Last class:

momentum

$$\vec{p} = m\vec{v}$$

$$\Delta\vec{p} = \vec{p}_f - \vec{p}_i$$

What are we trying to do? We want to be able to predict the motion of matter.

- -Our object of interest starts at this position with this velocity
- -Object then interacts in some way with some other matter
- -What does the object's motion look like now? What will it look like in the future? (Seconds, hours, years, millennia)

-Some notation: the "object of interest" is called the *system*. This can be anything. A ball, a car, an airplane. The thing whose motion we want to analyze is the system.

-Everything else is lumped into the "surroundings". Objects in the surroundings are what the system interacts with.

-The laws of physics are true regardless of our choice of system and surroundings, but this choice will affect our calculations

-So far we have learned one "law of physics". What is it?
Newton's first law: an object will move with constant velocity unless it interacts with something in its surroundings.

Specifically: an object will move with constant velocity "except to the extent" that it interacts with its surroundings

So stronger "interactions" result in more change of motion

At the same time, higher mass results in *less* change of motion (momentum)

It's time to quantify this:

Momentum Principle

$$\vec{p}_{future} = \vec{p}_{now} + \vec{F}_{net} \Delta t$$

Quantify strength of interaction w/ Force

$$\boxed{\Delta \vec{p} = \vec{F}_{net} \Delta t}$$

→ Examples of Force?

Force:

$\vec{F}$, measured in Newtons (N)

1 N ~ Force of gravity on an apple

- Notes

a) is a vector

magnitude + direction

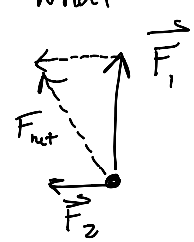
b) One way to measure force: a spring

apply Force $\vec{F}$, spring compresses a distance s.

Double the force, double the distance.

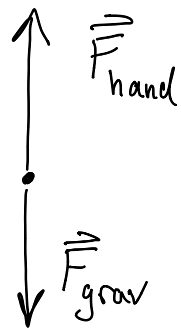
c) Can have multiple Forces acting at once

This is what "net" means



Hold chalk in hand

$$\vec{F}_{net} = \vec{0}$$



$$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \ldots$$

You may have seen $F = ma$

$$\Delta \vec{p} = \vec{F}_{net} \Delta t$$

$$\vec{p} = m\vec{v}$$

$$\Delta \vec{p} = m \Delta \vec{v} = \vec{F}_{net} \Delta t$$

$$\vec{F}_{net} = m \frac{\Delta \vec{v}}{\Delta t} = m \vec{a}$$

So that's force

Let's get back to momentum principle

$$\Delta \vec{p} = \vec{F}_{net} \Delta t$$

(aka Newton's 2^{nd} Law)

Example of cart on a track

Importance of Δt

Δt is the duration of the interaction

- The time over which $\vec{F}$ is applied

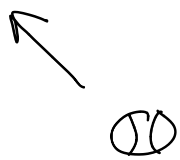
- $\vec{F}_{net} \Delta t$ is so important we give it its own name: Impulse

$$\text{Impulse} = \vec{F}_{net} \Delta t$$

Ex:

$\vec{p}_i = \langle 0, 0, 3 \rangle \ \frac{kg\,m}{s}$

LATER



$\vec{p}_f = \langle -2, 2, -1 \rangle \ \frac{kg\,m}{s}$

What was the impulse applied during contact w/ bat?

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

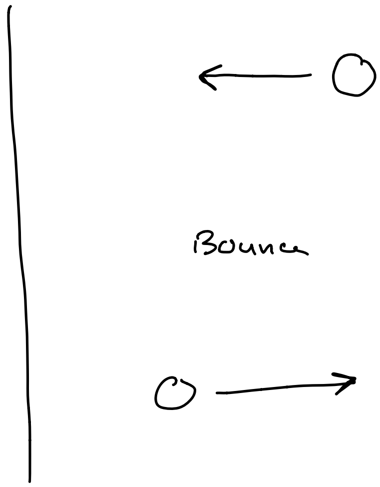
$$\langle -2, 2, -1 \rangle \frac{kg\,m}{s} - \langle 0, 0, 3 \rangle \frac{kg\,m}{s} = \vec{F}_{net} \, \Delta t$$

$$\boxed{\langle -2, 2, -4 \rangle \ kg \frac{m}{s} = \vec{F}_{net} \, \Delta t}$$

What is $\vec{F}_{net}$? Cannot say

Let $\Delta t = 0.5 \text{ ms} = 0.5 \times 10^{-3} \text{ s} = 5 \times 10^{-4} \text{ s}$

Then $\vec{F}_{net} = \frac{\Delta \vec{p}}{\Delta t} = \langle -4000, 4000, 8000 \rangle \ \frac{kg\,m}{s^2} \leftrightarrow N$



moving $-x$

$|\vec{p}| = 2.8 \ kg \frac{m}{s}$

Bounce

$|\vec{p}|$ is the same

moving $+x$

What is $\Delta\vec{p}$?

$p_f = 2.8$

$p_i = 2.8$

$\Delta p = p_f - p_i = 2.8 - 2.8 = 0$

?

$|\vec{p}|$ doesnt change, but direction does!

$\vec{p}_i = \langle -2.8, 0, 0 \rangle \ \frac{kg\,m}{s}$

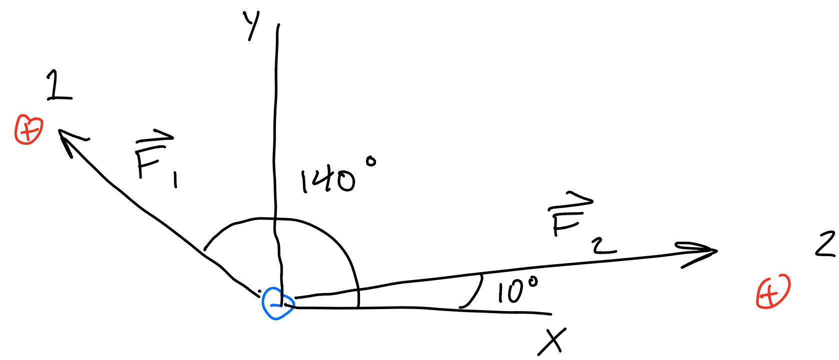
$\vec{p}_f = \langle 2.8, 0, 0 \rangle \ \frac{kg\,m}{s}$

$\Delta\vec{p} = \langle 5.6, 0, 0 \rangle \ \frac{kg\,m}{s}$

Example:

Finding $\vec{F}_{net}$

an electron surrounded by 2 protons



P1 exerts a Force of 5 N at an angle of 140°

P2 exerts F of 7 N at angle of 10°

What is $\vec{F}_{net}$?

$$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2$$

$$= 5 + 7 = 12 \text{ N} \quad \times$$

We are given

$|\vec{F}_1|$, $|\vec{F}_2|$, $\hat{F}_1$, $\hat{F}_2$

$$\vec{F}_1 = |\vec{F}_1| \hat{F}_1$$

$$\hat{r} = \langle \cos\theta_x , \cos\theta_y , \cos\theta_z \rangle$$

xy plane $\theta_z = 90°$

$$\theta_{x,1} = 140°$$

$$\theta_{y,1} = 140° - 90° = 50°$$

$$\hat{F}_1 = \langle \cos 140° , \cos 50° , 0 \rangle$$

$$\hat{F}_1 = \langle -0.77 , 0.64 , 0 \rangle$$

$$\vec{F}_1 = 5 \langle -0.77 , 0.64 , 0 \rangle \text{ N}$$

$$\vec{F}_1 = \langle -3.85 , 3.2 , 0 \rangle \text{ N}$$

$\hat{F}_2$:

$$\theta_x = 10°$$

$$\theta_y = 80°$$

$$\hat{F}_2 = \langle \cos 10° , \cos 80° , 0 \rangle$$

$$= \langle 0.98 , 0.17 , 0 \rangle$$

$$\vec{F}_2 = 7\,\langle 0.98, 0.17, 0\rangle\ \mathrm{N}$$

$$\vec{F}_2 = \langle 6.86, 1.19, 0\rangle\ \mathrm{N}$$

$$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2$$

$$= \langle -3.85, 3.2, 0\rangle$$

$$+ \ \langle 6.86, 1.19, 0\rangle$$

$$\vec{F}_{net} = \langle 3.01, 4.39, 0\rangle\ \mathrm{N}$$

$$|\vec{F}_{net}| = 5.32\ \mathrm{N}$$