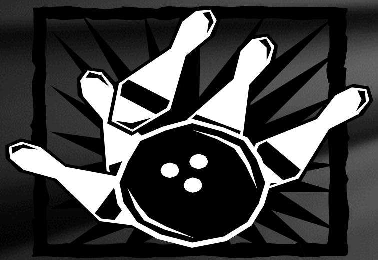
Momentum: Inertia in Motion

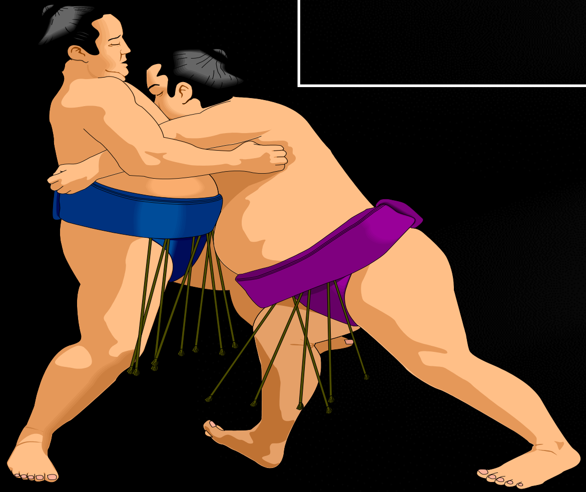
Momentum is the product of an object's *mass* & *velocity* and is represented by the vector **p**

$$\mathbf{p} = m\,\mathbf{v}$$



- Note that **p**(momentum) is a vector quantity & has the same direction as the velocity
- Note that a change in velocity results in a change in momentum: $\Delta \mathbf{p} = m\,\Delta \mathbf{v}$
- The SI units for momentum is: kg m/s

Newton's 2nd Law & Change in Momentum



Newton's 2nd Law:

$F = m\,a$

Substitute

Definition of acceleration:

$a = \Delta v/t$

$F = m\,(\Delta v/t)$

Change in momentum!

$F\,t = m\,\Delta v$

The Impulse-Momentum Relationship

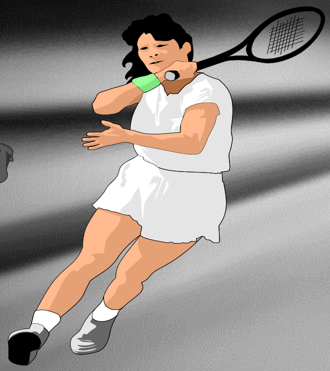
Impulse! | **Change in momentum!**

$$F\,t = m\,\Delta v$$

- **Impulse** is the product of a net *force* exerted over an interval of *time*
- The change in momentum (Δp) of an object is equal to the impulse given it
- The unit for impulse is the Newton second (N s)
- The direction of the impulse will be in the direction of the force

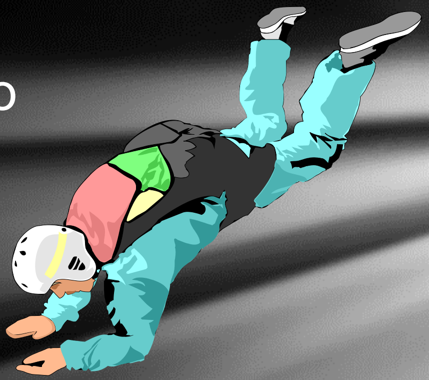
Increasing Momentum

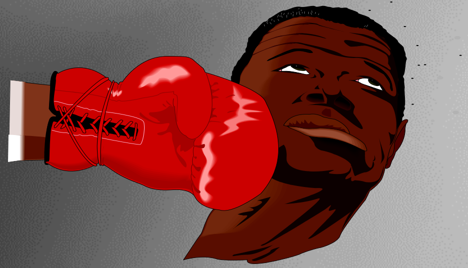
- Hitting a homerun
- Smashing a tennis ball
- Nailing a soccer goal
- Spiking a volleyball
- Using a long-barreled rifle



Decreasing Momentum

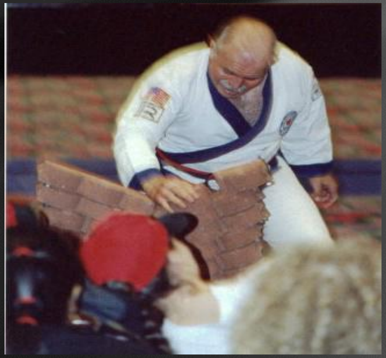
- Catching a football
- Jumping out of burning buildings into a trampoline vs. a board
- Crashing into water barrels vs. concrete
- Air bags vs. dashboard
- Landing from high places: bending your knees
- Rolling with punches





The Physics of Karate
Hammer Fist Strike

- F_{board} = 856 N
- F_{hand} = ?
- m = 0.5 kg
- Δv = -6 m/s
- t = 2.3 ms

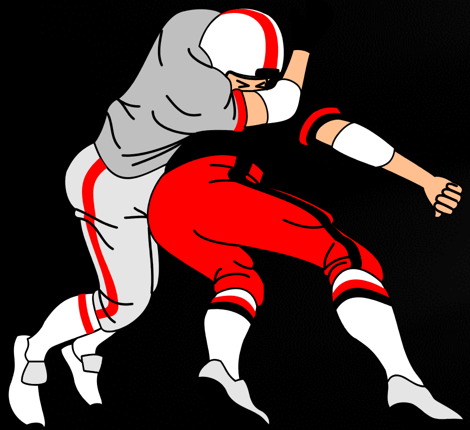


- Source: Scientific American, 1979
- Source: University of Nebraska, Engineering Mechanics, Wei-Sheng Tan

The Law of Conservation of Momentum

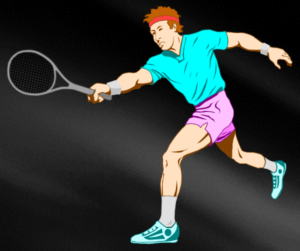
"The total momentum of an isolated system does not change"

- Isolated system: no net external force
- The initial momentum is equal to the final momentum of a system before & after a collision



$$p_{before} = p_{after}$$

Newton's 3rd Law & Conservation of Momentum



Newton's 3rd Law revisited:

- "A single force cannot exist in isolation--every force on a body is accompanied by an equal & opposite force on another body"

Conservation of Momentum:

- The momentum gained by one body in an interaction (collision) is equal to the momentum lost by the other body

$$p_{lost} = p_{gained}$$

Conservation of Momentum & Collisions

- Elastic Collisions (Bouncing):

$$m_1v_1 + m_2v_2 = m_1v_1' + m_2v_2'$$

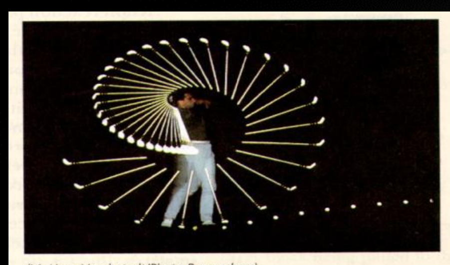
- Inelastic Collisions (Sticking):

$$m_1v_1 + m_2v_2 = (m_1 + m_2)\,v'$$

Velocity is a vector & direction is important!
Be careful of "+" and "-" signs!

Momentum & Newton's 3 Laws

- **Newton's 1st Law: Inertia**
  Momentum =
  inertia in motion!



- **Newton's 2nd Law: F_{net} = ma**
  Net Force over time =
  change in momentum!
  (Impulse!)

- **Newton's 3rd Law: Action-Reaction**
  Momentum lost =
  Momentum gained

Momentum is conserved!