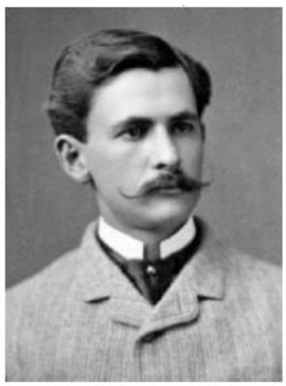
Homework 15.

Introduction to the special theory of relativity.
Michelson-Morley experiment.

As we discussed light as waves, there was a question: is there the media which “produces” light waves like water “produces” the waves on the water surface and air “produce” sound waves?In the end of 19^{th} century the physicists believed that such a media exists and called it “luminiferous aether”. As long as the Earth moving in space, theoretically we could measure the speed of the Earth with respect to the aether. To check this assumption, Albert Michelson and Edward Morley in 1887 performed their famous experiment in an attempt to register the motion of Earth through the aether by optical methods.



Albert Michelson (1852-1931).

Edward Morley (1838-1923).

As it was believed, the aether is a substance which penetrates the universe and is the medium for the propagation of light like, say, air is the medium for the sound waves. The motionless aether provides a good reference frame to register the motion of Earth. Assuming the velocity addition rule from classical mechanics the scientists expected to detect the difference in the speed of light propagating along and perpendicular to the direction of the Earth motion. No difference was detected. The experiment was later repeated many times at higher accuracy level – the result was negative. The speed of light was measured the same –independent from the direction of light propagation with respect to the Earth motion. All experimental attempts to detect the “aether wind” (in other words “to measure absolute motion”) failed.

Henri Poincaré, famous French mathematician and physicist suggested that the experiments failed not because of a lack of the experimental skill, but because it is a fundamental physical low: “detection of absolute velocity is impossible”.

Henri Poincaré

(1854-1912).

We know very well that all physics laws are invariant in all inertial reference frames (for example, Newton's second law). This is the Galileo's principle of relativity. The word *relativity* here means that the statement "the object is moving at a constant velocity" makes sense only if we specify the reference frame in which we are monitoring the position of the object. Just to remind: a reference frame is an object or a group of objects which we use to specify the spatial position of a physical body. If we know one inertial reference frame, all the reverence frames moving at constant velocities with respect to the initial reference frame are also inertial.

Imagine that we specify the position of an object A in space with respect to the certain reference frame XYZ. In our 3-dimensional world we have to specify 3 numbers: x, y and z coordinates.

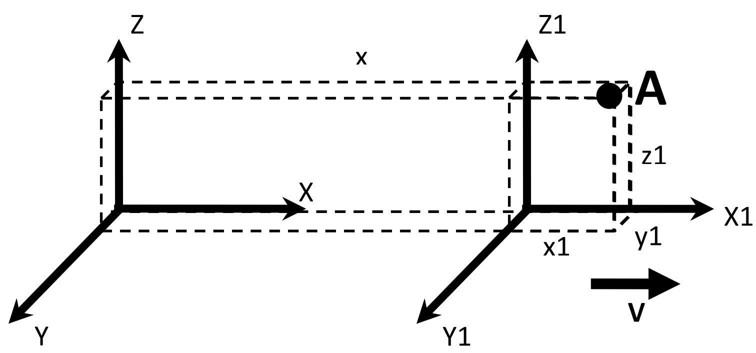


Fig.1

Imagine that we have another reference frame$X_1Y_1Z_1$ which moves at a velocity $\boldsymbol{V}$ with respect to the XYZ frame along the x axis (see Fig.1). The object A which is at rest in XYZ is moving in $X_1Y_1Z_1$. Assume that initially these reference frames had same origin. Now we can express the coordinates of **A** in the "moving" reference frame x_1, y_1, z_1 through the x, y and z in the following way:

$$\begin{aligned} x_1 &= x - Vt \\ y_1 &= y \\ z_1 &= z \end{aligned} \qquad (1)$$

Here t is time. If A is moving in the XYZ at a velocity $\boldsymbol{v}$ along the X axis we can use simple rule of velocity addition:

$$\boldsymbol{v}=\boldsymbol{v_1}+\boldsymbol{V} \qquad (2)$$

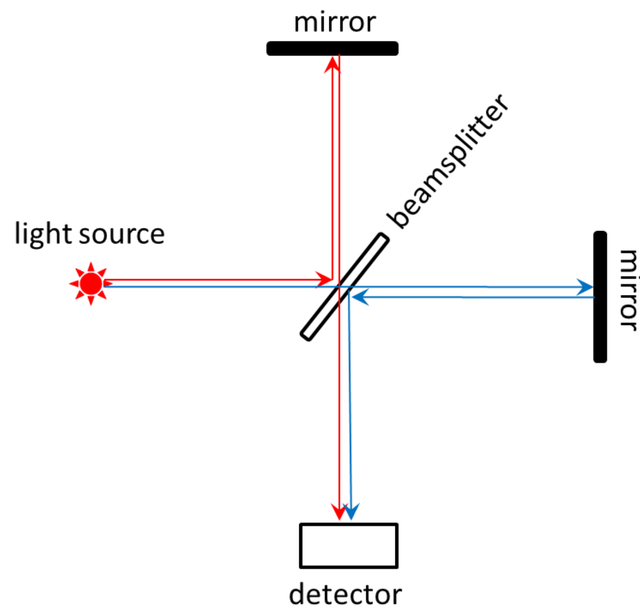
Here $\boldsymbol{v_1}$ is the velocity of A in the $X_1Y_1Z_1$.

But, as the results of the Michelson-Morley experiment indicate, the speed of light in vacuum is the same independently of the velocity of the reference frame. The motion faster than the light in vacuum is impossible. This absolutely contradicts to the velocity addition rule which is experimentally checked so many times!

Next time we discuss what would be the solution of this problem.

Problem:

The Michelson-Morley experimental setup (interferometer) is shown in the Figure below. The distances between the beam splitter and the mirrors are equal. Two rays of light (shown in red and blue in the Figure) are emitted from the source at the same time. You know how time T which is required for the light to travel from the beam splitter to a mirror and back when the interferometer is at rest. This time is the same for both mirrors. Now, imagine that the aether theory is correct and the setup is moving left to right at a velocity V with respect to "standing" aether. The speed of light in the aether is C. Find how will time T change for red and blue rays. Make a picture.


mirror
beamsplitter
light source
mirror
detector