



Physics 2D Lecture Slides

Sept 29

Vivek Sharma
UCSD Physics

Galilean Relativity

- Describing a Physical Phenomenon
 - Event (and a series of them)
 - Observer (and many of them)
 - Frame of reference (& an Observer's point of View !)
 - Inertial Frame of Reference
 - Accelerated Frame of Reference
- Newtonian Relativity and Inertial Frames
 - Laws of Physics and Frame of Reference
 - Galilean Transformation of coordinates
 - Addition law for velocities
- Maxwell's Equations & Light (EM Waves)
 - Light as Electromagnetic wave
 - Speed of Light is not infinite !
 - Light needs no medium to propagate

Event, Observer, Frame of Reference

- Event : Something happened $\Rightarrow (x,y,z,t)$
 - 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 \Leftarrow 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')

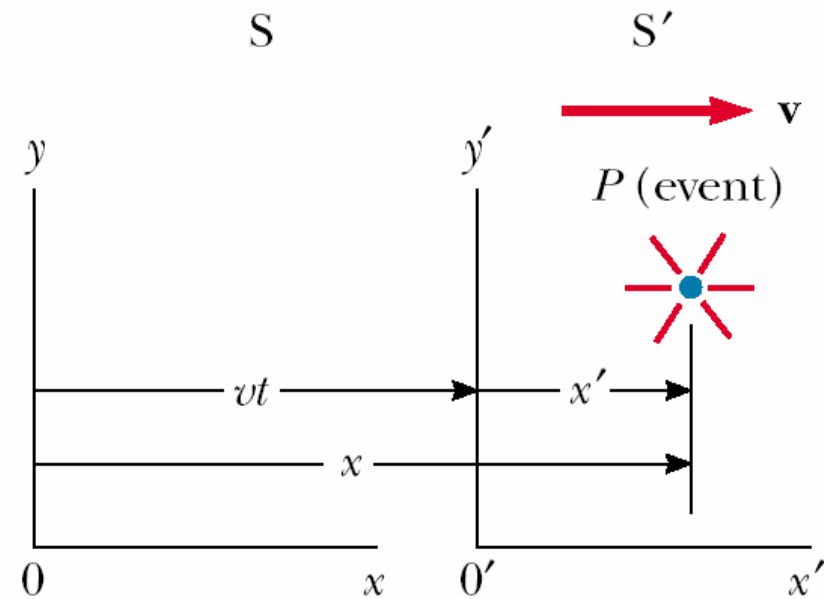


Figure 39.2 An event occurs at a point P . The event is seen by two observers in inertial frames S and S' , where S' moves with a velocity \mathbf{v} relative to S .

Galilean Transformation of Coordinates

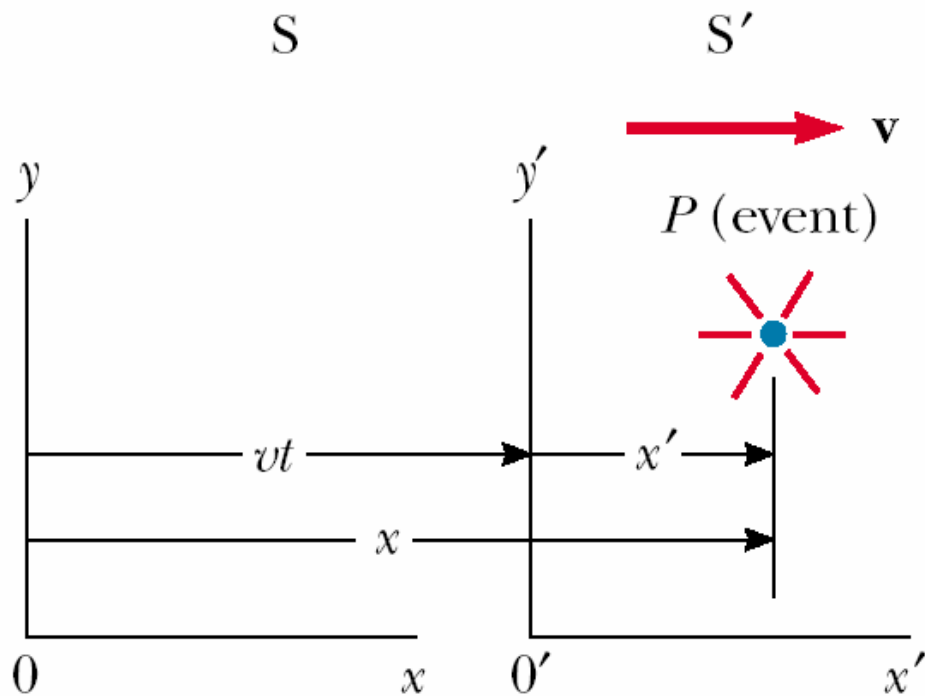


Figure 39.2 An event occurs at a point P . The event is seen by two observers in inertial frames S and S' , where S' moves with a velocity \mathbf{v} relative to S .

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

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

$$dx' = dx - v dt$$

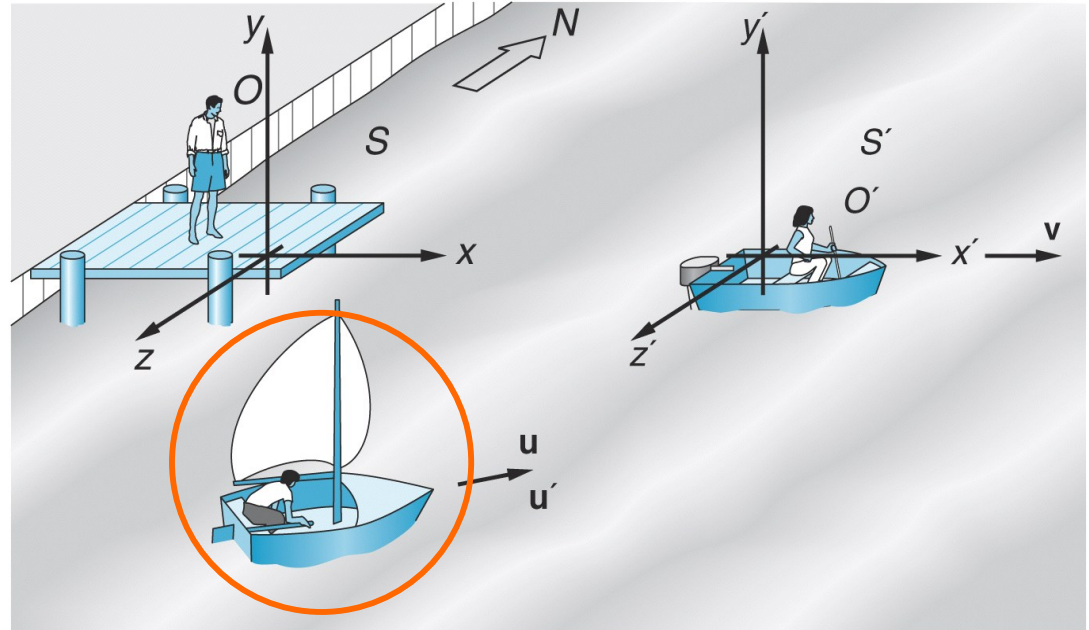
$$dt = dt'$$



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



$$u'_x = u_x - v$$



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 !

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



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

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 ABSOLUTE motion thru space is meaningless

⇒ There is no such thing as a preferred frame of reference

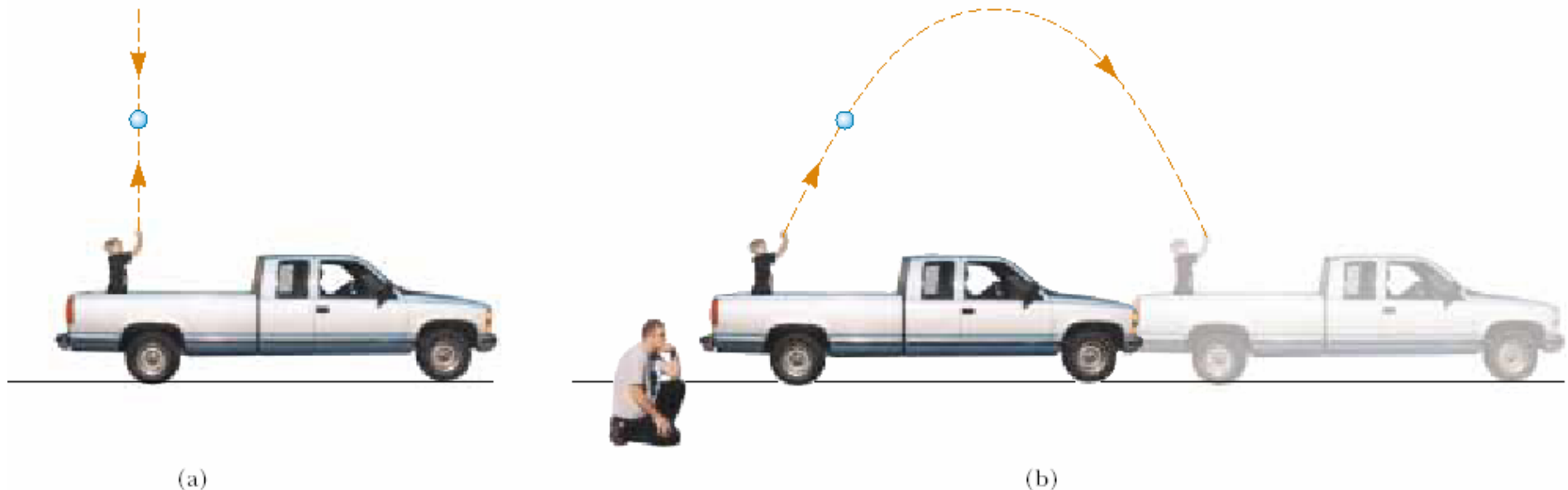


Figure 39.1 (a) The observer in the truck sees the ball move in a vertical path when thrown upward. (b) The Earth observer sees the path of the ball as a parabola.

Light Is An Electromagnetic Wave

- Maxwell's Equations:

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

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

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

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

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

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

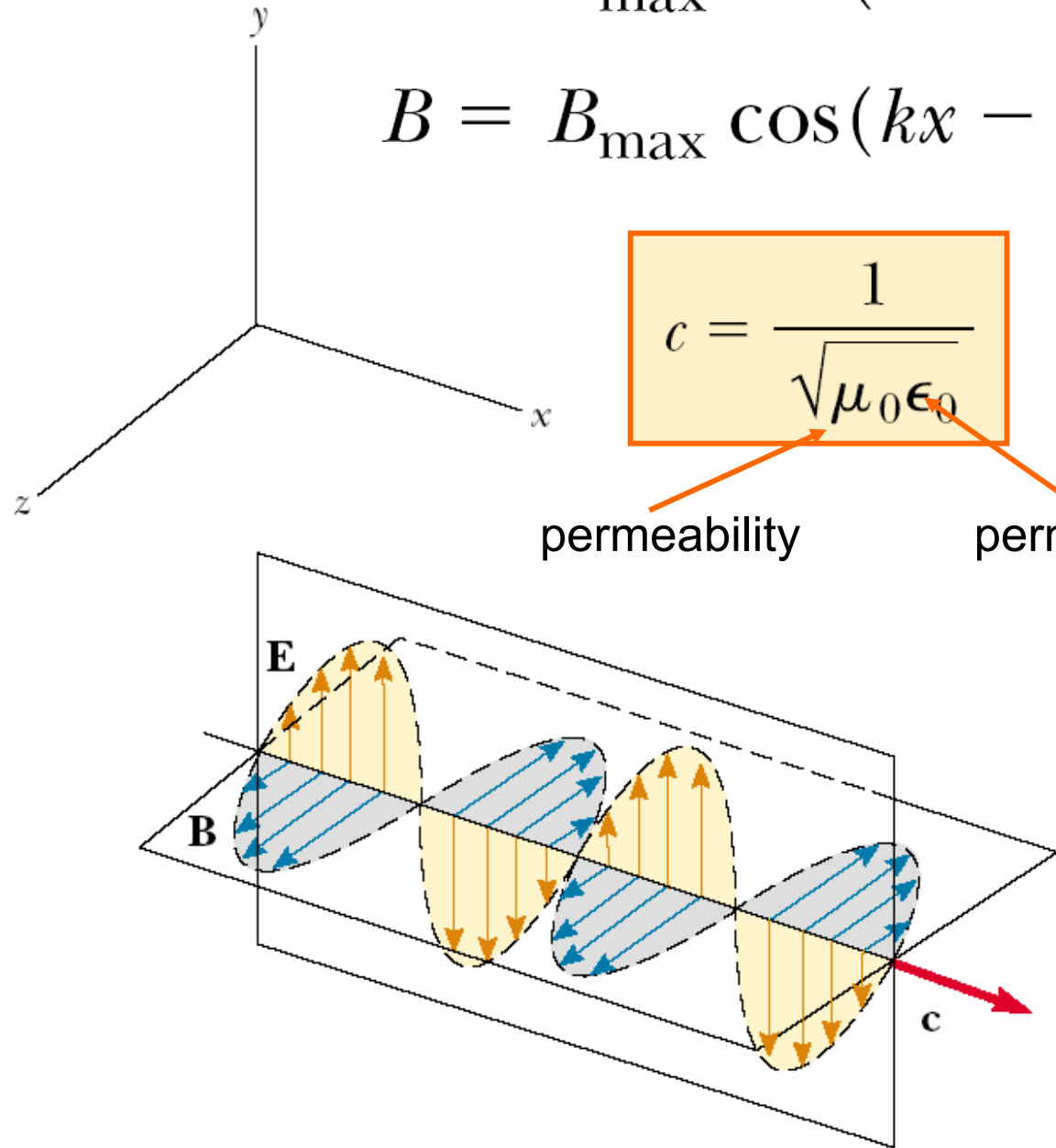
$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$

permeability

permittivity

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

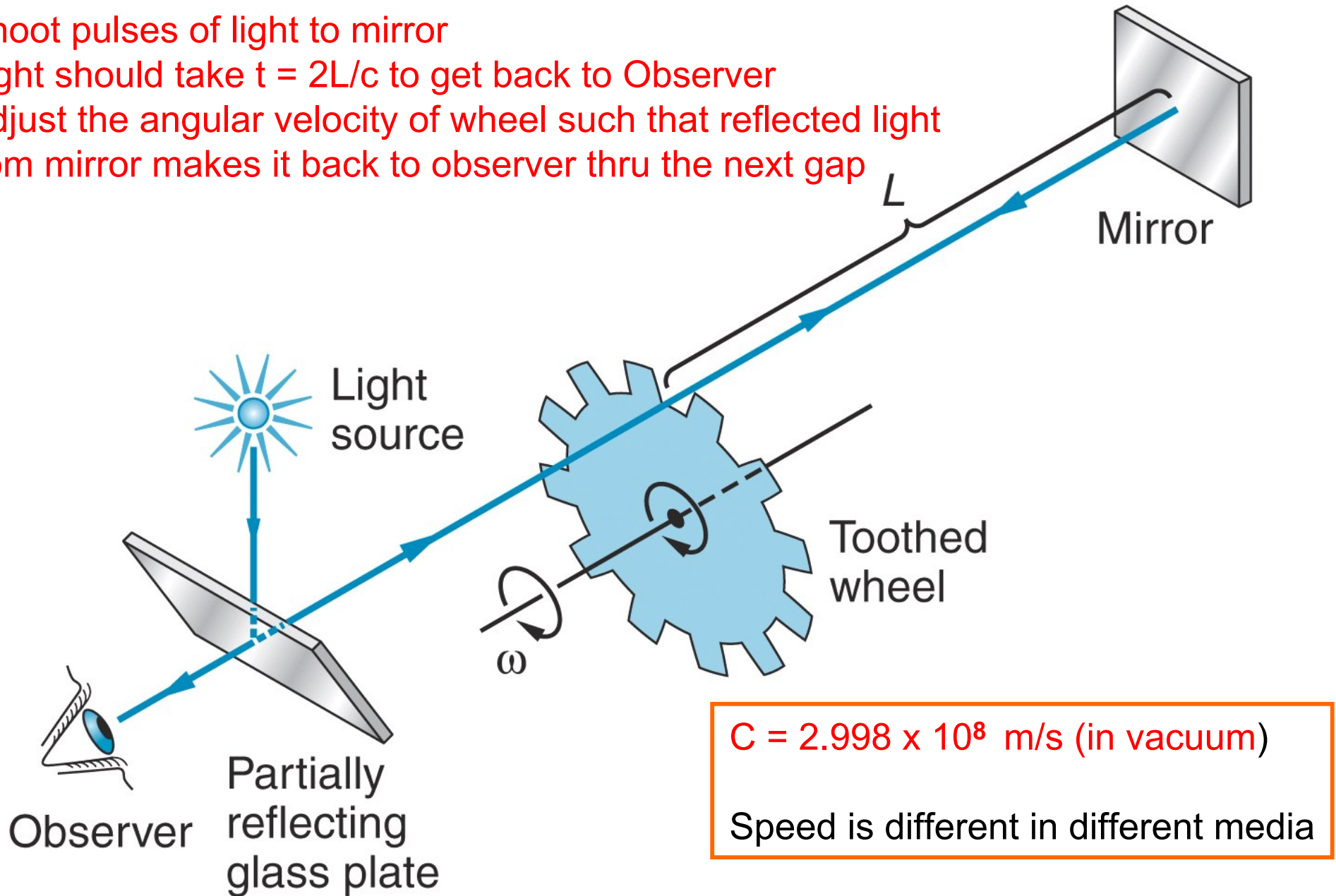
$$\frac{\partial^2 B}{\partial x^2} = \mu_0 \epsilon_0 \frac{\partial^2 B}{\partial t^2}$$



Measuring The Speed Of Light

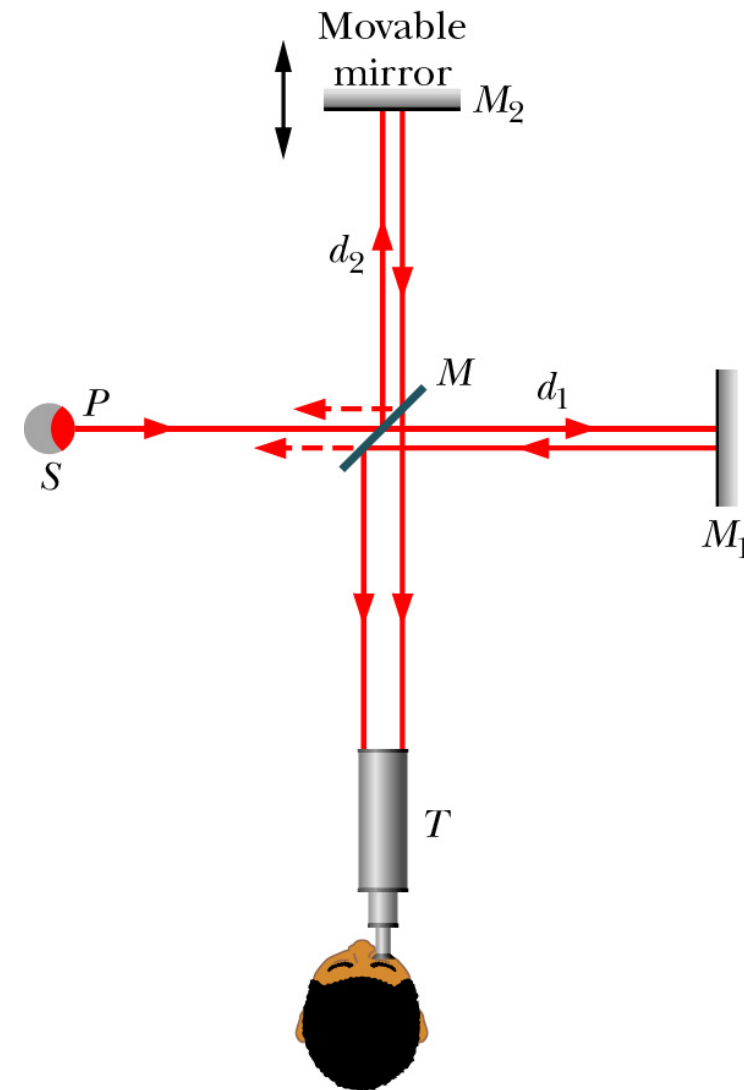
High Technology of 1880's: Fizeau measurement of speed of light

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

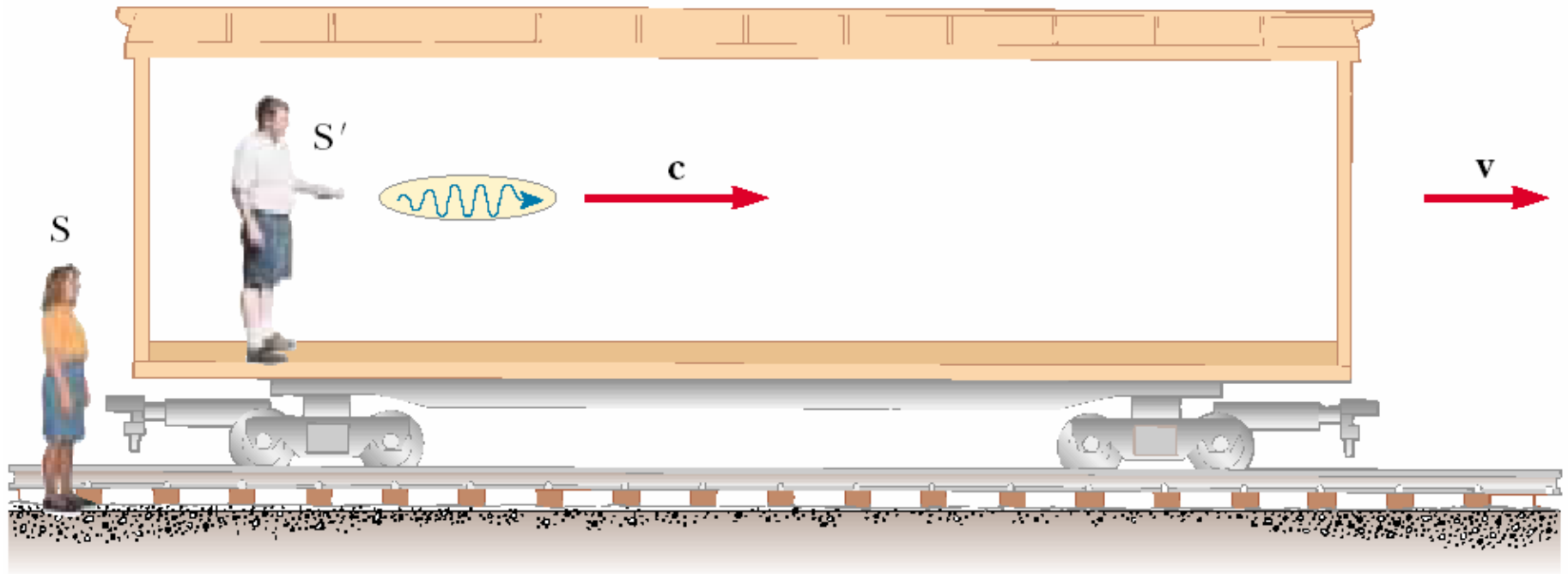


Does Light Need a Medium to Propagate ?

- 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

$$V_S = c + v$$

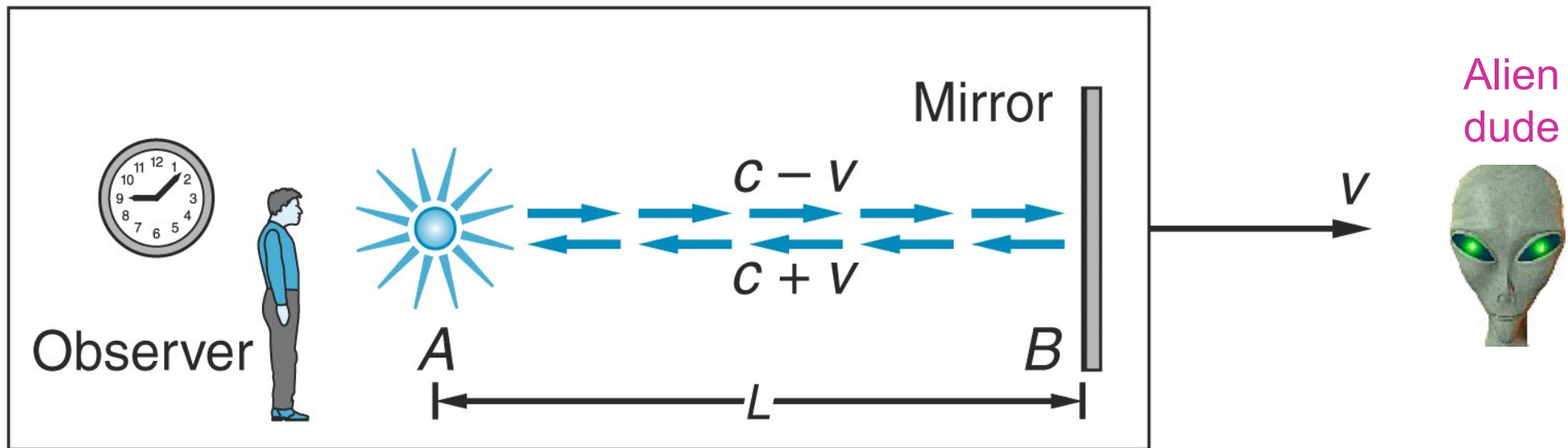
This contradicts Maxwell's theory of Light !

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??

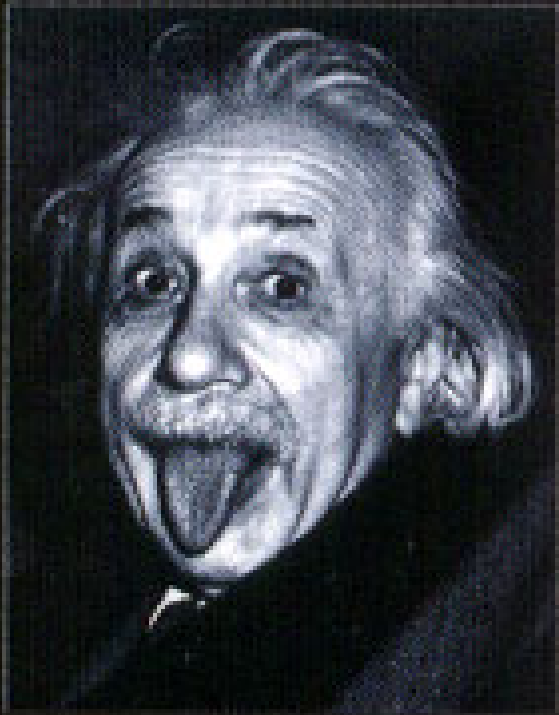
Must it be that laws of Mechanics behave differently from E&M in different inertial frames of references ? ...if so how inelegant would nature be!

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 ($c = 3.0 \times 10^8 \text{ m/s}$), in all inertial frames, regardless of the velocity of the observer or the velocity of the source emitting the light.

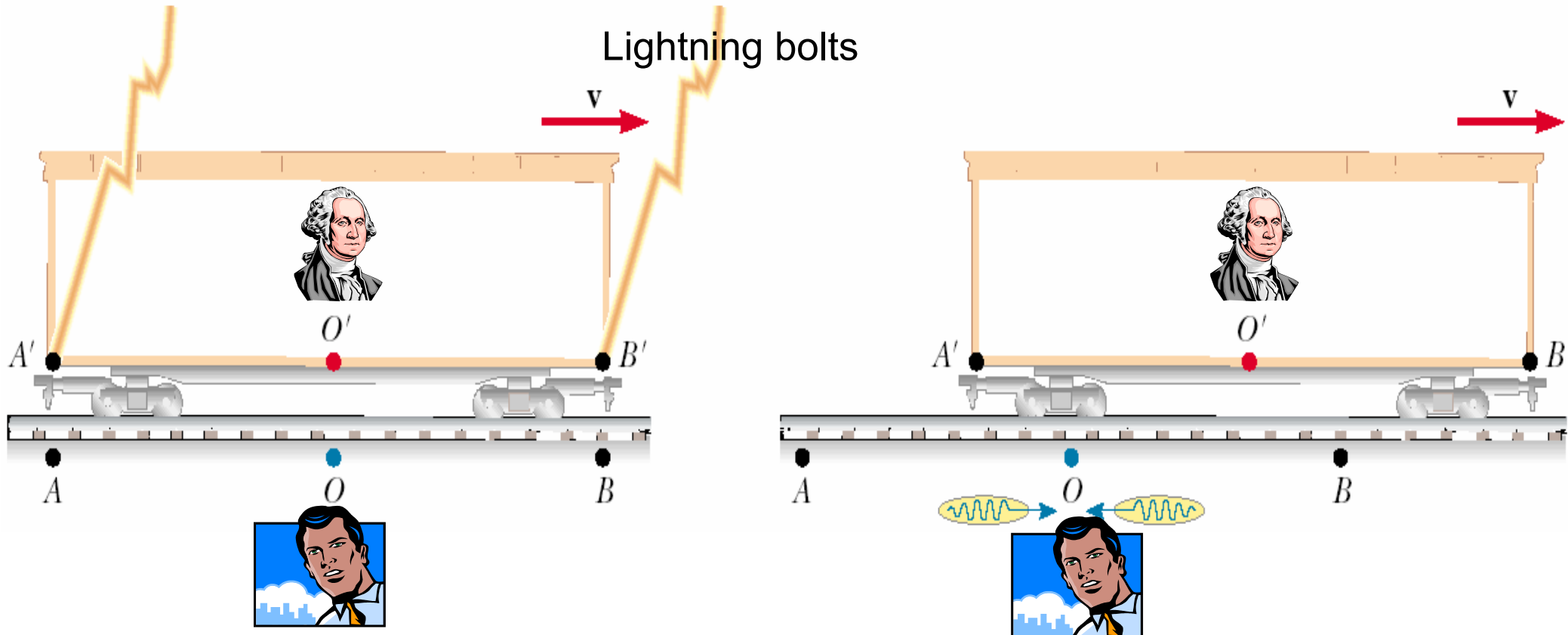
ALBERT EINSTEIN



"The unfortunately inevitable result is that our life has already passed away almost
by the time it has been given to us, but by accident, when the spirit could have written. This attempt
to distribute itself for some time with us, because of necessity, experience, habit, discipline
from all various causes, has evidently I think all this, inevitable participation and so I would rather
be more than for a part of us but we could do it as a creature that living under the shadow of
we in nothing but an act of nature."

Consequences of Special Relativity

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



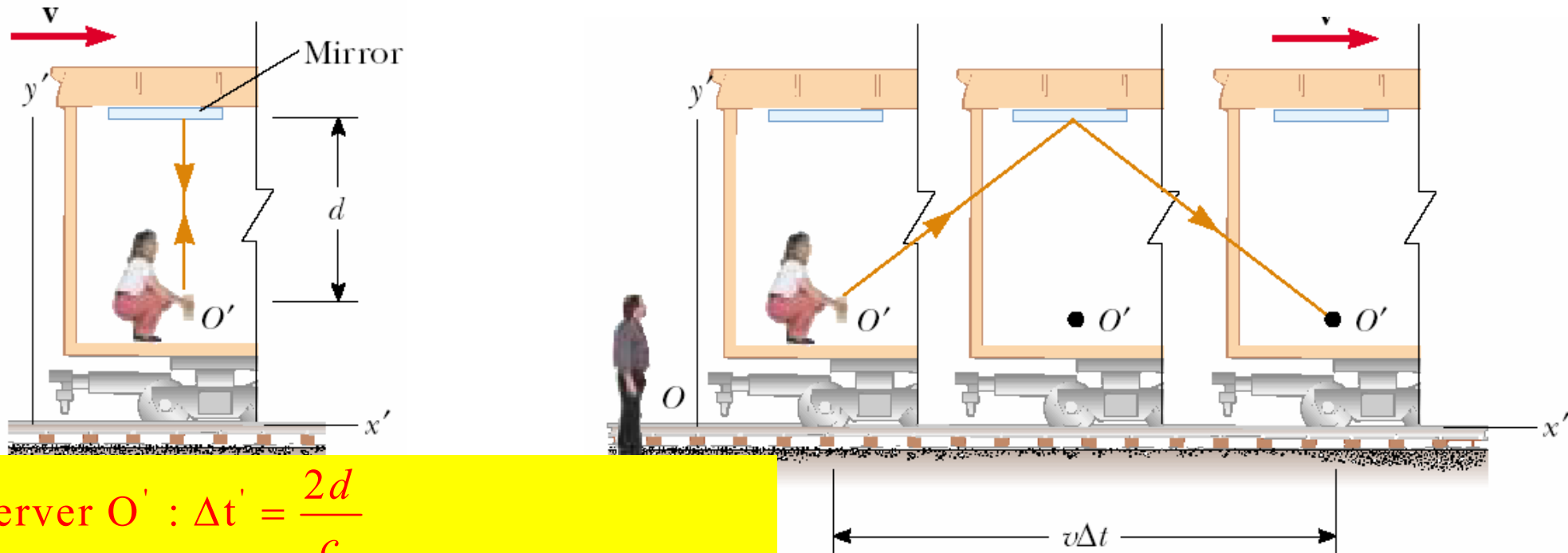
Events that are simultaneous for one Observer are **not simultaneous** for another Observer in relative motion

Simultaneity is not absolute !!

Time interval depends on the Reference frame it is measured in

Time Dilation and Proper Time

Watching a time interval with a simple clock



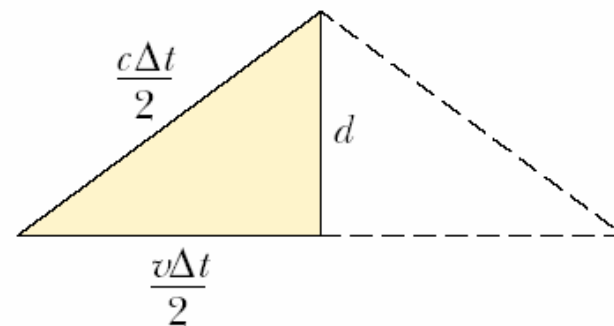
Observer O' : $\Delta t' = \frac{2d}{c}$

Observer O : Apply Pythagoras Theorem

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

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

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

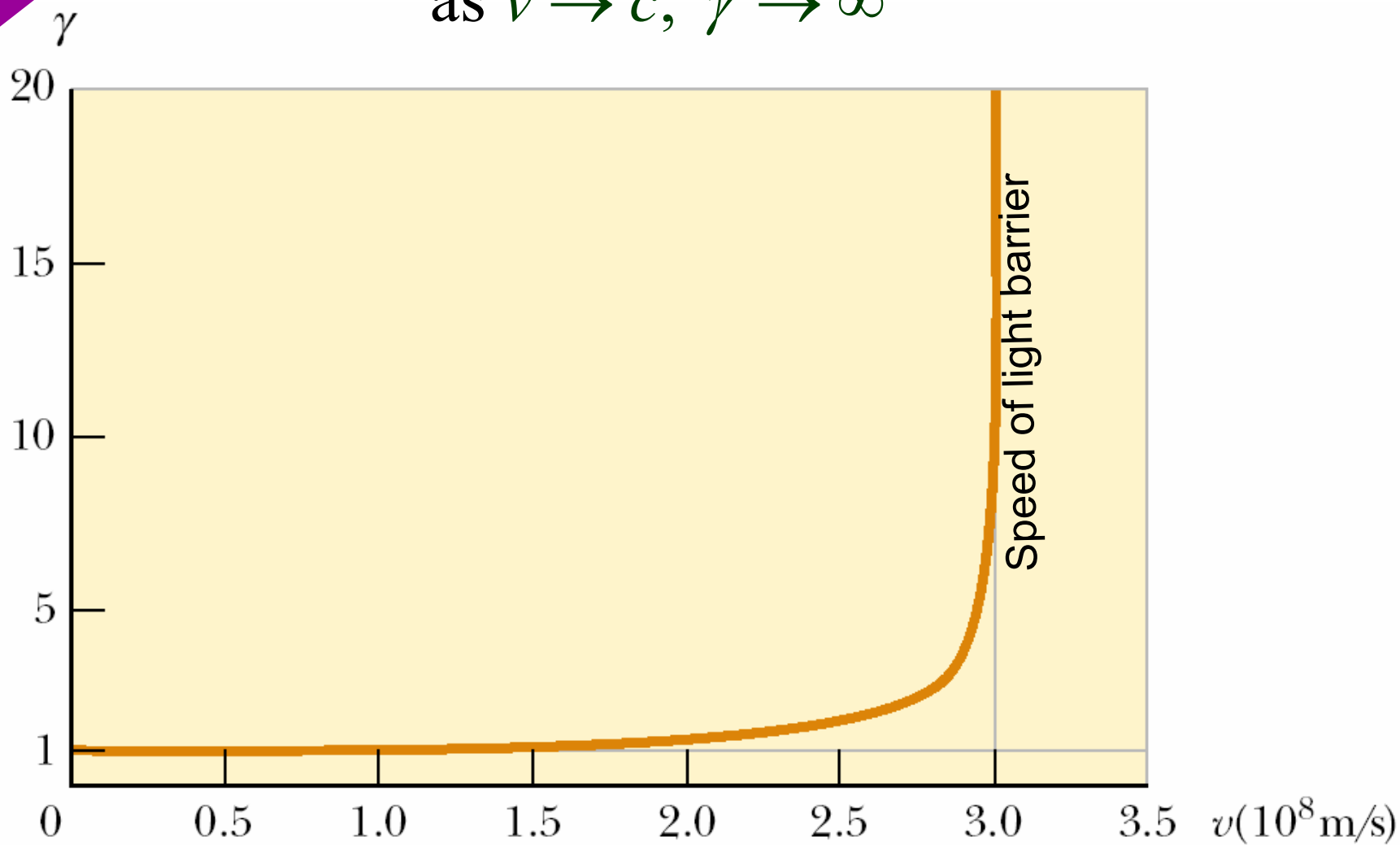


The γ factor

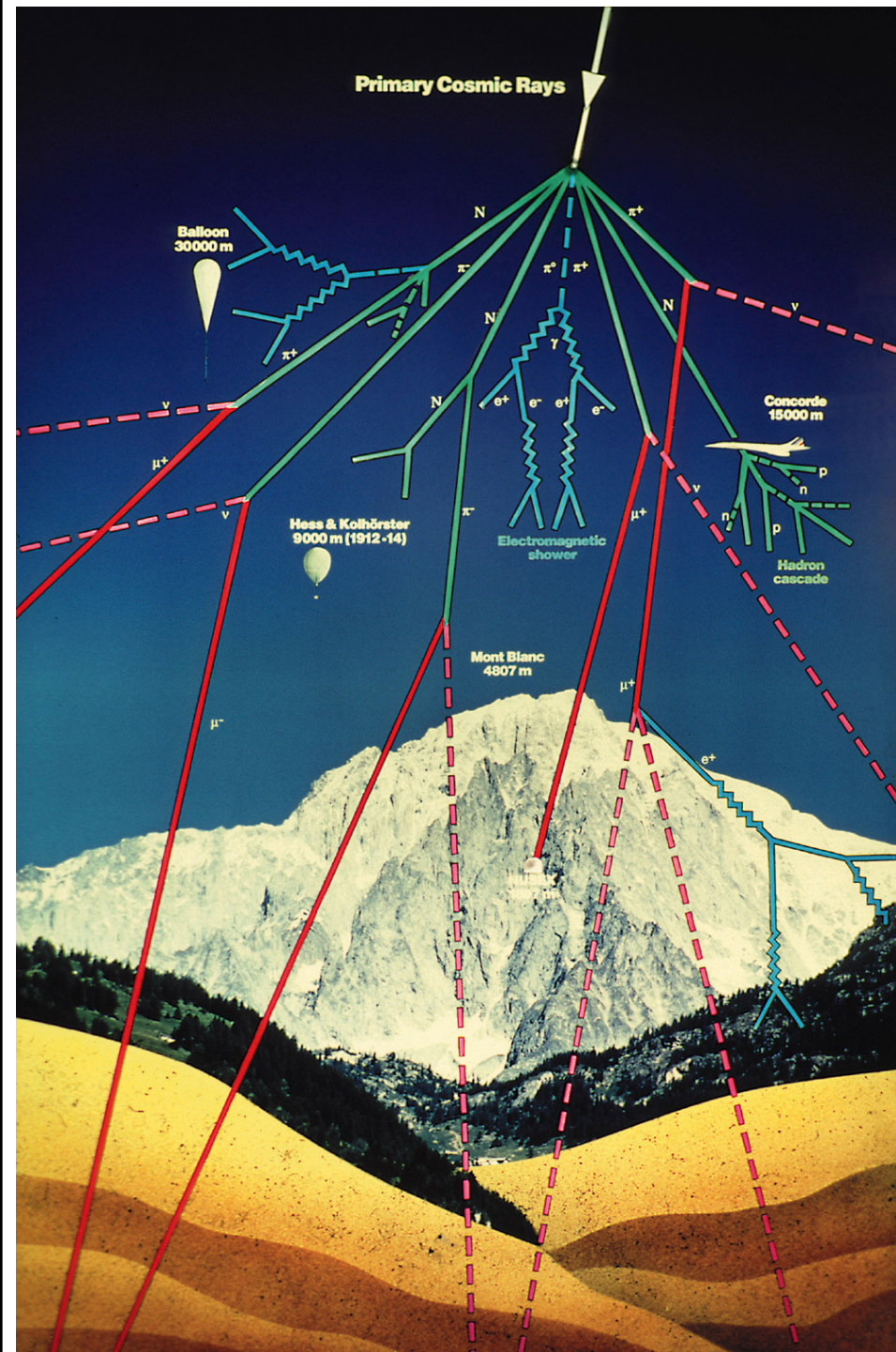
$$\gamma = \frac{1}{\sqrt{1 - v^2 / c^2}}$$

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

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

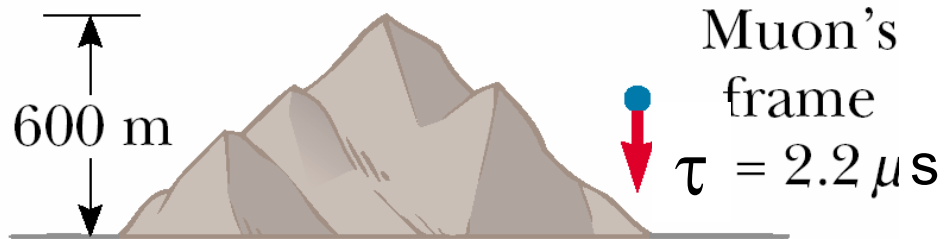


Cosmic Rays Bombarding the Earth

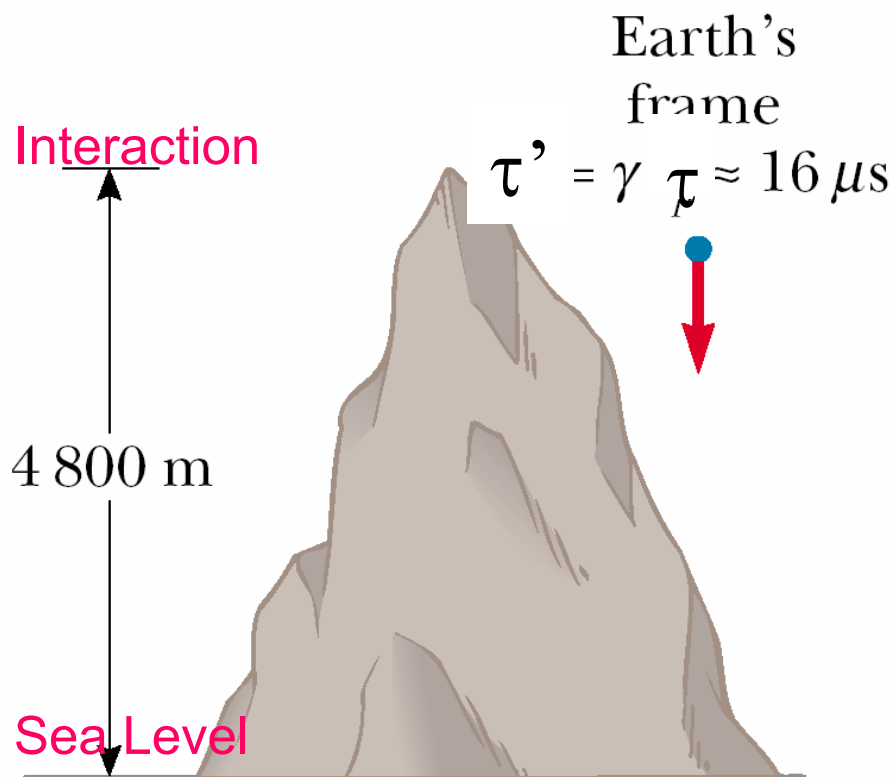


- Cosmic rays are messengers from space
 - Produced in violent collisions in the cosmos
 - Typical Kinetic energy ~ 100 GeV
 - Smash into Earth's outer atmosphere
 - **4700** m from sea level
 - Sometimes produce short lived **Muons**
-
- **Muon is electron like charged particle**
 - ~ 200 times heavier , same charge
 - Lifetime $\tau = 2.2\mu\text{s} = 2.2 \times 10^{-6}$ s
 - Produced with speed $v \equiv c$
 - Distance traveled in its lifetime
- $$d = c\tau = 650\text{m}$$
- 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



(a)



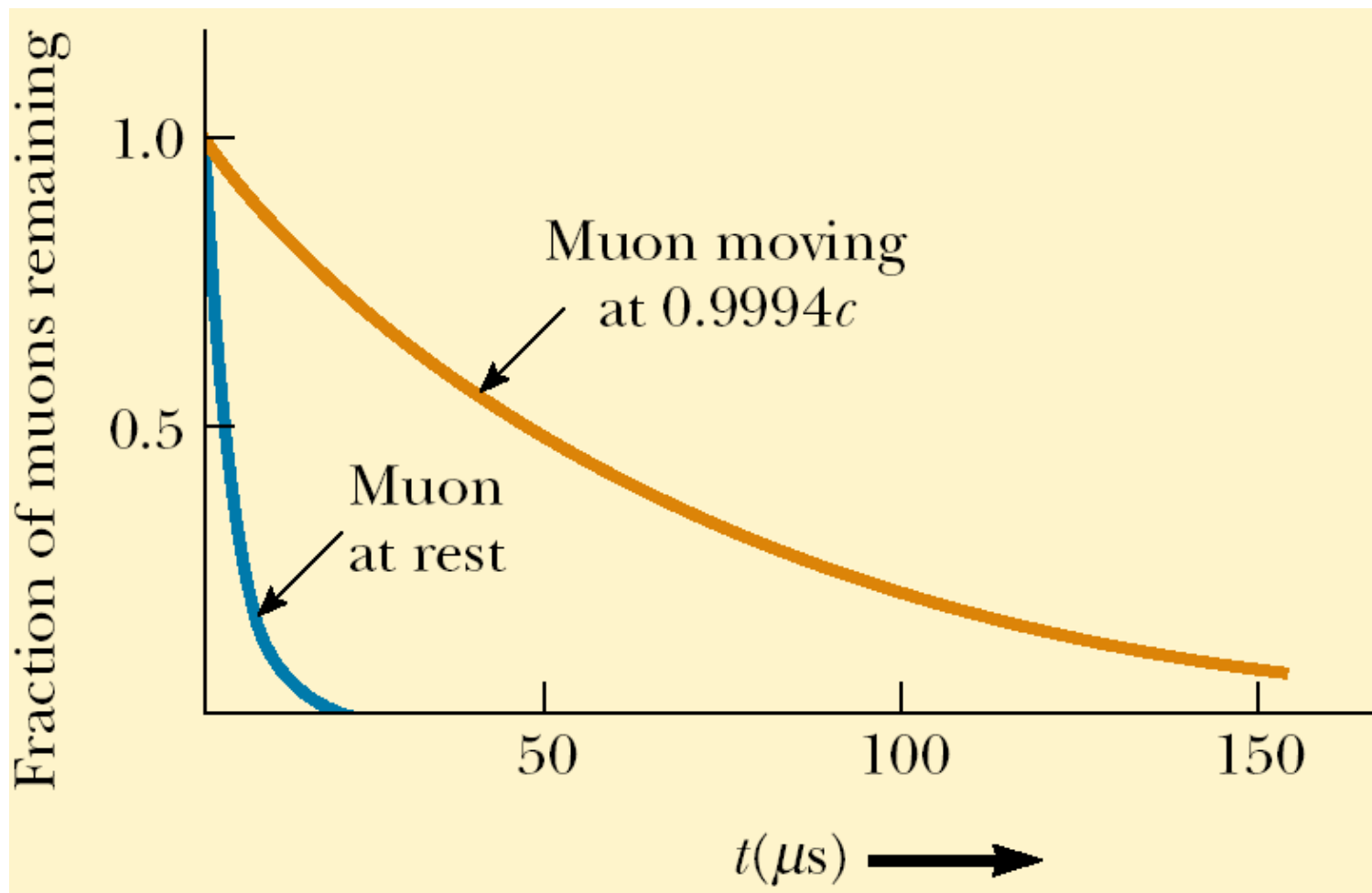
- Two frames of references
 1. Riding on the Muon
 2. On surface of earth
- Muon Rider has “Proper Time”
 - Time measured by observer moving along with clock
 - $\Delta t' = \tau = 2.2 \mu s$
 - $D' = v \Delta t' = 650m$
- Earthling watches a moving clock (muon's) run slower
 - $\Delta t' = \gamma \tau$
 - $v = 0.99c, \Rightarrow \gamma = 7.1$
 - $D = v \Delta t = 4700m$

Muon Decay Distance Distribution

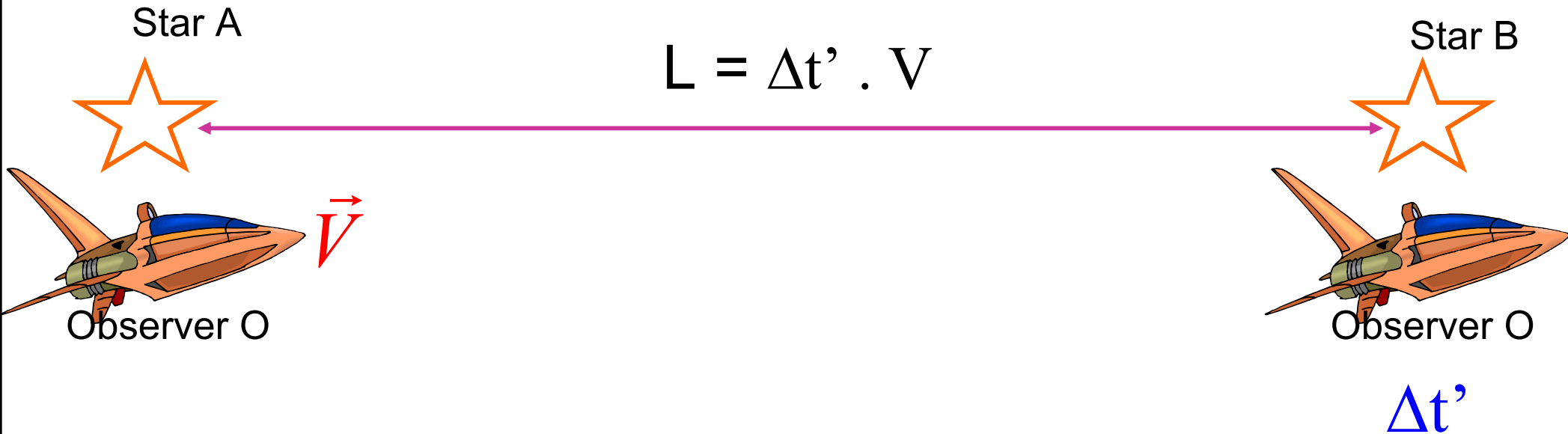
Relative to Observer on Earth Muons have a lifetime

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

Exponential Decay time Distribution : As in Radioactivity



Offsetting Penalty : Length Contraction



$$\Delta t = L' / V$$



Observer O'
At rest w.r.t stars A & B
Watches rocketship cross from
Star A to Star B in time Δt

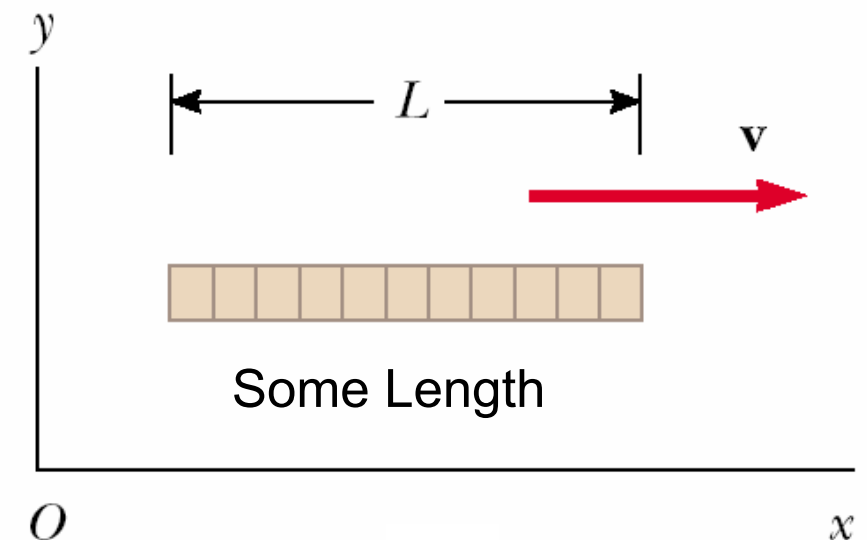
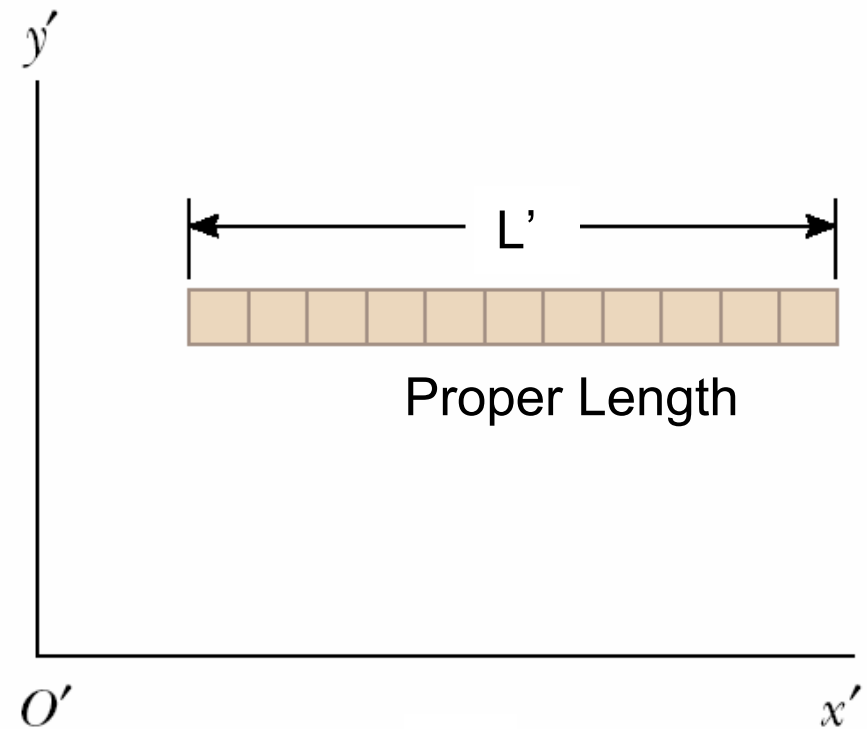
Rocketman Vs The Earthling

- 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
 - $L = \Delta t' \cdot V$
 - But $\Delta t' = \Delta t / \gamma$ (time dilation)
 - $\Rightarrow L = V \cdot (\Delta t / \gamma)$
 $= L' / \gamma$

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

$$L \leq L'$$

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 !