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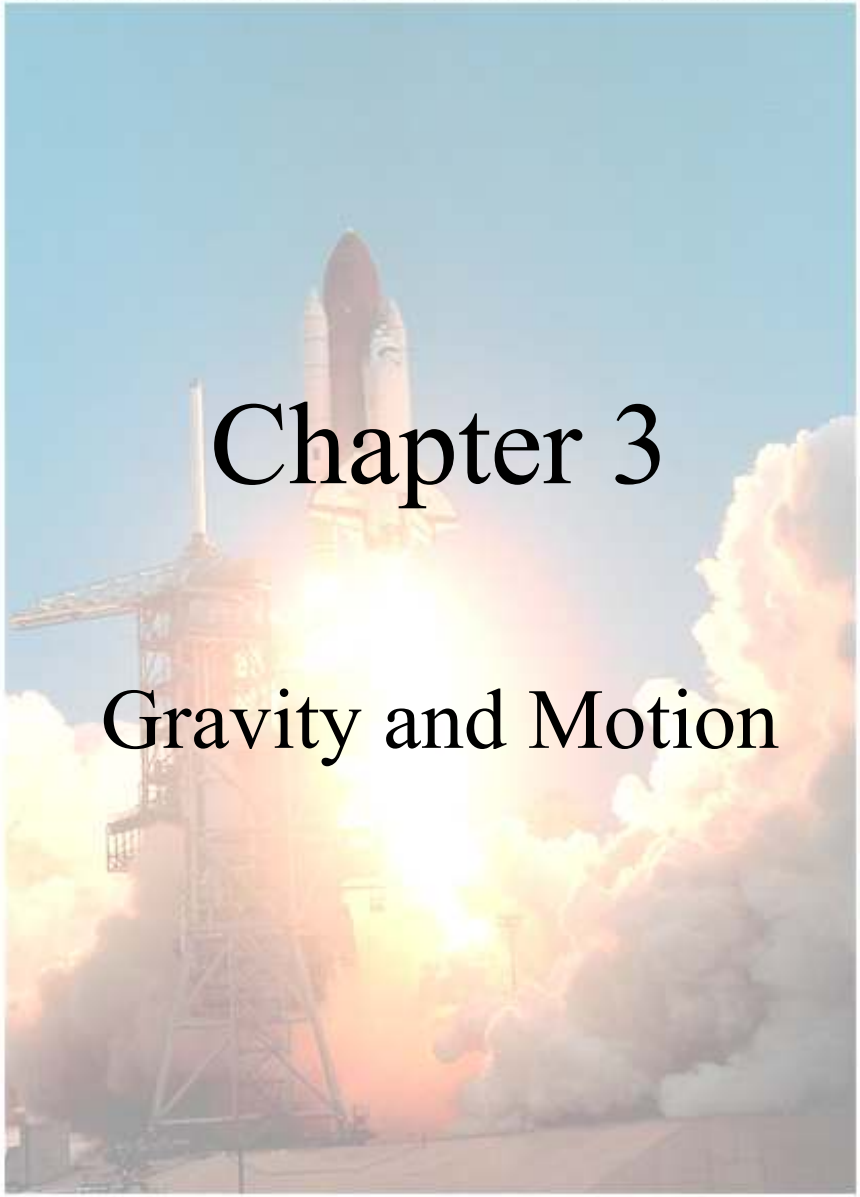

# Chapter 3

## Gravity and Motion

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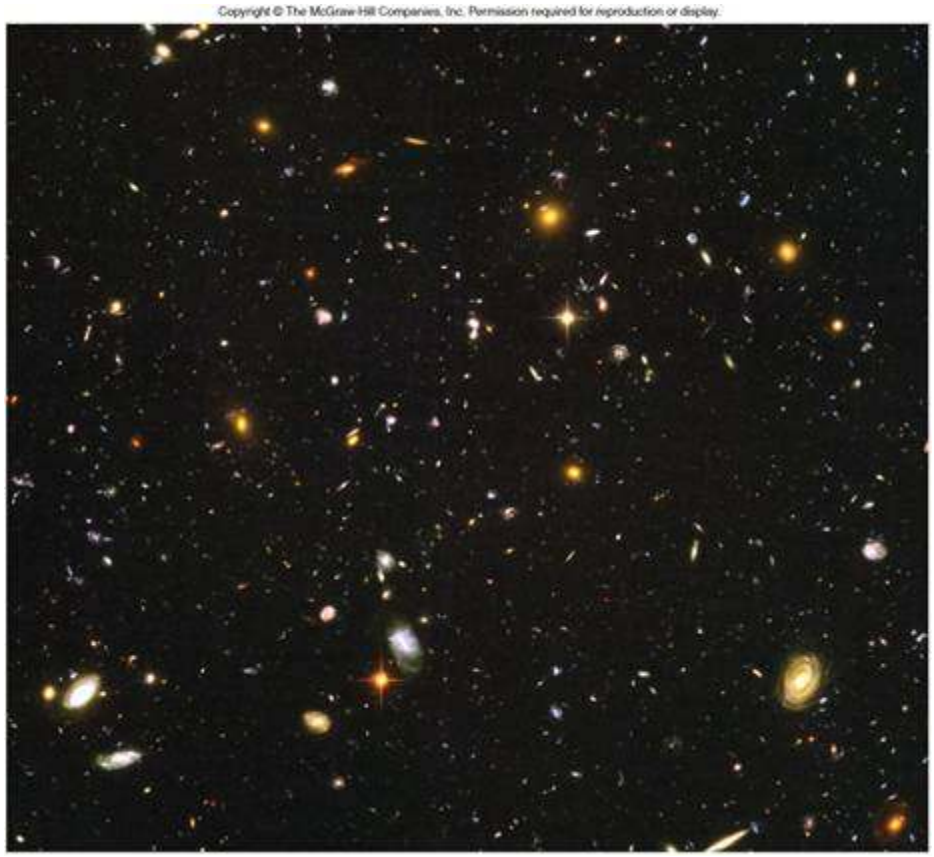
# Gravity

- Gravity gives the Universe its structure
  - It is a universal force that causes all objects to pull on all other objects everywhere
  - It holds objects together
  - It is responsible for holding the Earth in its orbit around the Sun, the Sun in its orbit around the Milky Way, and the Milky Way in its path within the Local Group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# The Problem of Astronomical Motion

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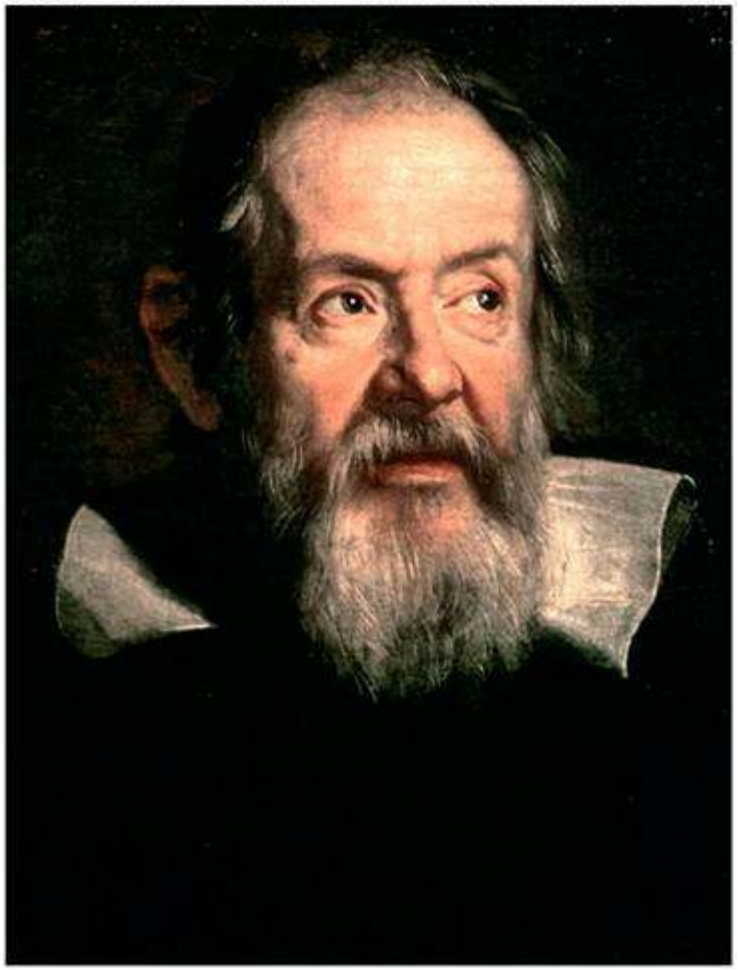


- Astronomers of antiquity did not connect gravity and astronomical motion
- Galileo investigated this connection with experiments using projectiles and balls rolling down planks
- He put science on a course to determine laws of motion and to develop the scientific method
- http://youtu.be/_Kv-U5tjNCY
- http://youtu.be/AYz_K3mwq6A
- http://youtu.be/KDp1tiUsZw8

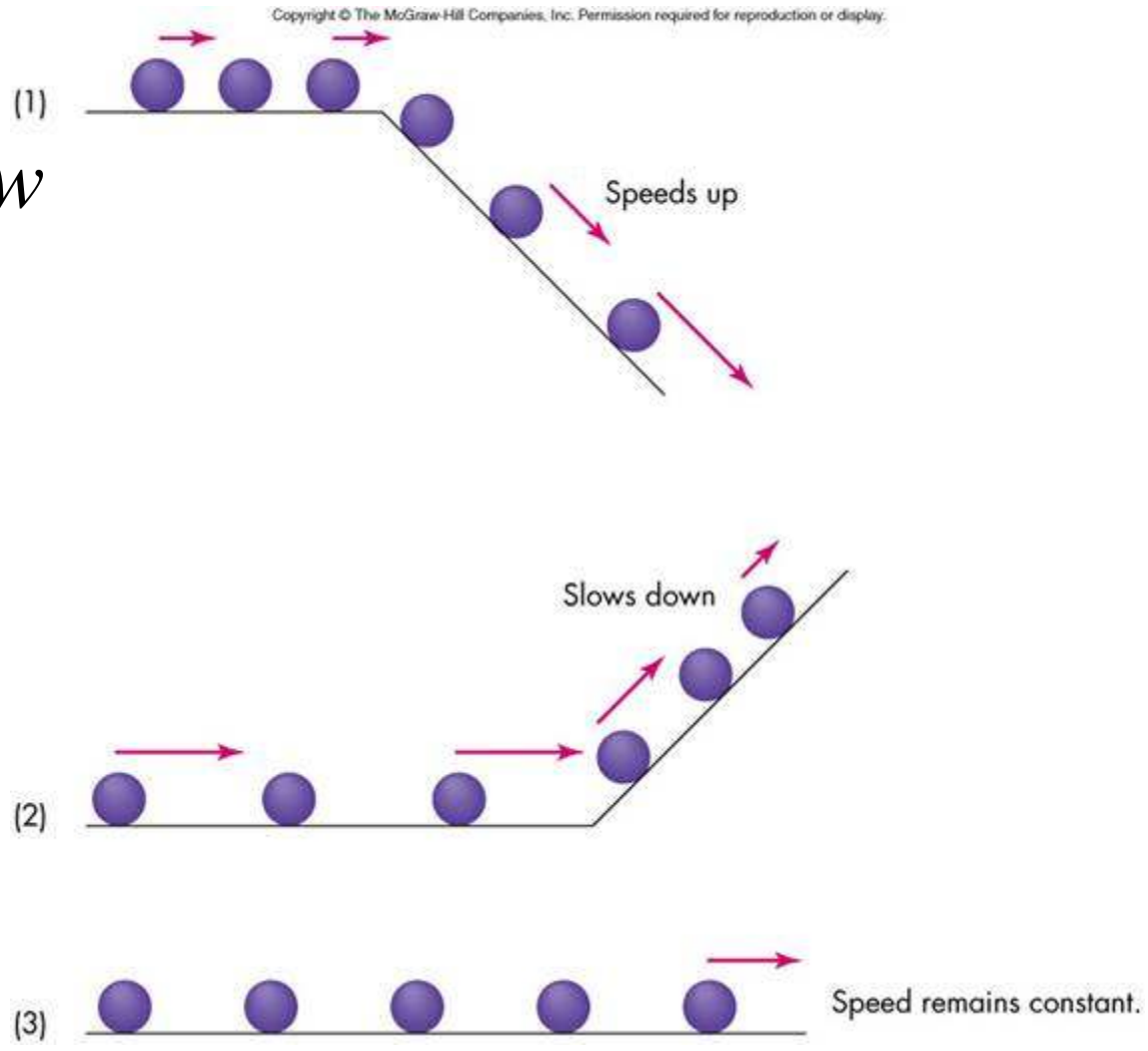
# Inertia

- Galileo established the idea of *inertia*
  - A body at rest tends to remain at rest
  - A body in motion tends to remain in motion
  - Through experiments with inclined planes, Galileo demonstrated the idea of inertia and the importance of forces (friction)
  - Famous tablecloth experiment
    - http://youtu.be/a0ki4dodKyY
  - Newton's Laws (http://youtu.be/NYVMlmL0BPQ)

# Inertia and Newton's First Law

- This concept was incorporated in *Newton's First Law of Motion:*

A body continues in a state of rest or uniform motion in a straight line unless made to change that state by forces acting on it



# Newton's First Law

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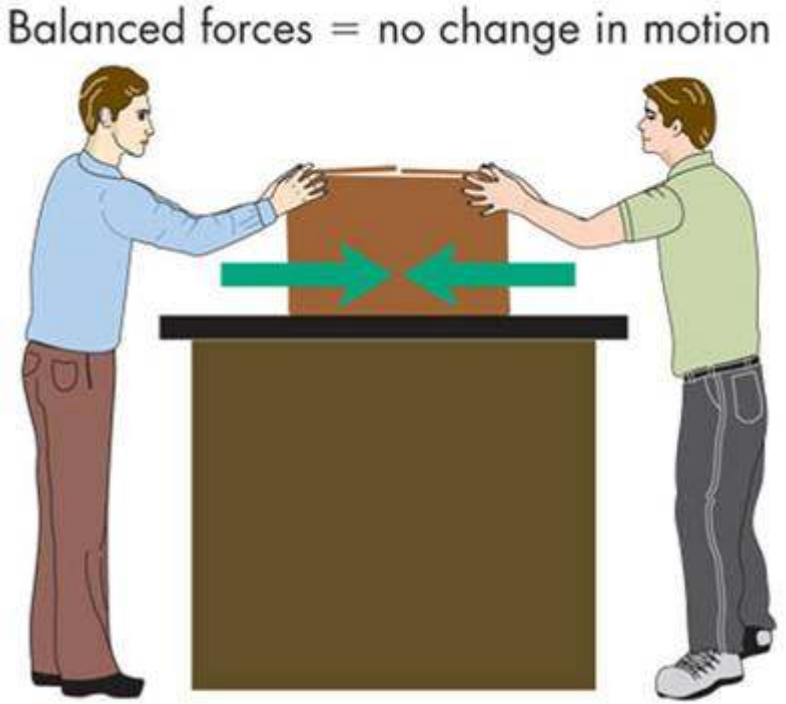


- Important ideas of Newton's First Law
  - Force: A push or a pull
  - The force referred to is a net force
  - The law implies that if an object is not moving with constant velocity, then a nonzero net force must be present

# Astronomical Motion

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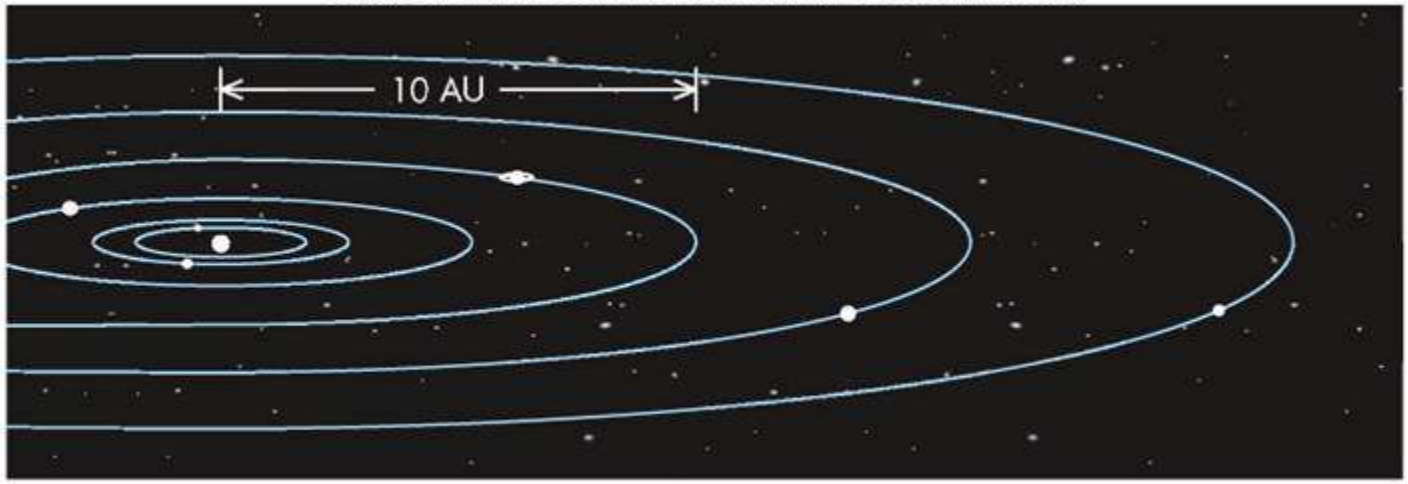


B

- As seen earlier, planets move along curved (elliptical) paths, or orbits.
- Speed and direction is changing

- Must there be a force at work?
- Yes!

# Gravity is that force!

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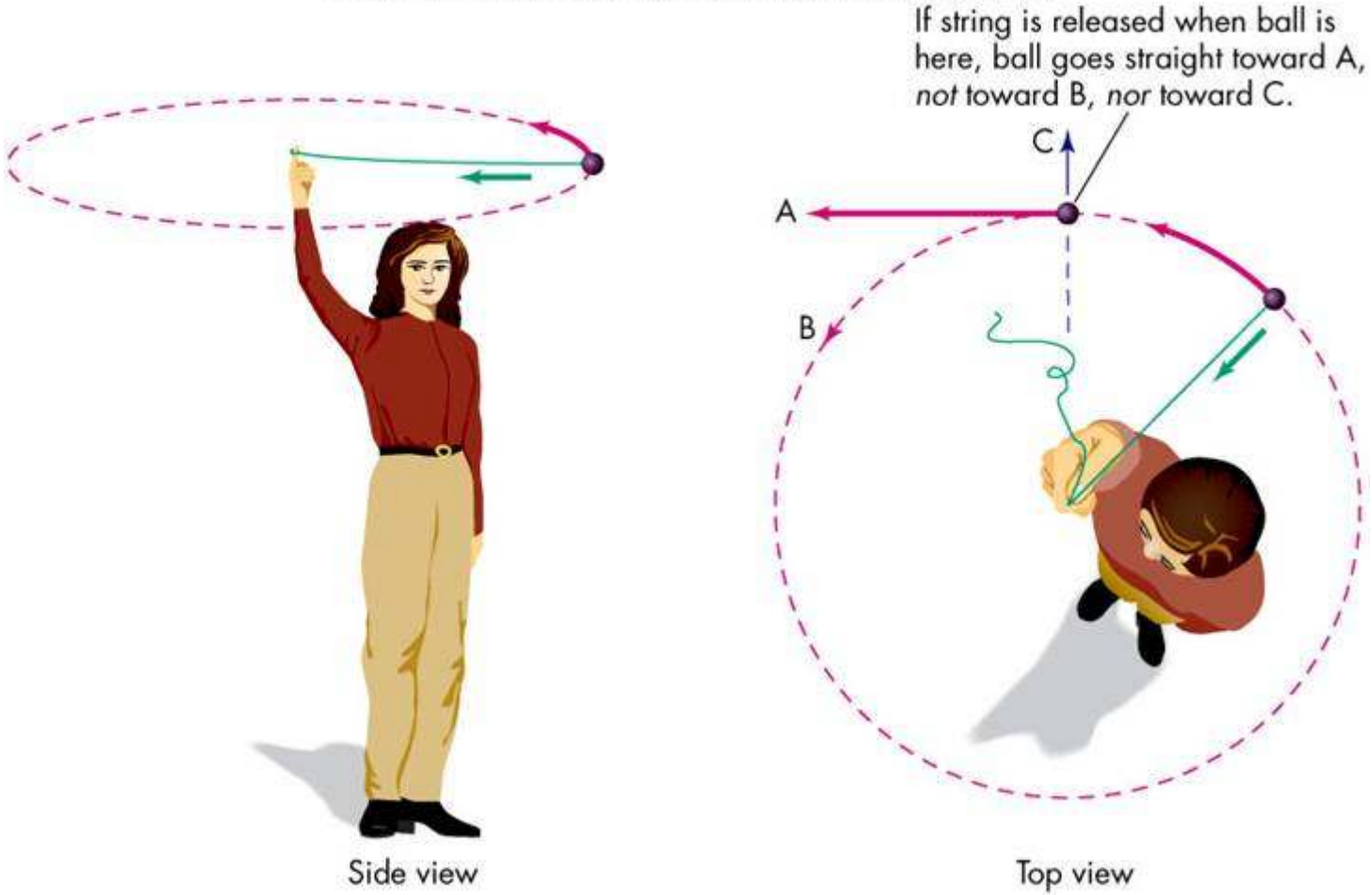
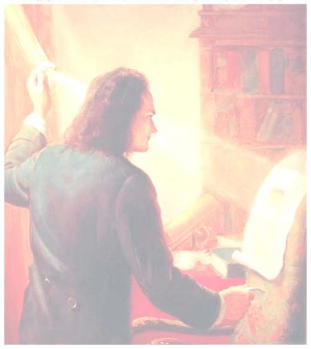


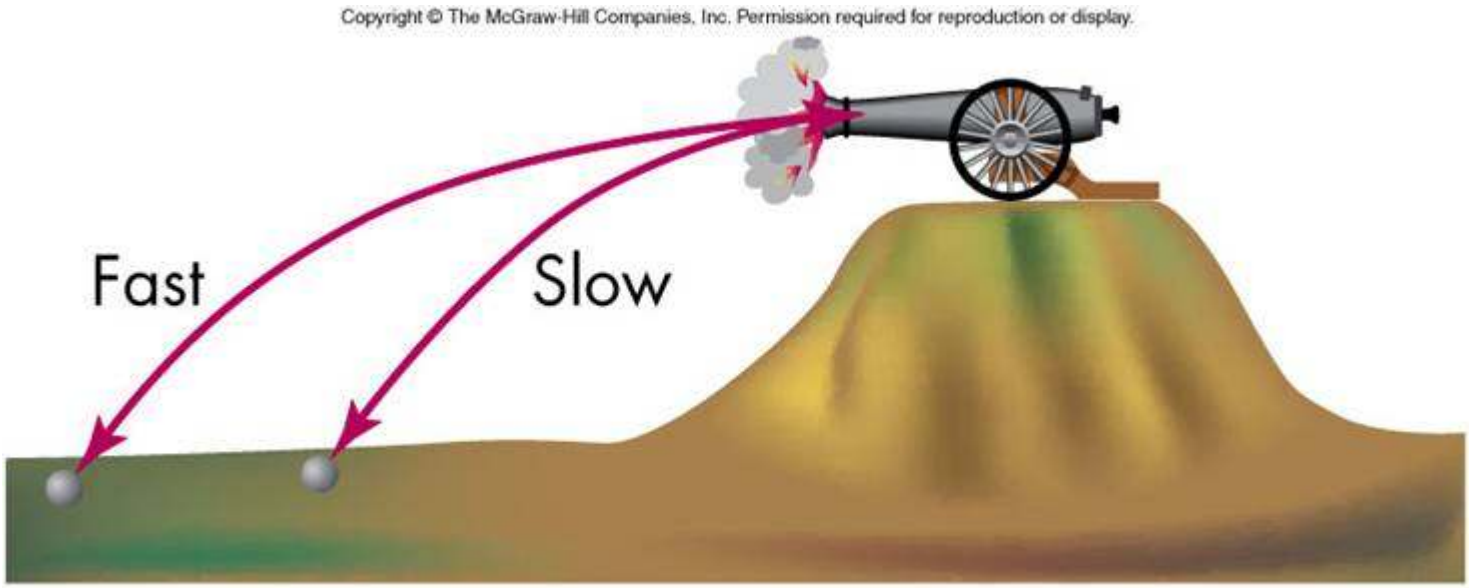
# Orbital Motion and Gravity

- Although not the first to propose gravity as being responsible for celestial motion, Newton was the first to:
  - Spell out the properties of gravity
  - Write the equations of gravity-induced motion



- Newton deduced that:
  - The Moon's motion could be explained by the existence of a force (to deviate the Moon from a straight inertial trajectory) and that such a force decreased with distance
  - Orbital motion could be understood as a projectile moving "parallel" to the Earth's surface at such a speed that its gravitational deflection toward the surface is offset by the surface's curvature away from the projectile

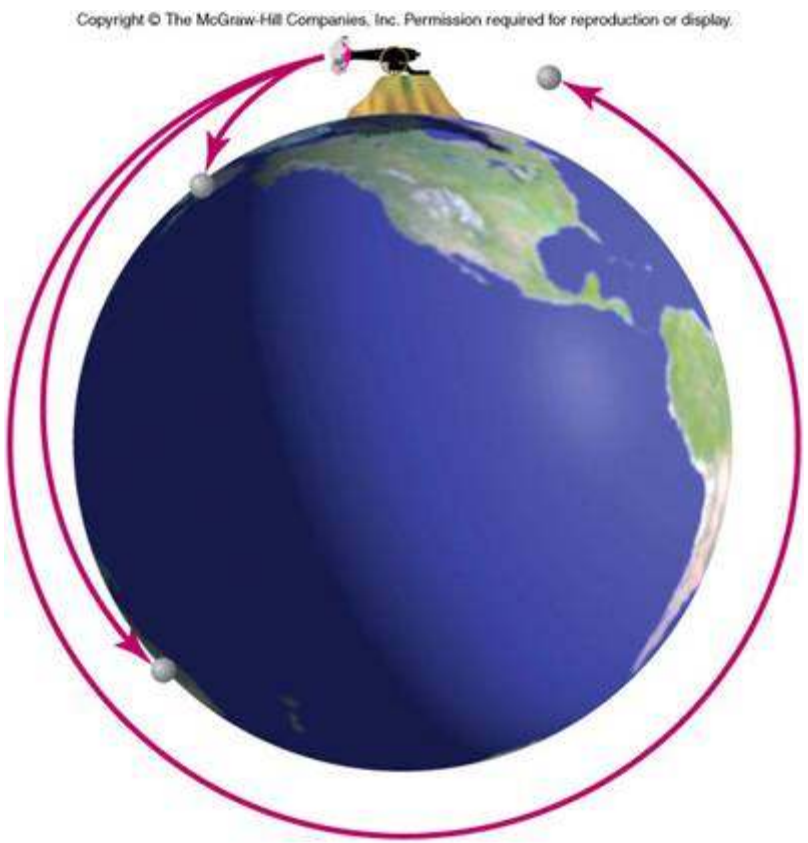
# Orbital Motion Using Newton's First Law




- A cannonball fired at slow speed experiences one force – gravity, pulling it downward
- A cannonball fired at a higher speed feels the same force, but goes farther

# Orbital Motion Using Newton's First Law

- At a sufficiently high speed, the cannonball travels so far that the ground curves out from under it.
- The cannonball literally misses the ground!
- The ball, now in orbit, still experiences the pull of gravity!



# Newton's Second Law: Motion
## (Motion, Acceleration, Mass)

- Motion
  - An object is said to be in uniform motion if its speed and direction remain unchanged
  - An object in uniform motion is said to have a constant velocity
  - A force will cause an object to have non-uniform motion, a changing velocity
  - *Acceleration* is defined as a change in velocity

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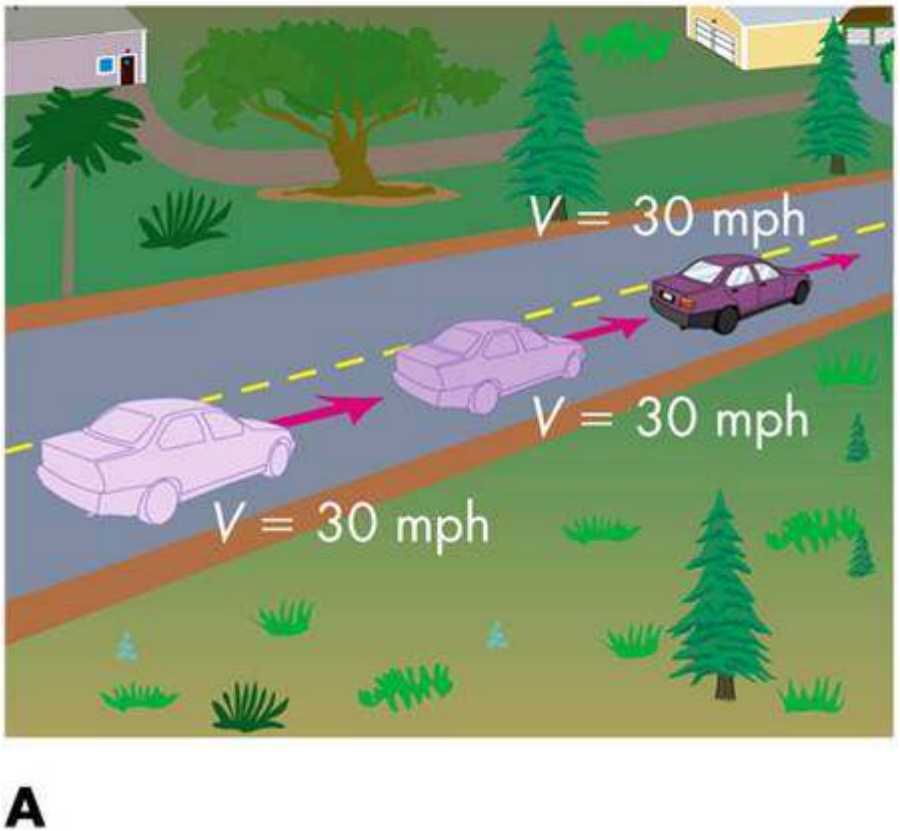
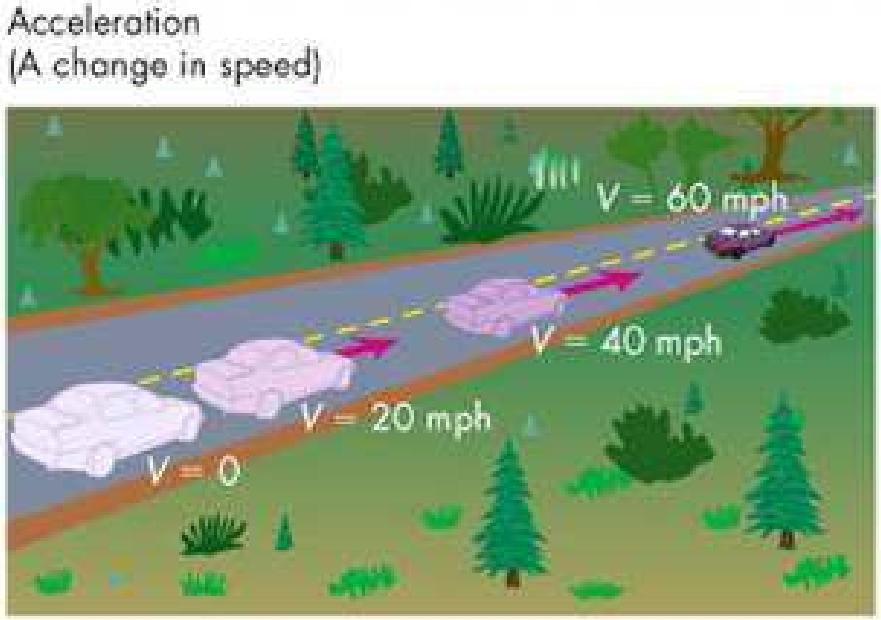
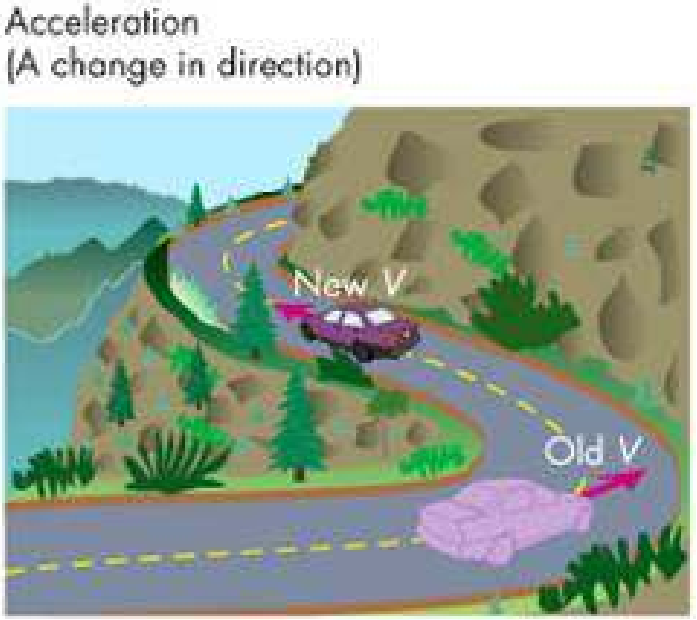


# Newton's 2nd Law: Acceleration




- Acceleration
  - An object increasing or decreasing in speed along a straight line is accelerating
  - An object with constant speed moving is a circle is accelerating
  - Acceleration is produced by a force and experiments show the two are proportional

# Newton's Second Law: Mass

- Mass
  - Mass is the amount of matter an object contains
  - Technically, *mass* is a measure of an object's inertia
  - Mass is generally measured in kilograms
  - Mass should not be confused with weight, which is a force related to gravity – weight may change from place to place, but mass does not

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# Newton's Second Law of Motion

$$F = ma$$

- Equivalently, the amount of acceleration (a) that an object undergoes is proportional to the force applied (F) and inversely proportional to the mass (m) of the object
  - This equation applies for any force, gravitational or otherwise

# F = ma

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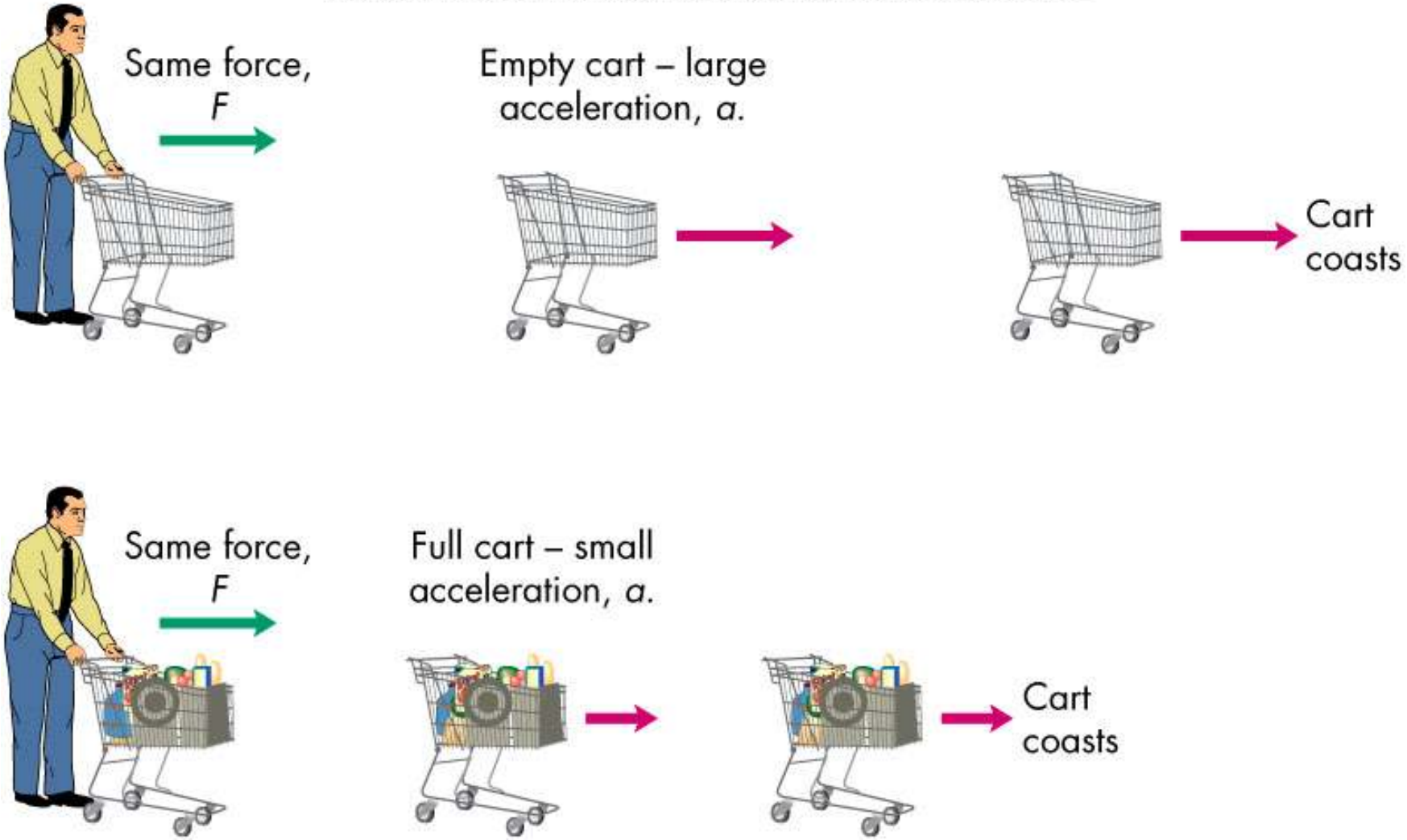

# Newton's Law of Universal Gravity

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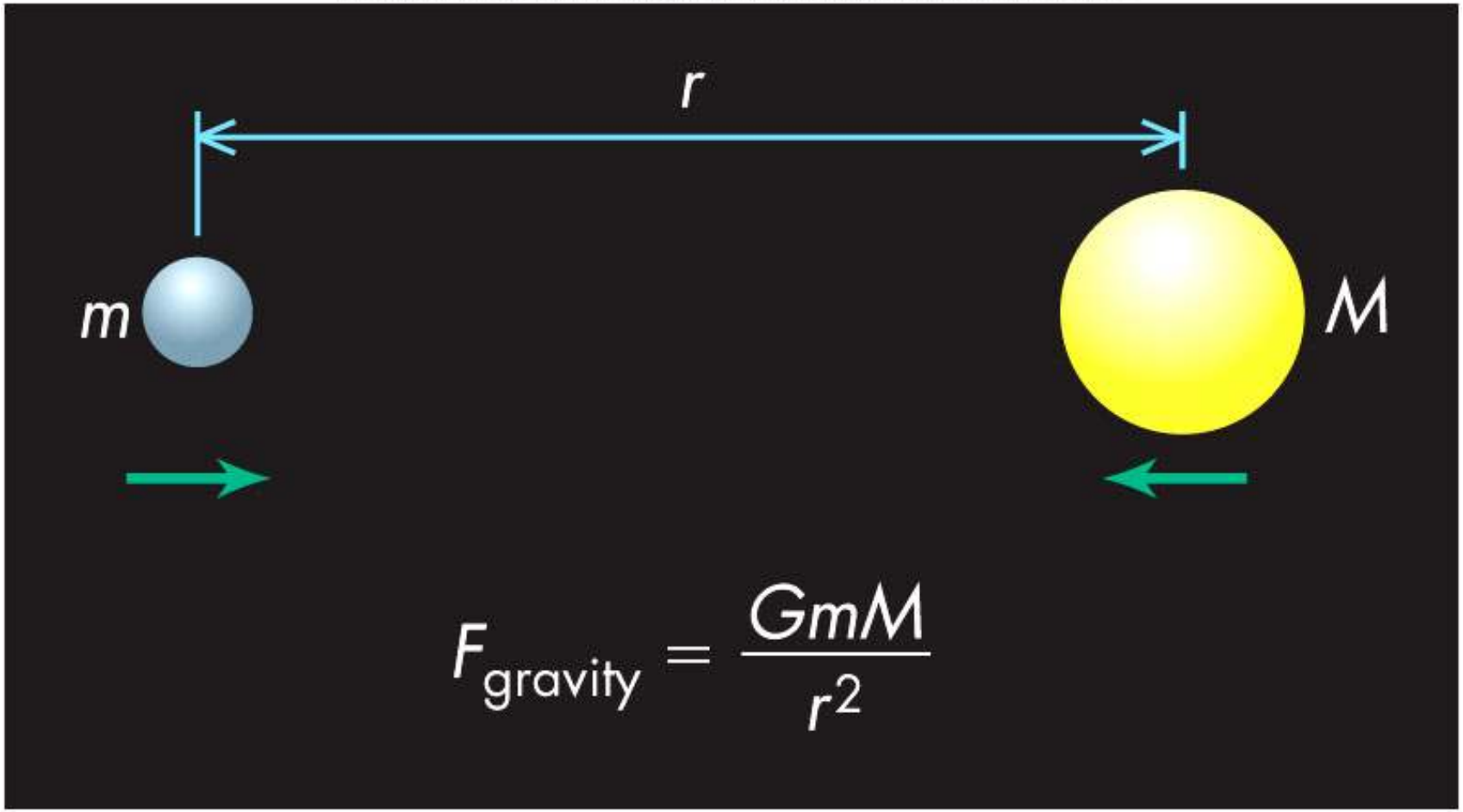


- Everything attracts everything else!!
  - http://youtu.be/Jk5E-CrE1zg

# Newton's Third Law of Motion

- When two objects interact, they create equal and opposite forces on each other
- This is true for any two objects, including the Sun and the Earth!

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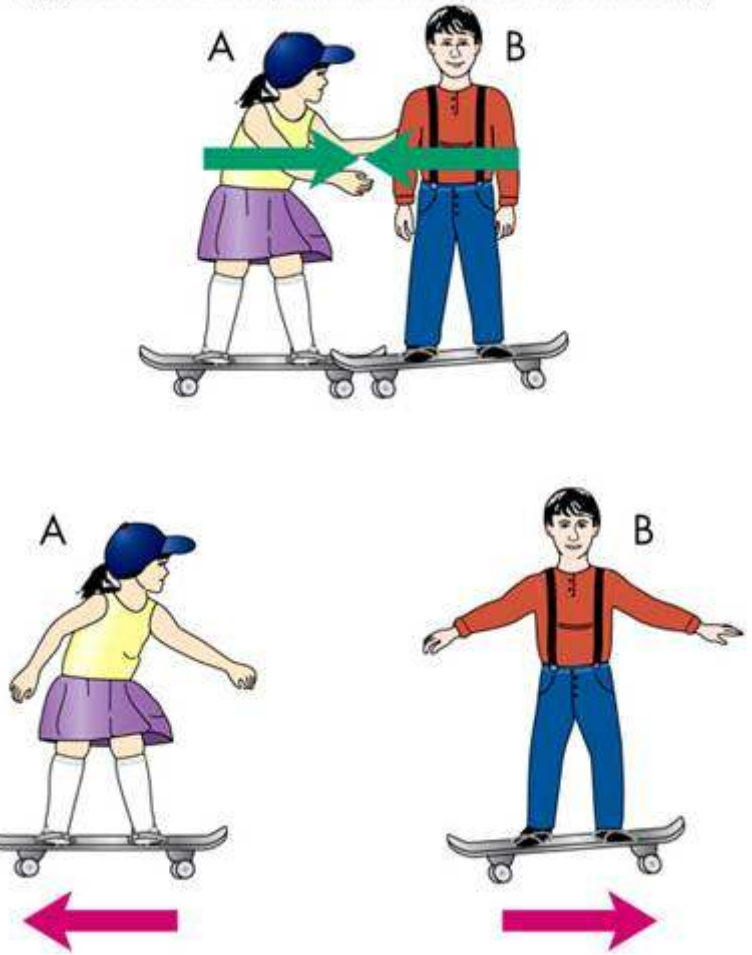

# Measuring an Object's Mass Using Orbital Motion

- Basic Setup of an Orbital Motion Problem
  - Assume a small mass object orbits around a much more massive object.
  - Massive object can be assumed at rest (very little acceleration)
  - Assume orbit shape of small mass is a circle centered on large mass. This equation is Newton's modified version of Kepler's Third Law:

$$\mathbf{M1 + M2 = A3 / P2}$$

    - Where M1 is the mass of the first object.
    - Where M2 is the mass of the second object.
    - A is the distance between the two objects.
    - P is the orbital period of the object whose mass is unknown.
- We will use this equation to calculate the mass of the moon!!!

# Escape Velocity

- To overcome a celestial object's gravitational force and escape into space, a mass must obtain a critical speed called the *escape velocity*
- Escape velocity:
  - Determines if a spacecraft can move from one planet to another
  - Influences whether or not a celestial object has an atmosphere
  - Relates to the nature of black holes

# Escape Velocity

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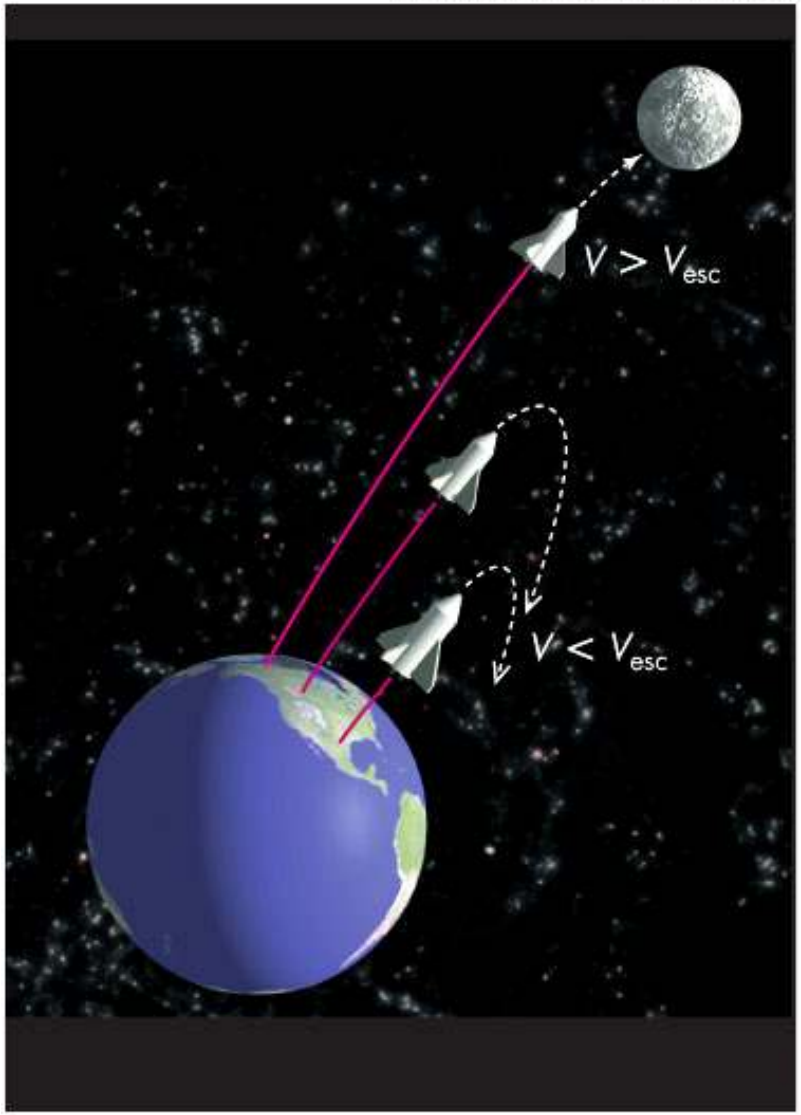


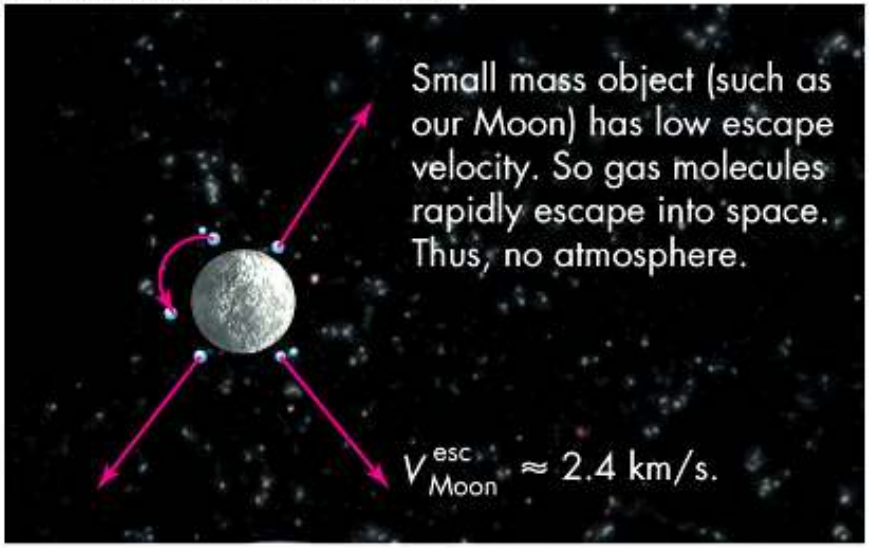


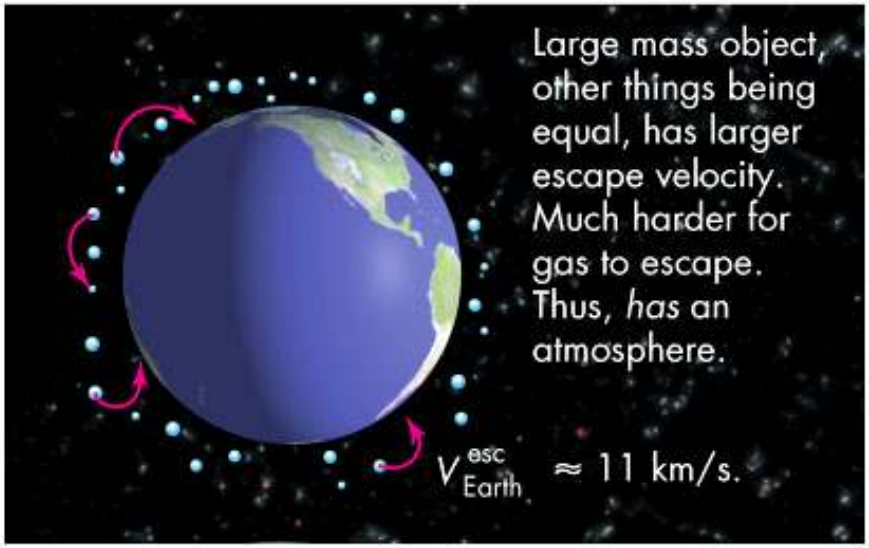

# Escape Velocity Calculation

- The escape velocity, $V_{esc}$, is determined from Newton's laws of motion and the Law of Gravity and is given by:

$$V_{esc} = (2GM/R)^{1/2}$$

  where M and R are the mass and radius of the celestial object from which the mass wishes to escape

- Notice dependence of $V_{esc}$ on M and R, but not m
- $V_{esc,Earth}$ = 11 km/s, $V_{esc,Moon}$ = 2.4 km/s
- Escape Velocity Handout!

# Escape Velocity

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