FORCE

- **Force** → a push or pull.
  - Results ***only*** from interaction with another object.
  - Without interaction, forces cannot be present.
- Measured in **Newtons (N)**
  - 1 Newton is the amount of force required to give accelerate a 1 kg mass at a rate of 1 m/s^2.
  - 1 N = 1 $kg \cdot m/s^2$
- Force is a vector quantity (dir'n matters).
- Representations of forces are called **free body diagrams**.

The 4 Fundamental Forces of Nature

- **Gravitational Force** → Weak, long-ranged, always attractive.
- **Electromagnetic Force** → Strong, long-ranged, can be attractive or repulsive.
- **Strong Nuclear Force** → Strong, short-ranged, holds nuclei together.
- **Weak Nuclear Force** → Weak, short-ranged, radioactive decay.

Contact Forces

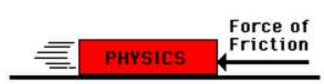
- **Contact forces** → forces resulting from two objects physically touching each other.
- Common contact forces we'll see this year:
  - Frictional force
  - Tension force
  - Normal force
  - Air resistance force
  - Applied force
  - Spring force

Action at a Distance Forces

- **Action at a distance forces** → forces exerted between two objects that are not physically touching.
  - aka ***field forces***
- Common action at a distance forces:
  - Gravitational force
  - Electrical force
  - Magnetic force

Newton's 1st Law

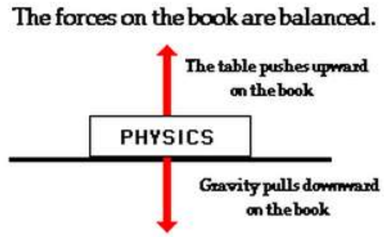
- **Newton's 1st Law** → objects in motion tend to stay in motion and objects at rest tend to remain at rest *unless* acted on by an outside force.
  - The Law of Inertia
- **Inertia** → the resistance an object has to changes in its state of motion.
  - The more mass something has, the more inertia it has.
- ***Forces are NOT necessary for an object to be moving***.
  - Forces simply change the state of motion of an object (i.e., accelerate it).



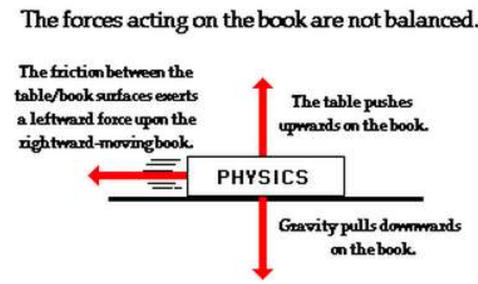
As a book slides across a table from left to right, the force of friction acts on the book to slow it down and bring it to rest.

- **State of Motion**
  - Defined by the object's velocity
  - Inertia: resistance to changes in velocity.
  - ***Inertia: resistance to acceleration***.

- **Balanced forces** → when the forces acting on an object are equal in size and opposite in direction.
  - Its state of motion does not change (it doesn't accelerate).
  - In a state of ***equilibrium***.



- **Unbalanced forces** → when there is are unbalanced forces acting on an object, the object's state of motion will change.
  - It accelerates.
  - ***Unbalanced forces cause accelerations.***



Conceptual Example 1
Ben is being chased through the woods by a bull moose that he was attempting to photograph. The enormous mass of the bull moose is extremely intimidating. Yet, if Ben makes a zigzag pattern through the woods, he will be able to use the large mass of the moose to his own advantage. Explain this in terms of inertia and Newton's first law of motion.

<u>Newton's 2nd Law</u>

- **Newton's 2nd Law** → Net forces cause accelerations.
  - Net force = unbalanced forces.

$$\Sigma F = ma$$

Variable	Meaning	Units
∑F	Net force	Newtons (N)
m	Mass	Kilograms (kg)
a	Acceleration	Meters per second squared (m/s^2)

Example Problem 1

A net force of 15 N is exerted on an encyclopedia to cause it to accelerate at a rate of 5 m/s^2. Determine the mass of the encyclopedia.

Weight

- **Weight →** a measure of the force of gravity on an object.

$$F_g = mg$$

Variable	Meaning	Units
F_g	Gravity/Weight	Newtons (N)
m	Mass	Kilograms (kg)
g	Acceleration due to gravity	Meters per second squared (m/s^2)

- There is a BIG difference between mass and weight.
  - Mass → how much matter something has.
  - Weight → a measure of the force of gravity on that mass.
  - Weight can change based off location. Mass cannot.

Example Problem 2

If a cube has a mass of 90.91 kilograms and a weight 890.9 N on Earth, what will its mass and weight be on the moon (g= 1.62 m/s^2)?

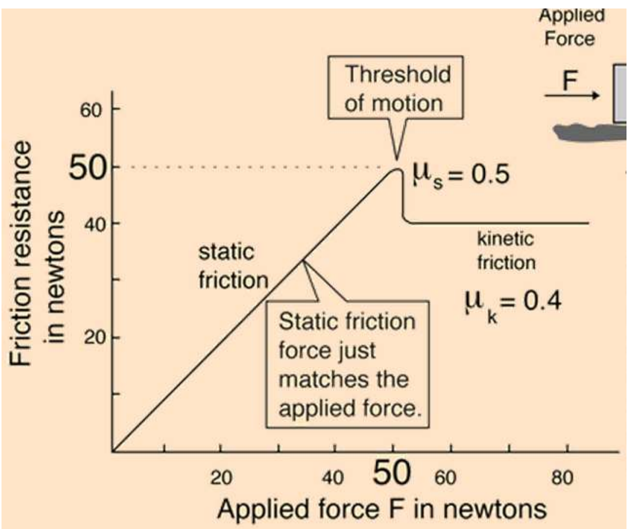
Friction

- **Friction →** a force that opposes an impending or actual motion.
  - 2 types: static and kinetic friction
- **Coefficient of friction (μ) →** determines how much friction is present.
  - Depends on the two materials involved.
  - Lower coefficient of friction = lower amount of friction present.
  - ***It has no units***.

$$F_f = \mu F_N$$

Variable	Meaning	Units
F_f	Friction	Newtons (N)
μ	Coefficient of friction	None
F_N	Normal force	Newtons (N)

- **Static friction →** friction that opposes an initial movement.
  - It's the minimum required force needed to cause an object to begin moving.
  - **The threshold of motion →** the maximum value possible for an object's static friction.
  - If you apply more force than the max value of static friction, the object will begin to move.



Approximate coefficients of friction [edit]

Materials		Static friction, μ_s	
		Dry and clean	Lubricated
Aluminium	Steel	0.61	
Copper	Steel	0.53	
Brass	Steel	0.51	
Cast iron	Copper	1.05	
Cast iron	Zinc	0.85	
Concrete	Rubber	1.0	0.30 (wet)
Concrete	Wood	0.62[11]	
Copper	Glass	0.68	
Glass	Glass	0.94	
Metal	Wood	0.2–0.6[11]	0.2 (wet)[11]
Polyethene	Steel	0.2[12]	0.2[12]
Steel	Steel	0.80[12]	0.16[12]
Steel	PTFE (Teflon)	0.04[12]	0.04[12]
PTFE (Teflon)	PTFE (Teflon)	0.04[12]	0.04[12]
Wood	Wood	0.25–0.5[11]	0.2 (wet)[11]

- **Kinetic friction →** a force that works opposite the direction of motion.
  - The friction associated with movement.
  - Always less than the value for static friction.
  - Most common type of friction we'll see in this class.

Example Problem 3

An applied force of 50 N is used to accelerate a 10 kg object to the right across a frictional surface. The object encounters 10 N of friction. Determine the normal force, the net force, and the acceleration of the object. (Neglect air resistance.)

Example Problem 4

A rightward force is applied to a 10-kg object to move it across a rough surface at constant velocity. The coefficient of friction between the object and the surface is 0.2. Determine the gravitational force, normal force, applied force, frictional force, and net force. (Neglect air resistance.)

Newton's 3rd Law

- **Newton's 3rd Law** → For every action there is an equal and opposite reaction.
  - **Reaction force** → a force exerted by one object back on another.
  - **Action-reaction pairs** → a description of the action and reaction forces between two objects.
  - Ex: We exert a force on the floor (weight), the floor exerts a force back on us (the **normal force**) that prevents us from falling through it.

Conceptual Example 2

For years, space travel was believed to be impossible because there was nothing that rockets could push off of in space in order to provide the propulsion necessary to accelerate. This inability of a rocket to provide propulsion is because:

a. Space is void of air so the rockets have nothing to push off of.
b. Gravity is absent in space.
c. Space is void of air and so there is no air resistance in space.
d. Rockets do accelerate in space and have been able to do so for a long time.

Explain your reasoning:

Conceptual Example 3

Is it possible to devise a technique to push on a table without it pushing back on you?

a. Yes, out in space
b. Yes, if someone else also pushes on it
c. A table never pushes in the first place
d. No, it is not possible

Explain your reasoning:

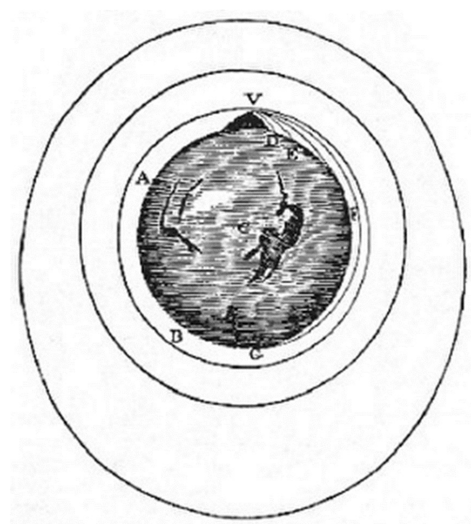
Conceptual Example 4

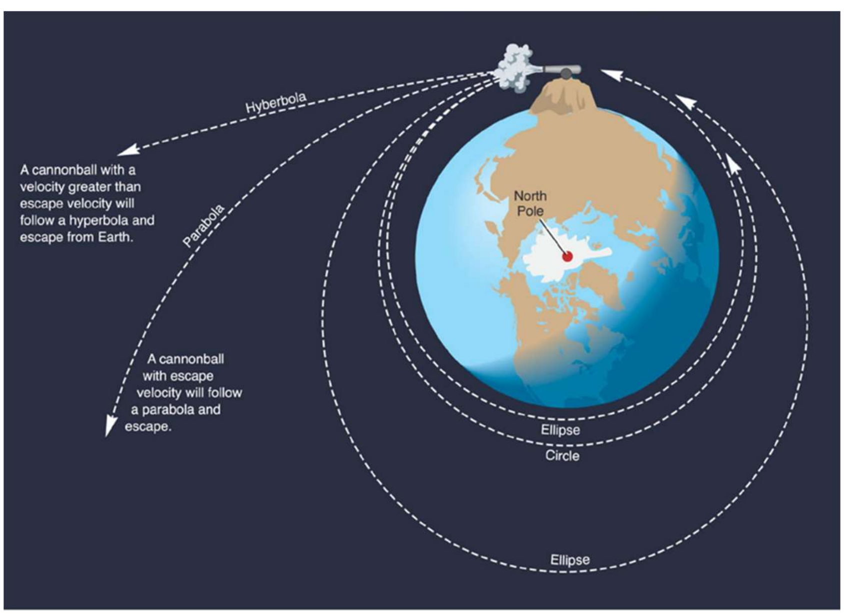
While driving down the road, a firefly strikes the windshield of a bus and makes a quite obvious mess in front of the face of the driver. This is a clear case of Newton's third law of motion. The firefly hit the bus and the bus hits the firefly. Which of the two forces is greater: the force on the firefly or the force on the bus?

<u>**Newton's Law of Universal Gravitation**</u>

- **Kepler's Laws of Planetary Motion**
  - Law of Ellipses
  - Law of Equal Areas
  - Law of Harmonies
  - These 3 laws provided an accurate description of planetary motion, but didn't give a "why."
  - Kepler believed the planets were "magnetically" driven by the sun to move as they do.

- **Newton's Mountain**
  - Newton wanted to know why the moon had a circular orbit, while planets had an elliptical ones.
  - Either way, these planets/moons are changing directions (accelerating).
  - Therefore a force must be acting on them to cause them to accelerate.





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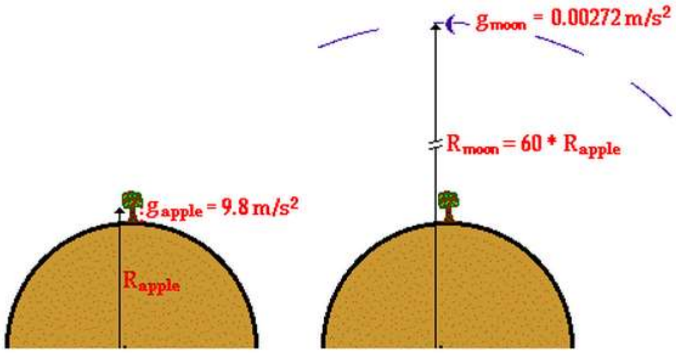
- The launch velocity of his imagined cannon ball determined the shape of the orbit.
- He concluded that the Moon is in a state of freefall, just like an apple falling from a tree.
- Next, he had to prove that the influence of gravity is dependent on the distance from the center of the Earth.

$$\frac{g_{moon}}{g_{apple}} = \frac{0.00272\ m/s^2}{9.8\ m/s^2} = \frac{1}{3600}$$



- The moon is 60x further from the center of the Earth. It also experiences 3600x less gravitational acceleration.
- ($60^2 = 3600$)
- Gravity must follow an **inverse square law**.
- ***The force of gravity is inversely related to the square of the distance***.
    - I.e., the further away you get from the center of the Earth, the less gravitational force you experience.

$$F_g \sim \frac{1}{d^2}$$

- **Law of Universal Gravitation** → All objects have a gravitational force of attraction with every other object.
    - That's where the "universal" part comes in.
- **Universal Gravitation Constant (G)** → nearly 100 years after Newton, in 1798, Lord Henry Cavendish discovered the missing constant to create an equation to calculate the force of gravity between any two objects.
    - **$G = 6.673 \times 10^{-11}\ Nm^2/kg^2$**

$$F_g = \frac{Gm_1m_2}{d^2}$$

Variable	Meaning	Units
F_g	Gravity	Newtons (N)
G	Universal Gravitation Constant	Nm^2/kg^2
m_1	Mass of object 1	Kilograms (kg)
m_2	Mass of object 2	Kilograms (kg)
d	Distance between the objects	Meters (m)

Example Problem 5

Determine the force of gravitational attraction between the earth (m = 5.98×10^{24} kg) and a 70-kg physics student if the student is standing at sea level, a distance of 6.38×10^6 m from earth's center.

Example Problem 6

Determine the force of gravitational attraction between the earth (m = 5.98×10^{24} kg) and a 70-kg physics student if the student is in an airplane at 40000 feet above earth's surface. This would place the student a distance of 6.39×10^6 m from earth's center.

- When rearranged, we can derive a formula to find the acceleration due to gravity on any planet.

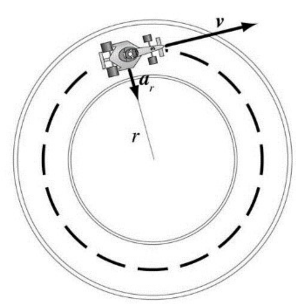
$$g = \frac{Gm_{planet}}{R^2}$$

Variable	Meaning	Units
g	Acceleration due to gravity	Meters per second squared (m/s^2)
G	Universal gravitation constant	Nm^2/kg^2
m_{planet}	Mass of the planet	Kilograms (kg)
R	Radius of the planet	Meters (m)

Example Problem 7

Mars has a mass of 6.4169×10^{23} kg and a radius of 3.397×10^{6} m. What is its acceleration due to gravity?

<u>**Uniform Circular Motion**</u>



- **Uniform circular motion** → when an object moves at a constant *speed* in a circle.
  - ➢ The object is accelerating because it is constantly changing directions.
  - ➢ This acceleration is called **centripetal acceleration**.
  - ➢ It is always directed towards the center of the circle.
- **Centripetal force** → the force responsible for causing an object to move in a circle.
  - ➢ It is really a net force; meaning the centripetal force is "caused" by another force (ex: tension, applied force).
  - ➢ Always directed towards the center of the circle
  - ➢ "Centripetal" → center-seeking
- **Centrifugal force** → a perceived force that is really just a demonstration of inertia.
  - ➢ **It DOES NOT exist.**