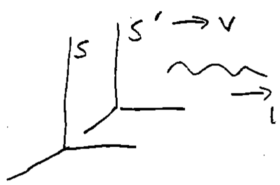
This is clearly unacceptable
The answer to the interpretation of the fundamental process involved depends on the inertial frame of reference of the observer
$\Rightarrow$ Science as we know it breaks down

Also Maxwell's eqns showed clearly light is a wave phenomenon — Waves were understood as propagating disturbances in mechanical media.
However Michelson-Morley expt. placed real constraints on theories of such media (Ether)

end oct 14, 1991 ←

According to Galilean transformations (i.e., classical Mechanics)



S measures $V_{light} = C$

S' should measure $V_{light} = C - V$

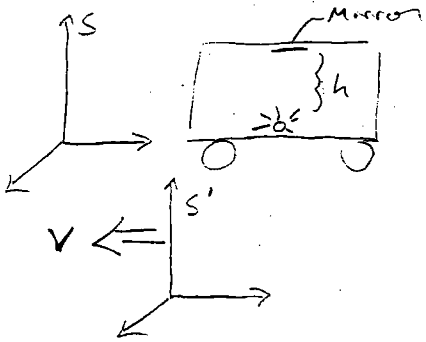
<u>Special</u> Theory of Relativity —

implies <u>only</u> Applicable to <u>inertial</u> reference frames

<u>Postulate 1</u> — (principle of relativity) The laws of physics are identical in <u>all</u> inertial reference frames

<u>Postulate 2</u> - The speed of light in a vacuum has the same value in all inertial reference frames (i.e., C)

Consequences of Einsteins 2 postulates :



light bulb in train car

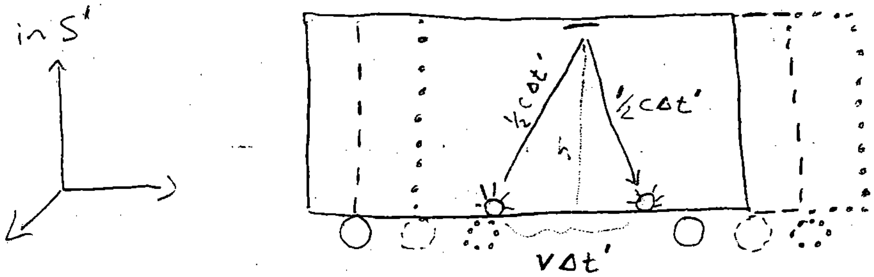
light bulb turned on

How long does it take light to hit Mirror and come back to the point where the light was emitted

From pt. of view in S (where train is at rest)

Mirror a distance h above bulb $\Delta t = 2h/c$

From pt. of view in S' (train moving at V)



Assume $h = h'$

$$\left(\tfrac{1}{2}c\Delta t'\right)^2 = h^2 + \left(\tfrac{1}{2}v\Delta t'\right)^2 \qquad (\text{Assumes } h = h')$$

$$(\Delta t')^2(c^2 - v^2) = (2h)^2 \qquad (\Delta t')^2 = \underbrace{\left(\frac{2h}{c}\right)^2}_{(\Delta t)^2} \frac{1}{1 - v^2/c^2}$$

$$\boxed{\Delta t' = \Delta t \frac{1}{\sqrt{1 - v^2/c^2}}} \qquad \Delta t' = \Delta t \frac{1}{\sqrt{1-\beta^2}} = \Delta t\, \gamma$$

$$\beta \equiv v/c \qquad \gamma \equiv \frac{1}{\sqrt{1-\beta^2}}, \quad \text{always} \geq 1 \quad \text{as we will see}$$

$\Delta t' > \Delta t$ Known as time dilation

Proper time $\equiv$ time interval between two events measured in the coordinate frame where the two events occur at the same place.

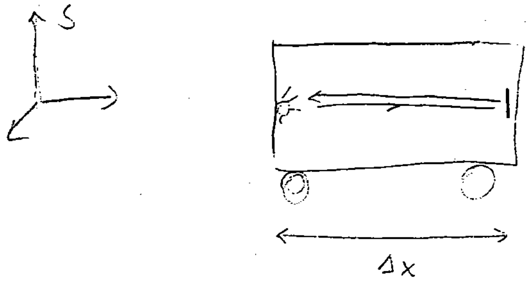
(Frame [illegible])

in this case Δt is the proper time interval
The time interval as measured in any inertial frame of reference <u>other</u> than the one where the proper time is measured will be longer.

Hold off on examples until I have developed the subject a little more

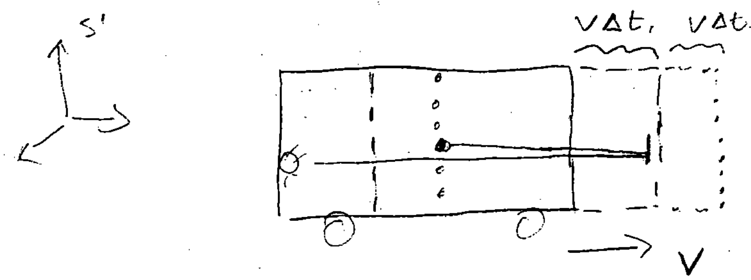
last lect April 26

Another Gedanken expt – From TRAIN



$$\Delta t = \frac{2\Delta x}{c}$$

Now from "ground" frame of reference S' (Moves $-v$ relative to train)



$$\Delta t_1' = \frac{\Delta x' + v\Delta t_1'}{c} \Rightarrow \Delta t_1' = \Delta x' \frac{1}{(1-v/c)} \qquad \Delta t_2' = \frac{\Delta x' - v\Delta t_2'}{c} \Rightarrow \Delta t_2' = \Delta x' \frac{1}{(1+v/c)}$$

emission to mirror

mirror back to source

$$\text{TOTAL Time } \Delta t' = \Delta t_1' + \Delta t_2' = \frac{\cancel{2}\Delta x'}{c}\left[\frac{1}{(1+v/c)} + \frac{1}{(1-v/c)}\right] = \frac{2\Delta x'}{c}\frac{1}{(1-v^2/c^2)}$$

Now we know $\Delta t' = \gamma \Delta t =$

$$\therefore \quad \gamma \Delta t = \frac{1}{\sqrt{1-v^2/c^2}} \, \frac{2\Delta x}{c} = \frac{2\Delta x'}{c} \, \frac{1}{(1-v^2/c^2)}$$

$$\therefore \quad \Delta x = \Delta x' \frac{1}{\sqrt{1-v^2/c^2}} = \Delta x' \gamma \qquad \gamma \geq 1$$

Observer on ground (prime system) measures a length for the car that is <u>shorter</u> than what an observer on the train measures.

$\Rightarrow$ Lorentz Contraction

The length as measured in the <u>object's</u> rest frame is the proper length,

The length as measured in any inertial reference frame moving with respect to the rest frame will be shorter.

This only occurs for lengths measured in the <u>direction</u> of relative motion

Let us use what we ~~have~~ learned so far to derive more general transformation equations between inertial frames of reference.

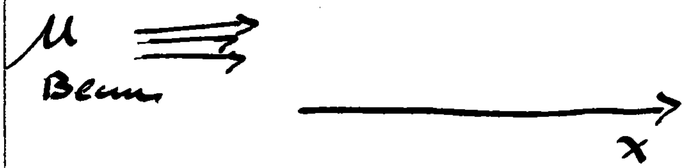
Example using time dilation

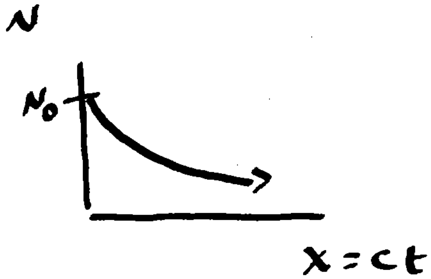
μ mass = 105.6 MeV

($e^- = 0.511$ MeV)

Mean $\tau = 2.2 \times 10^{-6}$ s

$$N = N_0 e^{-t/\tau}$$





let $v \approx c$ $\quad x = ct$

what is $c\tau = (3\times10^8 \text{ m/s})(2.2\times10^{-6}\text{ s}) = 660$ m

μ from "cosmic rays"

Particle interacts 15 km up in atmosphere

creates showers of other particles

(along w/ μ's)

Do you expect to see any μ at earth's surface?

$$N = N_0 e^{-t/\tau} \qquad t = \frac{15000}{3\times10^8} = 1\times10^{-4}$$

$N = 1.3\times10^{-10} N_0$ $\rightarrow$ don't expect many!

But we do see many μ at ground

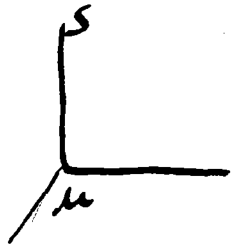
Why?

~~μ rest frame~~

μ lifetime is 2.2×10^{-6} s in μ rest frame

its proper frame

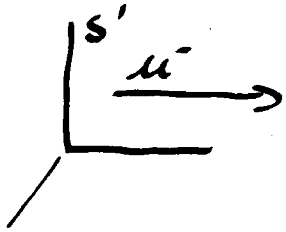
moves w/ μ



$\tau = 2.2\times10^{-6}$ s $\Delta t \approx \tau$
$= t_{decay} - t_{create}$

Suppose $\beta \equiv v/c = .95$

$\gamma = 3.2$



in earth lab frame

- moves at .95c w/ respect to S

proper frame $\Delta t' = (t'_{decay} - t'_{create})$

↓

$\gamma \Delta t = \Delta t' \Rightarrow \Delta t' = 7\times10^{-6}$

$\gamma > 1$ Δt always shortest in proper frame

Use This rule to avoid NOTATION confusion!!

if $v = .999c$ $\gamma = 22.3$ $\Delta t' = 4.9\times10^{-5}$

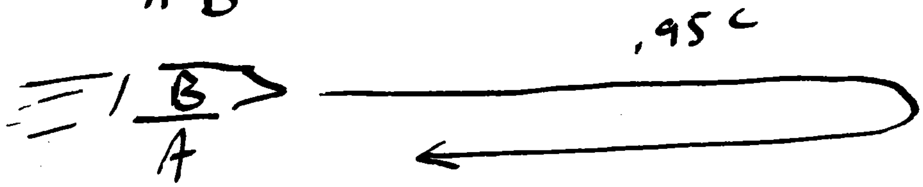
go back to μ produced at 15 km

$N = N_0 e^{1\times10^{4}/4.4\times10^{5}}$ $N = N_0 .36$

Twin Paradox

Twins

A B



B younger than A ?

or does A do the moving ??

Time dialation well established experimentally

Must take into account

Nucleus/particle expts

NASA

Precision timing

* GPS

relate Event (x, y, z, t) in S
to Event (x', y', z', t') in S'

PHYSICS 300
(1991)

Lorentz Transformations ;

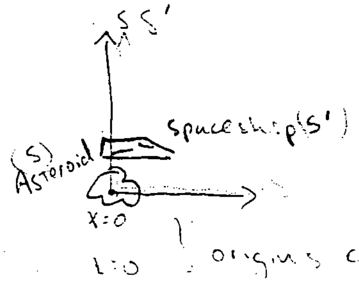
contains
Time dilation
length contraction
only in direction of relative movement

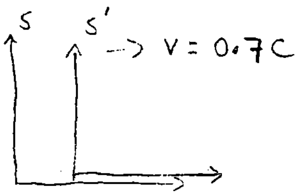
$$x' = \gamma(x - vt) \qquad x = \gamma(x' + vt')$$
$$y' = y \qquad y = y'$$
$$z' = z \qquad z = z'$$
$$t' = \gamma(t - \tfrac{v}{c^2}x) \qquad t = \gamma(t' + \tfrac{v}{c^2}x')$$

Note that t' depends on both t and x
The Relativistic Concept of Simultaneity is Not the same as the Classical one.

what does simultaneity mean

ex





~~spaceship flashes laser~~

Event 1
Spaceship passed asteroid

event 1 occurs in S at $x = 0$ at $t = 0$

laser flashing → event 2 occurs in S at $x = 3.0$ km, $t = 5\ \mu s$

what does S' see ?

On Asteroid ... laser seen to flash
$X = 3.0$ km from Asteroid at $t = 5\mu s$
(TAKES into account time for light to travel in S)

$$\gamma = \frac{1}{\sqrt{1 - \left(\frac{.7c}{c}\right)^2}} = 1.40$$

$x_1' = 0 \quad t_1' = 0$

$$x_2' = \gamma(x - vt) = 1.40\left[3.0 - (.7)(3\times10^5\ \mathrm{km/s})(5\times10^{-6}\ \mathrm{s})\right]$$

$$x_2' = 2.73\ \mathrm{km}$$

$$t_2' = \gamma(t - \tfrac{v}{c^2}x) = 1.4\left[(5\times10^{-6}\ \mathrm{s}) - \frac{.7 \quad 3.0\ \mathrm{km}}{3\times10^5\ \mathrm{km/s}}\right] = -2.8\ \mu s$$

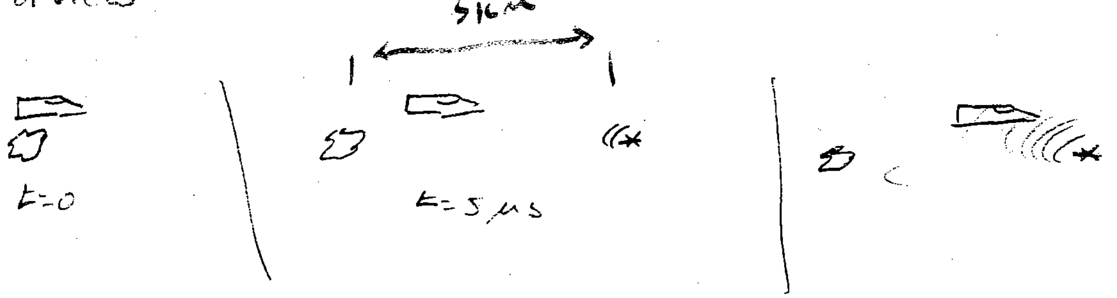
Flash of laser

Asteroid: 3 km away
5 μs after ship passed by
ship located at $(5\times10^{-6}\,s)(3\times10^{5}\,km/s) = 1.5$ km away
When flash ~~observed~~ happens

Spaceship:
Flash obs'n (to happen) 2.73 km in front
(NOT $3 - 1.5 = 1.5$ km)
Flash occurs 2.8 s
before spaceship passes by asteroid

Where all observers properly take into account the time it takes for light to travel from the flash point to them in measuring their times

Asteroid pt of view



Ship