Please turn on your clickers
• HW #1, due 1 week from today
• Quiz in class Wednesday
• Sections meet in Planetarium
• Honors meeting tonight in my office
  • Sterling 5520 at 5:30-6pm
Newton’s First Law

• An object in uniform motion will stay in motion, an object at rest will stay at rest.
• No change in velocity = no forces acting on it, or the forces cancel each other out.
Newton’s Second Law

- The force \( F \) acting on an object equals the product of its acceleration \( a \) and its mass \( m \): \[ F = m \times a \]

Small mass = BIG acceleration

Bigger mass = smaller acceleration
Newton’s Second Law

- The force ($F$) acting on an object equals the product of its acceleration ($a$) and its mass ($m$)
  - $F = m \times a$
- We can rearrange this to be:
  - $a = \frac{F}{m}$
- For an object with a large mass, the acceleration will be small for a given force
- If the mass is small, the same force will result in a larger acceleration!
- Though simple, this expression can be used to calculate everything from how hard to hit the brakes to how much fuel is needed to go to the Moon!
Newton’s Third Law

- When two bodies interact, they create equal and opposite forces on each other.
Newton’s Third Law

- When two bodies interact, they create equal and opposite forces on each other.
Circular Motion

- Where’s the force?
  - It’s the tension in the string that is changing the ball’s velocity
  - If the string breaks, the ball will move off in a straight line (while falling to the ground)
- Newton determined that this force called *Centripetal Force* can be described by the above equation:

\[ F_C = \frac{m \times V^2}{d} \]
Conservation of Angular Momentum

Since angular momentum is conserved, if either the mass, size or speed of a spinning object changes, the other values must change to maintain the same value of momentum.

- As a spinning figure skater pulls her arms inward, she changes her value of \( r \) in angular momentum.
  
- Mass cannot increase, so her rotational speed must increase to maintain a constant angular momentum.

- Works for stars, planets orbiting the Sun, and satellites orbiting the Earth, too!
4 Fundamental Forces in Nature

**Strong Force:** very strong, but very short-ranged, responsible for holding the nuclei of atoms together

**Electromagnetic Force:** causes electric and magnetic effects, long-ranged, but much weaker than the strong force

**Weak Force:** radioactive decay and neutrino interactions, very short range and, very weak

**Gravitational force:** weak, but very long ranged
The Tortoise and the Hare: Gravity Always Wins

• The four fundamental forces are all important in making the Universe, but gravitation is most important. This is because of two of its basic properties that set it apart from the other forces:
  1) it is long-ranged and thus can act over cosmological distances,
  2) it always supplies an attractive force between any two pieces of matter in the Universe.

• Although gravitation is extremely weak, it always wins over cosmological distances, thus it is the most important force for the understanding of the large scale structure and evolution of the Universe.
Unit 16

The Universal Law of Gravity
Orbital Motion and Gravity

- Astronauts in orbit around the Earth are said to be in free fall, a weightless state.
  - Are they falling? Yes!
- Imagine a cannon on top of a mountain that fires a cannonball parallel to the ground
- The cannonball leaves the cannon and is pulled toward the ground by gravity
- If the ball leaves the cannon with a slow velocity, it falls to the ground near the mountain
- If the cannonball has a higher velocity, it falls farther from the mountain.
- What if we gave the cannonball a very large velocity, so large that it “misses” the Earth?
- The cannonball would be in orbit around the Earth, and it would be falling!
Newton’s Universal Law of Gravitation

- Every mass exerts a force of attraction on every other mass. The strength of the force is proportional to the product of the masses divided by the square of the distance between them
  - Simply put, everything pulls on everything else
  - Larger masses have a greater pull
  - Objects close together pull more on each other than objects farther apart

\[ F_{\text{Gravity}} = \frac{GmM}{d^2} \]

- This is true everywhere, and for all objects
  - The Sun and the planets exert a gravitational force on each other
  - You exert a gravitational force on other people in the room!
Surface Gravity

- Objects on the Moon weigh less than objects on Earth
- This is because *surface gravity* is less
  - The Moon has less mass than the Earth, so the gravitational force is less
- We let the letter $g$ represent surface gravity, or the acceleration of a body due to gravity
- \[ F = mg \]

- On Earth, $g = 9.8 \text{ m/s}^2$
- $g$ on the Moon is around 1/6 as much as on the Earth!
Newton’s Modification of Kepler’s 3\textsuperscript{rd} Law

• Newton applied his ideas to Kepler’s 3\textsuperscript{rd} Law, and developed a version that works for any two massive bodies, not just the Sun and its planets!

\[ M_A + M_B = \frac{a_{AU}^3}{P_{YR}^2} \]

• Here, \( M_A \) and \( M_B \) are the two object’s masses expressed in units of the Sun’s mass.

• This expression is useful for calculating the mass of binary star systems, and other astronomical phenomena.
Masses from Orbital Speeds

- We know that for planets, the centripetal force that keeps the planets moving on an elliptical path is the gravitational force.
- We can set $F_G$ and $F_C$ equal to each other, and solve for $M$!

$$M = \frac{d \times V^2}{G}$$

- Now, if we know the orbital speed of a small object orbiting a much larger one, and we know the distance between the two objects, we can calculate the larger object’s mass!
If the Sun were suddenly replaced by a solar-mass black hole, the Earth would

a) move off the current orbit in a straight line
b) remain in the same orbit
c) move into a smaller orbit
d) be pulled into the black hole
Unit 18

Orbital and Escape Velocities

Extra material, if we get to it!
As we saw in Unit 17, we can find the mass of a large object by measuring the velocity of a smaller object orbiting it, and the distance between the two bodies.

We can re-arrange this expression to get something very useful:

$$V_{circ} = \sqrt{\frac{GM}{d}}$$

We can use this expression to determine the orbital velocity ($V$) of a small mass orbiting a distance $d$ from the center of a much larger mass ($M$).
Calculating Escape Velocity

- From Newton’s laws of motion and gravity, we can calculate the velocity necessary for an object to have in order to escape from a planet, called the escape velocity

\[ V_{esc} = \sqrt{\frac{2GM}{R}} \]

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What *Escape Velocity* Means

- If an object, say a rocket, is launched with a velocity less than the escape velocity, it will eventually return to Earth.
- If the rocket achieves a speed higher than the escape velocity, it will leave the Earth, and will not return!
The concept of escape velocity is useful for more than just rockets!

It helps determine which planets have an atmosphere, and which don’t

- Object with a smaller mass (such as the Moon, or Mercury) have a low escape velocity. Gas particles near the planet can escape easily, so these bodies don’t have much of an atmosphere.

- Planets with a high mass, such as Jupiter, have very high escape velocities, so gas particles have a difficult time escaping. Massive planets tend to have thick atmospheres.