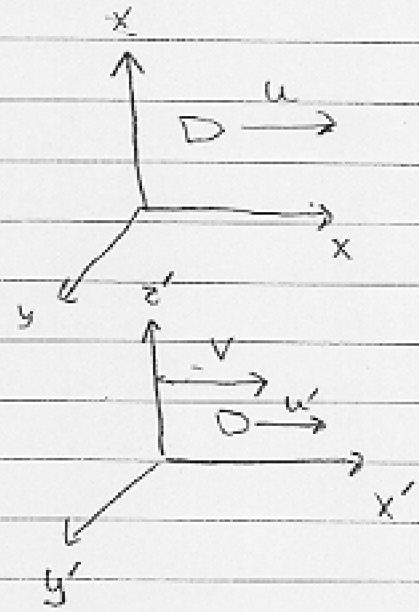
Last time



Earth Observer makes measurements of the raket

t, x, y, z, u

For instance the position of the rocket vs. time

$$x = ut$$

u = The velocity of the rocket

The observer on jupiter which is moving with respect to earth in the x direction measures different coordinates and velocities

$$t' = t$$

$$x' = x - vt$$

$$y' = y$$

$$z' = z$$

$$u' = u - v$$

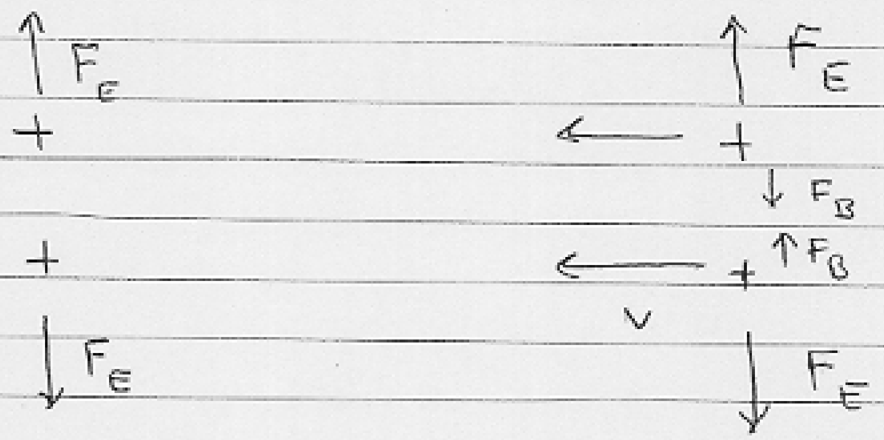
The Rules of Physics are supposed to be the same on jupiter and earth

For example $F = ma$ $\qquad F' = m'a'$

$$u = \frac{\Delta x}{\Delta t} \qquad u' = \frac{\Delta x'}{\Delta t'}$$

But: E & M Doesn't Seem to work

Earth view



F_B very smal

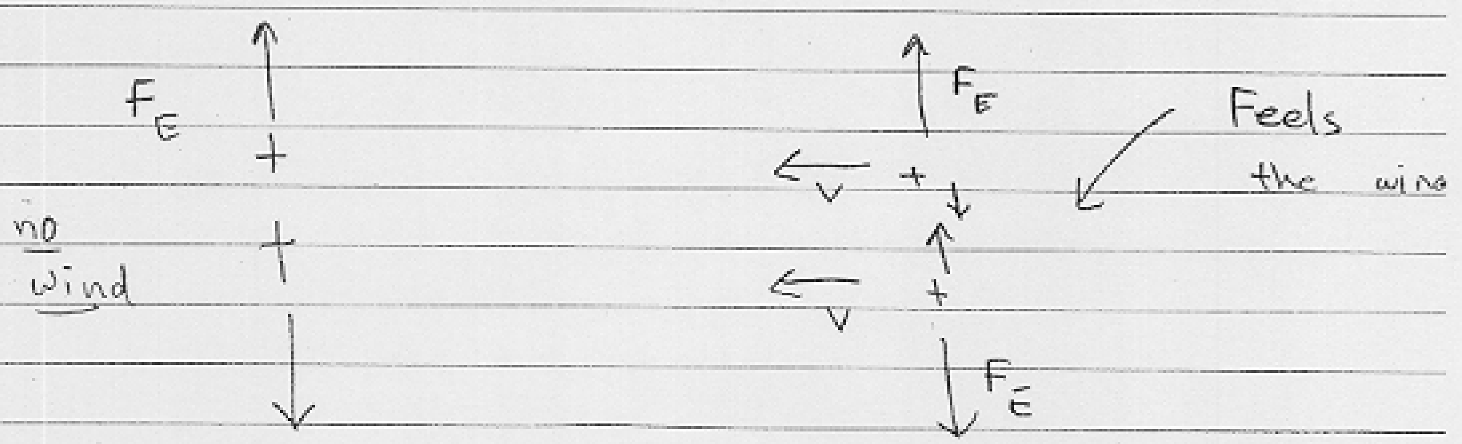
too small to measu

Maxwell's answer:

- Based on the thought that light is a disturbance of some medium aether

- Kind of Like sound is a disturbance of air. Then there is a preferred frame. Namely the frame where the aether is at rest.

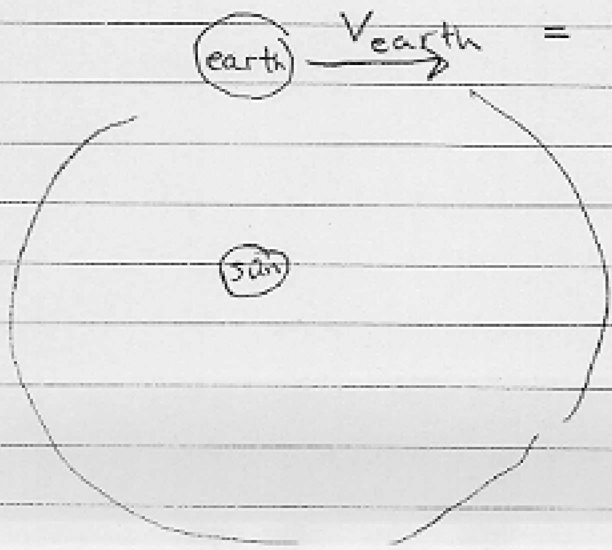
- For instance if you throw a ball straight up when your standing still you get a different answer than if you throw a ball straight up in a canvertible car, because of wind



- Need to move near the speed of light to feel the wind

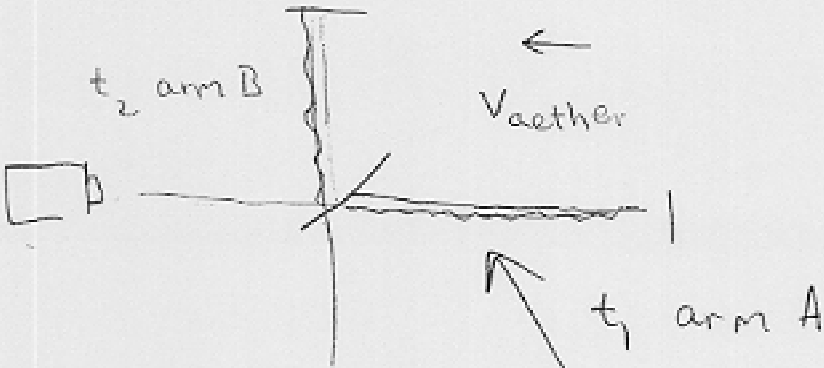
- There should be a aether wind all the time

$$v_{earth} = \frac{2\pi R}{1\,\text{year}} = 30\ \text{km/s}$$



$$v/c \simeq 1 \times 10^{-4}$$

The michelson - Morley experiment

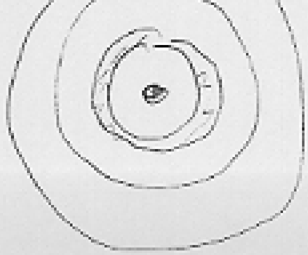


It takes longer to swim against the current and back than it does to swim with no current

t_2 arm B

- Then the time difference makes the light interfere

- By rotating the table can change the time difference between the arms



- expect the interference pattern to change based on the time difference

- Michelson saw no change in fringes

Einstein and Relativity

- The speed of light is constant in all inertial frames (i,e observers moving with constant velocity v)
- All Laws of Physics have the same form in all reference frames

Einstein Reasserts the principle of relativi that is change all unprimed equations to primed ones

$$u = \frac{\Delta x}{\Delta t} \qquad u' = \frac{\Delta x'}{\Delta t'}$$

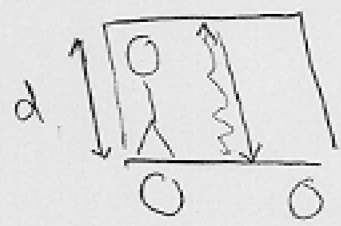
But changes the relation between u and u'

$$u' \neq u - v$$

Time Dilation

- The speed of light is constant in all frames

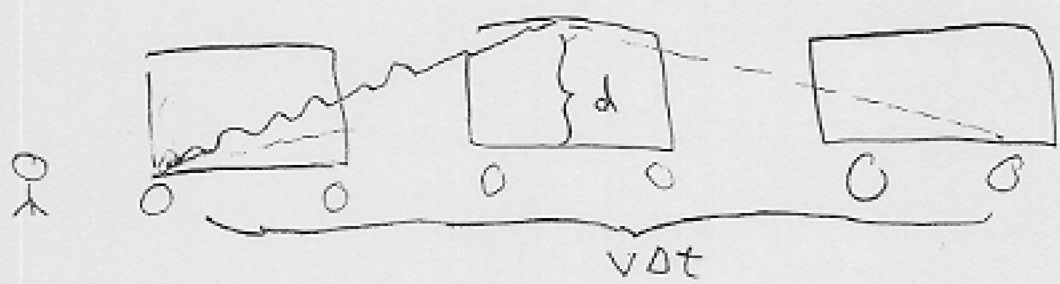
Time it take for person sitting still to throw and catch the light



$$\Delta\tau = \frac{2d}{c}$$

proper time: time measured at the same position at spac

For an observer moving to the left with speed V



$$\frac{\text{Total Distance}}{\text{Total time}} = \text{speed of Light} = C$$

$$\frac{2\sqrt{d^2 + (V\Delta t/2)^2}}{\Delta t} = C$$

Solve For Δt:

$$\sqrt{(2d)^2 + (V\Delta t)^2} = c\,\Delta t$$

$$(2d)^2 + (V\Delta t)^2 = c^2 \Delta t^2$$

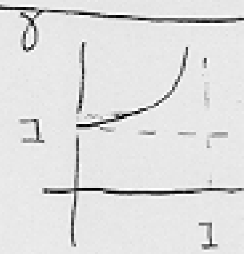
$$\left(\frac{2d}{c}\right)^2 + \left(\frac{v}{c}\right)^2 \Delta t^2 = \Delta t^2$$

$$\left(\frac{2d}{c}\right)^2 = \left[1 - \left(\frac{v}{c}\right)^2\right](\Delta t)^2$$

$$\frac{\left(\frac{2d}{c}\right)^2}{\left(1 - \left(\frac{v}{c}\right)^2\right)^2} = (\Delta t)^2 \qquad \Delta t$$

$$\boxed{\Delta t = \left(\frac{2d}{c}\right)\frac{1}{\sqrt{1-(v/c)^2}} \Rightarrow \Delta t = \frac{\tau}{\sqrt{1-(v/c)^2}}}$$

Define $\boxed{\gamma = \dfrac{1}{\sqrt{1-(v/c)^2}}}$



$\boxed{\bullet \text{ Moving: clocks run slow}}$

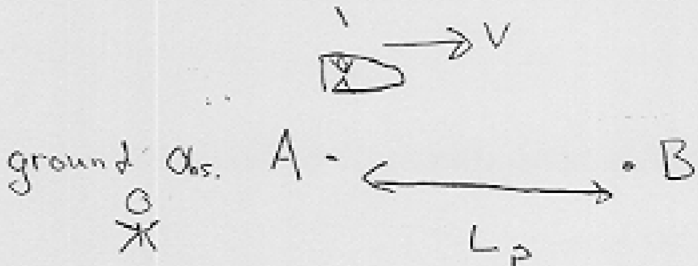
$$\Delta t = \gamma \Delta\tau \qquad \gamma > 1$$

time for someone on ground

time interval for someone on train

Length Contraction

Consider a Ruler Stick:



proper length = Length as measured by someone at rest w.r.t. the ruler stick

Consider the ground observer he sees that the space-ship takes a time to complete his journey

$$\Delta t = \frac{L_p}{v} \qquad\qquad \Delta\tau_s = \frac{L}{v}$$

Now

$$\gamma\Delta\tau = \frac{L_p}{v}$$

$$\Delta\tau = \frac{(L_p/\gamma)}{v} = \frac{\text{Length of ruler as seen by space g}}{v}$$

$$L = \frac{L_p}{\gamma}$$

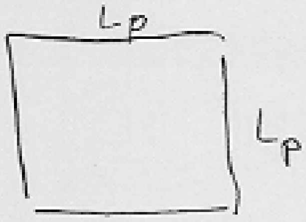
proper length

$\boxed{\text{Moving ruler sticks are length contracted}}$

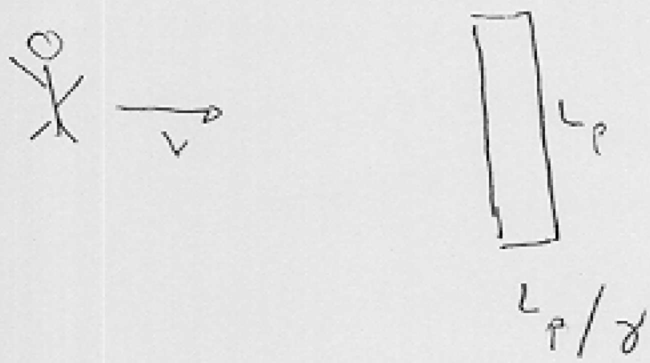
Remark:

- Only those directions in the direction of motion are Length contracted.
- Transverse Directions not contracted.

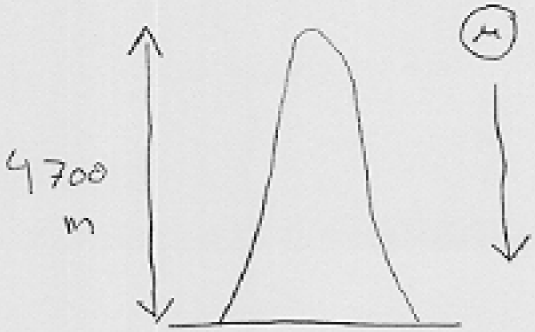
Fixed Observer:



Moving Observer:



Muon and mountain : Earth Observer



$V_{muon} = 0.99c$

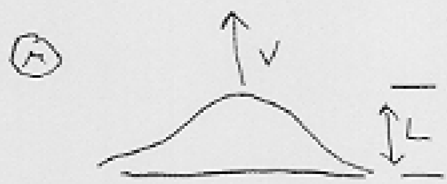
- The μ decays in $2.2\,\mu s$ in its own frame (a proper time)
- To an observer on earth the muon decays in

$$\Delta t = \gamma\, \Delta\tau \qquad \gamma = \frac{1}{\sqrt{1-(v/c)^2}} = 7.1$$

$$\Delta t = (7.1)(2.2\,\mu s) \simeq 16\,\mu s$$

- The distance travelled is $d = v\,\Delta t \approx c \cdot 16\,\mu s = 470$
  the muon reaches the bottom !

Muon and mountain: Muon Observer



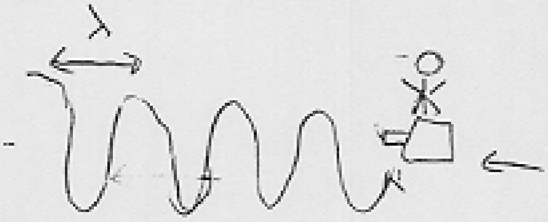
$$L = L_0/\gamma = \frac{4700\,m}{7.1} \simeq 65$$

The muon says $x = \Delta\tau\, v$ amount of mou passes him

$$x = 2.2\,\mu s\,(0.99c) \simeq 650\,m$$

The muon agrees he reaches the bottom

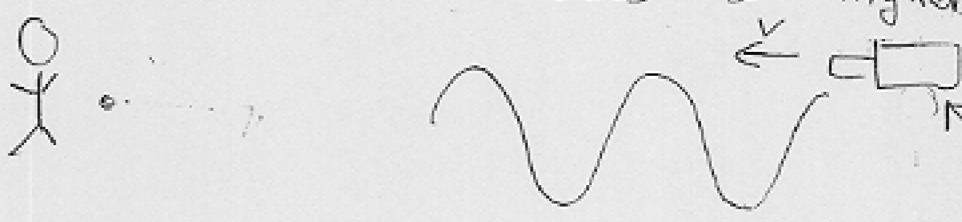
Doppler Shift

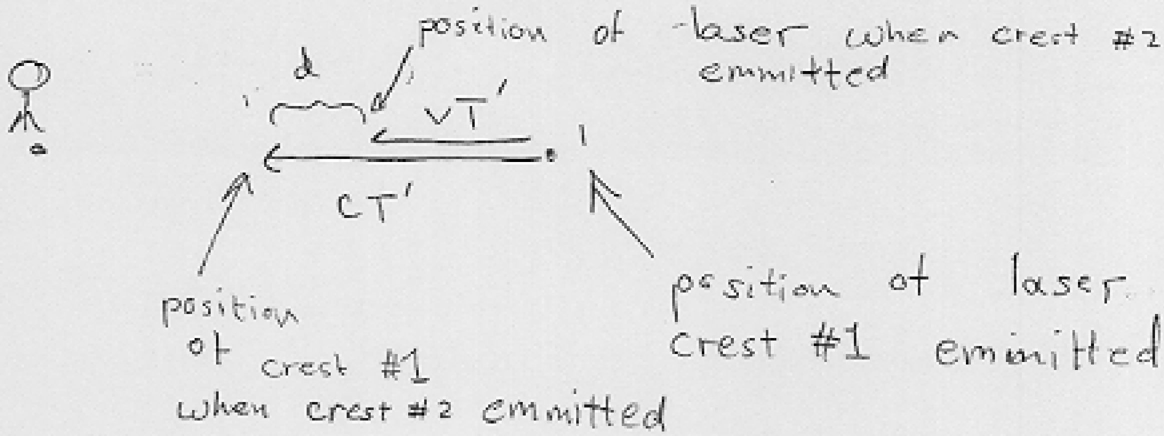


- For someone on the laser The crests of the waves emmitted with period τ_p:

$$c = \lambda f \qquad f = \frac{1}{\tau_p}$$

Observer O′ sees a higher laser frequency





distance between crests $= \lambda' = cT' - vT'$

T' = time betwee[n] crests as seen b[y] O′

time between crests for a lassar fixed in space

$$T' = \gamma \tau_p$$

$$\lambda' = (c-v)T' = (c-v)\gamma\tau_p$$

Now

$$c = \lambda' f' \Rightarrow f' = c/\lambda'$$

$$f' = \frac{c}{\lambda'} = \frac{c}{(c-v)\gamma\tau_p}$$

$$f' = \frac{1}{(1-v/c)\gamma\tau_p} = \frac{\sqrt{1-(v/c)^2}}{1-v/c} f_0$$

$$\sqrt{1-(v/c)^2} = \sqrt{(1-v/c)(1+v/c)}$$ so

$$\boxed{f' = f_0\sqrt{\frac{1+v/c}{1-v/c}}}$$