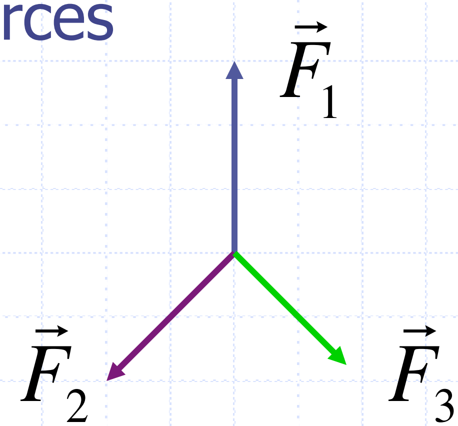
Chapter 5: Forces and Newton's Laws of Motion

- Previously, we have studied kinematics, which
  - describes the motion of an object (x, v, a)
  - does not explain the cause of the motion
- Now, we begin the study of the second part of mechanics – ***dynamics***
  - which does address the cause of motion
  - that cause is a *force,* a push or pull
- Force, $\vec{F}$, is a vector, has magnitude and direction
- How forces affect the motion of an object is described by Newton's Laws of Motion (Newtonian Mechanics)
- Objects are treated as point particles; in Chapter 12 we will consider the shape of an object in more detail

Newton's First Law of Motion

- An object at rest will remain at rest
- An object moving at a constant velocity will continue to move at the constant velocity, unless acted upon by a ***net force***
- What does it mean?
  - tendency for an object's motion not to change
- Net force = the sum of all applied forces

$$\sum_i \vec{F}_i = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 = 0$$



- No effect on the motion

- According to the 1st law, zero velocity (at rest) is equivalent to constant velocity
- An object with a constant velocity does not require a force to maintain its velocity
  - forces act to change motion, not to sustain the motion (e.g., the speed of the space shuttle)
  - *seems* contrary to everyday experience
- **Inertia** – tendency for an object to remain at rest, or to remain in motion with a constant velocity
  - all objects have inertia
- **Mass** – a quantitative measure of inertia (a scalar)
  - use symbol m - unit is kg (SI) or slug (British)
  - more mass, means more inertia
  - *not* equivalent to weight (a force)

Newton's Second Law of Motion

- If there is a net force, there is a change in velocity (an acceleration)

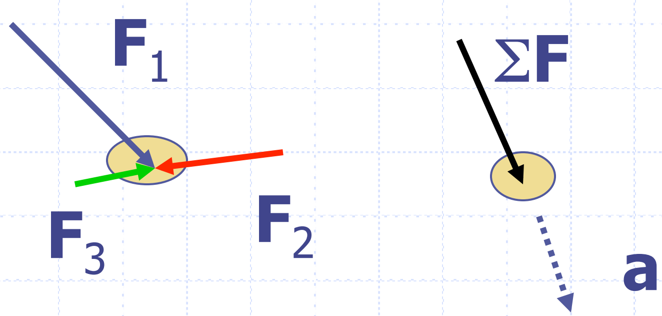
$$\sum_i \vec{F}_i = \sum \vec{F} = m\vec{a}$$

Eq. (5.6)

- 1^{st} law implies the 2^{nd} law

- Meaning: if a *net* external force acts on an object of mass *m*, it will be accelerated and the direction of the acceleration will be in the same direction as the *net* force

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



Demo 8.2.2

- All forces in Newton's second law are *external* – a force exerted on an object by some outside agent
- Units: $F=ma$ $[mass][L/T^2]$

  $\rightarrow (kg)(m/s^2)=N$, Newton

- The Newton is a derived unit

- In British units, force is given by the *lb* and mass is given by the *slug*

  $\rightarrow slug = lb\ s^2/ft$

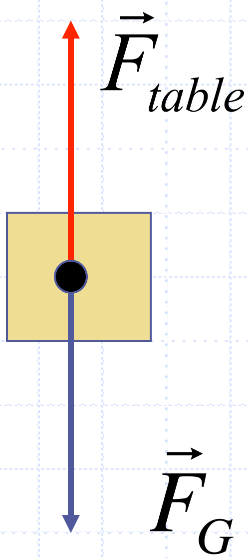
The Free Body Diagram (FBD)

- A schematic representation of *an object* and all the external forces that act upon it
- **Always draw in every problem!!!!**
- From Newton's 2nd law:

$$\sum \vec{F} = m\vec{a} = 0$$

$$\vec{F}_G + \vec{F}_{table} = 0$$

$$\vec{F}_{table} = -\vec{F}_G$$



Book at rest on the table

Fundamental Types of Forces

1. Gravitational
2. Electromagnetic – (electric and magnetic)
3. Weak Nuclear
4. Strong Nuclear

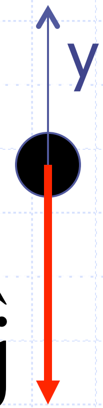
$\left.\begin{array}{l}\text{2. Electromagnetic}\\ \text{3. Weak Nuclear}\end{array}\right\}$ Electroweak

We will only consider the first two

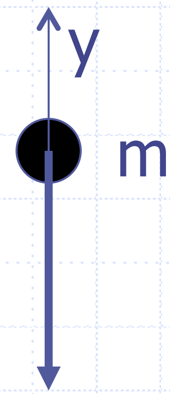
<u>Gravitational Force</u>

From our studies of free-fall motion and projectile motion → gravity causes an object to accelerate in the negative *y*-direction

$$\vec{a}_y = -g\,\hat{j}$$



Apply the second law



$$\vec{F}_G = -mg\,\hat{j}$$

- This is only an approximation which holds only near the surface of the Earth (as *g* is only constant near the surface). But a good approximation!

- We would like a more fundamental description of gravity
  - *g* is an empirical number
  - physicists don't like empirical numbers

- This lead Newton to devise his *Law of Universal Gravitation* (the subject of Chapter 13(?) and 6.3)

Example Problem

- Three forces acting on an object are given by $\vec{F}_1$=(-2.00 $\hat{i}$ + 2.00 $\hat{j}$) N, $\vec{F}_2$=(5.00 $\hat{i}$ – 3.00 $\hat{j}$) N, and $\vec{F}_3$=-45.0 $\hat{i}$ N. The object experiences an acceleration of magnitude 3.75 m/s^2. (a) What is the direction of acceleration? (b) What is the mass of the object? (c) If the object is initially at rest, what is its speed after 10.0 s? (d) What are the velocity components of the object after 10.0 s?