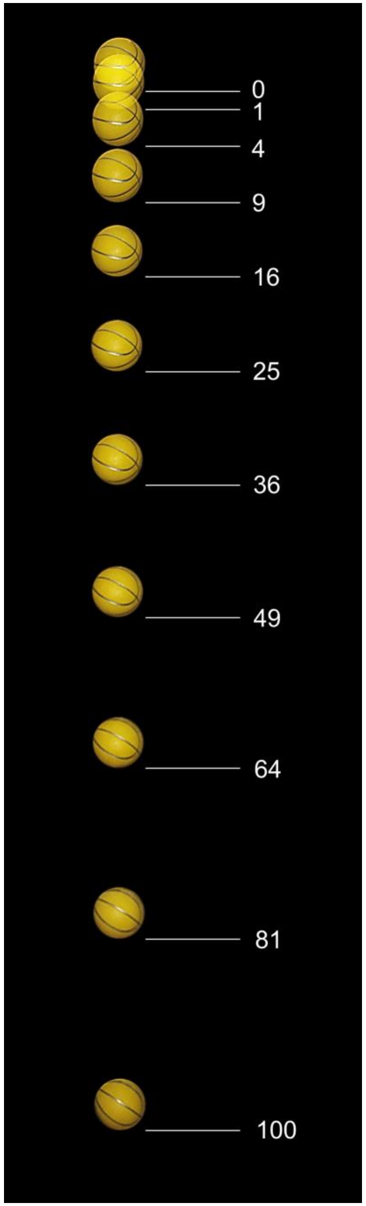
Chapter 3

Falling Objects and Projectile Motion

Interactive Question

Consider the ball falling in the picture to the right. A snapshot of the ball is shown at equal time intervals. What is true about the motion of the ball?

A) The ball is speeding up all the time
B) The ball is falling at a constant speed
C) The ball is speeding up for a little while then falling at a constant speed
D) The ball is slowing down all the time



Free Fall

Free fall is defined as the motion of an object when the only force acting on it is gravity (more about that in Chapter 4)

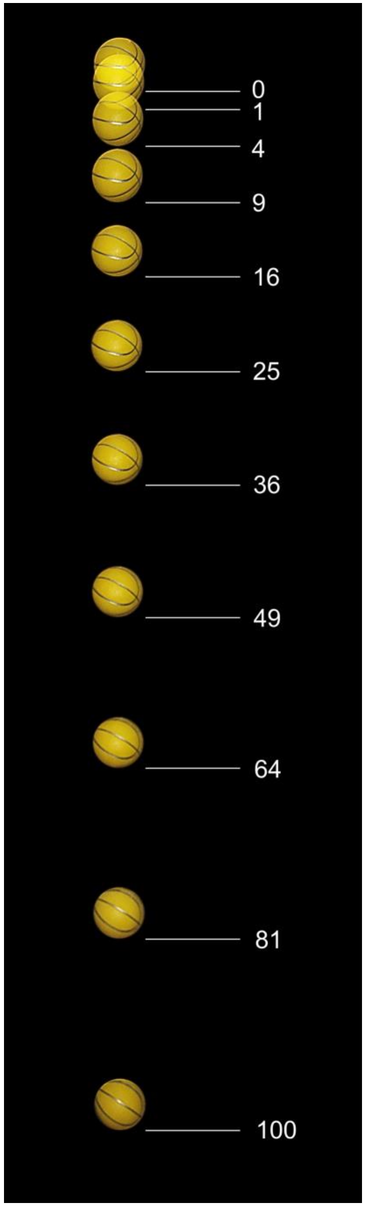
The picture shows snapshots taken at equal time intervals. The relative distance the ball has fallen in equal time intervals is:

Time	Distance
1	1
2	4
3	9
4	16
…	

Notice a pattern?

$$d \propto t^2$$

$$d = (1/2)at^2$$



Objects in a Uniform Gravitational Field

One of the most important cases of motion with constant acceleration is the case of objects that are near to earth which undergo free falling motion. In the late 1500' s Galileo showed that objects of different weights all fell at the same rate *if air resistance is neglected*.

The gravitational force exerted by the earth attracts objects to it. All objects near the surface of the earth fall with a constant acceleration of about 9.80 m/s^2 which we call g, the acceleration due to gravity.

The equations we used for constant acceleration apply to an object in free fall, neglecting air resistance with

$$a = -g = -9.8 \text{ m/s}^2 = -32 \text{ ft/s}^2 \approx -10 \text{ m/s}^2$$

(when up is defined as the positive direction.)

Everything falls with the same acceleration when there is no air resistance

Is this useful on earth? Can we neglect air resistance and still accurately describe what happens?

Interactive Question

An object is dropped from rest and is free-falling near the surface of the earth. Which of the following is true?

A) The velocity and the acceleration are increasing.
B) The velocity is increasing but the acceleration is constant.
C) The velocity is increasing, but the acceleration is decreasing.
D) The velocity and the acceleration are constant.

Interactive Question

A ball is thrown straight up and rises for a while then stops and falls. Which of the following is true.

A) The acceleration is first upward, then downward
B) The velocity is first upward, then downward, but the acceleration is always downward.
C) The acceleration is always downward, except when the ball is at its highest point.
D) The velocity and the acceleration are always in the same direction.
E) The velocity and the acceleration are always in opposite directions.

Interactive Question

If you drop a brick from a building in the absence of air resistance, it accelerates downward at 9.8 m/s^2. If instead you throw it downward, its acceleration after release

A) is always down with a magnitude less than 9.8 m/s^2

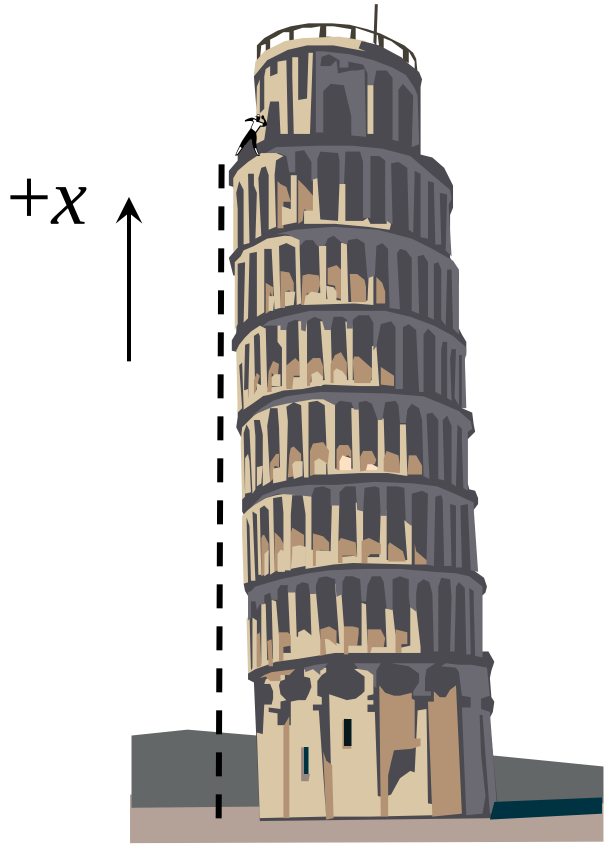
B) is always down with a magnitude equal 9.8 m/s^2

C) is always down with a magnitude more than 9.8 m/s^2

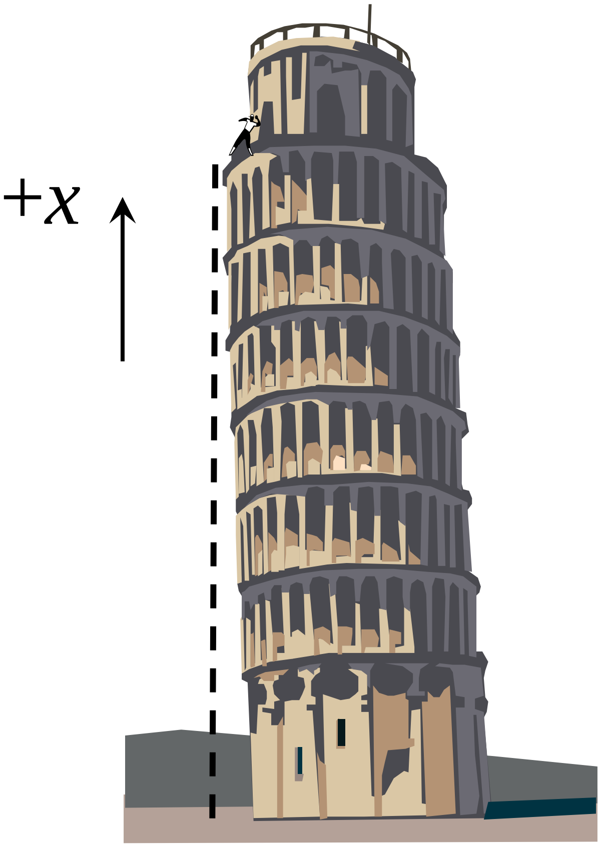
D) changes. Sometimes it is upward and sometimes it is downward

E) Is impossible to determine with the information given

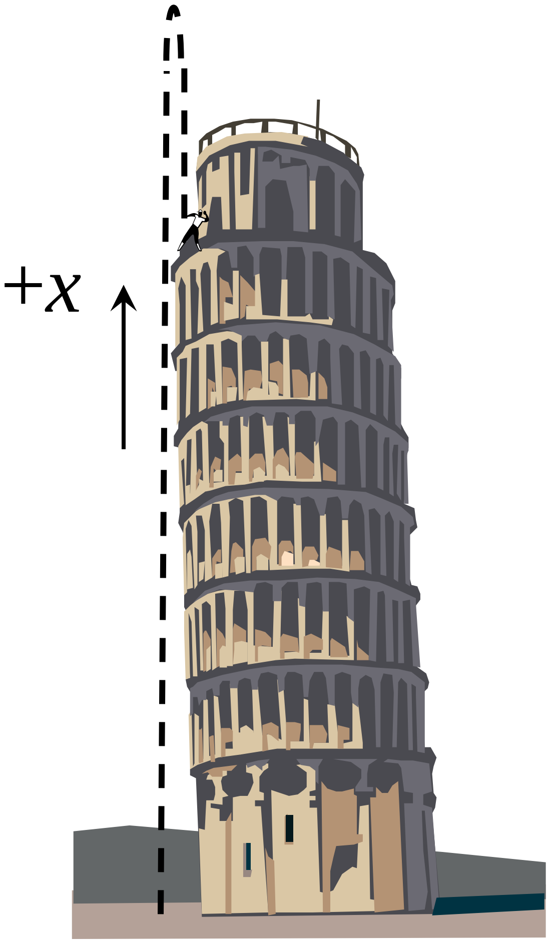
Problem: A boy drops a ball from rest from the top of a building 40.0 m high. How long will it take to reach the ground?



Problem: A boy drops a ball from rest from the top of a building 40.0 m high. How fast will it be moving when it hits the ground?



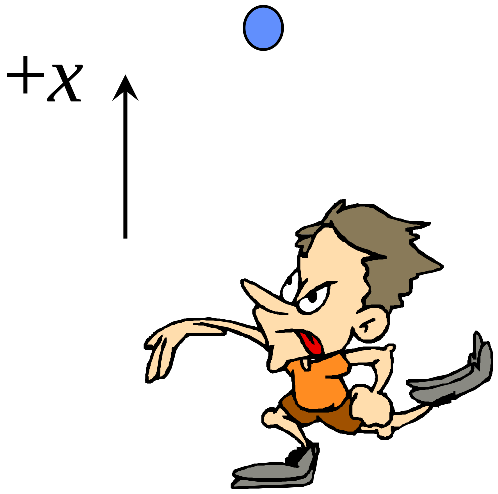
<u>Problem</u>: A boy throws a ball upward with a speed of 10.0 m/s from the top of a building 40.0 m high. What will be the velocity of the ball after (a) 0.5 seconds?, (b) 1.5 seconds



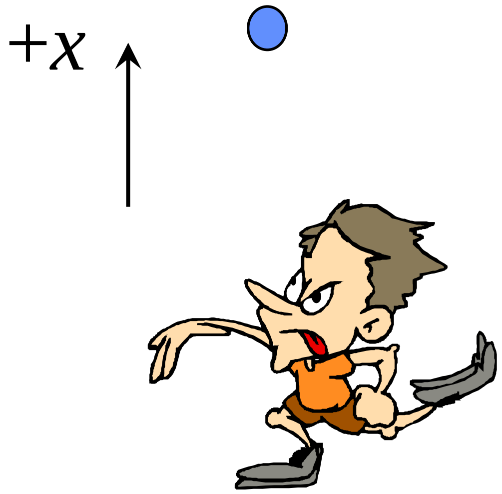
Problem: A boy standing on the ground throws a ball straight upward with a speed of 15.0 m/s.

a) How long will it take to reach its maximum height?

b) How high will it go?



Problem: A boy standing on the ground throws a ball straight upward and it rises to a height of 15 meters. How fast did he throw the ball?

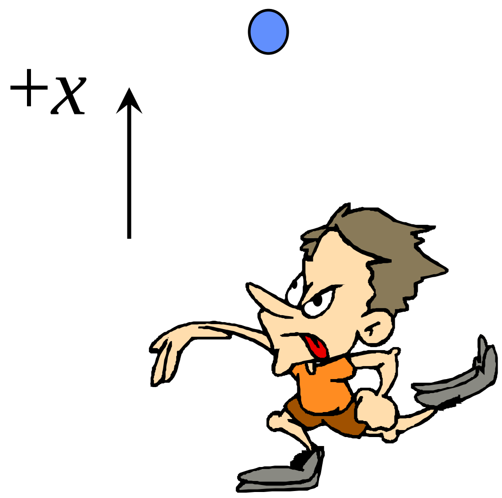


Interactive Question

Ball **A** is dropped from a window. At the same instant, ball **B** is thrown downward and ball **C** is thrown upward from the same window. Which statement concerning the balls is necessarily true if air resistance is neglected?

A) At one instant, the acceleration of ball **C** is zero.
B) All three balls strike the ground at the same time.
C) All three balls have the same velocity at any instant.
D) All three balls have the same acceleration at any instant.
E) All three balls reach the ground with the same velocity.

Problem: A boy standing on the ground throws a ball straight upward with a speed of 25.0 m/s. How long will it take to return to earth?



Problem: Two balls are dropped from different buildings. The first building is twice as tall as the second building. How much longer does the first ball take to hit the ground compared with the second ball? Ignore air resistance.

Interactive Question

Two balls are thrown straight up. The first is thrown with twice the initial speed of the second. Ignore air resistance. How much longer will it take for the first ball to reach its maximum height?

A) $\sqrt{2}$ times as long.
B) Twice as long.
C) Three times as long.
D) Four times as long.
E) Eight times as long.

Interactive Question

Two rocks are dropped into two different deep wells. The first one takes three times as long to hit bottom as the second one. Ignore air resistance. How much deeper is the first well than the second?

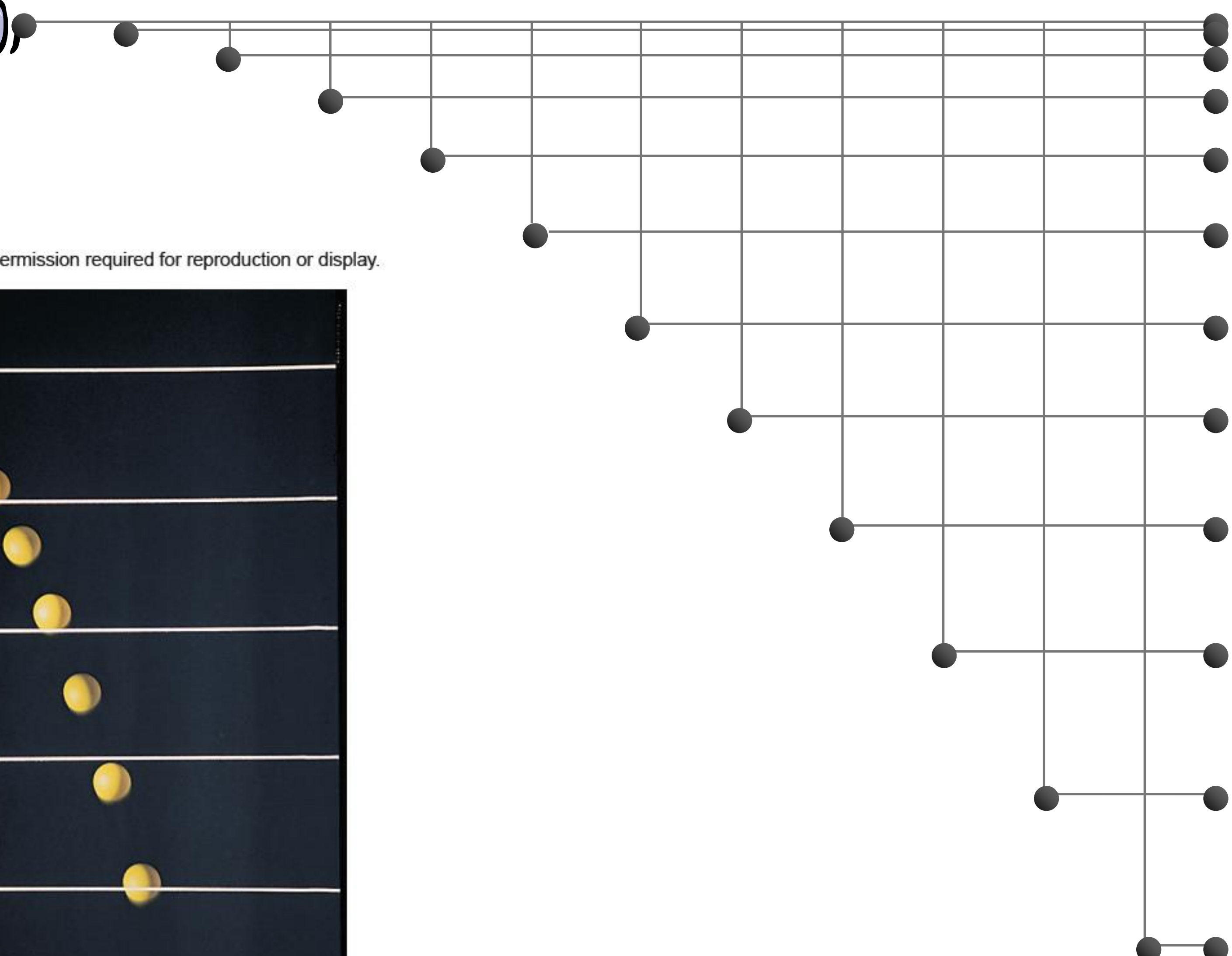
A) $\sqrt{3}$ times as deep.
B) Three times as deep.
C) Four and a half times as deep.
D) Six times as deep.
E) Nine times as deep.

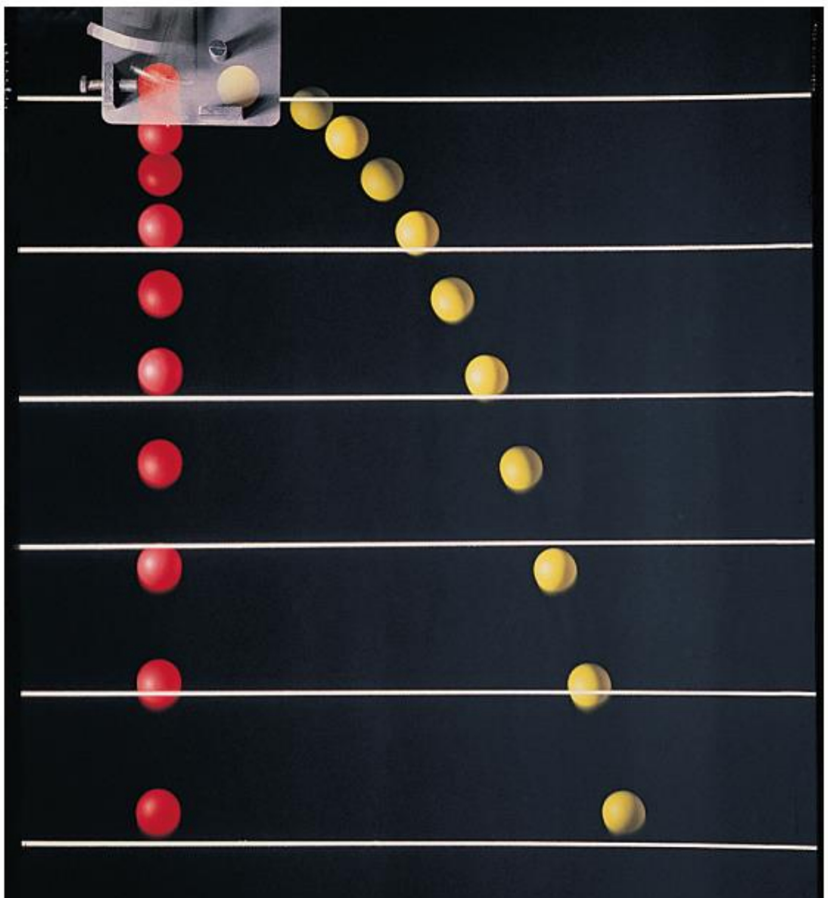
Projectile Motion

Projectile motion is the name we give to the motion of an object with a constant acceleration in one direction, and no acceleration in the other directions, like an object moving near the surface of the earth, if we neglect air resistance.

There is no acceleration in the horizontal direction, and the acceleration in the vertical direction is the same for all objects. The vertical and horizontal motions can be considered to act independently of each other.

Notice the horizontal and vertical motion





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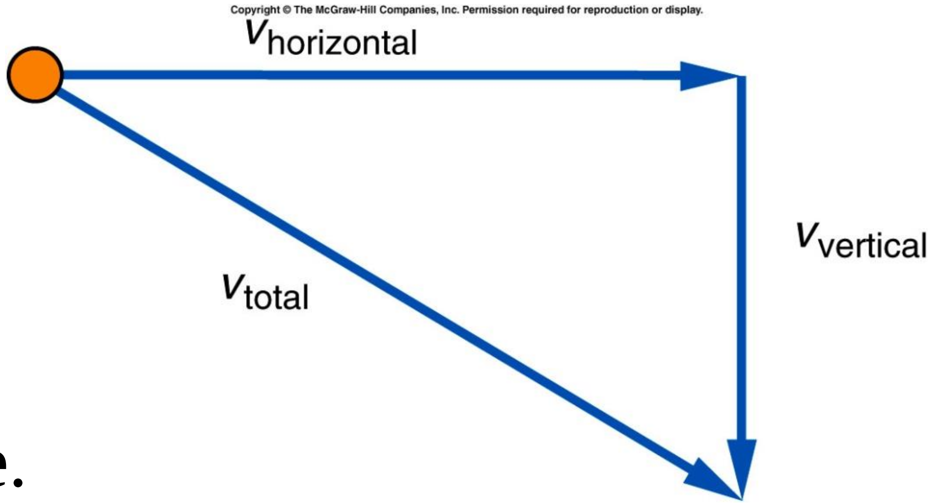
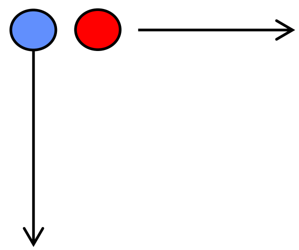
Finding the Total Velocity

- The total velocity at any point is found by adding the vertical component of the velocity, at that point, to the horizontal component of the velocity at that point.
- The horizontal velocity remains constant, because there is no acceleration in that direction.
- The length of the horizontal velocity vector doesn't change.
- While falling, the downward (vertical) velocity gets larger and larger, due to the acceleration from gravity.



Throw a ball (red) horizontally and drop a ball (blue)



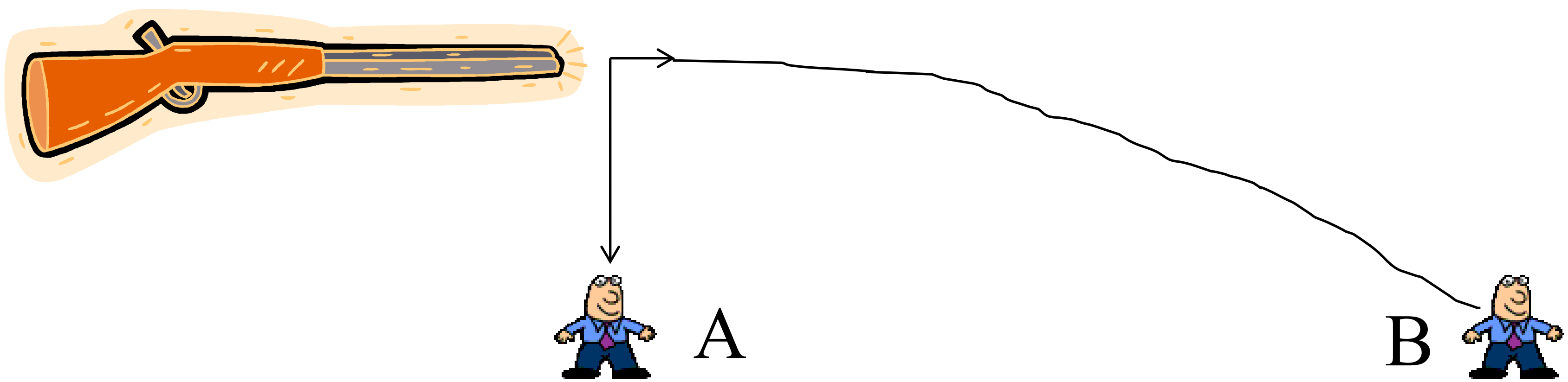
When the balls hit the ground:

Is the time in air the same or different?

Is the velocity the same or different?

Different example

Shoot a gun and drop a bullet



Where do you want to stand?

Vertical velocity is same

Horizontal velocity very different

At A horizontal velocity=0 but a B it is very large

$\mathbf{v}_{\text{total}} = \mathbf{v}_{\text{horizontal}} + \mathbf{v}_{\text{vertical}}$ Total velocity much larger for B

Interactive Question

Ben and Jerry release their snowballs from the same height and at the same time. Ben's is dropped while Jerry’s is thrown horizontally. Which one hits the ground first?

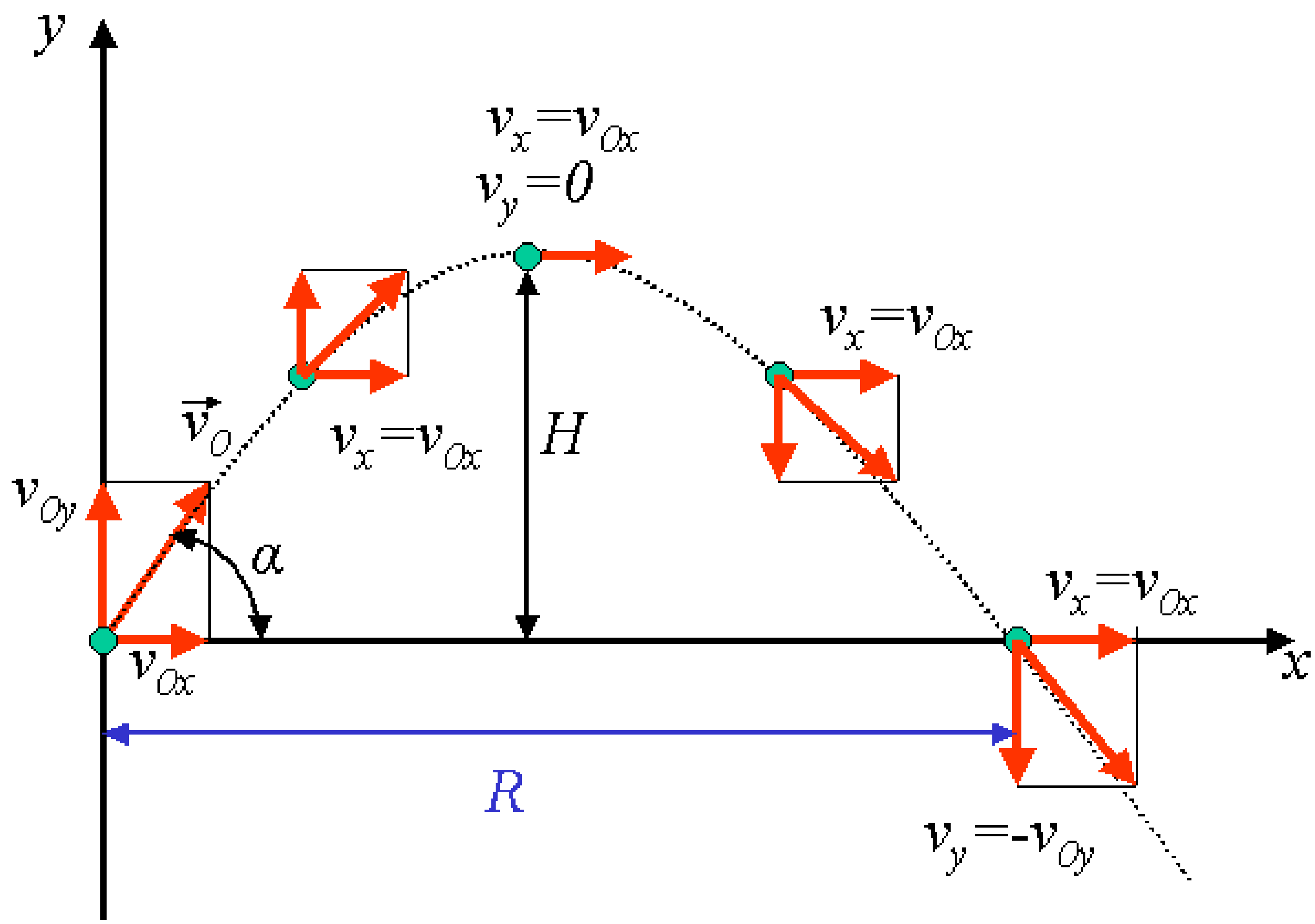
A)The dropped snowball

B)The thrown snowball

C) They hit at the same time

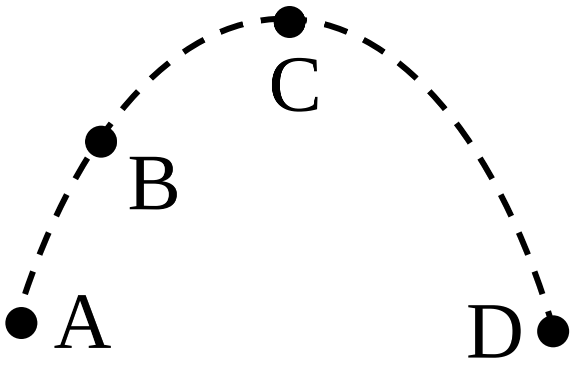
D) It depends on how hard Jerry threw

E) It depends on the initial height


y
x
$v_x = v_{0x}$
$v_y = 0$
$v_x = v_{0x}$
$v_x = v_{0x}$
$\vec{v}_0$
$v_x = v_{0x}$
H
v_{0y}
α
v_{0x}
R
$v_y = -v_{0y}$

Interactive Question

A tennis ball is thrown upward at an angle from point A and follows a parabolic path as shown. (The motion is shown from the time the ball leaves the person's hand until just before it hits the ground.)

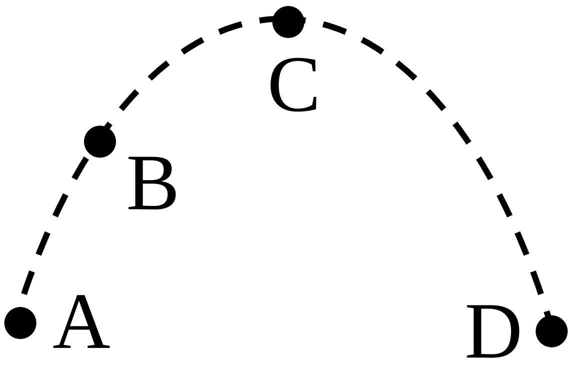


At what point is the vertical velocity equal to zero?

A) A
B) B
C) C
D) D
E) None of the above

Interactive Question

A tennis ball is thrown upward at an angle from point A and follows a parabolic path as shown. (The motion is shown from the time the ball leaves the person's hand until just before it hits the ground.)



At what point is the velocity equal to zero?

A) A
B) B
C) C
D) D
E) None of the above

Interactive Question

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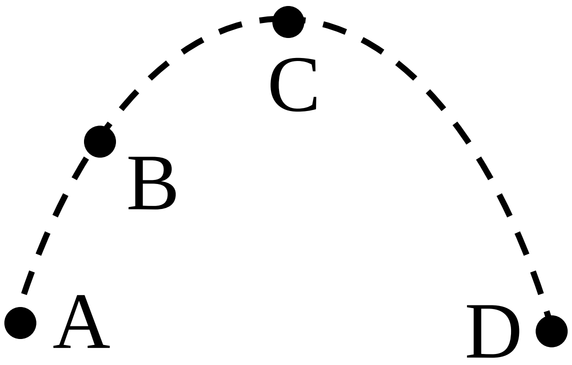
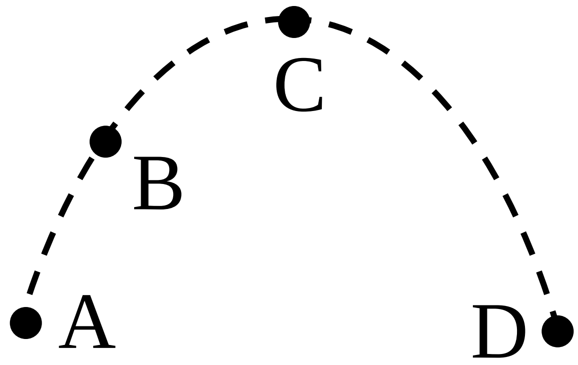


At what point is the vertical acceleration equal to zero?

A) A
B) B
C) C
D) D
E) None of the above

Interactive Question

A tennis ball is thrown upward at an angle from point A and follows a parabolic path as shown. (The motion is shown from the time the ball leaves the person's hand until just before it hits the ground.)

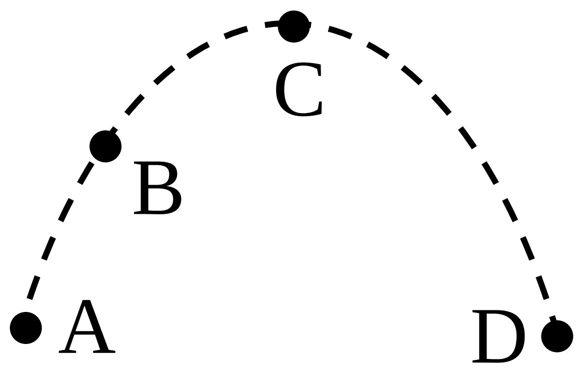


At what point is the horizontal velocity equal to the horizontal velocity at A?

A) B
B) C
C) D
D) All of the above
E) None of the above

Interactive Question

A tennis ball is thrown upward at an angle from point A and follows a parabolic path as shown. (The motion is shown from the time the ball leaves the person’s hand until just before it hits the ground.)

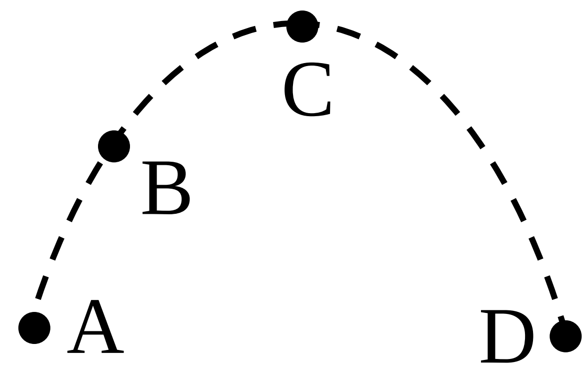


At what point is the horizontal acceleration equal to zero?

A) A
B) B
C) C
D) D
E) All of the above

Interactive Question

A tennis ball is thrown upward at an angle from point A and follows a parabolic path as shown. (The motion is shown from the time the ball leaves the person's hand until just before it hits the ground.)



At what point is the ball moving the slowest?

A) A
B) B
C) C
D) D
E) The speed is the same everywhere

Equations for Projectile Motion

In the x (horizontal) direction.

$d_x = v_x t$

In the y (vertical) direction. (with the positive direction being up, $a_y = -g = -9.8\ \text{m/s}^2$)

$v_y = v_{0y} + a_y t = v_{0y} - gt$

$d_y = v_{0y} t + (1/2) a_y t^2 = v_{0y} t - (1/2) g t^2$

The x and y directions are connected by time (t).

So sometimes we will use the horizontal equation to find the time, t, then use that time in the vertical equations, or vice-versa.

Problem: You are working as a consultant on a video game designing a bomb site for a World War I airplane. In this game, the plane you are flying is traveling horizontally at 30.0 m/s at an altitude of 150 m when it drops a bomb. You need to determine how far from the target you should drop the bomb neglecting air resistance.

Given:

Want:

If you are not sure what else may be given, you can think about all the possibilities that are used in the equations describing projectile motion:

$$d_x, v_x, t, v_{0y}, v_y, d_y, a_y$$

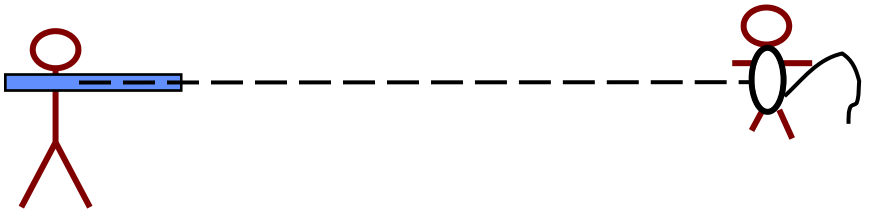
Always known for a falling object: $a_y = -g = -9.8 \text{ m/s}^2$

Interactive Question

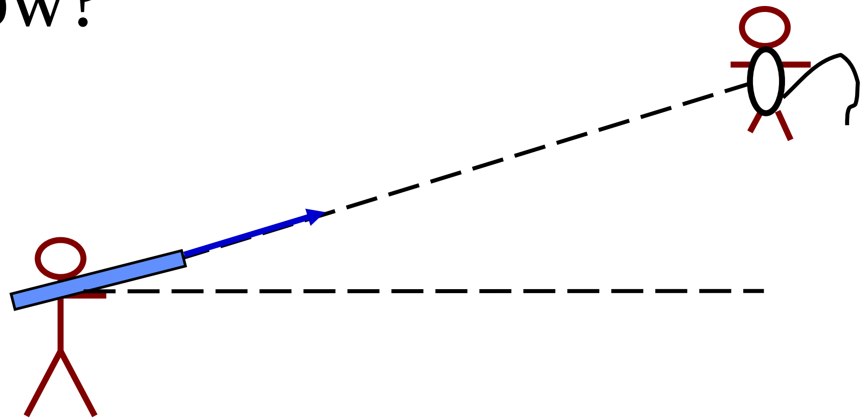
A pilot drops a bomb from a plane flying horizontally. When the bomb hits the ground, the horizontal location of the plane will

A) be behind the bomb.
B) be over the bomb.
C) be in front of the bomb.
D) depend on the speed of the plane when the bomb was released.

Problem: A hunter aims his gun at a monkey who sits across a canyon hanging on a branch, horizontal from where the hunter is. Just as the hunter shoots, the monkey drops from the branch to avoid the bullet. What happens?



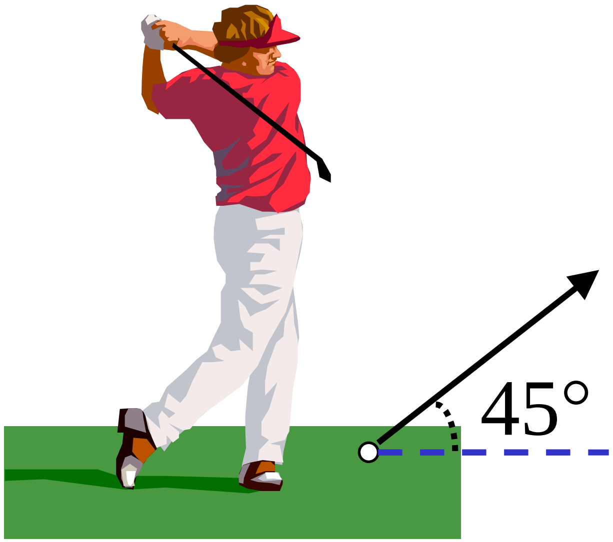
<u>Problem</u>: A hunter aims his gun at a monkey hanging on a branch above him. Just as the hunter shoots, the monkey drops from the branch to avoid the bullet. What happens now?



<u>Problem:</u> A golfer hits a ball from level ground at an angle of 45° above the ground, so that the initial velocity in the vertical direction is equal to the initial velocity in the horizontal direction. Both are equal to 60 mi/hr. Neglect air resistance

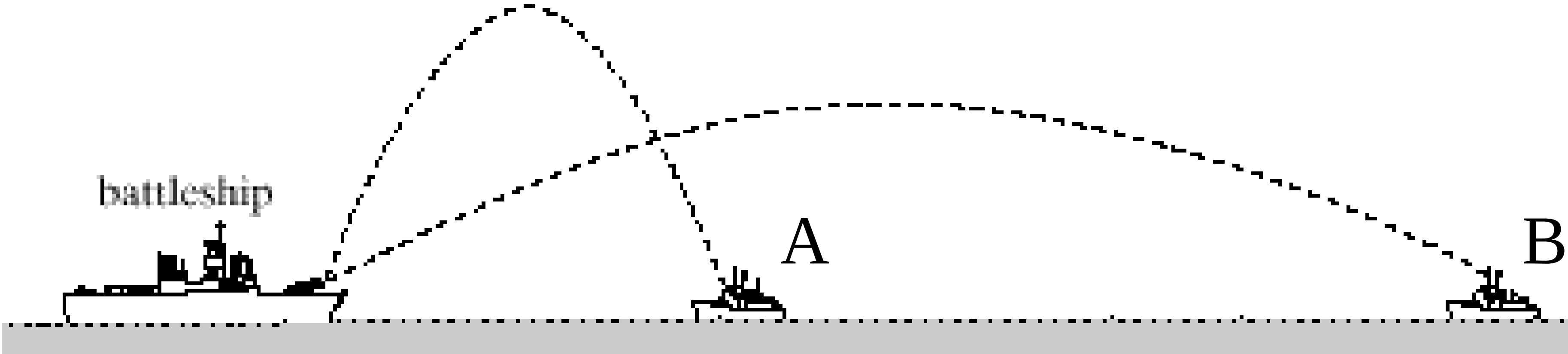
(a) How long is the ball in the air (in seconds)?

(b) How far does the ball go (in yards)?



Interactive Question

A battleship simultaneously fires two shells toward two enemy ships, one close by (A), and one far away (B). The shells leave the battleship at different angles and travel along the parabolic trajectories indicated. Which of the two enemy ships gets hit first?



A) A	B) B

C) They both get hit at the same time.

D) It is impossible to tell from the information given

Interactive Question

Before we answer the battleship question, let's ask another question. You throw two balls straight up at the same time. If you throw the first ball higher than the second ball, which one takes longer to come back to earth?

A) The first ball
B) The second ball
C) It takes the same amount of time
D) More information is needed to answer this question.