Wave - Particle Duality

what happens if you send an e^- though the double slit experiment.

→ for large slits e^- behaves like a ball

Large slit

Do many times get a histogram

But keep making the experement smaller and you will get

Small slits

histogram looks like interference patern

Sometimes e^- behaves as ball

ex → we only find e amount of charge and only measure one electron at the end of each run.

Other times e^- behaves as wave

ex. interference pattern implies e^- is traveling as a wave.

This is wave particle duality.

1923 Louis de Broglie proposed matter exhibits wave behavior

Proposed: $$\lambda = \frac{h}{p} \qquad p = \frac{mv}{\sqrt{1-\frac{v^2}{c^2}}}$$

as p gets large
λ gets small.

Could we do double slit experiment with a whole atom? Whole molecule? bacteria? cat!? Person!?

the larger (more massive) the object the larger p. large p → small λ.

ex

$\lambda_{baseball}$? for $V_{baseball} = 13\ m/s$

$\lambda \approx 3 \times 10^{-34}\ m$

10^{-35} → Plank length

wold not see wave nature of baseball.

what kind of waves are matter waves?

See Richard Feynman vid

truth is its not clear

→ Probably best to think of them as probability waves.

If probability waves does that mean we just have an incompleat theory that is governed by something deeper?

debatable but one thing is clear

→ Quantum effects are quite different than classical Physics.

we often describe a quantum state in terms of this wave → called a wave function

ψ psi

Schrödinger & Heisenberg

developed theory to determine wave function

↳ Quantum mechanics.

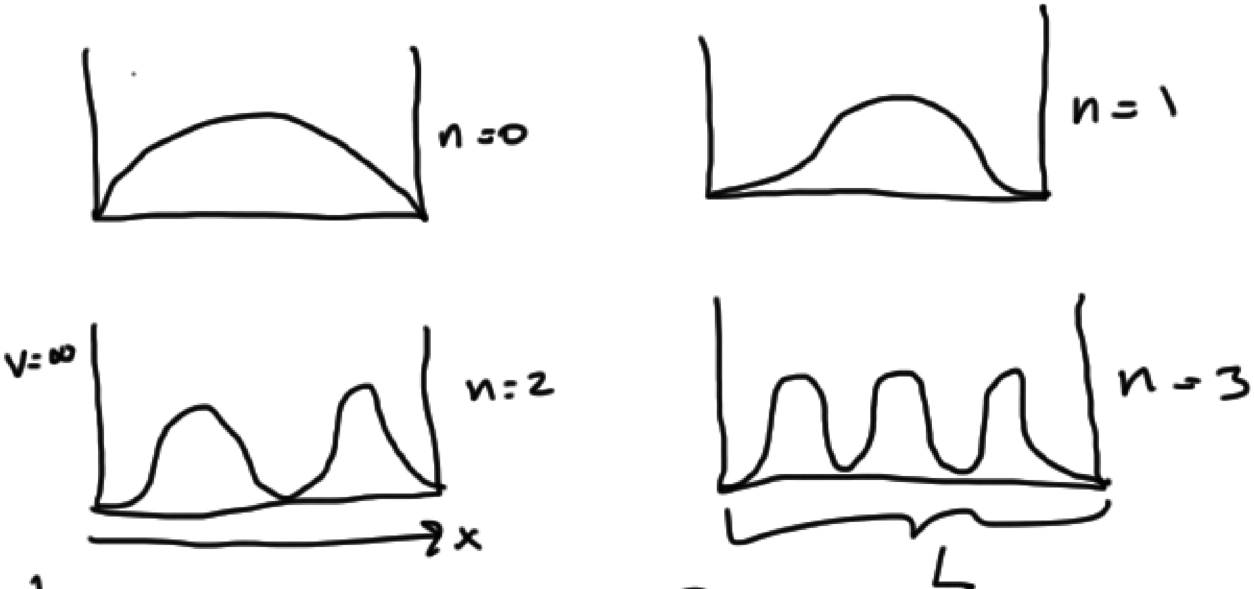
Lets put a ball in a box

say the ball is moving fast so its position is random if the time scale od the measurments is long compared to ball's vel.

Probability dist. (classical)

no more likely to be found in one place than another

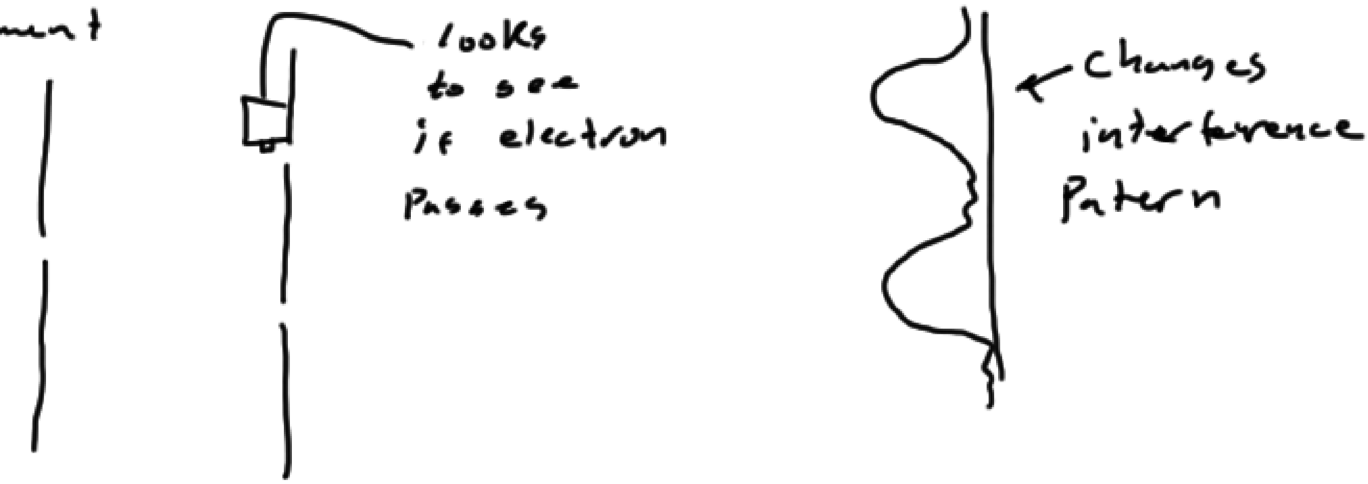
Quantum



$$P_{quant}(x) = |\psi(x)|^2 = \frac{2}{L}\sin^2\left(\frac{n\pi x}{L}\right)$$

Y can not ever know for sure where you will measure the particle to be you can only know the probability of finding it at a given location.

Place a measuring device in double slit experiment



In pop culture this is an argument for the imortance of the consious observer but lets think about whats really happening.

How do we see e^- → light

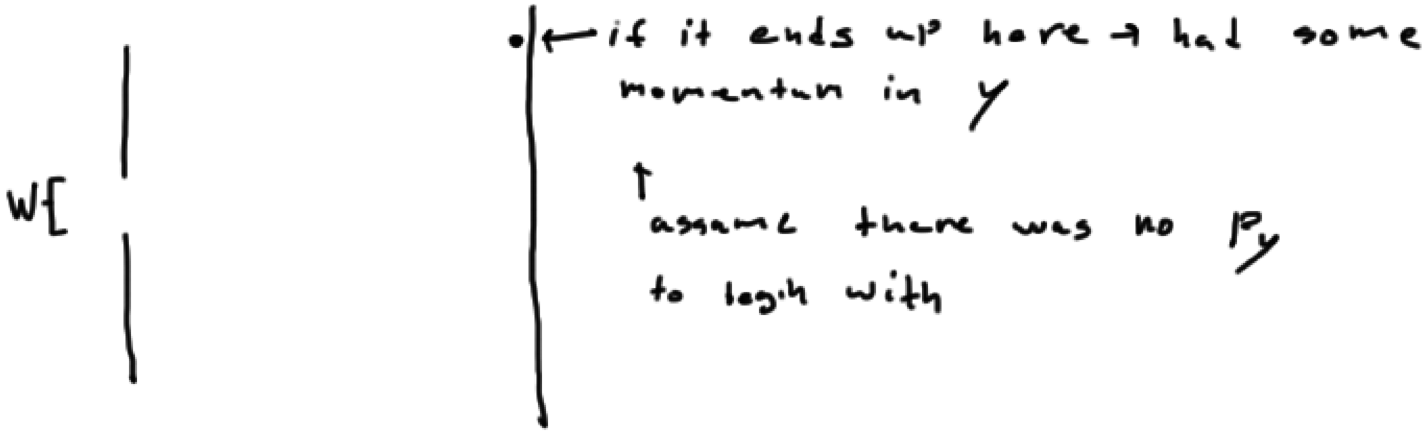
→ large λ does not disturb e^- as much but less likely to find e^-
  → only slightly changes interference pattern.

→ small λ → greatly disturbs e^-
  → more likely finds e^-
  → drastically changes interference pattern.

Concious observer not important
→ definition of observation is.

The Heisenberg uncertainty Priciple

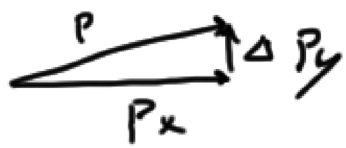
Take single slit



$$\sin\theta = \frac{\lambda}{W} \leftarrow \text{first dark fringe}$$

↑ for θ small $\sin\theta \approx \tan\theta$

$$\tan\theta = \frac{\Delta p_y}{p_x}$$



so $$\frac{\Delta p_y}{p_x} \approx \frac{\lambda}{W}$$

also know $\lambda = \frac{h}{p}$ so $p_x = \frac{h}{\lambda}$

$$\frac{\Delta p_y}{h/\lambda} = \frac{\lambda}{W} \rightarrow \boxed{\Delta p_y = \frac{h}{W}}$$

Also uncertainty in position

$\Delta y = \frac{W}{2}$ $\quad$ $W = 2\Delta y$ ← plug in

$\Delta p_y = \frac{h}{2\Delta y} \rightarrow$ $\boxed{\Delta p_y \Delta y = \frac{h}{2}}$ ← roughly

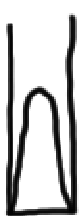
Gives us the idea. Actual expression:

$$\boxed{\Delta x \Delta p \geq \frac{\hbar}{2} \qquad \hbar = \frac{h}{2\pi}}$$

↗

Heisenberg Uncertainty Priciple

So what if we take our e^- in a box but make the box small?



← probability dist for n=0

↖ we know the position pretty well but

$$\Delta x \, \Delta p_x \geq \frac{\hbar}{2}$$

↗ if this is small

↖ then this must be pretty large.

Where do we find this in nature?
White dwarf stars

→ not enough matter to become black hole since all matter thats crunched up has large momentum.

White dwarf

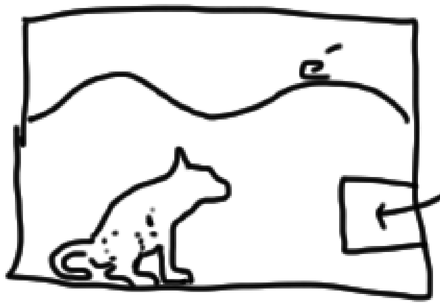
mass of sun size of earth.

→ burned all fusible matterial

→ will gradualy cool untill $\Delta x \Delta p \geq \frac{\hbar}{2}$ is supplying pressure that keeps it from collapsing.

Schrödinger's Cat

Complamty closed system



deadly device

↑

if id detects electron

is the cat alive or dead?

Superposition of states

(in reality → no) ← possible in quantum world.

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2 cats + devide the box

send them far away

50% chance has e^-

50% chance has e^-

each in supper position

entanglement

→ look in box 1 → find alive or dead

→ immedialy determines fate of other cat. → faster than light? yes but cannot share info faster than light

The Hydrogen atom

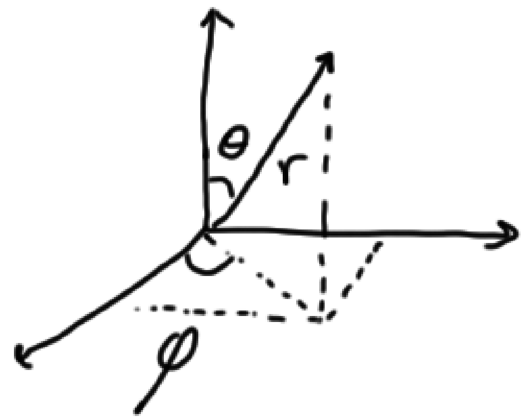
$$E_H = \frac{-E_0}{n^2} \qquad n = 1, 2, 3, \ldots$$

$n \equiv$ principal quantum #

$l \equiv$ orbital quantum #

$m \equiv$ magnetic quantum #

$s \equiv$ spin quantum #.



$$\Psi_H = R(r)\,\Theta(\theta)\,\Phi(\phi)$$

↑ radial: n ↑ polar: l ↑ azimuthal: m

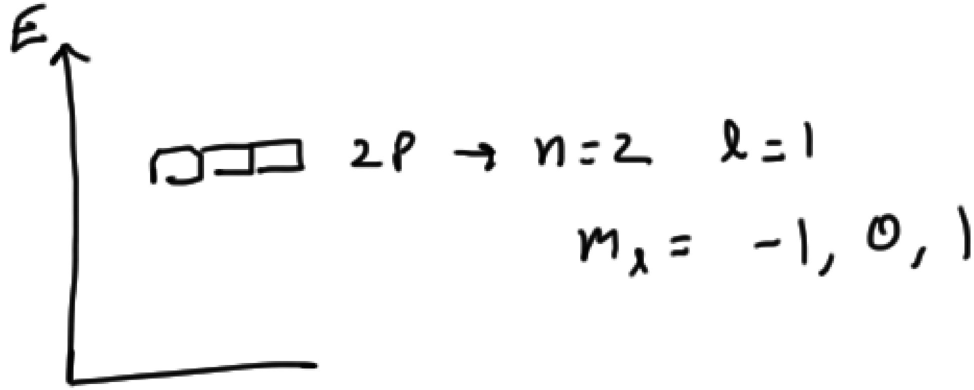
all play a role in wavefunction

$l = 0, 1, \ldots n-1$

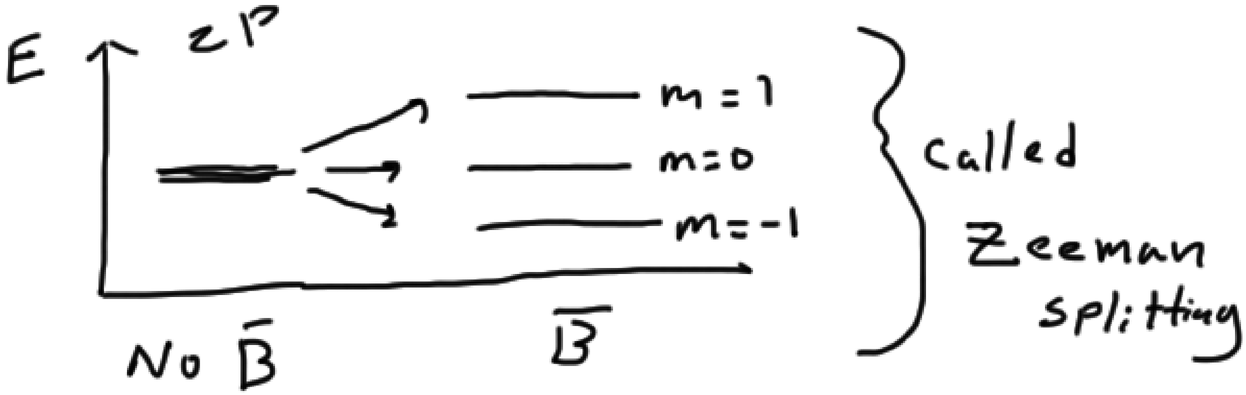
$m = -l, -l+1, \ldots, l-1, l$

$s = \pm \frac{1}{2}$

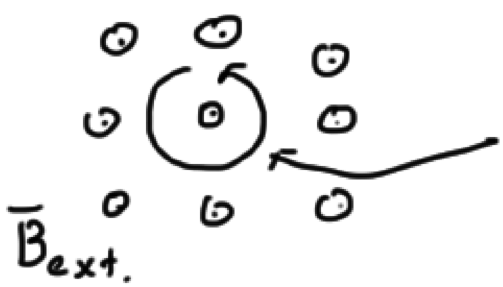
$m \rightarrow$ only have dif. energy in B field



Add B field



Dif. levels correspond to (classical pic)



moving like this the "current" makes B field that does not oppose external B

↑ less Potential E (m=-1)

this does oppose $\bar{B}_{ext}$

↑ Higher Potential E (m=1)

Some Review

Postulates of relativity

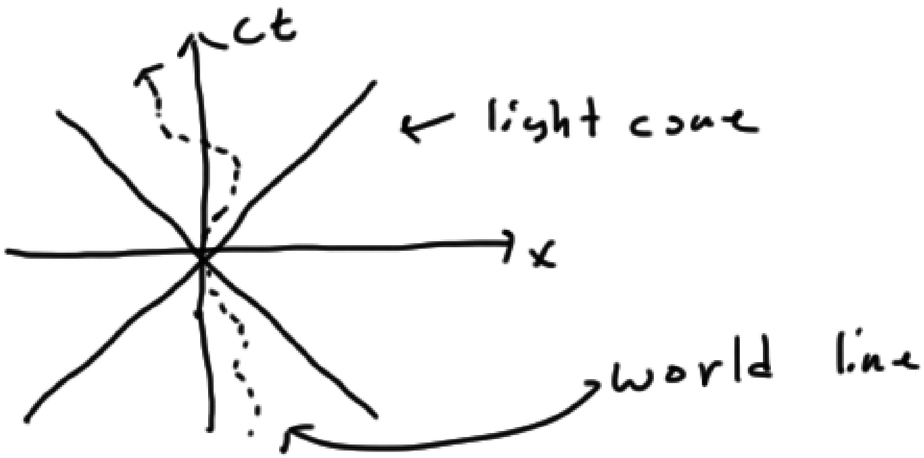
1) c always const

2) laws of phys. same in all inertial ref frames.

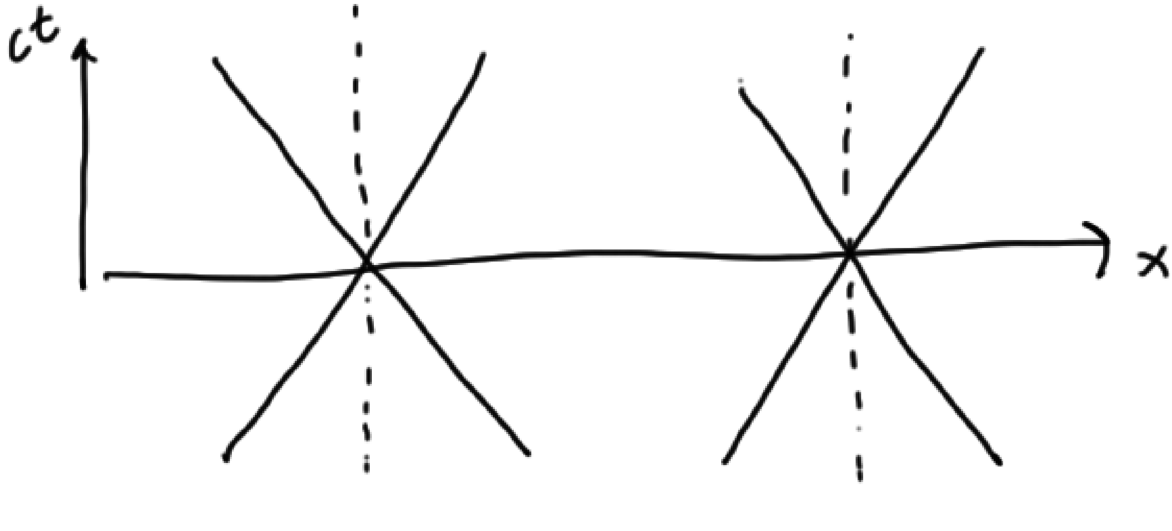
inertial ref. → not accel

this means no faster than light communication

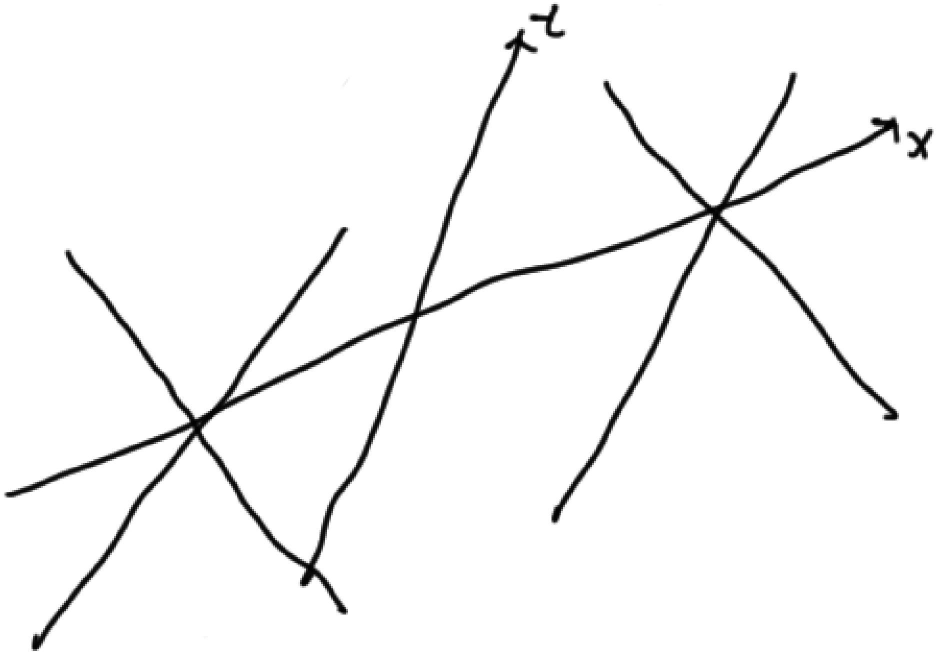
↑ why is this good? → breaking speed of light breaks causality... WHY?



2 people (not moving fast)



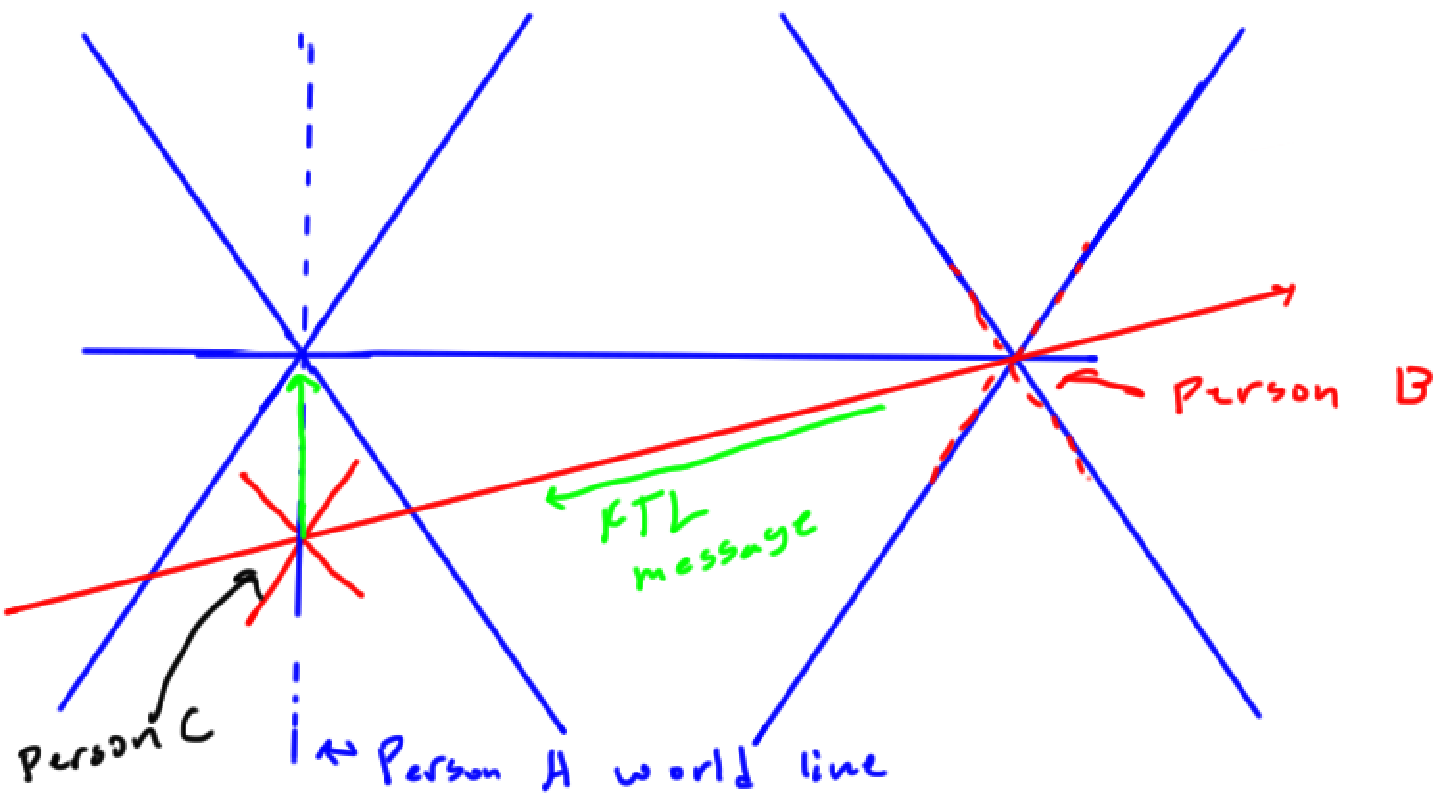
2 People moving fast



← skewed from Lorentz transformation

↗ if the can exchange info faster than light what happens?

↑ Lets say they do this right as they pass the first 2 ppl.



Person A can recive message from Person C because they are (momentarily) in the same place.

If A and B have FTL communication A can send a message to B who sends it to C who sends it to A.

↑ Thus A has sent a message back in time to her/him self!