01. Concepts and Principles

Position, Velocity & Acceleration in 1D

Kinematics is the formal language physicists use to describe motion. The need for a formal language is evidenced by a simple experiment: drop an object from about shoulder height and ask two people to independently describe the motion of the object. Chances are that the descriptions will not be in perfect agreement, even though both observers described the same motion. Obviously, a more formal way of describing motion is necessary to eliminate this type of descriptive ambiguity. Kinematics is the formal method of describing motion.

Three parameters are carefully defined and used by physicists to describe motion. Specifying these three parameters at all times forms a complete description of the motion of an object.

Position (r) Units: meters (m)

The position of an object is its location relative to a well-defined coordinate system at a particular instant of time. Without a specified coordinate system, position is a meaningless concept. A coordinate system is comprised of a*zero*, a specified *positive direction*, and a *scale*.

For example, in the hypothetical experiment in which the object was dropped from shoulder height, a coordinate system could have been defined in which the zero position was at ground level, the positive direction was up, and the scale used was meters. Using this coordinate system, the position of the object could have been specified at any particular instant of time. Of course, choosing the zero at the location at which the object was dropped, the positive direction as down, and the scale in feet is also perfectly acceptable. It doesn't matter what you choose as a coordinate system, only that you explicitly choose one. Depending on the coordinate system chosen, the position of an object can be positive, negative, or zero. We will use the symbol r to designate position.

Velocity (v) Units: meters per second (m/s)

Although the word velocity is often used loosely in everyday conversation, its meaning in physics is specific and well-defined. To physicists, the velocity is the rate at which the position is changing. The velocity can be specified at any particular instant of time.

For example, if the position is changing quickly the velocity is large, and if the position is not changing the velocity is zero. A mathematical way to represent this definition is

$$v = \frac{\Delta r}{\Delta t} = \frac{r_{\text{initial}} - r_{\text{initial}}}{t_{\text{final}} - t_{\text{initial}}} \tag{1}$$

where Δr represents the change in position and Δt the corresponding change in time. (Actually, this is the average velocity of the object over the time interval Δt, but as the time interval becomes smaller and smaller, the value of this expression becomes closer and closer to the actual rate at which the position is changing at one particular instant of time.)

Since the final position of the object (r_{final}) may be either positive, negative, or zero, and either larger, smaller, or the same as the initial position ($r_{initial}$), the velocity may be positive, negative, or zero. The sign of the velocity depends on the coordinate system chosen to define the position. A positive velocity simply means that the object is moving in the positive direction, as defined by the coordinate system, while a negative velocity means the object is traveling in the other direction.

Acceleration (a) Units: meters per second per second (m/s^2)

Again, although the word acceleration is often used loosely in everyday conversation, its meaning in physics is specific and well-defined. To physicists, the acceleration is the rate at which the velocity is changing. Again, the acceleration can be specified at any particular instant of time.

For example, if the velocity is changing quickly the acceleration is large, and if the velocity is not changing the acceleration is zero. If an object has non-zero acceleration, it does *not* mean that the object is speeding up. It simply means that the velocity is changing. Moreover, even if an object has a *positive* acceleration, it does not mean that the object is speeding up. A positive acceleration means that the change in the velocity points in the positive direction. (I can almost guarantee you will experience confusion about this. Take some time to think about the preceding statement right now.)

A mathematical way to represent acceleration is

$$a = \frac{\Delta v}{\Delta t} = \frac{v_{\text{initial}} - v_{\text{initial}}}{t_{\text{final}} - t_{\text{initial}}} \tag{2}$$

Again, this is actually the average acceleration of the object over the time interval Δt, but as the time interval becomes smaller and smaller, the value of this expression becomes closer and closer to the actual rate at which the velocity is changing at one particular instant of time.

Since v_{final} may be either positive, negative, or zero, and either larger, smaller, or the same as $v_{initial}$, the acceleration may be positive, negative, or zero. The algebraic sign of the acceleration depends on the coordinate system chosen to define the position. A negative acceleration means that the change in the velocity points in the negative direction. For example, the velocity could be in the positive direction and the object slowing down *or* the velocity could be in the negative direction and the object speeding up. Both of these scenarios would result in a negative acceleration. Conversely, a positive acceleration means that the change in the velocity points in the positive direction.

Kinematics is the correct use of the parameters position, velocity, and acceleration to describe motion. Learning to use these three terms correctly can be made much easier by learning a few tricks of the trade. These tricks, or analysis tools, are detailed in the following section.
