Recall: Kepler’s Laws

1) The orbit of a planet around the sun is an ellipse with the sun at one focus.
2) The line joining a planet to the Sun sweeps out equal areas in equal times as the planet travels around the ellipse.
3) The ratio of the squares of the revolutionary periods (P) for two planets is equal to the ratio of the cubes of their semi-major axes:

\[ \frac{P_1^2}{P_2^2} = \frac{a_1^3}{a_2^3} \]

BUT, Kepler’s ideas were largely ignored or disbelieved until after his death when Newton came along...

Isaac Newton

• Newton created the first theoretical model explaining gravity.
• He formulated 3 laws of motion and the law of gravitation – these laws describe the motion of objects in the modern world.
Newton’s Three Laws of Motion

• **1st Law:** A body remains at rest or moves in a straight line at a constant speed unless acted upon by an outside (net) force.

• **2nd Law:** Force = mass x acceleration

• **3rd Law:** Whenever one body exerts a force on a second body, the second body exerts an equal and opposite force on the first body.

Newton’s 1st Law

• The Law of Inertia
  • A body remains at rest or moves in a straight line at a constant speed unless acted upon by an outside (net) force.
  • Basically, objects don’t like to change.

Newton’s 2nd Law

• (net) Force = mass x acceleration or $F = ma$
  • Acceleration is the rate of change of velocity, or how quickly your motion is changing.
  • This can be in speed OR direction!
Newton’s 3rd Law

- Whenever one body exerts a force on a second body, the second body exerts an equal and opposite force on the first body.

Remember: 
\[ F = ma \]

Class Action!

You are an astronaut taking a space walk to fix your spacecraft with a hammer. Your lifeline breaks and the jets on your backpack are out of fuel. To return safely to your spaceship (without the help of someone else), you should...

(A) Throw the hammer at the spaceship to get someone’s attention
(B) Throw the hammer away from the spaceship
(C) Use a swimming motion with your arms
(D) Kiss your ship goodbye.

Newton’s Law of Gravity

- Newton came up with the idea of gravity using a thought experiment:
Newton's Law of Gravity

Law of Universal Gravitation

Every object in the Universe attracts every other object with a force directed along the line of centers for the two objects that is proportional to the product of their masses and inversely proportional to the square of the separation between the two objects.

\[ F_g = G \frac{m_1 m_2}{r^2} \]

- \( F_g \) is the gravitational force
- \( m_1, m_2 \) are the masses of the two objects
- \( r \) is the separation between the objects
- \( G \) is the universal gravitational constant

Mass vs. Weight

- Mass = how much “stuff” something has
  - Stays the same no matter where you are
- Weight = Force due to gravity
  - Changes based on your location – You would weigh less on the moon!
  - Why?
- How do scales work?

Gravitational acceleration

Newton’s 1st Law: \( F = m \times a \)

Gravity: \( F_g = \frac{G m_1 m_2}{r^2} \)

Gravitational Acceleration: \( a_g = \frac{G m}{r^2} \)

- Constant at surface of Earth!
- Everything has the same acceleration due to gravity.
Class Action!

The gravitational force is a(n) _______ force between objects that have _______.

(A) repulsive, charge
(B) attractive, energy
(C) attractive, mass
(D) repulsive, mass
(E) attractive, charge

Class Action!

Which of the following statements is NOT true regarding the gravitational force between mass \( m \) and mass \( M \)?

(A) the force decreases if the distance \( r \) between the two masses is decreased
(B) the force increases if the mass of \( m \) is increased
(C) the force decreases if the mass of \( M \) is decreased
(D) mass \( m \) is being pulled toward mass \( M \)
(E) mass \( M \) is being pulled toward mass \( m \)

Newton

- Newton derived Kepler’s Laws from his own theory of gravity. Kepler received wide recognition for his Laws after his death.
Newton and Kepler

Newton’s law of gravity is a theoretical explanation for Kepler’s laws.
1) Since planets are moving in an ellipse, they are always accelerating.
2) The acceleration depends on distance from the sun.

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Newton’s Law of Gravity

How did Newton go about getting credit for his idea of gravity?
Newton published them in a book in 1687 with financial help from Edmund Halley (Halley’s comet). He received wide recognition for his ideas, including a knighthood.

In his memoir, he wrote: “I do not know what I may appear to the world, but to myself I seem to have been only like a boy playing on the sea-shore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.”

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Class Action!

Which of the lettered arrows below indicates the direction of the gravitational force that the Sun exerts on the Earth?

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Class Action!

Astronauts inside the International Space Station float around as it orbits the Earth because

(A) There is no gravity in space  
(B) They are falling in the same way as the Space Station  
(C) They are above Earth’s atmosphere  
(D) There is less gravity inside the Space Station  
(E) More than one of the above.

Lecture Tutorial

• Break up into groups of 2-3  
  – NO MORE THAN 3  
• In your group, work through the following:  
  – Newton’s Law & Gravity (pages 29-31)  
  – Discuss the answers – don’t be silent!  
• I will be roaming around if you need help...  
• If your group finishes, check your answers with another group & finish up the Kepler lecture tutorials (pages 21-28).

Class Action!

At perihelion, the gravitational force the sun exerts on the Earth is:

\[ F = \frac{Gm_\text{Sun}m_\text{Earth}}{r^2} \]

\[ = \frac{(6.67 \times 10^{-11} \text{Nm}^2/\text{kg}^2)(1.99 \times 10^{30} \text{kg})(5.97 \times 10^{24} \text{kg})}{(1.47 \times 10^{11} \text{m})^2} \]

\[ = 3.67 \times 10^{22} \text{ N} \]

The force the Earth exerts on the Sun at this time is:

(A) larger  
(B) the same  
(C) smaller
Summary

Kepler’s Laws
Elliptical orbits with Sun at one focus

\[ \frac{R_1^3}{R_2^3} = \frac{T_1^2}{T_2^2} \]

Caused a Revolution in our way of thinking!