Physics 101: Mechanics
Lecture 4

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The Laws of Motion

- Newton's first law
- Force
- Mass
- Newton's second law
- Newton's third law
- Examples

Isaac Newton's work represents one of the greatest contributions to science ever made by an individual.

Kinematics and Dynamics

- Kinematics: Describing object's motion by answering: When? Where? How fast? How far? How long? without asking: Why is object moving in a certain way?
- Dynamics: Describing object's motion by answering: Why is the object moving in a certain way? What causes the object to change its velocity?
- Dynamics studies motion on a deeper level than kinematics: it studies the causes of changes in objects' motion!

Forces

- The measure of interaction between **two objects** (pull or push)
- Vector quantity: has ***magnitude and direction***
- May be a **contact force** or a **field force**
  - Contact forces result from physical contact between two objects
  - Field forces act between disconnected objects
    - Also called “action at a distance”

Figure 5.1
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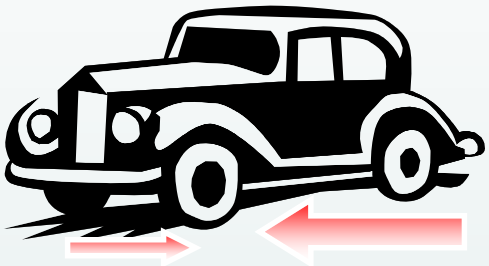
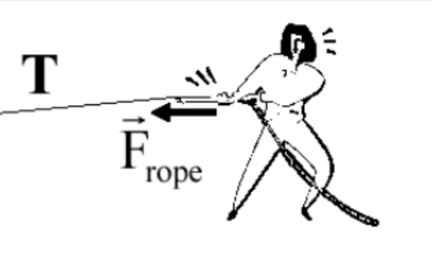
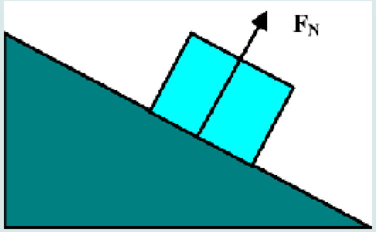
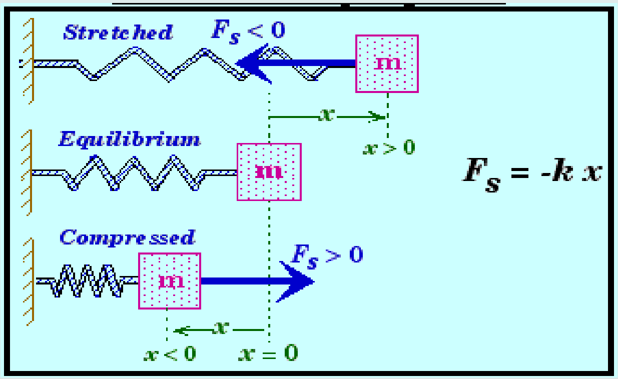
Forces



- Gravitational Force
- Archimedes Force
- Friction Force
- Tension Force
- Spring Force
- Normal Force







Vector Nature of Force

- Vector force: has ***magnitude and direction***
- Net Force: a resultant force acting on object

$$\vec{F}_{net} = \sum \vec{F} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + ...$$

- You must use the rules of vector addition to obtain the net force on an object

Figure 5.2
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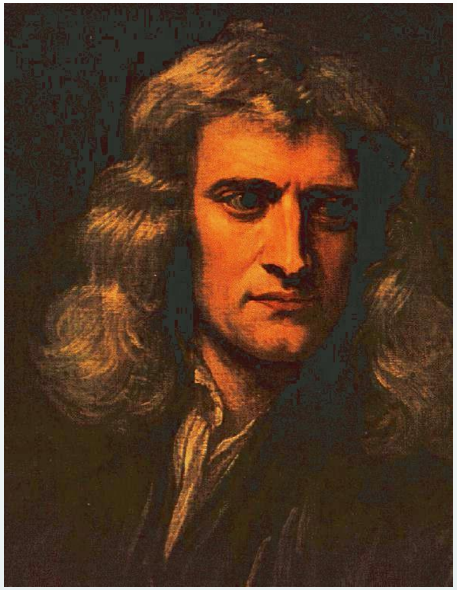
$$|\vec{F}| = \sqrt{F_1^{\,2} + F_2^{\,2}} = 2.24cm$$

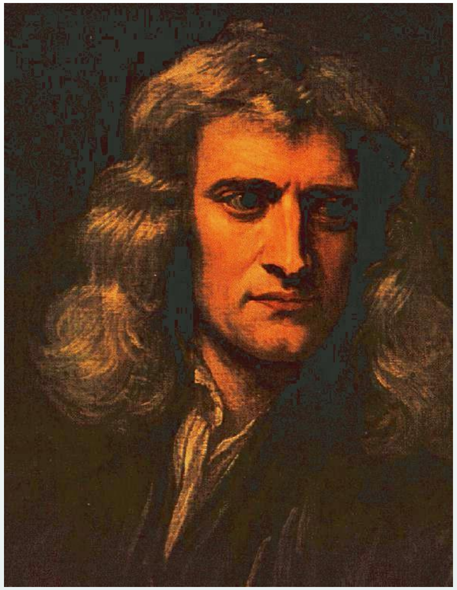
$$\theta = \tan^{-1}\left(\frac{F_1}{F_2}\right) = -26.6^\circ$$



Newton's First Law

- An object at rest tends to stay at rest and an object in motion tends to stay in motion with the same speed and in the same direction unless acted upon by an unbalanced force

- An object at rest remains at rest as long as no **net force** acts on it
- An object moving with **constant velocity** continues to move with the same speed and in the same direction (the same velocity) as long as no net force acts on it
- *"Keep on doing what it is doing"*



Newton’s First Law

- An object at rest tends to stay at rest and an object in motion tends to stay in motion with the same speed and in the same direction unless acted upon by an unbalanced force

- When forces are balanced, the acceleration of the objection is zero
  - Object at rest: $v = 0$ and $a = 0$
  - Object in motion: $v \neq 0$ and $a = 0$

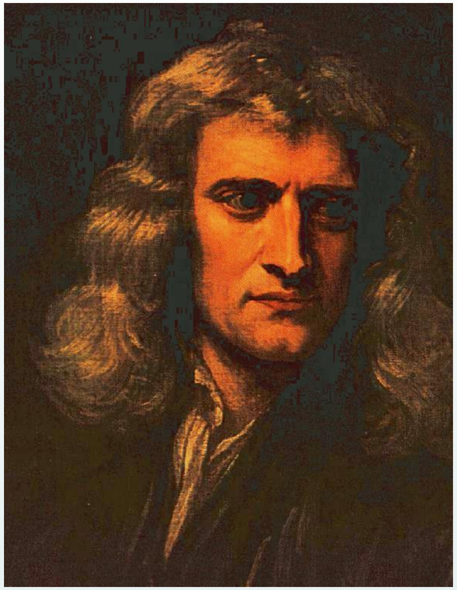
- The net force is defined as the vector sum of all the external forces exerted on the object. If the net force is zero, forces are balanced.

Mass and Inertia

- Every object continues in its state of rest, or uniform motion in a straight line, unless it is compelled to change that state by unbalanced forces impressed upon it
- **Inertia** is a property of objects

  to resist changes is motion!
- **Mass** is a measure of the

  amount of **inertia**.
- **Mass** is a measure of the resistance of an object to changes in its velocity
- Mass is an inherent property of an object
- Scalar quantity and SI unit: kg



Newton's Second Law

- The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass

$$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{net}}{m}$$

$$\vec{F}_{net} = \sum \vec{F} = m\vec{a}$$

Units of Force

- Newton's second law:

$$\vec{F}_{net} = \sum \vec{F} = m\vec{a}$$

- SI unit of force is a Newton (N)

$$1\,N \equiv 1\frac{kg\,m}{s^2}$$

- US Customary unit of force is a pound (lb)
  - 1 N = 0.225 lb

More about Newton's 2nd Law

- You must be certain about which body we are applying it to
- $\mathbf{F}_{\mathbf{net}}$ must be the vector sum of all the forces that act on that body
- Only forces that act on that body are to be included in the vector sum
- Net force component along an
  axis to the acceleration along
  that same axis

Gravitational Force

- Gravitational force is a vector
- Expressed by Newton's Law of Universal Gravitation:

$$F_g = G\frac{mM}{R^2}$$

  - G – gravitational constant
  - M – mass of the Earth
  - m – mass of an object
  - R – radius of the Earth
- Direction: pointing downward

Weight

- The magnitude of the gravitational force acting on an object of mass *m* near the Earth's surface is called the weight *w* of the object: $\boldsymbol{w = mg}$
- $\boldsymbol{g}$ can also be found from the Law of Universal Gravitation
- Weight has a unit of N

$$F_g = G\frac{mM}{R^2} \qquad w = F_g = mg$$

$$g = G\frac{M}{R^2} = 9.8\ \mathrm{m/s}^2$$

- Weight depends upon location

Normal Force

- Force from a solid surface which keeps object from falling through
- Direction: always perpendicular to the surface
- Magnitude: depend on situation

Figure 5.6
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$$w = F_g = mg$$

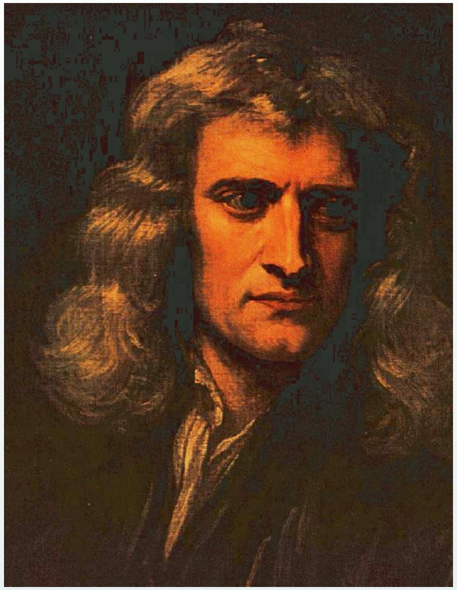
$$N - F_g = ma_y$$

$$N - mg = ma_y$$

$$N = mg$$

Tension Force: T

- A taut rope exerts forces on whatever holds its ends
- Direction: always along the cord (rope, cable, string ……) and away from the object
- Magnitude: depend on situation



Newton’s Third Law

- If object 1 and object 2 interact, the force exerted by object 1 on object 2 is equal in magnitude but opposite in direction to the force exerted by object 2 on object 1

Newton's Third Law cont.

- F_{12} may be called the *action* force and F_{21} the *reaction* force
  - Actually, either force can be the action or the reaction force
- The action and reaction forces act on **different** objects

Figure 5.5
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