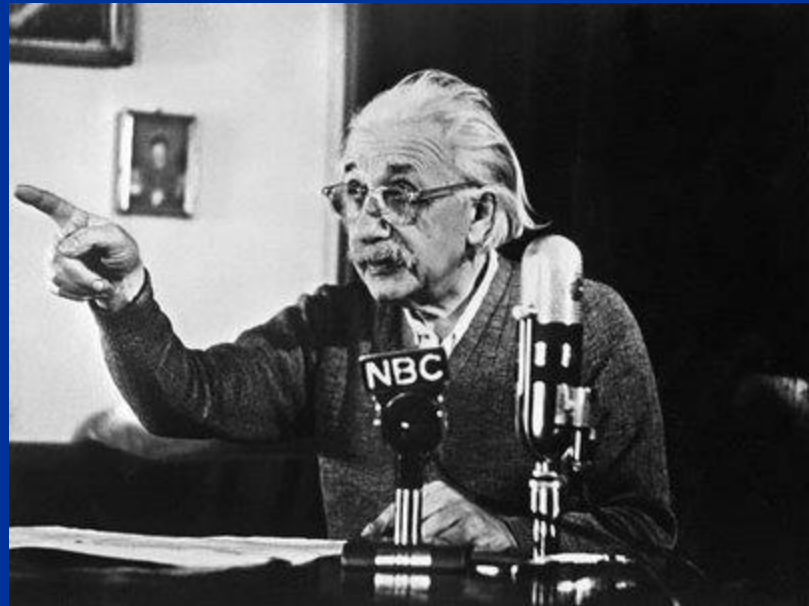


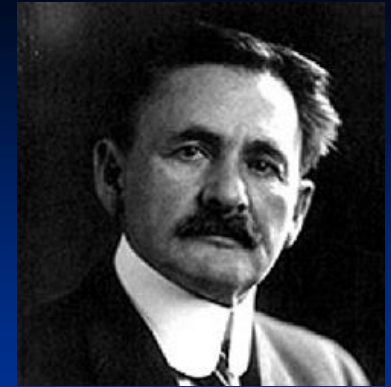
Special Theory of **Relativity**



2nd Lecture

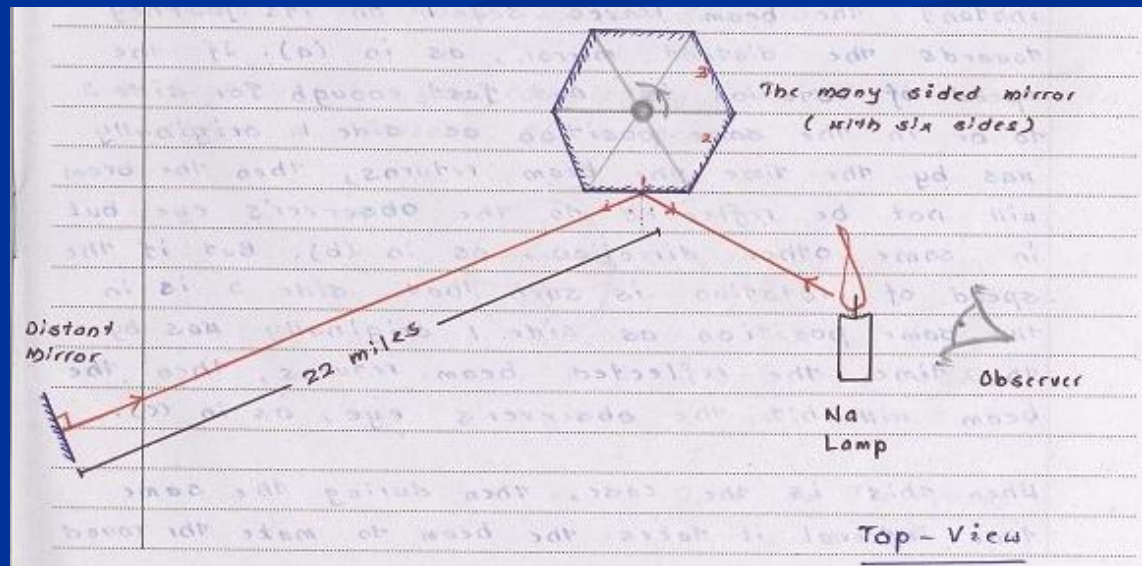
Michelson's Precise Method

The most widely known measurement of the velocity of light is that performed by Michelson (1852 - 1931) in 1879.



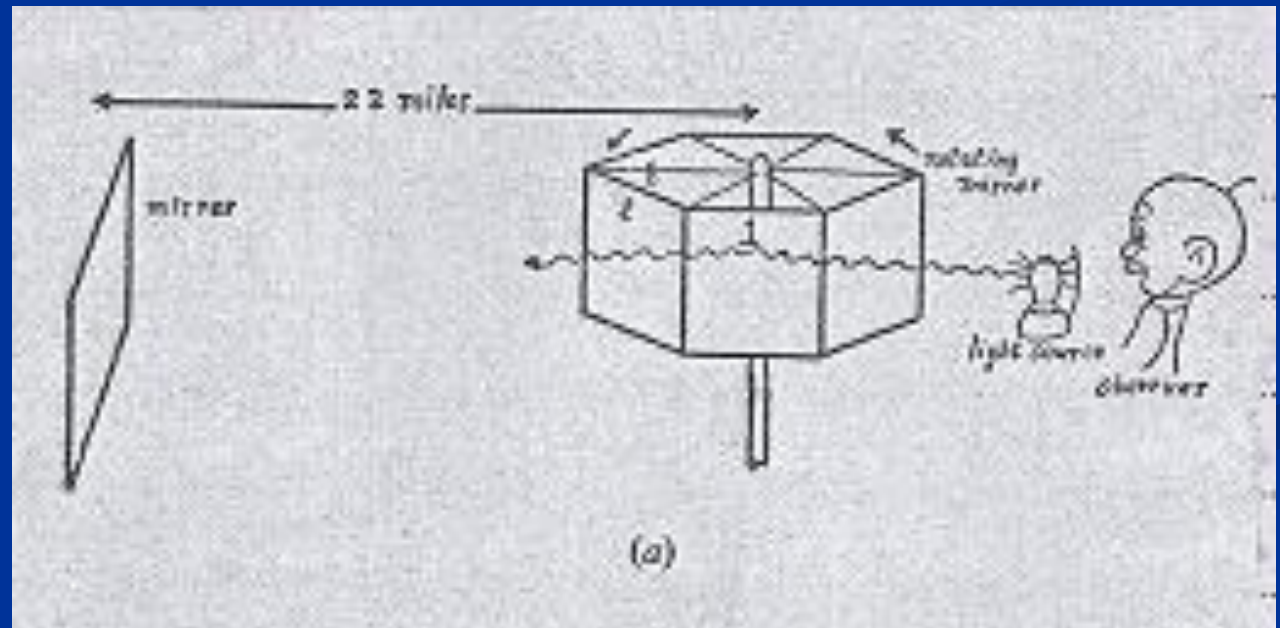
Michelson perfected the revolving mirror method. This is somewhat similar to Fizeau's cog-wheel but uses a rotating, many-sided mirror to chop up the original light wave into individual beams which, like Fizeau's are sent to a distant mirror (here 22 miles away!) and back again (see following figure).

The many-sided mirror is represented by one with six sides and can be rotated at any desired speed with an electric motor.

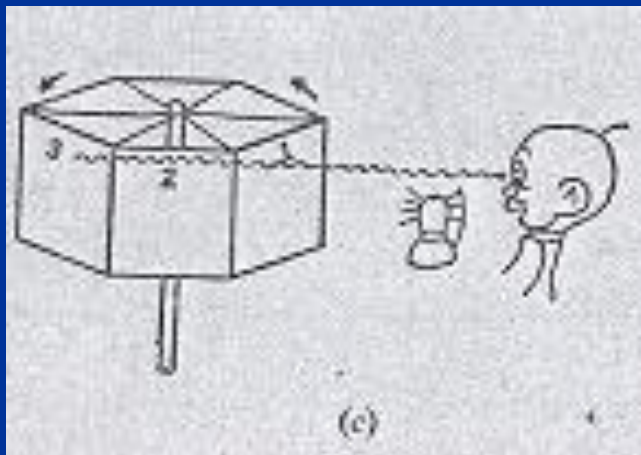
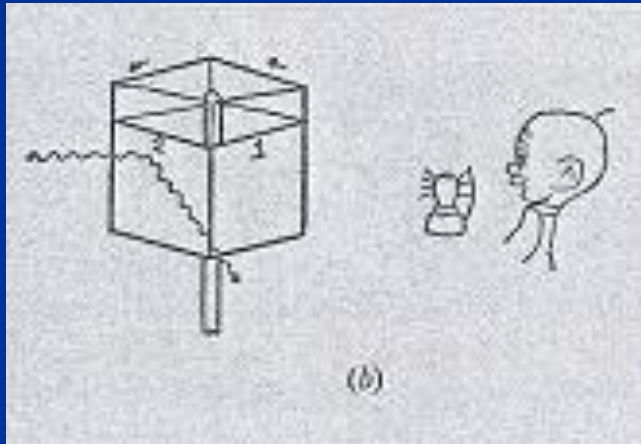
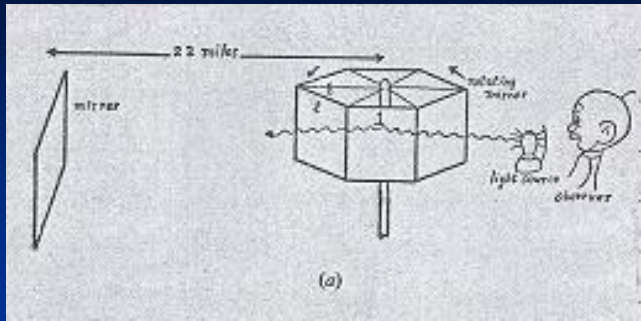


Michelson's Precise Method

We first consider that would happen if the mirror was not rotating and set at position (a). Light would leave the light source and hit side 1, from which it would be reflected to the distant mirror. Upon reflection there, it would return via the same general path, hit side 1 again, and would be seen by the eye near the lamp as it returned towards the general direction of the lamp.



Michelson's Precise Method



But now suppose, as happens in the actual experiment, that the mirror is rotated at the instant the beam leaves side 1 on its journey towards the distant mirror, as in (a). If the speed of rotation is not fast enough for side 2 to be in the same position as side 1 originally was by the time the beam returns, then the beam will not be reflected to the observer's eye but in some other direction, as in (b). But if the speed of rotation is such that side 2 is in the same position as side 1 originally was by the time the reflected beam returns, then the beam will hit the observer's eye as in (c).

Michelson's Precise Method

When this is the case, then during the same time interval it takes the beam to make the round trip to the distant mirror and back, the rotating mirror rotates by a sixth of a rotation. Further, since the speed of rotation of the mirror is known, the time for one revolution is known, and one sixth of this is the time it takes for the light beam to make its round-trip. Dividing the round trip distance by this time interval gives the velocity of light.

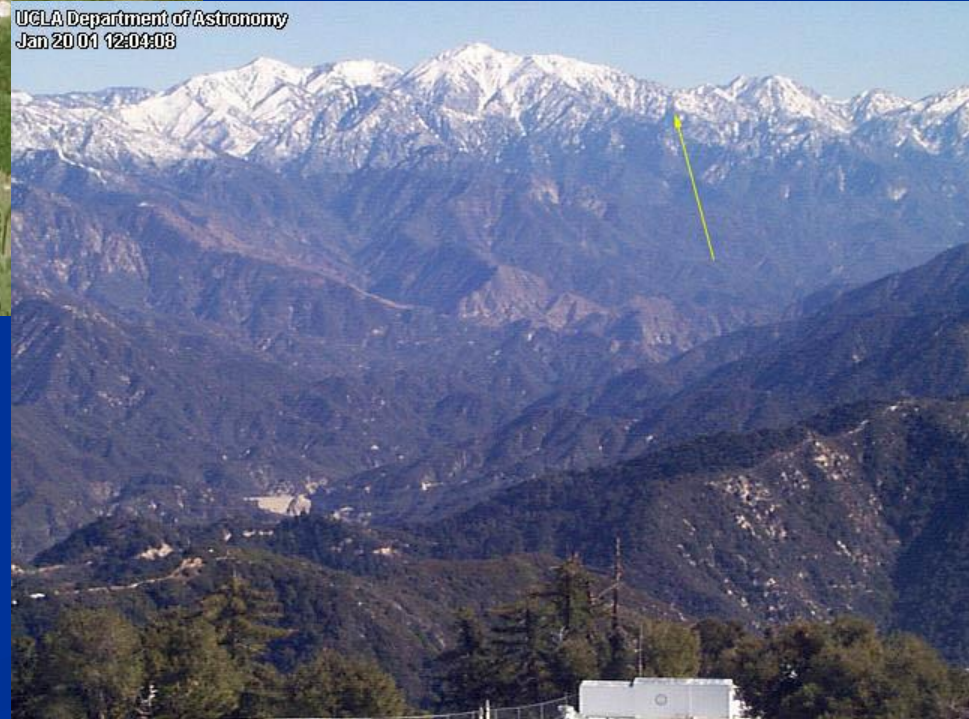
In Michelson's actual experiment various rotating mirrors of 8, 12 and 16 sides were used. This apparatus was set up on **Mount Wilson in California**. The mirror system comprising the distant mirror was set up on **Mount San Antonio**, approximately 22 miles away.

As a result of this and Michelson's subsequent experiments, the velocity of light is approximately **186,000 miles a second**.

Michelson's Precise Method



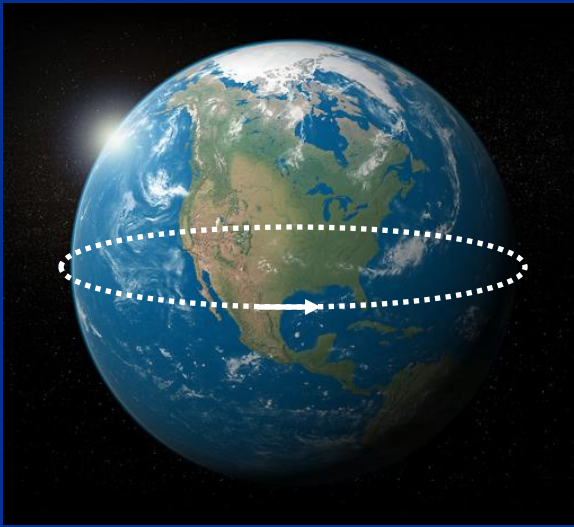
Mount Wilson in California



Mount San Antonio

Properties of Light Waves :

186,000 miles a second [297 600 000 m/s] may seem like too high speed to imagine, but it can be put into ideas with which we are familiar.



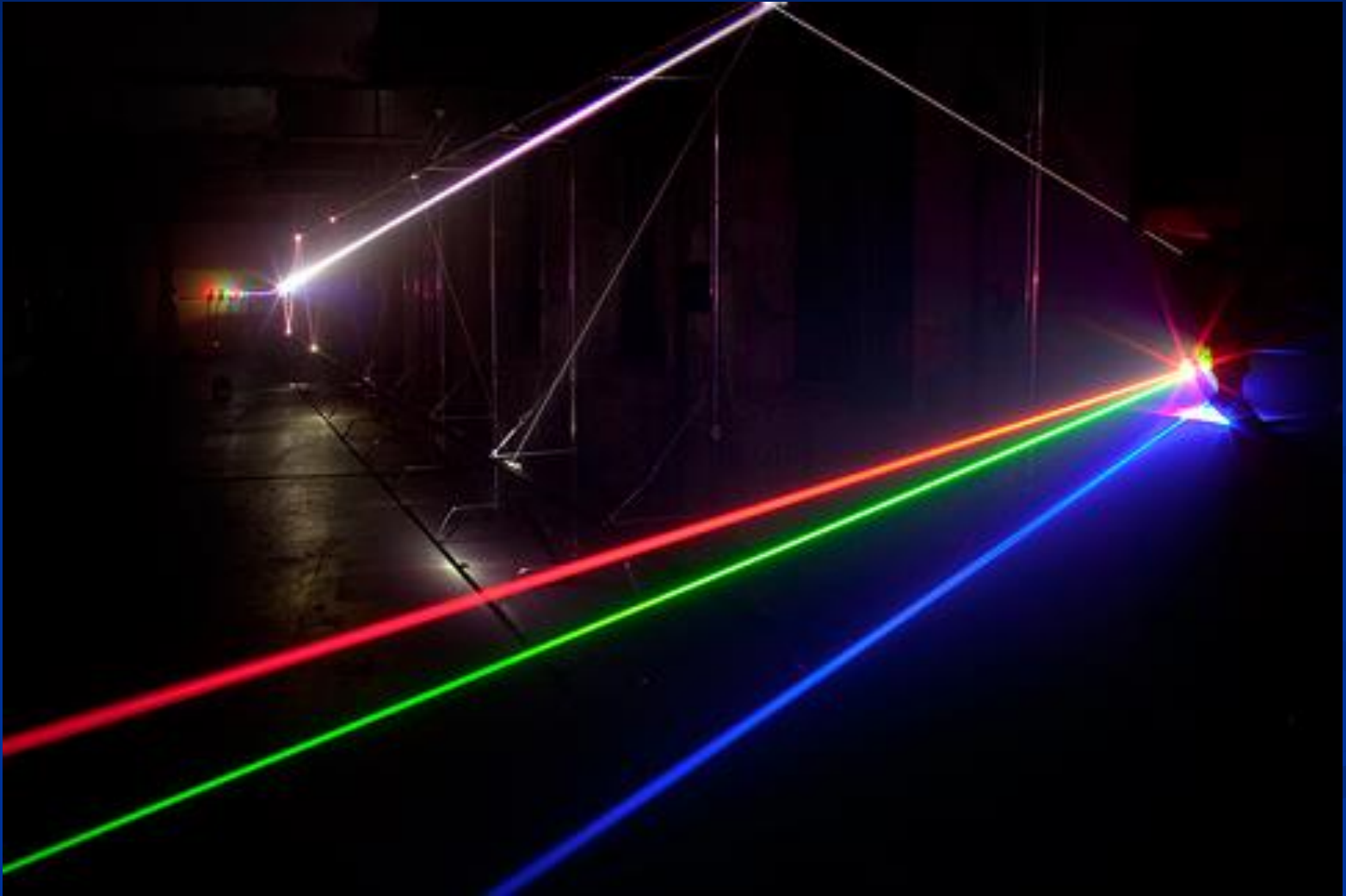
Light will go completely around the Earth in about a seventh of a second.

$$\sim \frac{1}{7} s$$

It takes about **08 minutes and 30 seconds** for sunlight to travel the 93 million miles from the Sun to the Earth.



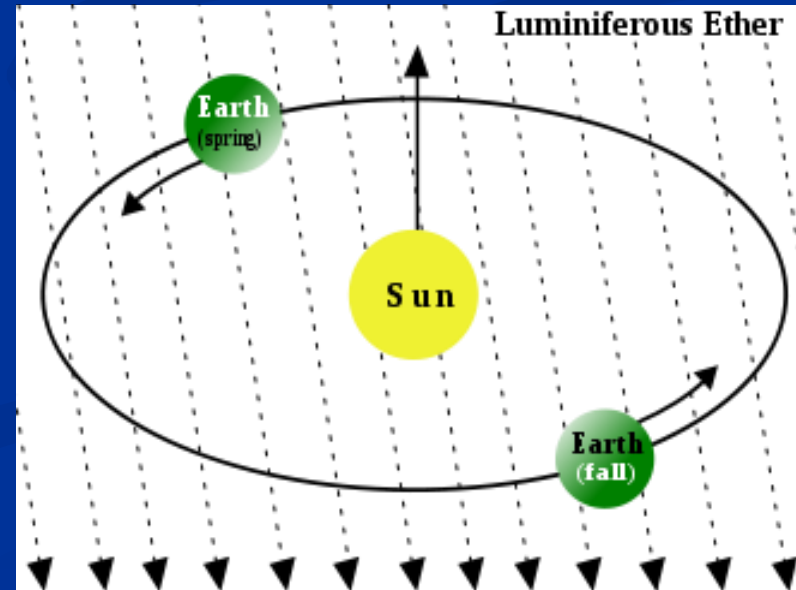
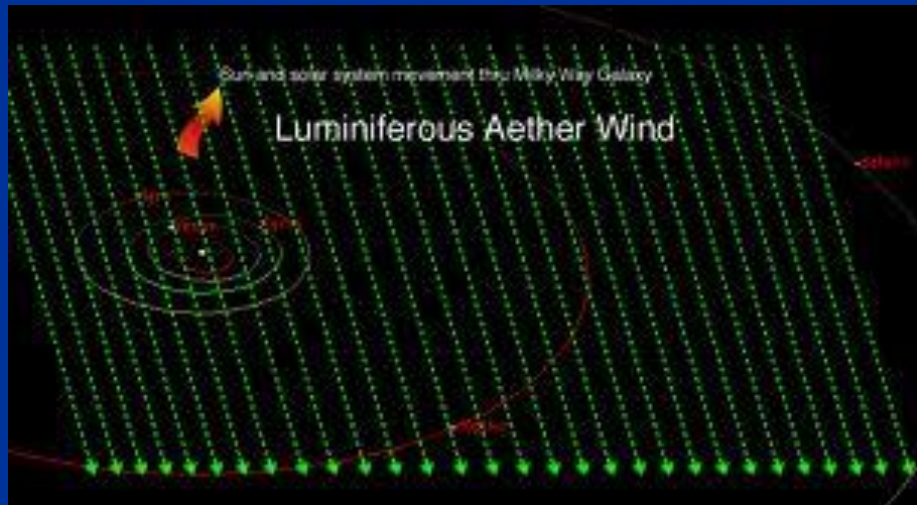
Propagation Media of Light



The concept of the *Ether* [luminiferous ether]

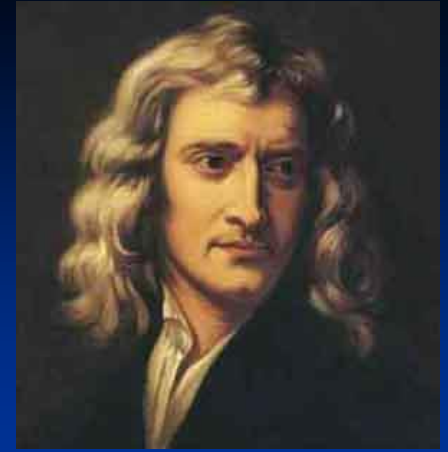
With proof afforded by many excellent experiments that light travels with a finite velocity of about 186000 miles a second, scientists next turned their attention to the consideration of the medium which carried or propagated the light waves.

Scientists created a special word for the hypothetical carrier of light waves. They called it the *luminiferous ether*, or just plain *ether*.



The history of the light and the *Ether*

Isaac Newton (1642-1727) contended that light made up of numerous small particles. This could explain such features as light's ability to travel in straight lines and reflect off surfaces.



Christian Huygn's (1629-1695), prior to Newton, had hypothesized that **light was a wave** propagating through an **ether**, but Newton rejected this idea.

However, a century later, Young and Fresnel revived the wave theory of light when they pointed out that light could be a transverse wave rather than a longitudinal wave. Light wave required a medium for propagation, and thus required Huygens's idea of an ether "gas" permeating all space.

Reference

Augustin-Louis Cauchy suggested that perhaps there was some sort of "dragging", or "entrainment", but this made the aberration measurements difficult to understand. He also suggested that the absence of longitudinal waves suggested that the ether had negative compressibility.

Reference

George Green pointed out that such a fluid would be unstable.

Reference

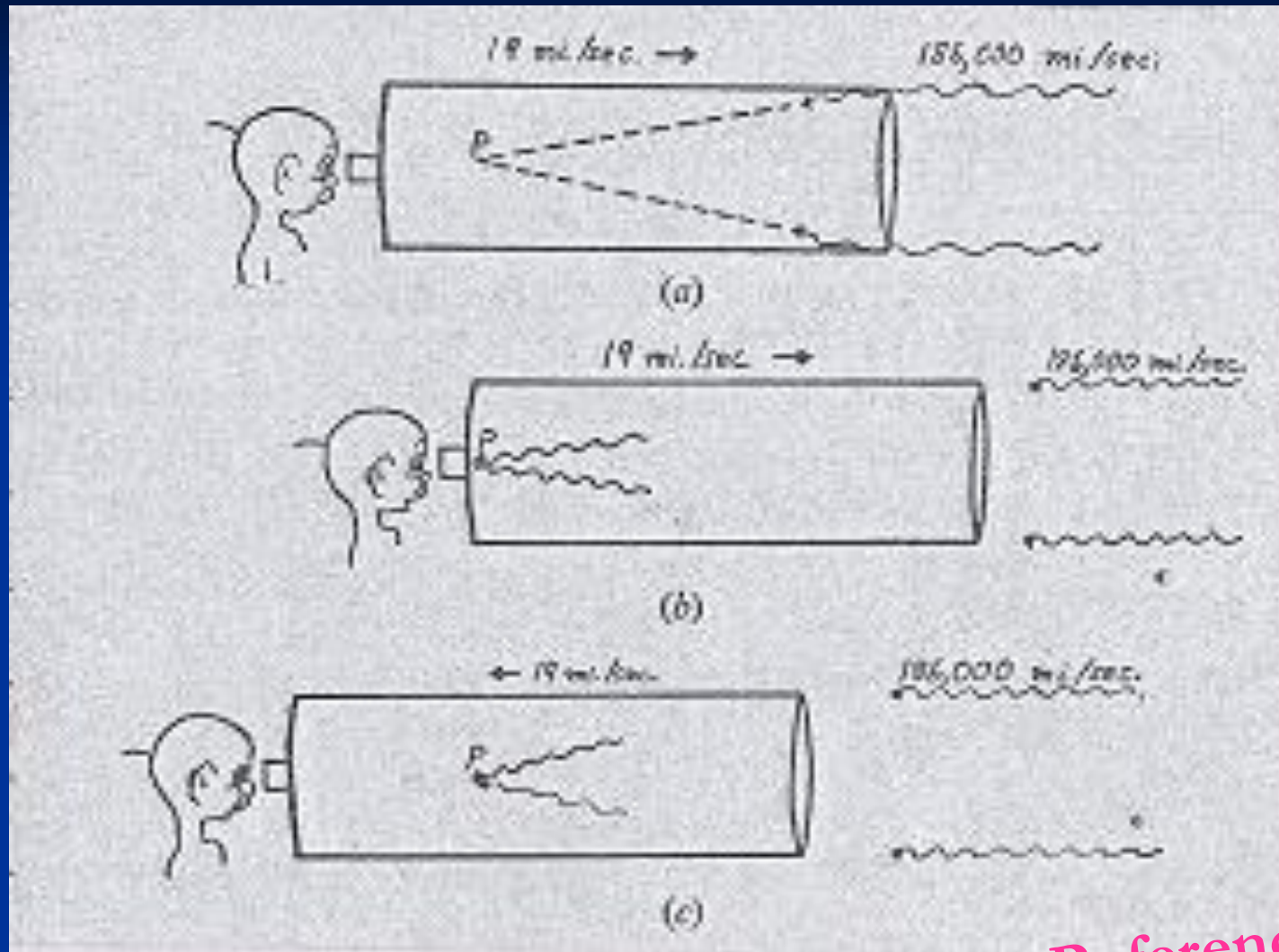
George Gabriel Stokes became a champion of the entrainment interpretation, developing a model in which the ether might be rigid at very high frequencies and fluid at lower speeds. Thus the Earth could move through it fairly freely, but it would be rigid enough to support light.

Reference

Later, Maxwell's equations showed that light is an electromagnetic wave. The apparent need for a propagation medium for such Hertzian waves can be seen by the fact that they consist of perpendicular electric (E) and magnetic (B or H) waves. In addition, Maxwell's equations required that all electromagnetic waves in vacuum propagate at a fixed speed, c . That is, the ether must be "still" universally, otherwise c would vary along with any variations that might occur in its supportive medium. Maxwell himself proposed several mechanical models of ether based on wheels and gears, and George FitzGerald even constructed a working model of one of them. These models had to agree with the fact that the electromagnetic waves are transverse but never longitudinal.

Reference

An expected *Ether* effect !



Reference

An expected *Ether* effect !

Reference

Assume we have a telescope set up on the earth. We focus it on a star which is in the direction the earth is travelling in its orbit. The light from the star is travelling at 186,000 miles a second through the assumed stationary ether between the star and the earth. Two of the light beams from the star have just entered the telescope in (a). These beams have been bent by the telescope lens so that they will come to a focus at point P, which is a point in the space within the telescope. Now since the telescope and observer are moving to the right with a velocity of 19 miles a second, the observer's eye will arrive at point P at the same time the light beams do in (b), and the observer will see the star in focus.

An expected *Ether* effect !

Reference

But now suppose the astronomer looks at the same star six months later and does not change the focus. The situation will be entirely different, since the earth will be on the other side of its orbit. Whereas before it was travelling towards the star, or to the right with respect to the ether, with a velocity of 19 miles a second, it will now be travelling away from it, or to the left with respect to the ether, with the same velocity. What was expected to happen is shown in (c). Since the telescope and observer are now running away from the incoming light wave, the observer's eye will no longer be at point P when the light beams arrive there, and as a consequence the observer will now see the star out of focus. If this reasoning were correct, then a telescope which was originally in focus on a distant star would be out of focus six months later. This effect was looked for but was never observed.

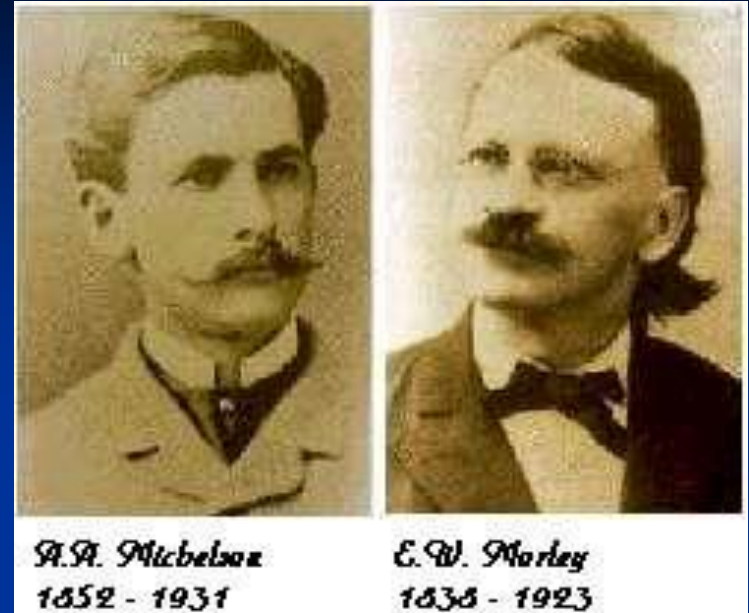
Fresnel's *Ether* drag :

A possible explanation for the failure to detect this effect was contained in a theory advanced by Fresnel in 1818. He believed that the ether was thicker in material bodies than it was in vacuum or outer space and that, as a result, when a transparent object, such as a telescope lens, moved through the ether, it dragged some of the ether along with it in much the same way a moving ship drags some water behind it.

Reference

This is similar to hanging a fish from a pole and tying it to a running dog so that it dangles in front of him: the dog never catches the fish because it moves whenever he moves.

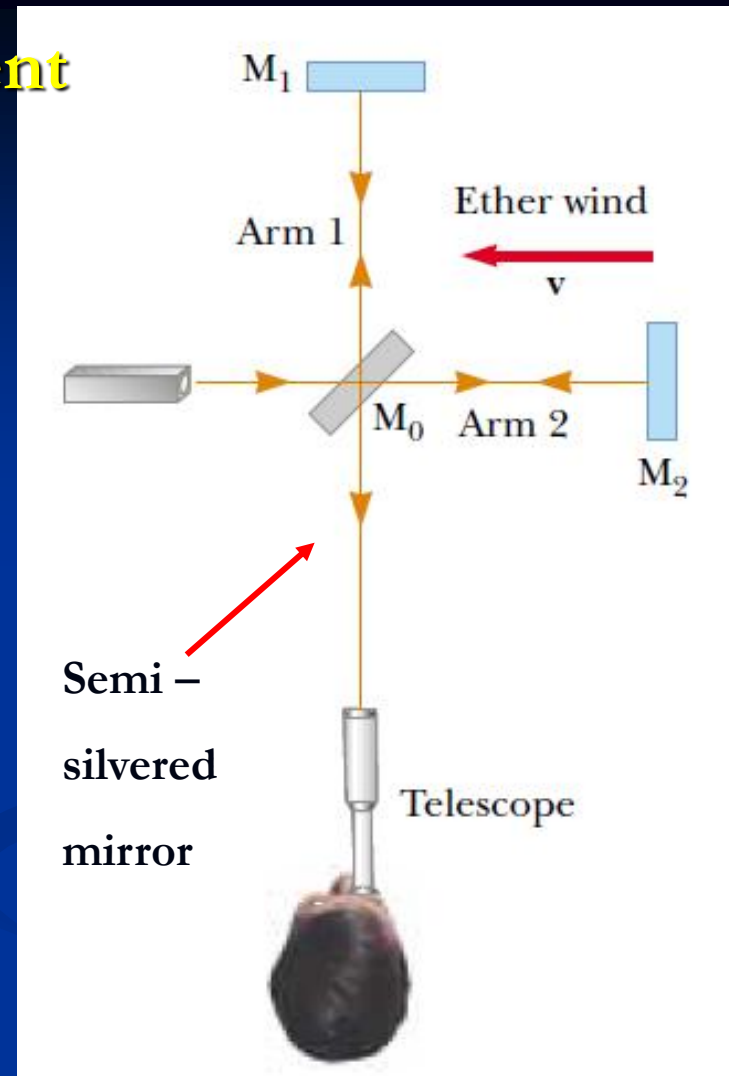
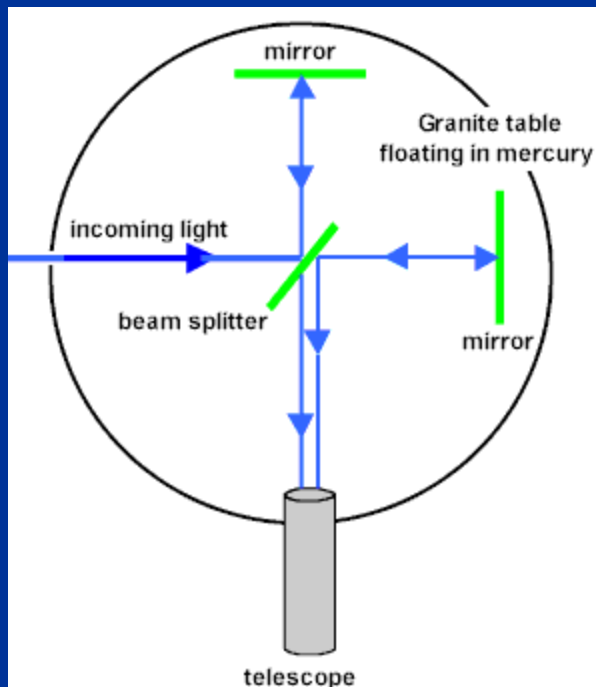
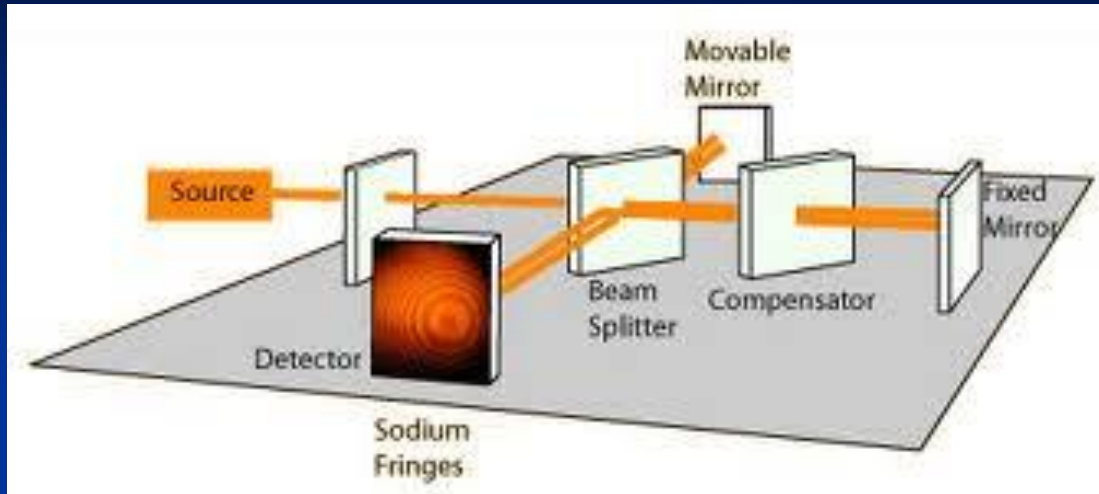
The Michelson – Morley Experiment



The Michelson – Morley experiment was performed in **1887** by **Albert Michelson** and **Edward Morley** at what is now **Case Western Reserve University**. Its results are generally considered to be the first strong evidence against the theory of a **luminiferous ether**.

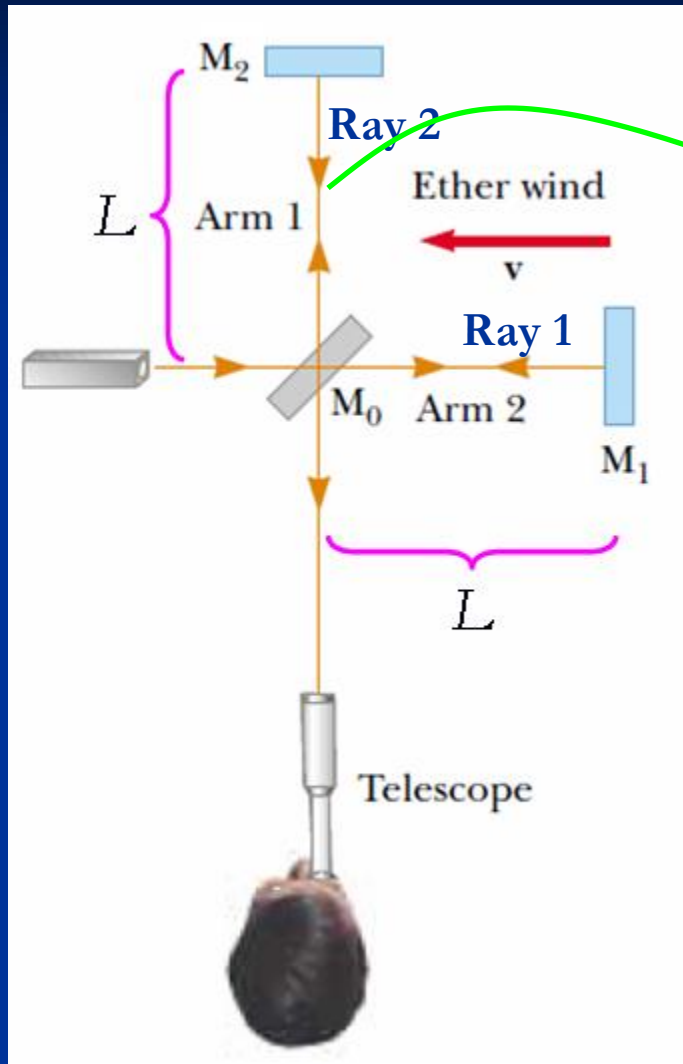
The experiment was designed to determine the velocity of the Earth relative to that of the hypothetical ether.

The Michelson – Morley Experiment

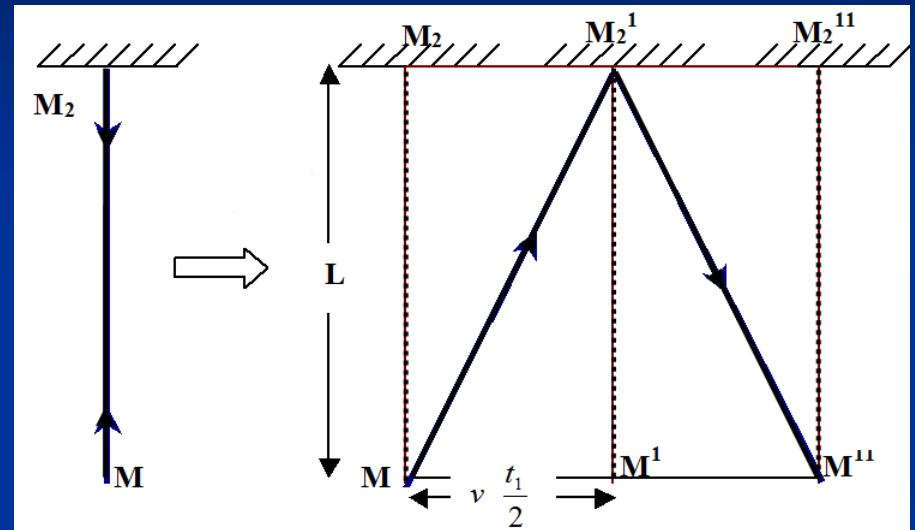


The experimental tool used was the Michelson interferometer is shown in the above Figures.

Details of the Michelson–Morley Experiment



For Ray 2:

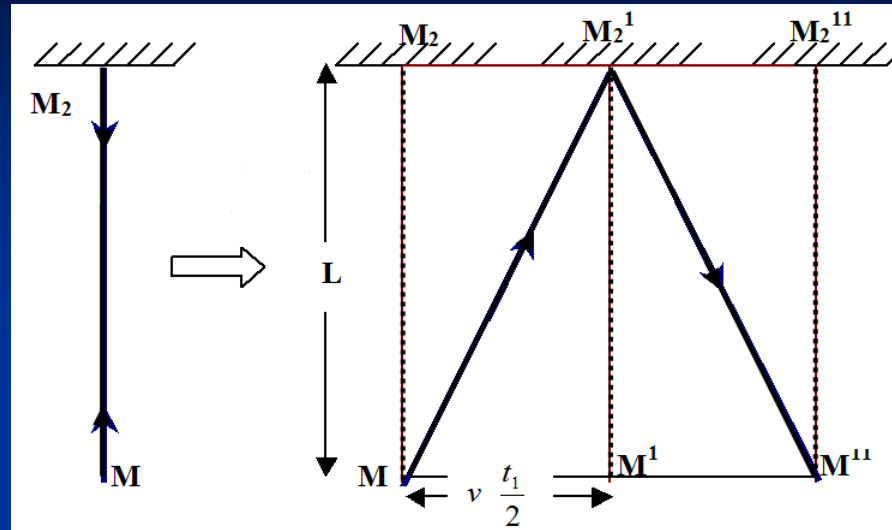


The distance of travel for each half of the trip is,

$$M M_2^1 = \sqrt{L^2 + \left(v \frac{t_1}{2}\right)^2}$$

Details of the Michelson–Morley Experiment

For Ray 2:



The total distance of travel for the round trip is,

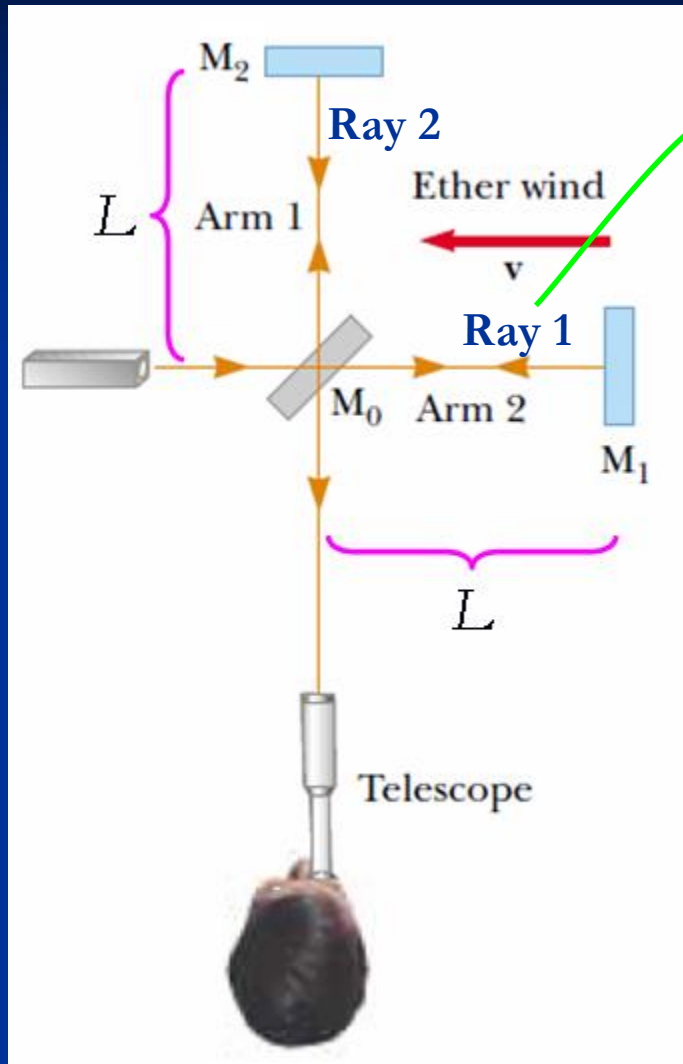
$$M M_2^1 M^{11} = 2\sqrt{L^2 + \left(v \frac{t_1}{2}\right)^2}$$

$\therefore$ The total time of travel for the round trip is,

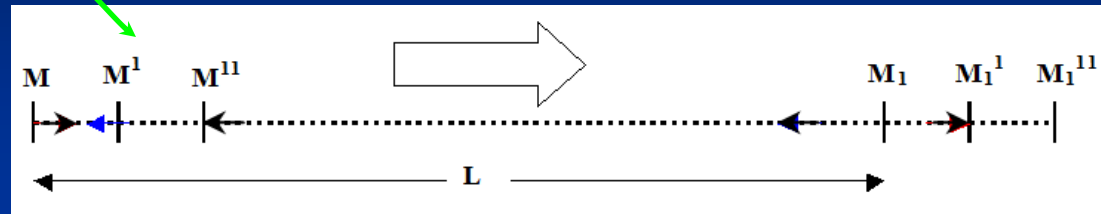
$$t_1 = \frac{2\left[L^2 + \left(v \frac{t_1}{2}\right)^2\right]^{1/2}}{c}$$

$$t_1 = \frac{2L}{c} \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Details of the Michelson–Morley Experiment



For Ray 1:



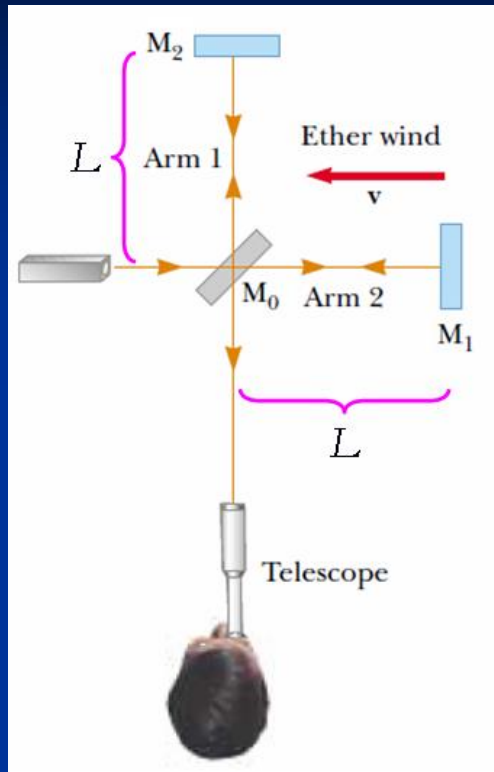
The time of travel to the right is $L/(c - v)$, and the time of travel to the left is $L/(c + v)$.

The total time needed for the round trip is,

$$t_2 = \frac{L}{c + v} + \frac{L}{c - v}$$

$$t_2 = \frac{2L}{c} \left[\frac{1}{1 - \frac{v^2}{c^2}} \right]$$

Details of the Michelson–Morley Experiment



Thus, the time difference between the horizontal round trip and the vertical round trip is,

$$t_2 - t_1 = \frac{2L}{c} \frac{1}{\left(1 - \frac{v^2}{c^2}\right)} - \frac{2L}{c} \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

If the ether wind exists, this time difference is not zero !

This time difference between the two instants at which the reflected beams arrive at the viewing telescope gives rise to a phase difference between the beams, producing an interference pattern when they combine at the position of the telescope.

Details of the Michelson–Morley Experiment

The instrument used by Michelson and Morley could detect shifts as small as 0.01 fringe. However, it detected no shift whatsoever in the fringe pattern. Since then, the experiment has been repeated many times by different scientists under a wide variety of conditions, and no fringe shift has ever been detected. Thus, it was concluded that the motion of the Earth with respect to the postulated ether cannot be detected.

The stage was set for Einstein, who solved the problem in 1905 with his special theory of relativity.

Special Theory of Relativity

In the previous section we noted the impossibility of measuring the speed of the ether with respect to the Earth. Einstein proposed a theory that boldly removed these difficulties and at the same time completely altered our notion of space and time. **He based his special theory of relativity on two postulates:**

What is a
Postulate
???

Statement	Validity
Postulate	True without requirement of proof.
Axiom	True without requirement of proof.

Special Theory of Relativity

What is a **Postulate** ???

1. Scientific assumptions / presuppositions for making a theory.
2. The verb “to postulate” means to assert a **claim as true, without proof**.
3. An **accepted statement without proof**.

Eg: Your parents,
The statement “ She loves me ”,

Special Theory of Relativity

Einstein's Two Postulates in STR

Postulate 01 : The Principle of Relativity:

The laws of physics must be the same in all inertial reference frames.

The laws of Physics are the same for all observers in uniform motion relative to one another.

Postulate 02 : The constancy of the speed of light :

The speed of light in vacuum has the same value, $c = 3 \times 10^8 \text{ m/s}$ in all inertial frames, regardless of the velocity of the observer or the velocity of the source emitting the light.

Measurement of Time in STR

What is Time ???



Time is the indefinite continued progress of **existence** and **events** that occur in apparently **irreversible** succession from the **past** through the **present** to the **future!**

Measurement of Time in STR

What is Time ???

Time is a component quantity of many measurements used to sequence events, to compare the durations of events and the intervals between them, and to quantify rates of change of quantities in material reality or in the conscious experience.

The fundamental unit of time in the International System of Units (SI) is the second (symbolized s or sec).

One second elapses during the occurrence of exactly 9,192,631,770 (9.192631770×10^9) cycles of the radiation produced by the transition between two levels of the cesium 133 atom.

Measurement of Time in STR

What is Time ???



The Gap between **two events** is called Time (difference) !
– Lord Buddha!



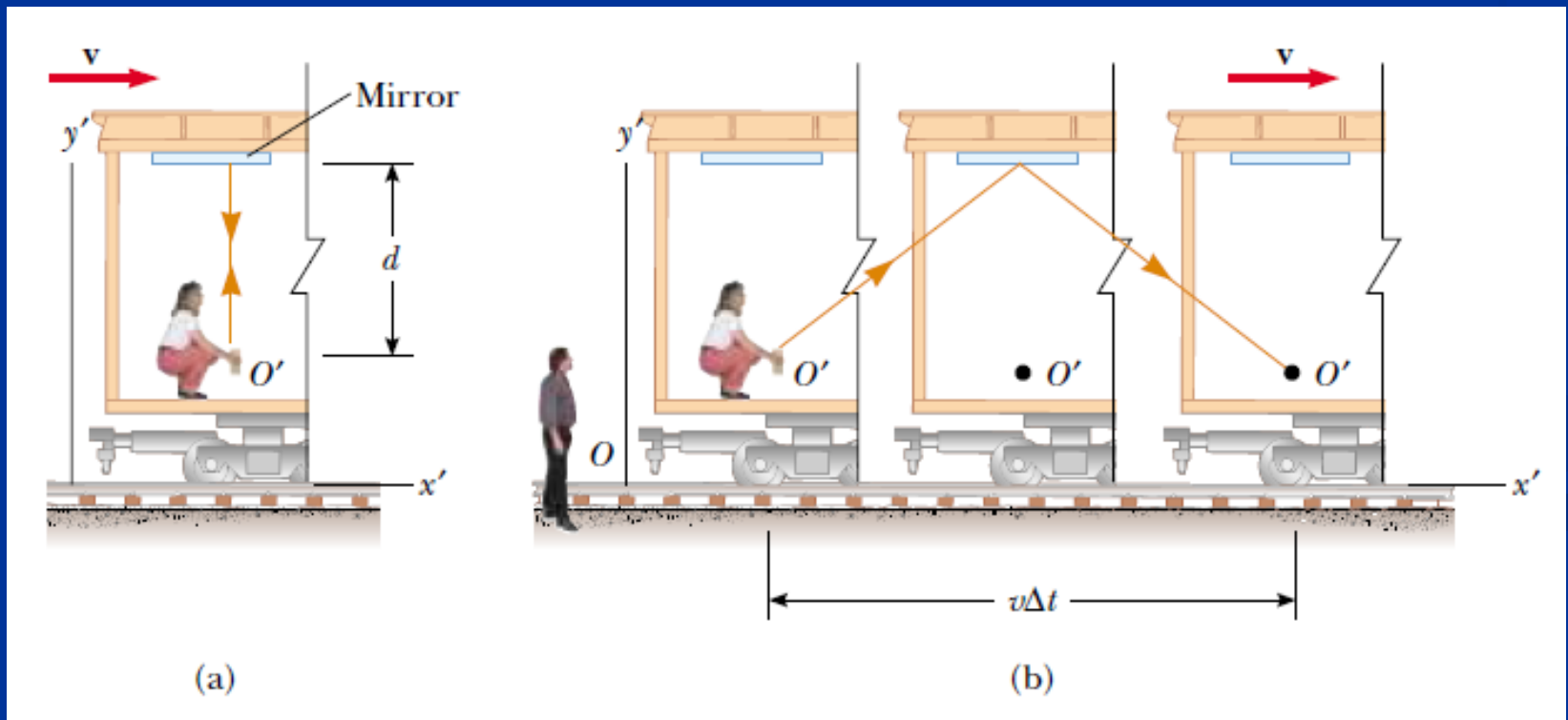
There is no belief in a personal god. Buddhists believe that nothing is fixed or permanent and that change is always possible. The path to Enlightenment is through the practice and development of morality, meditation and wisdom.

Buddhists believe that life is both endless and subject to impermanence, suffering and uncertainty. These states are called the *tilakhana*, or the three signs of existence. Existence is endless because individuals are reincarnated over and over again, experiencing suffering throughout many lives.

Measurement of Time in STR

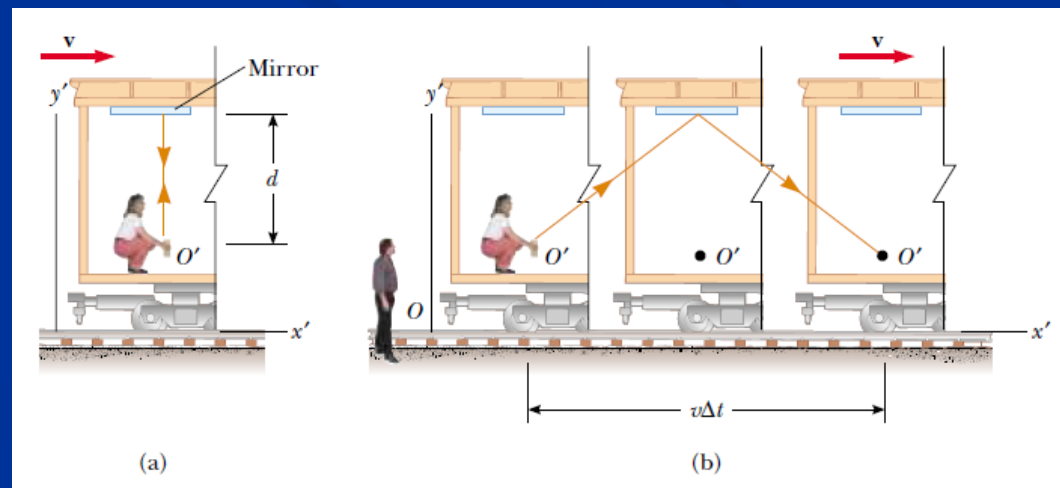
Now consider the same pair of events as viewed by observer O in a second frame, as shown in **Figure b**.

According to this observer, the mirror and laser are moving to the right with a speed v , and as a result the sequence of events appears entirely different.

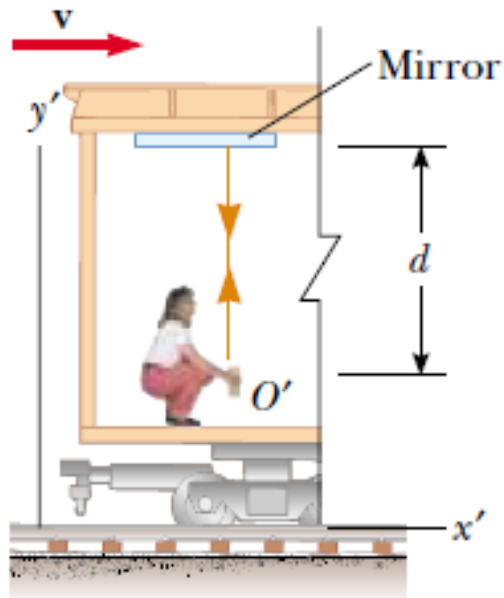


Measurement of Time in STR

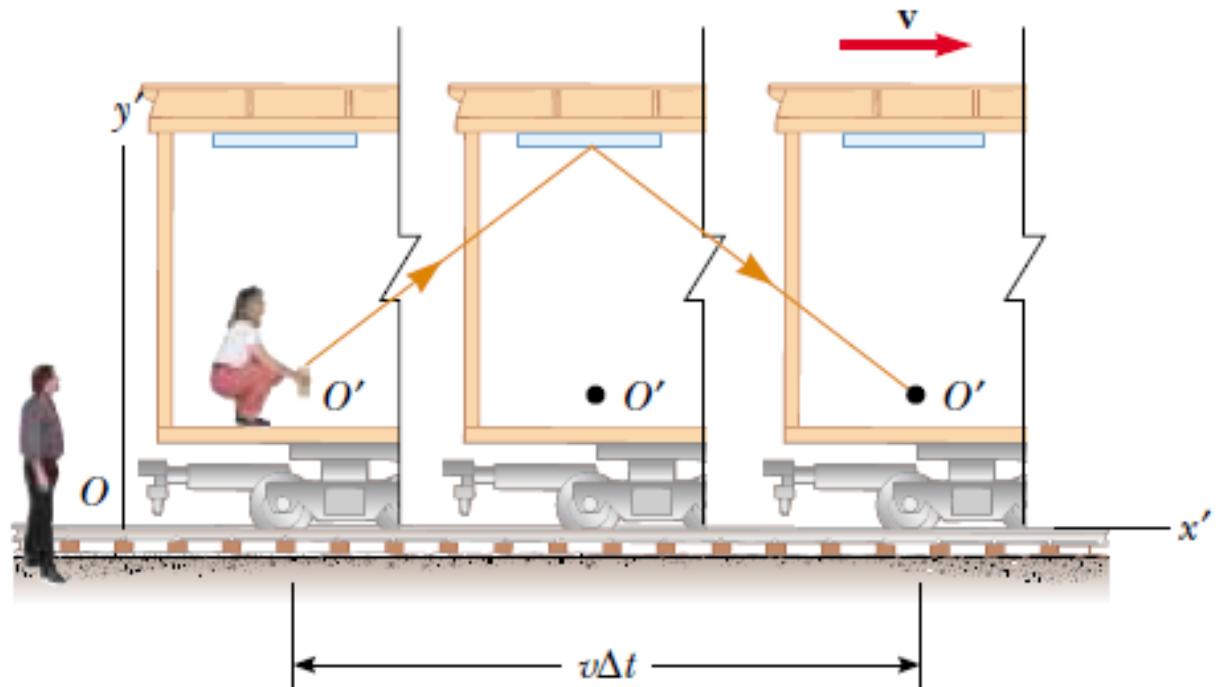
By the time the light from the laser reaches the mirror, the mirror has moved to the right a distance $v (\Delta t_o/2)$, where Δt_o is the time it takes the light to travel from O' to the mirror and back to O' as measured by O . In other words, O concludes that, because of the motion of the vehicle, if the light is to hit the mirror, it must leave the laser at an angle with respect to the vertical direction. Comparing Figure a and Figure b, we see that the light must travel farther in (b) than in (a).



Measurement of Time in STR

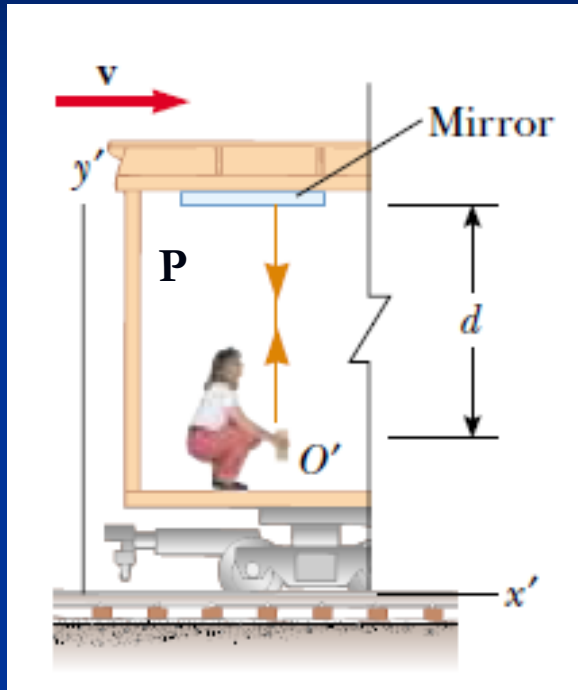


(a)



(b)

For the Observer, P on the vehicle :

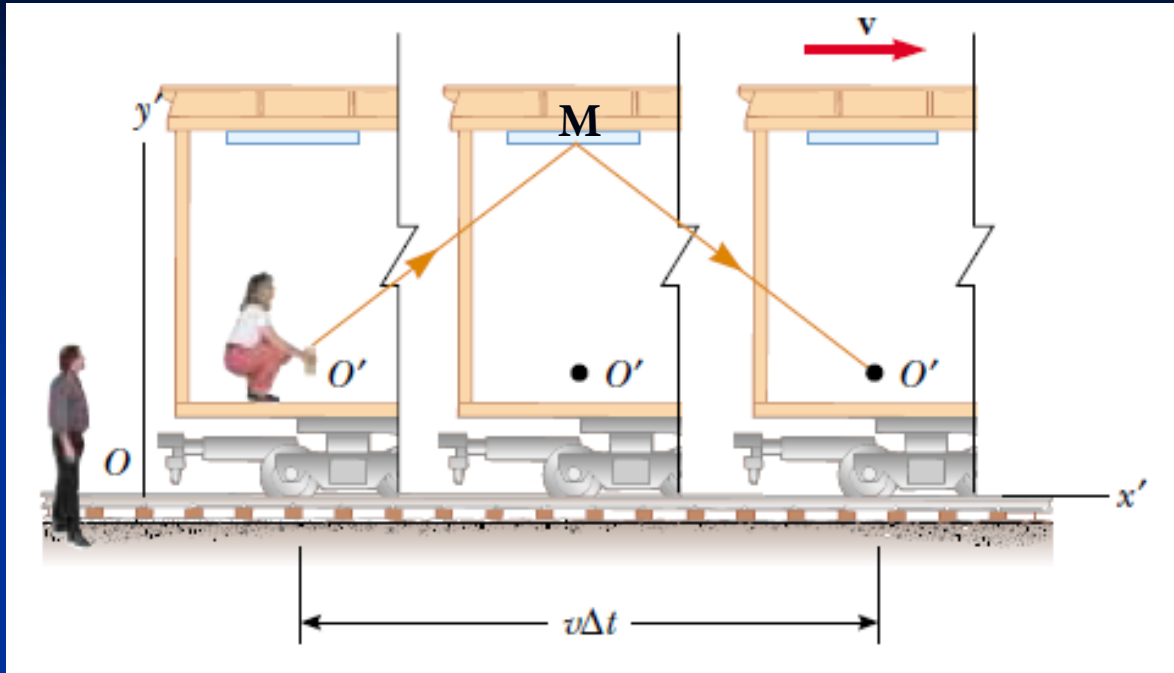


In the frame where the clock is moving, the light pulse traces out a path of length $2d$ and the period of the clock is $2d$ divided by the speed of light, c .

$$\Delta t_P = \frac{2d}{c}$$

where Δt_P is the time it takes the light to travel from O' to the mirror and back to O' as measured by P.

For the Observer, O on the ground :



Total time for the light pulse to trace its path with respect to O.

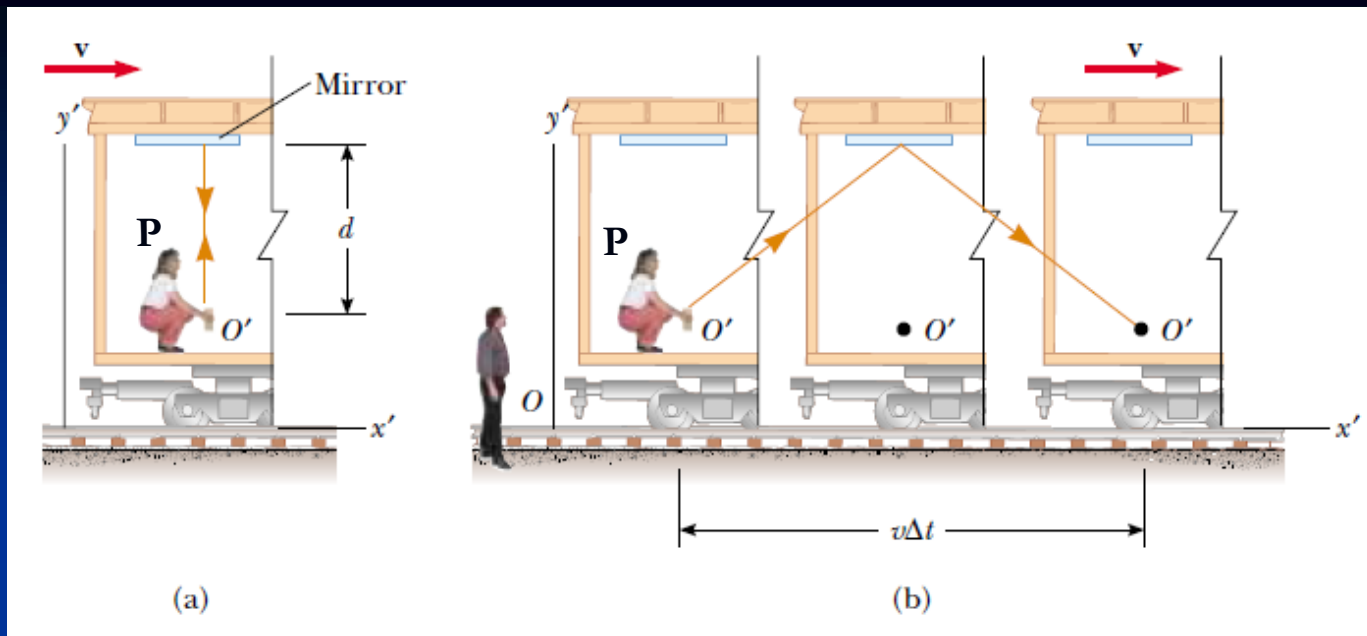
$$\Delta t_o = \frac{O^1 M O^1}{\text{velocity}}$$

(Using postulate 01)

$$\Delta t_o = \frac{2 \left(d^2 + \left[v \frac{\Delta t_o}{2} \right]^2 \right)^{1/2}}{c}$$

(Using postulate 02)

$$\Delta t_o = \frac{2d}{c} \frac{1}{\left(1 - \frac{v^2}{c^2} \right)^{1/2}}$$



$$\Delta t_O = \Delta t_P \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

This equation express the fact that for the moving observer the period of the clock is shorter than in the frame of the ground observer itself !

Where, v is the Relative Speed of the Two Frames

$$\Delta t_O > \Delta t_P$$

Time interval w. r. t
the stationary frame

Time interval w. r. t
the moving frame

Time Dilation

Suppose,

$$t_2 = t_1 \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

This equation is called
relativistic time equation!

If $v > 0$



$$\frac{v}{c} < 1$$



$$\frac{v^2}{c^2} < 1$$



$$1 - \frac{v^2}{c^2} < 1$$



$$\sqrt{1 - \frac{v^2}{c^2}} < 1$$



$$t_2 = t_1 \frac{1}{(\text{< 1})}$$

$$t_2 > t_1$$

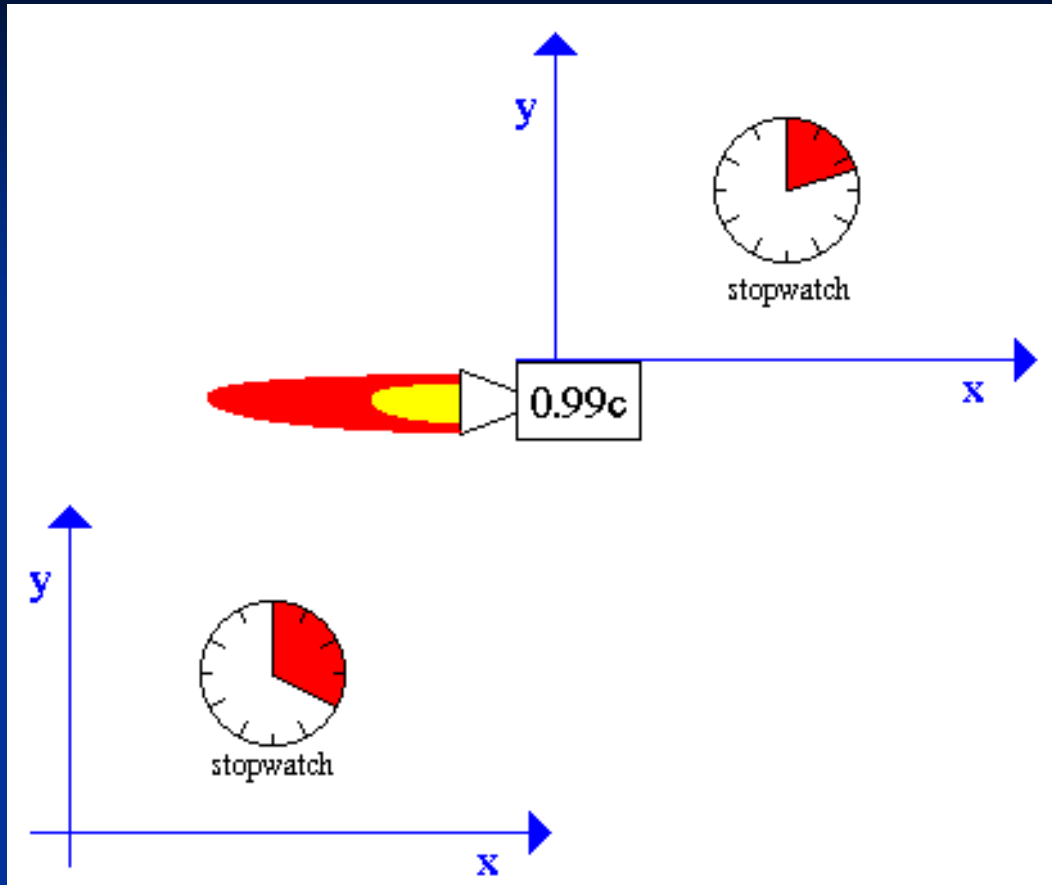
Time interval w. r. t
the stationary frame



Time interval w. r. t
the moving frame

This is called Time Dilation !

Time Dilation



Time dilation is an actual difference of elapsed time between two events as measured by observers either moving relative to each other.

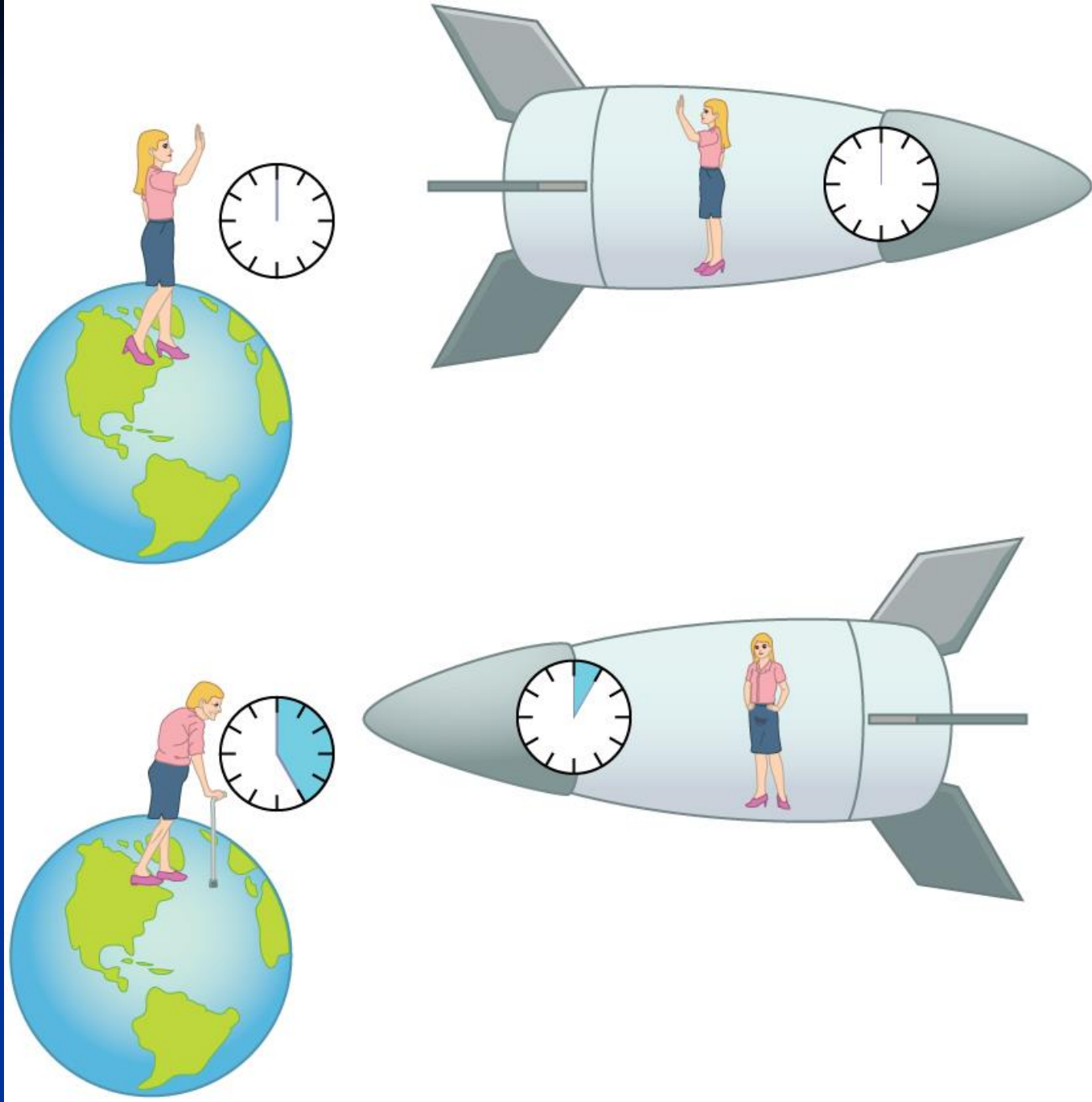
$$t_2 > t_1$$

Time interval w. r. t the stationary frame

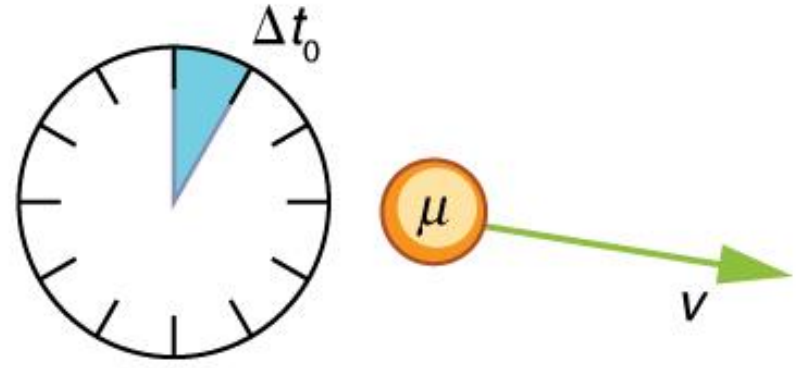
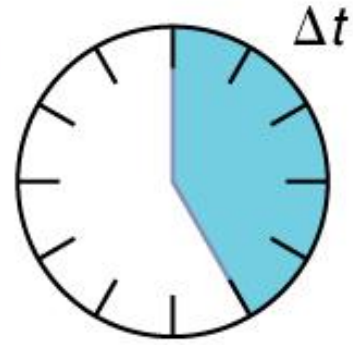
Time interval w. r. t the moving frame



Time Dilation



Time Dilation





Thank You!