Happy New Year !

Physics 2D Lecture Slides
Lecture 2: Jan 4 2005

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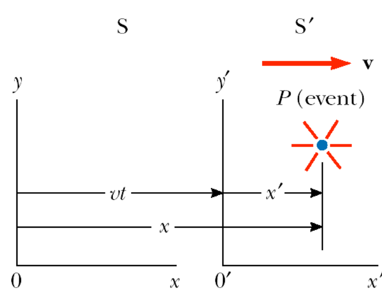
UCSD Physics

Announcements

- Pl. make the following changes in the handout:
  - Final exam is Thursday, March 17 at 11:30am, location TBA
  - Tuesday lectures are in Peterson 110, NOT WLH2005 !
  - TA discussion hours are
    - Wednesday 1:00 pm at WLH 2216
    - Thursday 5:30 pm at WLH 2216
    - Best way to reach TA is to email him: crs@physics.ucsd.edu
- Pl. review material from 2A, 2B, 2C. Read chapters from your past course text ***Physics for Engineers and Scientists (3rd edition)*** by Wolfson and Pasachoff
    - 16 : Waves
    - 34 : Maxwell's Eqn and Electromagnetic Waves
    - 37: Interference and Diffraction
  - Take advantage of Physics Tutorial Center for unlimited drop-in tutoring, see *http://physics.ucsd.edu/students/courses/tutorialcenter/*

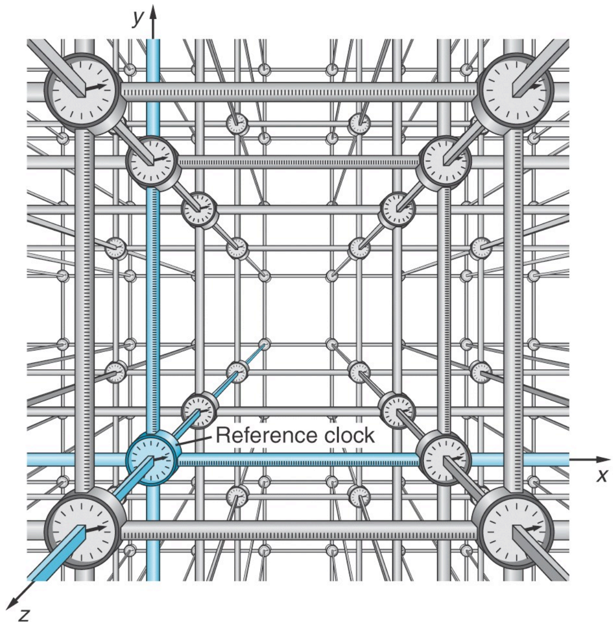
Event, Observer, Frame of Reference

- Event : Something happened => (x,y,z,t)
  - Same event can be described by different observers
- Observer(s) : Measures event with a meter stick & a clock
- Frame of Reference :observer is standing on it
  - Inertial Frame of reference ← constant velocity, no force
- An event is not OWNED by an observer or frame of reference
- An event is something that happens, any observer in any reference frame can assign some (x,y,z,t) to it
- Different observers assign different space & time coordinates to same event
  - S describes it with : (x,y,z,t)
  - S' describes same thing with (x',y',x',t')

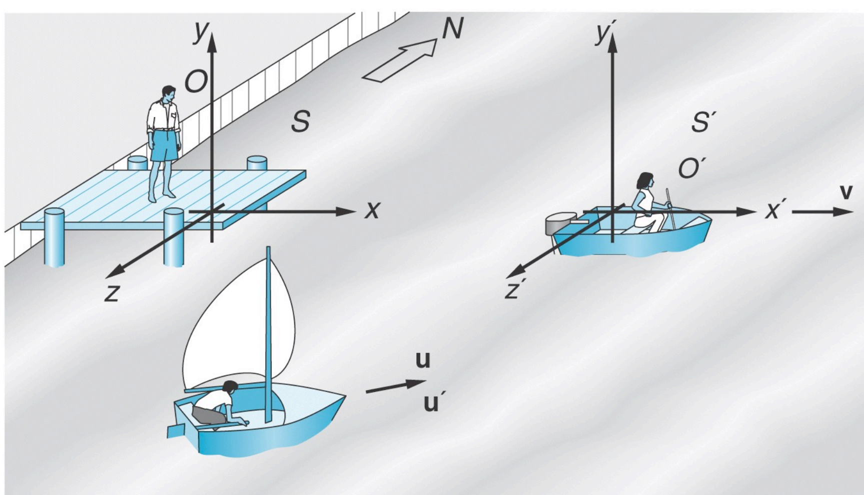


An event occurs at a point *P*. The event is seen by two observers in inertial frames S and S′, where S′ moves with a velocity **v** relative to S.

The Universe as a Clockwork of Reference Frames



“Imagining” Ref Frames And Observers



Galilean Transformation of Coordinates

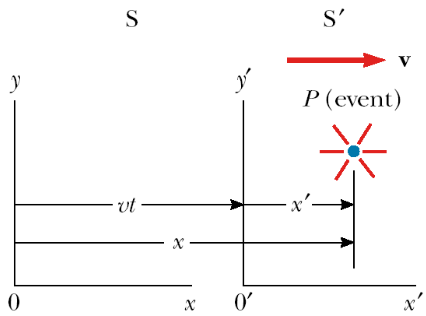


Figure 39.2 An event occurs at a point *P*. The event is seen by two observers in inertial frames S and S′, where S′ moves with a velocity **v** relative to S.

Galilean Rules of Transformation

$$x' = x - vt$$

$$y' = y$$

$$z' = z$$

$$t' = t$$

Quote from Issac Newton Regarding Time

"Absolute, true and mathematical time, of itself, and from nature, flows equably without relation to anything external"

$$t = t'$$

There is a universal clock

Or

All clocks are universal

Galilean Addition Law For Velocities

$$dx' = dx - v\,dt$$

$$dt = dt'$$

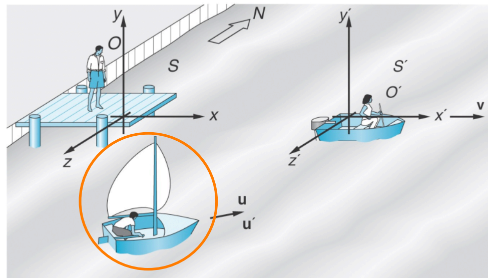
⇩

$$\frac{dx'}{dt'} = \frac{dx}{dt} - v$$

⇩

$$u'_x = u_x - v$$

This rule is used in our everyday observations (e.g. driving a car) and is consistent with our INTUITIVE notions of space and time



But what happens when I drive a car very fast !!

How fast: (v = ?)

- As fast as light can travel in a medium !!!

Newton's Laws and Galilean Transformation !

- But Newton's Laws of Mechanics remain the same in All frames of references !

$$\frac{d^2x'}{dt^2} = \frac{d^2x'}{dt^2} - \frac{dv}{dt}$$

$\Rightarrow$

$$a' = a \qquad \Rightarrow \vec{F}' = \vec{F}$$

Description of Force does not change from one inertial frame of reference to another

Newtonian/Galilean Relativity

Inertial Frame of Reference is a system in which a free body is not accelerating

Laws of Mechanics must be the same in all Inertial Frames of References
⇒Newton's laws are valid in all Inertial frames of references
⇒No Experiment involving laws of mechanics can differentiate between any two inertial frames of reference
⇒Only the relative motion of one frame of ref. w.r.t other can be detected
⇒ Notion of ABSOLTUTE motion thru space is meaningless
⇒There is no such thing as a preferred frame of reference

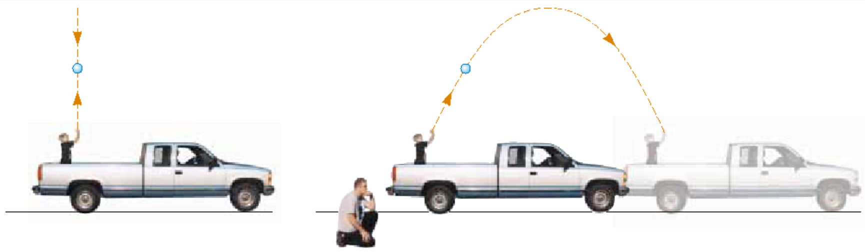


Figure 39.1 (a) The observer in the truck sees the ball move in a vertical path when thrown upward. (b) The Earth observer sees the path of the ball as a parabola.

Light Is An Electromagnetic Wave (2C)

- Maxwell's Equations:

$$\oint_S \mathbf{E} \cdot d\mathbf{A} = \frac{Q}{\epsilon_0}$$

$$\oint_S \mathbf{B} \cdot d\mathbf{A} = 0$$

$$\oint \mathbf{E} \cdot d\mathbf{s} = -\frac{d\Phi_B}{dt}$$

$$\oint \mathbf{B} \cdot d\mathbf{s} = \mu_0 I + \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$$

⇩

$$\frac{\partial^2 E}{\partial x^2} = \mu_0 \epsilon_0 \frac{\partial^2 E}{\partial t^2}$$

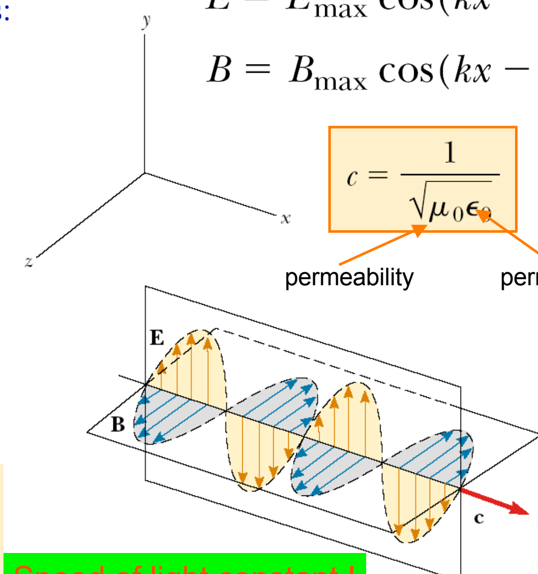
$$\frac{\partial^2 B}{\partial x^2} = \mu_0 \epsilon_0 \frac{\partial^2 B}{\partial t^2}$$

$$E = E_{\max} \cos(kx - \omega t)$$

$$B = B_{\max} \cos(kx - \omega t)$$

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$

permeability permittivity



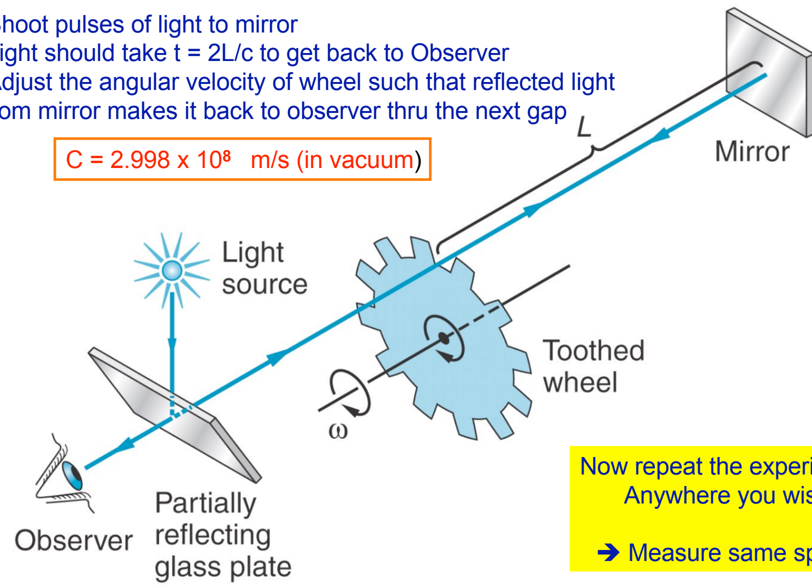
Speed of light constant !

Measuring The Speed Of Light

High Technology of 1880's: Fizeau's measurement of speed of light

1. Shoot pulses of light to mirror
2. Light should take t = 2L/c to get back to Observer
3. Adjust the angular velocity of wheel such that reflected light from mirror makes it back to observer thru the next gap

C = 2.998 x 10^8 m/s (in vacuum)

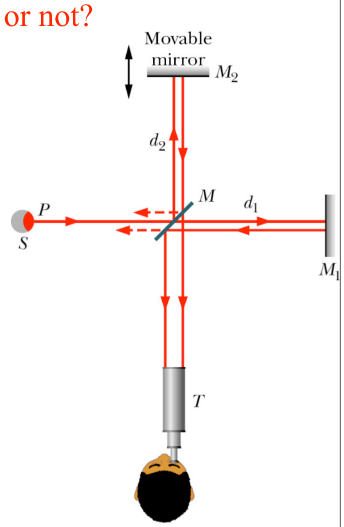


Now repeat the experiment Anywhere you wish

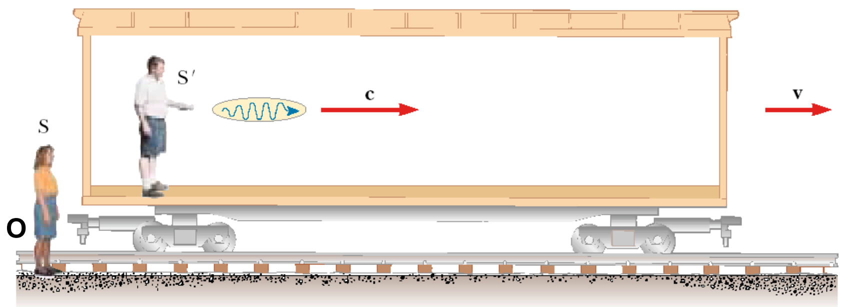
➔ Measure same speed

Does Light Need a Medium to Propagate ?

- EM waves are a different
  - What is the required medium of propagation ? Aether ??
    - How to verify whether Aether exists or not?
      - (Always) Do an Experiment !
- The Michelson-Morley Interferometer
  - Interferometer: device used to measure
    - Lengths or changes in lengths
  - Measured with great accuracy
    - Using interference fringes
- HW Reading : Section 1.3
  - If you don't understand this, pl. review
    - Wave Phenomena
- Bottomline: Light needs no medium



Galilean Relativity and EM Waves



It would appear to Observer O in S frame that velocity of light

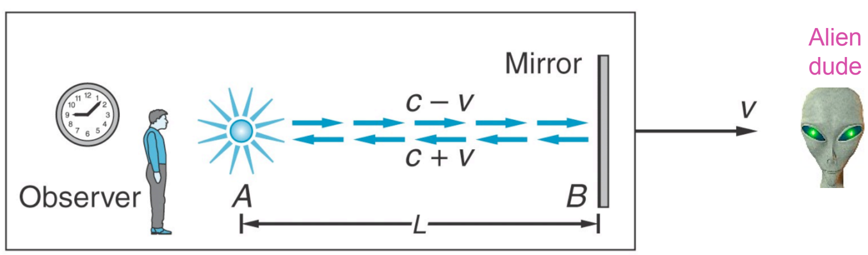
$V_S = c + v > c$

This contradicts Maxwell's theory of Light !

Are Newton's Laws and Maxwell's laws inconsistent??!!

Newtonian Relativity & Light !

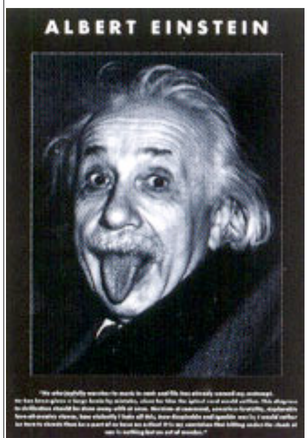
Light source, mirror & observer moving thru some medium with velocity V
Galilean Relativity ➔
• If the alien measures velocity of light = c
•Then observer must measure speed of light = c-v when it is leaving him
=c+v when it is reflected back



But Maxwell's Eq → speed of light is constant in a medium??

Must it be that laws of Mechanics behave differently from E&M in different inertial frames of references ? …if so how inelegant would nature be!

Einstein's Special Theory of Relativity

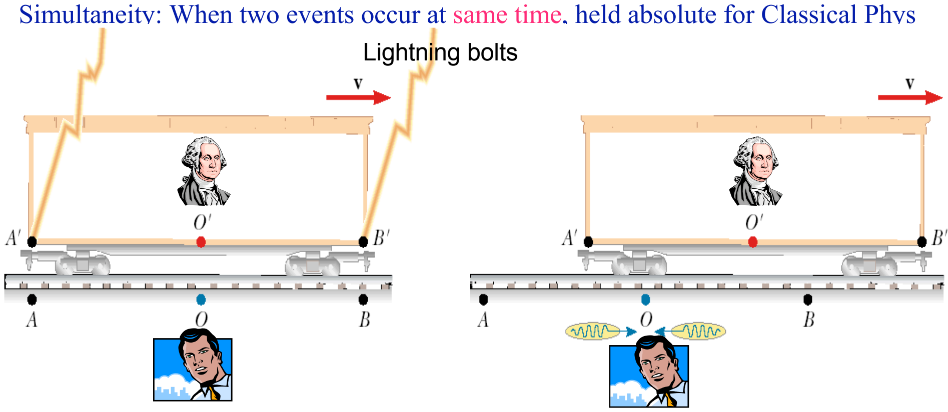


Einstein's Postulates of SR

- The laws of physics must be the same in all inertial reference frames
- The speed of light in vacuum has the same value (c = 3.0 x 10^8 m/s) , in all inertial frames, regardless of the velocity of the observer or the velocity of the source emitting the light.

Consequences of Special Relativity: Simultaneity not Absolute

Simultaneity: When two events occur at same time, held absolute for Classical Phys

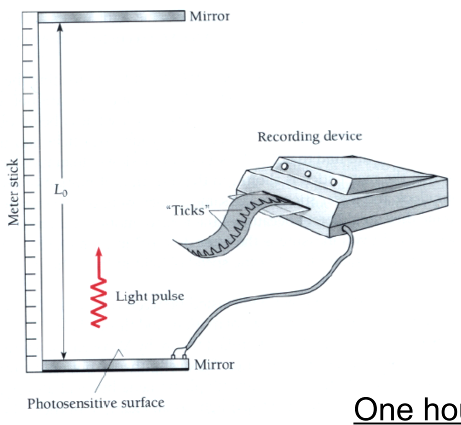


Events that are simultaneous for one Observer are not simultaneous for another Observer in relative motion

Simultaneity is not absolute !!

Time interval depends on the Reference frame it is measured in

A Simple Clock Measuring a Time Interval

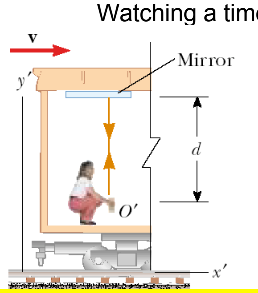


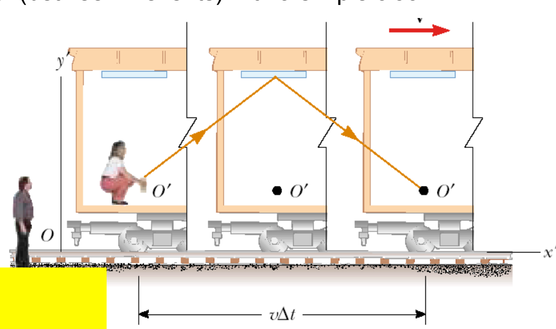
$$t = \int \Delta t$$

One hour = 60 x 1 minute time intervals

Time Dilation and Proper Time

Watching a time interval (between 2 events) with a simple clock





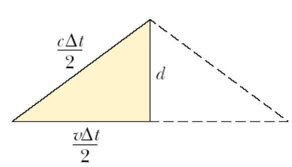
Observer O′ : $\Delta t' = \dfrac{2d}{c}$

Observer O : Apply Pythogoras Theorem

$$\left(\frac{c\Delta t}{2}\right)^2 = (d)^2 + \left(\frac{v\Delta t}{2}\right)^2, \text{ but } d = \left(\frac{c\Delta t'}{2}\right)$$

$$\therefore \quad c^2(\Delta t)^2 = c^2(\Delta t')^2 + v^2(\Delta t)^2$$

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

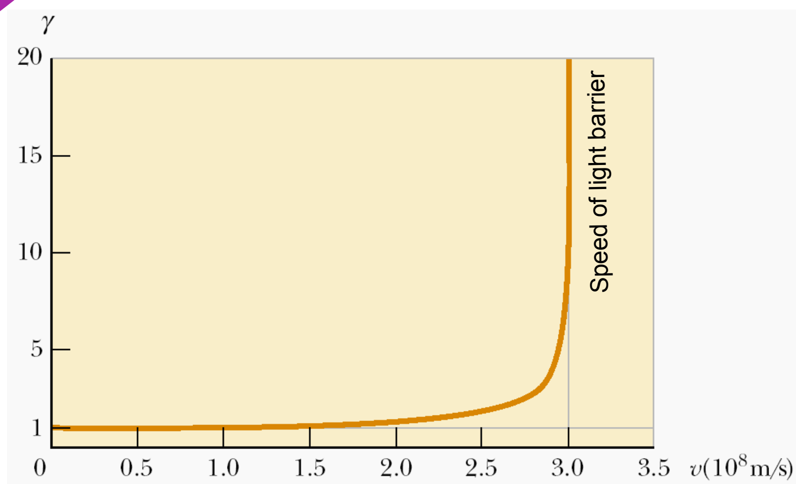


The γ factor

$$\gamma = \frac{1}{\sqrt{1 - v^2 / c^2}}$$

as $v \to 0, \ \gamma \to 1$

as $v \to c, \ \gamma \to \infty$



Measuring Time: Period of a Pendulum

- Period of a pendulum is 3.0 s in the rest frame of the pendulum
- What is period of the pendulum as seen by an observer moving at v=0.95c

Answer:

- Proper time T' = 3.0s
- Since motion is relative and time dilation does not distinguish between
  - relative motion →→ (V) from relative motion ← ← (-V)
- lets reformulate the problem like this (??)
  - A pendulum in a rocket is flying with velocity V =0.95c past a stationary observer
  - Moving clocks runs slower [w.r.t clock in observer's hand (rest)] by factor γ
  - ➔ Period T measured by observer = γ T'

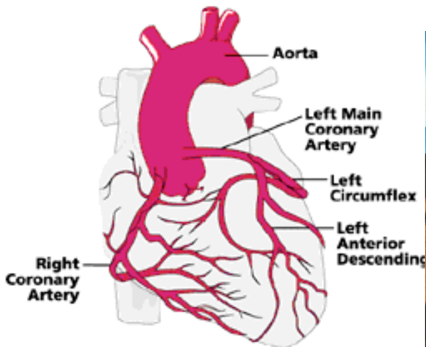
$$\gamma = \frac{1}{\sqrt{1-(v/c)^2}} = \frac{1}{\sqrt{1-(0.95)^2}} = 3.2$$

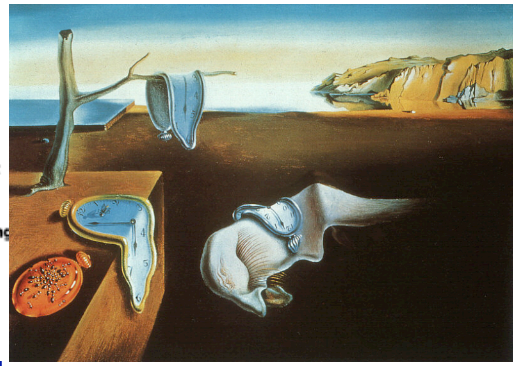
$$\Rightarrow T = \gamma T' = 3.2 \times 3.0s = 9.6s$$

Moving pendulum slows down ➔ takes longer to complete a period

All Measures of Time Slow down from a Moving Observer's Perspective !

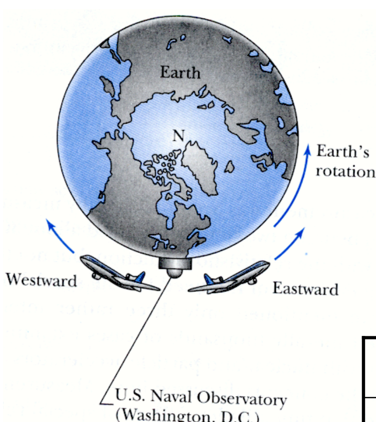
- Your heartbeat or your pulse





- Mitosis and Biological growth
- Growth of an inorganic crystal
- …all measures of time interval

Round The World With An Atomic Clock !

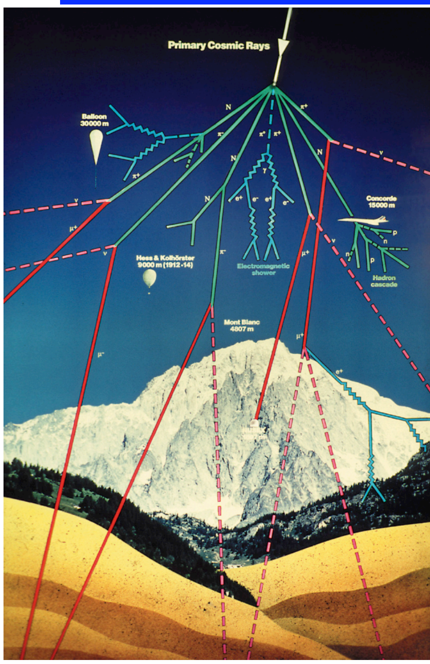


- Atomic Clock : certain atomic level transitions in Cesium atom
- Two planes take off from DC, travel east and west
  - Eastward trip took 41.2 hrs
  - Westward trip took 48.6
- Atomic clocks compared to similar ones kept in DC
- Need to account for Earth's rotation + GR etc

Travel	Predicted	Measured
Eastward	-40 ± 23 ns	-59 ± 10 ns
Westward	275 ± 21 ns	273 ± 7 ns

Flying clock ticked faster or slower than reference clock. Slow or fast is due to Earth's rotation

Cosmic Particles Are Bombarding the Earth



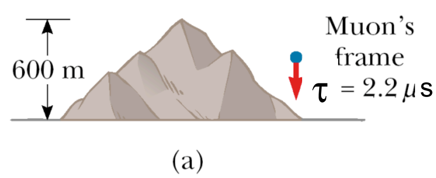
- Cosmic "rays" are messengers from space
- **Produced in violent collisions in the cosmos**
- **Typical Kinetic energy ~ 100 GeV**
- **Smash into Earth's outer atmosphere**
  - **4700 m from sea level**
- **Sometimes produce short lived Muons**

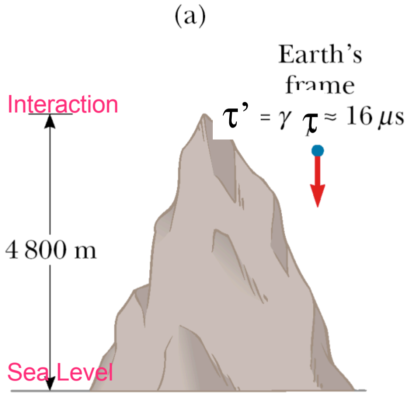
- **Muon is electron like charged particle**
  - **~ 200 times heavier , same charge**
  - **Lifetime τ= 2.2μs = 2.2 x10^{-6} s**
  - **Produced with speed v $\equiv$ c**
  - **Distance traveled in its lifetime**

$$d = c\tau = 650m$$

  - **Yet they seem to reach the surface!!**
    - **Why => Time Dilation**
    - **Must pay attention to frames of references involved**

Cosmic Rays Are Falling On Earth : Example of Time Dilation





- Consider Two frames of references
  1. You Riding on the Muon Particle
  2. Your twin watching On surface of earth

– Muon Rider has "Proper Time"
  – Time measured by observer moving along with clock
  – $\Delta t' = \tau = 2.2\mu S$
  – $D' = v\,\Delta t' = 650m$

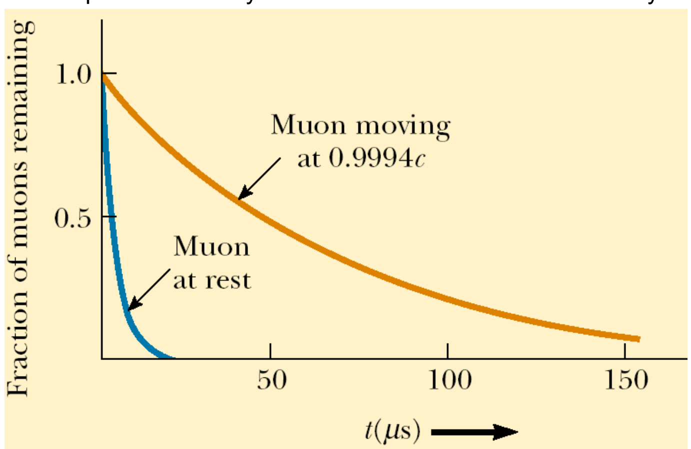
– Earthling watches a moving clock (muon's) run slower
  – $\Delta t' = \gamma\tau$
    – $v = 0.99c, \Rightarrow \gamma = 7.1$
    – $D = v\,\Delta t = 4700m$

Muon Decay Distance Distribution

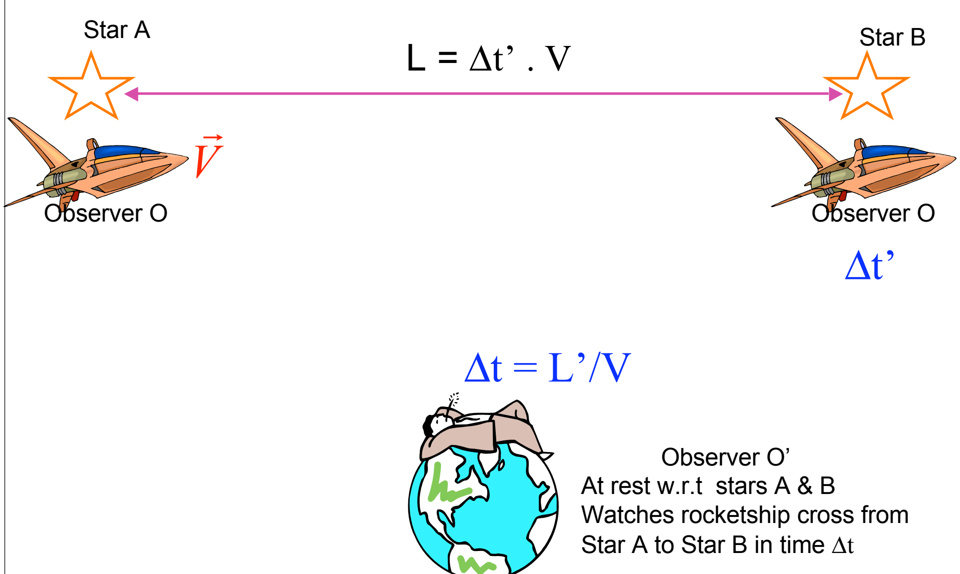
Relative to Observer on Earth Muons have a lifetime

$$t = \gamma\tau = 7.1\ \tau$$

Exponential Decay time Distribution : As in Radioactivity



Offsetting Penalty : Length Contraction



Rocketman Vs The Earthling

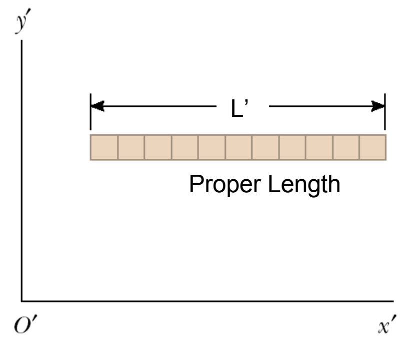
- Earth Observer saw rocketman take time $\Delta t = (L'/V)$
- Rocketman says he is at rest, Star B moving towards him with speed V from right passed him by in time $\Delta t'$, so
  - $L = \Delta t' . V$
  - But $\Delta t' = \Delta t / \gamma$ (time dilation)
  - $\Rightarrow L = V. (\Delta t / \gamma)$

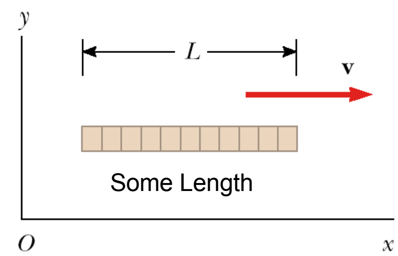
    $= L'/\gamma$

$$L = L' . \sqrt{1 - \frac{V^2}{c^2}}$$

$$L \leq L'$$

Moving Rods Contract in direction Of relative motion





Immediate Consequences of Einstein's Postulates: Recap

- Events that are simultaneous for one Observer are not simultaneous for another Observer in relative motion
- Time Dilation : Clocks in motion relative to an Observer appear to slow down by factor γ
- Length Contraction : Lengths of Objects in motion appear to be contracted in the direction of motion by factor γ^{-1}
- New Definitions :
  - Proper Time (who measures this ?)
  - Proper Length (who measures this ?)
  - Different clocks for different folks !