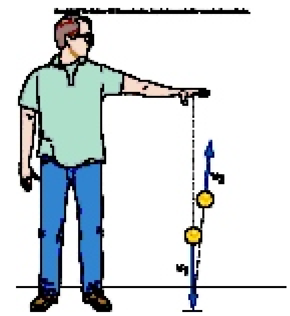
Chapter 7
Momentum and Impulse

How can we describe the change in velocities of colliding football players, or balls colliding with bats?
How does a strong force applied for a very short time affect the motion?
Can we apply Newton's Laws to collisions?
What exactly is ***momentum***? How is it different from force or energy?
What does "***Conservation of Momentum***" mean?

What happens when a ball bounces?



When it reaches the floor, its velocity quickly changes direction. There must be a strong force exerted on the ball by the floor during the short time they are in contact. This force provides the upward acceleration necessary to change the direction of the ball's velocity.
It will help to write Newton's second law in terms of the total change in velocity over time, instead of acceleration:

$$F_{net} = ma = m\left(\frac{\Delta v}{\Delta t}\right)$$

Multiply both sides of Newton's second law by the time interval over which the force acts:

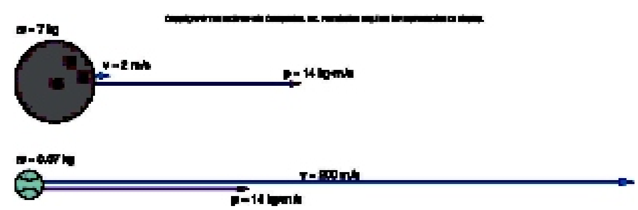
$$F_{net}\,\Delta t = m\,\Delta \mathbf{v}$$

The left side of the equation is ***impulse***, the (average) force acting on an object multiplied by the time interval over which the force acts. The right side of the equation is the ***change in the momentum*** of the object. **The *momentum* of the object is the mass of the object times its velocity.**

$$p = mv$$

Examples:

A bowling ball and a tennis ball can have the same momentum, if the tennis ball with its smaller mass has a much larger velocity.



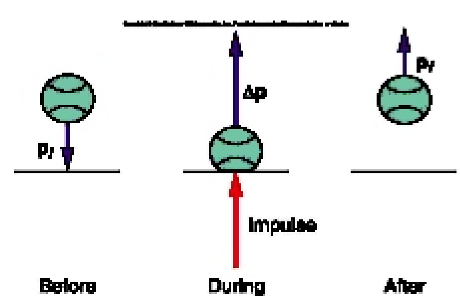
Impulse-Momentum Principle:

The impulse acting on an object produces a change in momentum of the object that is equal in both magnitude and direction to the impulse

$$\text{impulse} = \text{change in momentum} = \Delta p$$

Example:

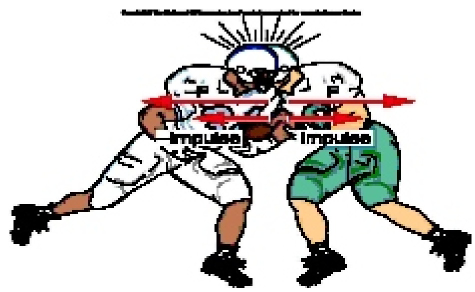
When a ball bounces back with the same speed, the momentum changes from *mv* to *-mv*, so the change in momentum is *2mv*.



Example: Find the momentum of an object of mass 250 kg moving at a speed of 30 MPH.

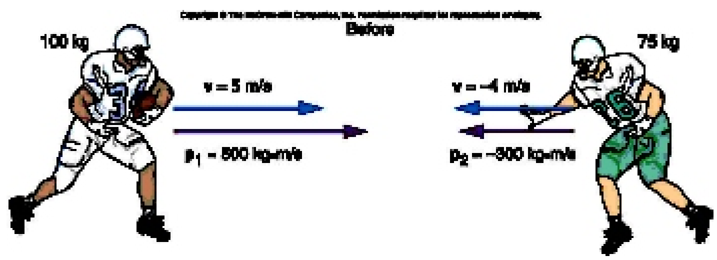
Conservation of Momentum:

If the net external force acting on a system of objects is zero, the total momentum of the system is ***conserved***



Example:

Consider the situation when a defensive back an a full back collide. Newton's third law still hold (For every action, there is an equal but opposite reaction). The defensive back exerts a force on the fullback and the fullback exerts an equal but opposite force on the defensive back. The impulses on both are equal and opposite. The changes in magnitude for each are equal and opposite. The total change of the momentum for the two players is zero.



Example:

a) A 100-kg fullback moving straight down field collides with a 75-kg defensive back. The defensive back hangs on to the fullback, and the two players move together after the collision. What is the initial momentum of each player?

Fullback:
$p = mv = (100\ \text{kg})(5\ \text{m/s}) = 500\ \text{kg}\cdot\text{m/s}$

Defensive back:
$p = mv = (75\ \text{kg})(-4\ \text{m/s}) = -300\ \text{kg}\cdot\text{m/s}$

b) What is the total momentum?

$$p_{total} = p_{fullback} + p_{defensiveback} = 500 kg \cdot m/s - 300 kg \cdot m/s = 200 kg \cdot m/s$$

c) What is the velocity of the two players immediately after the collision?

Total mass: $m = 100\ \text{kg} + 75\ \text{kg} = 175\ \text{kg}$

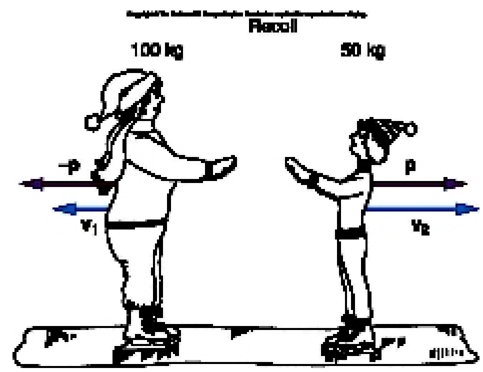
Velocity of both: $v = p_{total} / m = (200\ \text{kg}\cdot\text{m/s}) / 175\ \text{kg} = 1.14\ \text{m/s}$

Recoil:

Questions: Why does a shotgun slam against your shoulder when fired, sometimes painfully? How can a rocket accelerate in empty space when there is nothing there to push against except itself?

Example: Two skaters of different masses prepare to push off against one another. Which one will gain the larger velocity?

The net external force acting on the system is zero, so conservation of momentum applies. Before the push-off, the total initial momentum is zero. The total momentum after the push-off should also be zero.



Both must move with momentum values equal in magnitude but opposite in direction: $p_2 = -p_1$ .When added together, the total final momentum of the system is then zero. Since momentum is mass times velocity $p = mv$, the skater with the smaller mass must have the larger velocity: $m_1v_1 = m_2v_2$

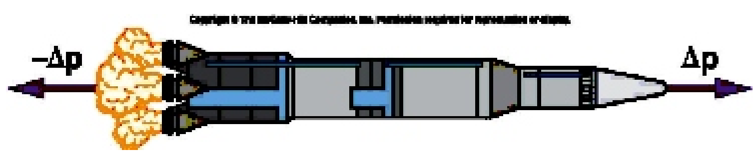
The lighter object attains the larger velocity to equalize the magnitudes of the momentums of the two objects. The total momentum of the system is conserved and does not change.

Definition:

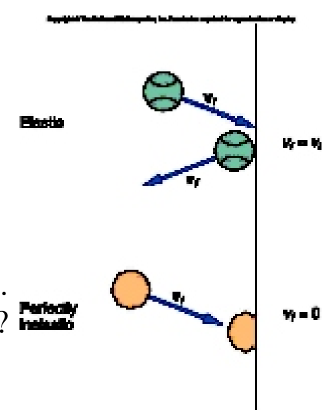
Recoil is what happens when a brief force between two objects causes the objects to move in opposite directions

Question: How does a rocket accelerate in empty space when there is nothing to push against?

The exhaust gases rushing out of the tail of the rocket have both mass and velocity and, therefore, momentum. The momentum gained by the rocket in the forward direction is equal to the momentum of the exhaust gases in the opposite direction. The rocket and the exhaust gases push against each other. Newton's third law applies.



Elastic and Inelastic Collisions:



Different kinds of collisions produce different results. Sometimes the objects stick together. Sometimes the objects bounce apart. What is the difference between these types of collisions? Is energy conserved as well as momentum?

A collision in which the objects stick together after collision is called a ***perfectly inelastic collision***. The objects do not bounce at all. If we know the total momentum before the collision, we can calculate the final momentum and velocity of the now-joined objects.

Examples:

1. The football players who stay together after colliding. (See page 2)

2. Coupling railroad cars: Four railroad cars, all with the same mass of 20,000 kg, sit on a track. A fifth car of identical mass approaches them with a velocity of 15 m/s. This car collides and couples with the other four cars.

What is the initial momentum of the system?
What is the velocity of the five coupled cars after the collision?
Is the kinetic energy after the railroad cars collide equal to the original kinetic energy of car 5?

Facts:

Energy is not conserved in a ***perfectly inelastic collision***.

If the objects bounce apart instead of sticking together, the collision is either ***elastic*** or ***partially inelastic***.

An ***elastic collision*** is one in which ***no energy is lost***.

A ***partially inelastic collision*** is one in which ***some energy is lost***, but the objects do not stick together.

The ***greatest portion of energy is lost*** in the ***perfectly inelastic collision***, when the objects stick.

A ball bouncing off a floor or wall with no decrease in the magnitude of its velocity is an ***elastic collision***. In this case, the kinetic energy does not decrease, no energy has been lost.

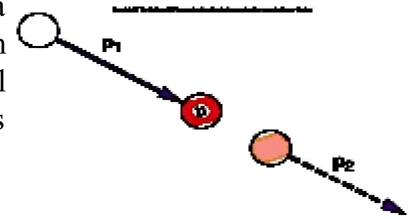
A ball sticking to the wall is a ***perfectly inelastic collision***. In this case, the velocity of the ball after the collision is zero, and Its kinetic energy is then zero, all of the kinetic energy has been lost.

Most collisions involve some energy loss, even if the objects do not stick, because the collisions are not perfectly elastic. Heat is generated, the objects may be deformed, and sound waves are created.

These would be ***partially inelastic collisions***.

Example: A head-on collision between the white cue ball and the eleven ball initially at rest.

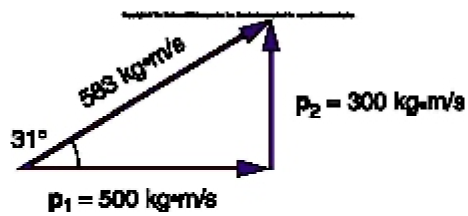
If spin is not a factor, the cue ball stops and the eleven ball moves forward with a velocity equal to the initial velocity of the cue ball. The eleven ball's final momentum is equal to the cue ball's initial momentum. Momentum is conserved. The eleven ball also has a final kinetic energy equal to the cue ball's initial kinetic energy. Energy is conserved

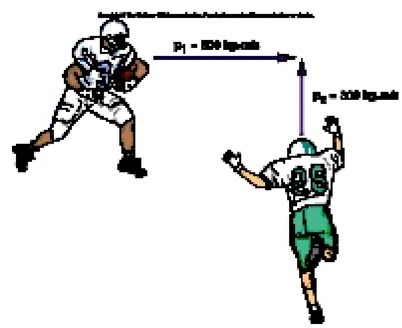


For equal masses, the only way for momentum and energy to both be conserved is for the cue ball to stop and the eleven ball to move forward with all the velocity.

Collisions at an Angle:

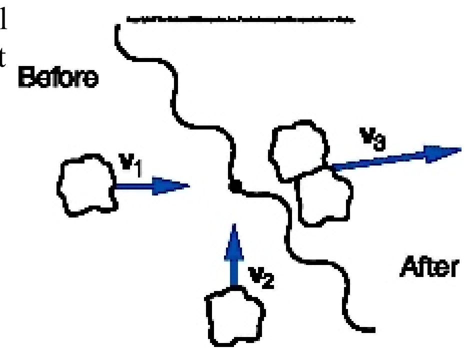
1. Two football players traveling at right angles to one another collide and stick together. What will be their direction of motion after the collision?
   The final momentum of the two players stuck together is equal to the total initial momentum.





2. Two lumps of clay of equal mass are traveling at right angles with equal speeds as shown, when they collide and stick together. Is it possible that their final velocity vector is in the direction shown?

   No. The final momentum will be in a direction making a 45° degree angle with respect to each of the initial momentum vectors.



3. Two cars of equal mass Collide at right angles to one another in an intersection. Their direction of motion after the collision is as shown. Which car had the greater velocity before the collision?

   Since the angle with respect to the original direction of A is smaller than 45°, car A must have had a larger momentum and thus was traveling faster.