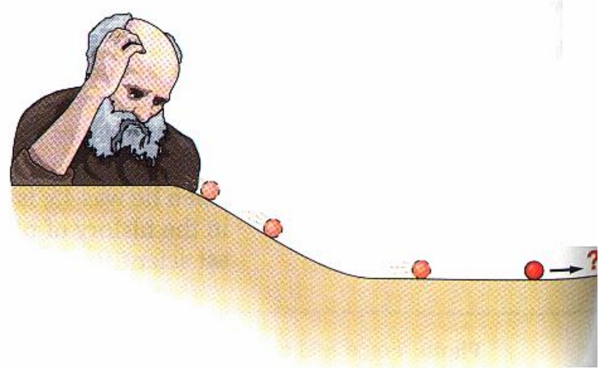
NEWTON'S LAWS OF MOTION

Background:

- **Aristotle** believed that the **natural state of motion** for objects on the earth was one of **rest**. In other words, objects needed a **force** to be kept in motion.

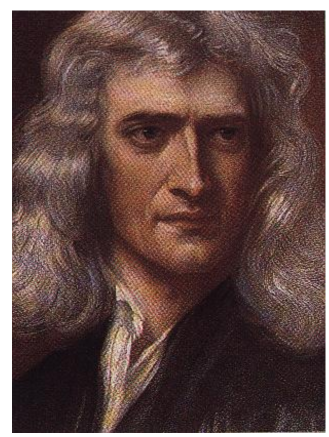
- **Galileo** studied motion of objects rolling down an inclined plane with smooth surfaces. He observed that the smoother the surface, the farther the ball traveled.



- **Galileo** reasoned that if the surface was perfectly smooth (**no friction**), the ball would travel **indefinitely**, until encountered by another object.

- Thus contrary to Aristotle, **Galileo** concluded that objects could **naturally remain in motion** rather than come to rest.

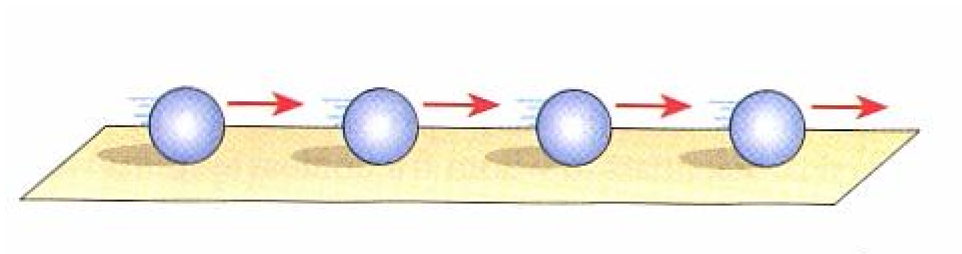
- Despite Galileo's insight into the cause of motion, it remained for **Sir Isaac Newton**, who was born the year Galileo died, to fully understand and explain the phenomena of moving objects on earth and the motions of celestial objects.



1ST LAW OF MOTION

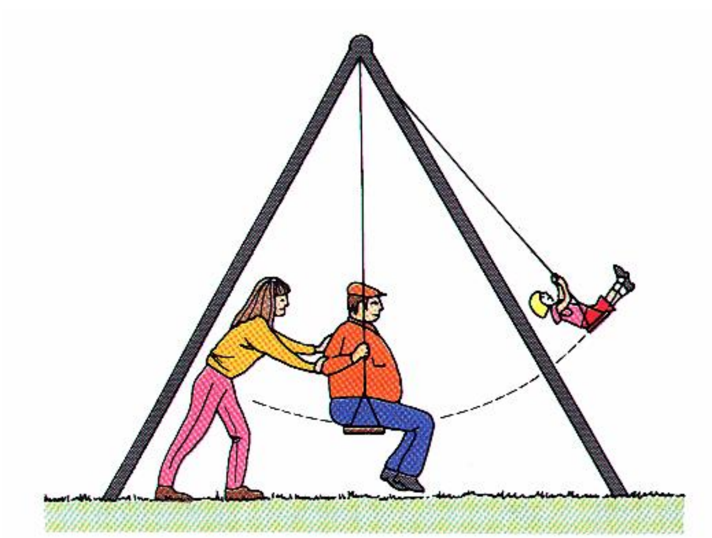
Law of Inertia:

- A object will remain at **rest** or in **uniform motion in a straight line** unless acted on by an **external, unbalanced force**.



With **no forces** acting on the ball, it continues to move along a **straight line** with **constant speed**.

- **Inertia** of a body is a property of the body that **resists changes in its motion**. Newton stated that **mass** is a measure of inertia.



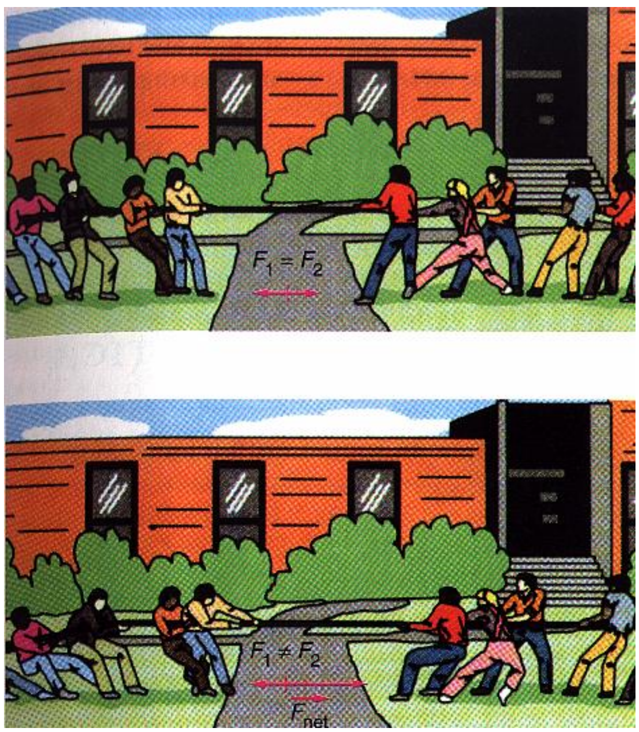
The **larger man** is more **difficult to push** to a motion because of his **larger inertia**

CONCEPT OF FORCE

- A **force** is a push or pull (**vector** quantity). Units of force of **Newtons** (N) or kgm/s^2.

- An **external** force is an applied force, such as kicking a ball. An **internal** force is a force from within an object, such as pushing on the dashboard of a car from inside the car. **External forces cause motion**, internal forces do not.

- A **net force** is the **resultant of several forces** acting in the same or different directions. **Balanced** forces are those that result in a **net force of zero**. **Unbalanced** forces are those that result in a **net force greater than zero**.



Balanced vs. Unbalanced Forces

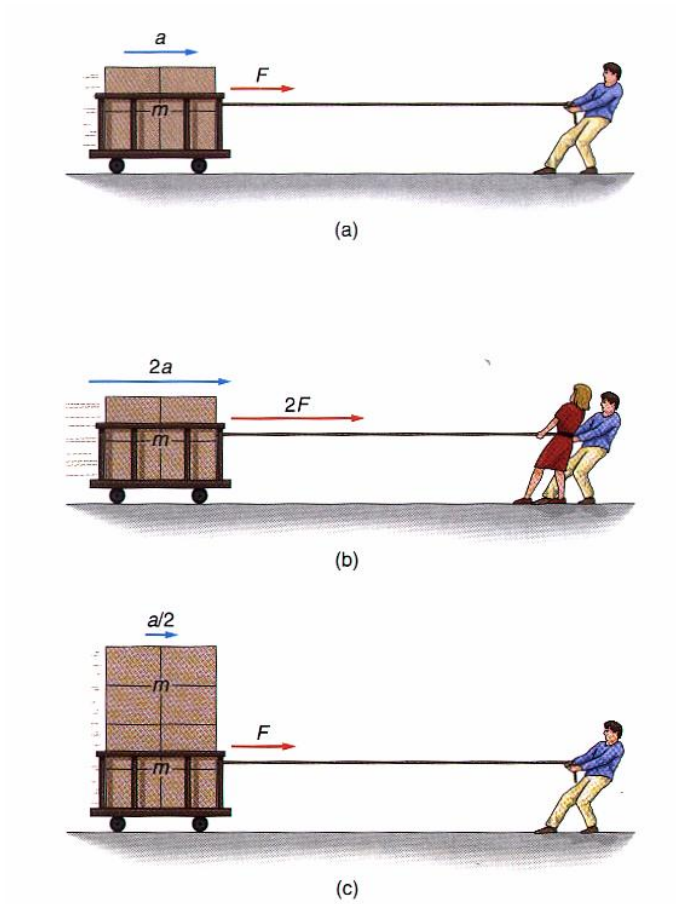
2[ND] LAW OF MOTION

The Force Law

- The **acceleration** of a body is **directly** proportional to the **net force** acting on the body, and **inversely** proportional to the **mass** of the body, and in the **direction** of the **net force**.

$$\text{Acceleration} = \frac{\text{Net Force}}{\text{Mass}}$$

$$a = \frac{F_{net}}{m} \quad \text{or} \quad F_{net} = ma$$



The relationship between Force, Mass and Acceleration

2^{ND} LAW OF MOTION

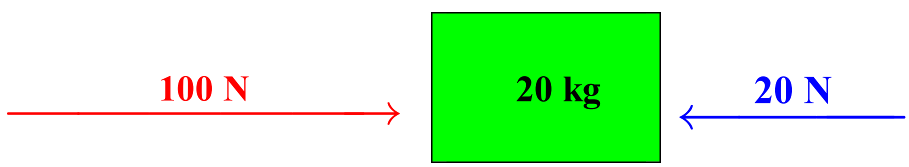
<u>Examples:</u>

1. What constant net force will give 2.0-kg object an acceleration of 5.0 m/s^2?

$$\mathbf{F = ma = (2.0\ kg)(5.0\ m/s^2) = 10\ N}$$

2. A net force of 90 N acts on a 60-kg ice skater. What is the acceleration?

3. A force of 100 N is applied to a box with a mass of 20-kg, to move it across a floor. If the friction between the box and the floor is 20 N, what is the acceleration of the box?



Net force =

Acceleration =

WEIGHT & MASS

- **Weight** of an object is the effect of **gravity** on the **mass** of the object, and is direct result of **Newton's 2nd Law**.

weight = mass x gravity

↑ ↑ ↑

F = m x a

Examples:

1. Calculate the weight of a 70.0-kg person on earth and on the moon, where gravity is 1/6 of the earth.

Earth $w = mg = (70.0\text{ kg})(10\text{ m/s}^2) = 700\text{ N}$

Moon $w = mg = (70.0\text{ kg})(\frac{10}{6})\text{m/s}^2) = 117\text{ N}$

2. A jar weighs 5.0 N. What is its mass?

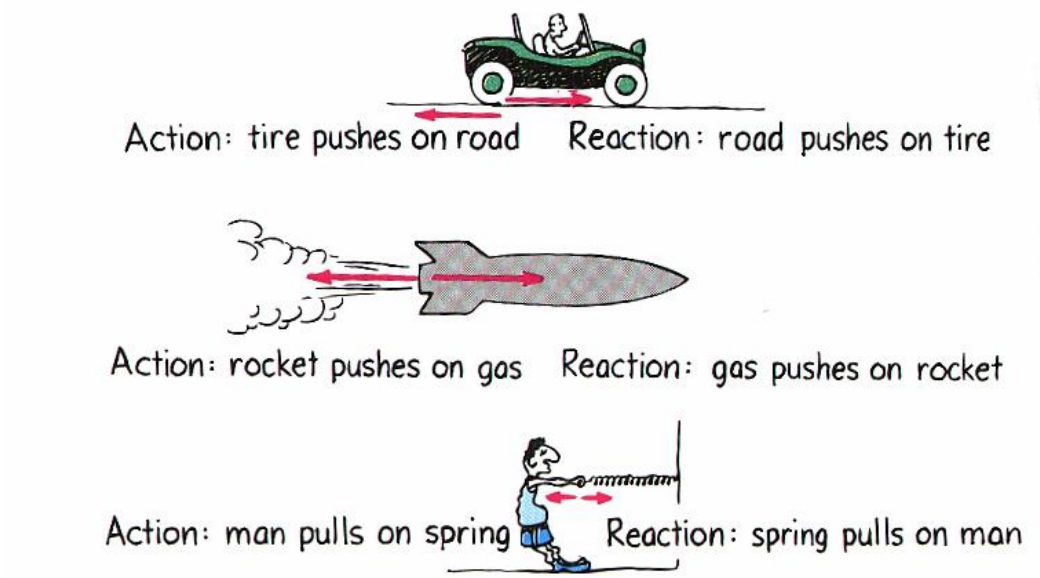
3. An 80.0-kg persons weights 765-N on top of a mountain. Calculate the acceleration due to gravity on the mountain.

$$g = \frac{w}{m} = \frac{765\text{ N}}{80.0\text{ kg}} = 9.56\text{ m/s}^2$$

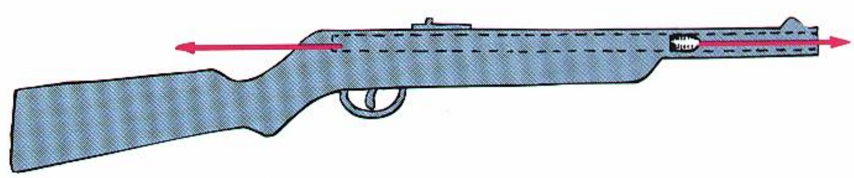
3rd Law of motion

Action-Reaction Law:

- For every **action** force, there an **equal** and **opposite reaction** force.



- The **force** exerted by the bullet on the rifle is **just as great** as the force exerted by the rifle on the bullet. Why does the **bullet accelerate more than the rifle**?



$$\frac{F}{m} = \mathbf{a}$$

Bullet

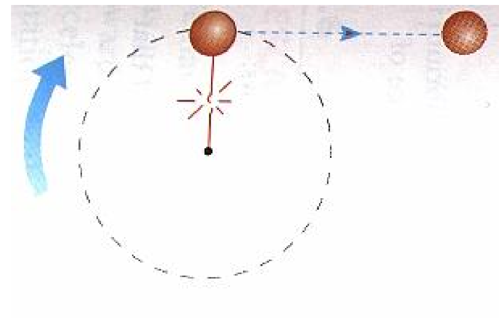
Based on Newton's 2nd Law, the **bullet accelerates rapidly** due to its **small mass.**

$$\frac{F}{\mathbf{m}} = a$$

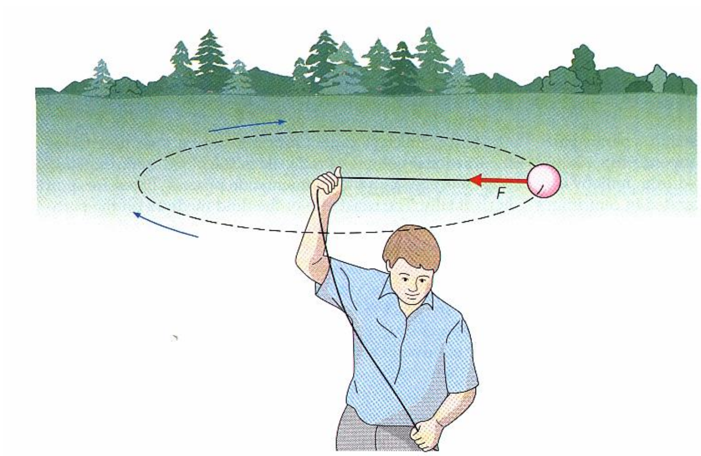
Rifle

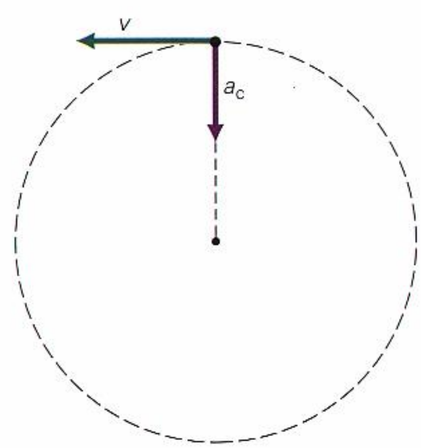
CIRCULAR MOTION

- Based on **Newton's 1st Law**, objects moving in **circular** motion, would fly off in a **straight line** if released.



- For objects to **continue in circular** motion, a **net force** must be acting on them, based on **Newton's 2nd Law**. This force is directed towards the **center** of the circle, and is thus called **centripetal** (center-seeking) **force**.





- The **centripetal force** causes **acceleration** directed towards the center of the circle, thus called **centripetal acceleration** (a_c).

LAW OF UNIVERSAL GRAVITATION

- Every body in the universe **attracts** every other body with a **force** that is **directly proportional** to the **product of their masses**, and **inversely proportional** to the **square of the distance** between them.

$$F = \frac{G m_1 m_2}{r^2}$$

where

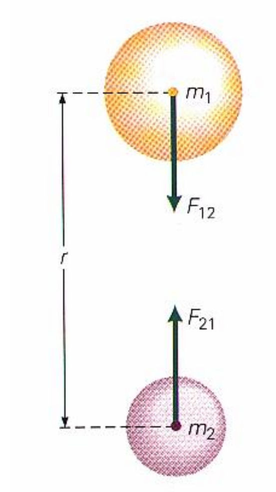
F=force of attraction between two bodies

G=gravitation constant

m_1=mass of one body

m_2=mass of second body

r=distance between two bodies



Examples:

1. By how much is the gravitational force between two bodies change when the distance between them is doubled? tripled?

2. Explain why you can feel the effect of gravity between you and the Earth, but not between you and your pencil.

LINEAR MOMENTUM

- **Momentum** is the **inertia** of **moving** objects.

- Momentum is the product of **mass** and **velocity**, and is a **vector** quantity.

momentum = mass x velocity

p = m**v**

- SI unit for momentum is ***kg·m/s*** or ***Ns***.

- To **change the linear momentum** of an object, a **net unbalanced force** is required.

Force produces linear motion

Examples:

1. Which has a greater momentum:
   the boulder or the runner? Why?

2. Calculate the momentum of a baseball that has a
   mass of 0.20 kg and is moving at a velocity of 30 m/s.

m =

v =

p =

3. A truck with a momentum of 85000 kgm/s is moving with a velocity of 50 m/s.
   Determine its mass.

m =

v =

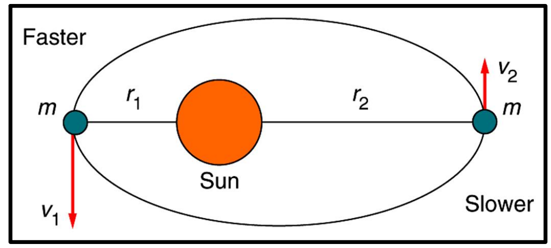
p =

ANGULAR MOMENTUM

- Objects that move around an **axis of rotation** possess **angular momentum**.

- A planet orbiting the sun (axis of rotation) possesses angular momentum.

- Angular momentum is the product of mass, velocity and distance from axis or rotation.

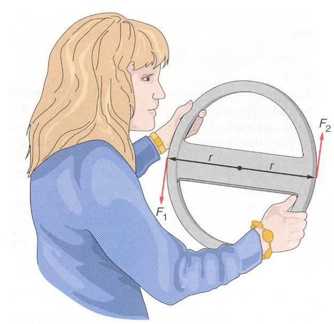


Angular momentum = mass x velocity x distance from axis of rotation

$$L = m\,v\,r$$

- To **change the angular momentum** of an object, a **net unbalanced torque** is required.

- The opposite forces applied to the steering wheel produce a net torque which rotates the wheel. Therefore,



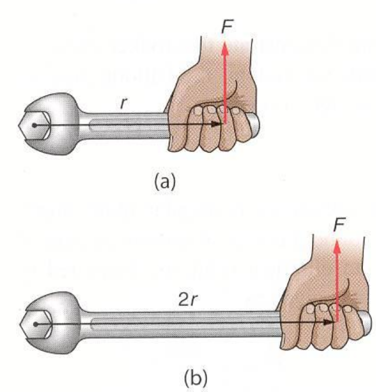
Torque produces rotational motion

- Torque is the product of force and lever arm.

Torque = force x lever arm

$$\tau = F \times r$$

- The same force applied through a longer lever arm produces a larger torque.



CONSERVATION OF MOMENTUM

- The ***total momentum*** of a ***system*** remains ***unchanged*** before and after an event.
- A ***system*** is a collection of objects under observation or study.

Total final momentum = Total initial momentum

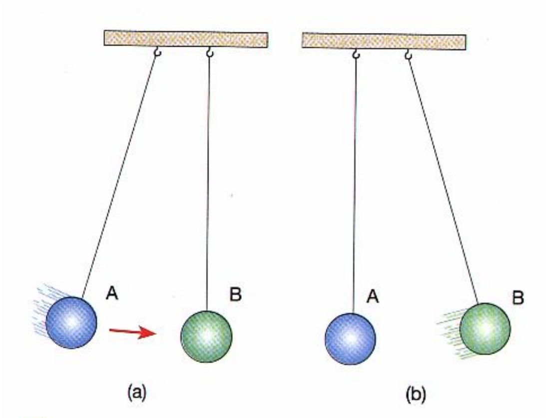
$P_f = P_i$ $\quad P = p_1 + p_2 + p_3 + \ldots$

Before collision (initial)

$$\mathbf{P_i = p_A + 0 = m_A v_A}$$

After collision (final)

$$\mathbf{P_f = 0 + p_B = m_B v_B}$$



Since $P_f = P_i$ then $m_B v_B = m_A v_A$

Examples:

1. A 2-kg ball with a velocity of 3 m/s strikes a 1-kg stationary ball and comes to stop. With what velocity will the 1-kg ball move after collision?

   $m_A =$

   $V_A =$ $\qquad V_B = \_\_\_\_\_\_\_\_\_\_ =$

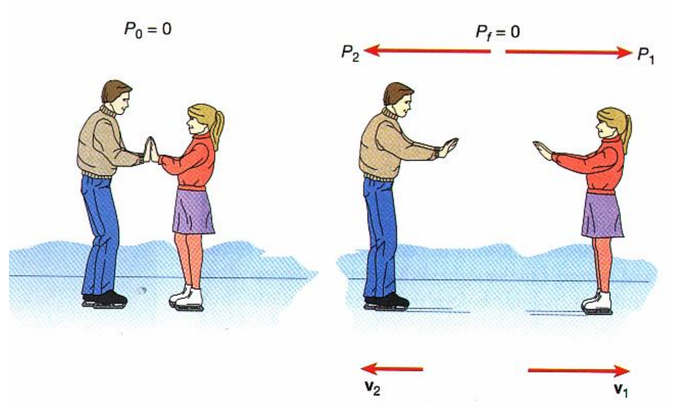
   $m_B =$

   $V_B =$

CONSERVATION OF MOMENTUM

Examples:

2. Two ice skaters push each other, and move in opposite directions. The mass of one is 75 kg, and his speed is 2 m/s. If the mass of the other is 30 kg, what is her speed?



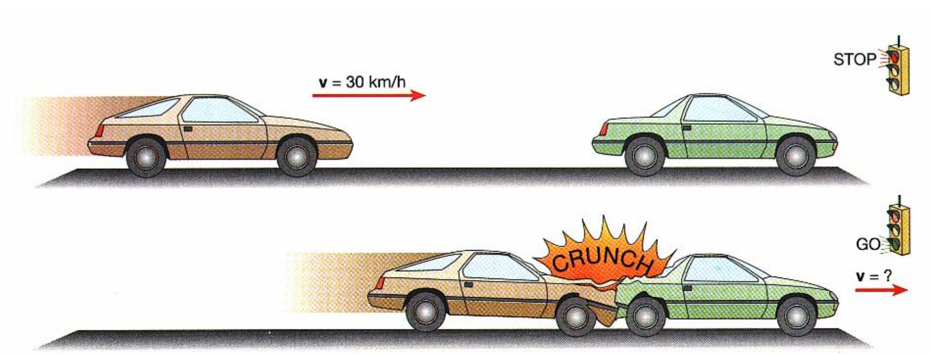
$$P_i = P_f = 0$$

$$P_f = m_1 v_1 + m_2 v_2 = 0$$

$$m_2 v_2 = - m_1 v_1$$

$$v_2 = -\frac{m_1 v_1}{m_2} = -\underline{\qquad\qquad\qquad} =$$

3. A car traveling at 30 km/h strikes a car of equal size that is stopped at a traffic light. After the collision the two cars lock bumpers. If the mass of each car is 500 kg, what is the velocity with which the cars move together after the collision?



$m_1 =$ $v_1 =$

$m_2 =$ $v_2 =$

$$P_i = P_f$$

$$P_i = m_1 v_1 + m_2 v_2 =$$

$$P_f = (m_1 + m_2)V =$$