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Ph1b Section 05

January 10, 2011

Outline

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Principles

Logistics

Principles

The principle of special relativity & the principle of the constancy or invariance of the speed of light

- All reference frames in rectilinear, uniform and irrotational motion, i.e. the so-called **inertial reference frames** shall be completely equivalent in physics. No inertial frame shall be distinguished from any other inertial frame by any property.
- The speed of light in the vacuum has the same value in each inertial frame, irrespective of the velocities of the light source or the light receiver. **it is a fundamental physics constant c=299,792,458 m/s**
- **March challenge (4U): write an essay titled "if $c = 45$ km/h the world would look like this:" (you will need to be quantitative)**
- **Q(4U):To what accuracy has the speed of light been measured?**
- **What is relative so far?**

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Not the speed of light

- the speed of light is **absolute** : c=299,792,458 m/s

In 1987 a supernova explosion happened in the large Magelanic cloud 165,000 light years away (1ly =9.5 $\times$ 10^{15} =m). Neutrinos, almost massless particles that travel with the speed of light, were emitted from the different nuclei (that had different velocities by as much as 10,000 km/s). All neutrinos and photons arrived within 10 s.

Physics Letters B
Browse 201, Issue 3, 11 February 1988, Pages 353-354

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The speed of light and the speed of neutrinos

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Received 4 November 1987. Available online 16 October 2002.

Abstract
The approximate equality in the arrival times of the neutrino and light signals from SN 1987A allows an accurate check of the hypothesis of special relativity that the limiting velocity for all forms of radiation is the same.

Article Outline

- References

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Time is Relative

Of all inertial observers, an observer at rest relative to a process measures the shortest time for that process. This time is called the *proper time* of the process and is denoted by τ (t')When a frame in motion (prime frame) at a contant velocity v relative to another frame (unprimed frame), any process (such as the tick of the clock) being at rest in the frame of motion, and requiring time t' in this prime frame, is lengthened for an observer at rest in the unprimed frame

$$t = \frac{t'}{\sqrt{1 - (v^2/c^2)}} = \frac{t'}{\sqrt{1 - \beta^2}} = \gamma t' \geq t'$$

where

$$\beta = \frac{v}{c}, \quad \gamma = \frac{1}{\sqrt{1 - \beta^2}}$$

This is called time dilation, literally time stretching

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Time is Relative

In 1971 time dilation was measured in the Hafele-Keating Experiment where two very precise atomic clocks went on two jets around the earth in different routes (eastbound and westbound).

Science 14 July 1972:
Vol. 177 no. 4044 pp. 166–168
DOI: 10.1126/science.177.4044.166

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Around–the–World Atomic Clocks: Predicted Relativistic Time Gains

J. C. Hafele and Richard E. Keating

± Author Affiliations

ABSTRACT

During October 1971, four cesium beam atomic clocks were flown on regularly scheduled commercial jet flights around the world twice, once eastward and once westward, to test Einstein's theory of relativity with macroscopic clocks. From the actual flight paths of each trip, the theory predicts that the flying clocks, compared with reference clocks at the U.S. Naval Observatory, should have lost 40 ± 23 nanoseconds during the eastward trip, and should have gained 275 ± 21 nanoseconds during the westward trip. The observed time differences are presented in the report that follows this one.

▸ Science 14 July 1972: Vol. 177 no. 4044 pp. 166-168

Time is Relative

Decaying sub-atomic particles are like very fast moving clocks. In their rest frame they decay with proper time τ while an observer at rest measures the time of their decay to be $\gamma\tau > \tau$.
A great example is that of the atmospheric muons that have proper decay time 1.4μ but on earth we measure their decay time to be ?
($v = 0.994c \Rightarrow \gamma = 9 \Rightarrow t = 14\mu \Rightarrow L =$?)

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And what about space?

The views of space and time which I wish to lay before you have sprung form the soil of experimental Physics and thein lies their strength. They are radical. Henceforth space by itself and time by itself are doomed to fade away into mere shadows and only one kind of union of the two will preserve an independent reality Minkowski 1908

will continue on Monday

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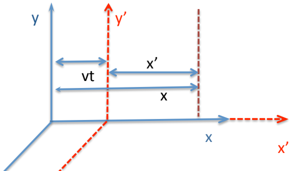
will continue on Monday

Lorentz transformation

To be consistent with the speed of light being constant, we have to modify the way in which we translate the observation in one inertial frame to that of another (i.e. The Galilei transformation are approximations)

$$x = x' + vt, t = t'$$

according the old transformation an event M (say a ball falling AT M) happens at $x = x' + vt$ at time t' (in the xyz inertial frame).

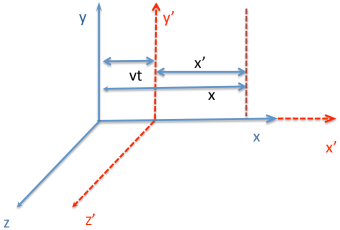


Lorentz transformation

According to special theory of relativity:

$$x = \frac{x' + vt}{\sqrt{1 - (v^2/c^2)}}, t = \frac{t' + \frac{vx}{c^2}}{\sqrt{1 - (v^2/c^2)}}$$

The new transformation is called Lorentz transformation. Lets check that indeed the speed of light is the same in the two frames (x, t) and (x', t')


y
y’
x’
vt
x
x
x’
z
z’

Let's say that a beam of light started out from the origin $x' = x = 0$ at time $t' = t = 0$. Since the speed of light is c, at time $t = T$, the beam of light would have traveled to the point $x = cT$ in the (x, t) frame. In the other frame, this point is observed as (someone should calculate on the board x', t' and take x'/t'). We can do this with spaceships etc.)

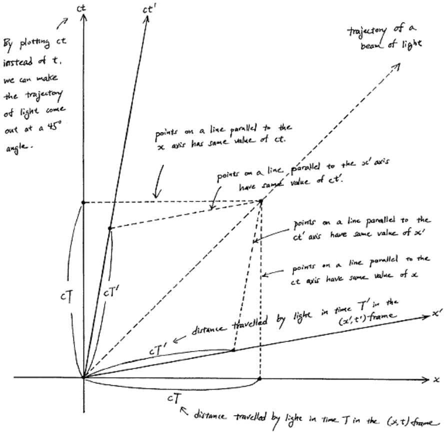
Check answer

$$
\begin{aligned}
x' &= \frac{cT - vT}{\sqrt{1-\frac{v^2}{c^2}}} = cT\frac{1-\frac{v}{c}}{\sqrt{1-\frac{v^2}{c^2}}},\\
t' &= \frac{T - \frac{v}{c^2}cT}{\sqrt{1-\frac{v^2}{c^2}}} = T\frac{1-\frac{v}{c}}{\sqrt{1-\frac{v^2}{c^2}}},
\end{aligned}
$$

$$
\frac{x'}{t'} = c.
$$

Spacetime diagram to show the constancy of the speed of light in the 2 frames)

Spacetime diagram explaining why the speed of light is the same in both frames:



Clocks that are synchronized in one frame will not be observed to be synchronized at another frame

Minkowski diagrams read handout

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Notes and other material/workbooks references etc will be posted in the 05 Section twiki
https://twiki.hep.caltech.edu/twiki/bin/view/Main/Smaria
(starting next week)
A student twiki will be set there for you (and an account)
Dr. Dorian Kcira dkcira@caltech.edu is managing the twiki and will be sending you info on the account

Reference Frames and Coordinate systems

- Reference frame is usually (but not always) a physical rather rigid object to which we refer our measurements and observations (car train plane, spaceship, the earth, the galaxy, even a cluster of galaxies etc)
- A Coordinate system is a way we specify a position by assigning to it a set of numbers (Cartesian, spherical, cylindrical etc); Geometrically thay can be represented as a triad of unit vectors $\hat{\vec{x}}$, $\hat{\vec{y}}$, $\hat{\vec{z}}$. A point in space is specified by the orthogonal projections of its position vector onto the corresponding directions.
- There are infinite such triads we can devise. They are all distinct and they can all be obtained from another by appropriate rotations and/or reflections.
- A reference frame and a coordinate system are different concept and specifically the former does not specify the latter

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Newtonian space and time (from Principia)

- Absolute space in its own nature, without regard to anything external, remains always similar and immovable
- Absolute time, and mathematical time, by itself and from its own nature, flows equally without regard to anything external and by another name it called **duration**

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