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AN EXPERIMENT IN THE SPECIAL

THEORY OF RELATIVITY

by

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ABSTRACT. The results of an experiment conducted to test the special theory of relativity as opposed to the new-source interpretation of the emission theory are presented. The apparatus used consisted of an interferometer whose beams went through moving pieces of glass; the hypothesis being that if the velocity of light took on any of the velocity of the moving glass, then the interference fringes would shift; but if the speed of light were a constant, as the special theory of relativity predicts, no fringe shift would occur. (The pieces of glass were not thick enough to require consideration of the Fresnel dragging coefficient.) It was concluded that the results of the experiment favor relativity.
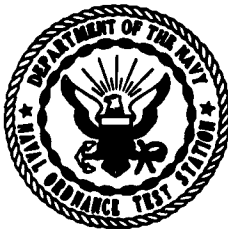
U.S. NAVAL ORDNANCE TEST STATION

China Lake, California

December 1962

FOREWORD

Results of an experiment, conducted to test the special theory of relativity as opposed to the new-source interpretation of the emission theory, are reported.

In the experiment, moving pieces of glass were caused to intercept the beams of an interferometer in order to measure the speed of light after it had traversed a moving piece of glass. The speed before and after traversing the glass was found to be very nearly the same as that predicted by the special theory of relativity.

This work, which is a part of the Station's overall study in the area of the theory of relativity, was done during the period January through May 1962 and was financed under exploratory and foundational research funds.

The report is issued at the working level for the benefit of NOTS personnel and others doing experimental work in this field.

In further exploration of the special theory of relativity, it is planned to repeat this experiment in a vacuum environment. Results will be published as soon as they are available.

F. M. ASHBROOK, Head
Instrument Development Division

Released under
the authority of
  IVAR E. HIGHBERG
Head, Test Department

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INTRODUCTION

The Ritz emission theory (Ref. 1)[*] was an attempt to explain the Michelson-Morley experiment without assuming that the velocity of light is independent of its source. There are several different interpretations of this theory, but the one that we are primarily concerned with is the new-source interpretation. This interpretation of the Ritz theory states that when light interacts with matter, the light takes on some or all of the velocity of the matter (see Fig. 1). Thus, when light goes through moving glass, it would take on the velocity of the glass. This is in direct contradiction to Einstein's theory of special relativity which says that the speed of light, after passing through a medium, is independent of the velocity of the medium.
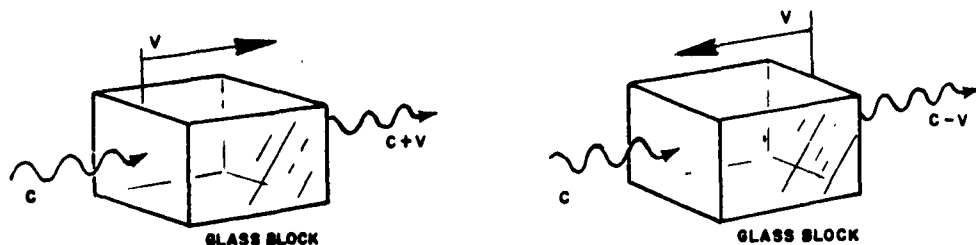
FIG. 1. Diagram Demonstrating Ritz Emission Theory.

Several experiments have been performed to determine the merits of the relativity and emission theories (Ref. 2, p. 240). Some of the experiments have involved moving sources and moving mirrors (Refs. 3, 4, 5). The results of all known experiments favor the relativity theory over the emission theory.

However, the experiment reported here was undertaken as the result of information from Wallace Kantor (Ref. 6), who reported that he had obtained experimental confirmation of the emission theory. After Mr. Kantor's apparatus had been observed in action, it was decided that the experiment should be considered in detail and NOTS was fortunate enough to obtain the use of most of Mr. Kantor's apparatus for this study.

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[*]The author has not seen this reference. It was obtained from "Some Emission Theories of Light" by R. C. Tolman printed in the PHYS REV, 35, 136 (1912); A History of the Theories of Aether and Electricity, the Modern Theories, by Sir Edmund Whittaker, Thomas Nelson and Sons, Ltd., New York and London, 1953.

The effect predicted by the emission theory should not be confused with the effect of the Fresnel dragging coefficient which is explained by relativity. For an explanation of the Fresnel dragging coefficient see any text on relativity (also Ref. 7, p. 396). The emission theory says that the speed of light after traversing a moving piece of matter is a function of the velocity of the matter; the Fresnel dragging theory says that the speed of light inside the moving matter is a function of the velocity of the matter. In this experiment the pieces of glass were so thin that the Fresnel dragging coefficient could be neglected.

THEORY OF THE INTERFEROMETER

An interferometer of the general type used in this experiment is shown in Fig. 2. The light is divided into two interfering beams, one being reflected and the other being transmitted by the beam splitter. The two beams travel the same path in opposite directions, until they again reach the beam splitter where they are reunited. Both beams then travel in approximately the same direction to the telescope where the interference fringes are observed.
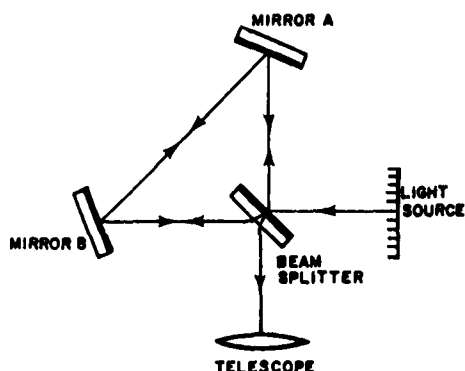
FIG. 2. Diagram of the General Type of Interferometer Used in This Experiment.

The first interferometer to use interfering beams traveling in opposite directions over the same path was by Fizeau (Ref. 8). The Fizeau form was a wavefront division type of interferometer. However, Michelson used a form with amplitude division that is very much the same as the one used in the present experiment (Refs. 9, 10, and 11).

The fringes observed may be classified into two types: real fringes and virtual fringes (Ref. 12). By a real fringe system, we mean a system that can be observed by intercepting the light beam with a screen as contrasted to the virtual fringe system which cannot be so observed. To observe the virtual fringe system, a lens must be used to form a real image. The real fringes are obtained mainly from point or slit light sources and are in focus over a wide range of distances from the source. Virtual

fringes are obtained from an extended light source such as an illuminated frosted glass and, in the case of this interferometer, are observed when the telescope is focused at infinity.

When the source is a slit, the view seen in the telescope (with the telescope focused on the slit) will be two slits which may fall on top of each other. The separation of the slits is determined by the angle of the beam splitter. This arrangement gives the classical situation for Young's experiment (Ref. 7, p. 237) as shown in Fig. 3. The distance from the center of the pattern to the bright fringes is given by $x = m\lambda D/d$, $m = 0,1,2,3, \ldots$ where x, D, and d are given in Fig. 3 and λ is the wavelength
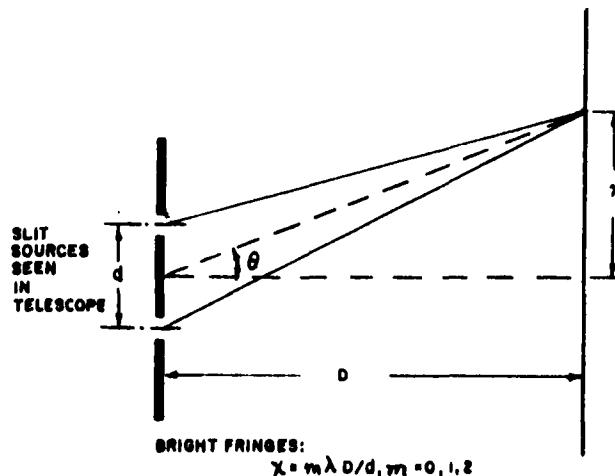
FIG. 3. Young's Experiment.

When the source is extended, as with an illuminated frosted glass, the fringes are in focus at infinity (or localized at infinity) and are fringes of equal inclination (Ref. 13, p. 282). This is true since a lens system focused at infinity will bring all light beams having the same angle with the optic axis to the same point on the image. Fringes of equal inclination may also be seen using a point or slit source if the telescope is focused at infinity.

Two major differences between extended and slit source fringes are important in this experiment: First, more light gets through the system to the photographic material when an extended source is used. Second, the fringes will be less disturbed by inhomogeneities of the transparent medium across the light path since light from the extended source takes many paths to reach each point of the image. Thus, with the extended source, the fringes will be sharper and less distorted by the glass windows used in the interferometer.

MIRROR B

GLASS PLATE

MIRROR A

LIGHT
SOURCE

BEAM
SPLITTER

LENS
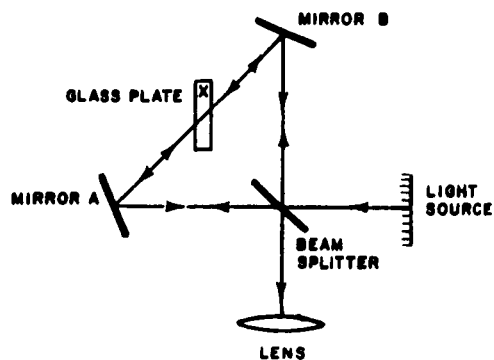
(a) SKETCH OF INTERFEROMETER WITH A GLASS PLATE

LIGHT
SOURCE

BEAM
SPLITTER

MIRROR
A

GLASS
PLATE

MIRROR
B

BEAM
SPLITTER

LENS
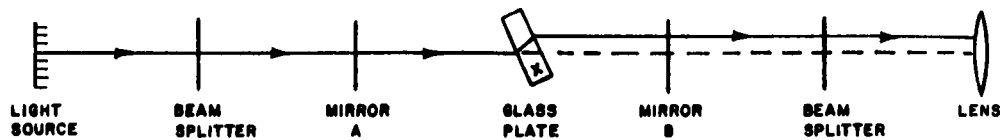
(b) RELATION OF INTERFEROMETER TO THE TRANSMITTED BEAM

LIGHT
SOURCE

BEAM
SPLITTER

MIRROR
B

GLASS
PLATE

MIRROR
A

BEAM
SPLITTER

LENS
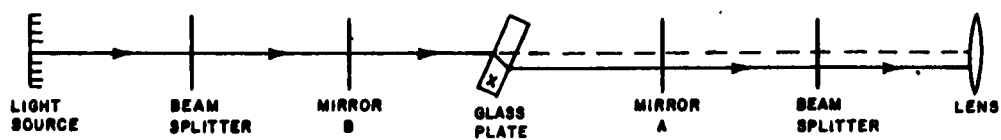
(c) RELATION OF INTERFEROMETER TO THE REFLECTED BEAM

FIG. 4. Illustrations of the Influence of a Glass Plate on the
Interference Fringes.

For this experiment we considered only interferometers with an even number of mirrors (not including the beam splitter) because an interferometer with an odd number of mirrors displaces the reflected beam from the transmitted beam so that the two interfering beams do not travel the same path.

Figure 4 illustrates the effect of an inclined glass plate on the fringes: (a) shows the location and orientation of the glass plate with respect to the rest of the interferometer; (b) and (c) show the interferometer with respect to the beam in order to illustrate the effect of the plate on each beam separately. It is apparent from these sketches that the separation of the two images of the source as seen by the observer will depend upon the inclination of the glass plate. Referring back to Fig. 3, it is seen that the separation of the images is d and that any change in d changes the width of the fringes.

Also, a fringe shift will result from placing a glass wedge instead of a glass plate in the interferometer, because both the reflected and the transmitted light beams will be displaced in the same direction.

A diagram of the actual interferometer used in this study is shown in Fig. 5. It is identical to the two-mirror interferometer described above except that it has four mirrors. Since two glass windows, separated by three reflections, are used, any effect due to an inclination of the windows is cancelled out if the windows are exactly the same thickness and mounted in parallel position.

According to the emission theory the velocity of the light beam with respect to the laboratory coordinate system will be as shown by the labeled arrows in Fig. 5. The velocity is given for only those paths where it is different from the velocity of light in a vacuum, c.
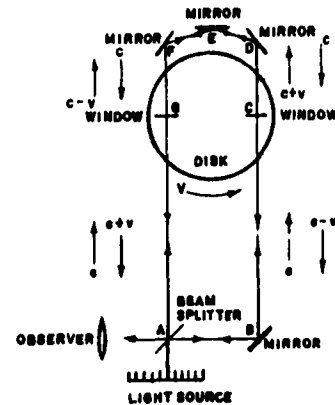
FIG. 5. Interferometer Used in This Experiment.

In the derivation of fringe shift as a function of window velocity which appears as an appendix to this report, the fringe shift expected on the basis of the emission theory is found to be $\Delta f = 2BL/\lambda$ where $B=V/C$, L is the distance from mirror B to mirror D in Fig. 5, and λ is the wavelength of light used. In this experiment B was about 1.5×10^{-7}, L was 115 cm, and (since white light was used) λ was about 5×10^{-5} cm. Thus, the expected value of Δf was about 0.7 of a fringe.

THE APPARATUS

The table used to support the mirrors in Kantor's original apparatus had a 1,500-lb zinc top to isolate the interferometer from the vibration of the motor. We found that a supporting table of one-half-inch thick aluminum could be used if the table and motor were isolated with supports of foam rubber. The mirrors and beam splitter were rather small--about 3.5 cm square--except for the middle mirror nearest the rotating disk which measured 3.5 by 7.5 cm. Three-point screw mountings were used for the mirrors to make them adjustable. The glass windows mounted on the disk were 1-cm square and the center of each window was 12 cm from the center of the disk. The electric motor was capable of a speed of 80 revolutions per second. However, the photographs were taken at 60 revolutions per second. A General Radio Strobolux driven by a Strobotac was the light source for visual observation, and a xenon flash tube driven by 60 m.f.d. at 2,000 V was the light source for the photographs. When an extended source was desired, a frosted piece of plastic was placed in front of the light source, and when a slit source was wanted, an adjustable razor blade slit was placed in front of the light source. The light source was always white light and the fringes observed were always white light fringes. A magnet embedded in the disk triggered the light source by inducing an electrical pulse in a coil of wire underneath the disk. This pulse was fed to a Tektronix 545 oscilloscope. The output of the scope fed a Beckman counter, which gave the revolutions per second; an audio amplifier drove a stepup transformer which triggered the Strobotac; and a thyratron triggered the xenon flash tube. By using the delayed trigger output of the oscilloscope it was possible to look at the disk during any phase of its revolution. The total delay of this electronic network was found to be about 100 μsec which corresponds to about 0.006 of a revolution of a disk at the highest speed used for photographs. Moving the disk by hand through a much larger arc than this made no difference in the fringes.

The telescope used was a Keuffel and Esser jig-alignment instrument with micrometer adjustments of one thousandth of an inch least count and a 4 to 46 power capability, depending upon focus.

Pictures were obtained on Polaroid 3000 speed film in a Graflex 4x5 with a ten-inch lens, by photographing through the telescope. It was possible to place the camera lens right at the eyepiece of the telescope because of the small exit pupil of the telescope.

RESULTS

SLIT LIGHT SOURCE

The original method of observation was to use a slit light source, and focus on the plane of the windows so that the field of view was cut in half by the top edge of a window. Theoretically, if rotation of the disk caused a fringe shift, then there would be a break or jog in the vertical lines of the fringes at the edge of the window, and the fringes seen through the windows would jump as the synchronization of the stroboscope was switched from the disk to the 60 cps power-line frequency. However, in actual practice, the glass windows caused a break or jog in the lines even when the disk was not rotating, apparently because the windows were either not uniform or not parallel. To determine conclusively whether or not there really was a fringe shift of the kind predicted by the emission theory, it was necessary to judge whether the amount of the jog changed as the speed of the disk changed.

Although the several observers all thought they saw the jog change with the speed of the disk, this effect was intermittent and generally associated with fringes of poor visibility. One set of photographs showed a shift in the fringes from the picture taken at zero to the one taken at 60 rps (Fig. 6). The only time this effect was observed was when the windows were the same thickness as those used by Kantor (ten-one thousandths (10/1000) inch thick microscope slide). Interposing stationary Mylar film in the interferometer path near the rotating disk did not change the fringes between zero and 60 rps as predicted by the emission theory. Since the shift was not affected by the stationary Mylar film, and since it did not appear with thicker (microscope slide or 5/32" thick optically ground glass) or thinner (Mylar film) windows, it seems safe to assume that the change in jog was due to a deformation of the windows.

Although a slight variation of jog as a function of the focus of the telescope was found, other photographs which were taken showed no difference between the fringes through the windows at 0 rps and 60 rps (see Fig. 7). The maximum jog in the fringes occurred at two points of focus: one between the slit and the first window, and the other on the other side of the slit toward infinity.

Four thicknesses of window were used at various times. Mylar film windows one thousandth of an inch thick had no affect at all on the

fringes and no jog was observed at any time when using them. Ten-thou-sandths-of-an-inch-thick microscope cover glass, specially selected by observing the fringe pattern of the light from a sodium lamp reflected from the top and bottom side of the sample, produced a jog. (However, the glass was not of good quality even though several boxes were searched.) Microscope slides thirty thousandths of an inch thick were selected in the same way as the cover glass. The jog was also apparent with the slide glass which distorted the fringes more than the cover glass be-cause the optical quality of the slide glass was inferior to that of the cover glass. Finally, good optical quality 5/32-inch glass windows were made and the fringes through these windows were almost as undistorted as with the Mylar film. The jog with these windows depended upon the adjust-ment of the beam splitter; it could be removed completely by careful ad-justment of the beam splitter.

To see how much effect an inclined glass plate would have on the fringes, one of the slide windows was removed leaving the remaining win-dow uncompensated. The fringes through the windows were shifted by 0.6 of a fringe when the disk was turned to the extremes where the window started to go out of the field of view, at between 5 and 10°.

EXTENDED LIGHT SOURCE

All of the above observations were made with fringes from a slit source. Much better quality fringes in focus at infinity were produced by an extended source, as is to be expected (see Theory of the Interfer-ometer, p. 2). For observations of fringes in focus at infinity to be meaningful, all light not going through the windows must be blocked off.

Color photographs were taken to determine the zero order of the fringes, and because the reflecting coating on the beam splitter was metallic, the zero order did not correspond exactly to either a maximum or a minimum. To make a measurement of the fringe shift using the ex-tended light source, two photographs (Fig. 8) were taken through the windows--one with the disk stationary (zero rps) and one with the disk rotating (60 rps). Microdensitometer traces were run on each photograph and the center of the fringe was determined on the tracing. The distance of the center of the dark fringe from the hairline was then measured on the trace. The results of the microdensitometer traces for each picture are presented in schematic form in Fig. 9. The table on page 10 shows how the fringe shift was calculated from the data in Fig. 9. Since the mean shift calculated is 0.006, it seems safe to assume that if more measurements were taken the mean shift would be smaller than 0.01. This figure does not seem to be too large for random error since the grain of the Polaroid film was large, the microdensitometer traces were jagged, and the measurements in the table are in inches requiring that a ruler be read to one hundredth of an inch.
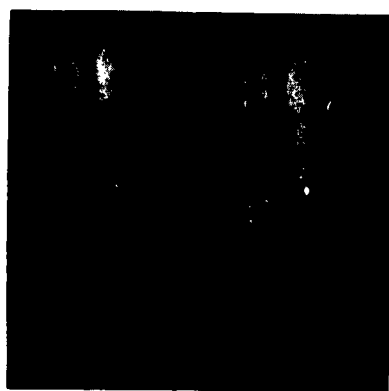
O RPS   60 RPS

FIG. 6. Fringes Obtained
With a Slit Source. The
window covers the lower
0.4 inch.
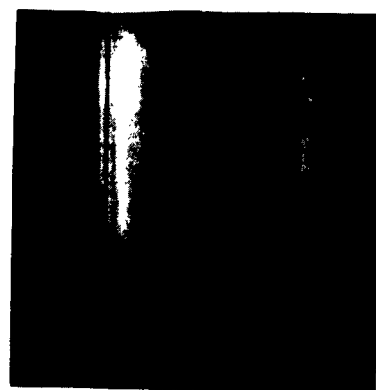
O RPS   60 RPS

FIG. 7. Real Fringes
Showing No Shift.

O RPS   60 RPS

FIG. 8. Extended Source Fringes.

9
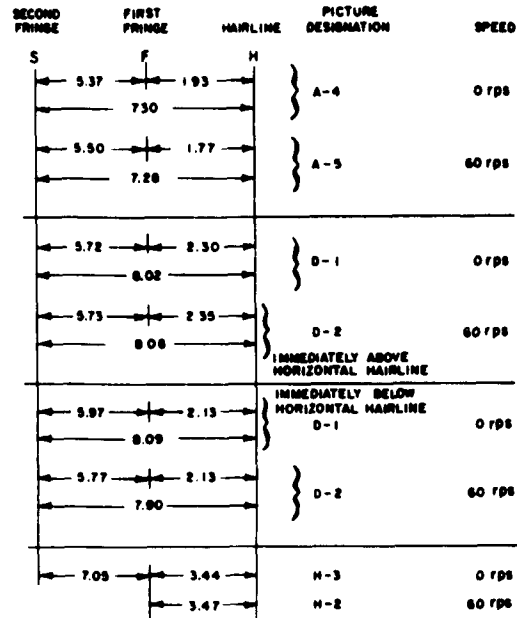
FIG. 9. Schematic of the Fringe Pictures.

Summary of Fringe Shift Calculations

Measurements	HF_0	HF_{60}	$HF_0 - HF_{60}$	FS_0	$S = \dfrac{HF_0 - HF_{60}}{FS_0}$
1	1.93	1.77	0.16	5.37	0.03
2	7.30	7.28	0.02	5.37	0.00
3	2.30	2.35	-0.05	5.72	-0.01
4	8.02	8.08	-0.05	5.72	-0.01
5	2.13	2.13	0.00	5.97	0.00
6	8.09	7.90	0.19	5.97	0.03
7	3.44	3.47	-0.03	7.05	0.00
					0.04

0.04/7 = 0.006
mean fringe shift

NOTE: HF_0 is the distance from the hairline to the fringe at zero
rps, HF_{60} is the distance from hairline to the fringe at
60 rps, FS_0 is the distance between fringes at 0 rps, and
S is the fringe shift.

Measurements 1 and 2 were made on the first and second
fringes, respectively, of photograph set A. Measurements
3, 4, 5, and 6 were made on photograph set D (see Fig. 8).
Measurements 3 and 4 were made just above the hairline,
and measurements 5 and 6 just below. Measurements 3 and
5 were of the first fringe, and measurements 4 and 6 were
of the second fringe. Measurement 7 was made on the first
fringe of photograph H.

CONCLUSIONS

The principal conclusion reached is that this experiment more nearly confirms the relativity theory than the emission theory since the emission theory predicts about a 0.7 fringe shift, the relativity theory predicts no, fringe shift, and the results from this experiment give a mean shift of approximately 0.01, which is not too large to attribute to random errors. This conclusion was reached assuming that the intermittent shift, which was observed only with the slit source and microscope cover glass windows, was due to a deformation of the rotating windows.

There are two secondary conclusions which relate to the interferometer used: (1) several conditions other than those involved in the emission theory affect the fringes, and (2) fringes from an extended source are much less affected by local inhomogeneities in the optical medium than those from a slit source, and are, consequently, clearer.

It is planned to repeat this experiment in a vacuum to explore information set forth by Fox (Ref. 14) which explains how the presence of air may invalidate most of the experiments that have supported the relativity theory. For the second experiment, the windows and mirrors of the test apparatus will be made larger to admit more light and to make the interferometer easier to align; the light paths will be made longer so that the interferometer will be more sensitive to the shift predicted by the emission theory; photographic film having greater resolution will be used; and a scanning microdensitometer of greater precision will be employed to measure the pictures.

Appendix

DERIVATION OF FRINGE SHIFT AS A FUNCTION OF WINDOW VELOCITY
ACCORDING TO THE EMISSION THEORY

The fringe shift will be determined by computing the phase dif-·
ference between the two paths of the interferometer. Several approxi-
mations will be made: First, the windows will be assumed to be thin
enough so that the Fresnel dragging coefficient, which is proportional
to the thickness of the glass, can be neglected. Second, it will be
assumed that the windows move a negligible amount compared with BD (see
Fig. 5), during the transit time of a light beam through the apparatus.
Third, the velocity of the windows squared, v^2, will be assumed negli-
gibly small compared to the velocity of light in a vacuum squared, c^2.
(To determine c, according to the theory of emission, the velocity of
the source and any matter in the path must be taken into consideration.)

The optical path is the distance light would travel in a vacuum in
the same length of time that it traverses the optical path, or

$$s = dn \tag{1}$$

where d is distance and n is the index of refraction. The optical path
may also be given as

$$s = dc/u \tag{2}$$

where c is the velocity of light in a vacuum and u is the velocity of
light over the optical path. Both c and u are given with respect to
the laboratory reference coordinate system.

Equation (2) will be used to find the optical path difference
around the two paths of the interferometer.

Since we are only interested in path difference, and since the
paths are the same over the legs of the interferometer $\overline{DE}$, $\overline{EF}$, and $\overline{AB}$
(see Fig. 5), we need not consider them. Therefore, for the transmitted
beam from A to G, $d = \overline{AG}$, $u = c$, and $s = \overline{AG}$. From G to F, $d = \overline{GF}$,·
$u = c-v$, and $s = \overline{GF}c/(c-v)$. From D to C, $d = \overline{GF}$, $u = c$, and $s = \overline{GF}$.
From C to B, $d = \overline{AG}$, $u = c-v$, and $s = \overline{AG}c/(c-v)$. So, for the part of
the beam which we are considering, the total optical path of the trans-
mitted beam is

$$s_t = \overline{GF}(c/(c-v)+1) + \overline{AG}(c/(c-v)+1) \tag{3}$$

or

$$s_t = (\overline{AG} + \overline{GF})[c/(c-v) + 1] \tag{4}$$

Since $\overline{AG} + \overline{GF} = L$,

$$s_t = L[(c/(c-v) + 1)]. \tag{5}$$

For the reflected beam from B to C, $d = \overline{AG}$ $u = c$, and $s = \overline{AG}$
From C to D, $d = \overline{GF}$ $u = c + v$, and $s = \overline{GF}c/(c+v)$. From F to G, $d = \overline{GF}$,
$u = c$, and $s = \overline{GF}$. From G to A, $d = \overline{AG}$, $u = c + v$, and $s = \overline{AG}c/(c+v)$.
Adding the above optical paths, the total optical path for the reflected
beam can be written as

$$s_r = \overline{AG}(c/(c+v) + 1) + \overline{GF}(c/(c+v) + 1) \tag{6}$$

or

$$s_r = (\overline{AG} + \overline{GF})[c/(c+v) + 1]. \tag{7}$$

Also

$$s_r = L[c/(c+v) + 1]. \tag{8}$$

Therefore

$$\Delta s = s_t - s_r = L[c/(c-v)-c/(c+v)] \tag{9}$$

$$\Delta s = \frac{Lc[(c+v) - (c-v)]}{(c-v)(c+v)} = \frac{2VLc}{c^2-v^2}. \tag{10}$$

It has been assumed that $v^2 \ll c^2$, so to a good approximation

$$\Delta s = 2LV/c. \tag{11}$$

But $V/c = \beta$, so

$$\Delta s = 2\beta L. \tag{12}$$

The fringe shift is found by dividing the optical path difference by the
wavelength, n, of the light being used. So the fringe shift is

$$\Delta f = 2\beta L/\lambda \tag{13}$$

13

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ABSTRACT CARD

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An Experiment in the Special Theory of Relativity,
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   ABSTRACT. The results of an experiment conducted
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An Experiment in the Special Theory of Relativity,
by Gary C. Babcock. China Lake, Calif., NOTS, De-
cember 1962. 14 pp. (NAVWEPS Report 8051, NOTS TP
3053), UNCLASSIFIED.
   ABSTRACT. The results of an experiment conducted
to test the special theory of relativity as opposed
to the new-source interpretation of the emission the-
ory are presented. The apparatus used consisted of
an interferometer whose beams went through moving

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velocity of light took on any of the velocity of the
moving glass, then the interference fringes would
shift; but if the speed of light were a constant, as
the special theory of relativity predicts, no fringe
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