الجامعة المستنصريـــــــــــة / كليـــــــــة العلوم

قســـــم الفيزيـــــــاء

Mustansiriyah University

College of Science

Physics Department

PhD-Lecture (I) : Michelson-Morley Experiment

Edited by:

- **Prof. Dr. Ali A. Al-Zuky**
- **Dr. Haidar J. Mohamad**
- **PhD students (2017-2018)**

Electromagnetic waves:

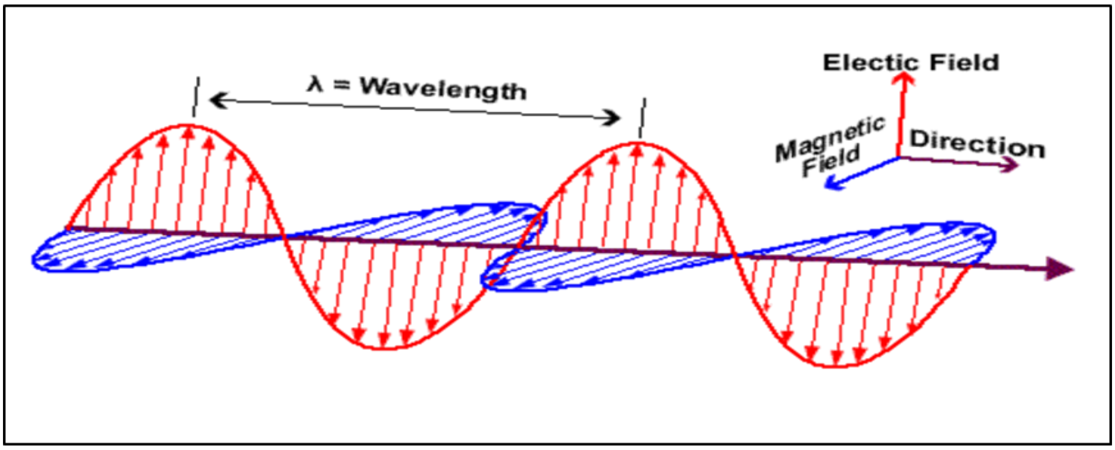
1. Classical physics laws:

1) Newton's law A motion and the law of gravity (Newton Mechanics)

2) Classical thermodynamics and Boltzmann statistics, Kinetics theory of gases.

3) Classical electrodynamics.

The equations of electrodynamics used to final Electromagnetic wave eq.s. The Electromagnet field is a wave of E- field and a wave of H- field perpendicular to each other.



$$E(y,t) = E_y \sin(kz - \omega t) \qquad (1)$$

$$H(x,t) = H_x sin\,(kz - \omega t) \qquad (2)$$

Wave propagation is any of the ways in which waves travel. With respect to the direction of the oscillation relative to the propagation direction, we can distinguish between longitudinal wave and transverse waves. For electromagnetic waves, propagation may occur in a vacuum as well as in a material medium. All geometrical and wave optics laws derived from Maxwell's equations. Classical physics after 1900 failed to explain many phenomena. Classical mechanics conflict with Maxwell's eq.s.

Newton mechanic.	Maxwell's equations
Charge motion equation $\vec{v}$, $\vec{p}$, $\vec{F}$,… Newton's laws depend on acceleration, so no reference frame is favored over any other.	Electromagnetic waves $C=\frac{1}{\sqrt{\mu_o \epsilon_o}}$ Maxwell's equations depend on velocity, so perhaps one "absolute" frame is favored.

2. Maxwell's equations:

Historically, they were developed by studying the different forms of electric and magnetic phenomena and first formulated as independent laws. These phenomena included the creation of electric fields by charges (*Gauss*' law) and by time dependent magnetic fields (Faraday's law of induction), and the creation of magnetic fields by electric currents (Ampere's law). We will first recall the form of each of these individual laws and next follow the important step of Maxwell by collecting these in a set of coupled equations for the electromagnetic phenomena. Maxwell's equations, which gain their most attractive form when written in relativistic

$\nabla \cdot E = \frac{\rho}{\epsilon_0}$ Gauss Law for electricity (Coulomb's Law) (3)

$\nabla \cdot B = 0$ Gauss Law for magnetism (no magnetic monopole) (4)

$\nabla \times E = -\frac{\partial B}{\partial t}$ Faraday's Law of Induction (5)

$\nabla \times B = \mu_0 J + \mu_0 \epsilon_0 \frac{\partial E}{\partial t}$ Ampere's Law (6)

Maxwell's equations in vacuum: In vacuum ρ= 0, J = 0

- Gauss' Law for electricity (Coulomb's Law)

$$\nabla \cdot \mathrm{E} = 0 \tag{7}$$

- Gauss' Law for magnetism (no magnetic charges)

$$\nabla . \mathrm{B} = 0 \tag{8}$$

- Faraday's Law of Induction

$$\nabla \times \mathrm{E} = -\frac{\partial B}{\partial t} \tag{9}$$

- Ampere's Law

$$\nabla \times \mathrm{B} = \frac{1}{\mathrm{c}^2}\frac{\partial \mathrm{E}}{\partial \mathrm{t}} \tag{10}$$

The wave is aperiodic disturbance in a media transforming energy without translating (transforming) the media. Light is an electromagnetic wave, how can be transferring in space?!

The Invention of the Ether

Since 1870s, Newton's Laws had stood the test of time for two centuries, and Maxwell's Laws, having a vintage of just 20 years or so, were young upstarts, the natural assumption was that Maxwell's Laws needed some modification. The first obvious conclusion was that, just as sound needed a medium to travel through—and the speed was constant relative to the medium—so light must need a medium too. (Remember that nobody had come across the idea of a wave without a medium until then). The Victorian scientists named this medium the *ether* (or ather, if you prefer). It had to have some strange properties:

• Invisibility, of course.

• It was massless.

• It filled all of space.

• High rigidity, so light could travel so quickly through it. (Something that springs back fast carries waves more quickly than something soft; sound travels faster through iron than air).

• It had no drag on objects moving through it: The Earth isn’t slowed down in its orbit.

• Other curious properties had to be assumed to explain new experimental results, such as...

The scientists assumed the presence of ether from Maxwell's equations can be find:

$$\left.\begin{aligned} &\nabla^2 B - \frac{1}{C^2}\frac{\partial^2 B}{\partial t^2} = 0 \\ &\nabla^2 E - \frac{1}{C^2}\frac{\partial^2 E}{\partial t^2} = 0 \end{aligned}\right\} \text{Differential wave equation}$$

A hypothetical transparence medium, falling all the space and serving to make possible the transmission of light of electromagnetic fields.

According to classical mechanics the speed of the wave in any medium given by:

$$v = \sqrt{\frac{Young\ modulus\ of\ the\ medium}{density\ of\ the\ medium}}$$

$$v = \sqrt{\frac{Y}{\rho}}$$

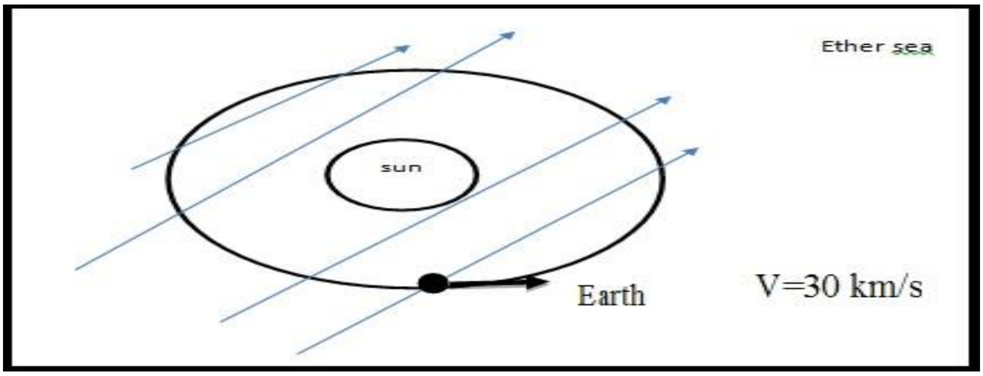
So, the light travels in ether $=3\times10^{8}$ (m / s), hence can be note the ether has strange and abnormal characteristics

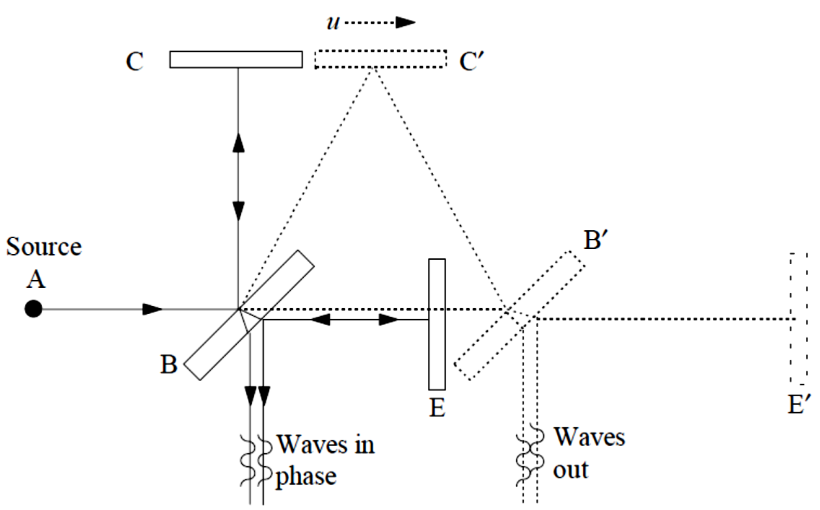
$K\uparrow\uparrow$ Very high

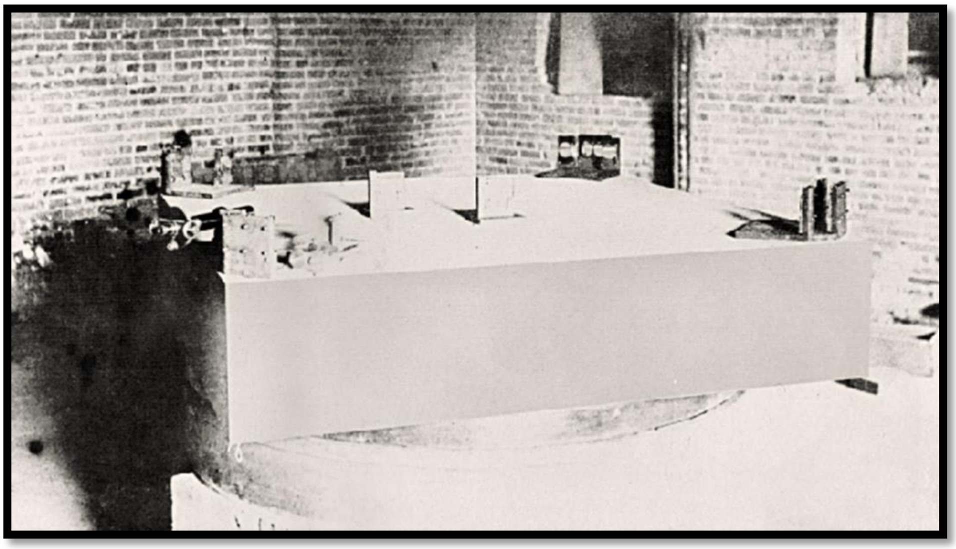
$\rho\downarrow\downarrow$ Very low

The main biggest objection of rotating the earth around the sun by speed 30 (Km /s). If the ether is around the earth (i.e. the earth swim in a sea of ether).

What is the earth speed relative to aether? The scientists have been used Michelson & Morley to estimate the relative motion of the earth in ether.







A pulse of light is directed at an angle of 45 degrees at a half-silvered, half transparent mirror, so that half the pulse goes on through the glass, half is reflected. These two half-pulses are the two swimmers. They both go on to distant mirrors which reflect them back to the half-silvered mirror. At this point, they are again half reflected and half transmitted, but a telescope is placed behind the half-silvered mirror as shown in the figure so that half of each half-pulse will arrive in this telescope. Now, if there is an aether wind blowing, someone looking through the telescope should see the halves of the two half-pulses to arrive at slightly different times, since one would have gone more upstream and back, one more across stream in general. To maximize the effect, the whole apparatus, including the distant mirrors, was placed on a large turntable so it could be swung around.

3. Newtonian & Galilean Transformation

Consider two people, Tony (standing still) and Bill (walking past at velocity u). Tony has a "reference frame" S in which he measures the distance to a point on the pavement ahead of him, and calls it x. Bill, who walks past at time $t = 0$, has a "reference frame" $S^{/}$ in which he measures the (continually changing) distance to the same point, and calls it x'. Then, a *Galilean transformation* links the two frames:

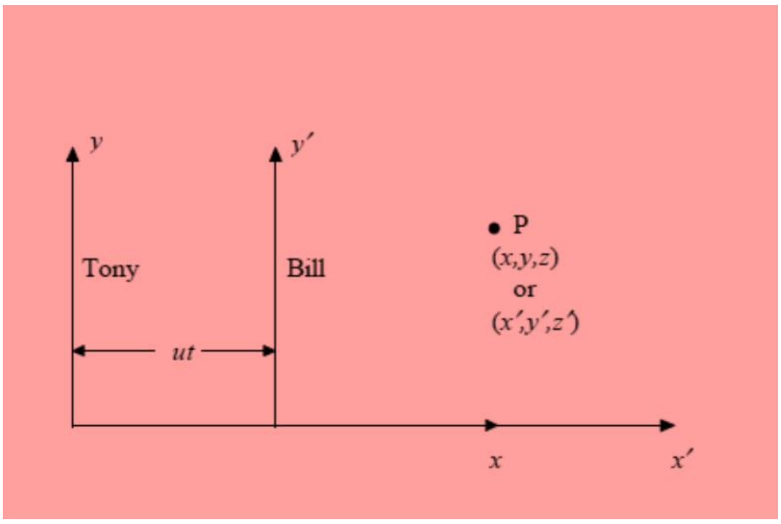
$$x' = x - vt$$

$$y' = y$$

$$z' = z$$

$$t' = t$$

This is commonsense: we can see how the distance that Bill measures to the point decreases with time, until it goes negative when Bill actually walks past the point. What about velocities? Suppose Tony is standing still to watch a bird fly past at speed v. He now calls the (changing)



distance to the bird x

4. Frame Dragging and Stellar Aberration

When an aero plane flies through the air, or a ship moves through the water, it drags a “boundary layer” of fluid along with it. Was it possible that the Earth in its orbit was some who "dragging” some ether along?

This idea - known as "frame dragging” would explain why Michelson and Morley could not find any motion of the Earth relative to the ether.

But this had already been disproved, by the phenomenon known as *stellar aberration*, discovered by Bradley in 1725.

Imagine a telescope, on a "still" Earth, pointed (for simplicity to look at a star vertically above it. (See diagram). Now suppose that the Earth is moving (and the telescope with it at a speed *v* as shown. In order for light that gets into the top of the telescope to pass all the way down the moving tube to reach the bottom, the telescope has to be tilted by a small angle δ, where

$$\tan \delta = \frac{v}{c}$$

The angle δ oscillates with Earth's orbit, and, as measured, agrees with Earths orbital speed of about 30 km/s. In this case, the ether cannot be being dragged along by the Earth after all, otherwise there would be no aberration.

5. The Lorentz Transformation

Notice that the difference in travel times for the two arms of the Michelson interferometer is a factor of

$$\frac{1}{\sqrt{1 - \left(\frac{v}{c}\right)^2}}$$

Lorentz suggested that, because all of the electrons in all of the materials making up the interferometer (and everything else) should have to interact with the ether, moving through the ether might make materials contract by just this amount in the direction of motion, but not in transverse directions. In that case, the experiment would give a null result! (Fitzgerald had also noticed that this "fix" would work, but could not suggest what might cause it). In developing this idea further, Lorentz found that clocks that were moving through the ether should run slowly too, by the same amount. He noticed that if, instead of the Galilean transformations, he made the substitutions

$$x' = x - vt/\sqrt{1 - (\frac{v}{c})^2}$$

$$y' = y$$

$$z' = z$$

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

Into the Maxwell equations, they became invariant! These equations are known as a Lorentz transformation

Let us take two rulers that are exactly the same and give one to a friend who agrees to mount it on his spaceship and fly past us at high speed in the x direction. His ruler will be mounted in the transverse (y) direction. As he flies by, we hold pieces of chalk at the 0 and 1 m marks on our ruler and hold it out so they make marks on his ruler. When he comes back, we look to see where those marks are. What do we find? They must, of course, be one meter apart, because if they were different then we would have a way of knowing which of us was "really" moving. Thus, for transverse coordinates, the transformations between his frame and ours must be

$$y' = y$$

$$z' = z$$

6. Lorentz Contraction

Consider one of the apparently long-lived muons coming down through the atmosphere. In its rest frame, it is created at some time t = 0, at (let us say) the origin of coordinates, x = 0. At some later time t (but at the same spatial coordinate x = 0), the surface of the Earth moves up rather quickly to meet it. If, say, t = 10–6 s, and *v* = 0.995c, the length of atmosphere that has moved past it is *v*t = 300 m. But this is far less than the 10 km distance separating the events in Earth's frame! It seems that not just time, but also length is changed by relative motion. To quantify this, let the distance that the muon travels in Earth's frame be x' = *v*t'; note that, from the muon's point of view, it is the Earth that is moving, and so we use primes to denote Earth's reference frame. The length of atmosphere moving past the muon in its rest frame is x = *v*t. Thus, to denote Earth's reference frame. The length of atmosphere moving past the muon in its rest frame is x = *v*t. Thus,

$$x = x'\sqrt{1 - (\frac{v}{c})^2}$$

Therefore, the length of atmosphere x as measured by the muon is contracted by a factor $\sqrt{1 - (\frac{v}{c})^2}$ relative to the length measured on Earth. Likewise, lengths in the muons rest frame are contracted as seen by Earth-bound observers; but, because the muon is a point-like particle, such lengths are difficult for us to measure directly.

He used length concentration to interpret Michelson experiment results

In 1905 Einstein said that Maxwell's eq. was true and newton's laws to conform to M.E. also, he assumes:

1- The law of physics should be satisfied Lorentz Transform(L.T.) and be the same for all inertial frames of reference (called principle of special relativity)
2- The velocity of light ($c = \frac{1}{\sqrt{\mu\epsilon}} = 3 * 10^8$ m/sec) in vacuum is same with respect to all inertial observers.

The spacetime manifold is composed of 3 spatial coordinates and one, so the spacetime interval given by Δs

x_1=x x_2= y x_3= z x_4= -ict

$$\Delta s = \sqrt{\Delta {x_1}^2 + \Delta {x_2}^2 + \Delta {x_3}^2 + \Delta {x_4}^2}$$

$$\Delta s = \sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2 - c\Delta t^2}$$

Spacetime interval invariant under L.T. for all inertial frames

$$\Delta S = \Delta S'$$

7. The Lorentz transformation as a rotation

The Lorentz transformation can be derived on the basis of the two postulates of Special Relativity. First, due to the isotropy of space contained in the second postulate, we can orient the spatial axes of an inertial frame *S*_ with those of another inertial frame *S* and limit ourselves to considering motion of the two frames in standard configuration. As a starting point for deducing the transformation relating two inertial frames *S* = {*t*, *x*, *y*, *z*} and *S*' = {*t*', *x*', *y*', *z*'} in relative motion with velocity *v* in standard configuration, it is reasonable to assume that the transformation is linear

The laws of physics must have the same form in *S* and *S*', and then one must obtain the inverse Lorentz transformation by the exchange *t*', **x'** ←→ *(t,* **x***)* and *v* ←→ *v'* (this is the Principle of Relativity again):

There is no relative motion in the *y* and *z* directions, hence these coordinates must not be affected by the transformation,

$$y = y' \qquad z = z'$$

$$\Delta s^2 = \Delta {x_1}^2 + \Delta {x_4}^2 = \Delta {x_1}'^2 + \Delta {x_4}'^2 = \Delta s'^2$$

$$x_1' = x_1 \cos\varphi + x_4 \sin\varphi \tag{11-a}$$

$$x_4' = -x_1 \sin\varphi + x_4 \cos\varphi \tag{11-b}$$

$$\begin{pmatrix} x_1' \\ x_4' \end{pmatrix} = \begin{bmatrix} \cos\varphi & \sin\varphi \\ -\sin\varphi & \cos\varphi \end{bmatrix} \begin{pmatrix} x_1 \\ x_4 \end{pmatrix} \tag{12}$$

If we have object at rest in s' system:

$$\frac{d\,x_1'}{d\,x_4'} = 0 \tag{13}$$

$$\frac{d\,x_1}{d\,x_4}=\frac{d\,x_1}{i\,c\,dt}=\frac{v}{ic}=-i\,\frac{v}{c} \tag{14}$$

From eq. 11 get

$$\frac{d\,x_1'}{d\,x_4'}=\frac{d\,x_1}{d\,x_4}\cos\varphi+\sin\varphi=0$$

$$\therefore\ \tan\varphi=\frac{\boldsymbol{i\,v}}{\boldsymbol{c}}=i\beta$$

Where $\frac{v}{c}=\beta$

$$\cos\varphi=\frac{1}{\sqrt{1-\beta^2}}=\frac{1}{\sqrt{1-\frac{v^2}{c^2}}}=\gamma$$

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

Sub. In eq. 11 get

$$x_1'=\frac{x_1-vt}{\sqrt{1-\frac{v^2}{c^2}}}=\ \gamma(x_1-vt)$$

$$x_4'=\frac{x_4-\frac{vx}{c^2}}{\sqrt{1-\frac{v^2}{c^2}}}=\ \gamma\left(x_4-\frac{vx}{c^2}\right)$$

Einstein derived length contraction

$$\Delta x'=\ \Delta x\sqrt{1-\frac{v^2}{c^2}}$$

$$L=\ L_{\circ}\sqrt{1-\frac{v^2}{c^2}}$$

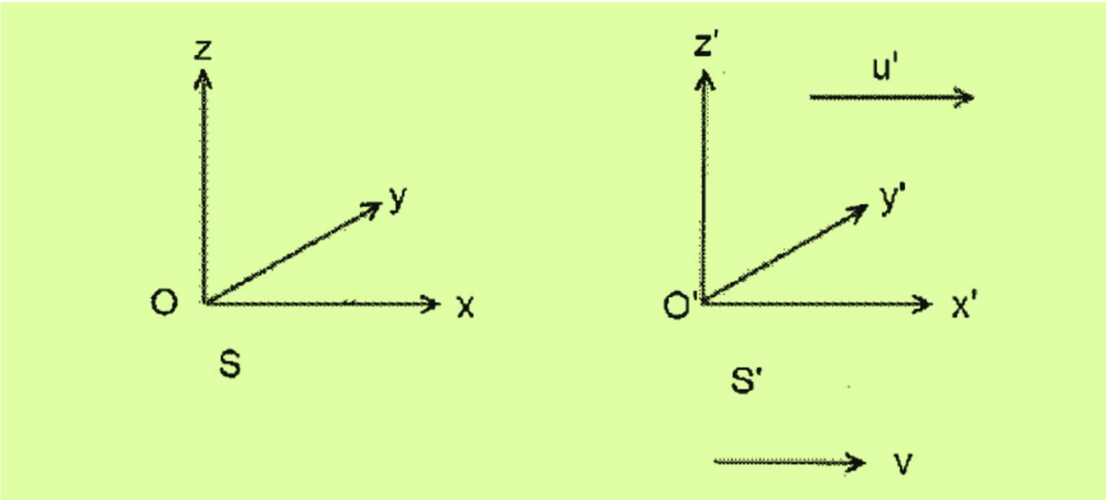
Time dilation

$$\Delta t = \frac{\Delta t_{\circ}}{\sqrt{1 - \frac{v^2}{c^2}}}$$

8. Transformation of Velocities in Special Relativity

Contrary to Newtonian mechanics, velocities do not simply "add up" in Special Relativity, otherwise an observer moving toward a light source would measure the speed of light to be larger than *c*, which contradicts the second postulate. In order to derive the correct formula for the composition of relativistic velocities,15 suppose that a particle has velocity $u^{x'} \equiv dx'/dt'$ relative to an inertial frame *S*' = {*t*', *x*', *y*', *z*'} ; we want to find its velocity *ux* with respect to another inertial frame *S* = {*t*, *x*, *y*, *z*}, with respect to which *t*', *x*', *y*', *z*' is moving with constant velocity *v*.

Remember the convention that the velocity *v* is positive if the inertial frame *S*' is moving *away* from *S*. Differentiate the Lorentz transformation to obtain:



$$dx' = \gamma\,(dx - vdt)$$

$$dt' = \gamma\left(dt - \frac{v\,dx}{c^2}\right)$$

We get

$$\frac{dx'}{dt'} = \frac{dx - v\,dt}{dt - \frac{v\,dx}{c^2}} = \frac{\frac{dx}{dt} - v}{1 - \frac{v}{c^2}\frac{dx}{dt}}$$

$$\therefore u = \frac{dx}{dt}$$

$$\therefore u' = \frac{dx'}{dt'}$$

$$u' = \frac{u - v}{1 - \frac{vu}{c^2}}$$

Note that we did not assume that the particle has uniform velocity **u**' in *S*; the derivation is valid for *instantaneous* velocities.

1- Classical relative velocity

$$u' = c - c = 0$$

2- Relativistic

$$u' = \frac{c - c}{1 - \frac{c^2}{c^2}} = \frac{0}{0} = undefined$$

$$u' = \lim_{h\to 0} \frac{c - (c - h)}{1 - \frac{c(c - h)}{c^2}} = \frac{-ch}{-h} = c$$

3- $u' = \frac{c+c}{1+\frac{c^2}{c^2}} = c$

No fixed time, no simultaneity we must define a measure of time, the proper time according to which all inertial observes agrees:

$$\Delta\tau = \Delta t\sqrt{1 - \frac{v^2}{c^2}}$$

Δt: Coordinate time

$\Delta\tau$: proper time

$$\Delta\tau = \Delta t_0$$