# Momentum

**<u>momentum</u> (p)**: *Ltn*. “motion” Momentum is a measure of the tendency of an body to remain in motion. Newton recognized that faster moving bodies are harder to stop, as well as more massive bodies. Both of these qualities (velocity and mass) is what he refered to as “quality of motion.”

This linear motion tendency can be described by two factors; mass & velocity. Therefore;

**p = m x v** [<u>units</u>; kgm/s] (p) has magnitude and direction ----> **vector!**

*An increase in either (m) or (v) will require more force (work) to bring objects to rest.
ex.’s; Supertankers cut engines 25 km out of port. Titanic, truck *<u>vs</u>*. bullet, football: running/half/fullbacks

>Can momentum be equated with inertia?
-Inertia is a property of an object (mass!), whereas momentum is acquired only when mass is set into motion.

ex; A 112 kg football player is running at 8.5 m/s. What is his (p)? p = m x v = **952 kgm/s**

>When Newton developed his $2^{nd}$ law of motion, he knew that an unbalanced force acting on an object caused a change in (p). $F = ma = m(v_f - v_i)/\Delta t = m\Delta v/\Delta t$ --------> $F = m\Delta v/\Delta t$ ---> $F\Delta t = m\Delta v$

$\mathbf{F\Delta t = m\Delta v = \Delta p}$ [Note that both have the same units: $kgm/s^2 s$ = kgm/s]

Newton’s $2^{nd}$ law was originally written in terms of (p) where;

$F = \text{change in momentum}/\text{change in time} = \Delta p/\Delta t$ ----> $= m\Delta v/\Delta t = ma$

**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. This is another way of expressing Newton’s second law of motion.

change in momentum ($\Delta$p) = Impulse (J) delivered [$F\Delta t = J$ (units = Ns)]

ex.’s; Catching (stopping) a pitcher’s fast ball:

>If contact time is small ($\Delta$t), then (F) will be large; [“sting” hands]
*Note that an incoming ball has a fixed (p) value!*

>If contact time is large ($\Delta$t), then (F) will be small; [SRS airbag]
Manipulate impulse by moving your hands in the direction of ball. [“cradle” ball]

>Jump from head-high wall: stiff-legged *<u>vs</u>*. bended knees [bending knees increases contact time]

>Cushion in heel of running shoes increases contact time and decreases impulse delivered.

>When hitting balls in sports, to drive ball faster or farther the player will increase the time of contact ($\Delta$t) by “following through” with the swing. Therefore, a larger impulse is delivered and thus a larger change in momentum (or velocity) results.

>In ballastic cannons, by increasing the time during which the force acts on the projectile in a longer barrel, then the (p) of the projectile will increase, since $F\Delta t = \Delta p$. Because the projectiles’ mass does not change, then its velocity must increase.
[longer barrel ----> more contact time ($F\Delta t$) ----> $\Delta p = m(\Delta v)$ ----> higher velocity ----> **greater range**]

seatbelts:

ex; A car is moving at 13.5 m/s (~ 30 mph) and is braked to a sudden stop in 3 s?

sol a) What is the force exerted on a 68 kg (~150 lb) passenger by the seatbelt?

$F = {}^{\Delta p}/_{\Delta t} = {}^{m(v_f - v_i)}/_{\Delta t} = {}^{68\text{ kg }(-13.5\text{ m/s})}/_{3.0\text{ s}}$ = **-306 N** (~ 69 lb) | 1.0 N ~ 0.25 lb |

b) What is the force exerted if no seatbelt is used, and the passenger is stopped in 0.5 s?

$F = {}^{\Delta p}/_{\Delta t} = {}^{m(v_f - v_i)}/_{\Delta t} = {}^{68\text{ kg }(-13.5\text{ m/s})}/_{0.5\text{ s}}$ = **-1,836 N** (~ 413 lb)

[A minus sign indicates that the force on the person is in an opposite direction to the initial velocity.]

ex; During a tennis serve a 60 gram tennis ball leaves the racquet with a speed of 40 m/s. If the contact time is 0.005 seconds, then what is the average force on the ball?

sol; $F = {}^{\Delta p}/_{\Delta t} = {}^{(0.06\text{ kg})(40\text{ m/s})}/_{0.005\text{ s}} = 480\text{ N}$ (~ 120 lb of force)

ex; A 1,500 kg car strikes a tree at 8.5 m/s, coming to a stop in 0.15 seconds. Find its initial momentum and the average force on the car while it is being stopped.

sol; p = mv = **$1.275 \times 10^4$ kgm/s**

$F = {}^{\Delta p}/_{\Delta t} = {}^{1.275 \times 10^4\text{ kgm/s}}/_{0.15\text{ s}}$ = **$8.5 \times 10^4$ N**

ex; A golf club exerts an average force of 500 N on a 0.1 kg golf ball. If the club is in contact with the ball for 0.01s;

a) What is the magnitude of the impulse delivered by the club?

b) What is the change in velocity of the golf ball?

sol; $J = F\Delta t = (500\text{ N})(0.01\text{ s})$ = **5 Ns**

$J = \Delta p = m\Delta v$ ----> $\Delta v = {}^{J}/_{m} = {}^{5\text{ Ns}}/_{0.01\text{ kg}}$ = **50 m/s**

ex; What force is delivered to a plane flying eastward at 180 m/s when it strikes a 4 kg bird flying westward at 15 m/s, where the impact lasts 0.001 seconds?

sol; $F = {}^{\Delta p}/_{\Delta t} = {}^{m(\Delta v)}/_{\Delta t} = {}^{m(v_2 - v_1)}/_{t} = {}^{4\text{ kg }[180\text{ m/s} - (-15\text{ m/s})]}/_{0.001\text{ s}}$ = **$7.8 \times 10^5$ N**

*space junk - 5,000 metric tons since Sputnik, and 200 metric tons added per year

**momentum & collisions**;

elastic - Bodies spring back to original shape after collision, and the energy that was used to temporarily deform the bodies is used to push each other body (law # 3), causing separation, and the restoration of the original shape. No energy is lost to deformation of the particles. [**(p) & KE are conserved**]

inelastic - Bodies are deformed (and remain distorted) after the collision, and stick together. The energy used for deformation is not fully converted into motion, but rather heat. [**Only (p) is conserved!**]
ex; dead-blow hammer

coefficient of restitution (*e*): A ratio of the relative velocities after the collision to that before. $[{}^{v_f}/v_i]$

When (*e*) = 1.0 ----> perfectly elastic, and when (*e*) = 0 ----> perfectly inelastic (stick together).