Chapter 3

Linear Motion

Aristotle (384-322) was the first one to study motion seriously.

Aristotle's Theory of Motion:

There are two kinds of motions; **natural**, and **violent.**

The natural motion depends upon the nature of objects. Each object has its place. Heavier objects fall faster (Proportional to the weight). This kind of motion is either up or down, it could be circular.

The violent motion resulted from pulling or pushing forces. This concept has a big difficulty which made him to think that there are squeezing forces.

In Summery: All motions are due to the nature of objects or due to a sustained push or pull.

This theory of motion was accepted for 2000 years until **Nicolaus Copernicus** (1473-1553) rejected it. He said: to explain the motion of the earth, sun, and the moon and other planets, we need to assume that earth circles the sun. **Galileo Galilie** (1564-1642) continued the work on the Copernicus's idea of motion, and finally discredited the Aristotelian concept of motion. He did that through **experiment and observation**.

It took several hundred years until Newton gave a precise definition of motion and related concepts.

First Things First:

Before we can accurately describe motion, we must provide clear definitions of our terms. The meanings of some terms as used in physics are different from the meanings in everyday use. Precise and specialized meanings make the terms more useful in describing motion.

Motion is relative: When we say that an object is moving, we mean the move is relative to a reference (even though we not say it).

We need clear, precise definitions.

The **rules of motion** involve the concept of **speed**, **velocity**, and **acceleration** and these concepts must be defined.

What's the difference between: **average speed** and **instantaneous speed**? **speed** and **velocity**? **speed** and **acceleration**?

Speed is how fast something is moving. Speed is the distance an object travel in a unit of time and it is always some distance divided by some time.

$$\text{Speed} = \frac{\text{some distance}}{\text{some time}} = \frac{d}{t}$$

Average speed is total distance divided by total time.

$$\text{average speed} = \frac{\text{total distance traveled}}{\text{total time}}$$

Units of Speed: Unit of speed is the unit of distance divided by the unit of time: m/s, km/h, mi/h, etc.

Examples:

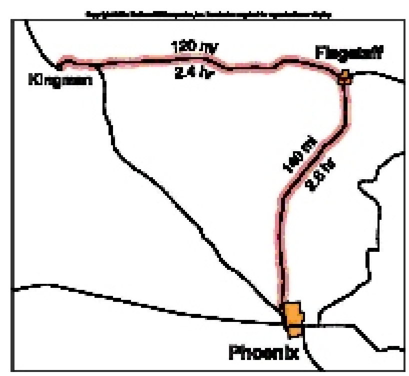
1. Convert 70 kilometers per hour to miles per hour:

   1 km = 0.6214 miles
   1 mile = 1.609 km

2. Convert 70 kilometers per hour to meters per second:

   1 km = 1000 m
   1 hour = 60 min
   1 min = 60 sec

3. Find the average speed between kingman and Phoenix



Rate is one quantity divided by another quantity. For example: gallons per minute, pesos per dollar, points per game. So average speed is the rate at which distance is covered over time

Instantaneous speed is the speed at that precise instant in time. It is the rate at which distance is being covered at a given instant in time. It is found by calculating the average speed, over a short enough time that the speed does not change much.

Remark: Average speed is different from the instantaneous speed.

Example: What does a car's speedometer measure? Which quantity is the highway patrol more interested in?

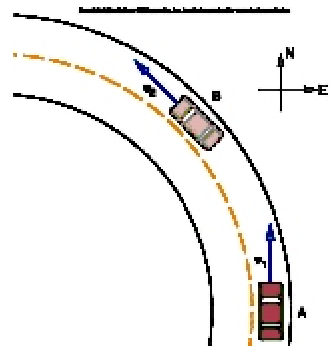
Velocity: In physics, speed and velocity are two different quantities. Velocity is speed in a given direction. Velocity involves direction of motion as well as how fast the object is going. Therefore velocity is a **vector quantity**.

Vectors have both **magnitude** and **direction** and can be shown by an arrow whose length indicates the magnitude of the vector and the arrow head indicates the direction.

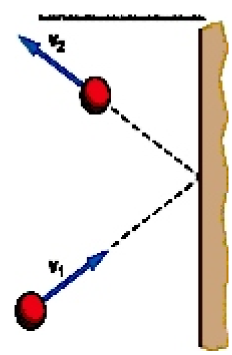
Velocity has a magnitude (the speed) and also a direction (which way the object is moving). A change in velocity can be a change in the object's speed or direction of motion.

Examples:

1. A car goes around a curve at constant speed. Is the car's velocity changing?

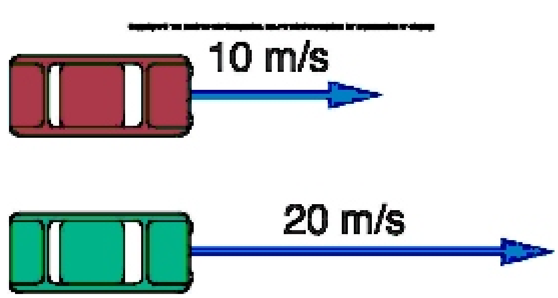


2. A ball bounces off a wall. Is the car's velocity changing?



Instantaneous speed + direction of motion = Instantaneous velocity

Instantaneous velocity is a vector quantity having a size (magnitude) equal to the instantaneous speed at a given instant in time, and a direction equal to the direction of motion at that instant



Remark: (Important special case) If an object is moving with a constant speed, then the instantaneous speed at any moment, average speed, the magnitude of instantaneous velocity are all the same.

Acceleration: We can change velocity of an object by changing its speed, direction or both. The acceleration of an object tells us how the velocity of the object is changing.

Acceleration is the rate at which **velocity** changes. Our bodies don't feel velocity, if the velocity is constant. Our bodies feel **acceleration**.

A car changing speed or direction.
An elevator speeding up or slowing down.

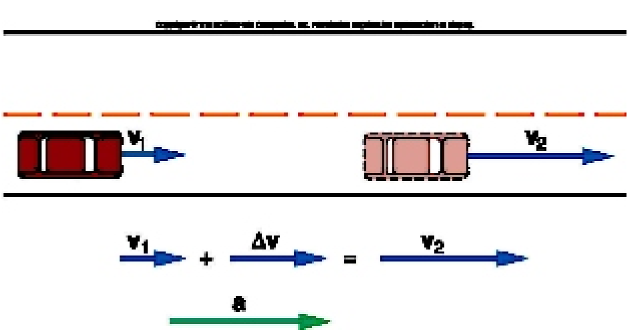
Acceleration can be either a change in the object's speed or direction of motion.

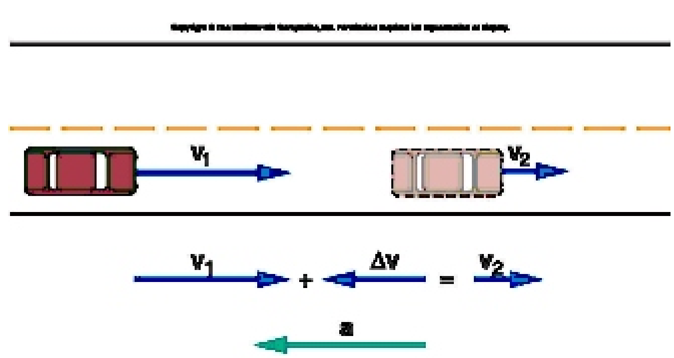
An elevator speeding up or slowing down.

Acceleration is also a vector quantity, with magnitude and direction. The direction of the acceleration vector is that of the change in velocity, Δv. Acceleration refers to any change in velocity. We even refer to a decrease in velocity (a slowing down) as an acceleration.

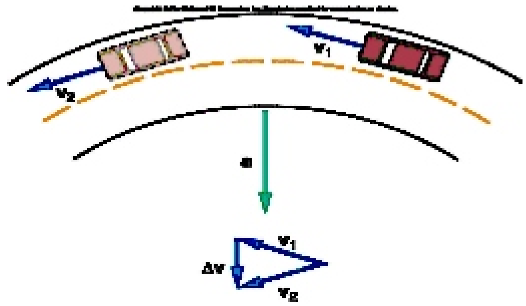
The direction of the acceleration vector is that of the change in velocity, Δv. If velocity is **increasing**, the acceleration is in the **same** direction as the velocity.

The direction of the acceleration vector is that of the change in velocity, Δv. If velocity is **decreasing**, the acceleration is in the **opposite** direction as the velocity.





The direction of the acceleration vector is that of the change in velocity, Δv. If speed is constant but velocity **direction** is changing, the acceleration is **at right angles to** the velocity.



Average acceleration is the change in velocity divided by the time required to produce that change The units of **velocity** are units of distance divided by units of time. The units of **acceleration** are units of velocity divided by units of time. So, the units of acceleration are units of distance divided by units of time:

$$\text{Average Acceleration} = \frac{\text{change in velocity}}{\text{totaltime}}$$

Hence, if the velocity at time t_0 is v_0 and at a later time t is v ,then:

$$a = \frac{v - v_0}{t - t_0} = \frac{\Delta v}{\Delta t}.$$

Example:

Have you ever experienced acceleration?

In our book (and even in general physics book) we consider motion of objects with constant acceleration.
In this case the average acceleration is called acceleration. Furthermore, if the object has an initial velocity v_0 at time $t_0 = 0$. So the above formula becomes

$$a = \frac{v - v_0}{t} \quad \text{or} \quad v = v_0 + a\,t$$

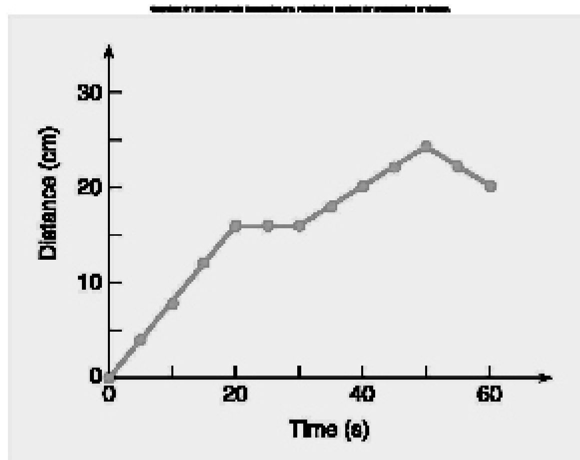
In this case it can be shown that

$$d = v_0 + \frac{1}{2}at^2$$

Another words, the velocity of an object is its acceleration times time.

Examples:

Graphing Motion: Let *d* represent the distance traveled and *t* be the time that took to travel *d*. We want to graph *d* vs *t*.



Consider the position of the toy car recorded in table 2.2 on page 28. And note its position every 5 seconds. We graph the data obtained

When is the car moving the fastest?

When is it moving the slowest?

When is the car not moving at all?

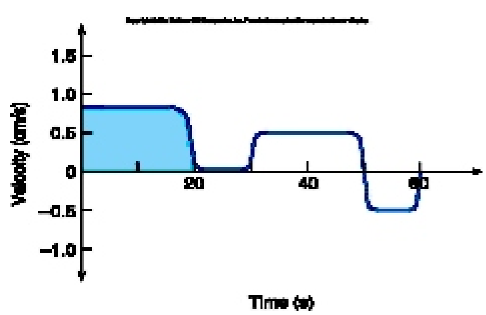
At what time does the car start moving in the opposite direction?

The ***slope*** at any point on the ***distance-versus-time*** graph represents the instantaneous ***velocity*** at that time

Slope of a line is a measure of how fast the line is rising and is change in vertical quantity, distance, divided by change in horizontal quantity, time. So the slope represents velocity. Similar to everyday meaning: steepest "slope" is between 0 s and 20 s. Slope is zero (flat) between 20 s and 40 s. Slope is negative between 50 s and 60 s.

To summarize the car's velocity information, let the horizontal axis represent ***time***, and the vertical axis represent ***velocity***.

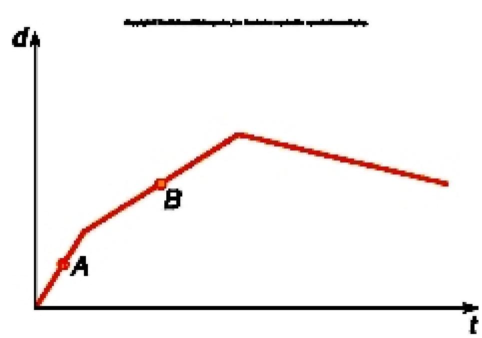
The velocity is constant wherever the slope of the distance-vs-time graph is constant.
The velocity changes only when the distance graph's slope changes. So we will get the following graph



Examples:

1. Consider a car whose graph of motion is given by the graph on the right.

Does the car ever go backward ?



A) Yes, during the first segment (labeled A).
B) Yes, during the second segment (labeled B).
C) Yes, during the third segment (not labeled).
D) No, never.

The distance traveled is ***decreasing*** during the third segment, so at this time the car is moving backward.

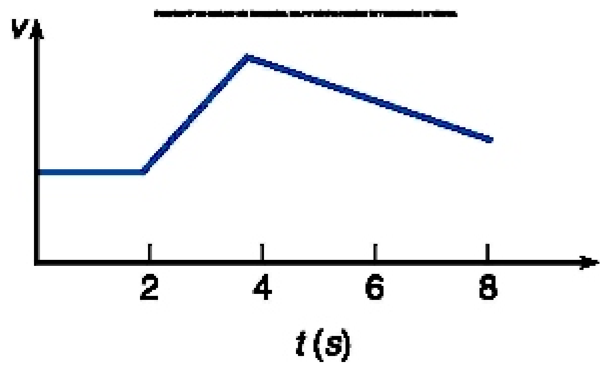
Is the instantaneous velocity at point A greater or less than that at point B?

A) Greater than
B) Less than
C) The same as
D) Unable to tell from this graph

The instantaneous velocities can be compared by looking at their slopes. The ***steeper slope*** indicates the ***greater instantaneous velocity***, so the velocity at A is greater.

2. In the graph shown, is the velocity constant for any time interval?

A) Yes, between 0 s and 2 s.
B) Yes, between 2 s and 4 s.
C) Yes, between 4 s and 8 s.
D) Yes, between 0 s and 8 s.
E) No, never.



The velocity is a constant value between 0 s and 2 s. The velocity is not changing during this interval, so the graph has a zero (flat) slope.

3. In the graph above, during which time interval is the acceleration greatest?

A) Between 0 s and 2 s.
B) Between 2 s and 4 s.
C) Between 4 s and 8 s.
D) The acceleration does not change

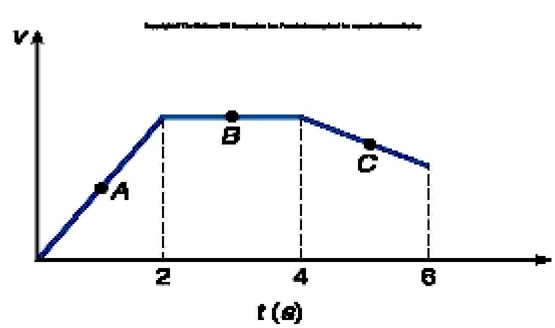
The acceleration is greatest between 2 s and 4 s. The velocity is changing fastest, and the graph has the greatest slope, during this interval.

4. A car moves along a straight road as shown below. Does it ever go backward?

A) Yes, between 0 s and 2 s.
B) Yes, between 2 s and 4 s.
C) Yes, between 4 s and 6 s.
D) No, never.
Although the velocity is decreasing between 4 s and 6 s, the velocity is still in the same direction (it is not negative), so the car is not moving backward

5. For the car in # 4, at which point is the magnitude of the acceleration the greatest?

A) Point A
B) Point B
C) Point C
D) The acceleration does not change



The magnitude of the acceleration is greatest when the velocity is changing the fastest (has the greatest slope). This occurs at point A.

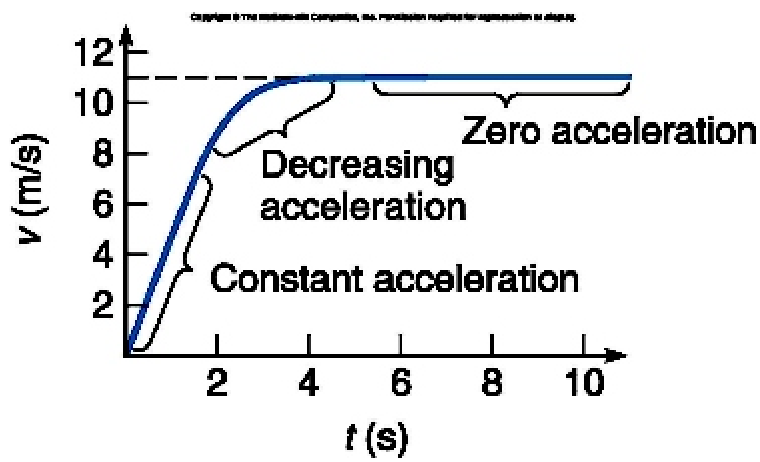
6. For the car in # 4, during which time interval is the distance traveled by the car the greatest?

A) Between 0 s and 2 s.
B) Between 2 s and 4 s.
C) Between 4 s and 6 s.
D) It is the same for all time intervals

The distance traveled is greatest when the area under the velocity curve is greatest. This occurs between 2 s and 4 s, when the velocity is constant and a maximum.

Example: The following graph shows the velocity of a runner.

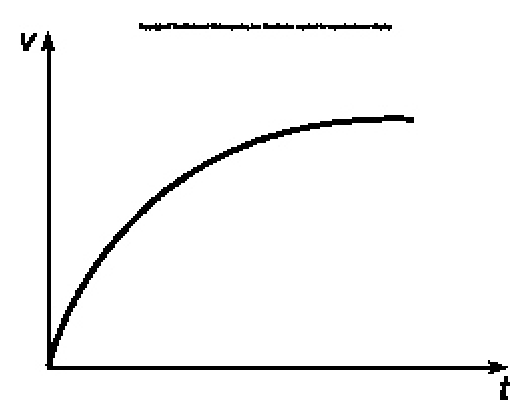
The runner wants to reach top speed as soon as possible.
The greatest acceleration is at the beginning of the race.
For the remaining portion of the race, the runner continues at a constant speed (the top speed) so acceleration is zero



Example: The velocity graph of an object is shown. Is the acceleration of the object constant?

A. Yes.
B. No.
C. It is impossible to determine from this graph.

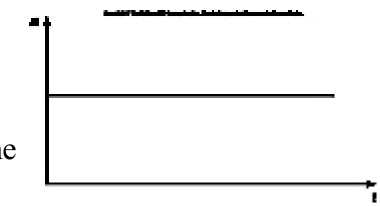
The slope of the velocity curve gradually decreases with time, so the acceleration is decreasing. Initially the velocity is changing quite rapidly, but as time goes on the velocity reaches a maximum value and then stays constant.



Uniform Acceleration is the simplest form of acceleration. It occurs whenever there is a constant force acting on an object. Most of the examples we consider will involve constant acceleration. A falling rock or other falling object. A car accelerating at a constant rate. The acceleration does not change as the motion proceeds

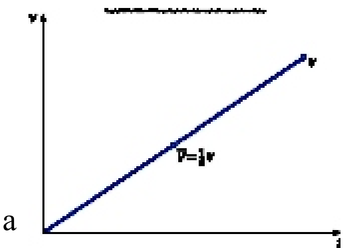
The acceleration graph for uniform acceleration is a horizontal line. The acceleration does not change with time.

$$a = c$$



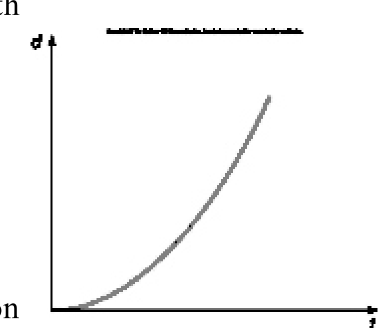
For example, a car moving along a straight road and accelerating at a constant rate.

The velocity graph for uniform acceleration is a straight line with a constant slope. The slope of the velocity graph is equal to the acceleration.



$$a = \frac{\Delta v}{t} = \frac{v - v_0}{t} \Rightarrow v = v_0 + at$$

The distance graph for uniform acceleration has a constantly increasing slope, due to a constantly increasing velocity. The distance covered grows more and more rapidly with time.



$$d = \frac{1}{2}at^2 \qquad d = v_0 t + \frac{1}{2}at^2$$

Examples: A car is traveling at 15 m/s. To pass a slow moving truck, the driver pushes on the gas and passes the truck with a uniform acceleration of 3 m/s^2. It takes 2.5 second to pass the truck.

a) Find the speed of the car when the car has passed the truck.

b) Find the length of the truck.