Gravity, Projectiles & Orbits

(Chapter 4)

Student Learning Outcomes: Compare and contrast descriptions for gravity; describe how gravity applies to objects in the universe; name sources of centripetal force; analyze projectile, circular and orbital motion.

1. *What is Newton's description of gravity?*
2. *What causes the perception of weightlessness?*
3. *What is Einstein's description of gravity?*
4. *What are the affects of gravity?*
5. *Why does a projectile have a parabolic trajectory?*
6. *How are circular and elliptical orbits achieved?*

What is Newton's description of gravity?

- **Newton's Universal Law of Gravitation**

  Every object with mass attracts every other object with mass, with a force that depends directly on the masses of the two objects and decreases with the distance squared.

$$\mathbf{F = \frac{GMm}{d^2}}$$

- The gravitational force is a mutual force of attraction, which means **both masses pull the same** amount on each other!

- This is the force that causes the acceleration due to gravity, **g = 9.81 m/s^2**.

- The inverse square of distance causes the gravitational force to decrease rapidly with distance.

Go To: http://hyperphysics.phy-astr.gsu.edu/hbase/forces/isq.html

Questions:

1. Would the acceleration due to gravity (9.81 m/s^2) be different for an object dropped from a high mountain top?

2. If Earth had twice as much mass, would this change everyone's weight? Would it change anyone's mass?

3. What is the gravitational attraction between Earth and a 75 kg person standing on the surface, at sea level ($M_E = 6 \times 10^{24}$ kg, $r_E = 6.4 \times 10^6$ m)? What do we normally call this?

4. How would the gravitational force change if the distance doubled?

What causes the perception of weightlessness?

- **The feeling of weightlessness occurs when an object and its reference frame accelerate at the same rate.**

- If there is no support force, then objects will fall together.

Examples:

- Airplane drops
- Large, rolling "bump" in the road
- Freefall ride
- Space shuttle

Questions:

1. Is the gravitational force zero somewhere? Are astronauts weightless when they are in space?

2. If you were standing on a scale in the elevator that measured your weight, how would the scale reading change as the elevator

a. accelerates up
b. accelerates down
c. free falls

What is Einstein's description of Gravity?

- **Every object with mass creates a curvature of space-time.**

- According to Einstein, mass does not create a force, but rather a warping of space which other objects follow.

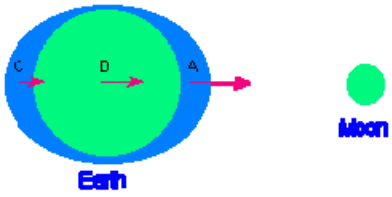
More Mass = More Curvature

- The curvature of space causes time to slow down.
- Objects fall independent of their mass because they all follow the same path in curved space-time.

Go To: http://www.youtube.com/watch?v=LoaOHvy5AcA

What are the affects of gravity?

- Objects move in a straight line unless there is an unbalanced force to change motion. (Newton's 1st Law)
- **Gravity is the unbalanced force that keeps astronomical objects in orbit.**
- **Gravity causes Earth's ocean tides.**
  - The gravitational pull of the Moon has the strongest affect on Earth's oceans.
  - Two bulges are created because the Moon has a different amount of gravitational pull on the "front" and "back" sides of Earth.



http://csep10.phys.utk.edu/astr161/lect/time/tides.html

  - As we spin into and out of regions where the resultant forces occur, we see high and low tides.
- The Sun's gravity also has an effect on Earth's oceans, causing *spring* and *neap* tides.

Go To: http://home.hiwaay.net/~krcool/Astro/moon/moontides/
http://www.youtube.com/watch?v=l37ofe9haMU&feature=related

Questions:

1. Why do the times for high and low tide change each day?

2. Why are the Sun's tidal affects weak as compared to the Moon?

- **Our Earth-Moon system is changed by gravitational affects.**
  - Earth's rotation is slowing (0.0015 seconds/century)
  - Our Moon is drifting away (3.8 cm/year)
  - The synchronous orbit of the Moon (same face)

- **Gravity affects many systems in the universe.**
  - Galaxies are held together by gravity.
  - Astronomical objects of sufficient mass are spherical.
  - Material is pulled together to form stars and planets
  - Locate exoplanets
  - Atmospheres

Why does a projectile have a parabolic trajectory?

- The addition of the horizontal velocity and the downward acceleration vectors yield a curved path, a parabola.

- **A projectiles motion in x does <u>not</u> affect its motion in y!**
  - Velocity in x is constant if there is no air resistance. *Why?*
  - Velocity in y changes. *Why?*

Go To: http://www.physicsclassroom.com/mmedia/vectors/hlp.cfm
http://www.physicsclassroom.com/mmedia/vectors/pap.cfm

- A projectile falls a vertical distance from the straight-line path it would follow in the absence of gravity, each second it is in flight.

$$\mathbf{y = 1/2gt^2}$$

- The range of a projectile depends on its horizontal velocity.

$$\boxed{x = vt}$$

- Projectiles launched at an angle are given a horizontal and vertical velocity.
  - The horizontal component of the velocity remains constant.
  - The vertical component of the velocity changes.
  - Objects launched at a 45^{o} angle travel farthest.

Go To :
http://galileoandeinstein.physics.virginia.edu/more_stuff/Applets/ProjectileMotion/jarapplet.html

Questions: A player throws a baseball parallel to the ground. This gives the baseball a horizontal velocity of 90 mph (40 m/s). Assume no air resistance.

a. What is the direction of the acceleration?

b. Does the horizontal speed change?

c. Does the vertical speed change?

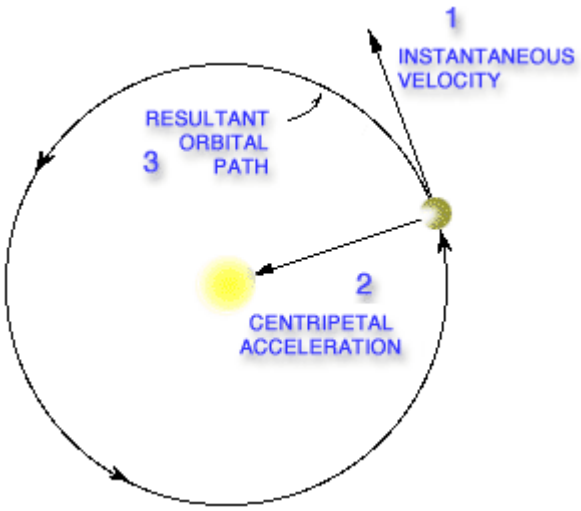
d. What is the horizontal speed the instant before the ball hits the ground?

e. If there was no gravity, what would be the path of the ball? Why?

f. How far will the ball travel if released from a height of 1.5 meters above the ground?

How are circular and elliptical orbits achieved?

- Objects move in a straight line unless there is an unbalanced force to change motion.
- In circular motion, a **centripetal force** ("center-seeking" force) causes a constant change in motion, a constant change in direction.
- **An object moving in a circular path must have a net force (and acceleration) toward the center of the circle.**



http://www2.jpl.nasa.gov/basics/bsf3-3.php

Go To: http://www.physicsclassroom.com/mmedia/circmot/ucm.cfm

Questions:

1. If the force keeping an object in a circular orbit is removed, what will the orbiting object do?

2. What are some examples of centripetal forces?

- The minimum velocity to maintain a circular orbit around Earth is **8 km/s.**
- Objects in orbit around the Earth, are falling at a constant rate around the Earth.
- The actual shape of the orbit depends on the **escape velocity**.

V_e(Earth) = **11.2 km/s** (25,059 mph)

Go To: http://www.physicsclassroom.com/mmedia/vectors/sat.cfm
http://www.youtube.com/watch?v=-sjWe9Aj_Wo

- Escape velocity is the minimum velocity an object must have in order to escape gravity, to achieve orbit and not fall back to the surface.

- Escape velocity depends on the <u>mass of the gravity source</u>, and on the <u>distance</u> to be achieved.

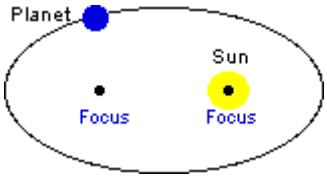
$$V_{esc} = \sqrt{\frac{2GM}{d}}$$

- **Escape velocity does <u>not</u> depend on mass of the object sent into orbit.**

- A projectile with a velocity greater than the minimum required for a circular orbit will end up in an elliptical orbit. ("sling-shot" effect)

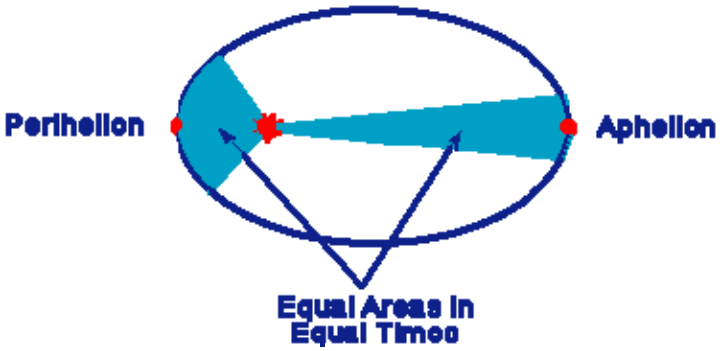
- **Elliptical orbits are maintained by conservation of energy.**

- Planets move in elliptical orbits with the Sun at one focus of the ellipse.



http://www.enchantedlearning.com/subjects/astronomy/glossary/indexk.shtml

- Planets move most rapidly when they are at **perihelion** and most slowly when they are at **aphelion**.



http://csep10.phys.utk.edu/astr161/lect/history/kepler.html

Go To: http://science.nasa.gov/science-news/science-at-nasa/2001/ast04jan_1/

- The orbital periods of the planets depend on the semi-major axis of the orbit.

$$\boxed{P^2 = a^3}$$

P = Period in Earth Years
a = Semi-major axis in AU

Go To: http://www.exploratorium.edu/ronh/age/