Unit 1 Parent Guide: Kinematics

Kinematics is the study of the motion of objects. Scientists can represent this information in the following ways: written and verbal descriptions, mathematically (with the use of equations), graphically and through illustrations. The goal is to provide ways to describe and understand real-world phenomena.

Motion

When you tell someone where an object is, you describe its position. *Position* is the exact location of an object. If the position of an object has moved, the object has moved. Motion describes the movement of an object from one place to another. Therefore, motion is a change of position.

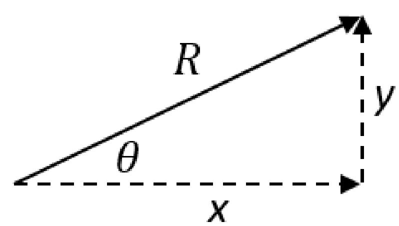
Scalar versus Vector

One way of describing a measured quantity of an object is to represent its numerical value, such as how big, how tall or how long. This quantity represents the *magnitude* (or amount). Examples of such quantities are distance, time, speed height and mass. These quantities are called *scalar* quantities. Quantities in which not only the magnitude but also a directional component can be determined are called *vector* quantities. Examples of vector quantities include displacement, velocity and acceleration. These quantities can also be represented visually with an "arrow" where the size of the arrow represents the object's magnitude and the direction represents, well, its direction. So a speed of 10 m/s or a distance of 5 meters are scalar quantities whereas velocity of 10 m/s north and a displacement of 5 meters to the right represent vector quantities.

Vector Addition

Vector quantities (velocity, acceleration, displacement, or force) can be mathematically "added". If the directions of two vectors are the same, the magnitudes of the vectors can be added together. The magnitudes of vectors with opposite directions can be subtracted. Two perpendicular vectors are "added" together by using the pythagorean theorem. If two vectors are pointed in some other direction that is not perpendicular, their components must be added separately, then combined using the pythagorean theorem.

Vector Resolution



A resultant vector with magnitude and direction can be *resolved* into vector components. Vector resolution uses the trigonometry functions sine and cosine. The diagram below summarizes trigonometry of a right triangle. *R* represents the resultant, which is the hypotenuse of the triangle. θ represents the angle of the resultant vector, measured from the horizontal axis. Vector *y* is the vertical component, which is the opposite side of the angle θ. Vector *x* is the vertical component, which is the adjacent side of the angle θ. To resolve the resultant vector into components, use $x = Rcos\theta$ and $y = Rsin\theta$.

Speed vs Velocity

Speed is a measurement of distance traveled during a period of time, or simply a "rate of motion". Speed is measured in units of distance and time for example in miles per hour or kilometers per hour. The speedometer in a car shows instantaneous speed, the rate of motion at any given instant. A speed that does not vary over time is called a constant speed. The term *velocity* refers to both the speed and direction of a moving object. If a car goes around a curve in the road, its direction changes. Even if the speed remains constant, the velocity changes because the direction changes. Velocity has two components, speed and direction, and is mathematically represented as a vector quantity. To properly describe velocity both components must be given. For example, a car drove 50 mph SE. Speed is the <u>magnitude</u> of velocity.

The speed of a moving object is calculated by measuring the distance (d) through which the object travels and dividing that distance by the time (t) it took to travel that distance. The metric units of measure for speed are centimeters/second (cm/s), meters/second (m/s), or kilometers/second (km/s). The units of measure for velocity (v) are the same as that for speed. Velocity is calculated in the same way, but includes a "directional arrow" to show the object's direction.

speed (v) = distance (d) ÷ time (t) (common units: m/sec, ft/sec, miles/hr, km/hr)

<u>Acceleration</u>

When an object changes its speed, it is accelerating. Speeding up and slowing down are examples of acceleration. An object has zero acceleration if it moves at a constant speed. For example, when you put your car on "cruise control", the speed your car stays the same; and acceleration is zero. Acceleration also refers to changes in direction. Even if a car's speed is steady, the car accelerates when there is a change in its direction. Acceleration is described mathematically as the rate of change of the velocity of an object.

Whereas speed or velocity is a change in distance (or position) over a change in time, acceleration is a change in velocity over a change in time. *Acceleration* is also a vector quantity representing a change in either the magnitude (speed) of an objects and/or its direction.

acceleration (a) = $\Delta v / \Delta t = v_f - v_i / t_f - t_i$ (common units: m/sec^2, ft/sec^2)

where "Δ" means "change in" and where v_f represents the final velocity and v_i represents the initial velocity

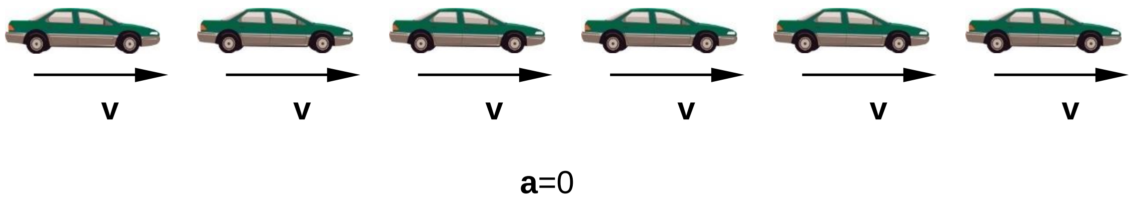
Acceleration is a look at how an object's velocity changes with respect to time, thus the standard units of m/sec per sec (m/sec^2).

<u>Cases of Motion using Physical Representations</u>

A motion diagram is a pictorial way of representing a system's motion that separately shows each of the important motion concepts in a qualitative way to help the student understand what is physically taking place in the motion.

As an example, if we consider a car moving at a constant velocity with zero acceleration, the motion diagram would look like:

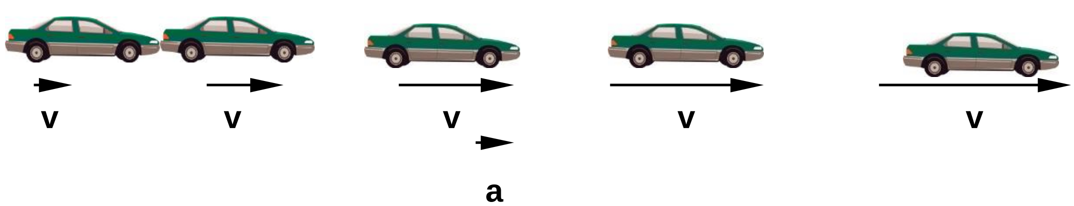
Case 1:



The car is represented at equal time intervals (say 1 second) as it travels to the right at a constant speed. For each instant, the position of the car is represented along with an arrow representing the velocity. The direction of the arrow represents the direction of the velocity as the length of the arrow represents its magnitude or speed. In this case, since the acceleration is zero, there is no change in the velocity so the length of the arrows remains the same and the spacing between the cars remains equal. For a car traveling to the right in what we'll call the positive direction, the velocity can be thought of as being positive as well.

In our next case, let us consider a car that starts from rest and has an acceleration to the right. Since velocity is a vector quantity (meaning direction is important), we can represent the velocity of an object as being positive or negative as a way to denote this direction component. For our examples, we will equate velocity to the right as movement in the positive direction:

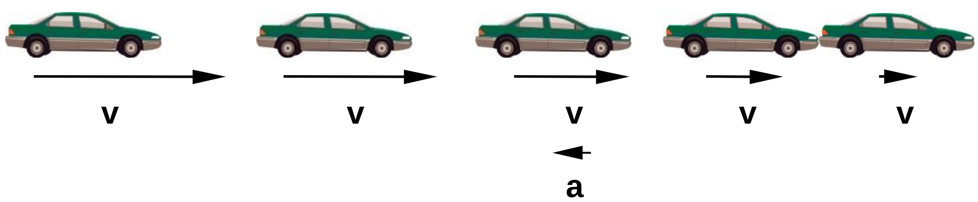
Case 2:



In this case, the car is speeding up to the right. This is represented in the drawing by the spacing of the car at successive time intervals increasing as well as the length of the velocity vectors increasing. This means that at each successive time interval, the distance the car travels will be larger than in the interval before it. Notice here that the car's acceleration is pointed in the same direction as the car's velocity.

Now, let us consider a car that is already moving towards the right that begins to slow down due to an acceleration that is pointing to the left (or, in the negative direction):

Case 3:



In this case, the car is slowing down while moving to the right. This is represented in the drawing by the spacing of the cars at successive time intervals decreasing as well as the length of the velocity vectors getting smaller. This means that at each successive time interval, the distance the car travels will be smaller than in the time interval before it. Notice here that the car's acceleration is pointed in the opposite direction as the car's velocity. So the car demonstrated a positive velocity (moving to the right) and a negative acceleration.

If the car's acceleration is occurring in the same direction as the velocity of the car, the car will speed up. So if the acceleration and the velocity are both to the right (positive), the car's velocity will increase. If the acceleration is negative, (it is pointed in the same direction) and the velocity is negative, the magnitude of the velocity will increase and the car will speed up in the negative direction (such as speeding up going to the left). If the acceleration is in the opposite direction of the velocity (i.e. positive velocity and negative acceleration), the car will slow down. In summary, the rule of thumb for determining whether an object will speed up or slow down is: if the velocity and the acceleration point in the same direction (or have the same sign), the object will speed up; if the velocity and the acceleration are in opposite directions (or if they have opposite signs), the object will slow down.

When the velocity and acceleration have opposite signs and the object reaches zero, if there is still an acceleration then the object will reverse directions and then begin to speed up. An excellent example of this is a ball that is tossed into the air. After the ball leaves the thrower's hand, it will travel upward, slowing down due to its velocity vector pointing upwards while the acceleration vector is pointing downward. What is causing the acceleration is gravity and this acceleration due to gravity (on earth) is a constant 9.8 m/s^2 in the downward direction. It will continue to slow down until it stops. At this point, the acceleration of gravity is still a constant 9.8 m/s^2 pointed downwards so the object will reverse direction and begin to fall. Now the velocity vector will point downward and increase indicating that the ball is speeding up until it is caught. And, as the ball returns to the ground, the acceleration due to gravity points down and remains constant and thus we see an increase in velocity in the same direction as the acceleration.

<u>Quantifying a change in position during uniform acceleration</u>:

As previously mentioned, acceleration can be mathematically determined by dividing the change in velocity by the change in the time during which the acceleration occurred. When an object is accelerating, its change in position (distance) does not occur in equal increments. As seen in Cases 2-3, as the car accelerated, its change in position was not constant.

To determine the change in distance while an object is experiencing uniform (constant) acceleration, use the following equation:

$$d_f = d_i + v_i t + \frac{1}{2}at^2$$

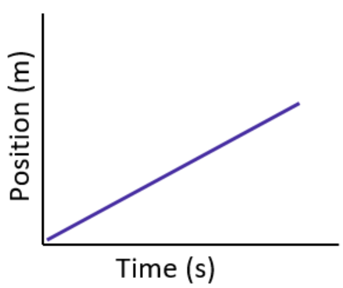
where:

d_f represents the object's final position
d_i represents the object's initial position
v_i represents the initial velocity of the object
t represents the time interval during which the change in position occurred
a represents the acceleration of the object

An example of such a situation would be to examine a ball thrown vertically. If we knew the ball's initial velocity and its initial release height, we could determine its position at various time intervals along its path. One assumption is the only reason the ball's velocity is changing is because of gravity. Variables such as air resistance or wind should be ignored so that acceleration is uniform. This example resembles what is occurring in Case 3. The velocity is upward and the acceleration will be downward. Since the quantities are occurring in opposite directions, they will have opposite signs.

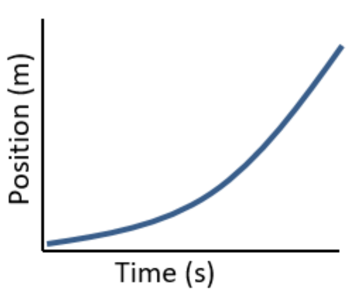
<u>Graphical Representations of position, velocity and acceleration:</u>

Position vs. Time Graph

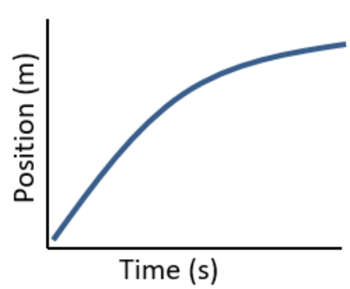


$$\text{slope} = \frac{rise}{run} = \frac{\Delta y}{\Delta x} = \frac{change\ in\ position}{change\ in\ time} = \text{velocity}$$

This graph represents position as a function of time. The *slope* of the line, the change in the y axis variable divided by the change in the x axis variable, would be equal to the velocity.

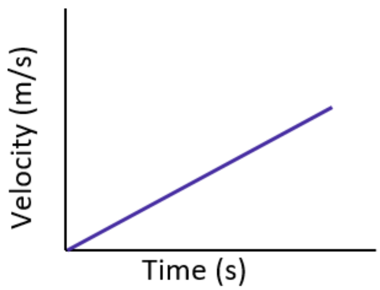


This graph has increasing positive slope, or increasing positive velocity. In other words, moving forward and speeding up.



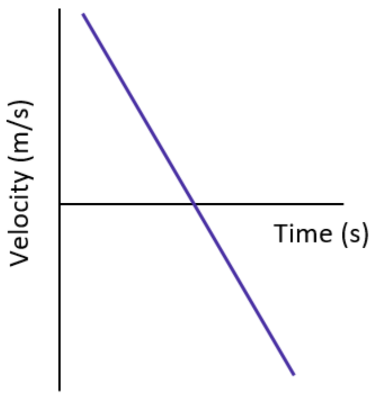
This graph has decreasing positive slope, or decreasing positive velocity. In other words, moving forward and slowing down.

Velocity vs. Time Graph



$$\text{slope} = \frac{rise}{run} = \frac{\Delta y}{\Delta x} = \frac{change\ in\ velocity}{change\ in\ time} = \text{acceleration}$$

This graph represents velocity as a function of time. The slope of the line, the change in the y axis variable divided by the change in the x axis variable, would be equal to the acceleration.



This graph has constant negative slope, or constant negative acceleration. Above the x axis is positive velocity. The point at the x axis represents when motion has momentarily stopped. Below the x axis is negative velocity. An object thrown straight up which falls back down has a graph like this.