XXXIV International Workshop on High Energy Physics

"From Quarks to Galaxies: Elucidating Dark Sides"

Protvino, November 22-24, 2022.

RELATIVITY THEORY : FROM GENESIS TO COMPLETION

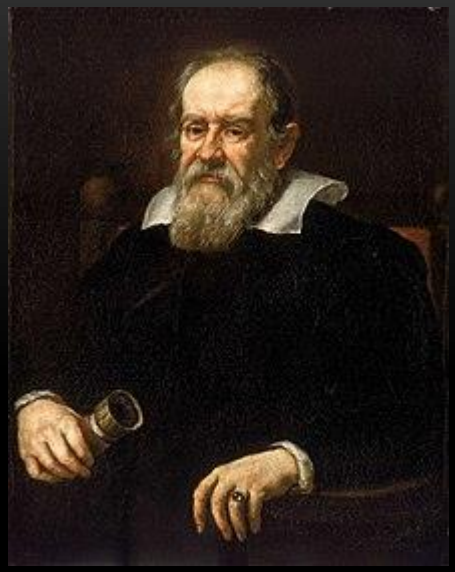
Vladimir A. Petrov,

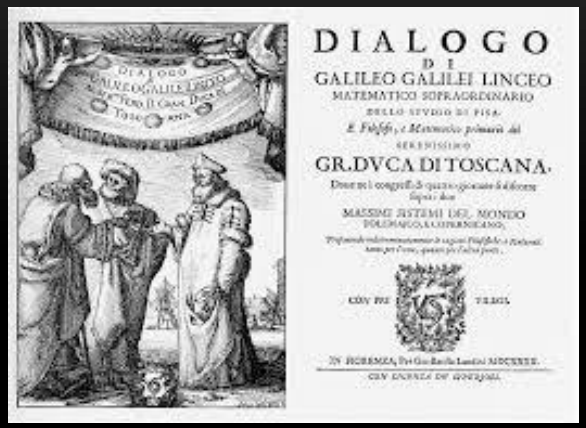
Logunov Institute

for High Energy Physics ,

NRC KI, Protvino, Russian Federation

RELATIVITY: THE START





"...have the ship proceed with any speed you like, so long as the motion is uniform and not fluctuating this way and that. You will discover not the least change in all the effects named, nor could you tell from any of them whether the ship was moving or standing still."

“WHAT IS THERE IN PLACES EMPTY OF MATTER?”

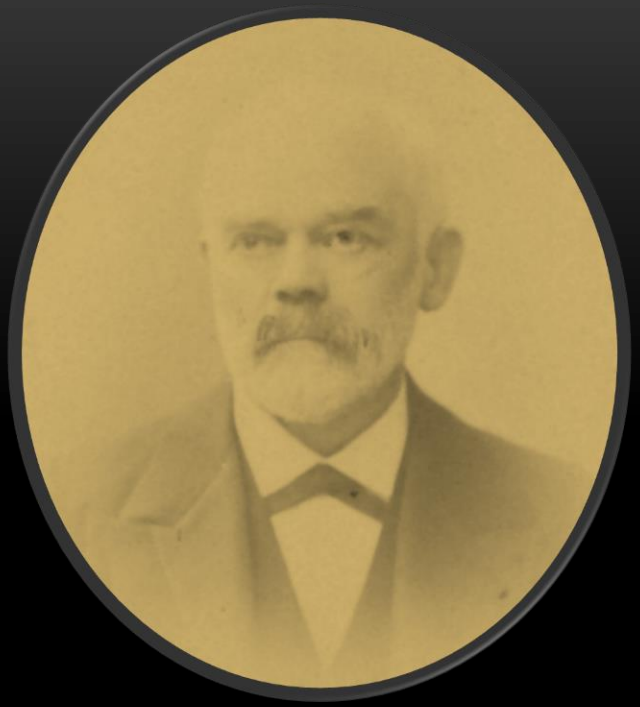
1706

- René Descartes: the ether!

1644

“ THE ETHER WIND?”

1878

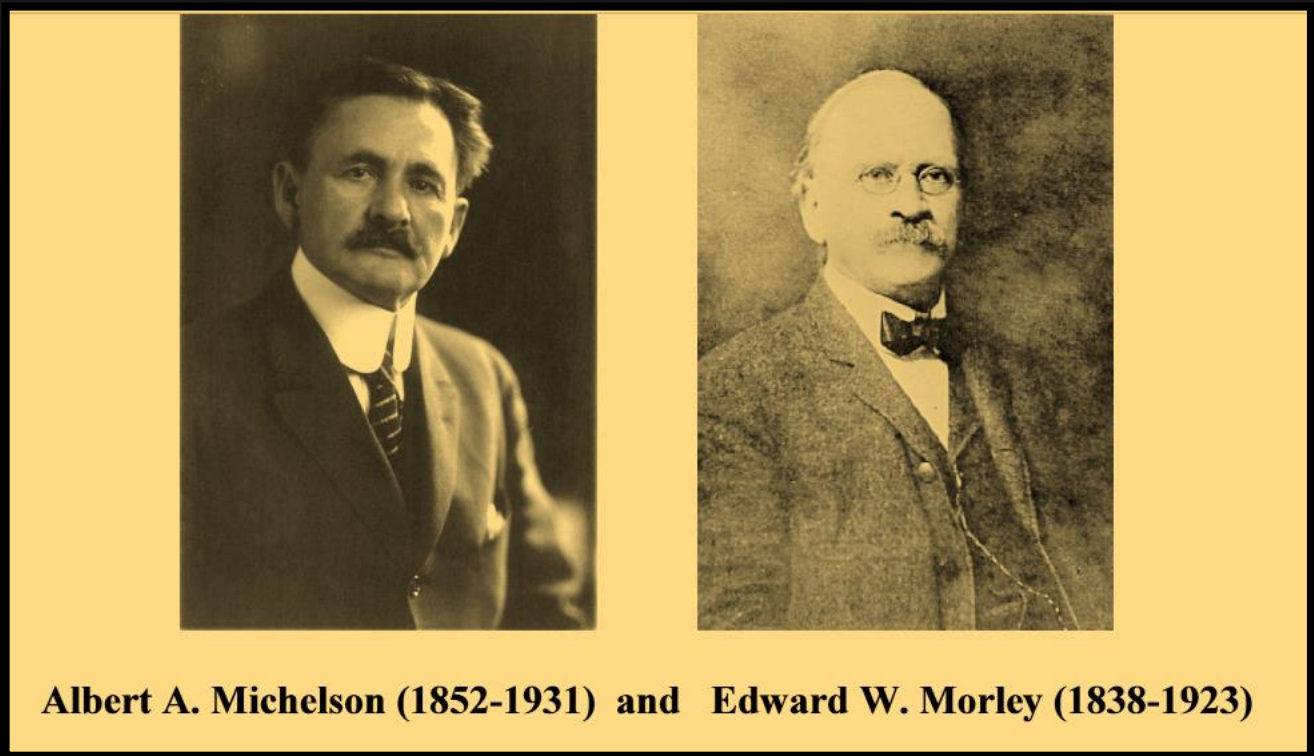


Éleuthère Mascart

"The general conclusion of this memoir would be that the translational movement of the earth has no appreciable influence on optical phenomena produced from a terrestrial source or solar light, that these phenomena do not give any means of measuring the absolute motion of a body, and that relative movements are the only we can measure."

1872

À LA RECHERCHE DE L'ÉTHER*



Albert A. Michelson (1852-1931) and Edward W. Morley (1838-1923)

April - July 1887

** À la recherche du temps perdu (M. Proust)*

SYMMETRY OF THE WAVE EQUATION

$$x' = x - vt, \quad y' = y\sqrt{1 - v^2/c^2}, \quad z' = z\sqrt{1 - v^2/c^2}, \quad t' = t - vx/c^2 \qquad (V)$$

Woldemar Voigt (1850-1919)

March 1887

The field of the moving charge gets ellipsoidal (1889)

HEAVISIDE

The moving rod shortens (1889)

FITZGERALD

LARMOR

:"...*individual electrons describe corresponding parts of their orbits in times shorter for the (rest)system*" [6].

~~Lo~~…Larmor Transformations

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

$$y' = y$$

$$z' = z$$

$$t' = \frac{t - \frac{vx}{c^2}}{\sqrt{1 - \frac{v^2}{c^2}}}$$

(1889)

LORENTZ

The moving rod shortens (1892)

"Simplified Theory of Electrical and Optical Phenomena in Moving Systems“ (1899)

"Electromagnetic phenomena in a system moving with any velocity smaller than that of light" (1904)

POINCARÉ

We have not a direct intuition of the equality of two intervals of time.

…light has a constant velocity, and in particular that its velocity is the same in all directions. That is a postulate(1899).

1. There is no absolute space, and we only conceive of relative motion; and yet in most cases mechanical facts are enunciated as if there is an absolute space to which they can be referred.

2. There is no absolute time. When we say that two periods are equal, the statement has no meaning, and can only acquire a meaning by a convention.

3. Not only have we no direct intuition of the equality of two periods, but we have not even direct intuition of the simultaneity of two events occurring in two different places.

Science and Hypothesis (1902)

"The laws of physical phenomena must be the same for a fixed observer and for an observer in rectilinear and uniform motion so that we have no possibility of perceiving whether or not we are dragged in such a motion."

POINCARÉ (1904)

Sur la dynamique de l'électron (Short version, 5 June 1905)

Sur la dynamique de l'électron (Long version, 23 July 1905)

EINSTEIN

1. The laws by which the states of physical systems undergo change are not affected, whether these changes of state be referred to the one or the other of two systems of co-ordinates in uniform translatory motion.

2. Any ray of light moves in the "stationary" system of co-ordinates with the determined velocity c, whether the ray be emitted by a stationary or by a moving body. Hence

"On the Electrodynamics of Moving Bodies" 23
(30 June 1905)

MINKOWSKI

"...The views of space and time which I wish to lay before you have sprung from the soil of experimental physics, and therein lies their strength. They are radical. Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality."

Raum und Zeit (1908)

HERMANN WEYL

The foundation and creation of the theory of relativity is the work of one single person: Albert Einstein (24.10.1950)

" Science...is a collective creative work, and it cannot be anything else; it is like a monumental construction that has to be constructed for centuries, and where everybody must bring a stone to, and this stone can cost him a whole life. Hence, it gives us a feeling of a necessary cooperation, solidarity of our labour with the labour of our contemporaries, our predecessors and our followers".

POINCARÉ Henri,
Dernières pensées

Einstein:

- The principle of relativity and the principle of constancy of the velocity of light are both necessary for a consistent theory of relativity

- **Are they?**

IGNATOWSKI
(1875-1942)

" I've asked myself the question, at which relations or transformation equations one arrives when only the relativity principle is placed at the top of the investigation, and whether the Lorentzian transformation equations are the only ones at all, that satisfy the relativity principle".

On the Relativity Principle (Moscow, December 1909)

EINIGE ALLGEMEINE BEMERKUNGEN ÜBER DAS RELATIVITÄTSPRINZIP

PHYSIKALISCHE ZEITSCHRIFT. 11. (1910), PP. 972–976

Some general remarks on the relativity principle.

W. v. IGNATOWSKY

When EINSTEIN introduced the relativity principle some time ago, he simultaneously assumed that the speed of light shall be a universal constant, i.e. it maintains the same value in all coordinate systems. Also MINKOWSKI started from the invariant in his investigations, although it is to be concluded from his lecture "Space and Time"[1], that he attributed to the meaning of a universal space-time constant rather than that of the speed of light.

Now I've asked myself the question, at which relations or transformation equations one arrives when only the relativity principle is placed at the top of the investigation, and whether the LORENTZian transformation equations are the only ones at all, that satisfy the relativity principle.

In order to answer this question, we again repeat what is given to us by the relativity principle *per se*.

$$x' = (x - vt)/\sqrt{1 - v^2 n}, y' = y, z' = z, t' = t - vnx/\sqrt{1 - v^2 n}$$

$n = 1/c^2$ c = the maximum allowed velocity

ON THE LIMITING VELOCITY

$$ds^2 = c^2dt^2 - dx^2 - dy^2 - dz^2 = \eta_{\mu\nu}dX^\mu dX^\nu$$

$$\eta_{\mu\nu} = diag(1, -1, -1, -1)$$

$$x^\alpha(X^\mu)$$

$$ds^2 = \gamma_{\mu\nu}(x)dx^\mu dx^\nu$$

$$ds^2 = 0$$

$$\gamma_{\mu\nu}(x) = \frac{\partial X^\alpha}{\partial x^\mu}\frac{\partial X^\beta}{\partial x^\nu}\eta_{\alpha\beta}.$$

$$c^2[\sqrt{\gamma_{00}} + \gamma_{0i}dx^i/c\sqrt{\gamma}_{00}]^2 - [-\gamma_{ik} + \gamma_{0i}\gamma_{0k}/\gamma_{00}]dx^i dx^k = 0.$$

$$d\tau \doteq \sqrt{\gamma_{00}} + \gamma_{0i}dx^i/c\sqrt{\gamma}_{00} = \gamma_{0\lambda}dx^\lambda/c\sqrt{\gamma_{00}}$$

Physical time

$$dl^2 = \chi_{ik}dx^i dx^k$$

$$\chi_{ik} = -\gamma_{ik} + \gamma_{0i}\gamma_{0k}/\gamma_{00}$$

$$c = \frac{dl}{d\tau}$$

$$\mathbf{c}_{\text{coordinate}} = \frac{d\boldsymbol{x}}{dt} = c_{\text{coordinate}}\mathbf{e}$$

$$c_{\text{coordinate}} = c[\gamma_{00}dt/(\sqrt{\gamma}_{00} - \gamma_{0i}e^i)]$$

DOWN WITH ETHER!

insofern als überflüssig erweisen, als nach der zu entwickelnden Auffassung weder ein mit besonderen Eigenschaften ausgestatteter „absolut ruhender Raum“ eingeführt, noch einem Punkte des leeren Raumes, in welchem elektromagnetische Prozesse stattfinden, ein Geschwindigkeitsvektor zugeordnet wird.

The introduction of a “luminiferous ether” will prove to be superfluous inasmuch as the view here to be developed will not require an “absolutely stationary space” provided with special properties, nor assign a velocity-vector to a point of the empty space in which electromagnetic processes take place.

Einstein (30 June 1905)

BACK TO ETHER ?

- "Recapitulating, we may say that according to the general theory of relativity space is endowed with physical qualities; in this sense, therefore, there exists an ether. According to the general theory of relativity space without ether is unthinkable; for in such space there not only would be no propagation of light, but also no possibility of existence for standards of space and time ..."

(Albert Einstein 5 May 1920)

QUANTUM VACUUM STATE $|\Omega>$ AS ETHER ?

- Invariant under the Poincaré group:

$$U(a,\Lambda)|\Omega> = |\Omega>$$

- In particular

$$P^{\mu}|\Omega> = 0$$