SECTION 1

Displacement and Velocity

SECTION OBJECTIVES

- Describe motion in terms of frame of reference, displacement, time, and velocity.
- Calculate the displacement of an object traveling at a known velocity for a specific time interval.
- Construct and interpret graphs of position versus time.

MOTION

Motion happens all around us. Every day, we see objects such as cars, people, and soccer balls move in different directions with different speeds. We are so familiar with the idea of motion that it requires a special effort to analyze motion as a physicist does.

One-dimensional motion is the simplest form of motion

One way to simplify the concept of motion is to consider only the kinds of motion that take place in one direction. An example of this one-dimensional motion is the motion of a commuter train on a straight track, as in **Figure 1.**

In this one-dimensional motion, the train can move either forward or backward along the tracks. It cannot move left and right or up and down. This chapter deals only with one-dimensional motion. In later chapters, you will learn how to describe more complicated motions such as the motion of thrown baseballs and other projectiles.

frame of reference

a system for specifying the precise location of objects in space and time

Motion takes place over time and depends upon the frame of reference

It seems simple to describe the motion of the train. As the train in **Figure 1** begins its route, it is at the first station. Later, it will be at another station farther down the tracks. But Earth is spinning on its axis, so the train, stations, and the tracks are also moving around the axis. At the same time, Earth is moving around the sun. The sun and the rest of the solar system are moving through our galaxy. This galaxy is traveling through space as well.

When faced with a complex situation like this, physicists break it down into simpler parts. One key approach is to choose a **frame of reference** against which you can measure changes in position. In the case of the train, any of the stations along its route could serve as a convenient frame of reference. When you select a reference frame, note that it remains fixed for the problem in question and has an origin, or starting point, from which the motion is measured.

Figure 1
The motion of a commuter train traveling along a straight route is an example of one-dimensional motion. Each train can move only forward and backward along the track.

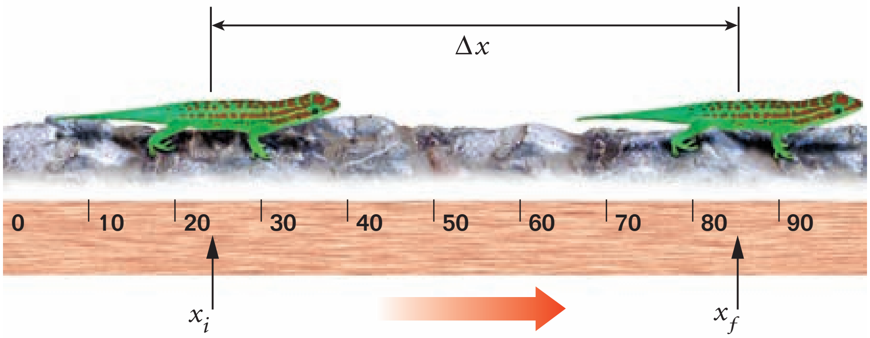


Figure 2
A gecko moving along the x-axis from x_i to x_f undergoes a displacement of $\Delta x = x_f - x_i$.

If an object is at rest (not moving), its position does not change with respect to a fixed frame of reference. For example, the benches on the platform of one subway station never move down the tracks to another station.

In physics, any frame of reference can be chosen as long as it is used consistently. If you are consistent, you will get the same results, no matter which frame of reference you choose. But some frames of reference can make explaining things easier than other frames of reference.

For example, when considering the motion of the gecko in **Figure 2,** it is useful to imagine a stick marked in centimeters placed under the gecko's feet to define the frame of reference. The measuring stick serves as an x-axis. You can use it to identify the gecko's initial position and its final position.

displacement

the change in position of an object

DISPLACEMENT

As any object moves from one position to another, the length of the straight line drawn from its initial position to the object's final position is called the **displacement** of the object.

Displacement is a change in position

The gecko in **Figure 2** moves from left to right along the x-axis from an initial position, x_i, to a final position, x_f. The gecko's displacement is the difference between its final and initial coordinates, or $x_f - x_i$. In this case, the displacement is about 61 cm (85 cm – 24 cm). The Greek letter delta (Δ) before the x denotes a *change* in the position of an object.

DISPLACEMENT

$$\Delta x = x_f - x_i$$

displacement = change in position = final position – initial position

TIP *A change in any quantity, indicated by the Greek symbol delta (Δ), is equal to the final value minus the initial value. When calculating displacement, always be sure to subtract the initial position from the final position so that your answer has the correct sign.*

Why it Matters

Conceptual Challenge

1. Space Shuttle

A space shuttle takes off from Florida and circles Earth several times, finally landing in California. While the shuttle is in flight, a photographer flies from Florida to California to take pictures of the astronauts when they step off the shuttle. Who undergoes the greater displacement, the photographer or the astronauts?

2. Roundtrip

What is the difference between the displacement of the photographer flying from Florida to California and the displacement of the astronauts flying from California back to Florida?

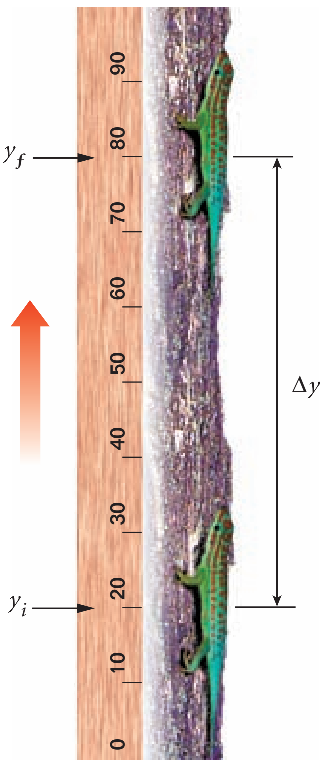


Figure 3
When the gecko is climbing a tree, the displacement is measured on the *y*-axis. Again, the gecko's position is determined by the position of the same point on its body.

Now suppose the gecko runs up a tree, as shown in **Figure 3.** In this case, we place the measuring stick parallel to the tree. The measuring stick can serve as the y-axis of our coordinate system. The gecko's initial and final positions are indicated by y_i and y_f, respectively, and the gecko's displacement is denoted as Δy.

Displacement is not always equal to the distance traveled

Displacement does not always tell you the distance an object has moved. For example, what if the gecko in **Figure 3** runs up the tree from the 20 cm marker (its initial position) to the 80 cm marker. After that, it retreats down the tree to the 50 cm marker (its final position). It has traveled a total distance of 90 cm. However, its displacement is only 30 cm ($y_f - y_i = 50\text{ cm} - 20\text{ cm} = 30\text{ cm}$). If the gecko were to return to its starting point, its displacement would be zero because its initial position and final position would be the same.

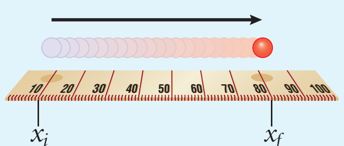
Displacement can be positive or negative

Displacement also includes a description of the direction of motion. In one-dimensional motion, there are only two directions in which an object can move, and these directions can be described as positive or negative.

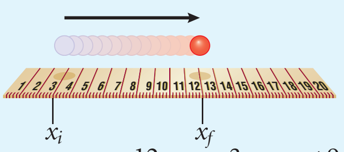
In this book, unless otherwise stated, the right (or east) will be considered the positive direction and the left (or west) will be considered the negative direction. Similarly, upward (or north) will be considered positive and downward (or south) will be considered negative. **Table 1** gives examples of determining displacements for a variety of situations.

Table 1 Positive and Negative Displacements

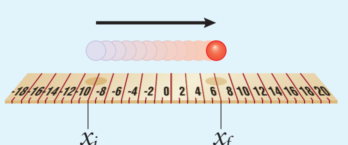
Positive



$\Delta x = x_f - x_i = 80\text{ cm} - 10\text{ cm} = +70\text{ cm}$

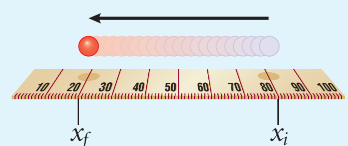


$\Delta x = x_f - x_i = 12\text{ cm} - 3\text{ cm} = +9\text{ cm}$

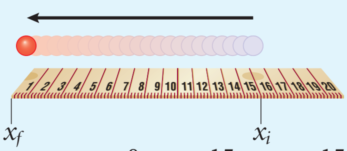


$\Delta x = x_f - x_i = 6\text{ cm} - (-10\text{ cm}) = +16\text{ cm}$

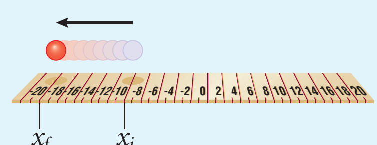
Negative



$\Delta x = x_f - x_i = 20\text{ cm} - 80\text{ cm} = -60\text{ cm}$



$\Delta x = x_f - x_i = 0\text{ cm} - 15\text{ cm} = -15\text{ cm}$



$\Delta x = x_f - x_i = -20\text{ cm} - (-10\text{ cm}) = -10\text{ cm}$

VELOCITY

Where an object started and where it stopped does not completely describe the motion of the object. For example, the ground that you're standing on may move 8.0 cm to the left. This motion could take several years and be a sign of the normal slow movement of Earth's tectonic plates. If this motion takes place in just a second, however, you may be experiencing an earthquake or a landslide. Knowing the speed is important when evaluating motion.

Average velocity is displacement divided by the time interval

Consider the car in **Figure 4.** The car is moving along a highway in a straight line (the *x*-axis). Suppose that the positions of the car are x_i at time t_i and x_f at time t_f. In the time interval $\Delta t = t_f - t_i$, the displacement of the car is $\Delta x = x_f - x_i$. The **average velocity,** v_{avg}, is defined as the displacement divided by the time interval during which the displacement occurred. In SI, the unit of velocity is meters per second, abbreviated as m/s.

AVERAGE VELOCITY

$$v_{avg} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}$$

$$\text{average velocity} = \frac{\text{change in position}}{\text{change in time}} = \frac{\text{displacement}}{\text{time interval}}$$

The average velocity of an object can be positive or negative, depending on the sign of the displacement. (The time interval is always positive.) As an example, consider a car trip to a friend's house 370 km to the west (the negative direction) along a straight highway. If you left your house at 10 A.M. and arrived at your friend's house at 3 P.M., your average velocity would be as follows:

$$v_{avg} = \frac{\Delta x}{\Delta t} = \frac{-370 \text{ km}}{5.0 \text{ h}} = -74 \text{ km/h} = 74 \text{ km/h west}$$

This value is an average. You probably did not travel exactly 74 km/h at every moment. You may have stopped to buy gas or have lunch. At other times, you may have traveled more slowly as a result of heavy traffic. To make up for such delays, when you were traveling slower than 74 km/h, there must also have been other times when you traveled faster than 74 km/h.

The average velocity is equal to the constant velocity needed to cover the given displacement in a given time interval. In the example above, if you left your house and maintained a velocity of 74 km/h to the west at every moment, it would take you 5.0 h to travel 370 km.

TIP *Average velocity is not always equal to the average of the initial and final velocities. For instance, if you drive first at 40 km/h west and later at 60 km/h west, your average velocity is not necessarily 50 km/h west.*

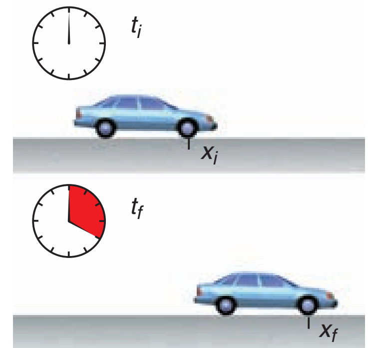


Figure 4
The average velocity of this car tells you how fast and in which direction it is moving.

average velocity

the total displacement divided by the time interval during which the displacement occurred

SCILINKS.
www.scilinks.org
Topic: Motion
Code: HF60996

Did you know?

The branch of physics concerned with motion and forces is called *mechanics*. The subset of mechanics that describes motion without regard to its causes is called *kinematics*.

SAMPLE PROBLEM A

Average Velocity and Displacement

PROBLEM

During a race on level ground, Andra runs with an average velocity of 6.02 m/s to the east. What is Andra's displacement after 137 s?

SOLUTION

Given: $v_{avg} = 6.02$ m/s
$\Delta t = 137$ s

Unknown: $\Delta x = ?$

Rearrange the average velocity equation to solve for displacement.

$$v_{avg} = \frac{\Delta x}{\Delta t}$$

$$\Delta x = v_{avg}\Delta t$$

$$\Delta x = v_{avg}\Delta t = (6.02 \text{ m/s})(137 \text{ s}) = \boxed{825 \text{ m to the east}}$$

CALCULATOR SOLUTION

The calculator answer is 824.74 m, but both the values for velocity and time have three significant figures, so the displacement must be reported as 825 m.

PRACTICE A

Average Velocity and Displacement

1. Heather and Matthew walk with an average velocity of 0.98 m/s eastward. If it takes them 34 min to walk to the store, what is their displacement?
2. If Joe rides his bicycle in a straight line for 15 min with an average velocity of 12.5 km/h south, how far has he ridden?
3. It takes you 9.5 min to walk with an average velocity of 1.2 m/s to the north from the bus stop to the museum entrance. What is your displacement?
4. Simpson drives his car with an average velocity of 48.0 km/h to the east. How long will it take him to drive 144 km on a straight highway?
5. Look back at item 4. How much time would Simpson save by increasing his average velocity to 56.0 km/h to the east?
6. A bus travels 280 km south along a straight path with an average velocity of 88 km/h to the south. The bus stops for 24 min. Then, it travels 210 km south with an average velocity of 75 km/h to the south.
   a. How long does the total trip last?
   b. What is the average velocity for the total trip?