NATURE OF MATTER ⇒ MATTER IS ONLY "INTERESTING" when an interaction occurs.

What is matter? (Condensed "energy" → $E = mc^2$)
↳ Takes up space & has "weight"

KINDS OF MATTER

size ↓
- Sub-atomic
- atoms
- molecules
- Solids
- planets
- stars
- galaxies
- ⋮

Length Scale

$1\ nm = 0.000000001\ m = 10^{-9}\ m$

H_2O molecule ≃ 0.1 nm
Virus molecule ≈ 100 nm
Grain of sand ≃ 10^{6} m

Humans ≃ 1 m
Sun ≃ 1.4×10^9 m
Galaxy ≃ 10^5 lt. yr
$\simeq 10^5\ \text{lt. yr} \times \frac{10^{16}\ m}{\text{lt. yr}}$
$\simeq 10^{21}$ m

We will mostly consider matter from size of sand grains to galaxies!

Footnote: We will start by considering day to day experience. Newton's laws work in this regime. Small sized system (1nm) ⇒ QUANTUM MECHANICS. VERY FAST speeds ⇒ RELATIVITY. Two of the PROFOUND ACHIEVEMENTS of the 20th Century!!

Focus of our work ⇒ THREE principles. THESE ALWAYS WORK FOR "EVERY DAY" experiences ⇒

(1) Conservation of MOMENTUM

(2) CONSERVATION OF ENERGY

(3) Conservation of ANGULAR MOMENTUM

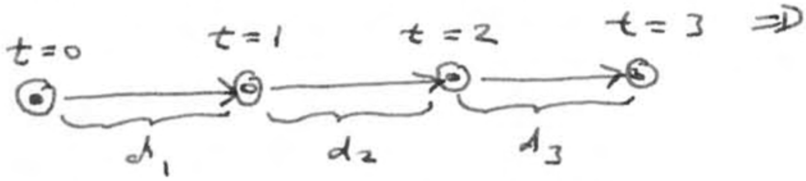
THE TEXTBOOK FOCUSES ON THESE PRINCIPLES

NEWTON'S FIRST LAW

(RELATED TO MOMENTUM CONSERVATION)

> AN OBJECT MOVES IN A STRAIGHT LINE AT CONSTANT SPEED EXCEPT TO THE EXTENT THAT IT INTERACTS WITH OTHER OBJECTS.

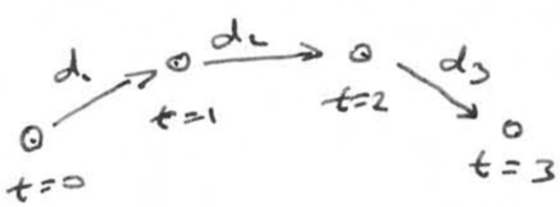
Need to be more quantitative



$d_1 = d_2 = d_3$

MEANS OBJECT DOES NOT INTERACT

What about this particle?



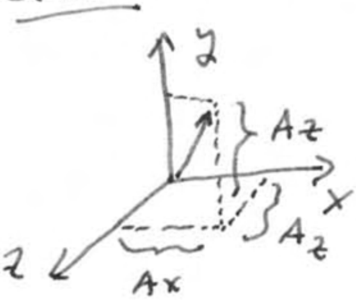
$d_1 \neq d_2 \neq d_3$ and NOT STRAIGHT LINE.

↳ THIS PARTICLE INTERACTS

WE NEED TO FIGURE OUT A MEASURE OF THIS "INTERACTION" ⇒ VECTOR

VECTOR → HAS A "MAGNITUDE" and a "DIRECTION"

Notation: $\vec{A}$ = VECTOR A = SCALAR ← NO DIRECTION



$\vec{A} = \langle A_x, A_y, A_z \rangle$

↙ PYTHAGOREAN THEOREM

Magnitude

$$A = |\vec{A}| = \sqrt{A_x^2 + A_y^2 + A_z^2}$$

Example: $\vec{A} = \langle 4, 3, 2 \rangle = \sqrt{16 + 9 + 4} = \sqrt{29}$

Units? $|\vec{A}|$ has units of length, e.g. meters.

TEXT BOOK'S GONE WILD →

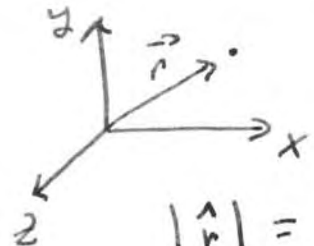
Can $\vec{A}$ be negative? Can pigs fly?

$\vec{A} = \langle A_x, A_y, A_z \rangle$ No positive or negative for $\vec{A}$

Unit VECTORS

$\vec{r} = \langle x, y, z \rangle$

$r = \sqrt{x^2 + y^2 + z^2}$



Look at

$\hat{r} \equiv \frac{\vec{r}}{r}$ ⇒ UNIT VECTOR

↑ Definition

$$|\hat{r}| = \frac{1}{r}|\vec{r}| = \frac{1}{r}\sqrt{x^2+y^2+z^2}$$

$$= \frac{r}{r} = 1$$

ANY VECTOR, $\vec{A}$, where $|\vec{A}| = 1$ is a unit vector.

SPECIAL unit vectors →

$\hat{i} = \langle 1, 0, 0 \rangle$

$\hat{j} = \langle 0, 1, 0 \rangle$

$\hat{k} = \langle 0, 0, 1 \rangle$

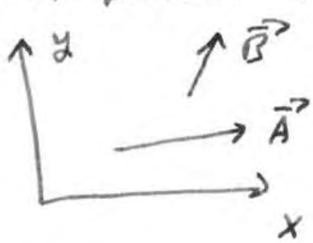
Any vector can be expressed like this

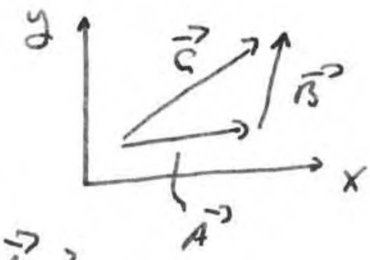
$$\vec{r} = x\,\hat{i} + y\,\hat{j} + z\,\hat{k}$$

MATH with VECTORS

$$\vec{A} + \vec{B} = \langle A_x + B_x, A_y + B_y, A_z + B_z \rangle$$
$$= \langle B_x + A_x, B_y + A_y, B_z + A_z \rangle = \vec{B} + \vec{A}$$

Graphical addition





Put tail of $\vec{B}$ at head of $\vec{A}$.

$\vec{C} = \vec{A} + \vec{B} = \vec{B} + \vec{A}$

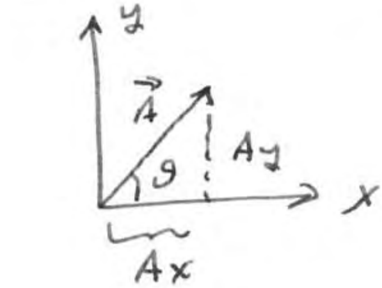
Try it!

Does $\vec{A} - \vec{B} = \vec{B} - \vec{A}$?
(Seriously? See book)

Special VECTOR

$\vec{0} = \langle 0, 0, 0 \rangle$ $\quad \vec{A} + \vec{0} = \vec{A}$

Angles

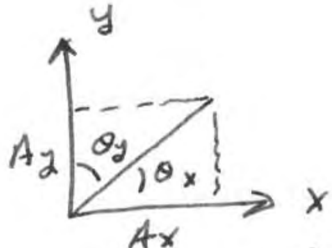


$$\cos\theta = \frac{A_x}{A} \qquad \sin\theta = \frac{A_y}{A}$$

$$\cos^2\theta + \sin^2\theta = \frac{1}{A^2}(A_x^2 + A_y^2) = \frac{A^2}{A^2} = 1$$

SPECIAL CASE

$|\vec{A}| = 1$ $\quad \boxed{\cos\theta = A_x}$



$\cos\theta_x = A_x \qquad \cos\theta_y = A_y$

Note: $\theta_x + \theta_y = 90$

$\cos(90 - \theta_x) = \cos(90)\cos(-\theta_x) - \sin(90)\sin(-\theta_x)$

$= \sin\theta_x$

$A_x = \cos\theta_x$

$A_y = \sin\theta_x$

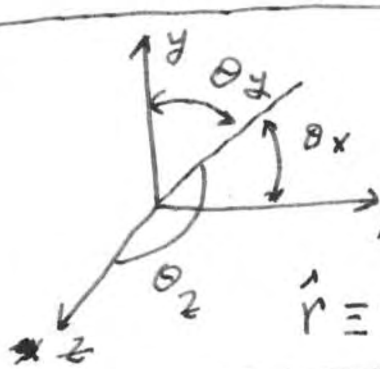
$A_x^2 + A_y^2 = \cos^2\theta_x + \sin^2\theta_x$

$= 1$

GENERAL 3D PROBLEM

$A_x = \cos\theta_x \qquad A_y = \cos\theta_y$

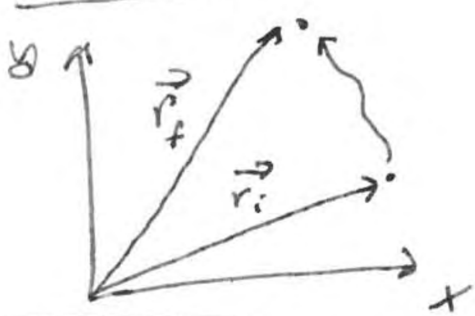
$A_z = \cos\theta_z$



USEFUL ↓

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

CHANGE IN VECTORS



$$\boxed{\Delta\vec{r} \equiv \vec{r}_f - \vec{r}_i}$$

Definition

Δr is change in position from $\vec{r}_i$ to $\vec{r}_f$

Scalar

$\Delta t = t_f - t_i$

UNITS!

The book mostly uses SI units.

SI = STANDARD INTERNATIONAL

(meters, kilograms and seconds)