Force and Motion

PHY 106 General Physics I

School of Architecture and Design

Force and Motion

- Why do things move?
- What is the cause of motion?

- The Answer was given by Sir Isaac Newton

How Fast Are You Going?

- **In your chair, you might say you are at rest.**
  - **Clarification: At rest with respect to the surface of Earth.**
- **But Earth is spinning**
  - It takes 24 hours to travel ~25,000 miles (Earth's circumference) so v=1000 mph.
- **But Earth is going around the sun:**
  - Circumference: D = 2πR = 2π(93x106 miles)
  - Period: T = 1 year = 365 days = 8760 hours
  - V= D/T = 66,700 mph
- **But the sun is moving about the Milky Way**
  - V = 540,000 mph
- **How fast are you going??**
  - **Bad question, must ask:**

How fast are you going with respect to ….

Newton's Three Laws

- Inertia:

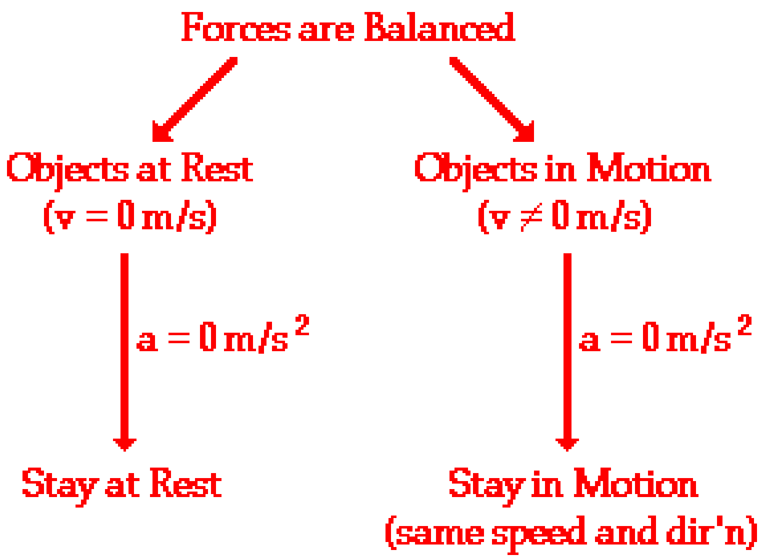
  "Every body continues in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by a force impressed on it."

- Force, Mass, Acceleration (F=ma):
  - "The change in motion [rate of change of momentum] is proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed."

- "Action = Reaction":
  - "To every action [change of momentum] there is always opposed an equal reaction; or, the mutual actions of two bodies are always equal, and directed to contrary parts."

Newton's First Law
or **"law of inertia"**

- 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.



Newton's First Law
or **“law of inertia”**

- A body will stay at rest…
- A body will continue to move with the same ***velocity*** unless…
- **A *net* force acts on the body**
  - e.g., to speed up or slow down an object’s motion, and/or to change an object’s direction of motion, and object’s inertia must be overcome.

Newton's First Law
or **"law of inertia"**

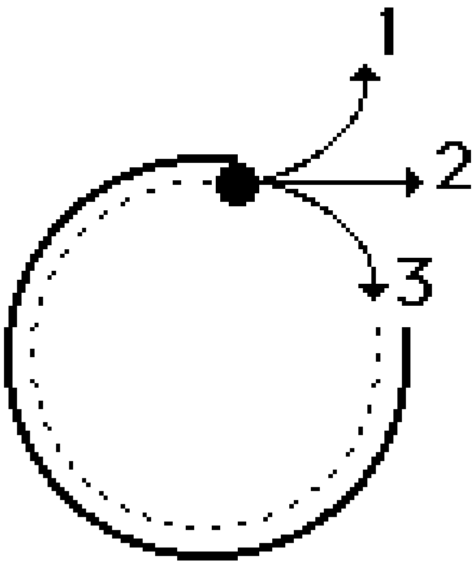
- Everyday Applications of Newton's First Law!!!!
- Could you please give me an example?

State of Motion

- Inertia is the tendency of an object to resist changes in its state of motion.
- Inertia = tendency of an object to resist changes in its velocity.
- Inertia = tendency of an object to resist accelerations.

State of Motion

- The GBS physics teachers are taking some time off for a little putt-putt golf. The 15th hole at the Hole-In-One Putt-Putt Golf Course has a large metal rim which putters must use to guide their ball towards the hole. Mr.Somchai guides a golf ball around the metal rim When the ball leaves the rim, which path (1, 2, or 3) will the golf ball follow?



Force

- An Interaction that causes an acceleration of a body.
- A push or a pull applied to an object
- That which is needed to change the state of
- motion (i.e., velocity) of an object

- Force is a vector quantity.
- Force is a quantity which is measured using the standard metric unit known as the **Newton**.

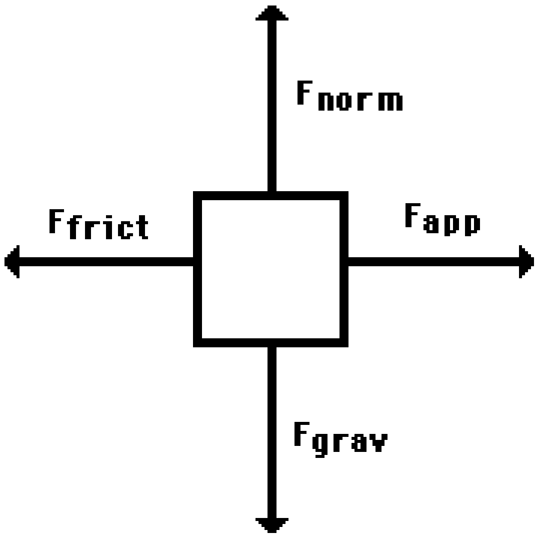
$$1\ \text{Newton} = 1\ \text{kg} * \frac{\text{m}}{\text{s}^2}$$

Type of Force

Contact Forces	Action-at-a-Distance Forces
Frictional Force	Gravitational Force
Tensional Force	Electrical Force
Normal Force	Magnetic Force
Air Resistance Force	
Applied Force	
Spring Force	

Drawing Free-Body Diagrams

- Free-body diagrams are diagrams used to show the relative magnitude and direction of all forces acting upon an object in a given situation.



Newton's Second Law or "Law of acceleration"

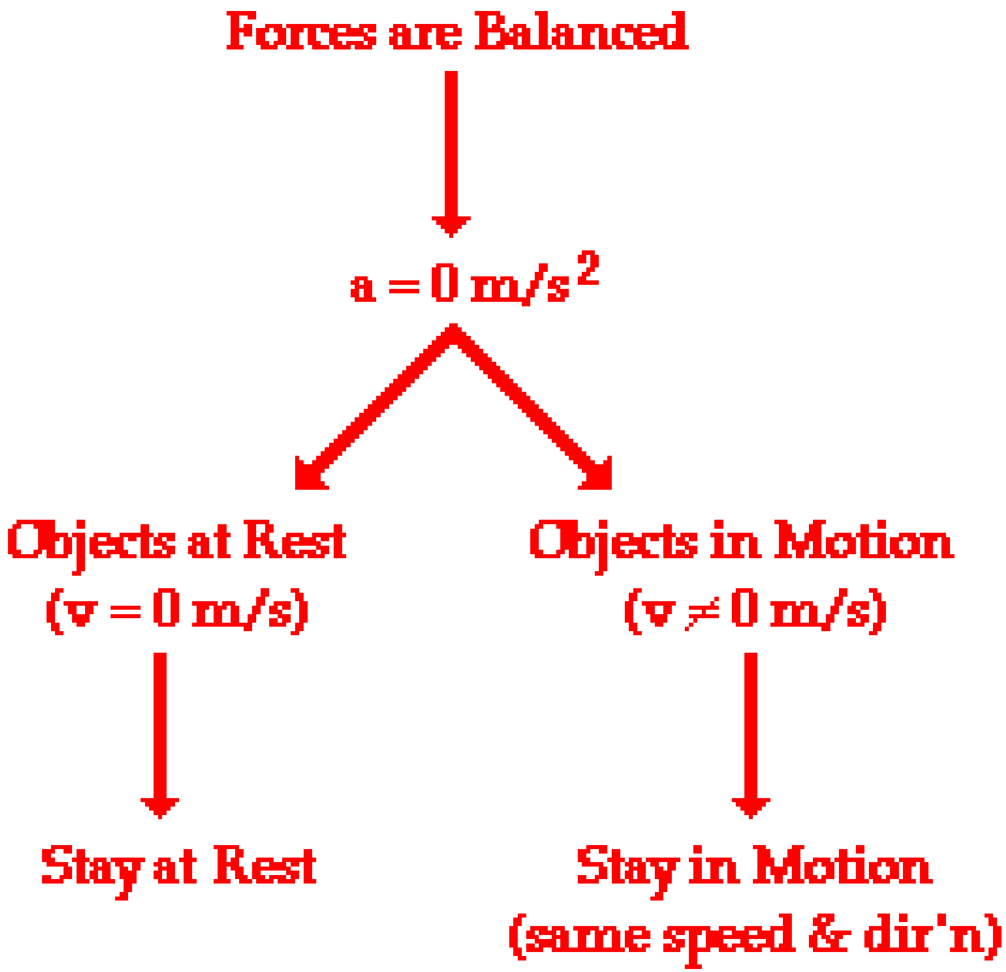
- The Total force acting on a body is equal to the mass of the body times its acceleration.
- Force affected by mass

Equation:
Force = mass x acceleration

$$\vec{F} = m\,\vec{a}$$

- In terms of momentum: $\vec{p} = m\,\vec{v}$
- $\vec{F} = m\,\vec{a} = m\,\Delta\vec{v}/\Delta t = \Delta\vec{p}/\Delta t$
- Thus Force = rate of change of momentum

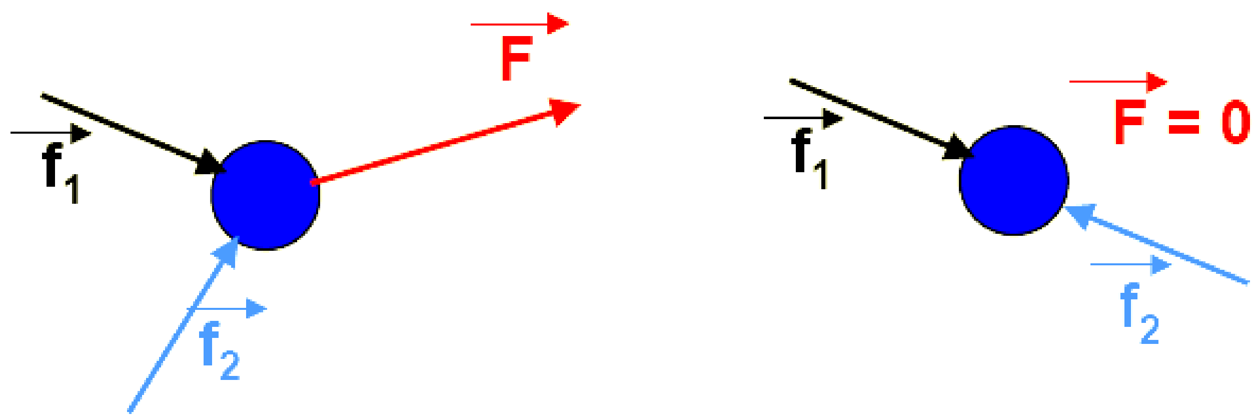
Newton’s Second Law



Force is a vector

- The "Net Force" or "Total Force" on an object is the vector sum of all the forces on it due to other objects
- This what goes in Newton's Equation

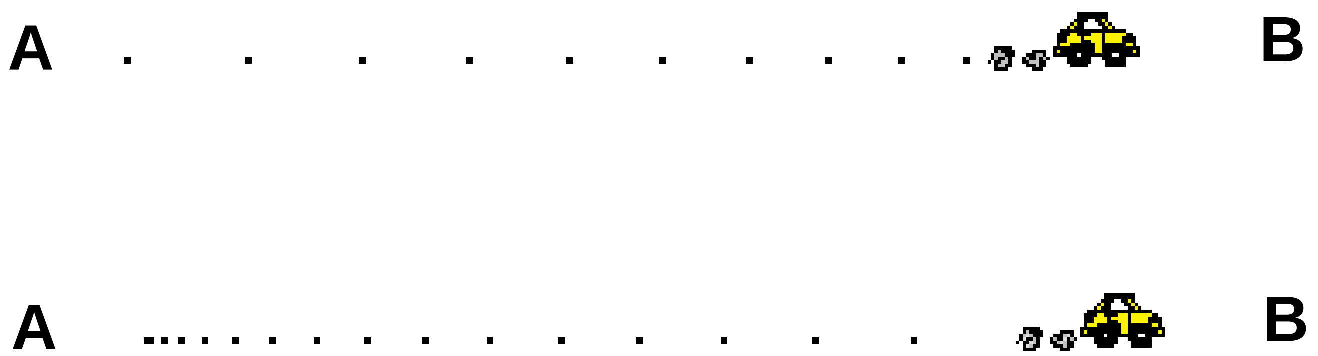
Force = mass x acceleration $\vec{F} = m \vec{a}$



Net Force F is the vector sum of the three applied forces

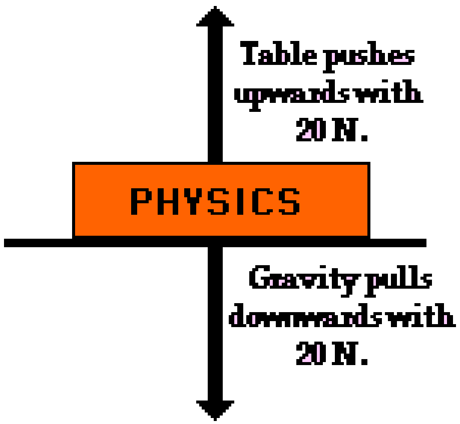
Net Force direction

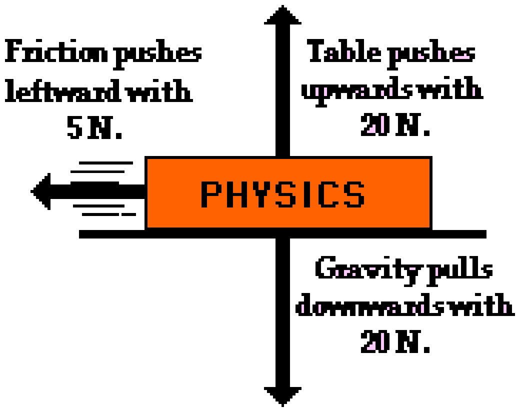
- Which direction?



Balance and Unbalance Force

- the two individual forces "balance each other"
- the force of friction acts leftwards, and there is no rightward force to balance it. In this case, an unbalanced force acts upon the book to change its state of motion.

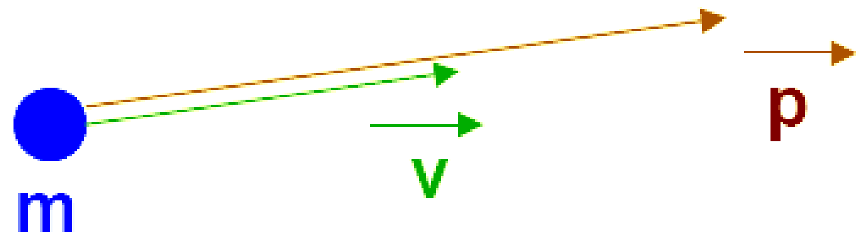




Vectors: Velocity, Acceleration, Momentum

- Momentum was known to Galileo & Descartes:
  Measure of "quantity of motion"

- Momentum Vector $\vec{p} = m \vec{v}$



- Note: m = mass is a scalar (a value, NOT a vector)

- Momentum has same direction as velocity
- Magnitude: $p = m v$
- (More on vectors later)

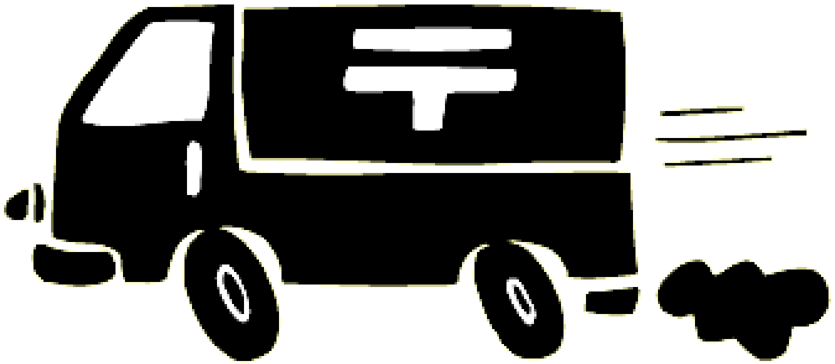
Which has more momentum?

- A bullet, mass = 100 grams, speed = 1000m/s

100 grams = 0.1kg

p=mv = 0.1 kg x 1000m/s = 100 kg-m/s

- A truck, mass=1000kg, speed = 10m/s



p=mv = 1000 kg x 10m/s

= 10,000 kg-m/s

Mass

- What is this thing called Mass?
- Mass is a property of an object. In Newton's theory it is always constant for a given object.
- Mass is not weight, not volume, ...
- Mass is a quantitative measure of how hard it is to accelerate the object.
    - Mass of objects can be calibrated by measuring their acceleration by the same force
    - Tested experimentally -- found to be true that different measurements with different forces give consistent values of the mass

Mass vs. Weight

- Mass is an intrinsic property of an object.
  - A rock has same mass whether it is on the moon or on Earth
- Weight is the force exerted on an object by gravity.
  - This is different depending upon the strength of the gravitational force.
- On the surface of Earth, gravitational force is constant so we can easily convert from mass to weight.

	English	Metric
Mass	Slug	Kilogram
Weight	Pound	Newton

1 pound = 1 slug - ft/s^2

1 Newton = 1 kg - m/s^2

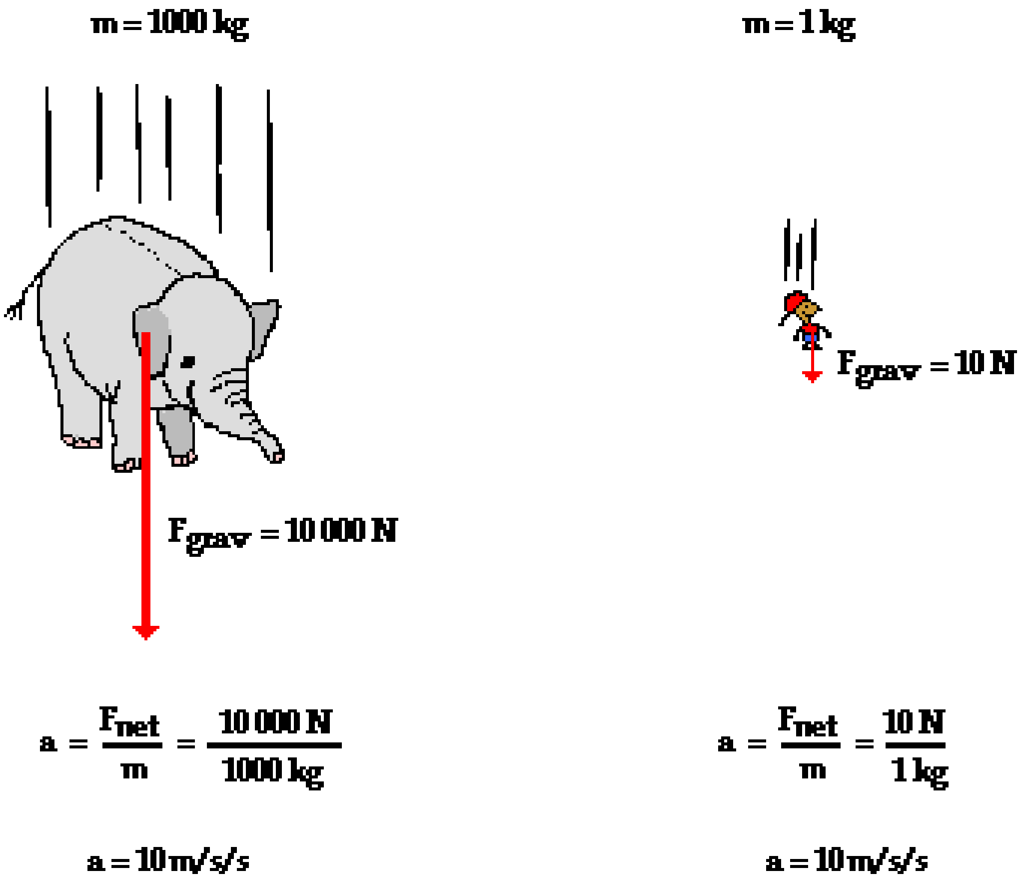
1 kg x 9.8m/s^2 = 9.8 Newtons

9.8 Newtons = 2.2 pounds

So, we say it's 2.2 pounds per kilogram.
Does this work on Mt. Everest?

Free Fall Motion

- all objects will fall with the same rate of acceleration, regardless of their mass.



Example

- What average net force must a baseball catcher apply to an 80 mph (35.8 m/s) pitch to stop it over a time of .025 s? (mass = 4.5 oz = 0.13 kg)
  - Know:
    $m = .13$ kg; $t = 0.025$ s; $vi = 35.8$ m/s; $vf = 0$ m/s
  - Need:
    F
  - Use:
    $F = ma$ ...but…we must find a first and $a = (vf - vi)/t$
  - Answer:
    $F = ma = 0.13\ kg \times (0\ m/s - 35.8\ m/s)/0.025\ s = -186.2\ N$

Newton's 3rd Law: Action/Reaction

- Action-reaction: describes how objects interact with one another.
  - If one body exerts a force on a second body, the second exerts back on the first a force of **equal** magnitude but **opposite** direction
  - example: Vertical jumping
    - "Action" force is applied by **person (via muscles)** and acts on **ground**.
    - "Reaction" force is applied by **ground** and acts on **person**.

Demonstration:
Newton's Third Law: Action/Reaction

- Examples of equal and opposite forces
  - Does not matter which body "caused" the force
- Person pushing on a table
- How does a rocket accelerate?

Exercise: Action/Reaction

- Suppose a tennis ball (m= 0.1 kg) moving at a velocity v = 40 m/sec collides head-on with a truck (M = 500 kg) which is moving with velocity V = 10 m/sec.
  - During the collision, the tennis ball exerts a force on the truck which is smaller than the force which the truck exerts on the tennis ball. TRUE or FALSE ?
  - The tennis ball will suffer a larger acceleration during the collision than will the truck. TRUE or FALSE ?
  - Suppose the tennis ball bounces away from the truck after the collision. How fast is the truck moving after the collision?

    < 10 m/sec = 10 m/sec > 10 m/sec ?

Exercise: Action/Reaction solution

- Suppose a tennis ball (m= 0.1 kg) moving at a velocity v = 40 m/sec collides head-on with a truck (M = 500 kg) which is moving with velocity V = 10 m/sec.
  - During the collision, the tennis ball exerts a force on the truck which is smaller than the force which the truck exerts on the tennis ball. TRUE or **FALSE** ?

  Equal and opposite forces!

  The tennis ball will suffer a larger acceleration during the collision than will the truck. **TRUE** or FALSE ?

  Acceleration = Force / mass

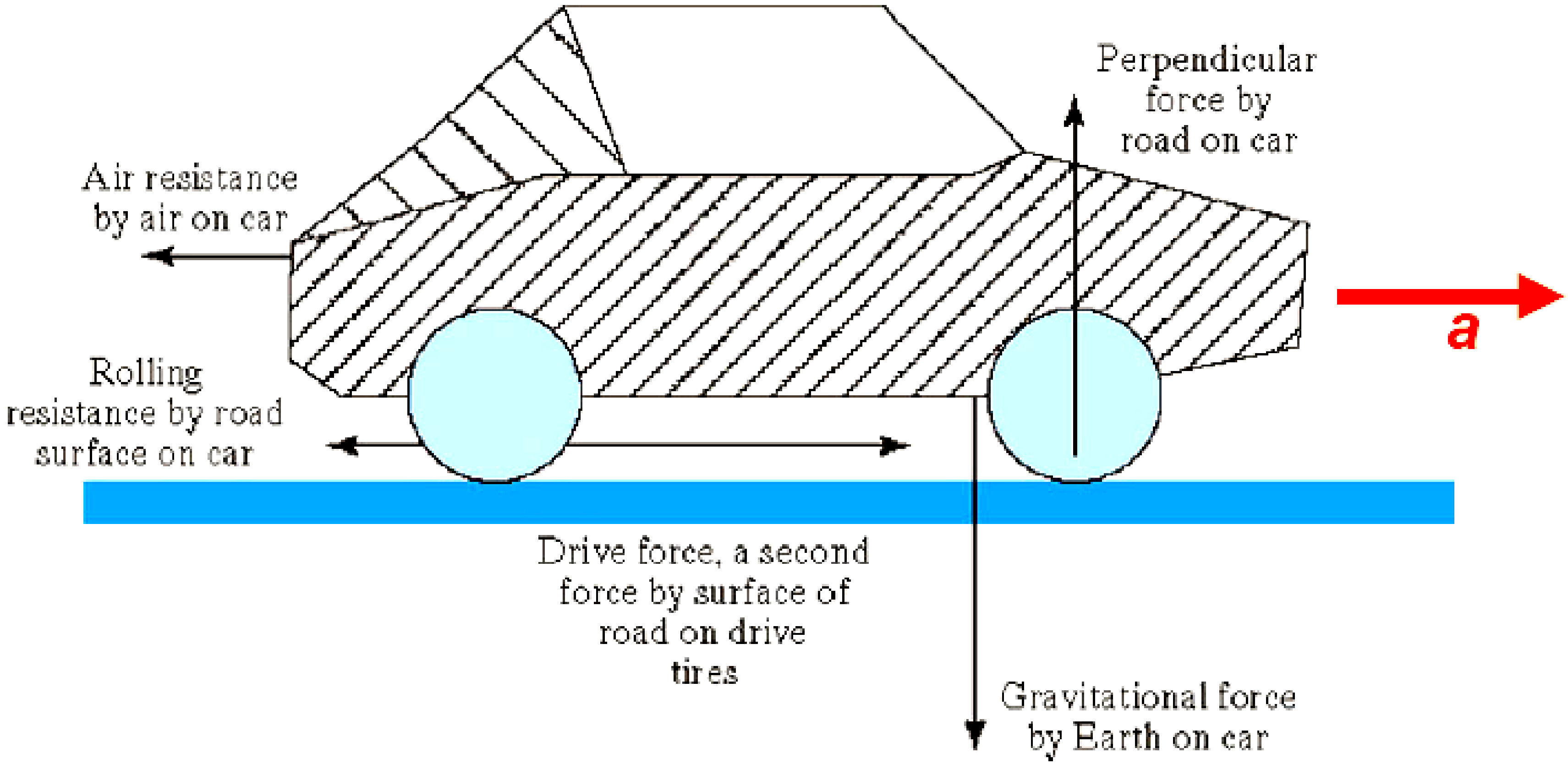
  - Suppose the tennis ball bounces away from the truck after the collision. How fast is the truck moving after the collision?

  < 10 m/sec = 10 m/sec > 10 m/sec ?

  To conserve total momentum, the truck's speed must decrease since the tennis ball moves in the opposite direction after the collision.

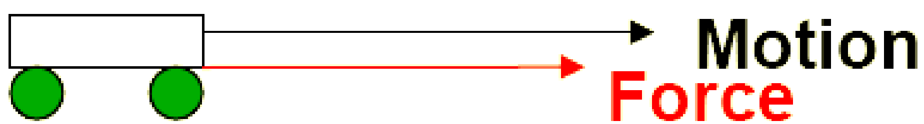
How Does a Car Move?

- Each arrow represents a force.
  - Your car is accelerating forward, meaning there is a net force in that direction.

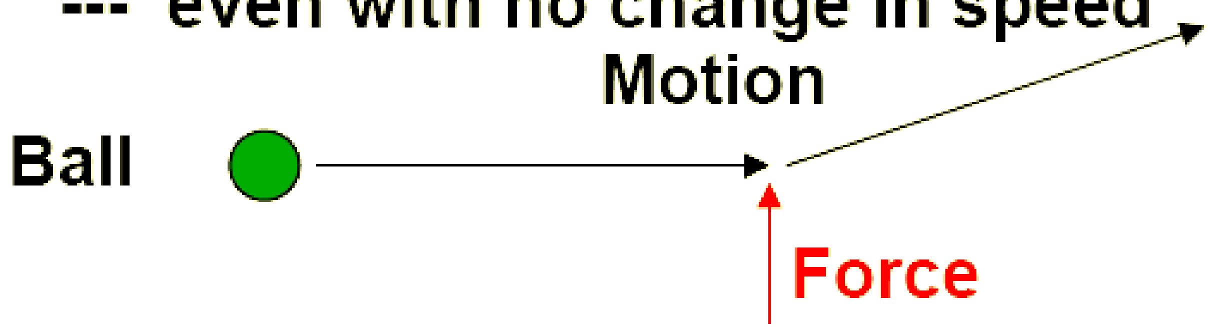


Force is required to change the Magnitude or Direction of Velocity

- From First law motion continues in straight line at constant velocity unless there is a force
- Change of speed in the same direction requires a force in that direction
  - Car speeding up - positive acceleration
  - Car slowing down - braking - negative acceleration
  - Demonstration last time of string applying force to a cart on wheels



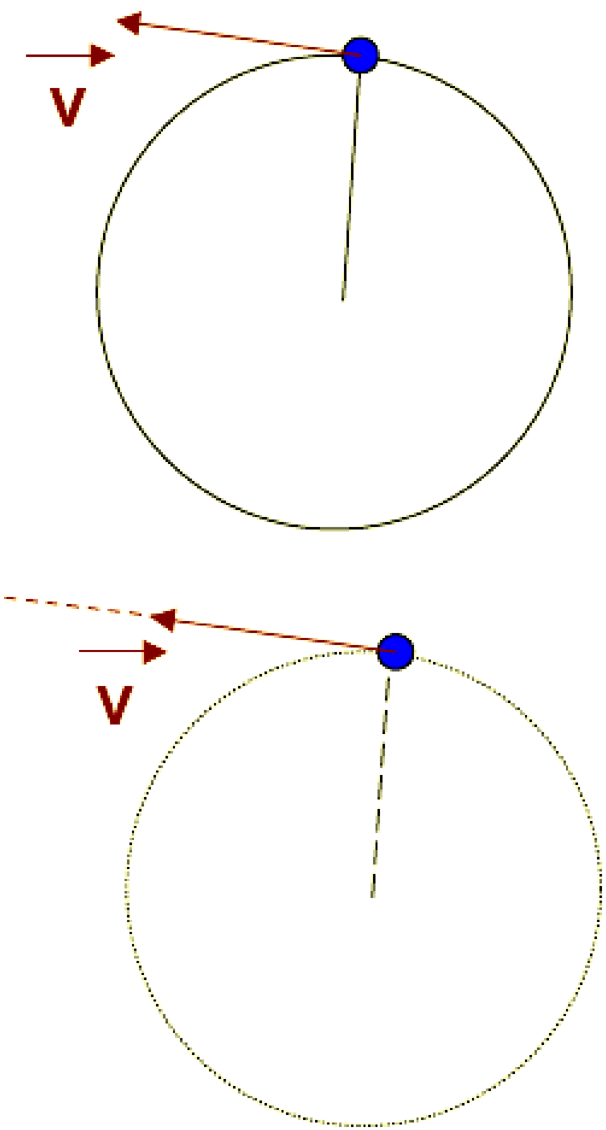
- Change of direction of motion requires a force
  --- even with no change in speed



Force is required to change the Direction of Velocity

- Example: Circular Motion
- Accelerates even though speed does not change!
- Object moves in circle because of force from string

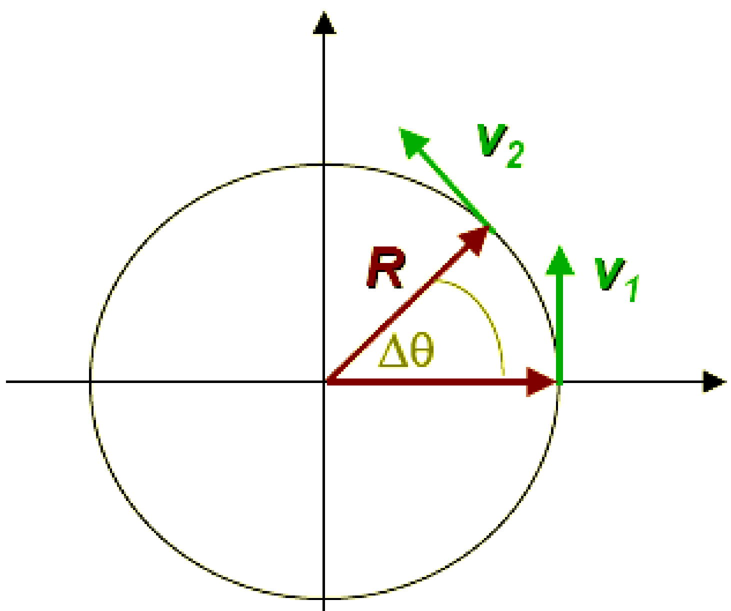
- If string were suddenly cut, ball would move in straight line at constant velocity



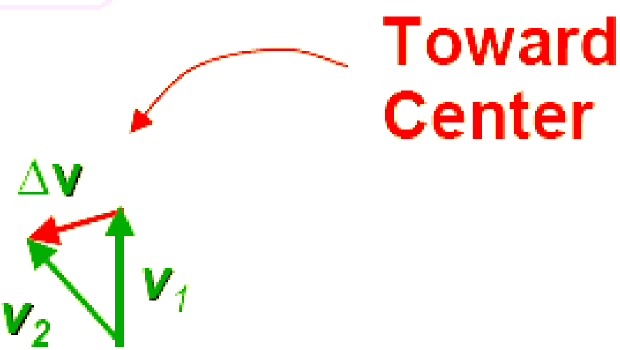
Acceleration & Circular Motion

- Acceleration is the change in velocity per unit time.
- Velocity is a vector (magnitude & direction).

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t}$$



$$|\vec{v}_1| = |\vec{v}_2| = v$$



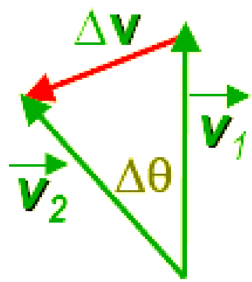
The direction of the acceleration is centripetal, i.e. toward the center of the circle.

Acceleration & Circular Motion

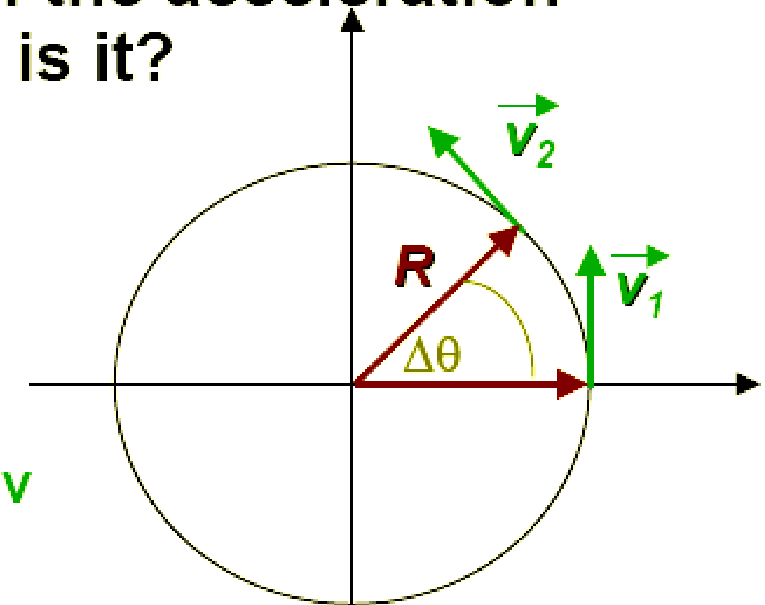
- We now know the direction of the acceleration (toward the center). How big is it?

For small angles $\Delta\theta$, measured in radians:

$$\Delta v = v\Delta\theta$$



$|\vec{v}_1| = |\vec{v}_2| = v$



- To find the acceleration, we need to know how $\Delta\Theta$ is related to Δt :
  - For one revolution, the angular displacement is: $\Delta\theta = 2\pi$ (radians)
  - The time required for one revolution (period) is: $\Delta t = 2\pi R / v$
  - Therefore, $\Delta\theta / \Delta t = v / R$
  - Combining these equations:

$$a = \frac{\Delta v}{\Delta t} = v\,\frac{\Delta\theta}{\Delta t} = \frac{v^2}{R}$$

Circular Motion

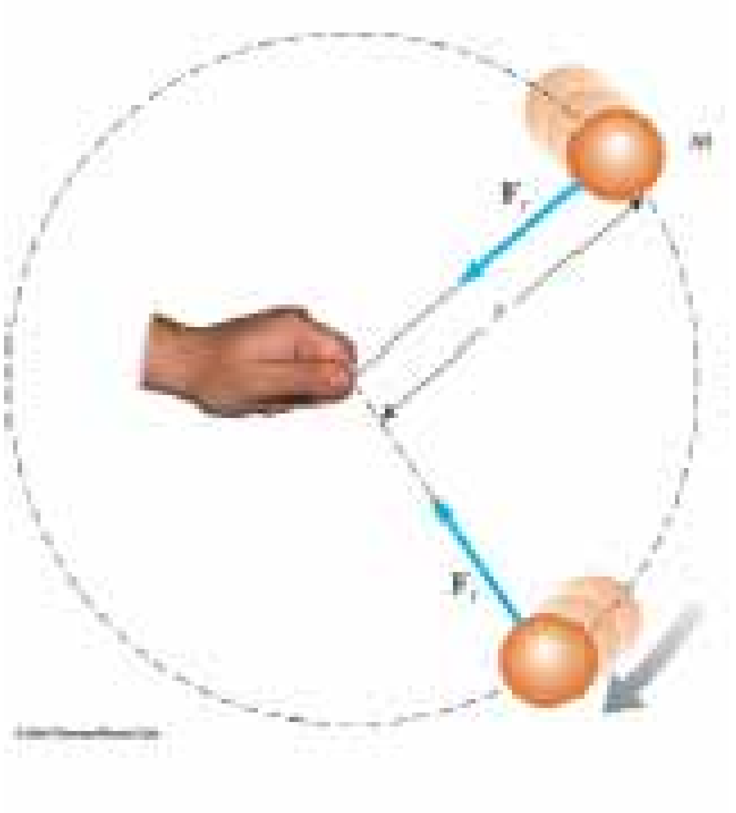
and

Other Applications of Newton's Laws

Uniform Circular Motion

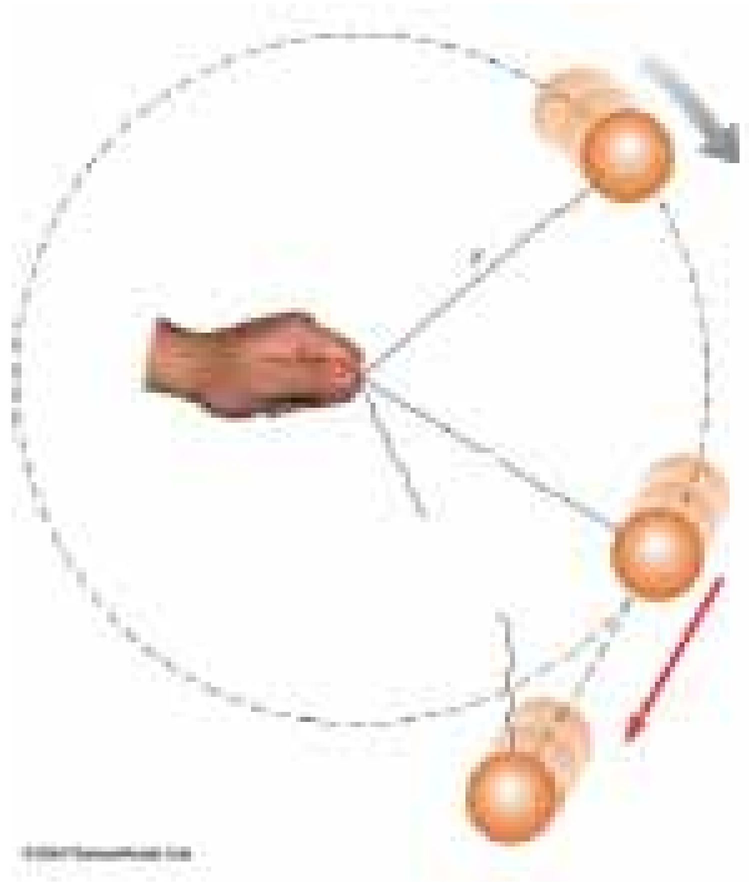
- A force, $\mathbf{F}_r$, is directed toward the center of the circle
- This force is associated with an acceleration, $\mathbf{a}_c$
- Applying Newton's Second Law along the radial direction gives

$$\sum F = ma_c = m\frac{v^2}{r}$$



Uniform Circular Motion

- A force causing a centripetal acceleration acts toward the center of the circle
- It causes a change in the direction of the velocity vector
- If the force vanishes, the object would move in a straight-line path tangent to the circle

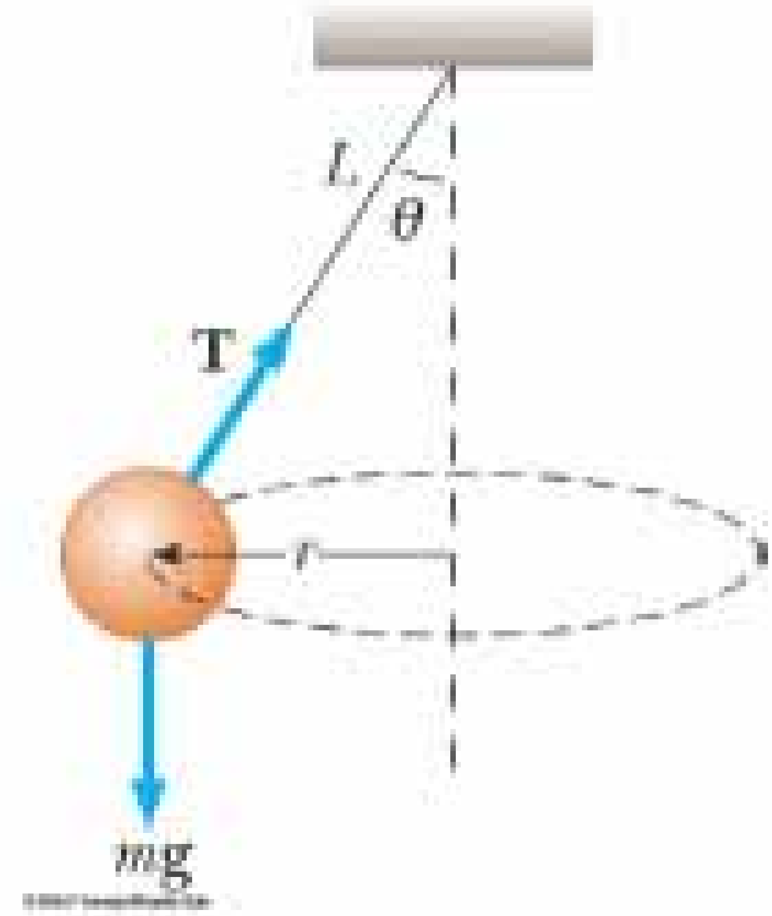


Conical Pendulum

- The object is in equilibrium in the vertical direction and undergoes uniform circular motion in the horizontal direction

$$v = \sqrt{Lg \sin\theta \tan\theta}$$

- *v* is independent of *m*



Motion in a Horizontal Circle

- The speed at which the object moves depends on the mass of the object and the tension in the cord
- The centripetal force is supplied by the tension

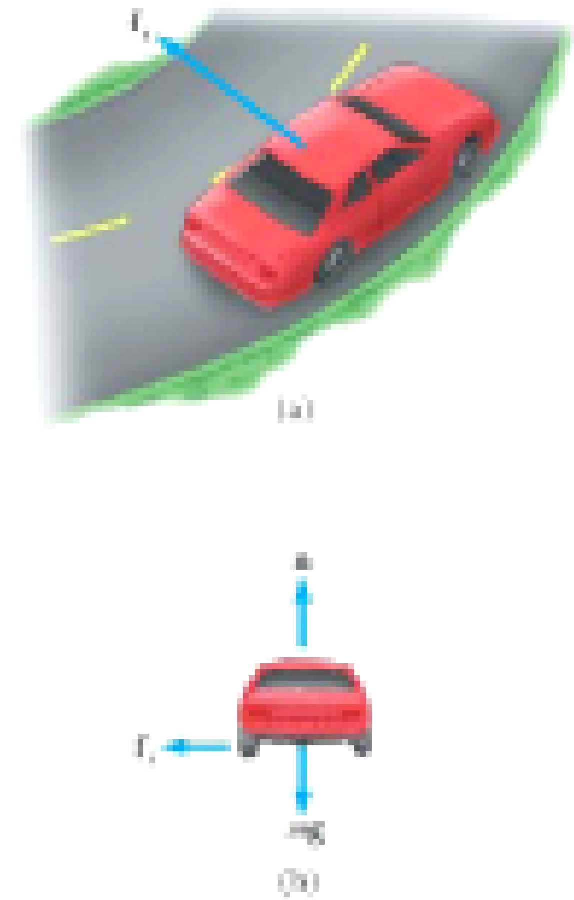
$$v = \sqrt{\frac{Tr}{m}}$$

Horizontal (Flat) Curve

- The force of static friction supplies the centripetal force
- The maximum speed at which the car can negotiate the curve is

$$v = \sqrt{\mu g r}$$

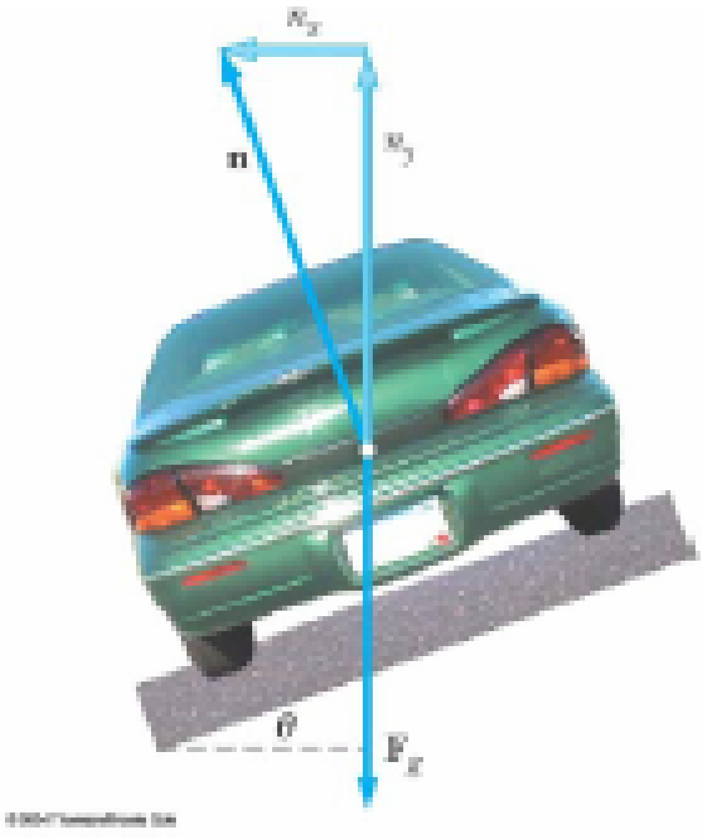
- Note, this does not depend on the mass of the car



Banked Curve

- These are designed with friction equaling zero
- There is a component of the normal force that supplies the centripetal force

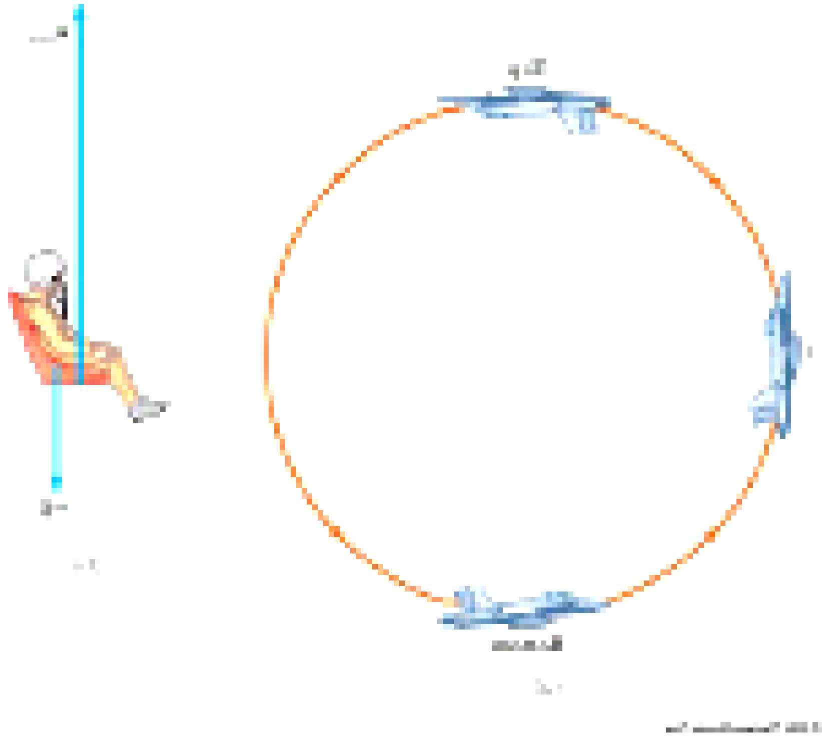
$$\tan\theta = \frac{v^2}{rg}$$



Loop-the-Loop

- This is an example of a vertical circle
- At the bottom of the loop (b), the upward force experienced by the object is greater than its weight

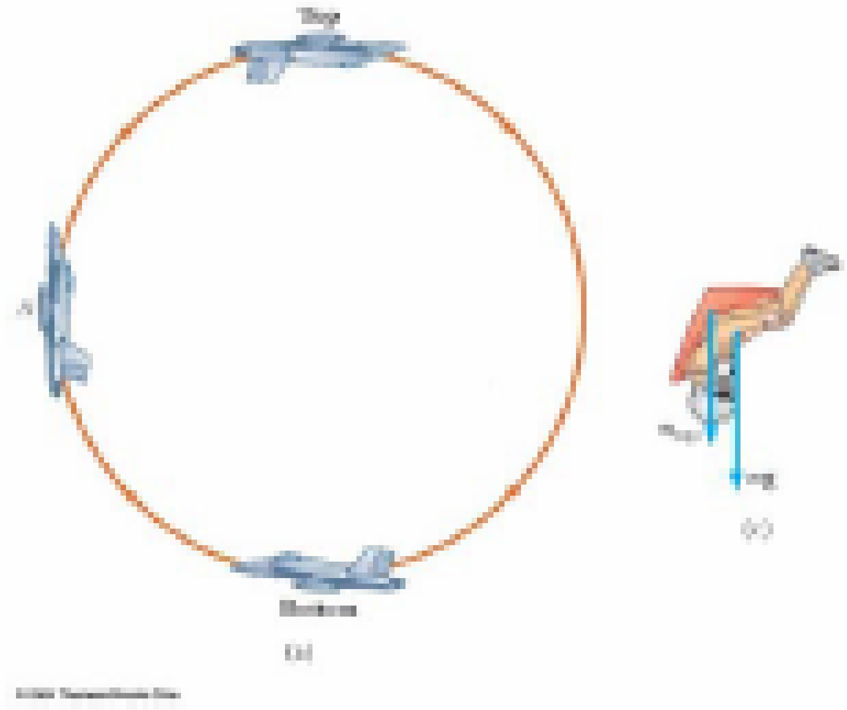
$$n_{bot} = mg\left(1 + \frac{v^2}{rg}\right)$$



Loop-the-Loop

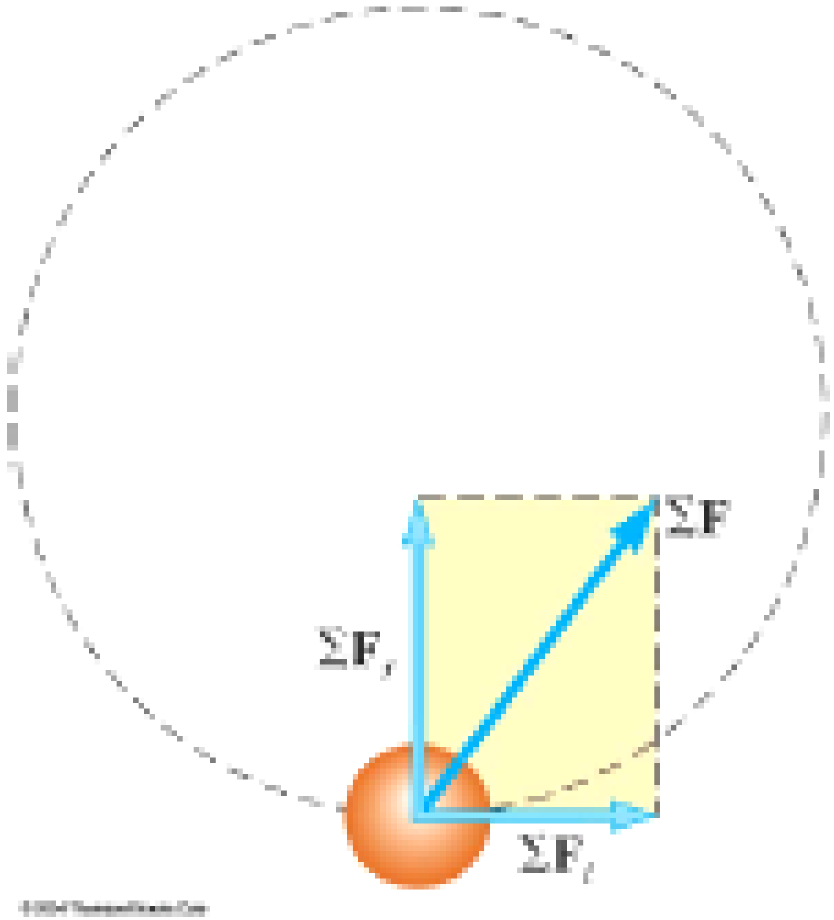
- At the top of the circle (c), the force exerted on the object is less than its weight

$$n_{top} = mg\left(\frac{v^2}{rg} - 1\right)$$



Non-Uniform Circular Motion

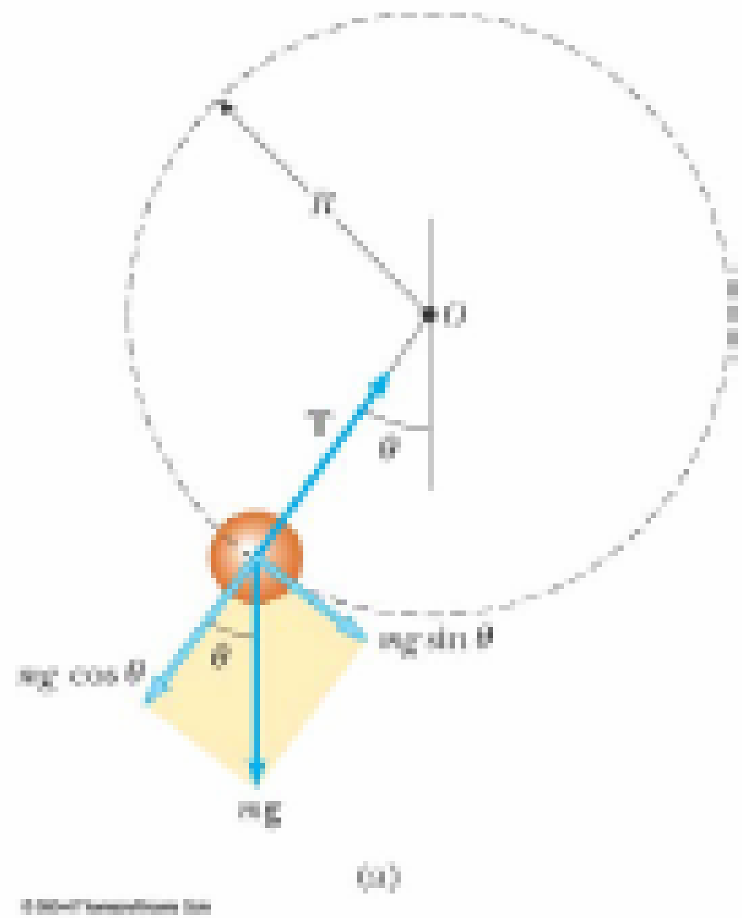
- The acceleration and force have tangential components
- F_r produces the centripetal acceleration
- F_t produces the tangential acceleration
- $\Sigma \mathbf{F} = \Sigma \mathbf{F}_r + \Sigma \mathbf{F}_t$



Vertical Circle with Non-Uniform Speed

- The gravitational force exerts a tangential force on the object
  - Look at the components of F_g
- The tension at any point can be found

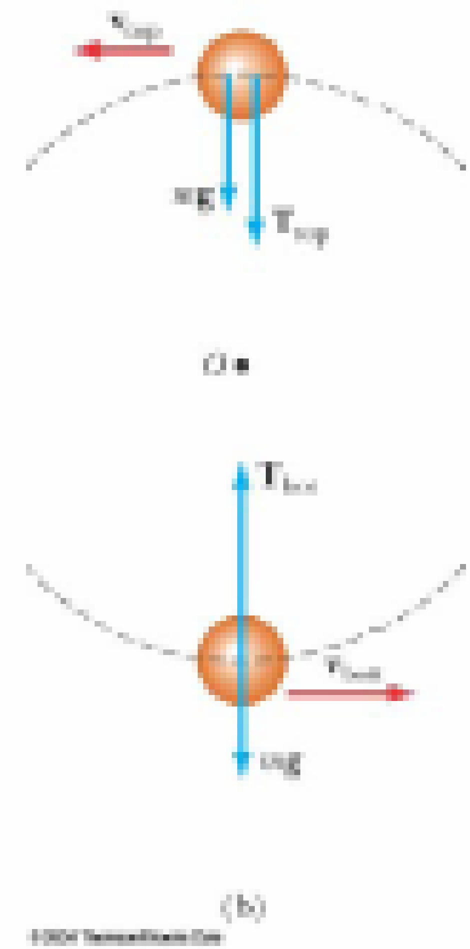
$$T = m\left(\frac{v^2}{R} + g\cos\theta\right)$$



Top and Bottom of Circle

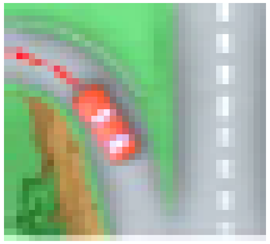
- The tension at the bottom is a maximum
- The tension at the top is a minimum
- If $T_{top} = 0$, then

$$v_{top} = \sqrt{gR}$$



“Centrifugal” Force

- From the frame of the passenger (b), a force appears to push her toward the door
- From the frame of the Earth, the car applies a leftward force on the passenger
- The outward force is often called a *centrifugal* force
  - It is a fictitious force due to the acceleration associated with the car's change in direction



Fictitious Forces, examples

- Although fictitious forces are not real forces, they can have real effects
- Examples:
  - Objects in the car do slide
  - You feel pushed to the outside of a rotating platform

Fictitious Forces in Linear Systems

- The inertial observer (a) sees

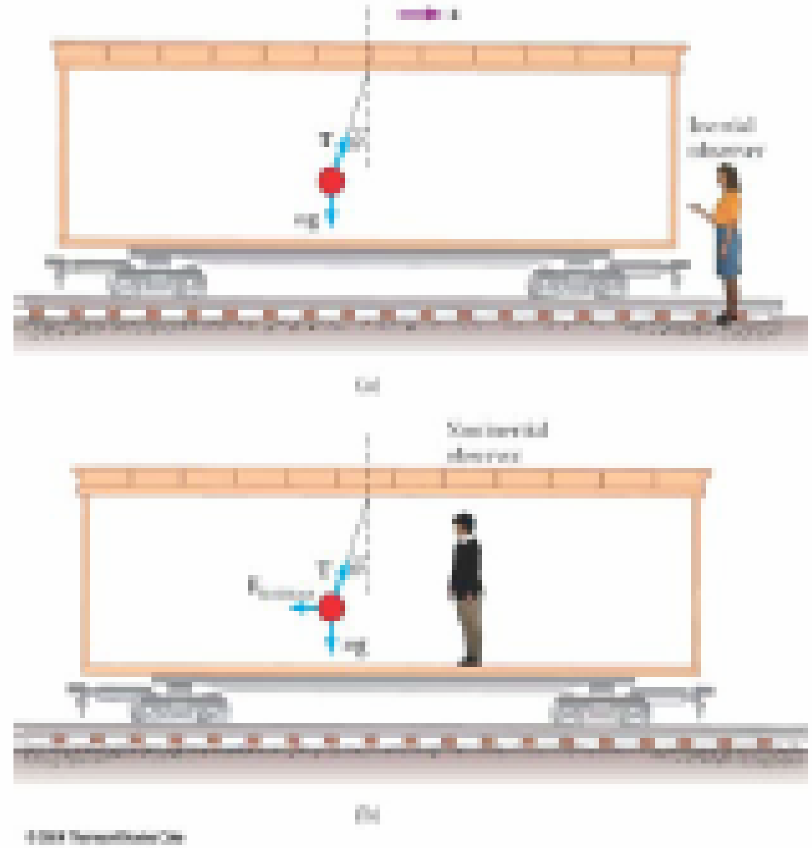
$$\sum F_x = T\sin\theta = ma$$

$$\sum F_y = T\cos\theta - mg = 0$$

- The noninertial observer (b) sees

$$\sum F'_x = T\sin\theta - F_{fictitious} = ma$$

$$\sum F'_y = T\cos\theta - mg = 0$$



Fictitious Forces in a Rotating System

- According to the inertial observer (a), the tension is the centripetal force

$$T = \frac{mv^2}{r}$$

- The noninertial observer (b) sees

$$T - F_{fictitious} = T - \frac{mv^2}{r} = 0$$

Newton's Law of Gravitation

- A fundamental physical principle that describes the concept of gravity...
- Any two particles of matter (any objects or bodies) attract one another with a force directly proportional to the product of their masses and inversely proportional to the square of the distance between them (i.e., distance between their centers).

$$F = G \cdot \frac{(m_1 \cdot m_2)}{l^2}$$

G = gravitational constant = 6.7×10^{-11} $N \cdot m^2/kg^2$

- Like it or not, there is a force of attraction between you and the person sitting next to you.
  - However, this force is so small that you don't notice it.
  - When one of the objects is the earth (with its huge mass), the force of attraction (i.e. gravity) is very significant.

Example

$$F = G \cdot \frac{(m_1 \cdot m_2)}{l^2}$$

- Two students sitting 1.5 m apart

$$F = \left(6.7x10^{-11}\ N \cdot m^2 / kg^2\right) \cdot \frac{(70\ kg)(50\ kg)}{(1.5m)^2}$$

$$F = 10422x10^{-11} = 1.04x10^{-7}\ N$$

- Attraction between earth and student

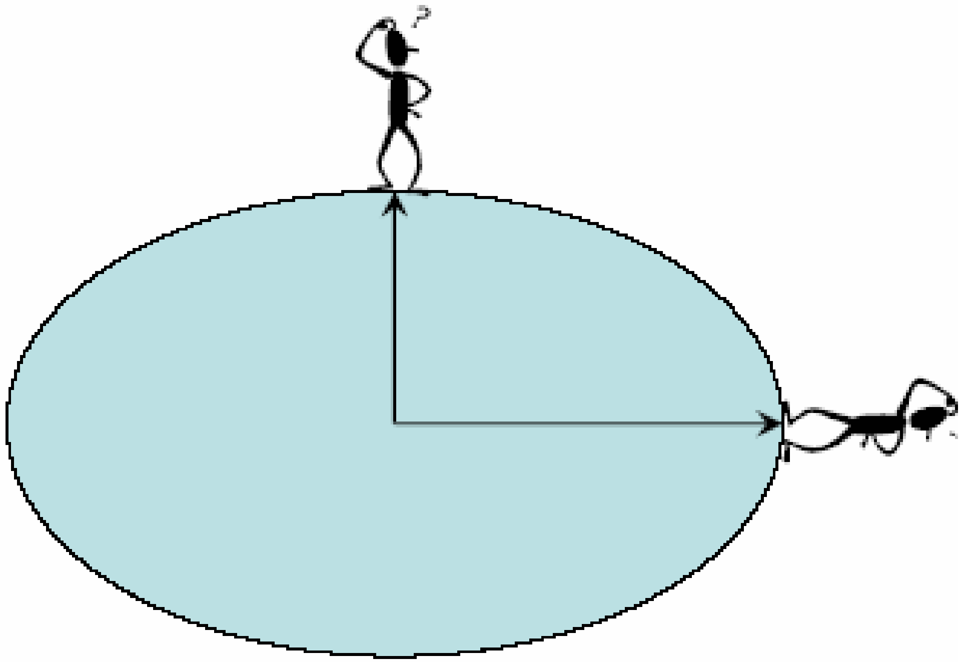
$$F = \left(6.7x10^{-11}\ N \cdot m^2 / kg^2\right) \cdot \frac{(5.98x10^{24}\ kg)(50\ kg)}{(6.38x10^{6} m)^2}$$

$$F = 4.92x10^{1} = 491\ N$$

Weight

- Question: Is earth's gravitational attraction the same for all objects on or near the earth's surface?

- Answer: **NO**...this force is dependent on the involved masses and the distance between the CM of the object and the CM of the earth.



Weight vs. Mass

- Are weight and mass the same thing? **NO** (Why or why not)
  - An objects **weight** represents the force of attraction between the earth and the object. Mass represents the **quantity of matter or stuff of which a body is composed**.
- Simplified relationship for the link between weight and mass on earth:

$$W = mg$$

where $g = G \cdot \frac{m_{earth}}{l^2}$