Conceptual Physics

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Table of Contents

Historical Overview

- In 19th century ☞ it was thought that
  just as water waves must have medium to move across (water)
  & audible sound waves require medium to move through (e.g. air)
  so also light waves require a medium
  which was called “luminiferous” (i.e. light-bearing) “æther”
- If this were the case ☞ as Earth moves in its orbit around Sun
  flow of æther across Earth could produce detectable “æther wind”
- Unless æther were always stationary with respect to Earth
  speed of beam of light emitted from source on Earth
  would depend on magnitude of æther wind and on beam direction
- 1881 Michelson-Morley experiment
  to measure speed of light in different directions
  became most famous failed experiment to date
  and first strong evidence against luminiferous æther

Historical Overview (cont'd)

(1892 -1909)

- To explain nature's apparent conspiracy to hide æther drift
  Lorentz developed theory based on two *ad hoc* hypotheses:
  - Longitudinal contraction of rigid bodies
  - slowing down of clocks (time dilation)

  when moving through æther at speed v ☞ both by $(1 - v^2/c^2)^{1/2}$
- This would so affect every aparatus designed to measure
  æther drift as to neutralize all expected effects

(1898)

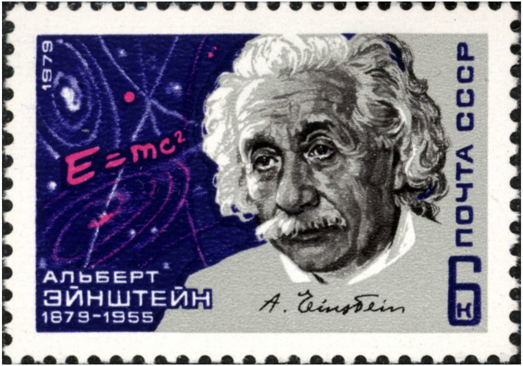
- Poincare arugued that æther might be unobservable
  and suggested concept would be thrown aside as useless
  BUT he continued to use concept in later papers of 1908

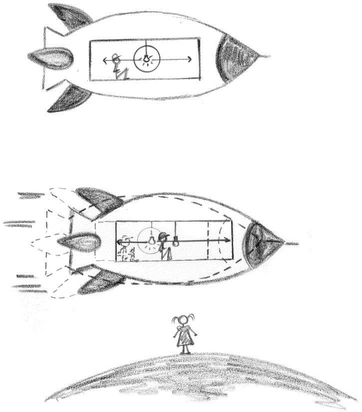
(1905)

- Einstein advanced principle of relativity

1. *All laws of nature are the same in all uniformly moving reference frames*
2. *Speed of light in free space has the same value for all observers regardless of the motion of source or motion of observer*

   ☞ *speed of light (in free space) is a constant*



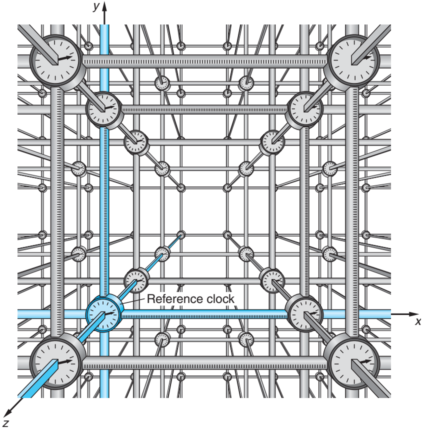


- From Harrys viewpoint light from travels equals distances to both ends of rocket ☞ striking both ends simultaneously
- Events of striking front and the end of spacecraft are not simultaneous in Sallys reference frame
- Because of rockets motion light strikes back end sooner than front end

How does observer in uniformly moving frame describe event?

- Event ☞ an occurrence characterized by: three space coordinates and one time coordinate
- Events are described by observers who do belong to particular uniformly moving frames of reference
- Different observers in different uniformly moving (u.m.) frames would describe same event with different spacetime coordinates
- Observer's rest frame is also known as proper frame
- Up until now it was enough for us to have a measuring stick for each reference frame a rigid body that defined units of a coordinate system
- But we could all depend on just one clock a master timepiece that was used by all observers
- Now what we need is a measuring stick with clocks all along it so that when something happens we can record both time and place

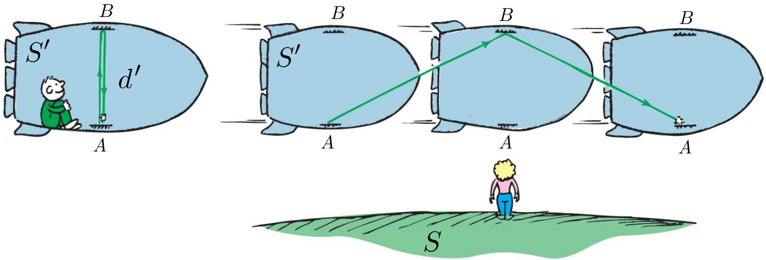
Confederate scheme for coordinatizing any event

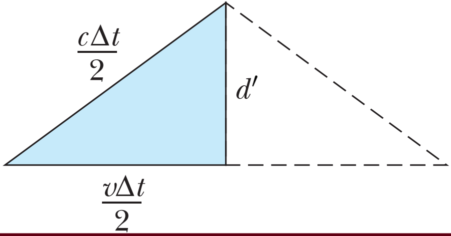


- Observer establishes lattice of confederates
  with identical synchronized clocks
- Label of any event in spacetime
  is reading of clock and location of nearest confederate to event

Einstein's thought experiment

- Idealized clock
  light wave is bouncing back and forth between two mirrors
- Clock "ticks" when light wave makes a round trip
  from mirror A to mirror B and back
- Assume mirrors A and B are separated a distance d' in rest frame
- Llight wave will take $\Delta t' = 2d'/c$ for round trip $A \to B \to A$





Time dilation

Since light has velocity c in all directions

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

$$\Delta t = \frac{2d'}{\sqrt{c^2 - v^2}} = \frac{\Delta t'}{\sqrt{1 - v^2/c^2}}$$

Ticking of clock in Hary's frame
which moves @ v wrt Sally in direction $\perp$ to separation of mirrors
is slower by $\gamma = (1 - v^2/c^2)^{-1/2}$

Twin Paradox

- Consider two synchronized standard clocks A and B at rest at point P of uniformly moving frame S
- Let A remain @ P while B is briefly accelerated to some velocity v with which it travels to distant point Q
- There it is decelerated and made to return with velocity v to P
- If one of two twins travels with B while other remains with A ☞ B twin will be younger than A twin when meet again

Can't B claim with equal right it was her who remained where she was while A went on round-trip ☞ A should be younger when meet again?

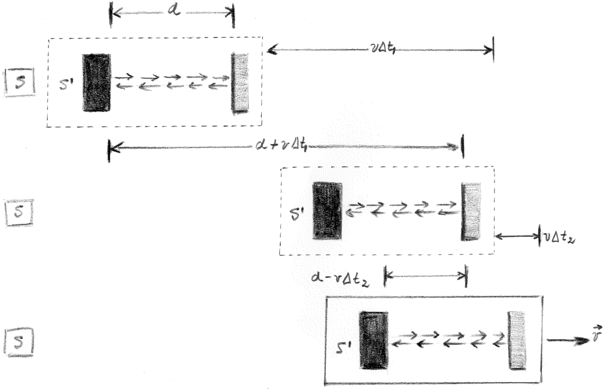
Answer is NO ☞ this solves paradox

- A remained at rest in single u.m. frame while B accelerated out of his rest frame: @P, @Q, and once again @P
- Accelerations recorded on B's accelerometer she can be under no illusion that it was her who remain at rest
- Two accelerations at P are not essential (age comparison could be made in passing) but acceleration in Q is vital

Answer is NO ☞ this solves paradox

- Eperimet involves 3 u.m. frames:
  1. earth-bound frame S
  2. S' of outbound rocket
  3. S'' of returning rocket
- Experiment not symmetrical between twins:
  - A stays at rest in single uniformly moving frame S
  - but B occupies at least two different frames
- This allows result to be unsymmetrical

Rotate clock by 90° before setting it in motion



A-B

$$d + v\,\Delta t_1 = c\,\Delta t_1$$

$$\Delta t_1 = \frac{d}{c - v}$$

B-A

$$d - v\Delta t_2 = c\Delta t_2$$

$$\Delta t_2 = \frac{d}{c + v}$$

Length contraction

1. Interval between two consecutive ticks in the moving frame is

$$\begin{aligned}\Delta t &= \Delta t_1 + \Delta t_2 = \frac{2d}{c(1 - v^2/c^2)} \\ &= \left(\frac{d}{d'}\right) \frac{\Delta t'}{1 - v^2/c^2}\end{aligned}$$

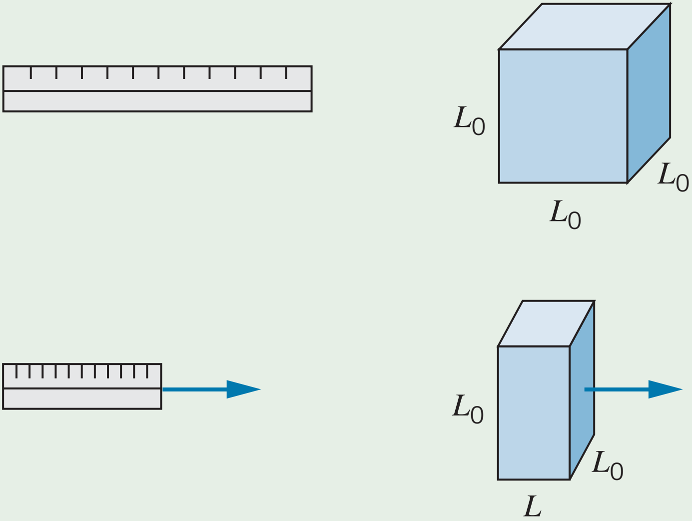
2. Because of time dilation

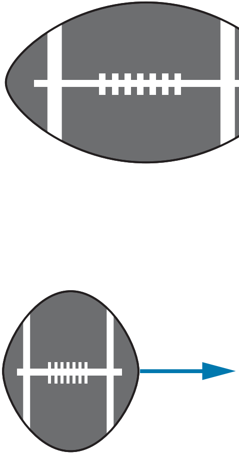
$$\Delta t' = \Delta t \, \sqrt{1 - v^2/c^2}$$

we get

$$d = \left(1 - \frac{v^2}{c^2}\right)^{1/2} d'$$

Example





- Newtons law is not compatible with special relativity
- It should't be possible to send messages faster than speed of light
- Newtons relation would allow us to do so using gravity
- Newton stated that gravitational force
  depends on separation between objects at given instant of time
- To solve this problem ☞ introduce concept of gravitation field
  (akin to electric field)
- Einstein used this idea to develop general theory of relativity
  in which gravitational field is related to geometry of spacetime
- Major forecast of general relativity:
  when two massive objects crash into each other
  there should be a release of gravitational waves
  which transport energy as gravitational radiation