Chapter 2: Motion along a straight line

This chapter uses the definitions of length and time to study the motions of particles in space. This task is at the core of physics and applies to all objects irregardless of size (quarks to galaxies).

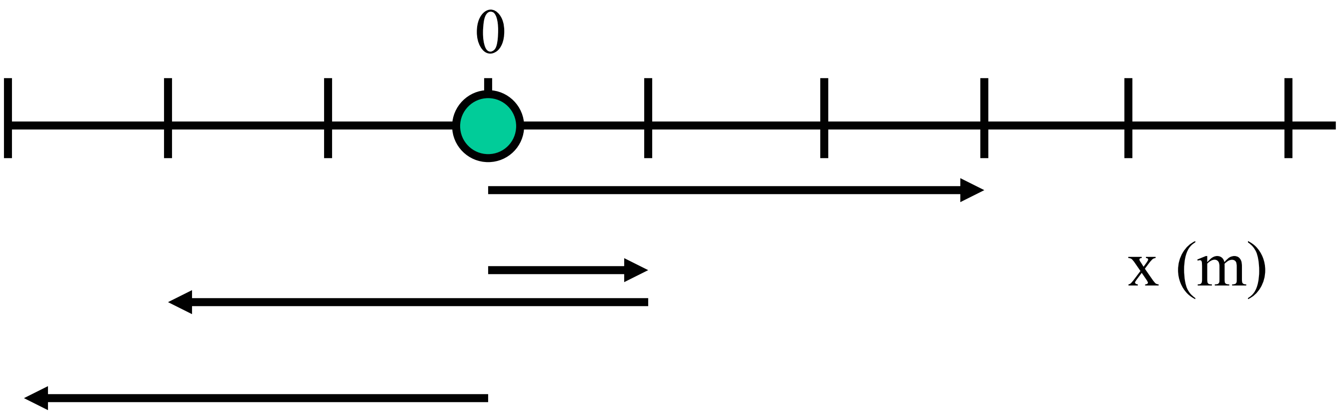
Just remember our definitions of length and time will have to be modified next semester to deal with very small lengths and/or high velocities!

Question?

An object travels a distance 3 m along a line. Where is it located?

Answer:

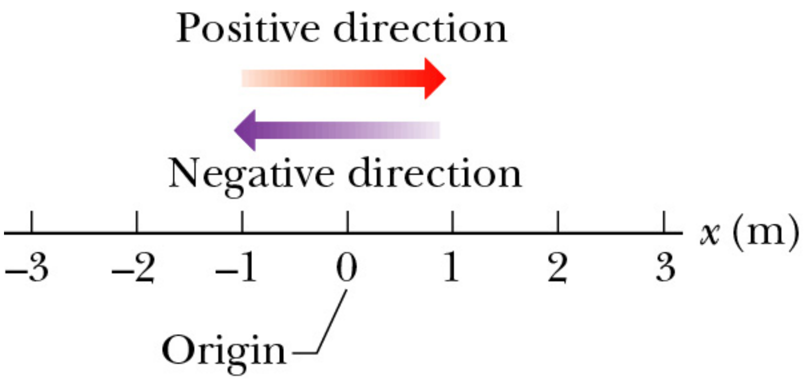
Not enough information!!!



Displacement

- Displacement is the change in position (or *location*)

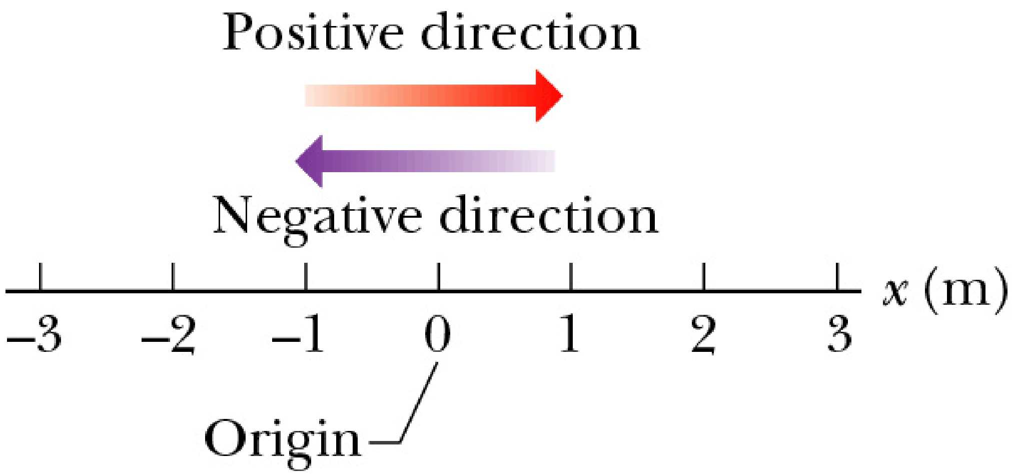
$$\Delta x = x_2 - x_1$$



- Displacement is a vector with both **magnitude** and **direction**

Ch. 2 Motion along a straight line

- Position:
  - We locate an object by finding its position with respect to the origin



Directions are Important in Space!

Vector (direction ***important***) Quantities:

- displacement
- velocity
- acceleration

Scalar (direction ***not*** important) Quantities:

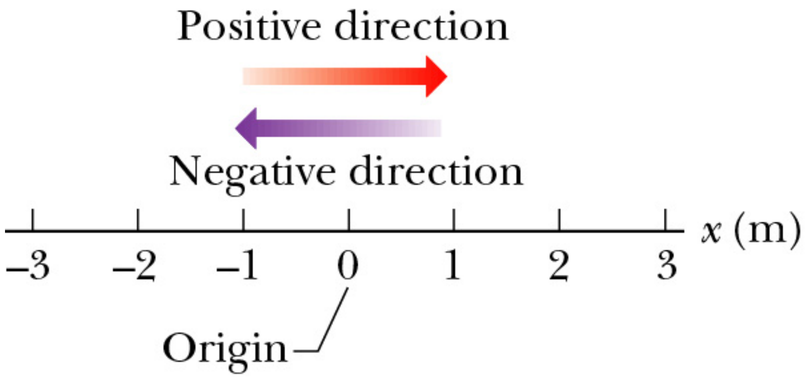
- distance
- speed
- magnitude of acceleration (sometime loosely called acceleration in common language)

Displacement

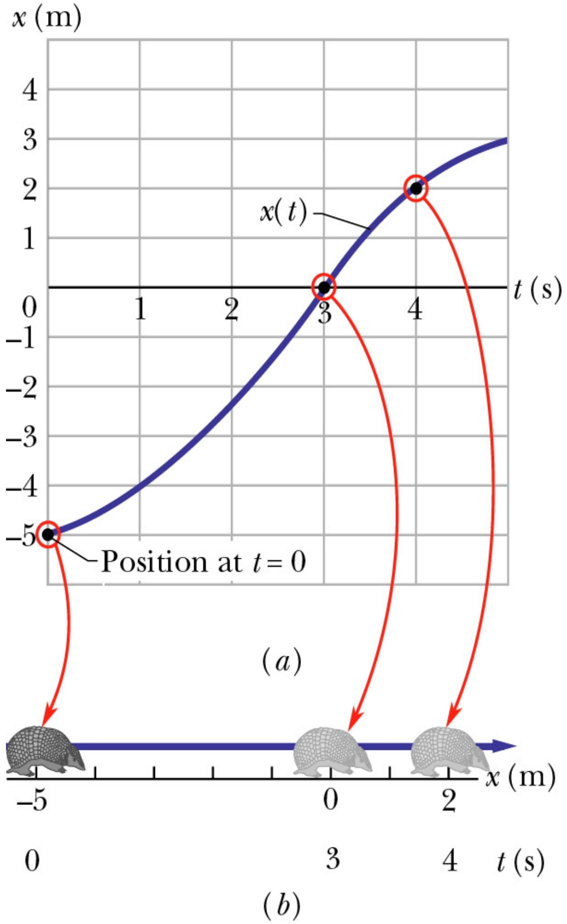
- Displacement is the change in position

$$\Delta x = x_2 - x_1$$

- Displacement is a vector
  - With both a magnitude and a direction



x(t) curve



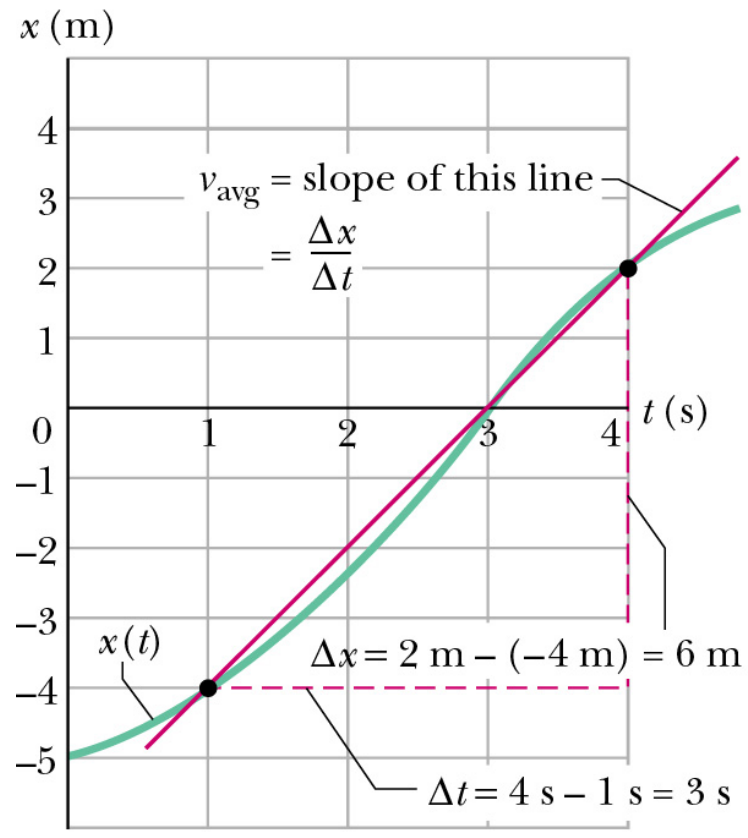
- Plotting of position *x* vs. time *t*:
  - *x(t)*
  - A good way to describe the motion along a straight line

Average velocity

- Average velocity

$$v_{avg} = \frac{\Delta x}{\Delta t} = \frac{x_2 - x_1}{t_2 - t_1}$$

- v_{avg} is also a vector – same sign as displacement



Average Speed

- S_{avg} = total distance/Δt

Instantaneous velocity

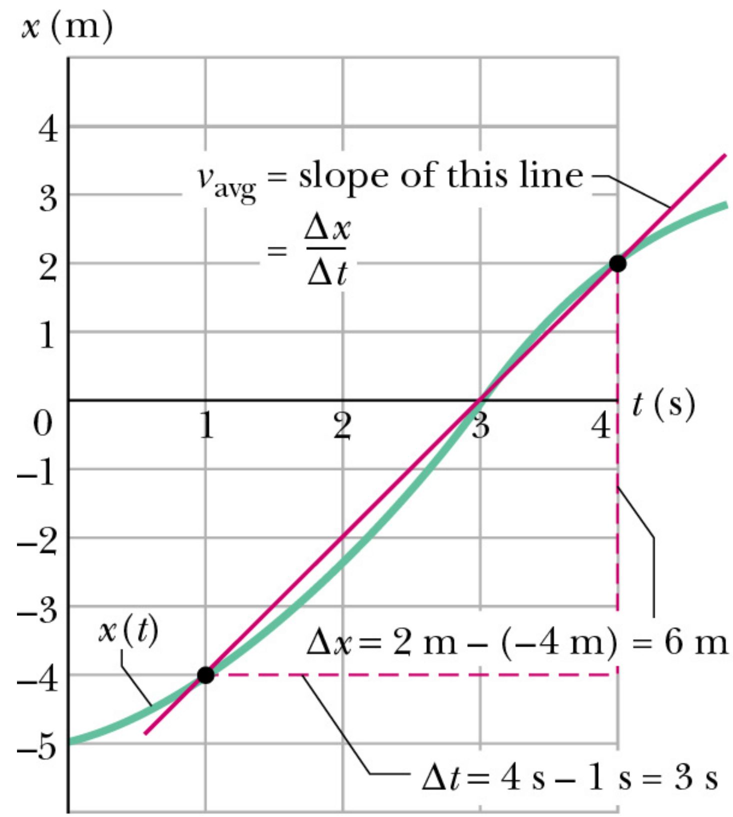
- Velocity at a given instant

  $V = \lim_{\Delta t \to 0} (\Delta x/\Delta t) = dx/dt$

  – the slope of x(t) curve at time t

  – the derivative of x(t) with respect to t

- (Instantaneous) speed is the magnitude of the (instantaneous) velocity



Acceleration

- Acceleration is the change in velocity
- The average acceleration

$$a_{avg} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{\Delta v}{\Delta t}$$

- (Instantaneous) acceleration

$$a = \frac{dv}{dt} \qquad a = \frac{dv}{dt} = \frac{d}{dt}\left(\frac{dx}{dt}\right) = \frac{d^2 x}{dt^2}$$

- Unit: m/s^2
- It is a vector

Question: A marathon runner runs at a steady speed 15 km/hr. When the runner is 7.5 km from the finish, a bird begins flying from the runner to the finish at 30 km/hr. When the bird reached the finish line, it turns around and flies back to the runner, and then turns around again, repeating the back-and-forth trips until the runner reaches the finish line.

How many kilometers does the bird travel?

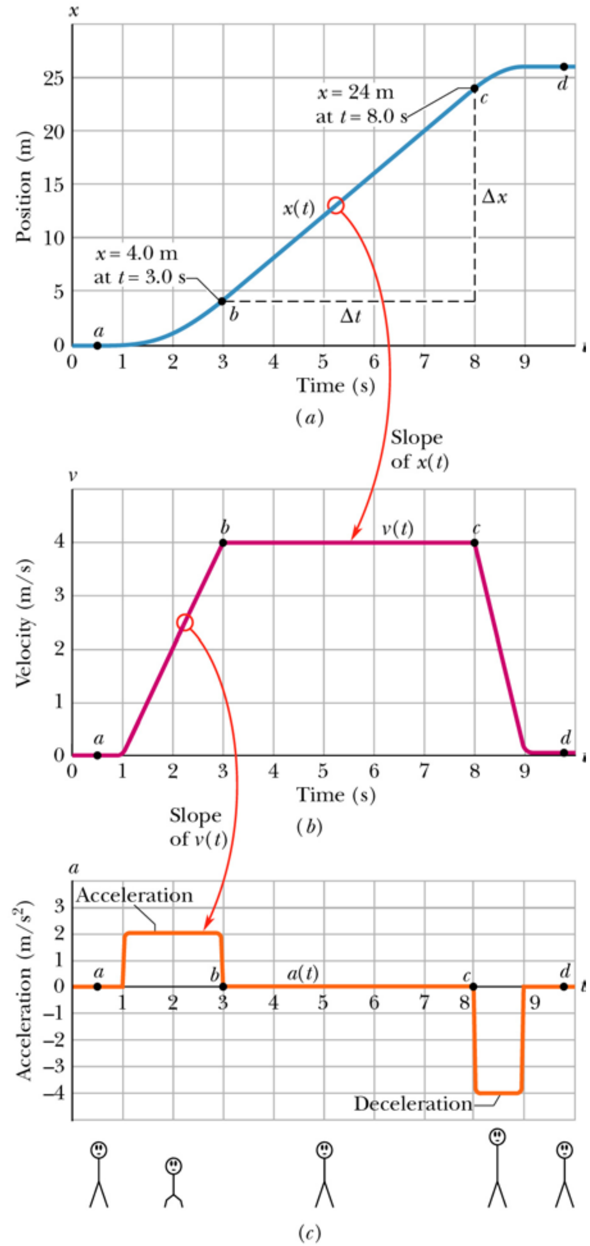
A) 10 km

B) 15 km

C) 20 km

D) 30 km

- Sample problem 2-2. Fig. 1 is an x(t) plot for an elevator which is initially stationary, then moves upward, then stops. Plot v(t) and a(t)



Constant acceleration

- Special (but humanly-important) case because we are on the surface of a large object called the "Earth" and gravity (an acceleration) is nearly constant and uniform in everyday life for us.

- But remember that this is a ***SPECIAL*** case!

Constant acceleration

- Let's look at a straight line, constant "a" motion between $t_1 = 0$ (position = x_0, velocity = v_0) to $t_2 = t$ (position = x, velocity = v)

Since a = constant, ==>

$a = a_{avg} = (v - v_0) /(t - 0)$

==> $\mathbf{v = v_0 + a\,t}$

For linear velocity function:

$v_{avg} = (v_0 + v) /2 = (v_0 + v_0 + a\,t) /2 = v_0 + ½a\,t$

We knew $v_{avg} = (x - x_0) / t$

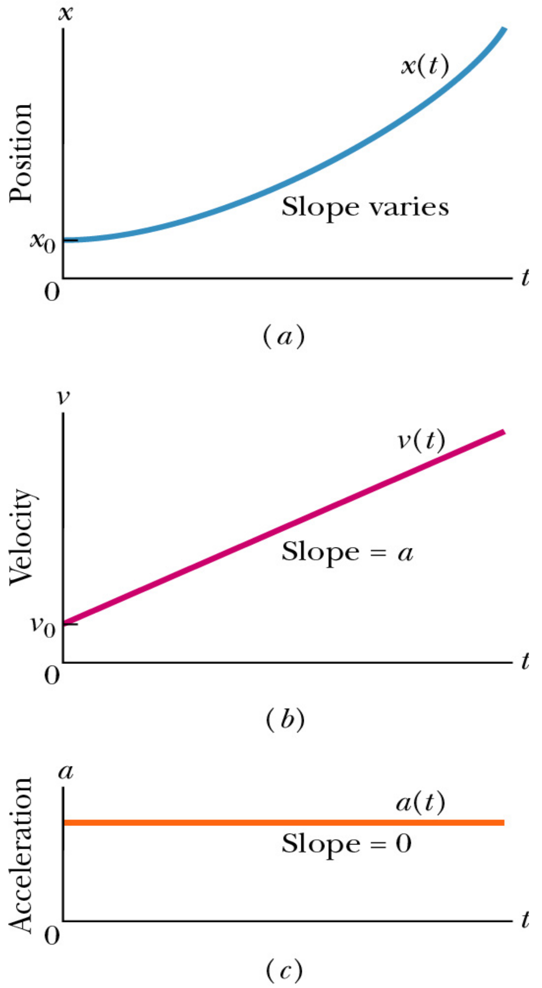
==> $\mathbf{x - x_0 = v_0\,t + ½\,a\,t^2}$

Equations	Involves	missing
$v = v_0 + a\,t$	v, v_0, a, t	$(x-x_0)$
$x - x_0 = v_0\,t + \frac{1}{2}\,a\,t^2$	$(x-x_0), v_0, a, t$	v

Constant Acceleration

$v = v_0 + a\,t$

$x - x_0 = v_0\,t + \frac{1}{2}\,a\,t^2$



For constant acceleration

- Five quantities involved: $(x-x_0)$, v_0, v, t, a

Equations	Involves	missing
$v = v_0 + a\,t$	v, v_0, a, t	$(x-x_0)$
$x - x_0 = v_0\,t + \frac{1}{2}\,a\,t^2$	$(x-x_0)$, v_0, a, t	v
$v^2 - v_0^2 = 2a\,(x - x_0)$	$(x-x_0)$, v_0, a, v	t
$x - x_0 = \frac{1}{2}\,(v_0 + v)\,t$	$(x-x_0)$, v_0, v, t	a
$x - x_0 = v\,t - \frac{1}{2}\,a\,t^2$	$(x-x_0)$, v, a, t	v_0

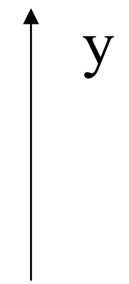
- Above equations only apply for a = constant

Free-fall Acceleration

- Free fall object experiences an acceleration of $g = 9.8\ m/s^2$ in the downward direction (toward the center of the earth)

Define **upward** direction to be **positive**

Then $a = -g = -9.8\ m/s^2$



"free-falling object": the object could travel **up** or **down** depending on the initial velocity

Free-fall acceleration

For the constant **a** equations, replace **a** with **(- g),** and **x** with **y**:

$$v = v_0 - g\,t$$

$$y - y_0 = v_0\,t - \tfrac{1}{2}\,g\,t^2$$

$$v^2 - v_0^2 = -\,2g\,(\,y - y_0\,)$$

$$y - y_0 = \tfrac{1}{2}\,(\,v_0 + v\,)\,t$$

$$y - y_0 = v\,t + \tfrac{1}{2}\,g\,t^2$$

Question?

If you drop an object in the absence of air resistance, it accelerates downward at 9.8 m/s^2. If instead you throw it downward, its downward acceleration after release is:

A) Less than 9.8 m/s^2

B) 9.8 m/s^2

C) more than 9.8 m/s^2

Answer: B) it still accelerates at 9.8 m/s^2 downward. The only thing you've changed is the initial velocity!

You are throwing a ball straight up in the air. At the highest point, the ball’s

A) Velocity and acceleration are zero.

B) Velocity is nonzero but its acceleration is zero

C) Acceleration is nonzero, but its velocity is zero

D) Velocity and acceleration are both nonzero.

Sample problem: a car is traveling 30 m/s and approaches 10 m from an intersection when the driver sees a pedestrian and slams on his brakes and decelerates at a rate of 50 m/s^2.

(a) How long does it take the car to come to a stop?

$v - v_o = a\,t$, where $v_o = 30$ m/s, $v = 0$ m/s, and $a = -50$ m/s^2

$t = (0 - 30)/(-50)$ s $= 0.6$ s

(b) how far does the car travel before coming to a stop? Does the driver brake in time to avoid the pedestrian?

$$x - x_0 = v_o\,t + \frac{1}{2}\,a\,t^2 = (30)(0.6) + \frac{1}{2}(-50)(0.6)^2 = 18 - 9 = 9 \text{ m}$$

I throw a ball straight up with a initial speed of 9.8 m/s, $a = -g = -9.8\ m/s^2$

- How long does it take to reach the highest point?

$$v = v_0 - g\,t \qquad t = 1s$$

0   9.8m/s $9.8m/s^2$

- How high does the ball reach before it start to drop?

1s

$$x - x_0 = v_0\,t - \tfrac{1}{2}\,g\,t^2 \quad (1s)^2 \quad x=4.9m$$

0   9.8m/s $9.8m/s^2$

- How long does it take to reach half the the maximum height?

2.45m

$$x - x_0 = v_0\,t - \tfrac{1}{2}\,g\,t^2$$

9.8m/s $9.8m/s^2$

$$t_{half\ height} = 0.29s$$