CH 2 & 3: MOTION

Kinematics is the science of describing the motion of objects using words, diagrams, numbers, graphs, and equations.

The motion of objects can be described by words. Even a person without a background in physics has a collection of words that can be used to describe moving objects. Words and phrases such as *going fast*, *stopped*, *slowing down*, *speeding up*, and *turning* provide a sufficient vocabulary for describing the motion of objects. We will be expanding upon this vocabulary list with words such as *distance*, *displacement*, *speed*, *velocity*, and *acceleration*. The mathematical quantities that are used to describe the motion of objects can be divided into two categories. The quantity is either a vector or a scalar.

- **Scalars** are quantities that are fully described by a magnitude (or numerical value) alone.
- **Vectors** are quantities that are fully described by both a magnitude and a direction.

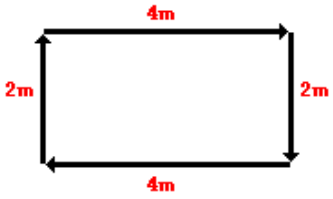
Distance and displacement are two quantities that may seem to mean the same thing yet have distinctly different definitions and meanings.

- **Distance** is a scalar quantity that refers to "how much ground an object has covered" during its motion.
- **Displacement** is a vector quantity that refers to "how far out of place an object is"; it is the object's overall change in position.

To test your understanding of this distinction, consider the motion depicted in the diagram below. A physics teacher walks 4 meters East, 2 meters South, 4 meters West, and finally 2 meters North.

1. What is the total distance of the physics teacher? _____

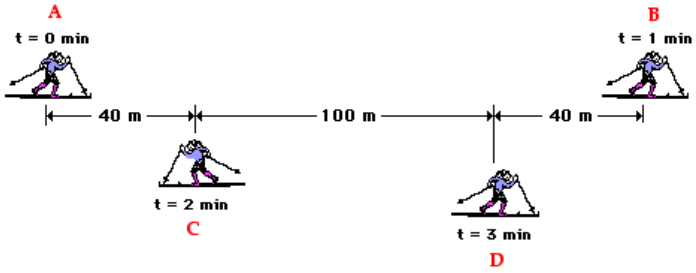
2. What is the displacement of the physics teacher? _____



Use the diagram to determine the resulting displacement and the distance traveled by the skier during these three minutes. At each of the indicated times, the skier turns around and reverses the direction of travel. In other words, the skier moves from A to B to C to D.

3. What is the total distance of the skier? _____

4. What is the displacement of the skier? _____



5. What is the distance and the displacement of the race car drivers in the Indy 500? _____

Speed is a scalar quantity that refers to "how fast an object is moving." Speed can be thought of as the rate at which an object covers distance. A fast-moving object has a high speed and covers a relatively large distance in a short amount of time. Contrast this to a slow-moving object that has a low speed; it covers a relatively small amount of distance in the same amount of time. An object with no movement at all has a zero speed.

Velocity is a vector quantity that refers to "the rate at which an object changes its position." Imagine a person moving rapidly - one step forward and one step back - always returning to the original starting position. While this might result in a frenzy of activity, it would result in a zero velocity. Because the person always returns to the original position, the motion would never result in a change in position. Since velocity is defined as the rate at which the position changes, this motion results in zero velocity. If a person in motion wishes to maximize their velocity, then that person must make every effort to maximize the amount that they are displaced from their original position. Every step must go into moving that person further from where he or she started.

Velocity is *direction aware*. When evaluating the velocity of an object, one must keep track of direction. It would not be enough to say that an object has a velocity of 55 mi/hr. One must include direction information in order to fully describe the velocity of the object. For instance, you must describe an object's velocity as being 55 mi/hr, **east**. This is one of the essential differences between speed and velocity.

The average speed during the course of a motion is often computed using the following formula:

$$\text{Average Speed} = \frac{\text{Distance Traveled}}{\text{Time of Travel}}$$

In contrast, the average velocity is often computed using this formula

$$\text{Average Velocity} = \frac{\Delta \text{position}}{\text{time}} = \frac{\text{displacement}}{\text{time}}$$

Since a moving object often changes its speed during its motion, it is common to distinguish between the average speed and the instantaneous speed. The distinction is as follows.

- **Instantaneous Speed** - the speed at any given instant in time.
- **Average Speed** - the average of all instantaneous speeds; found simply by a distance/time ratio.

You might think of the instantaneous speed as the speed that the speedometer reads at any given instant in time and the average speed as the average of all the speedometer readings during the course of the trip.

The physics teacher walks 4 meters East, 2 meters South, 4 meters West, and finally 2 meters North. The entire motion lasted for 24 seconds.

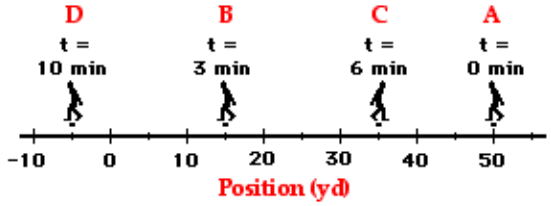
6. Determine the average speed. _____

7. Determine the average velocity. _____

Consider a football coach pacing back and forth along the sidelines. The diagram below shows several of coach's positions at various times. At each marked position, the coach makes a "U-turn" and moves in the opposite direction. In other words, the coach moves from position A to B to C to D.

8. What is the coach's average speed? _____

9. What is the coach's average velocity? _____



Acceleration is a vector quantity that is defined as the rate at which an object changes its velocity. An object is accelerating if it is changing its velocity.

Sports announcers will occasionally say that a person is accelerating if he/she is moving fast. Yet acceleration has nothing to do with going fast. A person can be moving very fast and still not be accelerating. Acceleration has to do with changing how fast an object is moving. If an object is not changing its velocity, then the object is not accelerating. Anytime an object's velocity is changing, the object is said to be accelerating; it has an acceleration.

$$\text{Ave. acceleration} = \frac{\Delta \text{velocity}}{\text{time}} = \frac{v_f - v_i}{t}$$

Acceleration values are expressed in units of velocity/time. Typical acceleration units include the following:

m/s/s, mi/hr/s, km/hr/s, or m/s^2