3.1 Position, Displacement, and Distance

Position, Displacement, and Distance

Key Ideas

- The **position** of an object is where the object is in space at a specific time. **Motion** refers to changes in position as time elapses.
- **Displacement** is the change in position of an object during a given time period. Displacement is a vector that points from the initial position to the final position of the object.
- **Distance** is a number (scalar) equal to the total lengths an object moves along. For motion in just one direction, distance is equal to the magnitude of the displacement. For motion with changes in direction, distance is the sum of the magnitudes of each of the one-direction displacements.
- Coordinate systems are used to define positions and motion. A Cartesian coordinate system consists of an **origin** or center and a set of perpendicular directions or axes.
- Different coordinate systems can be used to solve any specific motion problem. A wise choice of coordinates can simplify the solution.

Learning Objectives

By the end of this section, you should be able to:

- correctly describe motion of objects using positions and displacements,
- understand the **Particle Model** for real objects and correctly describe when it can and cannot be used, and
- create coordinate systems useful for solving motion problems in one dimension and use them to describe positions and displacements as vectors.

When you're in motion, the basic questions to ask are: Where am I? Where am I going? How far have I gone? The answers to these questions require that you specify your position and displacements, the physical properties we define in this section.

Position

To describe the motion of an object in one dimension, you must first be able to define its **position $\vec{x}(t)$,** *where the object is at any particular time.* We will describe positions using the mathematics of vectors from Chapter 2 and by using a convenient coordinate system ([Coordinate Systems and Vector Components](#)). For motion problems, the coordinate system is often referred to as the **Frame of Reference**. This consists of a point of reference, or **origin**, and a set of axes that define perpendicular directions. The position of an object is given by the scalar components of the object along each axis. A point fixed on the Earth is often used as the origin of the frame of reference. For example, a rocket launch could be described in terms of the position of the rocket with respect to the launch point and a cyclist's position could be described relative to a building she passes, as in [Figure 3.2](#). In other cases, we use reference frames that are in motion relative to Earth. For example, the position of a person walking down the aisle of a flying airplane can be described using a reference frame with the airplane's nose as the origin.

To define the position of real objects, such as people, cars, or airplanes, we are going to need to pick a point on the object and treat that as the position of the entire object. This approximation, called the **Particle Model**, is a useful simplification for many problems describing solid objects. For other situations, more complicated models are needed. For example, if we are interested in determining the winner of a 100-m sprint, modeling each runner as a "particle" is likely sufficient. If we are working with a coach to improve the time for one runner, we need a more sophisticated model

of the runner that includes the motion of the legs and arms, the angle of the body, etc. For the next two chapters on motion and kinematics, the choice of the point on the object used as the position is somewhat arbitrary. Often, we will choose the center of the object as our particle. In later chapters, we will develop a more precise definition of the "particle" and consider ways to extend the particle model to consider objects rotating, objects that stretch and bend, and non-solid systems of fluids and gases.

This chapter will explore simple one-dimensional motion to build understanding of the basic concepts and to develop mathematical skill. Of course, to simplify problems, the coordinate systems we will define have one of the coordinate axes in the direction of motion. The position of objects will be given as, for example, $\vec{x}(t) = x(t)\,\hat{i}$ or $\vec{y}(t) = y(t)\,\hat{j}$, depending on the direction of motion and our definition of the coordinate system.

Figure 3.2 The position of these cyclists in Vietnam can be described relative to a building or a point on the canal. Their motion is the change in position, or displacement. (credit: modification of work by Suzan Black)

Displacement

If an object changes position, for example, if a professor moves from left to right in front of the whiteboard in the following figure, this change in position is called **displacement**. The displacement is a vector that starts at the initial position of the object and ends at the final position.
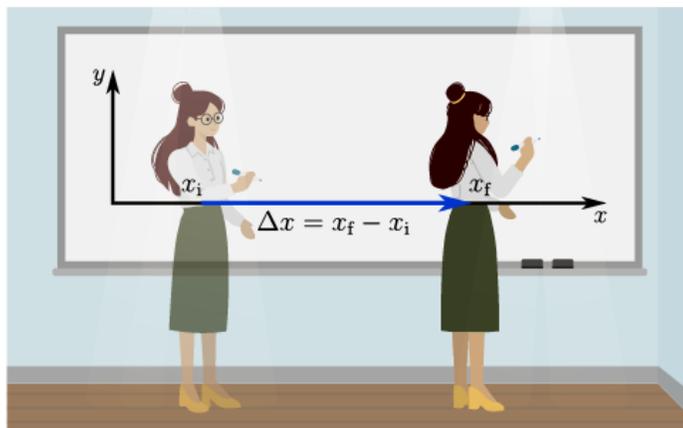

Figure 3.3 An instructor walks in front of a whiteboard. Her initial and final positions are shown relative to a coordinate system. The blue arrow

indicates her displacement vector, $\Delta\vec{x}$.

Consider the frame of reference shown in [Figure 3.3](#) with the origin on the left side of the whiteboard and the positive x-direction directed toward the right, the direction the professor moves. The initial position is $\vec{x_i} = x_i\,\hat{i}$, the final position is $\vec{x_f} = x_f\,\hat{i}$, and the displacement is found as the final position minus the initial position, $\Delta\vec{x} = (x_f - x_i)\,\hat{i}$.

DISPLACEMENT

Displacement $\Delta\vec{x}$ is the change in position of an object:

$$\Delta\vec{x} = \vec{x_f} - \vec{x_i} \qquad \boxed{3.1}$$

where $\Delta\vec{x}$ is displacement, $\vec{x_f}$ is the final position, and $\vec{x_i}$ is the initial position. The SI unit for displacement is the meter (m).

We use the uppercase Greek letter delta (Δ) to mean "change in" whatever quantity follows it; thus, $\Delta\vec{x}$ means *change in position* (the final position minus the initial position). The "change in" a physical property will always mean its final value minus its initial value. Changes indicated by Δ will usually refer to changes in time of some physical property (position, velocity, energy, etc.). Although the SI unit for displacement is the meter, sometimes we'll use kilometers or other units of length. Always be aware of the units used and the potential need to convert between units.

Be Prepared 3.1

Although we will often just use the (scalar) position coordinates, it's important to remember that positions and displacements (and velocities and accelerations defined in the next sections) are vectors. It is correct to say that a vector points to the right or left, but it is **not** correct to say a vector is "negative". The components of a vector can be positive or negative, but *that depends on our choice of coordinate system*. This choice is entirely up to us; our choice should make problem-solving easier.

For example, consider the example shown in Figure 3.3. The frame of reference used gives the (scalar) x-coordinates related as $x_f > x_i > 0$ and the x-component of the displacement vector is positive, $x_f - x_i > 0$. If, for example, we define a new coordinate system with the origin on the right side of the whiteboard and the new x-direction is positive to the left, the displacement of the professor to the right would have a negative x-component in this new coordinate system. Of course, these are two descriptions of exactly the same motion.

Objects in one dimensional motion can also go through a series of displacements by stopping and starting and, more importantly, turning around. Perhaps the pacing professor above moves to the right for some distance, writes on the

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