Dynamics

So far have been focused on "kinematics"

Two parts to describing motion of things in space & time:

<u>Kinematics</u>: Description of how things move

<u>Dynamics</u> Explanation of why things move the way they do.

Typically (classically) much more emphasis on Dynamics. Good reason for this.

In classical physics the kinematics straightforward

$v \to v + v_s$ not much else to say...

We've seen in these 1st 3 weeks this is

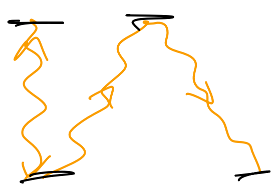
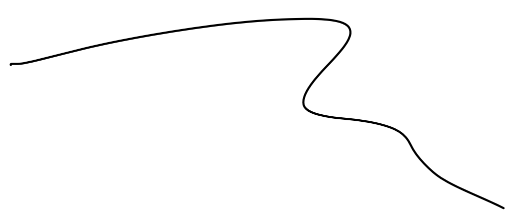
Not the case for Space-time!

Will now switch gears and talk about the more "exciting" stuff. the "why"s

We will see, like w/ kinematics, significant differences w.r.t. "common sense" Newtonian Physics.

These differences will be seen to have a profound impact on our understanding of the world. (Sources of unlimited clean powerful Energy & the ultimate weapons of war.) (Heaven & Hell.)

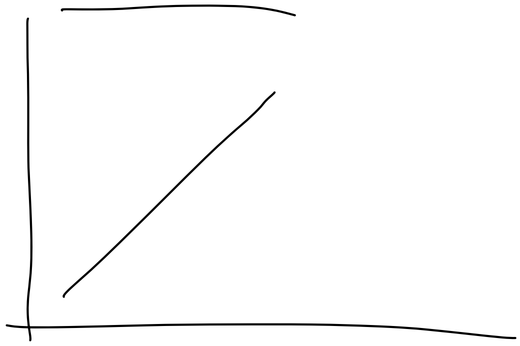
We will see they all fundamentally follow from what we have already studied

P.O.R  

Physics about matter in motion and the causes of the motion.

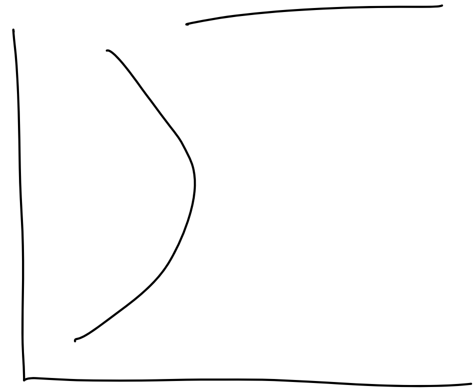
Classically talk about forces as causing changes in motion.

No force



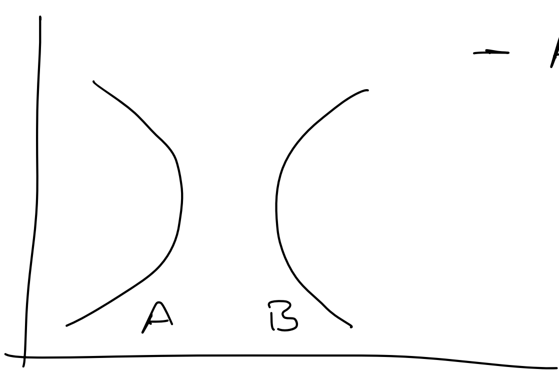
vs

w/ force



Have never found a change in velocity like above w/o something to cause it.

In fact all known forces can be described in terms of interactions



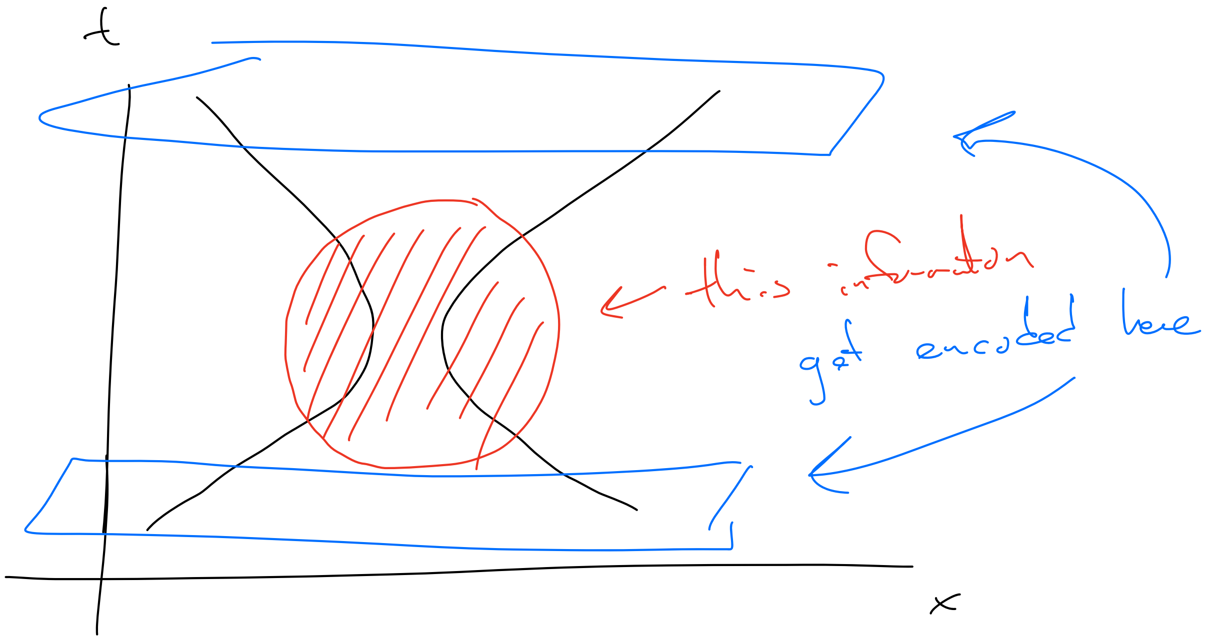
- A affects B &
  B " A

- After particles separate see $\Delta p_A = \Delta p_B$

Instead of talking about Forces between particles can talk about their changes of momentum.

Deeper way of looking at the problem.

Kind of "Duality" that comes up in physics over and over again.



w/ Relativity (& esp. QM + Relativity)
Much more natural to talk about the boundaries (ops)

Here, will focus on the changes in momentum.

Classical Momentum

$$p = mv = m\beta$$

Why is this useful?

↳ Conserved! Turns out only true $\beta \ll 1$

Experiments show that $m\beta$ **Not** conserved when $\beta \sim 1$

What to do?

Either Abandon

- Newtonian expression for mom.
- law of conservation.

QM gives a deep reason to expect these

Much more useful to start w/ conservation laws

Demand that quantity related to mass & velocity is conserved in interactions.

Derive what the expression for mom must be.

We will do this 3 times.

Each will produce a revolution in our way of looking at nature.

May sound circular ...

Defining momentum such that it is conserved!

Deep & Subtle character of physical law.

Both Defines what the important concepts & then makes use of them.

Using one experiment to establish the conserved quantity then the subsequent ones to verify that it is really conserved.

We will start with establishing the conserved quantities ... We will see the checking of them is constantly happening (w/o fail!) in experimental physics.

Think about Units

Classical Physics in sensible units.

$$[m] = \text{mass}$$

$$[p] = [m\beta] = [m] = \text{mass}$$

$$[E] = [\tfrac{1}{2} m \beta^2] = [m] = \text{mass}$$

Yet another good reason to measure time in m!

then Energy, Mom & Mass all have the same units.

Seems trivial, But already a deep statement about the relation between them

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Will use units of mass for E & P

$$P = m\beta$$

$$KE = \frac{1}{2} m \beta^2$$

Can always convert back with "conversion factor" c

$$P_{converted} = m\beta c = mv$$

$$KE_{converted} = \frac{1}{2} m \beta^2 c^2 = \frac{1}{2} m v^2$$

Ok, plan now is to find p & KE

in generic $\beta \sim 1$ case.

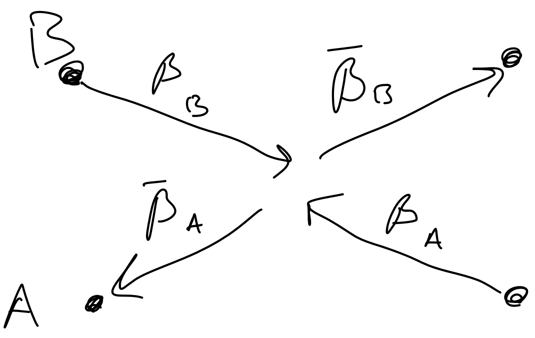
Know when $\beta \ll 1$ should recover

$$m\beta \quad \& \quad \frac{1}{2} m \beta^2$$

Momentum

Start by considering perfectly elastic collision

All motion in one plane.



Reminder Newton $\beta_A, \beta_B \longrightarrow \bar{\beta}_A \; \bar{\beta}_B$ ← Bar means final.

Can always find 4 numbers, such that

$$c_1 \beta_A + c_2 \beta_B = c_3 \bar{\beta}_A + c_4 \bar{\beta}_B$$

Newton $\Rightarrow$ $c_1 = c_3 = m_A$ ← invariant properties of A, B

$c_2 = c_4 = m_B$ ←

So, observing these $(\beta \ll 1)$ collisions leads us to introduce parameters we call "inertial mass"

And define $\sum m_i \beta_i = P_{tot}$ to be conserved.

Relativistic Physics ($\beta \sim 1$)

Things not as simple... will try to keep as close as we can.

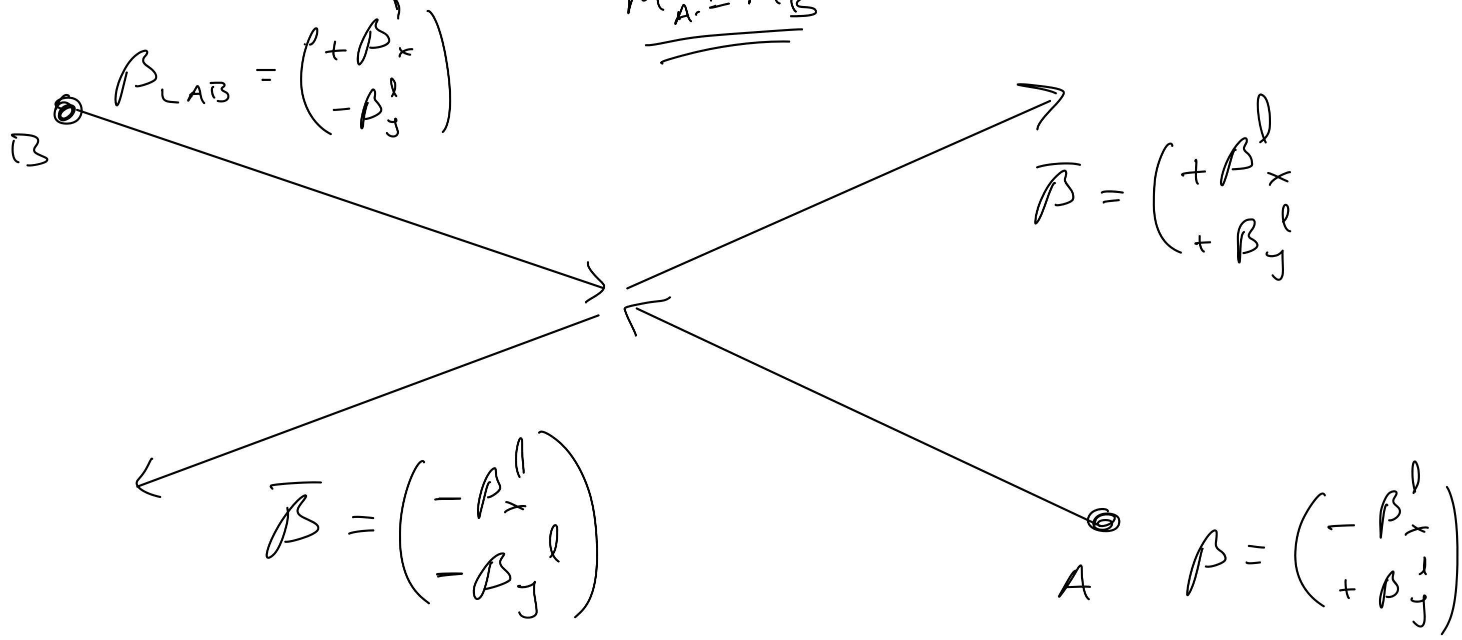
Assert conservation of momentum in extended sense

$$\underbrace{C(m_A,\beta_A)}\beta_A + C(m_B,\beta_B)\beta_B = C(m_A,\beta'_A)\beta'_A + C(m_B\beta'_B)\overline{\beta}$$

$\hookrightarrow$ C's no longer invariant, but can only be a function of particle mass + speed.

Consider a Symmetric Collision

$m_A = m_B$

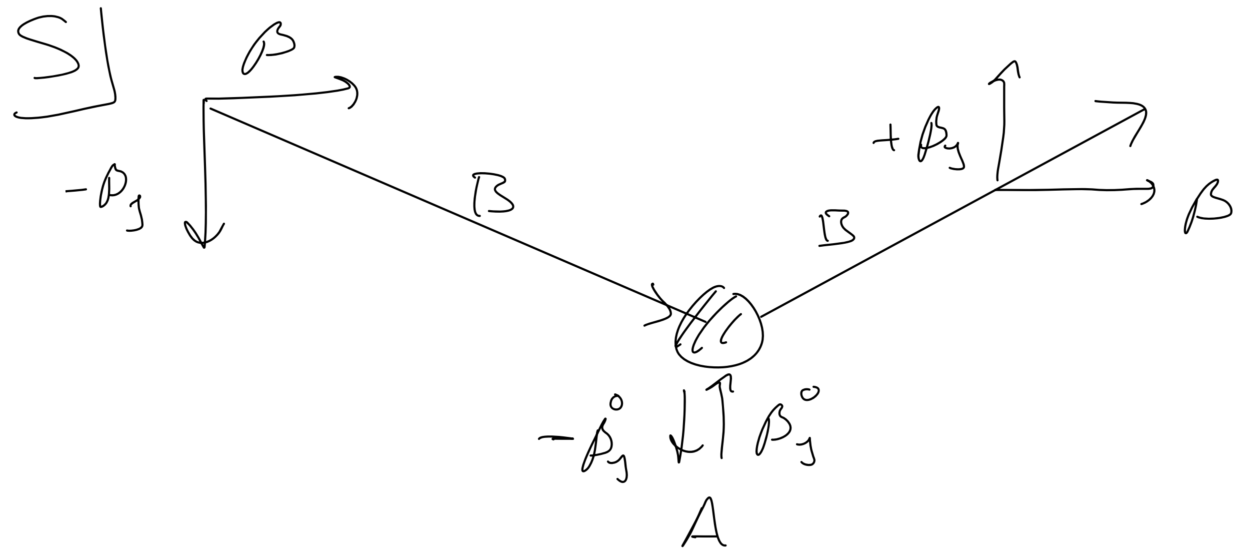


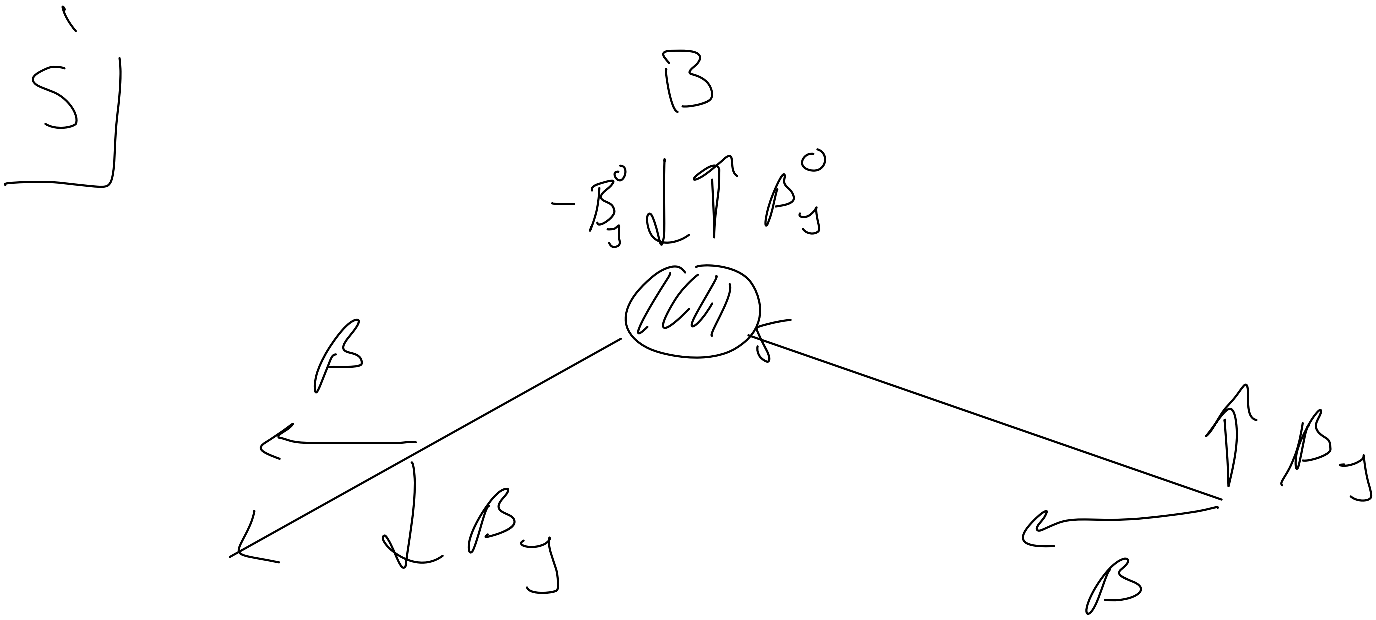
Find the C's by considering two observers S, S'

S will shoot A $\quad \beta = \begin{pmatrix} 0 \\ \beta_y^0 \end{pmatrix}$ $\quad$ w/ $\beta_y^0 \ll 1$

S' will shoot B $\quad \beta = \begin{pmatrix} 0 \\ \beta_y^0 \end{pmatrix}$

But β between S & S' large





S frame

$$\beta_A = \begin{pmatrix} 0 \\ \beta_y^0 \end{pmatrix} \qquad \bar{\beta}_A = \begin{pmatrix} 0 \\ -\beta_y^0 \end{pmatrix}$$

$$\beta_B = \begin{pmatrix} \beta \\ -\beta_y \end{pmatrix} \qquad \bar{\beta}_B = \begin{pmatrix} \beta \\ +\beta_y \end{pmatrix}$$