Motion and Momentum

Applying Newton's Laws

$P = mv$

Newton's Laws

- Explain why some objects are in motion or are stationary.
- Its not easy to measure acceleration so we measure it by finding a change in velocity.
- Newton originally expressed his Second law in a different way. He talked about a quantity of motion and this is what we now call **Momentum**

The second Law

- Newton Originally wrote the second law like this:
- Look at this equation and compare it to our version, are they the same?

$$F = \frac{\Delta(mv)}{\Delta t}$$

$$F = ma$$

$$\text{but } a = \frac{\Delta v}{\Delta t}$$

Momentum

- We now call the product of mass and velocity **Momentum**
- It is given the symbol ***p***
- *We can write Newtons second law like this*

$$F = \frac{\Delta p}{\Delta t}$$

Momentum

- Thus we can say that the unbalanced force equals the rate of change of momentum with respect to time.

- Any moving body has momentum equal to the product of the bodies mass and its velocity.

The Law Of Momentum

- Momentum is a conserved quantity in a closed system.
- A closed system is a system in which no outside forces act.
- Momentum is neither created or destroyed, thus we can say that the **total momentum is constant**

Newton's Third Law

State Newtons Third Law

For every action there is an equal but opposite reaction

Mathematically this looks like this:

$$F_{A\ on\ B} = -F_{B\ on\ A}$$

$$F = -F$$

$$\therefore \frac{\Delta(m_B v_B)}{\Delta t} = -\frac{\Delta(m_A v_A)}{\Delta t}$$

since the time intervals are the same,

$$\Delta(m_B v_B) = -\Delta(m_A v_A)$$

$$\therefore \Delta(m_B v_B) + \Delta(m_A v_A) = 0$$

$$\text{or } \Delta p_A + \Delta p_B = 0$$

The total change in momentum within the closed system is zero

This means that **momentum is conserved**

Impulse

- If the second law is stated as

$$F = \frac{\Delta(mv)}{\Delta t}$$

- Then we can rearrange it to look like this:

$$F\Delta t = \Delta(mv)$$

- We call this **Impulse :**

$$\text{impulse} = \text{F} \bullet \Delta\text{t}$$

Units…

Momentum: kg.m/s

Impulse: N.s

Since impulse is equal to the change in momentum, these units must be equivalent.

We can show this to be true:

$$[N.s] = [kg.m/s^2].[s] = [kg.m/s]$$

Example 1(a)

What is the momentum of a 112kg rugby player running at 3.6 m/s?

Solution:

$$p = mv$$

$$= (112kg)(3.6m/s)$$

$$= 403.2 \text{ kg.m/s}$$

Example1(b)

What impulse must a tackler impart to the rugby player to bring him to a stop?

Solution:

$$
\begin{aligned}
\text{Impulse} &= F\Delta t \\
&= \Delta(mv) \\
&= 0 - 402.3\,\text{N.s} \\
&= -402.3\,\text{N.s}
\end{aligned}
$$

Example 1(c)

If the tackle is completed in 0.80s, what average force did the tackler exert on the first player?

Solution:

$$F = \frac{impulse}{\Delta t}$$

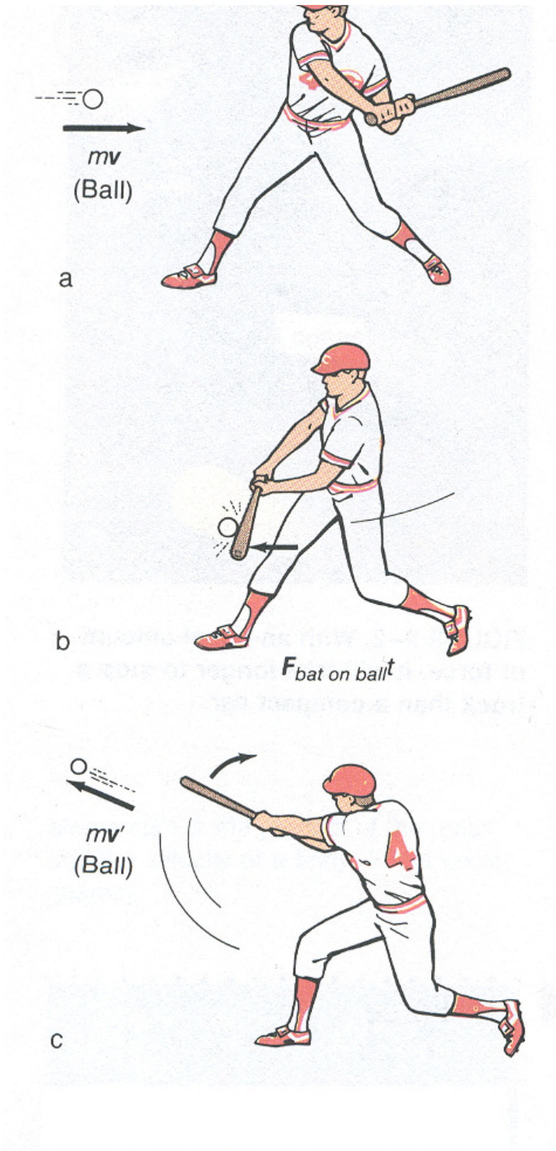
$$= \frac{403.2 N.s}{0.80 s}$$

$$= -504\ N$$

Impulse and Momentum change

A 0.144 kg baseball is pitched horizontally at +38 m/s. After it is hit by a bat it moves at -38 m/s.

a) What impulse did the bat deliver to the ball?
b) If they were in contact for 0.80ms, what force was delivered to the ball?
c) Find the average acceleration of the ball during its contact with the bat



Answer: part a)

$$F\Delta t = \Delta p$$

$$\Delta p = mv_2 - mv_1$$

$$= m(v_2 - v_1)$$

$$= (0.144kg)(-76m/s)$$

$$= -11kgm/s\text{(in the direction of the batted ball)}$$

Answer: part b)

$$F\Delta t = \Delta p$$

$$\text{so } F = \frac{\Delta p}{\Delta t}$$

$$= \frac{-11kg.m/s}{0.80ms}$$

$$= -1.4\times 10^4\ \text{N}$$

Answer part C)

$$F = ma$$

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

$$a = \frac{-1.4\times10^{4}\,\mathrm{N}}{0.144\mathrm{kg}}$$

$$= -9.7\times10^{4}\,m/s^{2}$$

Part II
Conservation Of Momentum

During the study of colliding objects Newton discovered a very interesting phenomenon:

The total momentum of the colliding objects was the same before and after a collision.

Conservation of Momentum

- The momentum in a closed system is conserved, or we can say that the net momentum is 0

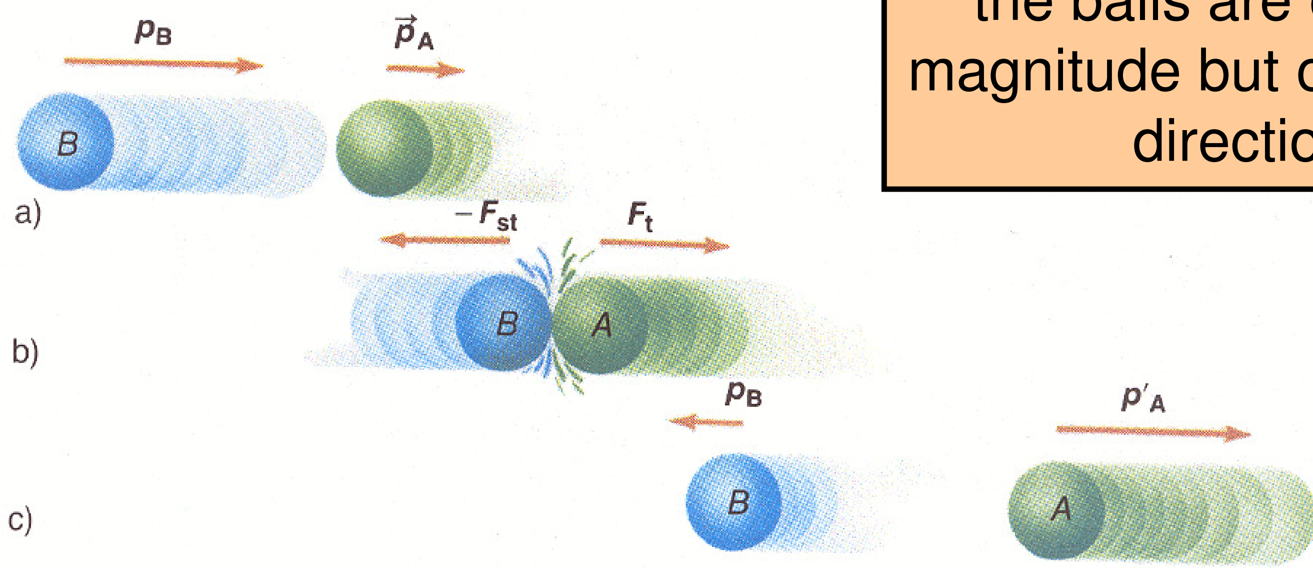
Another way to say this is that the momentum before an event is exactly the same as the momentum after

Or

$$\vec{p}_{before} = \vec{p}_{after}$$

a) Ball A is moving with momentum P_A while ball B is moving with its momentum P_B

b) The balls collide and the impulses provided to the balls are equal in magnitude but opposite in direction



c) After the collision ball A moves with a new momentum and so does ball B

Lets try an example

Ball A of mass 0.355 kg rolls along at 0.095 m/s. It collides with ball B of mass 0.710 kg moving in the same direction with a velocity of 0.045 m/s. After the collision ball A continues with as velocity of 0.035 m/s, what is the velocity of B after the collision?

$$\text{Basic Equation}: \vec{p}_A + \vec{p}_B = \vec{p}_A{}' + \vec{p}_B{}'$$