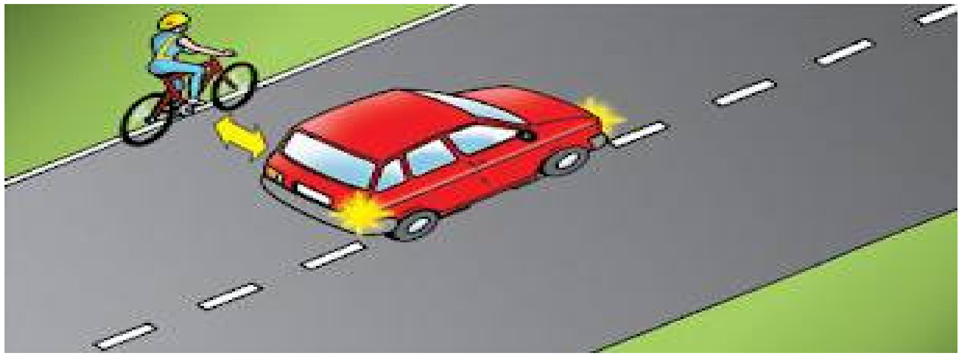
Motion Along a Straight Line 2



2-1 WHAT IS PHYSICS?

In this chapter, we study the basic physics of motion where the object (race car, tectonic plate, blood cell, or any other object) moves along a single axis. Such motion is called *one-dimensional motion*.

2-2 | Motion

The classification and comparison of motions (called **kinematics**)

In this chapter,

1. The motion is along a straight line only. The line may be vertical, horizontal, or slanted, but it must be straight.
2. Forces (pushes and pulls) cause motion but will not be discussed until Chapter 5. In this chapter we discuss only the motion itself and changes in the motion.
3. The moving object is either a **particle** (by which we mean a point-like object such as an electron) or an object that moves like a particle

Physical Quantities

Physical Quantities

Vector Quantities

magnitude + direction

Follow certain rules of addition and multiplication

Scalar Quantities

+Ve Number

-Ve Number

Follow the rules of ordinary algebra

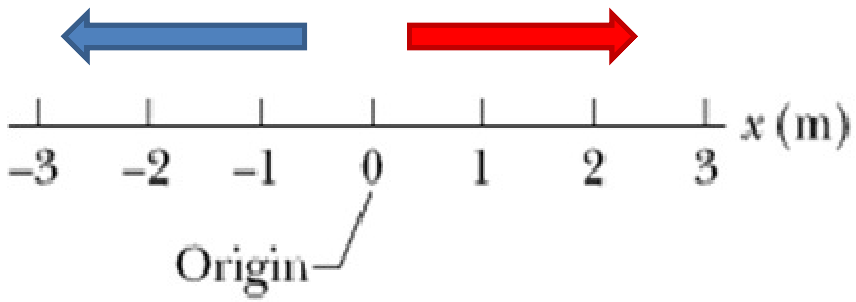
2-3 | Position and Displacement

To locate an object means to find it's position relative to reference point origin (or zero point) of an axis .

On the X- axis

Negative direction

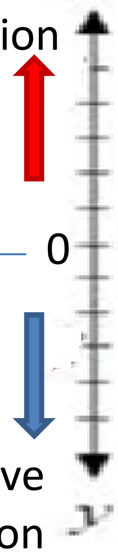
Positive direction



On the Y- axis

Positive direction

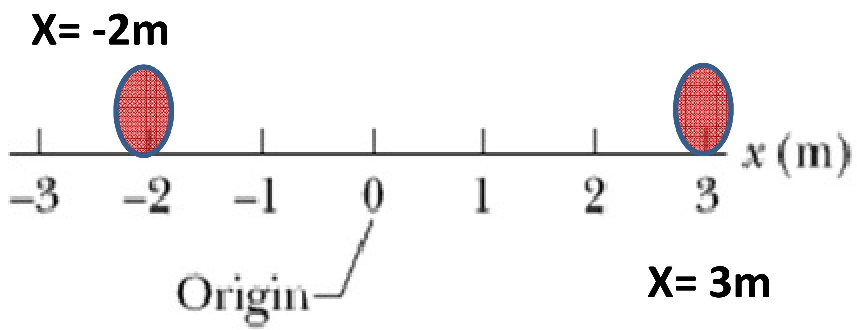
origin — 0



Negative direction

2-3 | Position and Displacement

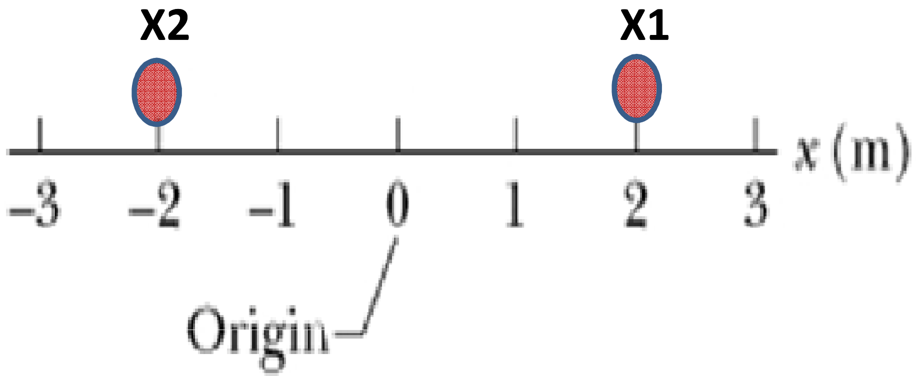
First: Position



- Position: x
- Unit: m.

Second: Displacement

If the particle move from the position x_1 to the position x_2



$\Delta X=(-2)-(2)=-4m$

$\therefore\ \Delta x = 4m$ to the left

Displacement : $\Delta x = x_2 - x_1$

- **Unit: m.**
- **It is a vector quantity: has magnitude and direction.**
- **Direction: if Δx is positive $\Rightarrow$ moving to the right**
  if Δx is negative $\Rightarrow$ moving to the left

Distance : d

It is a scalar quantity: has no direction.

What is the difference between displacement and distance?

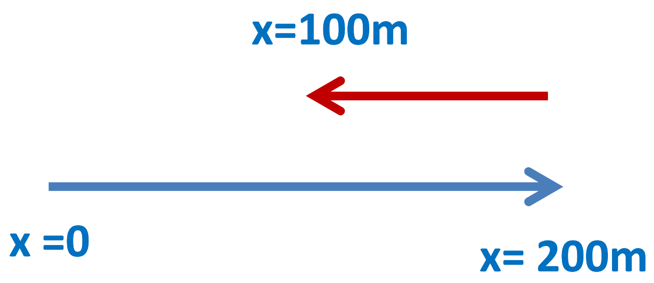
if a particle moves from x =0 m to x= 200m and then back to x=100m

<u>**Displacement**</u>

Δx= 100 – 0 =100 m

<u>**Distance**</u>

d= 200+100=300 m

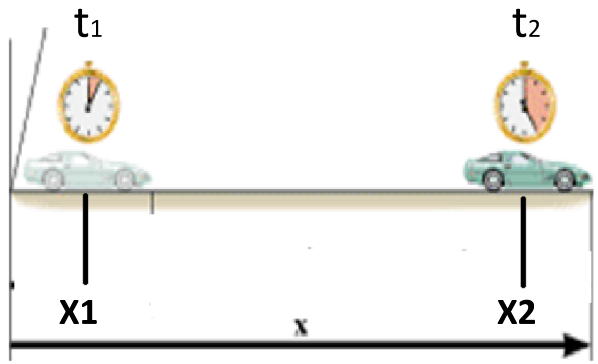


2-4 | Average Velocity and Average Speed

Average Velocity:

- The ratio of displacement that occurs during a particular time interval to that interval.

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



- **Unit of is m/s.**
- v_{avg} **is a vector quantity.**

  - **if it is positive $\Rightarrow$ moving to the right**
  - **if it is negative $\Rightarrow$ moving to the left**

2-4 | Average Velocity and Average Speed

Average Speed:

- The ratio of total distance that occurs during a particular time interval to that interval

$$s_{avg} = \frac{\text{total distance}}{\Delta t}.$$

- Unit of S_{avg} is m/s
- s_{avg} is a scalar quantity

Sample Problem 2-1

You drives a truck along a straight road for 8.4 km at 70 km/h, at which point the truck runs out of gasoline and stops. Over the next 30 min, you walk another 2.0 km farther along the road to a gasoline station.

What is your overall displacement from the beginning of your drive to your arrival at the station? (a)

$$x_1 = 0$$

$$x_2 = 8.4 + 2.0 = 10.4 \text{ km}$$

$$\Delta x = x_2 - x_1 = 10.4 \text{ km} - 0 = \underline{\underline{10.4 \text{ km}}}$$

What is the time interval Δt from the beginning of your drive to your arrival at the station? (b)

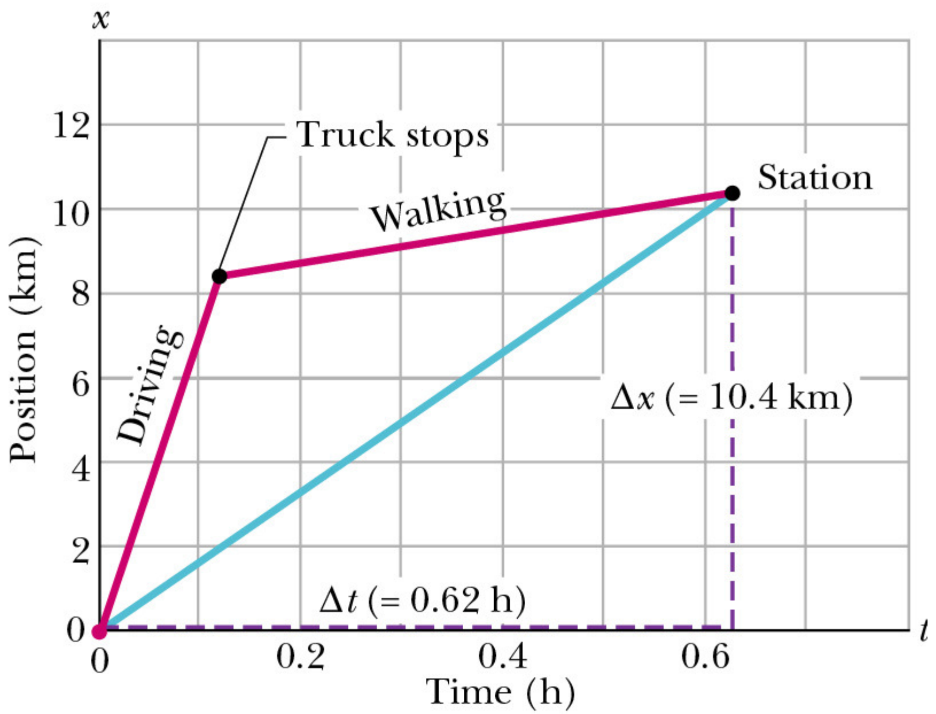
$$\Delta t_{\text{drv}} = \frac{8.4 \text{ km}}{70 \text{ km/h}} = 0.12 \text{ h}$$

$$\Delta t_{\text{wlk}} = 30 \text{ min} = 0.5 \text{ h}$$

$$\Delta t = \Delta t_{\text{drv}} + \Delta t_{\text{wlk}}$$

$$= 0.12 \text{ h} + 0.5 \text{ h} = \underline{\underline{0.62 \text{ h}}}$$

What is your average velocity v_{avg} from the beginning of your drive to your arrival at the station? Find it both numerically and graphically. (c)



$$v_{avg} = \frac{\Delta x}{\Delta t} = \frac{10.4\ \text{km}}{0.62\ \text{h}}$$

$$= \underline{\underline{16.77\ \text{km/h}}}$$

Suppose that to pump the gasoline, pay for it, and walk back to the truck takes you another 45 min. What is your average speed from the beginning of your drive to you return to the truck with the gas? (d)

$$\text{total distance} = 8.4 + 2 + 2 = 12.4 \text{ km}$$

$$\text{total time interval} = 0.12 + 0.5 + 0.75 = 1.37 \text{ hr}$$

$$s_{\text{avg}} = \frac{\text{total distance}}{\Delta t} = \frac{12.4 \text{ km}}{1.37 \text{ hr}} = \underline{\underline{9.05 \text{ km/h}}}$$

Sample Problem 2-1

You drive a beat-up pickup truck along a straight road for 8.4 km at 70 km/h, at which point the truck runs out of gasoline and stops. Over the next 30 min, you walk another 2.0 km farther along the road to a gasoline station.

(a) What is your overall displacement from the beginning of your drive to your arrival at the station?

(b) What is the time interval Δt from the beginning of your drive to your arrival at the station?

(c) What is your average velocity v_{avg} from the beginning of your drive to your arrival at the station? Find it both numerically and graphically.

(d) Suppose that to pump the gasoline, pay for it, and walk back to the truck takes you another 45 min. What is your average speed from the beginning of your drive to your return to the truck with the gasoline?

2-5 | Instantaneous Velocity and Speed

Instantaneous Velocity (or velocity)

The velocity at any instant is obtained from the average velocity by shrinking the time interval Δt closer and closer to 0. As Δt dwindles, the average velocity approaches a limiting value, which is the velocity at that instant:

$$\boxed{v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}.}$$

Note that v is the rate at which position x is changing with time at a given instant; that is, v is the derivative of x with respect to t.

- **Unit of is m/s.**
- v **is a vector quantity.**
  - **if it is positive $\Rightarrow$ moving to the right**
  - **if it is negative $\Rightarrow$ moving to the left**

2-5 | Instantaneous Velocity and Speed

Speed:

Speed is the magnitude of velocity; that is, speed is velocity that has been stripped of any indication of direction, either in words or via an algebraic sign.

Sample Problem 2-3

The position of a particle moving on an x axis is given by

$$x = 7.8 + 9.2t - 2.1t^3, \qquad (2\text{-}5)$$

with x in meters and t in seconds. What is its velocity at $t = 3.5$ s? Is the velocity constant, or is it continuously changing?

2-6 | Acceleration

When a particle's velocity changes, the particle is said to undergo **acceleration** (or to accelerate).

Acceleration

Average Acceleration

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

Instantaneous Acceleration (Or Acceleration)

$$a = \frac{dv}{dt}.$$

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

Rem: If the signs of the velocity and acceleration of a particle are the same, the speed of the particle increases. If the signs are opposite, the speed decreases.

If

$$\left.\begin{aligned} v &= +ve \\ a &= +ve \\ &or \\ v &= -ve \\ a &= -ve \end{aligned}\right\}$$ Speed increase

$$\left.\begin{aligned} v &= +ve \\ a &= -ve \\ &or \\ v &= -ve \\ a &= +ve \end{aligned}\right\}$$ Speed decrease

Sample Problem 2-4 Build your skill

A particle's position on the x axis of Fig. 2-1 is given by

$$x = 4 - 27t + t^3,$$

with x in meters and t in seconds.

(a) Because position x depends on time t, the particle must be moving. Find the particle's velocity function $v(t)$ and acceleration function $a(t)$.

(b) Is there ever a time when $v = 0$?

2-7 | Constant Acceleration: A Special Case

- **Constant acceleration does not mean the velocity is constant, it means the velocity changes with constant rate.**

- **Constant acceleration does not mean a=0. If a=0 $\Rightarrow$ v is constant.**

TABLE 2-1

Equations for Motion with Constant Acceleration[a]

Equation	Missing Quantity
$v = v_0 + at$	$x - x_0$
$x - x_0 = v_0 t + \frac{1}{2}at^2$	v
$v^2 = v_0^2 + 2a(x - x_0)$	t
$x - x_0 = \frac{1}{2}(v_0 + v)t$	a
$x - x_0 = vt - \frac{1}{2}at^2$	v_0

$x_0 \rightarrow$ Initial position

$x \rightarrow$ final position

$x - x_0 \rightarrow$ displacment

$v_0 \rightarrow$ Initial velocity

$v \rightarrow$ final velocity

$t \rightarrow$ time

$a \rightarrow$ Constant acceleration

Rem:

- when the object starts from rest $\boxed{\Rightarrow v_0 = 0}$
- when the object stops $\boxed{\Rightarrow v = 0}$
- $x_0 = 0$ unless something else mentioned in the problem.

Sample Problem 2-5

The head of a woodpecker is moving forward at a speed of 7.49 m/s when the beak makes first contact with a tree limb. The beak stops after penetrating the limb by 1.87 mm. Assuming the acceleration to be constant, find the acceleration magnitude in terms of g.

Equation
$v = v_0 + at$
$x - x_0 = v_0 t + \frac{1}{2}at^2$
$v^2 = v_0^2 + 2a(x - x_0)$
$x - x_0 = \frac{1}{2}(v_0 + v)t$
$x - x_0 = vt - \frac{1}{2}at^2$

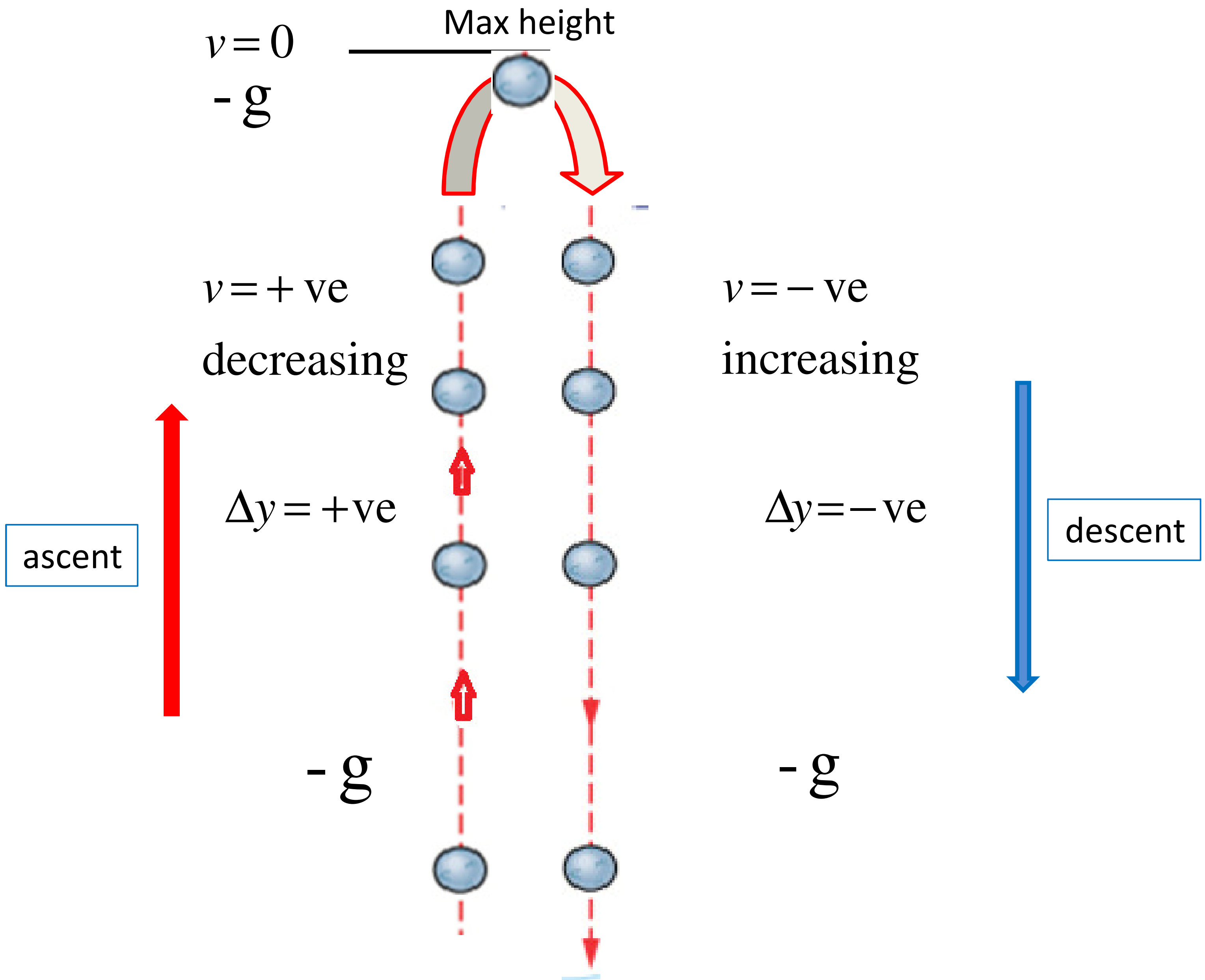
2-9 | Free-Fall Acceleration

•Free fall is the motion of an object under influence of Gravity and ignoring any other effects such as air resistance.

•All objects in free fall accelerate downward at the same rate and is independent of the object's mass, density or shape.

• This acceleration is called **the free-fall acceleration**.

$$\boxed{g = 9.8\, m/s^2 \quad downward}$$


Max height
$v = 0$
- g
$v = +\,\text{ve}$
decreasing
$v = -\,\text{ve}$
increasing
ascent
$\Delta y = +\text{ve}$
$\Delta y = -\text{ve}$
descent
- g
- g

Equations of motion

- The motion along y axis $x \rightarrow y$
- $a = -g$

$$v = v_0 + at \quad \rightarrow \quad \boxed{v = v_0 - gt}$$

$$x - x_0 = v_0 + \frac{1}{2}at^2 \quad \rightarrow \quad y - y_0 = v_0 - \frac{1}{2}gt^2$$

$$v^2 = v_0^2 + 2a(x - x_0) \quad \rightarrow \quad v^2 = v_0^2 - 2g(y - y_0)$$

$$x - x_0 = \frac{1}{2}(v_0 + v)t \quad \rightarrow \quad y - y_0 = \frac{1}{2}(v_0 + v)t$$

$$x - x_0 = vt - \frac{1}{2}at^2 \quad \rightarrow \quad y - y_0 = vt + \frac{1}{2}gt^2$$

Rem

- When substituting for g in the equations

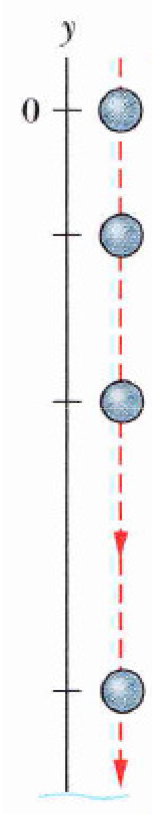
$g = 9.8m/s$.

- when the object is moving up (ascent).
- When the object is moving down (descent)

Sample Problem 2-7

On September 26, 1993, Dave Munday went over the Canadian edge of Niagara Falls in a steel ball equipped with an air hole and then fell 48 m to the water (and rocks). Assume his initial velocity was zero, and neglect the effect of the air on the ball during the fall.

(a) How long did Munday fall to reach the water surface?



Equation
$v = v_0 + at$
$x - x_0 = v_0 t + \frac{1}{2}at^2$
$v^2 = v_0^2 + 2a(x - x_0)$
$x - x_0 = \frac{1}{2}(v_0 + v)t$
$x - x_0 = vt - \frac{1}{2}at^2$

(b) Munday could count off the three seconds of free fall but could not see how far he had fallen with each count. Determine his position at each full second.

Equation
$v = v_0 + at$
$x - x_0 = v_0 t + \frac{1}{2}at^2$
$v^2 = v_0^2 + 2a(x - x_0)$
$x - x_0 = \frac{1}{2}(v_0 + v)t$
$x - x_0 = vt - \frac{1}{2}at^2$

(c) What was Munday's velocity as he reached the water surface?

(d) What was Munday's velocity at each count of one full second? Was he aware of his increasing speed?

Equation
$v = v_0 + at$
$x - x_0 = v_0 t + \frac{1}{2}at^2$
$v^2 = v_0^2 + 2a(x - x_0)$
$x - x_0 = \frac{1}{2}(v_0 + v)t$
$x - x_0 = vt - \frac{1}{2}at^2$

Equation
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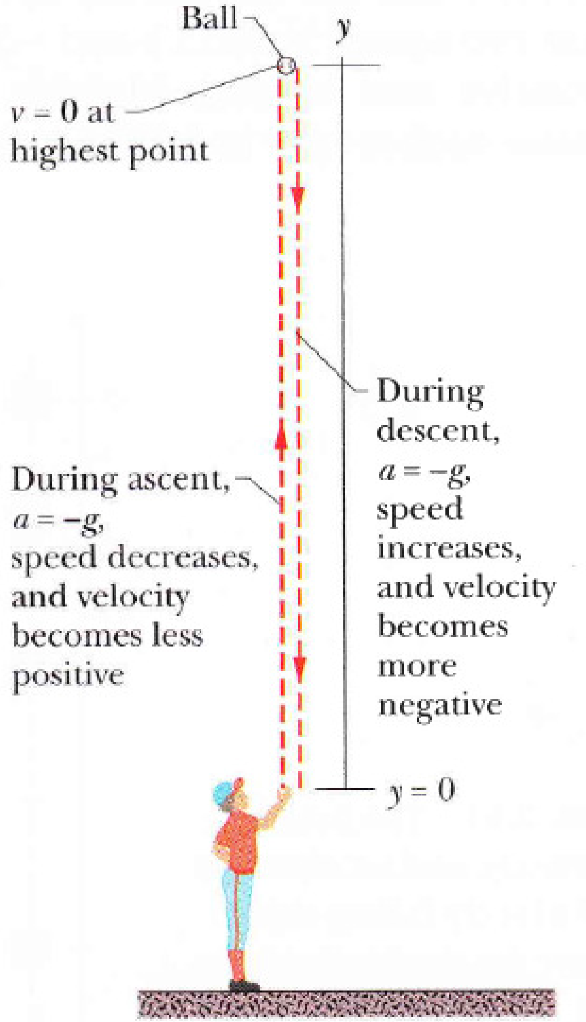
$v^2 = v_0^2 + 2a(x - x_0)$
$x - x_0 = \frac{1}{2}(v_0 + v)t$
$x - x_0 = vt - \frac{1}{2}at^2$

Sample Problem 2-8

In Fig. 2-12, a pitcher tosses a baseball up along a y axis, with an initial speed of 12 m/s.

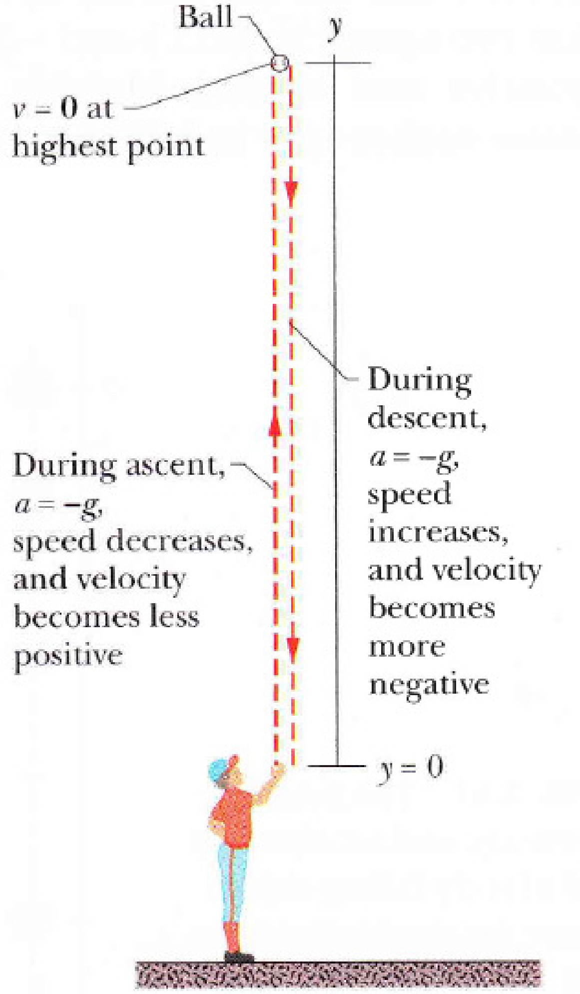
(a) How long does the ball take to reach its maximum height?

(b) What is the ball's maximum height above its release point?



Equation
$v = v_0 + at$
$x - x_0 = v_0 t + \frac{1}{2}at^2$
$v^2 = v_0^2 + 2a(x - x_0)$
$x - x_0 = \frac{1}{2}(v_0 + v)t$
$x - x_0 = vt - \frac{1}{2}at^2$

(c) How long does the ball take to reach a point 5.0 m above its release point?



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