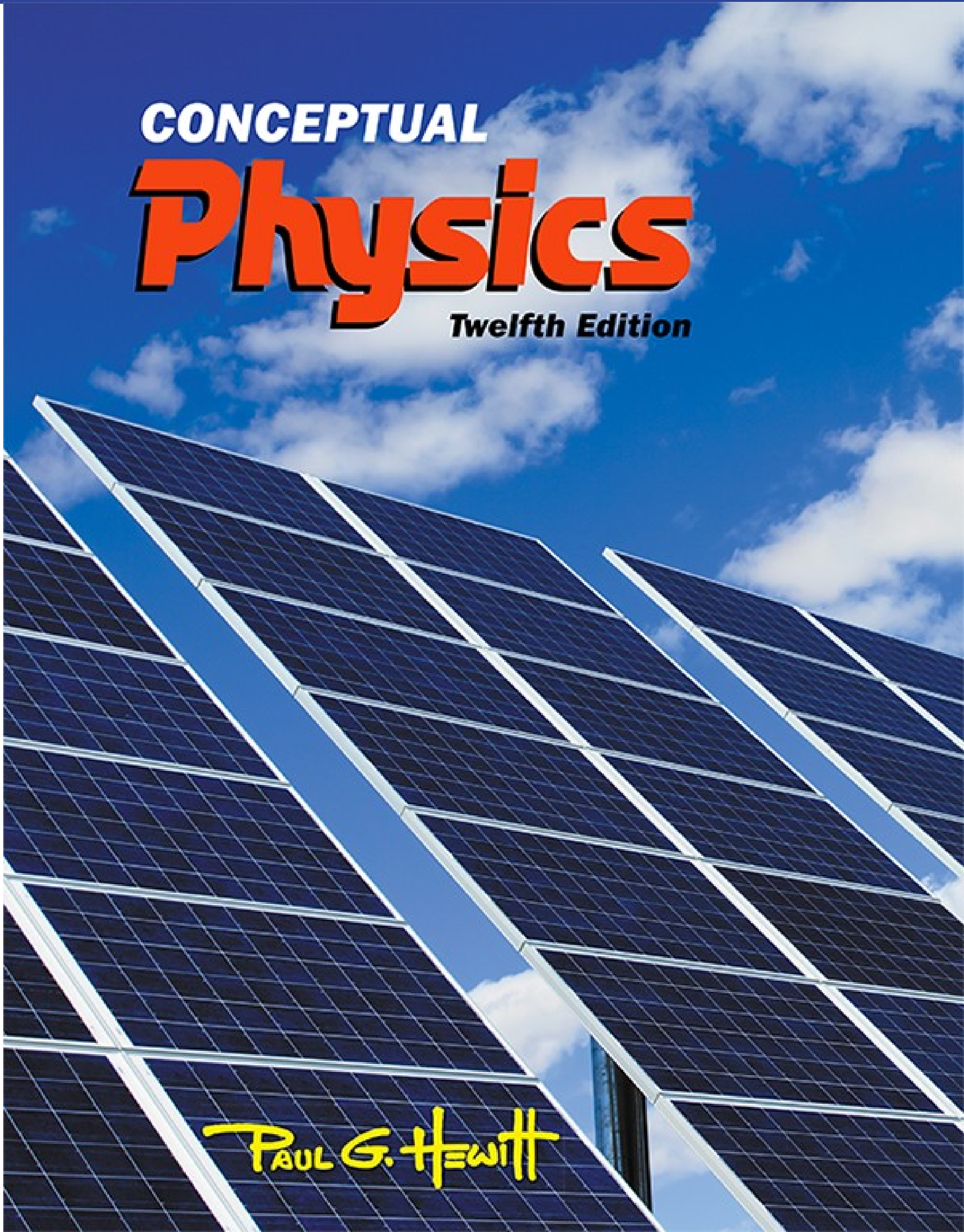


Chapter 10: Projectile and Satellite Motion

This lecture will help you understand:

- Projectile Motion
- Fast-Moving Projectiles – Satellites
- Circular Satellite Orbits
- Elliptical Orbits
- Kepler's Laws of Planetary Motion
- Energy Conservation and Satellite Motion
- Escape Speed

Projectile Motion

- Without gravity, a tossed object follows a straight-line path.
- With gravity, the same object tossed at an angle follows a curved path.
- Projectile:
  - Any object that moves through the air or space under the influence of gravity, continuing in motion by its own inertia

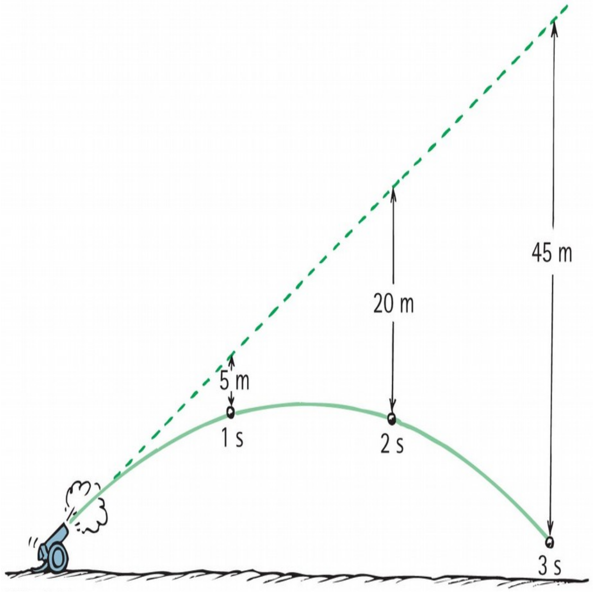
Projectile Motion, Continued

- Projectile motion is a combination of
  - a horizontal component, and

  - a vertical component.

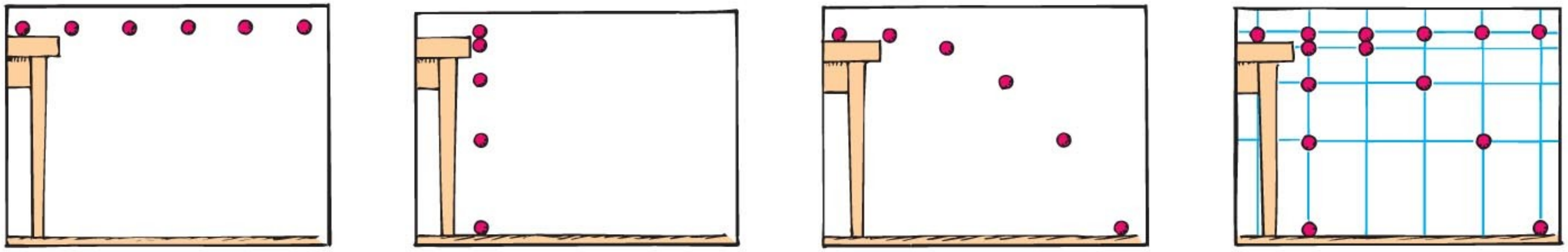
Projectile Motion, Continued-1

- Projectiles launched horizontally
- Important points:
- Horizontal component of velocity doesn't change (when air drag is negligible).
  - Ball travels the same horizontal distance in equal times (no component of gravitational force acting horizontally).
  - Remains constant.



Projectile Motion, Continued-2

- Vertical positions become farther apart with time.
  - Gravity acts downward, so ball accelerates downward.
- Curvature of path is the combination of horizontal and vertical components of motion.



Horizontal motion with no gravity

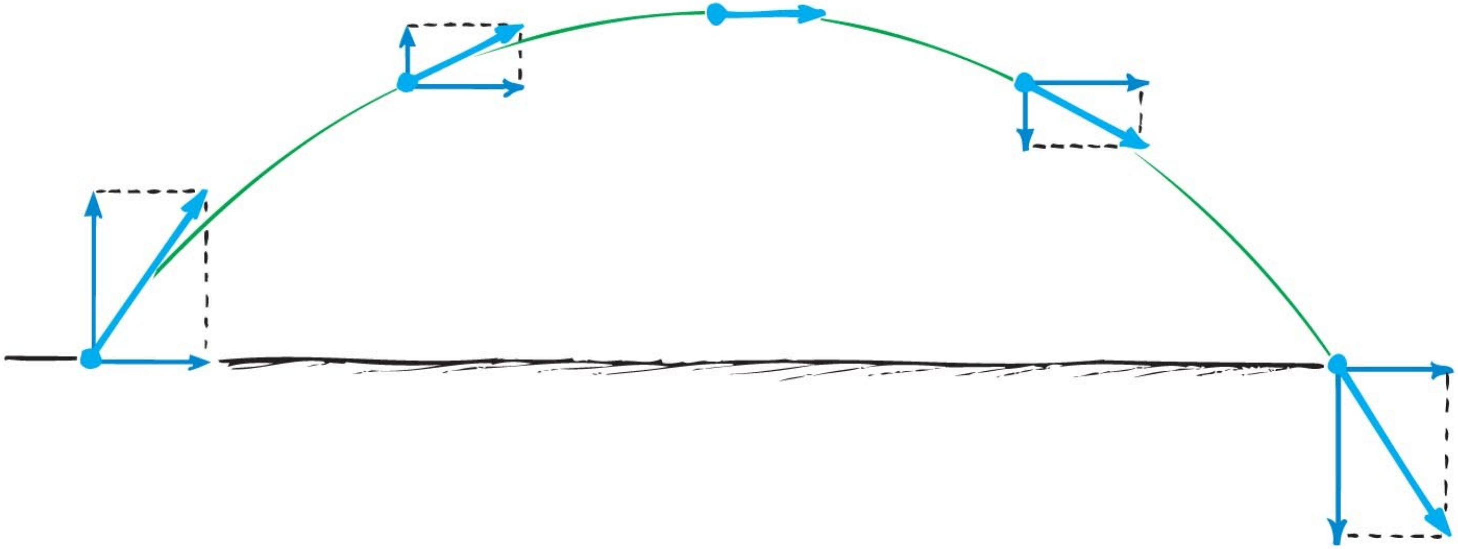
Vertical motion only with gravity

Combined horizontal and vertical motion

Superposition of the preceding cases

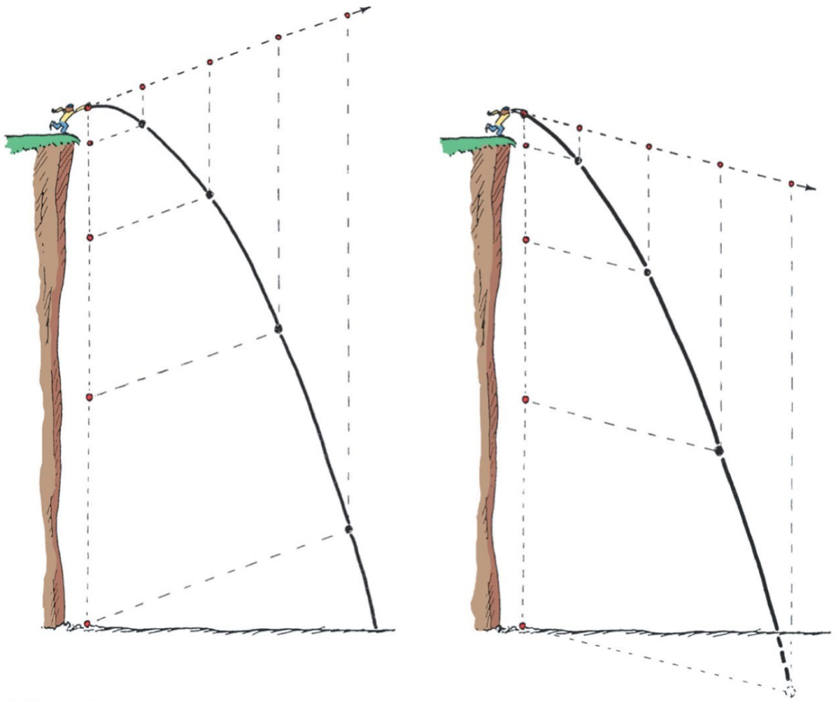
Projectile Motion, Continued-3

- Parabola:
  - Curved path of a projectile that undergoes acceleration only in the vertical direction, while moving horizontally at a constant speed



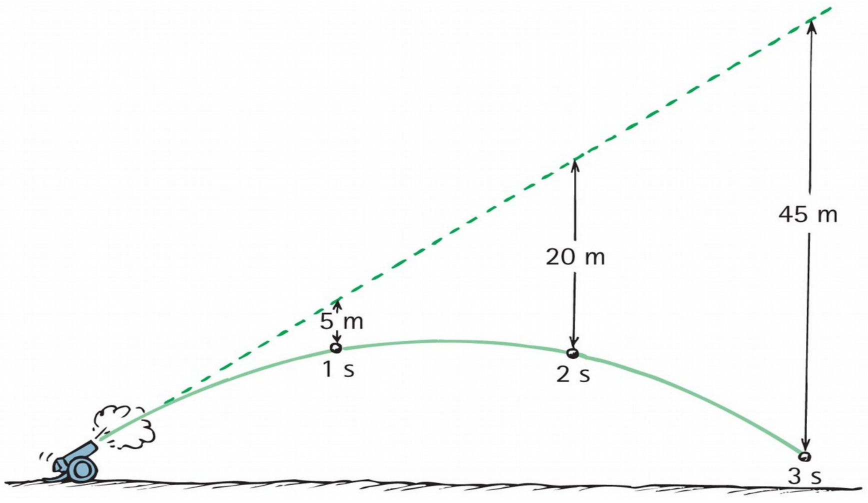
Projectile Motion, Continued-4

- Projectiles launched at an angle:
  - Paths of stone thrown at an angle upward and downward
    - Vertical and horizontal components are independent of each other.



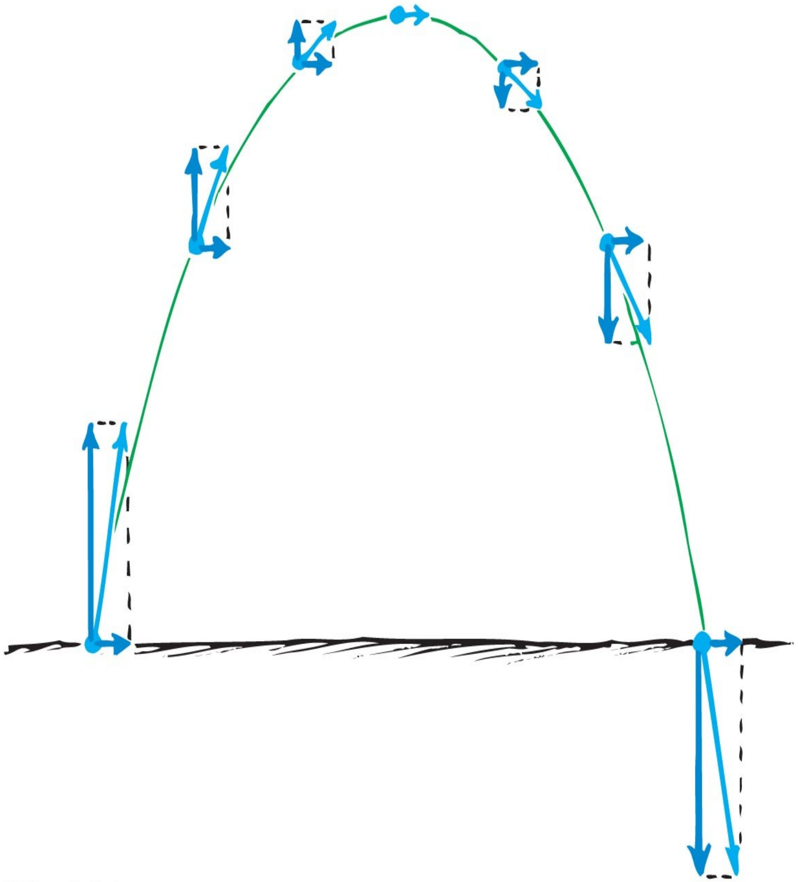
Projectile Motion, Continued-5

- Paths of a cannonball shot at an upward angle
  - Vertical distance that a stone falls is the same vertical distance it would have fallen if it had been dropped from rest and been falling for the same amount of time ($5t^2$).



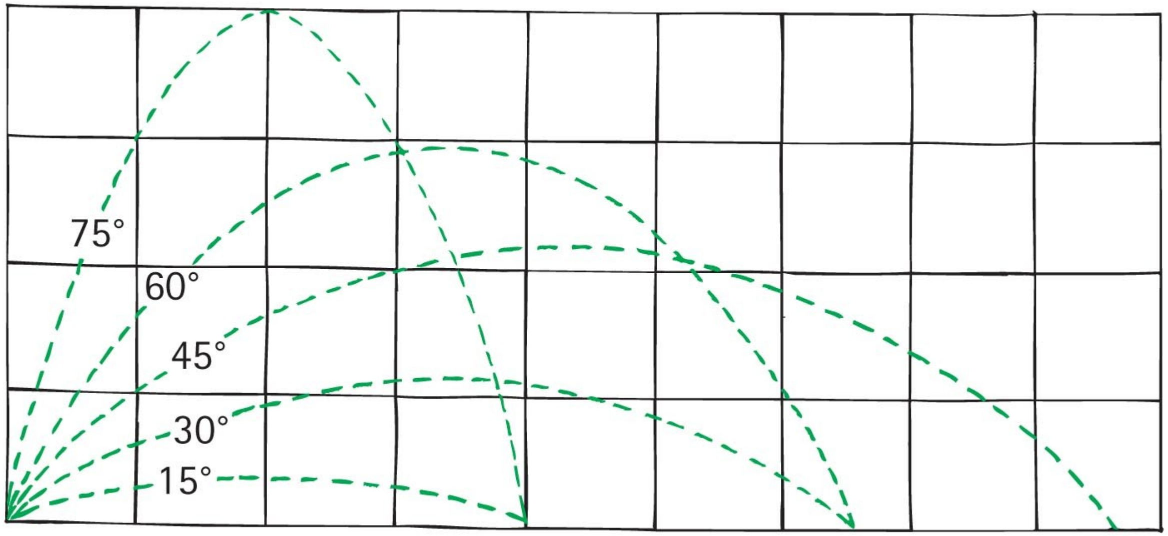
Projectile Motion, Continued-6

- Paths of projectile following a parabolic trajectory
  - Horizontal component along trajectory remains unchanged.
  - Only vertical component changes.
  - Velocity at any point is computed with the Pythagorean theorem (diagonal of rectangle).



Projectile Motion, Continued-7

- Different horizontal distances
  - Same range is obtained from two different launching angles when the angles add up to 90°.
    - Object thrown at an angle of 60° has the same range as if it were thrown at an angle of 30°.

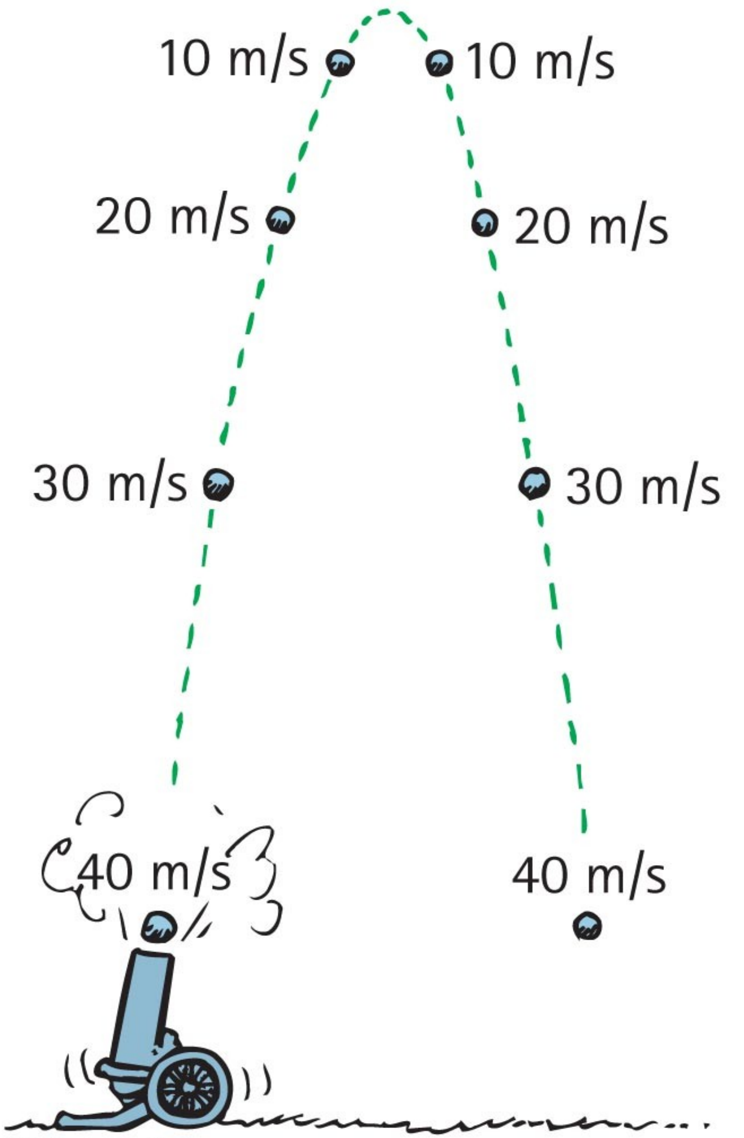


Projectile Motion, Continued-8

- Different horizontal distances (continued)
  - Maximum range occurs for ideal launch at 45°.
  - With air resistance, the maximum range occurs for a baseball batted at less than 45° above the horizontal (~25°–34°).
  - With air resistance the maximum range occurs when a golf ball is hit at an angle less than 38°.

Projectile Motion, Continued-9

- Without air resistance, the time for a projectile to reach maximum height is the same as the time for it to return to its initial level.



Projectile Motion
CHECK YOUR NEIGHBOR

The velocity of a typical projectile can be represented by horizontal and vertical components. Assuming negligible air resistance, the horizontal component along the path of the projectile

A. increases.

B. decreases.

C. remains the same.

D. Not enough information.

Projectile Motion
CHECK YOUR ANSWER

The velocity of a typical projectile can be represented by horizontal and vertical components. Assuming negligible air resistance, the horizontal component along the path of the projectile

C. **remains the same.**

Explanation:

Since there is no force horizontally, no horizontal acceleration occurs.

Projectile Motion
CHECK YOUR NEIGHBOR, Continued

When no air resistance acts on a fast-moving baseball, its acceleration is

A. downward, *g*.
B. a combination of constant horizontal motion and accelerated downward motion.
C. opposite to the force of gravity.
D. centripetal.

Projectile Motion
CHECK YOUR ANSWER, Continued

When no air resistance acts on a fast-moving baseball, its acceleration is

A. **downward, *g*.**

Projectile Motion
CHECK YOUR NEIGHBOR, Continued-1

Neglecting air drag, a ball tossed at an angle of 30° with the horizontal will go as far downrange as one that is tossed at the same speed at an angle of

A. 45°.

B. 60°.

C. 75°.

D. None of the above.

Projectile Motion
CHECK YOUR ANSWER, Continued-1

Neglecting air drag, a ball tossed at an angle of 30 with the horizontal will go as far downrange as one that is tossed at the same speed at an angle of.

B. 60°

Explanation:

Same initial-speed projectiles have the same range when their launching angles add up to 90° . Why this is true involves a bit of trigonometry—which, in the interest of time, we'll not pursue here.

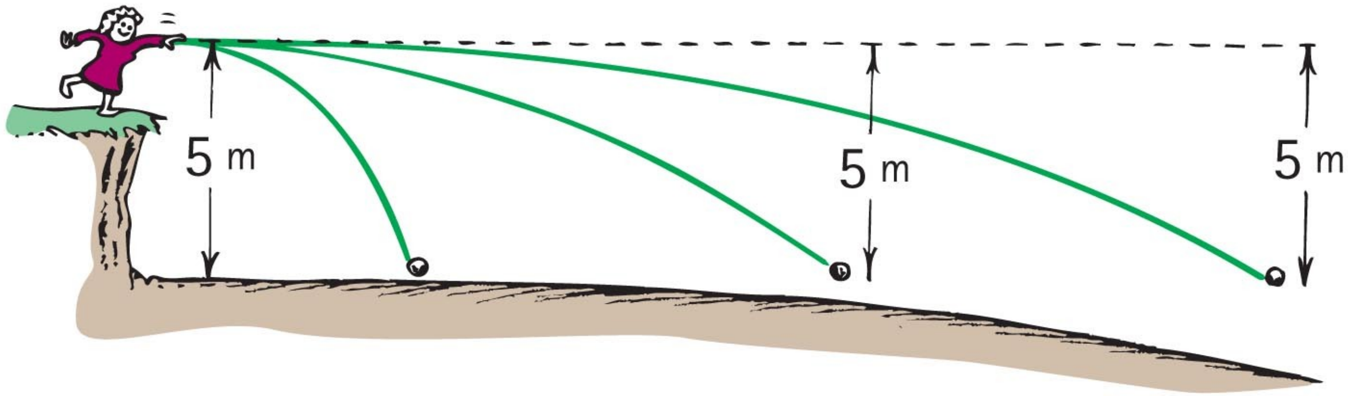
Fast-Moving Projectiles—Satellites

- Satellite motion is an example of a high-speed projectile.
- A satellite is simply a projectile that falls around Earth rather than into it.
  - Sufficient tangential velocity needed for orbit.
  - With no resistance to reduce speed, a satellite goes around Earth indefinitely.

Fast-Moving Projectiles—Satellites
CHECK YOUR NEIGHBOR

As the ball leaves the girl's hand, 1 second later it will have fallen

A. 10 meters.
B. 5 meters below the dashed line.
C. less than 5 meters below the straight-line path.
D. None of the above.



Fast-Moving Projectiles—Satellites
CHECK YOUR ANSWER

As the ball leaves the girl's hand, 1 second later it will have fallen

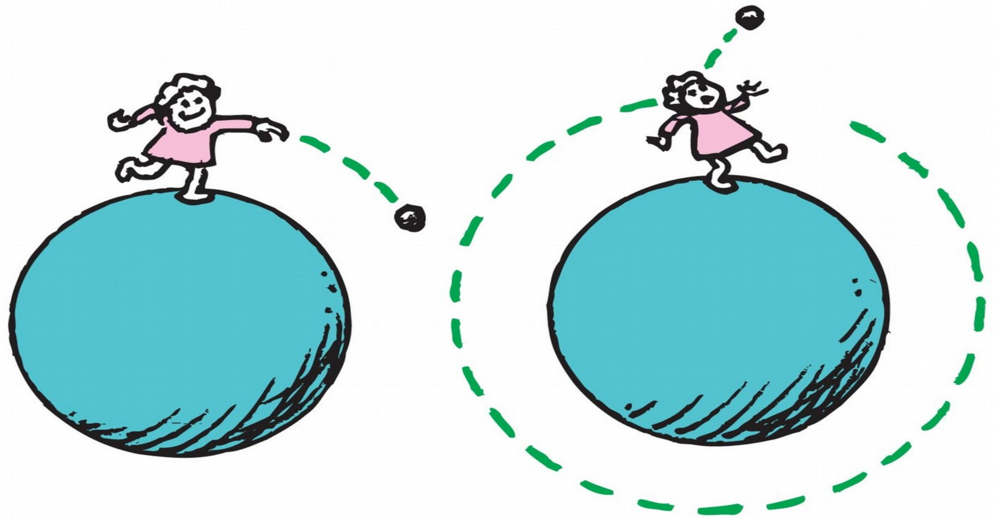
B. **5 meters below the dashed line.**

Comment:

Whatever the speed, the ball will fall a vertical distance of 5 meters below the dashed line.

Circular Satellite Orbits

- Satellite in circular orbit
  - Speed
    - must be great enough to ensure that its falling distance matches Earth's curvature.
    - is constant—only direction changes.
    - is unchanged by gravity.



Circular Satellite Orbits, Continued

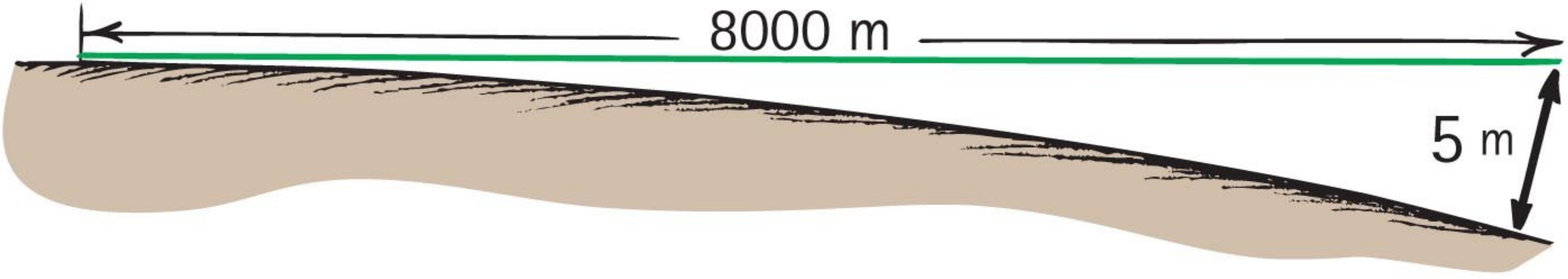
- Positioning:
  - beyond Earth's atmosphere, where air resistance is almost totally absent
  - Example: Space shuttles are launched to altitudes of 150 kilometers or more, to be above air drag (But even the ISS, as shown experiences *some* air drag, which is compensated for with periodic upward boosts.)

Circular Satellite Orbits, Continued-1

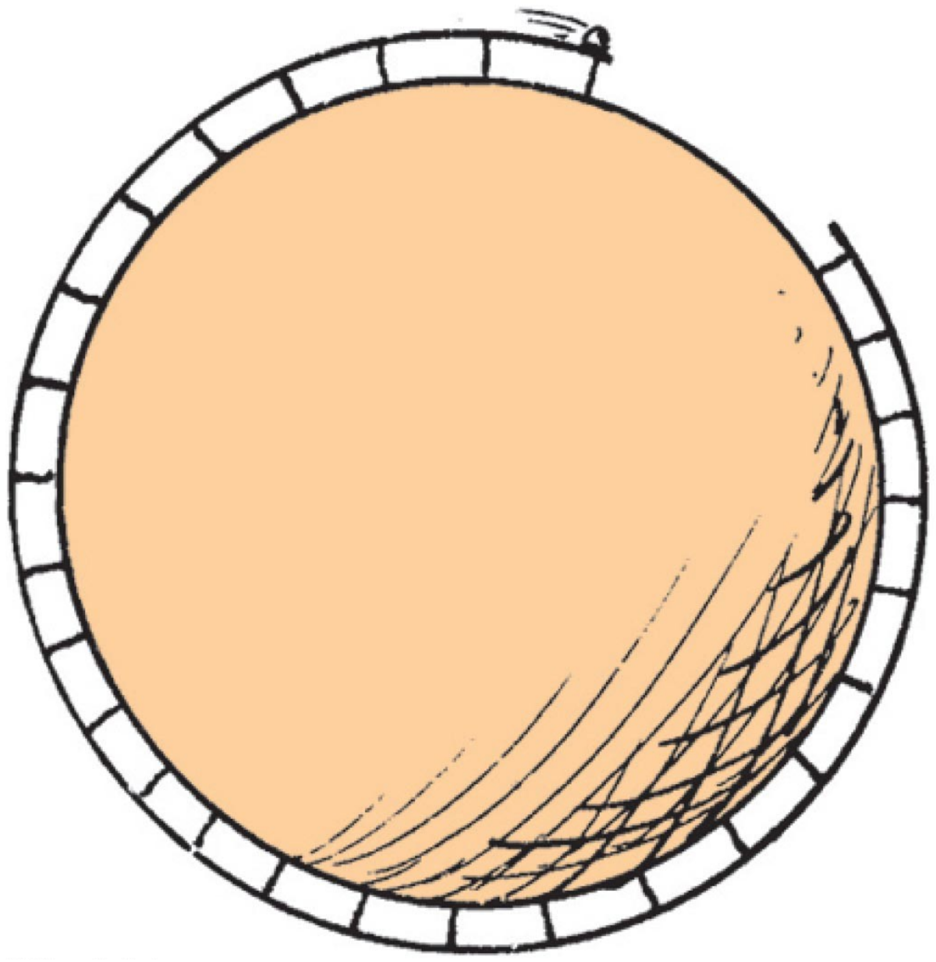
- Motion
  - moves in a direction perpendicular to the force of gravity acting on it
- Period for complete orbit about Earth
  - for satellites close to Earth—about 90 minutes
  - for satellites at higher altitudes—longer periods

Circular Satellite Orbits, Continued-2

- Curvature of Earth
  - Earth surface drops a vertical distance of 5 meters for every 8000 meters tangent to the surface



Circular Satellite Orbits, Continued-3



- What speed will allow the ball to clear the gap?

Circular Satellite Orbits
CHECK YOUR NEIGHBOR

When you toss a projectile sideways, it curves as it falls. It will be an Earth satellite if the curve it makes

A. matches the curved surface of Earth.
B. results in a straight line.
C. spirals out indefinitely.
D. None of the above.

Circular Satellite Orbits
CHECK YOUR ANSWER

When you toss a projectile sideways, it curves as it falls. It will be an Earth satellite if the curve it makes

A. matches the curved surface of Earth.

Explanation:

For an 8-km tangent, Earth curves downward 5 m. Therefore, a projectile traveling horizontally at 8 km/s will fall 5 m in that time, and follow the curve of Earth.

Circular Satellite Orbits
CHECK YOUR NEIGHBOR, Continued

When a satellite travels at a constant speed, the shape of its path is

A. a circle.
B. an ellipse.
C. an oval that is almost elliptical.
D. a circle with a square corner, as seen throughout your book.

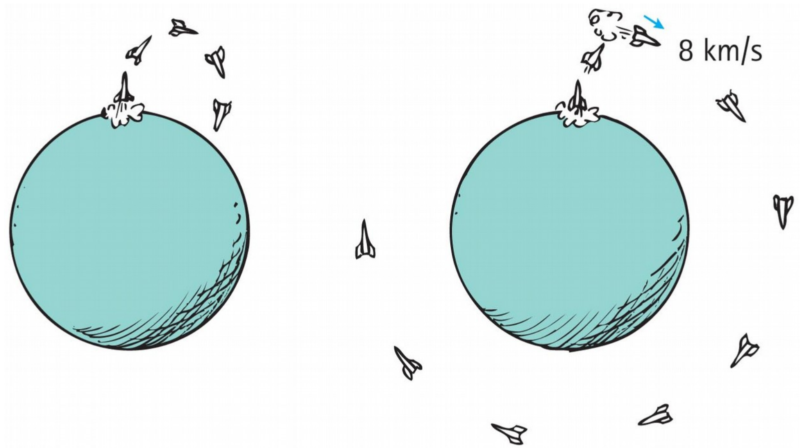
Circular Satellite Orbits
CHECK YOUR ANSWER, Continued

When a satellite travels at a constant speed, the shape of its path is

A. **a circle.**

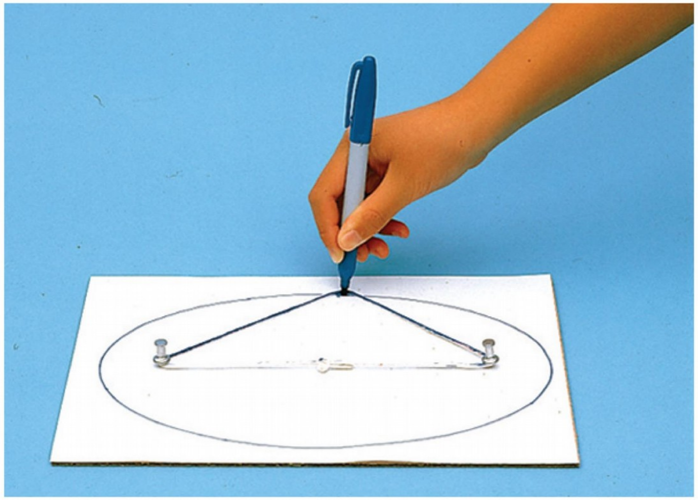
Circular Satellite Orbits, Continued-4

- A payload into orbit requires control over
- direction of rocket.
  - Initially, rocket is fired vertically, then tipped.
  - Once above the atmosphere, the rocket is aimed horizontally.
- speed of rocket
  - Payload is given a final thrust to orbital speed of 8 km/s to fall around Earth and become an Earth satellite.



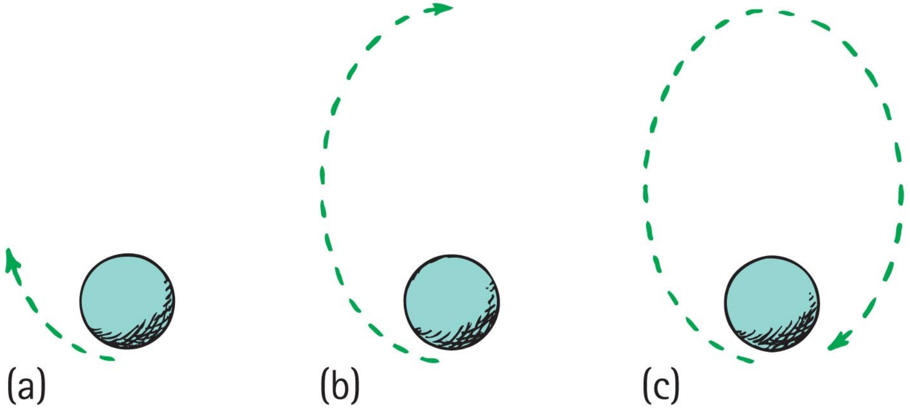
Elliptical Orbits

- A projectile just above the atmosphere will follow an elliptical path if given a horizontal speed greater than 8 km/s.
- Ellipse
  - specific curve, an oval path
    - Example: A circle is a special case of an ellipse when its two foci coincide.



Elliptical Orbits, Continued

- Elliptical orbit
- Speed of satellite varies.
  - Initially, if speed is greater than needed for circular orbit, satellite overshoots a circular path and moves away from Earth.
  - Satellite loses speed and then regains it as it falls back toward Earth.
  - It rejoins its original path with the same speed it had initially.
  - Procedure is repeated.



Elliptical Orbits
CHECK YOUR NEIGHBOR

The speed of a satellite in an elliptical orbit

A. varies.
B. remains constant.
C. acts at right angles to its motion.
D. All of the above.

Elliptical Orbits
CHECK YOUR ANSWER

The speed of a satellite in an elliptical orbit

A. varies.

Comment :

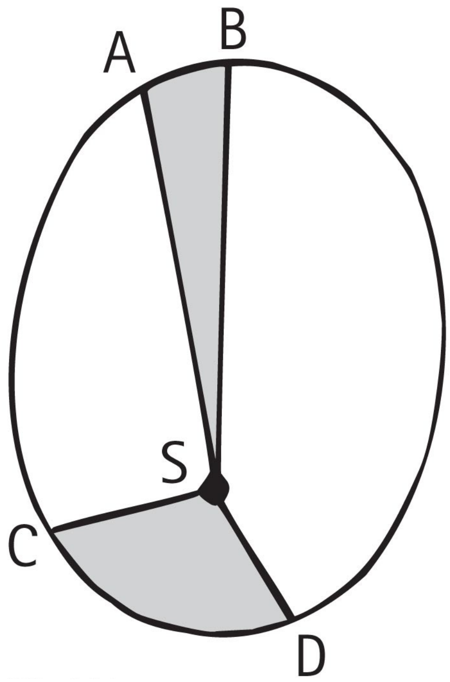
A satellite in an elliptical orbit half the time recedes from Earth and loses speed and half the time approaches Earth and gains speed.

Kepler's Laws of Planetary Motion

- Kepler was assistant to the famous astronomer Brahe, who directed the world's first observatory.
- He used data his mentor Brahe had collected on planetary motion to figure out the motion of planets.
- He found that the motion of planets was not circular; rather, it was elliptical.

Kepler's Laws of Planetary Motion, Continued

- 1st Law: The path of each planet around the Sun is an ellipse with the Sun at one focus.
- 2nd Law: The line from the Sun to any planet sweeps out equal areas of space in equal time intervals.
- 3rd Law: The square of the orbital period of a planet is directly proportional to the cube of the average distance of the planet from the Sun (for all planets).

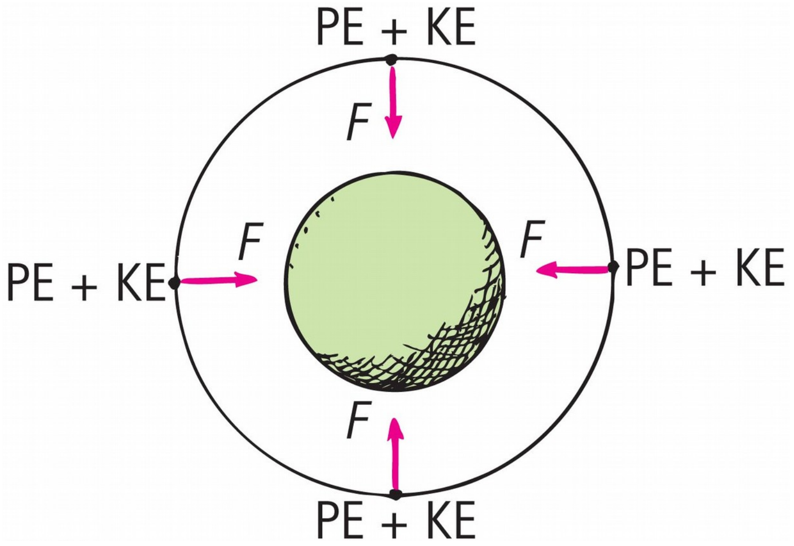


Energy Conservation and Satellite Motion

- Recall the following:
  - Object in motion possesses KE due to its motion.
  - Object above Earth's surface possesses PE by virtue of its position.
  - Satellite in orbit possesses KE and PE.
    - Sum of KE and PE is constant at all points in the orbit.

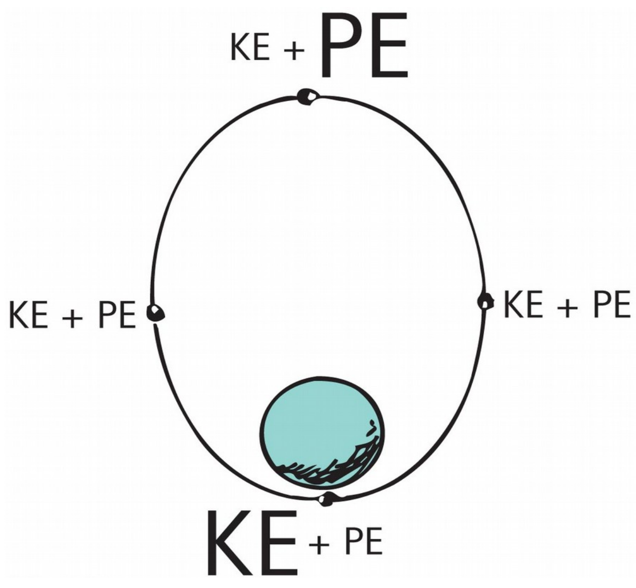
Energy Conservation and Satellite Motion, Continued

- PE, KE, and speed in circular orbit:
  - Unchanged.
  - distance between the satellite and center of the attracting body does not change—PE is the same everywhere.
  - no component of force acts along the direction of motion—no change in speed and KE.



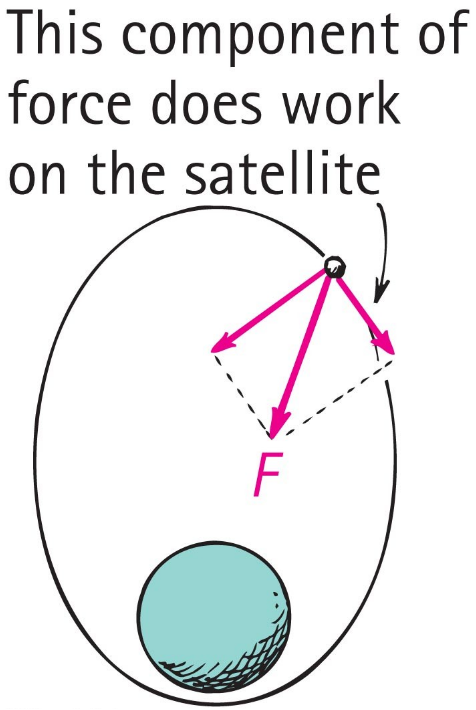
Energy Conservation and Satellite Motion, Continued-1

- Elliptical Orbit Varies.
  - PE is greatest when the satellite is farthest away (apogee).
  - PE is least when the satellite is closest (perigee).
  - KE is least when PE is the most and vice versa.
  - At every point in the orbit, sum of KE and PE is the same.



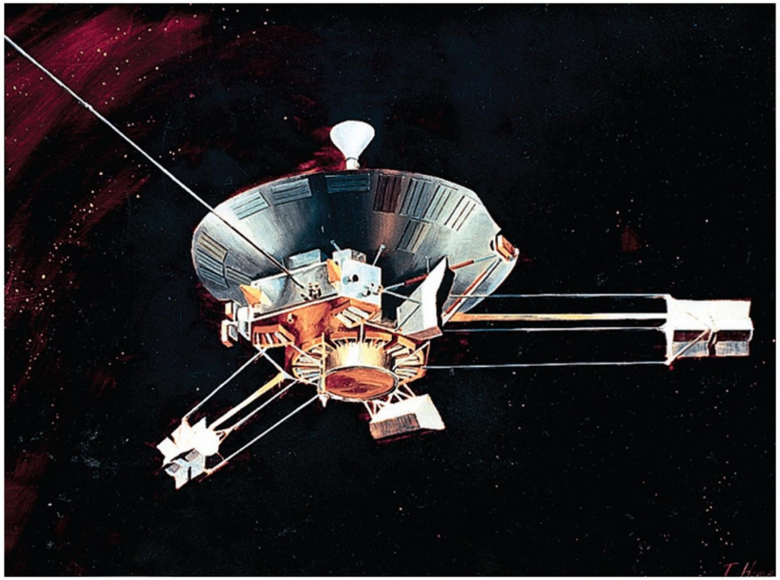
Energy Conservation and Satellite Motion, Continued-2

- When satellite gains altitude and moves against gravitational force, its speed and KE decrease and decrease continues to the apogee.
- Past the apogee, satellite moves in the same direction as the force component and speed and KE increase. Increase continues until past the perigee and cycle repeats.



Escape Speed

- First probe to escape the solar system was *Pioneer 10*, launched from Earth in 1972.
  - Accomplished by directing the probe into the path of oncoming Jupiter



Escape Speed
CHECK YOUR NEIGHBOR

When a projectile achieves escape speed from Earth, it

A. forever leaves Earth's gravitational field.
B. outruns the influence of Earth's gravity, but is never beyond it.
C. comes to an eventual stop, returning to Earth at some future time.
D. All of the above.

Escape Speed
CHECK YOUR ANSWER

When a projectile achieves escape speed from Earth, it

B. **outruns the influence of Earth's gravity, but is never beyond it.**

Escape Speed, Continued

- Voyages to the Moon, Mars, and beyond begin with launches that exceed escape speed from Earth.