<div align="center">**Linear Momentum**</div>
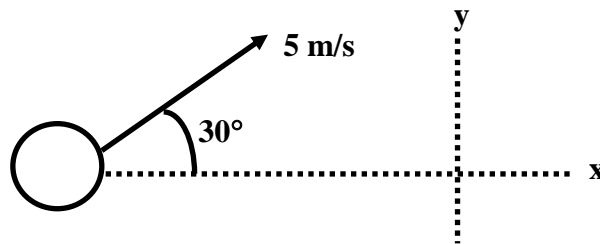
I.   **Linear Momentum**

A.   **Definition**
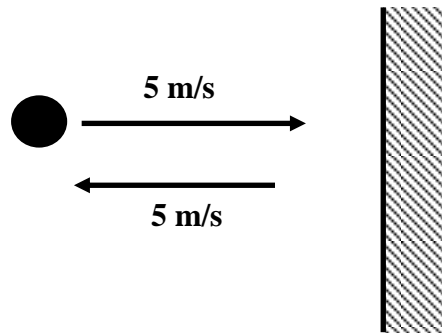
$$\vec{p} = M\vec{v}$$

Linear Momentum is a **VECTOR** !!

EXAMPLE: A 2.00 kg ball is traveling at 5 m/s as shown below:

A)   What is the ball's linear momentum in polar form?

B)   What is the ball's linear momentum in Cartesian form?

Example 2: A 2.00 kg ball initially traveling at 5.00 m/s strikes a wall and bounces backward at the same speed as shown below.

5 m/s

5 m/s

What is the change in the momentum of the ball?

What caused a change in linear momentum?

II.   Newton's 2nd Law (Varsity Form)

A.

The time-rate-of-change of an object's linear momentum is equal to the net external force applied to the body.

$$\sum \vec{F}_{EXT} = \lim_{\Delta t \to 0} \frac{\Delta \vec{p}}{\Delta t}$$

It's NEW!
It's Improved!
It's Newton II!!

B.   Newton's second law says that the **linear momentum** of an object will **only change** if it is <u>acted</u> upon by a **net external force**.

C.   Why Was Newton II Modified?

$$\sum \vec{F}_{Ext} = \lim_{\Delta t \to 0} \frac{\Delta (M\vec{v})}{\Delta t}$$

$$\sum \vec{F}_{Ext} = \lim_{\Delta t \to 0} \left(\frac{\Delta M}{\Delta t} \vec{v} + M \frac{\Delta \vec{v}}{\Delta t} \right)$$

$$\sum \vec{F}_{Ext} = \lim_{\Delta t \to 0} \left(\frac{\Delta M}{\Delta t} \right) \vec{v} + M\vec{a}$$

$$\sum \vec{F}_{Ext} - \lim_{\Delta t \to 0} \left(\frac{\Delta M}{\Delta t} \right) \vec{v} = M\vec{a}$$

Thus, an object may accelerate if:
1) acted upon by a net external force (like a falling ball)
2) expelling mass in the direction opposite the desired acceleration (like rockets)
3) obtaining mass in the same direction as acceleration (like radiation pressure)

In our previous work, we restricted Newton II to a particle (object of constant mass). Thus, we have using our new work that

$$\frac{\Delta M}{\Delta t} = 0$$

which gives us our previous result that

$$\sum \vec{F}_{Ext} = M\vec{a}$$

> Our Improved Newton II is better because it also works for rockets and other systems in which the mass is not constant.

III. Impulse

A. Definition

B. Graphical Interpretation

Graphically, the impulse is the _____ _____

a _____ _____ _____.

F_x

t

C.   **Connection Between Impulse And Newton II**

Using Calculus, one can rewrite the varsity form of Newton II to show a
connection between the impulse and the change in linear momentum.

The impulse due to the net external force is the **Change** in

the **Linear Momentum** of the object.

D.   **Impulse and Average (Constant) Force**

Many problems involve forces that change drastically with time. For example, the
forces involved in a car collision change very quickly and are difficult to predict
or measure. Such forces are called impulse forces.

We can use the concept of the impulse to **replace these forces with an average
force** that would produce the same area under the force-time curve (change in
momentum). **Thus, by measuring the initial and final velocity of an object, we
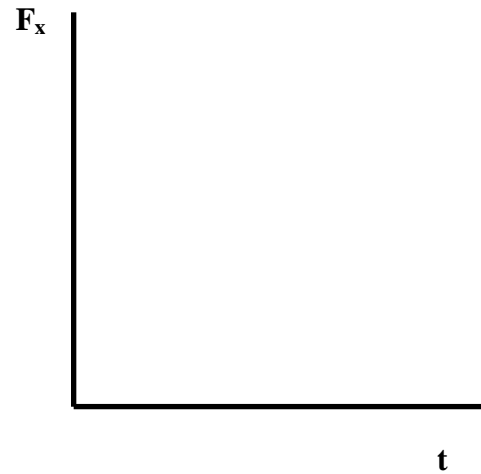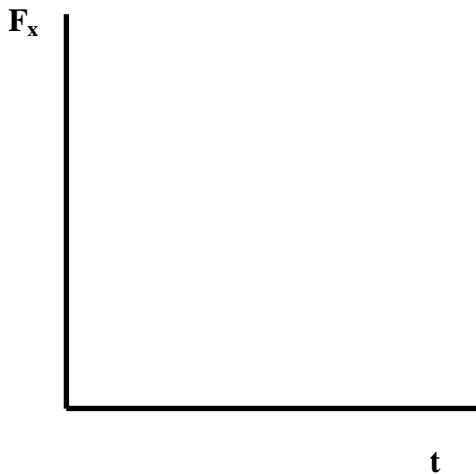can determine the average force that was exerted upon the object.**

The impulse for the average (constant) force is given by

$$\vec{I} = \vec{F}_{av}\,\Delta t$$

"This is just the area of a rectangle!!!"

Thus, we have that

$$\vec{I} = \Delta \vec{p} = \vec{F}_{av}\,\Delta t$$

F_x

F_x

t   t

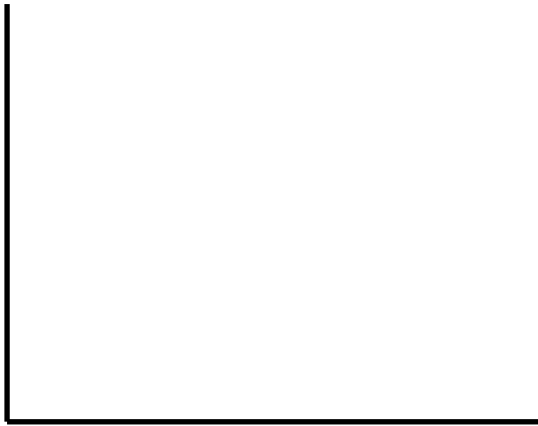**Graphs are equivalent in their change of linear momentum (impulse)!!**

Example: How does our previous discussion relate to the operation of seat belts, air bags, catching baseballs, karate chops and boxing punches?

Solution:

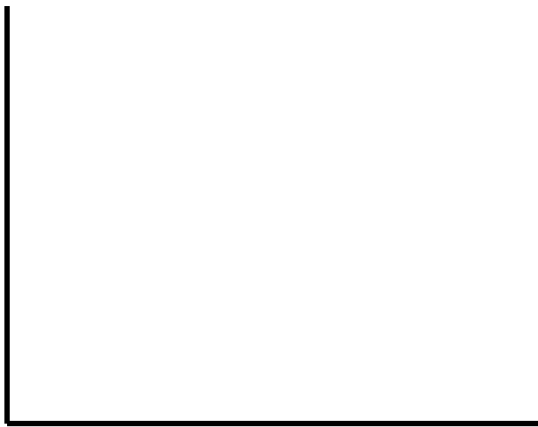In each case the _____ in _____ _____ is

fixed. However, the _____ required to produce this

_____ depends dramatically on the interaction _____.

_____ Force

_____ Time

_____ Force

_____ Time

IV.   Conservation of Linear Momentum

A.   Isolated System

> If there is **No Net External Force** acting on a body, then the **body's linear momentum** is **conserved**. Such bodies are called **isolated systems**.
>
> **Newton II**
>
> If $\sum \vec{F}_{Ext} = 0$ then $\dfrac{\Delta \vec{p}}{\Delta t} = 0$, thus
>
> $$\vec{p} = \text{constant}$$
>
> **This is actually Newton's First Law in a more generalized form.**

B.   Collisions and Explosions

> If the time of interaction is approximately zero, the impulse due to finite external forces can be neglected and the linear momentum of the system is conserved.
>
> $$\Delta \vec{p} = \vec{F}_{av} \, \Delta t = 0$$

The most common examples of this type of problem are explosions and collisions in which the dominating interaction forces occur over time intervals as short as 10^{-18}s!