2.1 Picturing Motion

SECTION OUTCOMES

- Identify the frame of reference for a given motion and distinguish between fixed and moving frames.
- Draw diagrams to show how the position of an object changes over a number of time intervals in a particular frame of reference.
- Analyze position and time data to determine the speed of an object.

KEY TERMS

- frame of reference
- at rest

In the introductory investigations, you observed marbles moving in different ways. Some were moving at a constant rate or speed. Some were starting at rest and speeding up, while others were slowing down. How easy or difficult did you find it to describe the relative motion of the marbles and the pattern of their motion?

Although you might think you can readily identify and describe motion based on everyday experiences, when you begin to carefully examine the physical world around you, motion can be deceiving. A few examples were discussed in the chapter introduction. To describe motion in a meaningful way, you must first answer the question, "When are objects considered to be moving?" To answer this seemingly obvious question, you need to establish a **frame of reference**.

Frames of Reference

Figure 2.1 For more than 50 years, movie producers have used cameras that move to give you, the viewer, the sense that you are moving around the set of the movie and interacting with the actors.

Movie producers use a variety of reference clues to create images that fool your senses into believing that you are experiencing different kinds of motion. In the early years of moving making, film crews such as those in Figure 2.1, could drive motorized carts carrying huge cameras around a stage. To create the sense that the actors were in a moving car, the crew would place a large screen behind a stationary car and project a moving street scene on the screen so the viewer would see it through the car windows. Today, the movie crew might ride on a moving dolly that is pulling the car down an active street. In this case, the crew and the viewer would be **at rest** relative to the car in which the actors are riding. The buildings and street would be moving relative to the stationary actors.

COURSE CHALLENGE: SPACE-BASED POWER

Getting into Orbit

Research the current types of orbits given to satellites. Investigate which type of orbit would best meet the needs of a satellite that was to be used for a space based power system. Should the satellite be in motion relative to Earth?

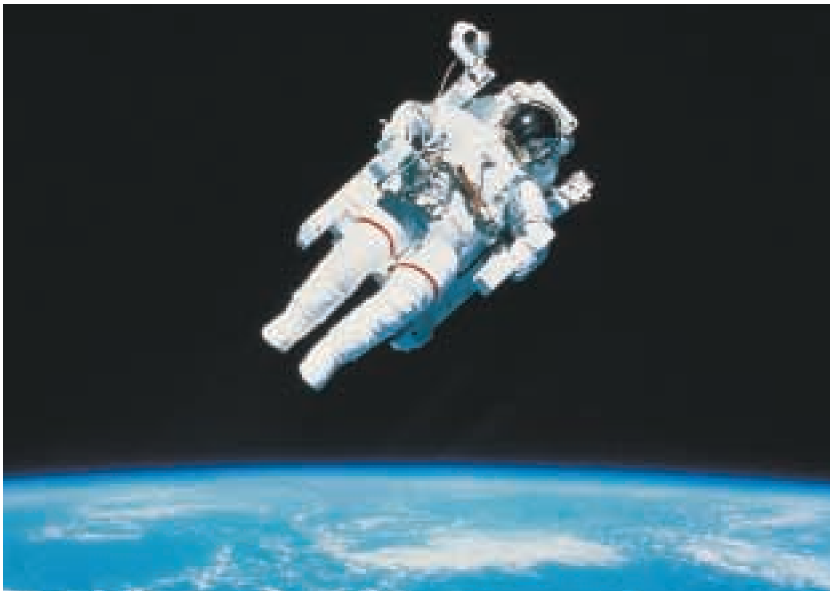


Figure 2.2 Does this astronaut appear to be hurtling through space at 28 000 km/h?

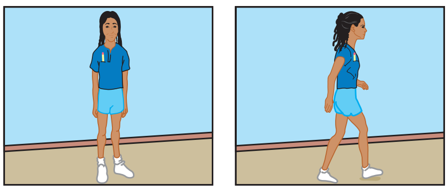
PHYSICS FILE

Kinesiologists often record the motion of an athlete using a camcorder that takes 30 frames per second. By attaching reflective tags to different parts of the athlete's body, the kinesiologist can study, in detail, the motion of each part of the athlete's body while running, rowing, swinging a tennis racquet, or high-jumping. The kinesiologist might be able to help the athlete escape injury by avoiding movements that are likely to damage a joint or pull a muscle. The kinesiologist might also be able to help the athlete improve his or her performance by eliminating energy-wasting motions. The human body is an amazing instrument when properly trained.

In everyday life, Earth's surface seems to provide an adequate frame of reference from which to consider the motion of all objects. However, Earth's reference frame is limited when you consider present-day scientific endeavours such as the flight of aircraft and space shuttles. As you examine the meanings of terms such as "position," "velocity," and "acceleration," you will need to consider the frame of reference within which objects are considered to be moving.

Conceptual Problem

- For each picture shown here, describe a frame of reference in which the pencil
  (a) is moving
  (b) is not moving



Illustrating Motion

Because you need to establish a frame of reference to study motion, diagrams and sketches are critical tools. Diagrams show how the object's position is changing in relation to a stationary frame, during a particular time interval or over several time intervals. When comparing the object's position in each of a series of pictures, you can determine whether the object is at rest, speeding up, slowing down, or travelling at a constant speed.

Your diagrams could be as elaborate as pictures taken by a camcorder (see the Physics File on page 31), as simple as stick-people, or even just dots. In any case, you would superimpose (place one on top of the other) each image, ensuring that something visible in the background is in the same place in each frame. This point provides your frame of reference. Knowing the time that passed between the recording of each image, you can analyze the composite picture or diagram and determine the details of the motion.

The four stick diagrams in Figure 2.3 illustrate four different kinds of motion. Each diagram shows the position of a sprinter after five equal time intervals. In diagram A, the sprinter has not changed position, and is therefore at rest. In diagram B, she changes her position by an equal amount during each time period, and therefore she is travelling at a constant speed. In diagram C, she is changing her position by an increasing amount in each time interval, and therefore she is speeding up. In diagram D, she is changing her position by a decreasing amount, and therefore is slowing down.

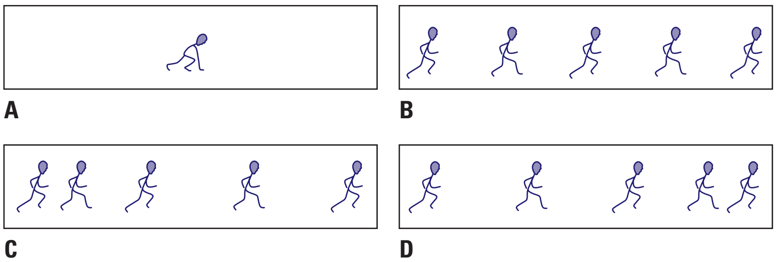


Figure 2.3 Stick diagrams illustrating the position of a sprinter after five equal time intervals

A diagram of the composite picture of the sprinter in motion can be made even simpler by considering a single point on her waist. This point is approximately her centre of mass. In other words, this point moves as though the sprinter's entire mass was concentrated there. You can measure the distance between points, and the analysis of her motion then becomes straightforward. The diagrams in Figure 2.4 show how a picture can be drawn simply as a set of dots to show how the position of an object changes over a number of time intervals in a particular frame of reference.

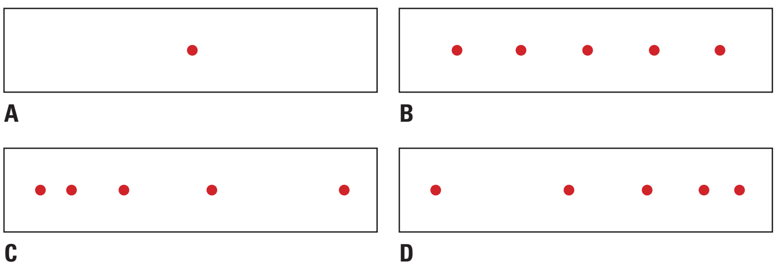


Figure 2.4 Dots can be used to show how the position of an object changes over a number of time intervals in a particular frame of reference.

Coordinate System

In order to describe an object's position and motion mathematically, you need to establish a coordinate system within your frame of reference. One of the most commonly used systems is the Cartesian coordinate system, which has an origin and three mutually perpendicular axes to define direction.

Imagine that you were studying the motion of objects inside a car. You might begin by gluing metre sticks to the inside of the vehicle so you could precisely express the positions of passengers and objects relative to an origin. You might choose the centre of the rearview mirror as the origin and then you could locate any object by finding its height above or below the origin, its distance left or right of the origin, and its position in front of or behind the origin. The metre sticks would define a coordinate system for measurements within the car, as shown in Figure 2.5. The car itself would be called the frame of reference for the measurements. Coordinate systems are always attached to or located on a frame of reference.

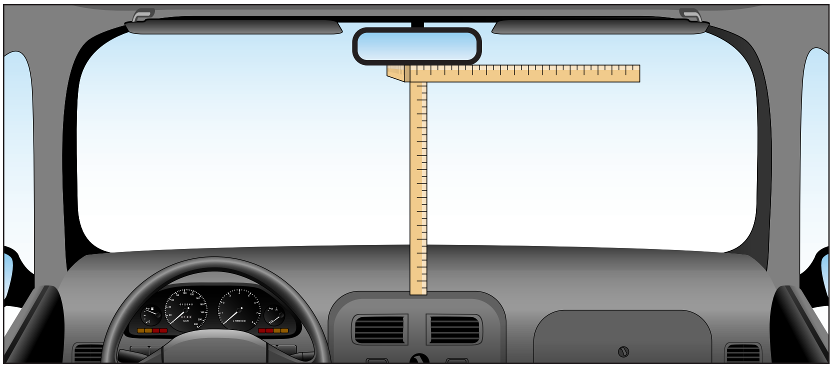


Figure 2.5 Establishing a coordinate system and defining a frame of reference are fundamental steps in motion experiments.

The Importance of Relative Motion

Assume that you have selected a frame of reference in which you are at rest. For example, when you are dozing off in the back seat of a car that is traveling smoothly along a super highway, you may be unaware of your motion relative to the ground. The sensation is even more striking when you are in a large, commercial airliner. You are often entirely unaware of any motion at all relative to the ground. You become aware of it only when the motion of your frame of reference changes. If the car or airplane speeds up, slows down, or turns, you become very aware of the change in the motion of your reference frame. Physicists and engineers need to understand these relative motions and their effects on objects that were at rest in that reference frame. As you solve motion problems and move on into a study of forces, always keep the reference frame and its motion in mind.

2.1 Section Review

1. K/U Draw dot diagrams, such as those illustrated in Figure 2.4 on page 32, of the motion described in the following situations.
   (a) A sprinter running at a constant speed.
   (b) A marble starting from rest and rolling down a ramp.
   (c) A car starting from rest, speeding up, and then travelling at a constant speed. Finally, the car slows down and stops.

2. K/U Alex is sitting at a bus stop facing north. Darcy walks by heading west. Jennifer jogs by going east. Draw dot diagrams of the motion of each person from:
   (a) Alex's frame of reference,
   (b) Darcy's frame of reference, and
   (c) Jennifer's frame of reference.

3. I Draw dot diagrams according to the following directions then write two scenarios for each diagram that would fit the motion.
   (a) Draw seven, evenly spaced dots going horizontally. Above the fourth dot, draw five vertical dots that are evenly spaced.
   (b) Draw a square. Make a diagonal line of dots starting at the upper left corner to the lower right corner. Make the dots closer together at the upper left and getting farther apart as they progress to the lower right.
   (c) Draw a horizontal line of dots starting with wide spacings. The spacing becomes smaller, then, once again gets wider on the right end.
   (d) Start at the lower left with widely spaced dots. The dots start going upward to the right and get closer together. They then go horizontally and become evenly spaced.

4. C Sketch two frames of reference for each of the following:
   (a) a ferry boat crossing a river.
   (b) a subway car moving through a station.
   (c) a roller coaster cart at Canada's Wonderland.

5. C Use single points (centre of mass) to sketch the motion in the following situations: (The distance between dots should represent equal time intervals.)
   (a) a person on a white water rafting trip jumps off a cliff.
   (b) a person hops across the length of a trampoline.
   (c) an Olympic diver jumps off a high dive board, hits the water and comes back to the surface.

6. MC Explain how the frequency of frames affects the quality of a Disney cartoon.

7. I A marble rolls down a 1.0 m ramp that is at an angle of 30° with a horizontal bench. The marble then rolls along the bench for 2.0 m. Finally, it rolls up a second 1.0 m ramp that is at an angle of 40° with the bench.
   (a) Draw a scale diagram of this situation and use dots to illustrate your predictions of the marble's motion. Use at least four position dots on each ramp.
   (b) Design and conduct a brief investigation to determine the accuracy of your predictions.
   (c) Describe your observations and explain any discrepancies with your predictions.