How The Laser Helped to Improve the Test of Special Theory of Relativity?

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(Received: 01.12. 2012, Accepted: 05.02.2013)

Abstract

In this paper of I have reviewed the test done for validating the special theory of relativity using masers and lasers in last one century. Michelson-Morley did the first experimental verification for the isotropy of space for the propagation of light in 1887. It has an accuracy of $1/100^{th}$ of a fringe shift. The predicted fringe shift on the basis of propagation of light through ether was 0.4 but Michelson-Morley did not observe any fringe shift and came up with a negative result. Their experiment was repeated with modern and more sophisticated versions using highly monochromatic masers and lasers which have kept any ether drag to the limit of $< 1/1000^{th}$ of the earth's orbital velocity and validated the isotropy of the space to the extraordinary limit of one part in10^{15}. The necessary discussion on masers, lasers, its properties and applications with brief definition of beats is also given in this paper for the completeness of the discussion apart of the experimental method for validating the constant speed of light in different directions using masers and lasers.

Keywords: Second relativity principle, isotropy of space, laser resonators, ether drag, Michelson-Morley experiment, Thorndike experiment, cryostat

A Brief History and Introduction to Special Relativity

Far before A. Einstein postulated the constancy of speed of light in 1905, Michelson examined for the presence of absolute rest frame of ether in 1881 in which the speed of light remains invariant. It was said to have a constant value c, which might vary with the relative motion of the source and the observer in this frame following the analogy with the mechanical waves. A. A. Michelson repeated his experiment with his student E. Morley in 1887 (figure-1) and improved his accuracy to $1/100^{th}$ shift of a fringe. The negative results removed the centuries old classical conceptions of Omni present ether that was first proposed by Newton and his disciples in the early seventeenth century. The contemporary physicist of Michelson, James Clarke Maxwell gave his electromagnetic theory in 1865 twenty years earlier to Michelson when no experimental evidence was there in favor of constant speed of light. The Maxwell's electromagnetic theory argued for the existence of electromagnetic waves which travel with constant speed $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$ and it does not require any medium to propagate in. Later light was also proven to be an electromagnetic wave. There was a period of conflict between the theories of mechanics and electrodynamics. The electromagnetic theory suffered inconsistency because of disobeying the Galilean transformation. In parallel Hertz produced electromagnetic waves and proven that those travel with a constant speed c irrespective of the motion of the source or the observer. Galilean transformation fails for electromagnetic waves as it throws extra terms in the equation? In 1904 H. A. Lorentz proposed a new set of transformation equations in four-dimensional world by partially mixing and transforming the space and time co-ordinates among each other. But he lacked any deeper physical insight and consequences as Einstein had. It was Albert Einstein who proposed these transformations in form of special theory of relativity based on two fundamental postulates called principles of relativity. The first relativity principle (FRP) states that laws of physics must hold in all inertial frames of reference. The constancy of speed of light is called the second relativity principle (SRP). SRP gives a special status to the speed of light (Singh, 2012), (Singh, 2009), (Singh, 2011). Thus Einstein has discarded the existence of any universal rest frame of ether by giving a constant value to the speed of light. Special theory of relativity hammered the foundations of classical concepts by stating that the mass and length are no longer universal constants for a body but must depend on the relative motion of the object and the observer. The pace of time also depends on the relative motion of the clocks. Fortunately, the Lorentz transformations were in favor of electromagnetic theory. The Maxwell's equations for electromagnetic waves are invariant under Lorentz transformation. I have done this exercise to show that electromagnetic waves show Lorentz invariance. The theory of electromagnetism argued for the constant speed of light (Robert, 2000).

Maxwell's equations in differential form can be written as:

$$\nabla.E = \frac{\rho}{\varepsilon_0}, \nabla.B = 0, \nabla \times B = \mu_0 \left[j + \frac{\varepsilon_0 \partial E}{\partial_t} \right] \text{ and } \nabla \times E = -\frac{\partial B}{\partial t} \tag{1}$$

The spatial components of the above vector equation can be written as:

$$\frac{\partial E_z}{\partial y} - \frac{\partial E_y}{\partial z} = -\frac{\partial B_x}{\partial t};\ \frac{\partial E_x}{\partial z} - \frac{\partial E_z}{\partial x} = -\frac{\partial B_y}{\partial t};\ \frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y} = -\frac{\partial B_z}{\partial t} \tag{2}$$

This gives,

$$\frac{\partial B_x}{\partial t} + \frac{\partial B_y}{\partial t} + \frac{\partial B_z}{\partial t} = 0 \tag{3}$$

The one set of variables (*x*, *y*, *z*, *t*) in frame ∑ is related to another set of variables in frame ∑' moving with velocity v along X-axis with respect to the rest frame ∑ and is given by Lorentz transformation:

$$x' = \gamma(x - vt), y' = y, z' = z \text{ and } t' = \gamma\left(t - \frac{vx}{c^2}\right) \tag{4}$$

We have

$$\frac{\partial}{\partial x} = \frac{\partial x'}{\partial x}\frac{\partial}{\partial x'} + \frac{\partial y'}{\partial x}\frac{\partial}{\partial y'} + \frac{\partial z'}{\partial x}\frac{\partial}{\partial z'} + \frac{\partial t'}{\partial x}\frac{\partial}{\partial t'} \tag{5}$$

From Lorentz transformation equations:

$$\frac{\partial x'}{\partial x} = \gamma \equiv \left[1-\left(\frac{v}{c}\right)^2\right]^{1/2}, \ \frac{\partial y'}{\partial x} = 0, \ \frac{\partial z'}{\partial x} = 0 \text{ and } \frac{\partial t'}{\partial x} = -\frac{\gamma v}{c^2} \tag{6}$$

Now

$$\frac{\partial}{\partial x} = \gamma\left(\frac{\partial}{\partial x'} - \frac{v}{c^2}\frac{\partial}{\partial t'}\right), \ \frac{\partial}{\partial y} = \frac{\partial}{\partial y'}, \frac{\partial}{\partial z} = \frac{\partial}{\partial z'} \text{ and } \frac{\partial}{\partial t} = \gamma\left(\frac{\partial}{\partial t'} - v\frac{\partial}{\partial x'}\right) \tag{7}$$

$$\frac{\partial E_x}{\partial z} - \frac{\partial\left[\gamma\left(E_z + vB_y\right)\right]}{\partial x'} = \frac{\partial \gamma\left(B_y + \frac{vE_z}{c^2}\right)}{\partial t'} \tag{8}$$

And

$$\frac{\partial E_x^{'}}{\partial z'} - \frac{\partial E_z^{'}}{\partial x'} = -\frac{\partial B_y^{'}}{\partial t'} \tag{9}$$

On comparison we get

$$E_x^{'} = E_{x'} B_y^{'} = \gamma\left(B_y + \frac{vE_z}{c^2}\right) \text{ and } E_z^{'} = \gamma\left(E_z + vB_y\right) \tag{10}$$

These equations are exactly the transformations for the electromagnetic field components obtained using relativity. So, the electromagnetic waves show Lorentz invariance.

Because of the earlier discussed reasons, the second relativity principle has been tested again and again with newer and more sophisticated instruments. More than four hundred experiments have been performed to test the constancy of the speed of light till last decade and fortunately the premises of the special theory of relativity still stand unparallel. It has been a very intriguing question since Einstein

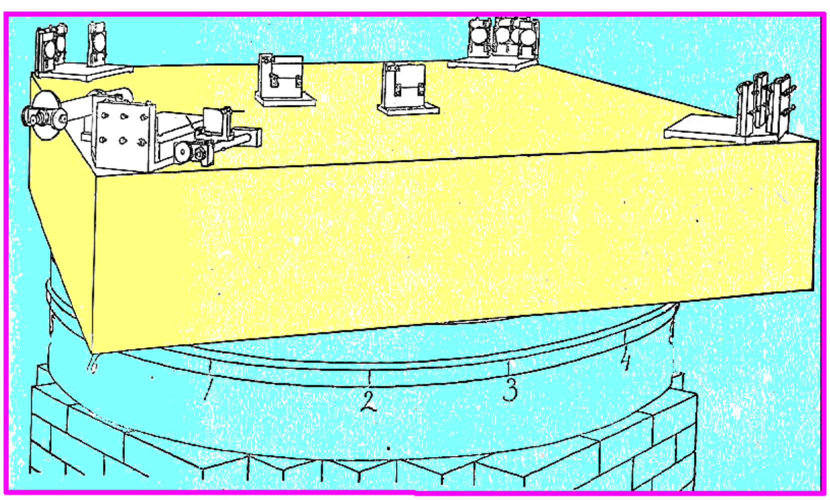


Figure 1. *Ray diagram of set up of original Michelson-Morley experiment is as shown in the figure. They placed their interferometer arrangement over a slab of stone floating on mercury. They have holders that could fix the rotation in particular direction.*

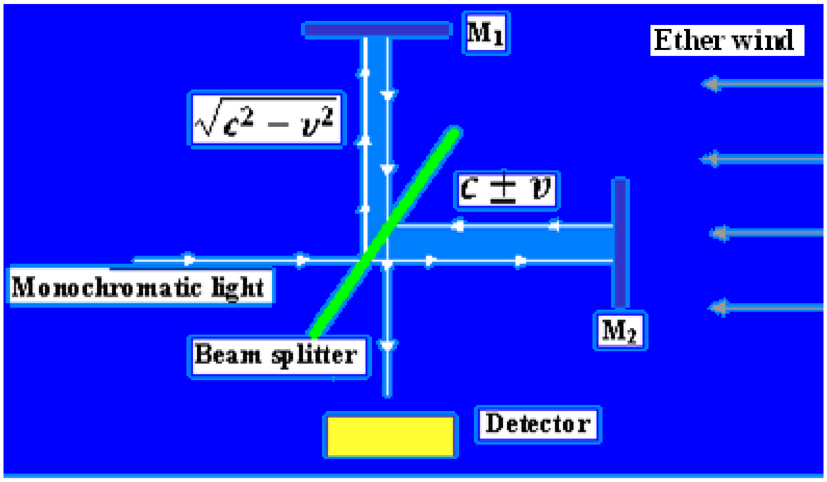


Figure 2. *Speed of light along two different directions alongside the stream of the ether and one across the stream.*

published his special theory of relativity in 1905 and the isotropy of the space for the propagation of light has been proven to be true with the accuracy of one part in 10^{15}. The constancy of the speed of light is directly related to the isotropy of the space because for anisotropic space the speed of light must vary. When C. H. Town invented MASER (Microwave Amplification by Stimulated Emission of Radiation) he decided to test the speed of light (i.e. electromagnetic waves) using infrared and light maser in place of light as it was in the case of Michelson-Morley experiment because the maser is highly monochromatic radiation which allows for more accurate measurements. Even the early versions of the maser-based interferometers gave three times better results than Michelson-Morley experiment (figure-2). In fact, Ali Jawan and C. H. Towns were the first to do the more precise Michelson-Morley experiment (Townes, 1964). Highly monochromatic frequencies of optical and infrared maser allows for very sensitive detection of any change in distance travelled by light in round trip- one along the direction of the orbital velocity of the earth and that one perpendicular to the earlier. The experiments done with highly monochromatic maser and laser have proven that there is no anisotropy in space for the propagation of light in different directions and no effect of any ether drift larger than $1/1000^{th}$ of the small fractional term $(v/c)^2$ associated with the earth's orbital velocity through ether is possible. A brief introduction to lasers and its applications can be cited to validate the Second Relativity Principle i.e. the constancy of speed of light as below.

Introduction to the Laser

Year 2010 marked the 50^{th} anniversary of the creation of Laser. Stimulated emission was first theoretically predicted by A. Einstein in 1917 when he introduced the term for stimulated emission. Charles H. Townes (the father of Maser) won the Nobel Prize for pioneering the concept which led to Laser phenomena. In 1960, Theodore Maiman, a physicist at Hughes Research Laboratory constructed the first Laser of visible wavelength. Laser is supposed to be one of the best 100 inventions of man. The invention of the laser, which stands for light amplification by stimulated emission of radiation, can be dated to 1958 with the publication of the scientific paper, *Infrared and Optical Masers*, by Arthur L. Schawlow, then a Bell Labs researcher, and Charles H. Townes, a consultant to Bell Labs. That paper published in the *Physical Review* journal of the American Physical Society, launched a new scientific field and opened the door to a multibillion-dollar industry. Maser (Microwave Amplification by Stimulated Emission of Radiation) was invented first (Singh, 2010). In 1960, Theodore Maiman, a physicist at Hughes Research Laboratory constructed the first Laser of visible wavelength. Laser is a nearly monochromatic and coherent beam of photons (figure-3).

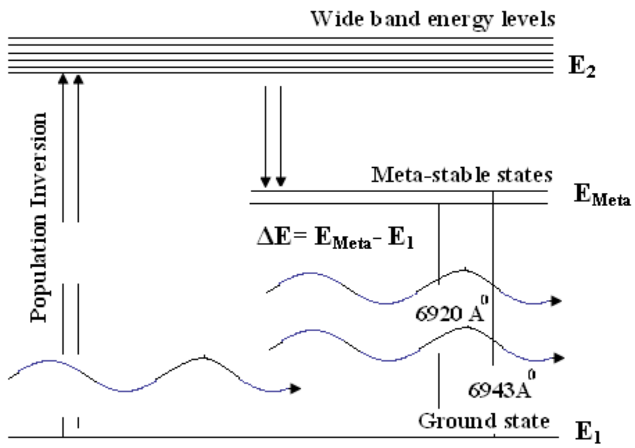


Figure 3. *Schematic sketch of lasing phenomenon in Ruby Laser*

It has a property of spatial and temporal coherence by virtue of which it does not spread even traveling thousands of kilometers and the light signals remain in phase and are not distorted in any manner (figure-4). The most stringent test of the coherence of lasers can be learnt by citing the example of Apolo-11 mission to moon in which laser signals were sent to moon and reflected rays were received on earth station. It has established the earth-moon distance with an extraordinary accuracy of < 10 cm. A schematic diagram is shown to represent laser phenomenon for recalling it in brief (White, 1981).

$$\Delta\Phi = \Phi(x_1, t) - \Phi(x_2, t) = Const\ or\ 0 \quad \text{i.e. Spatial Coherence}$$
$$\Delta\Phi = \Phi(x, t_1) - \Phi(x, t_2) = 0 \quad \text{i.e. Temporal Coherence}$$

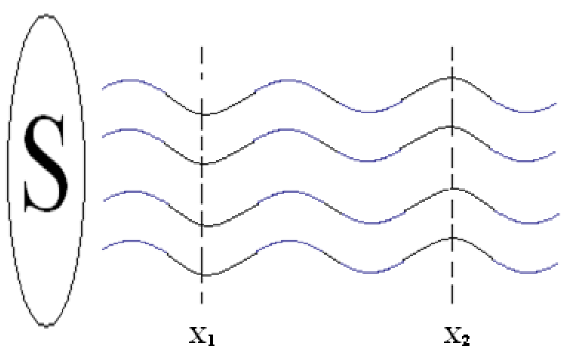


Figure 4. *The spatial and temporal coherence of lasers*

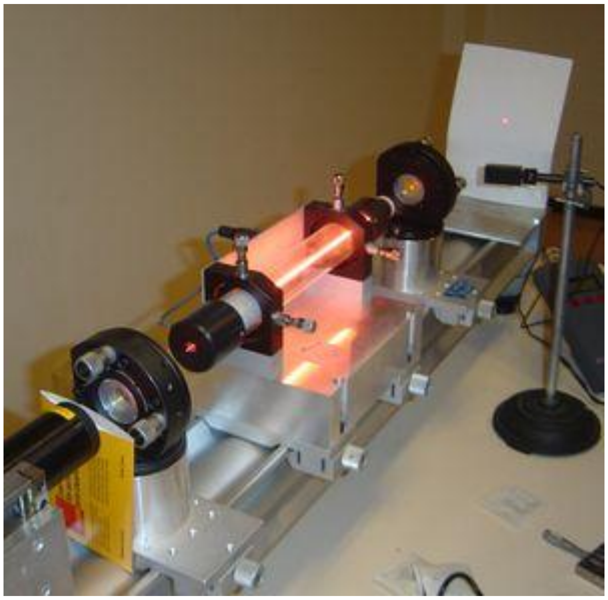


***Figure 5**. The He-Ne laser set up*

Some important commercial applications of Laser:

- Laser can check out our groceries (reading bar codes). These bar codes help to check the genuinity of the items and the price and other related information can also be encoded and read using laser devices.
- It can read or write CDs and DVDs. The memory devices work on flip-flop techniques of spins or their domains. These spin states are used to code the message. When matching quanta of some radiation preferably laser falls on such domains it changes the spin states and allows us to read and write the messages.
- It can guide commercial aircraft. The laser properties of maintaining its coherence to longer distances are very beneficial for guiding commercial aircrafts with more safety.
- Laser can guide for eye surgery and for dental repairs. The laser has drastically improved the diagnosis and micro surgery methods and has emerged as new area in medical sciences. Where as it's intense, narrow and focused beams can break the gall bladder stones, the infra red radiations can help in mapping the diseased part of any organ of the body including brain.
- Laser (based communication) is used for transmitting and receiving information/data packets using optical fibers with a much faster speed of light.
- Laser printers are used for quality and faster printing jobs. Laser is directed on a charged rotating drum coated with selenium. It makes the exposed region neutral because of photoconductivity principle as per the digitally encrypted image of the original data/page to be xeroxed. The toner particles (i.e. ink of the printer) are punched on to the charged area and a duplicate comes out on paper.
- It is used for cutting metal sheets. A 2 kilowatts laser (power used by your hair dryer) can cut through 1 inch of carbon steel.
- Laser guns and laser directed bombs have been developed using which one can accurately target and destroy the target in a fraction of seconds.
- More recently American scientists have started projects for inducing and controlling fusion of hydrogen atoms using high energy intense extremely narrow pencil beams of lasers.

Some important research applications of Laser:

- In the initial phase of its inventions the laser concept was not taken very seriously. Most of the scientist could only guess its dark side of the applications as beam of death rays. In the 1960s there occurred a huge expansion in laser research which included the development of high-power gas lasers (figure-5), chemical lasers and semiconductor lasers. The entire fundamental field of cold atoms would never have opened up without the advent of lasers. Research in this area has led to the several discoveries including Bose–Einstein condensates (BEC). The lasers have become indispensible research tools.
- Dye lasers can be tuned over a nearly continuous range of frequencies. The laser spectroscopy requires a continuous range of frequency and the absorption occurs when the frequency matches the energy gap. Laser spectroscopy has advanced the precision measurement of the spectral lines. This has enriched our fundamental understanding of basic atomic processes. This precision is obtained by passing two laser beams through the absorption sample in opposite directions. This selectively triggers absorption only in those atoms that have a zero velocity component in the direction of the beams. This eliminates the Doppler broadening of spectral lines efficiently from the distribution of atomic velocities present in the sample.
- Laser interaction with matter at quantum levels have become important probe in research. They can be used to follow chemical reactions and elucidate structure at the atomic and molecular scale giving information about the back bone chain, functional groups and the presence of other radicals. Life scientists are also employing lasers in new types of microscopy designed to highlight cellular structures.
- The Scientists at University of St Andrews, New Zealand have developed laser optical tweezers to manipulate biological cells to contribute to the burgeoning area of bio-photonics. Several UK research groups have developed a new semiconductor laser called the quantum cascade laser, which can be an excellent source of terahertz radiation (between infrared and microwaves). It can be introduced for national security screening. New laser technology will also play a role in developing the all-optical computer.
- Fibre lasers can be made to emit low-power light allowing physicists to manipulate single photons. These are required for fundamental experiments aiming to development of the concept of quantum computing which would allow the processing of unbelievable amounts of data several thousands of order more than the present day. It would also improve the quantum cryptography offering an ultra-secure means of transmitting data.
- In this paper we have already an ongoing discussion of the masers and laser that how these have helped to improve the test of special theory of relativity. In fact laser and special relativity both are listed among the 100 top discoveries of last century. It is interesting to learn that one has helped to improve the other. The validation of special theory of relativity proves the important role of the application of the laser in the development of science.

The Beat Frequency

Let us consider two waves given by:

$$y_1 = aSin(\omega_1 t - k_1 x) \quad (11)$$

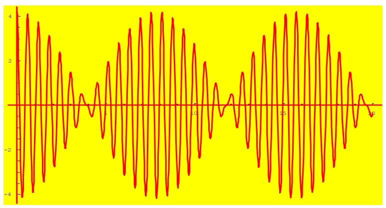
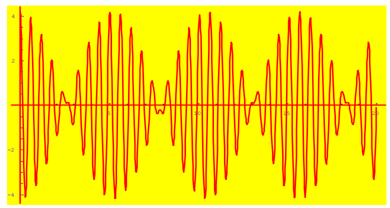
$$y_2 = aSin(\omega_2 t - k_2 x) \quad (12)$$

According to the superposition principle, the resultant displacement caused by the two waves will be the vector sum of displacement caused by the two waves at any point in space which gives,

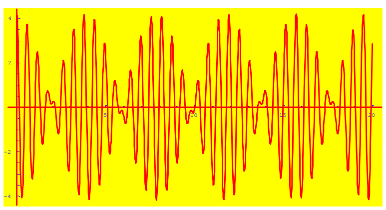
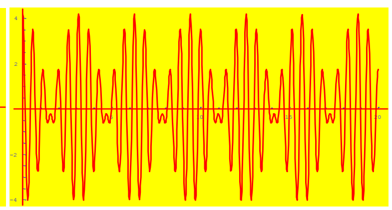
$$y = y_1 + y_2 = 2aSin[(\omega + \omega_2)t/2 - (k_1 + k_2)x/2] \times Cos[(\omega_1 - \omega_2)t/2 - (k_1 - k_2)x/2] \quad (13)$$

It can be written as-

$$y = ASin[\omega_{av}t - k_{av}x] \quad (14)$$

(a) (b)

(c) (d)

Figure 6. *The superposition of two waves of angular frequencies $\omega_1 - \omega_2$ with a) 8% b) 12% c) 16% and d) 20%.*

Here A is the resultant amplitude given by- A=2 a Cos [$\Delta\omega$ t/2 – Δk x /2]. The amplitude A is a time varying function which varied very slowly in case if $\Delta\omega = \omega_1 - \omega_2$ is small. $\Delta\omega = \omega_1 - \omega_2$ i.e. $\Delta 2\pi f = 2\pi f_1 - 2\pi f_2$. $f_1 - f_2$ is called the beat frequency at a fix x. The beat frequencies with x=0 are plotted as in figure-6 for different cases of relative frequency difference. In case of audible beat tone for ear the relative frequencies should vary for more than 6% so that the fundamental and the beat tones are heard separately. This principle acts in a similar fashion for the case of light producing beats if there occurs any relative change because of the propagation of the light rays along and across the ether wind.

Experimental Method to Test The Isotropy Of Space

After learning the necessary part of laser and beat phenomenon we shall discuss its use to validate Second Relativity Principle.

In four dimensional Euclidean space and time, one can write the space time metric as,

$$ds^2 = c^2dt^2 - (dx^2 + dy^2 + dz^2) \quad (15)$$

In a rest frame at earth say- $\sum$. In another frame $\sum$ ' moving with constant velocity v along X-axis with respect to $\sum$ the metric becomes,

$$ds^2 = g_0^2 c^2 dt'^2 - \left[g_1^2 dx'^2 + g_2^2\left(dy'^2 + dz'^2\right)\right] \qquad (16)$$

The transformation between the two equations (15) and (16) which satisfies the Lorentz equation can be written as,

$$g_0 = \left[1 - \left(\frac{v}{c}\right)\right]^{1/2} a_{00} \qquad (17)$$

$$g_1 = \left[1 - \left(\frac{v}{c}\right)^2\right]^{1/2} a_{11} \qquad (18)$$

$$g_2 = \left[1 - \left(\frac{v}{c}\right)^2\right]^{1/2} a_{22} \qquad (19)$$

Here a_{00}, $a_{11}$and a_{22} represents the transformation coefficients for dt↔dt', dx↔dx' and dy↔dy' respectively. For the case of special relativity $g_0=g_1=g_2=1$. This also means that the space-time is isotropic. This condition is generally met locally. Because of this reason the invariance is also called Local Lorentz Invariance. Thus precise determination of ratios of g_0, g_1 and g_2 serves as a strong test of isotropy of the space and also validates the Local Lorentz Invariance. Any deviation from this condition breaks the Local Lorentz Invariance which means that the space-time is anisotropic for the propagation of light. The transformation of time was tested by Ives and Stilwell with an accuracy of about one part in 30 in the year 1938. They determined this

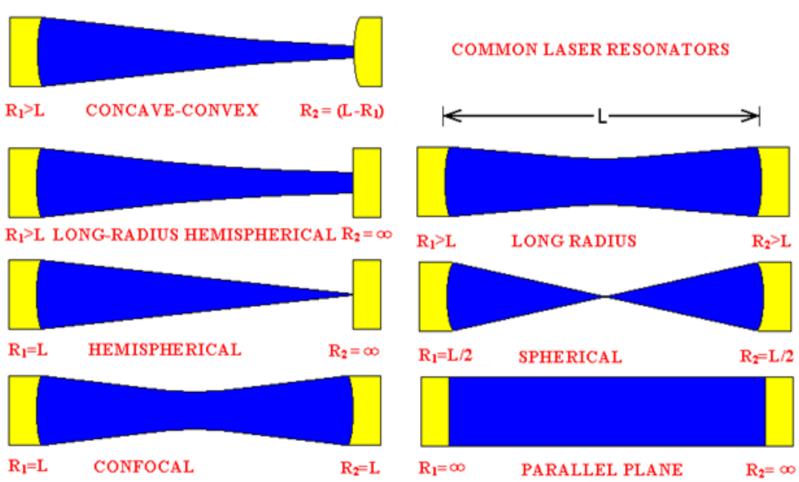


Figure 7. *Some common Laser resonators*

quantity $1 - a_{00} \equiv \frac{1}{2}\left(\frac{v}{c}\right)^2$. More high precision experiments were done with two ammonia masers mounted in two perpendicular directions – one in the direction of the orbital velocity of the earth and the other perpendicular the first one. No significant changes in the relative frequency of the two masers are observed. The beat frequency of the two masers ($\nu_1 \sim \nu_2$) also verifies the value of g_0. The improved experiments with masers have verified $1-a_{00} \equiv \frac{1}{2}\left(\frac{v}{c}\right)^2$ to an accuracy of one part in 1000.

This imposes a limit on the ether drag as it should not be more than 1/1000th of the earth's orbital velocity. The frequencies remain unchanged when two maser rays travel in two perpendicular directions and do not vary more than 1 part in 10^{12}. On the basis of ether theory one can predict a shift in relative frequencies according to the formula

$$\text{Change in two optical lengths} = 2L_0 a_{11}\left[1-\left(\frac{v}{c}\right)^2\right] - 2L_0 a_{22}\left[1-\left(\frac{v}{c}\right)^2\right]^{1/2} \qquad (20)$$

Here L_0 is the length of the Febry-Perot Etalon Interferometer. This allows one to infer that

$$a_{22} = a_{11}\left[1-\left(\frac{v}{c}\right)^2\right]^{1/2} \qquad (21)$$

The most precise experiment was done by Joos who estimated $\frac{(a_{22}-a_{11})}{a_{22}} \equiv \frac{1}{2}\left(\frac{v}{c}\right)^2$ with an accuracy of one part in 375.

The relation between the beat frequency and the term v/c can be obtained as follows- An optical or infrared maser consisting of excited atoms between two parallel reflecting planes of a cavity or a resonator oscillates with a frequency given by-

$$\upsilon = (\upsilon_c Q_c + \upsilon_a Q_a)/(Q_c + Q_a) \qquad (22)$$

Here ν_a and ν_c are the atomic and resonance frequency of the cavity. $\nu_c = n/\Delta t$. Here n is a large integer and $\Delta t=2L_0/c$ is the time taken by the round trip for light rays between two reflectors. So, $\nu_c = nc/2L_0$. Usually $Q_c >> Q_a$ so that the frequency of the maser is $\nu_c \cong nc/2L_0$ (Townes, 1964), (Anderson, 1990). If maser or laser – I is placed parallel to the streaming velocity v of the ether $\nu_c^1 = nc/2L_0$. For the maser or laser- II perpendicular to the ether streaming $\nu_c^2 = n\,c\,(1-v^2/c^2)^{1/2} / 2\,L_0$. Two such masers or lasers at perpendicular directions (figure-8) would give rise to a beat frequency as follows

$$2\left[\upsilon_c^1 - \upsilon_c^2\right] \cong \left(\frac{v}{c}\right)^2 \qquad (23)$$

$(v/c)^2$ is equal to 10^{-8}. Thus this must give a frequency change of 3×10^6 cps for infrared light of wavelength λ= 1 micron i.e. ν= 3×10^{14}. The measured frequency difference was observed as- $\frac{\Delta\upsilon_{Beat}}{\upsilon} = \pm 10^{-8}$. Dieter Hils and J. L. Hall carried out a more precise experiment by observing the sidereal variations between the frequency of a laser to an I_2 reference line and one He-Ne laser λ= 6328

A^0 locked to the resonance frequency of a highly stable cavity (Hall , 1979), (Hall, 1990). They obtained a fractional frequency shift of $\frac{\Delta \upsilon_{Beat}}{\upsilon} = \pm 2.5 \times 10^{-15}$ with 90 % confidence limit. They obtained a result 300 fold more accurate than the previously taken best measurement of Kennedy and Thorndike in 1932. They have taken the fundamental standard of length as the length of the Febry-Perot Etalon interferometer as- L_0=30.0 cm, diameter=15.0 cm. The radii of curvature in their experiment were taken as- R_1=575 cm, and $R_2=\infty$ with transmission ratio T=30 part per million (figure-7). The beat frequency is equal to $v^2/2c^2$ thus beat frequency also measures any variation of the $v^2/2c^2$ associated with the earth's orbital motion in the rest frame of the ether. Ali Javan and C. H. Town observed no anisotropy of space-time or effect of ether drag larger than 1/1000th associated with the earth's orbital velocity in the ether. The experimental determination of the ratios of g_0, g_1 and g_2 using highly monochromatic lasers has established the test of the isotropy of the space with great accuracy as one part in 10^{15}.

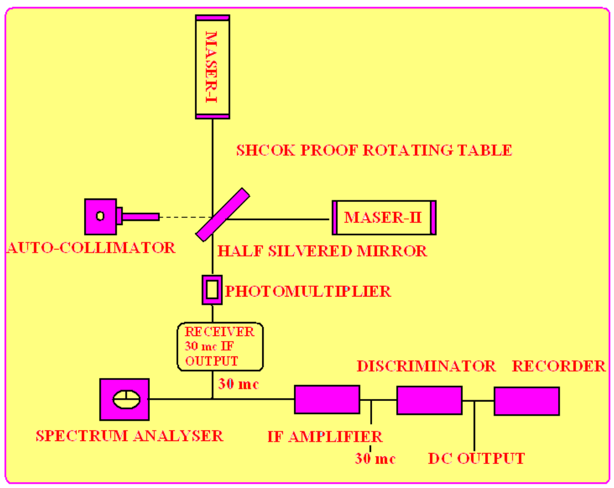


Figure 8. *The arrangement of two masers for measuring their beat frequency caused by the motion of the earth through the hypothetical ether medium.*

The fundamental quantity indicating anisotropy due to violation of Local Lorentz Invariance is the variation in the beat frequency of the two masers or lasers. The amplitude of the beat signal is modulated due to earth's rotation ω and earth's orbital motion Ω. The beat frequency can be written as the Fourier sum of the dominant contribution of the earth's angular velocity ω (Schiller, 2005), (Peters, 1997). (as follows)

$$\frac{\Delta \upsilon_{Beat}}{\upsilon} = C(t)\sin 2\omega t + K(t)\cos\ 2\omega t \quad (24)$$

$$C(t) = C_0 + C_{11}\sin\omega t + C_{12}\cos\omega t + \sin 2\omega t + C_{22}\cos 2\omega t + ... \quad (25)$$

$$K(t) = K_0 + K_{11}\sin\omega t + K_{12}\cos\omega t + \sin 2\omega t + K_{22}\cos 2\omega t + ... \quad (26)$$

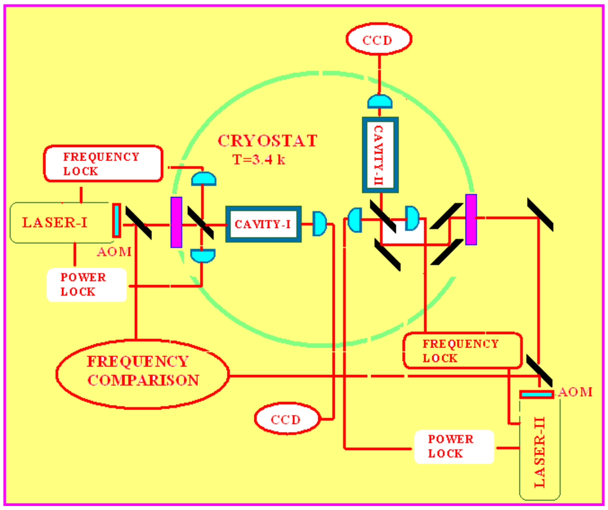


Figure 9. *More sophisticated arrangement of two lasers for measuring their beat frequency caused by the motion of the earth through the hypothetical ether medium. Uses of ultra-cold cryostat at temperature around 4 mK restrict any variation in length of the two cavities.*

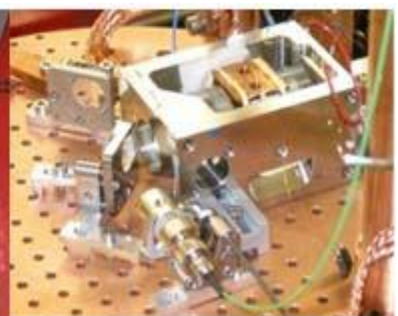


Figure 10: View of the open cryostat. The grey cylinder on the top is parts of the pulse tube cooler. Vertical size is about 1.2 m. Detail view of the optical components inside cryostat. An optical fiber (green) brings the laser light to the core (located inside the box)

Source Website for the images: http://www.exphy.uni-duesseldorf.de/ResearchInst/WelcomeFP.html

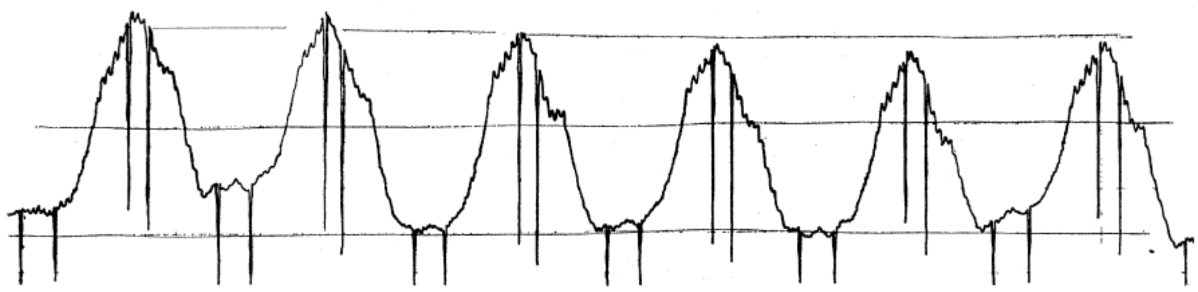


Figure 11*. A sinusoidal variation in the sampled beat frequency with sidereal rotation of one of the cavities with reference to one of the cavities fixed along the orbital motion of the earth.*

The Fourier coefficients {C_i, K_i} are determined by fitting the sampled variations in beat frequency. The anisotropy in speed of light is obtained from $\Delta c = B\left(\frac{v}{c}\right)^2 \sin^2\theta$ where θ is the direction of propagation of light with respect to the earth's orbital motion (Peters, 1997). The coefficient B is obtained from the Fourier coefficients from the beat observed using two laser resonators or cavities along and across the motion of ether.

Conclusion

Even though there have been various technical difficulties as controlling the positions and angle of rotation of the cavity, the variation in length because of minor temperature variations (controlled using ultra cold cryostat as shown in figure-9 &10) in the vicinity apart of stabilizing the laser in cavity (i.e. making the two cavity walls parallel else the laser becomes unstable in successive collisions with the glass windows and power and phase is lost) the uses of masers and lasers have restricted the anisotropy of space to 10^{-15}. It has validated the special theory of relativity with extraordinary limits and confidence. The speed of light is still an upper bound except some recent measurements done with neutrinos which have exceeded this with negligible fractions may be attributed to the mysterious fluctuations in the space time (Singh, 2009). The existence of high energy cosmic rays has also imposed strong limits on the violations of Local Lorentz Invariance as $c-1<1.5\times10^{-15}$ (Glashow, 1997). Thus the results obtained with the masers and lasers are still at the frontier edge for the verification of Local Lorentz Invariance or the validation of special theory of relativity.

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