to describe the position of the object.
a. You will find the diary in the upper right-hand drawer of the chest of drawers.
b. Sandwiched between Manhattan and Long Island, Queens supports a substantial, largely commuter, population.
c. The fifth car from the corner has Oregon plates.
d. The North Star is the first bright star you reach as you trace the Big Dipper and extend the line upward from the bowl.

B2. You tell a friend that a book is to the right. She moves to your left to pick up the book. Where is she relative to you? (There is more than one possibility!)

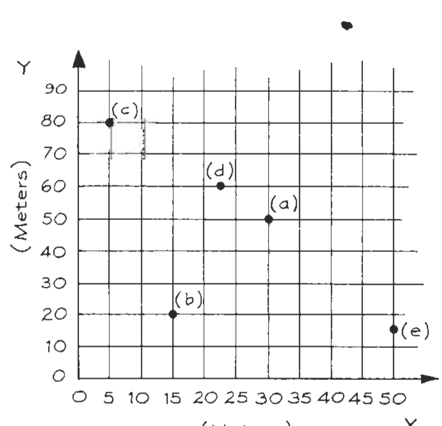
B3. A football player starts halfway between two side boundaries on the 50-yard (yd) line. He drags several tacklers and is finally stopped halfway between the boundaries on the 5-yd line located at the north end of the field. With this information you can calculate only one of the quantities: distance or displacement. Which one can you calculate? Calculate the one you can and explain why you cannot calculate the other.

B4. Three astronauts, labeled A, B, and C, are oriented differently in Skylab, as illustrated in Figure 1-B4. Their descriptions of the location of the toolbox can differ because of their different orientations. For any two astronauts, write observations that differ because of:
  a. reference object chosen
  b. reference directions chosen
  c. both reference object and reference directions chosen

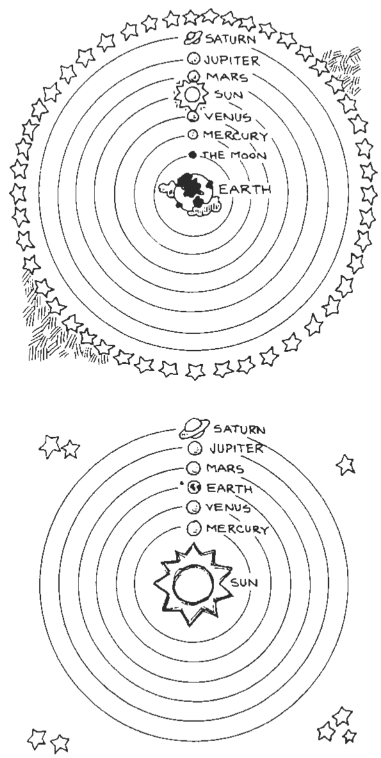


B5. A friend gives you these instructions: To get to my house from the bank, go two blocks north, then three blocks east and two blocks south. What distance, in blocks, do you travel to get to your friend's house? What is your displacement? (If you have trouble, draw a picture of the route.)

B6. Describe the location of the five dots in Figure 1-B6.



B7. Figure 1-B7 shows two different models of the universe that sparked an intense controversy between science and religion during the time of Galileo. Use the concept of reference frame to describe how the two models are different.



B8. What are the distances moved for each set of starting and ending coordinates listed below?
  a. (0 m, 10 m) to (0 m, 5 m)
  b. (2 m, 15 m) to (2 m, 60 m)
  c. (3 m, 5 m) to (1 m, 5 m)
  d. (20 m, 15 m) to (15 m, 15 m)

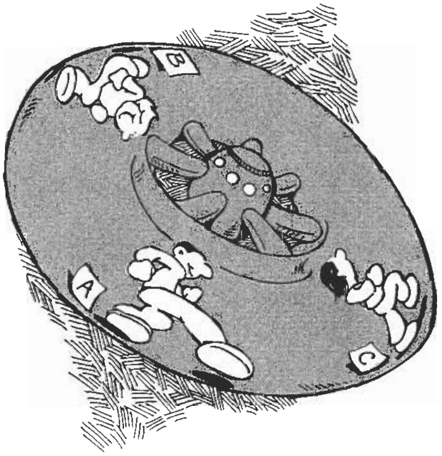
B9. How many dimensions are required of a coordinate system used in each of the following situations?
  a. highway mileage signs
  b. crossword puzzle
  c. football field
  d. location of airplane in flight

B10. The distance between New York and London is 5500 km. What are the distance and displacement of the Concorde supersonic airplane when it completes a New York-London round trip?

C. Extensions to New Situations

C1. Read the cartoon in Figure 1-7. Draw a picture of Zero's coordinate system. Show the location of the origin and orientation of the coordinate axes.

C2. One design for space stations is a large ring as sketched in Figure 1-C2. As the ring rotates, artificial gravity is created, allowing people to walk on the outer edges of the space station. How do each of the people in the diagram define the direction down?



C3. From *Through the Looking Glass:*

> *And they went so fast that at last they seemed to skim through the air, hardly touching the ground, till suddenly, just as Alice was getting quite exhausted they stopped . . . .*
>
> *Alice looked round her in great surprise. "Why, I do believe we've been under this tree the whole time! Everything's just as it was!"*
>
> *"Of course it is," said the Queen . . . . "Now, here, you see, it takes all the running you can do to keep in the same place. . . ."*

a. What reference object is Alice using to describe her motion?

b. What is her position relative to this object at the beginning and at the end of her run?

c. How far did she move relative to her reference object?

d. Can you explain Alice's lack of change of position? (Remember, this story is a fantasy, so anything is possible.)

C4. A construction very similar to a two-dimensional coordinate system combines one dimension in space with time. For example, in describing our location while traveling we could say, "I will leave Springfield now. In 30 minutes I will be 50 kilometers away; in 60 minutes, 100 kilometers away; and in 90 minutes, 150 kilometers away."

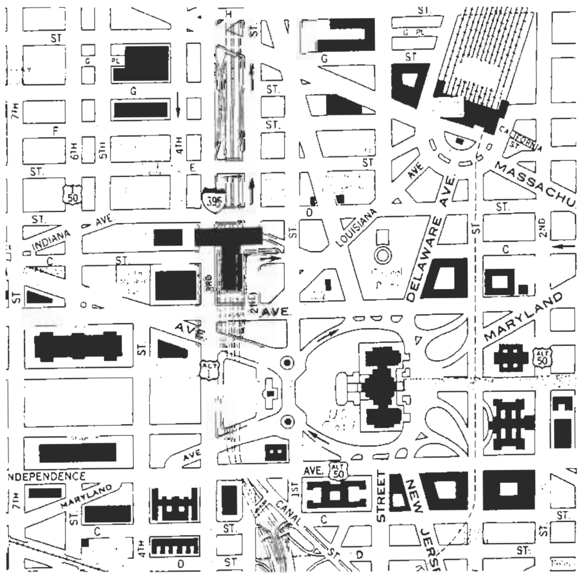
a. Draw a (space, time) system with 0 km, 0 minutes (min) as the origin.

b. Locate the given (space, time) coordinates on the system drawn in (a).

c. By looking at the information on this coordinate system can you predict the distance away from Springfield at 120 minutes?

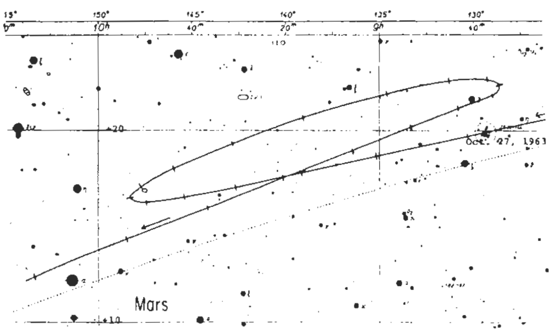
C5. Draw a coordinate system in which a dot's location is (0 m, 10 m). Draw a second coordinate system with the same scale in which the same dot's location is (0 m, 20 m). What is different about the two coordinate systems?

C6. Look at the map shown in Figure 1-C6. Are there regions where rectangular coordinate systems have been used? Regions where there is no rectangular system? Can you invent another type of coordinate system to fit the maps?



C7. We can measure the length of a piece of paper in two different reference frames. In reference frame A, one corner of the paper is located at 0.00 m and the other at 0.29 m. In reference frame B, the first corner is located at 0.10 m and the second at 0.39 m.
a. What is the length of the paper in reference frame A?
b. What is the length of the paper in reference frame B?
c. Compare your answers in (a) and (b). Does the length of an object depend on the reference frame chosen?
d. How is length different from position?

C8. Planets were first distinguished from stars because they appeared to wander relative to the constellations. Figure 1-C8 shows the motion of Mars relative to the constellations of Virgo, Libra, and Scorpius. As measured from Earth, will the distance Mars travels be different from its displacement?



C9. In each of the situations below, will the distance and the magnitude of the displacement of the object be the same or different?
a. A batter hits a fly ball to center field.
b. An apple falls from the tree.
c. The moon orbits the earth.
d. A golfer tees off, sending the ball to the green.

Use the examples to describe the circumstances under which the magnitude of the displacement will equal the distance moved.

C10. In Self-Check 1C you calculated the distance and displacement for the two routes shown in Figure 1-10. Use vector addition to measure several other routes. Convince yourself that the two routes in Figure 1-10 are the minimum and maximum displacements possible. Any other choice of direction for the 2-km displacement leads to a net displacement between 1 km, east, and 5 km, east.

D. Activities

D1. Select one building on your campus. Describe the coordinate system used to locate that building on a campus map. What reference objects are needed?

D2. Obtain a globe or map of the earth.
a. What coordinate system is used to locate positions on the earth's surface?
b. How many dimensions does the system have?
c. Where is its origin?
d. What are the locations of Sydney, Australia; Moscow, USSR; the South Pole; and your present position?

D3. Visual illusions such as that shown in Figure 1-D3 are often created because a reference object is used to trick our eyes. Consult a book dealing with illusions, such as R. L. Gregory, *The Intelligent Eye* (McGraw-Hill, 1970) and describe how a reference object was used to help create the illusion.

D4. List common situations in which:
a. Distance would be more useful than displacement.
b. Displacement would be more useful than distance.