Summary

11.1 Distance and Displacement

To describe motion accurately and completely, a frame of reference is needed. A frame of reference is a system of objects that are not moving with respect to one another.

The answer to how fast something is moving depends on the frame of reference you choose to measure the moving object's motion. Relative motion is movement in relation to a frame of reference. For example, as a train moves past a platform, people standing on the platform will see those on the train speeding by. But when the people on the train look at one another, they don't seem to be moving at all.

On a train, looking at a seat or the floor may tell you how fast you are walking relative to the train. It doesn't tell you, however, how fast you are moving relative to the ground outside. Choosing a meaningful frame of reference allows you to describe motion in a clear and relevant manner.

Distance is the length of a path between two points. When an object moves in a straight line, the distance is the length of the line connecting the object's starting point and its ending point.

The SI unit for measuring distance is the meter (m). For very large distances, it is more common to make measurements in kilometers (km). Distances that are smaller than meters are measured in centimeters (cm). One centimeter is one hundredth of a meter.

Displacement is the direction from the starting point and the length of a straight line from the starting point to the ending point. Displacement gives information both about how far away an object is from a given point and in what direction the object is from that point. For example, accurate directions give the direction from a starting point as well as the distance.

Displacement is an example of a vector. A vector is a quantity that has magnitude and direction. The magnitude can be size, length, or amount. Vector addition is the combining of vector magnitudes and directions.

Add displacements by using vector addition. When two displacements—represented by two vectors—have the same direction, you can add their magnitudes. If two displacements are in opposite directions, the magnitudes subtract from each other.

When two or more displacement vectors have different directions, they may be combined by graphing. The vector sum of two or more vectors is called the resultant vector. The resultant vector points directly from the starting point to the ending point.

11.2 Speed and Velocity

Speed is the ratio of the distance an object moves to the amount of time the object moves. The SI unit of speed is meters per second (m/s).

Two ways to describe the speed of an object are average speed and instantaneous speed. Average speed is computed for the entire time of a trip. Instantaneous speed, by contrast, is measured at a particular instant. In different situations, either one or both of these measurements may be a useful way to describe speed.

Sometimes it is useful to know how fast something moves for an entire trip. Average speed, $\overline{v}$, is the total distance traveled, d, divided by the time, t, it takes to travel that distance. This can be written as an equation:

$$\text{Average speed} = \frac{\text{Total distance}}{\text{Total time}}, \text{ or } \overline{v} = \frac{d}{t}$$

During the time an object is moving, its speed may change, but this equation tells you the average speed over the entire trip.

Sometimes, you need to know how fast you are going at a particular moment. Instantaneous speed, v, is the rate at which an object is moving at a given moment in time.

A distance-time graph is a good way to describe motion. On a line graph, slope is the change in the vertical axis value divided by the change in the horizontal axis value. The slope of a line on a distance-time graph is speed, or the change in the distance divided by the change in time.

Together, the speed and direction in which an object is moving are called velocity. Velocity is a description of both speed and direction of motion. Velocity is a vector. A change in velocity can be the result of a change in speed, a change in direction, or both.

Sometimes the motion of an object involves more than one velocity. Two or more velocities add by vector addition.

11.3 Acceleration

The rate at which velocity changes is called acceleration. Acceleration can be described as changes in speed, changes in direction, or changes in both. Acceleration is a vector.

Scientifically, acceleration applies to any change in an object's velocity. This change may be either an increase or a decrease in speed. Acceleration can be caused by positive (increasing) change in speed or by negative (decreasing) change in speed.

An example of acceleration due to change in speed is free fall, which is the movement of an object toward Earth solely because of gravity. The unit for acceleration is meters per second per second, or meters per second squared (m/s^2). Each second an object is in free fall, its velocity increases downward at a rate of 9.8 meters per second. The change in the object's speed is 9.8 m/s^2, the acceleration due to gravity.

Acceleration isn't always the result of changes in speed. A horse on a carousel is traveling at a constant speed, but it is accelerating because its direction is constantly changing. Sometimes motion is characterized by changes in both speed and direction at the same time.

The velocity of an object moving in a straight line changes at a constant rate when the object is experiencing constant acceleration. Constant acceleration is a steady change in velocity.

You calculate acceleration for straight-line motion by dividing the change in velocity by the total time. If a is the acceleration, v_i is the initial velocity, v_f is the final velocity, and t is the total time, this equation can be written as follows.

$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Total time}} = \frac{v_f - v_i}{t}$$

Notice in this formula that velocity is in the numerator and time is in the denominator. If the velocity increases, then the numerator is positive and thus the acceleration is also positive. If the velocity decreases, then the numerator is negative and the acceleration is also negative.

You can use a graph to calculate acceleration. The slope of a speed-time graph is acceleration. The slope is change in speed divided by change in time. Constant acceleration is represented on a speed-time graph by a straight line. A linear graph is a line graph on which the displayed data form straight-line parts.

Accelerated motion is represented by a curved line on a distance-time graph. In a nonlinear graph, a curve connects the data points that are plotted.

Instantaneous acceleration is how fast a velocity is changing at a specific instant.