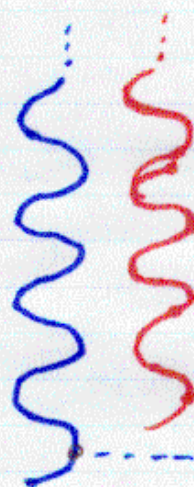
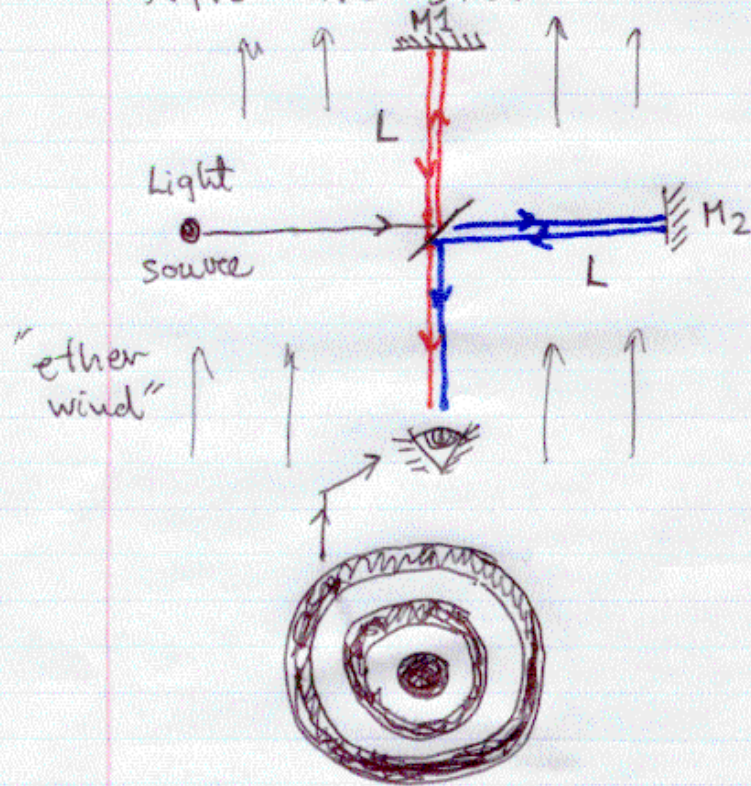


To explain the idea of the Michelson-Morley experiment - let's assume that there is "ether-wind".

We now run the animation...

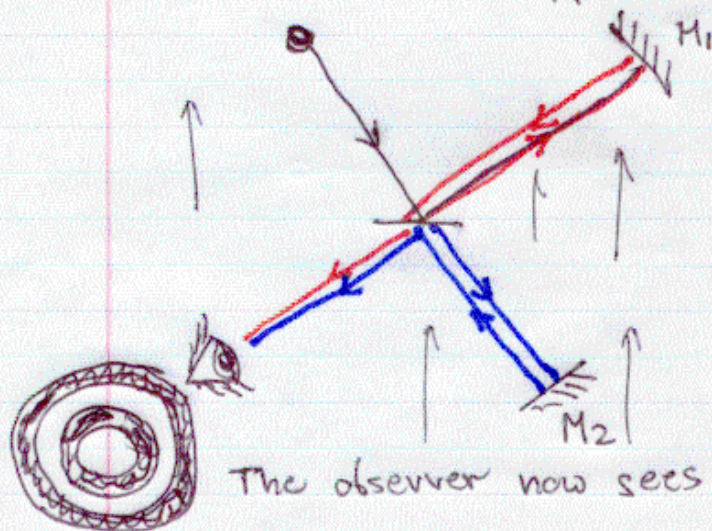
After the show:



For the "cross-stream" beam it takes less time to go through the flight path forth and back

Suppose that the time difference corresponds to one-half wavelength. So, when the beams are recombined, the interference is destructive - the observer sees a black spot at the center.

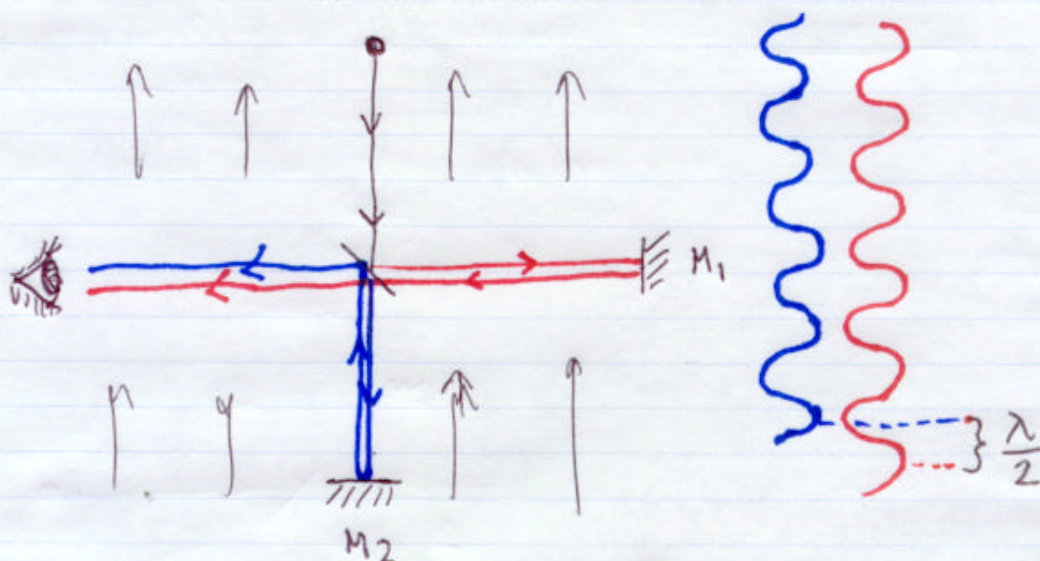
Now, rotate the apparatus by  $45^\circ$ :



Now, the effect of ether motion is the same for both beams - no phase shift, the interference is constructive.

The observer now sees a bright spot in the center.

Now, rotate by another  $45^\circ$ :



Now, the red beam is the "cross-stream" beam and it arrives first, so again there is a phase shift by one-half wavelength and the interference again is destructive. Again there is a "black spot" in the center:



So, when we rotate the apparatus by  $90^\circ$ , then the "ring pattern" goes through a full cycle: black central spot - bright central spot - black central spot again.

Michelson-Morley experiment was repeated many times, with better and better precision.

The results clearly showed: there is no "ether wind"!

The experiments clearly indicated that light propagates with the same speed in all directions, even though Earth is moving!

Clearly, light was found not to obey the Galilean Transformation!

And now Albert Einstein appears on the stage...

Some time earlier, physicist became aware of one <sup>more</sup> puzzling fact. Namely, the laws of physics should be the same in all inertial frames, even if they move relative to each other. In other words, if we apply the Galilean Transformation to the equations expressing a given law, the equations should not change - we say: "the laws should be invariant with respect to the Galilean Transformation".

For instance:  $\vec{F} = m \cdot \vec{a}$  - the II Newton Law

We showed that the Galilean Transformation does not change the acceleration  $\vec{a}$  in the moving frame - so, the II Law does not change in this frame.

Equivalently, one can say: "the II Newton Law is invariant with respect to the Galilean Transformation".

So, Michelson and Morley experiments showed that there was something strange with light...

Also, about the same time physicists noticed that the famous Maxwell Equations are not invariant with respect to the Galilean Transformation...

The transformation, with respect to which the Maxwell Equations were found to be invariant, was an "exotic" transformation formula discovered by Einstein's friend, Lorentz.

In 1905 Einstein took a courageous step: He postulated that the speed of light is the same in all frames of reference, no matter of what their own speed is.

He explained it by the fact that all laws of physics are invariant with respect to the Lorentz Transformation, not only the Maxwell Equations.

Galilean Transformation, Einstein explained, is the limit of the Lorentz Transformation when the speed  $\rightarrow 0$

Look at:

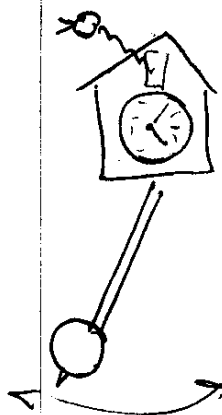
[http://en.wikipedia.org/wiki/Lorentz\\_transformation](http://en.wikipedia.org/wiki/Lorentz_transformation)  
to find the math form of the transformation.

What Einstein discovered, was the special theory of relativity.

## Relativity of time

To measure time, we use clocks.

The heart of any clock is a "pacemaker":

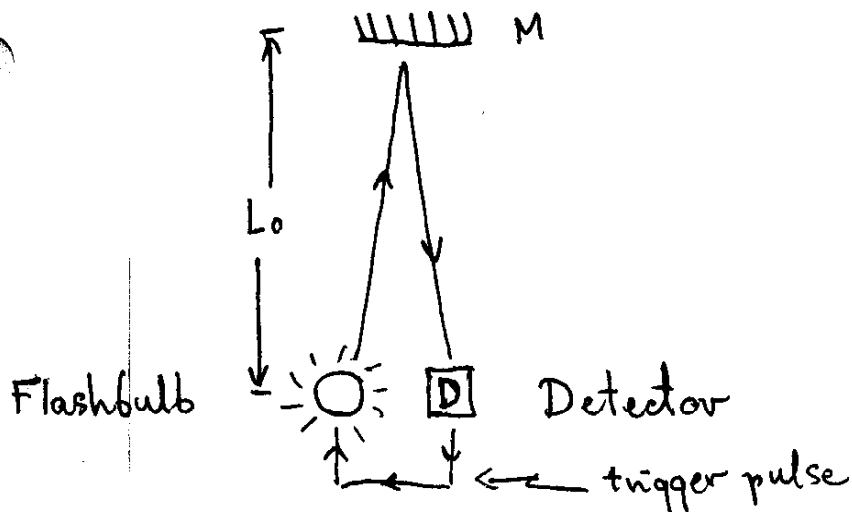


In "grandpa's clock", it was a swinging pendulum;

In your electronic wrist watch, it's a tiny element made of quartz ( $\text{SiO}_2$  crystal).

In atomic clocks (the most accurate existing clocks) it's a beam of Cesium atoms oscillating between two energy states.

But since the speed of light is constant, why shouldn't we use light as a "pacemaker"?



Flashbulb flashes, and when the light pulse is reflected back and reaches the detector (D), it produces an electronic pulse that ~~releases~~ releases another flash, and so on.

The bulb will flash at intervals  $\Delta t = \frac{2L_0}{c}$

Question: why such clocks are not being used?

We will now use the animation in the "Weekly Web" - Week 2, Applet # 3.

(the same material is on pages 26-27, but nothing is moving in the book).

We will derive the equation for the time dilation:

$$\Delta t = \frac{\Delta t_0}{\sqrt{1 - u^2/c^2}}$$