THE MICHELSON INTERFEROMETER

**OBJECT:** To calibrate a Michelson interferometer and to use the calibration for measuring unknown wavelengths including the wavelength difference between the two sodium D lines.

**METHOD:** A Michelson interferometer is put into proper adjustment, the movable mirror is displaced, and the resulting changes in the fringe system are observed. The instrument is calibrated using a known wavelength of light, and the interferometer is then used to make wavelength measurements of other "unknown" light sources.

**THEORY:** Interference is accomplished in the Michelson interferometer by separating a beam of light into two beams which, after having proceeded along different paths, are subsequently united, as shown in Fig. 1. The optical components of such an interferometer consist of two highly polished mirrors, M₁ and M₂, and two glass plates, P₁ and P₂. Plate P₂ is lightly silvered on one surface so that light falling upon it is partially reflected and partially transmitted towards mirrors M₁ and M₂, respectively. After reflection from these mirrors, a portion of the light that follows path (1) will continue on through plate P₁, and a portion of the light that follows path (2) will be reflected by P₁. These two rays will then be travelling in the same direction and thus be in a position to interfere with each other. An eye in the position shown will thus see two images of the source. If the source is monochromatic and extended in area, the resulting field of view will be crossed by bright and dark interference fringes.

When the reflecting surface of P₂ is the front surface, as in Fig. 1, the portion of the light that travels path (2) passes through plate P₁ three times. To compensate for this, a second plate P₃ is inserted in path (1). Without such a compensating plate the optical paths would vary with wavelength because of the dispersion of the glass. This plate must be made of the same glass, have the same thickness, and be oriented at the same angle as P₂. A compensating plate is not needed for monochromatic light, but it is required for viewing fringes in white light. On some interferometers P₃ is mounted in such a manner that it can be rotated slightly to bring it into more accurate parallelism with P₁.

In all Michelson interferometers, mirror M₃ is mounted on a base plate that is supported on well-machined tracks or "ways" so that it can be moved towards or away from the beam splitting plate P₃, and mirror M₃ is mounted on the main frame of the instrument at a fixed distance from P₁. In the Atomic Laboratories (Cenco) M-4 interferometer, the movable plate rests directly on the ways, and it is held securely against them by a lock screw that passes through a slot in the plate. The plate can be moved very slowly in a horizontal direction by means of the micrometer screw that projects from the base of the instrument. This screw acts through an intermediate set of levers, one of which is connected to the lock screw. When the lock screw is loosened the movable plate can be moved to any desired position by hand.

---

**Fig. 1.** Optical system of the Michelson interferometer.

**Fig. 2.** The Atomic Laboratories M-4 interferometer.
The nature of the interference pattern produced by a Michelson interferometer can be visualized most simply by observing that the light which follows path (2) can be thought of as being reflected from a partially reflecting mirror $M'_1$ which is the image of $M_1$ formed by reflection from $P$, as shown in Fig. 1. The equivalent optical system is shown in Fig. 3 where, by omitting the initial reflection from $P$, the extended source of light is in effect behind the observer, and $S$ and $S_1$ are its images in mirrors $M_1$ and $M'_1$, respectively. When the mirrors are separated by distance $d$, the virtual images will be separated by $2d$, and the two rays shown will experience constructive or destructive interference, depending on the path difference $2d \cos \phi$. If the two mirrors are accurately parallel (i.e., if the real mirrors on the interferometer are accurately perpendicular to each other), interference fringes will consist of concentric circles with bright fringes in those directions for which $2d \cos \phi$ is an integral number of whole wavelengths—the condition for fringes of equal inclination.

If the separation of the two mirrors in Fig. 3 is a centimeter or so, the fringes will be closely spaced, and quite a large number of circular fringes will be visible in the field of view. If $M_1$ is moved inwards so that the separation is decreased the fringe system will contract, since, for each fringe, $2d \cos \phi$ must remain constant. Fringes will thus disappear one at a time at the center of the pattern. Furthermore, as $M_1$ approaches $M'_1$, the fringes become more widely spaced until, when $d = 0$, the central fringe will fill the entire field of view. On continuing this motion, fringes will begin to appear at the center and move outwardly, and more and more fringes become visible as the separation is increased.

In general, as mirror $M_1$ is moved a distance $d$, $n$ fringes will either appear or disappear at the center (or pass a given point near the center) when $n \lambda = 2d$ if $\lambda$ is the wavelength of the light. Thus, if one counts fringes for a measured motion of the mirror, the wavelength can be calculated. Conversely, the mechanism for moving the mirror can be calibrated in terms of known wavelength.

**Fringes in White Light:** If an incandescent lamp or some other source of white light is substituted for the monochromatic source, colored fringes are produced, but they can be seen only when the distance $d$ is nearly zero—i.e., only when the two optical paths in the real interferometer are nearly equal in length. This is because white light consists of a continuous distribution of wavelengths, and at anything but a very small value of $d$ the fringe systems for the various components so completely overlap that the field of view is uniformly white.

**APPARATUS:** Michelson interferometer, sodium arc, mercury arc with green filter, low-power telescope (magnification about one or slightly higher).

**Cautions:** The components of an interferometer are delicate and can easily be damaged; they must be handled with care. Under no circumstances should the mirrors or glass surfaces be touched or the adjustment of any of the parts be forced. Do not attempt to use the instrument until you have studied and thoroughly understood the following material.

**PROCEDURE:** The interferometer should be mounted on a platform that is as free of vibration as possible and at a height that is convenient for viewing. Using a millimeter rule, adjust the position of the movable mirror $M_1$ so that it is approximately the same distance from the beam splitting plate as is mirror $M_2$, and mount a monochromatic source of light in the position $S$ shown in Fig. 1. The monochromatic source might well be a mercury arc fitted with a filter which passes the 5461 Å green line (e.g., a Wratten No. 77 or 77A filter or a thin film interference type filter of appropriate thickness). A frosted glass plate ($G$ in Fig. 1) mounted between the source and the interferometer will serve as an extended source of nearly uniform brightness.

To simplify adjusting the mirrors to perpendicularity, a needle or pin should be mounted between the source and the interferometer, as at $N$ in Fig. 1. The Atomic Laboratories instrument has a pin mounted on the bed of the instrument for this explicit purpose. Two images of the pin will be visible, one reflected from each of the two mirrors. (A weaker set of images may also be visible, due to reflection at the unaltered surface of the beam splitting plate. These may be disregarded.) By turning the two adjustable screws that control the orientation of the mirrors, one at a time, the two images can be superposed, whereupon fringes appear. Turn the screws slowly; for it will very likely be necessary to bring the two images past the position where they should be superposed several times before fringes are observed. (If a sodium source is used and if fringes cannot readily be obtained, mirror $M_1$ should be moved a short distance; it may be that the initial setting of the mirror is such that the fringe systems corresponding to the two components of the sodium doublet are out of step as will be explained later.) After fringes have been obtained, the center of the fringe system can be brought into view by further small adjustment of the screws, a little at a time, and in such a direction as to increase the curvature of the fringes.

When an interferometer is properly adjusted the two mirrors are perpendicular to each other and $M'_1$ is parallel to $M_1$. The adjustment can be checked by moving one's head from side to side. The concentric circular fringes will then move across the field of view, remain the same size, and appear to be at infinity.

Fringes can be viewed either with the unaided eye or with a low-power telescope which has crosshairs in the eyepiece. The magnifying power of the telescope does not need to be more than one. The crosshairs provide a convenient reference system for counting fringes that pass as mirror $M_1$ is moved.

After having learned how to obtain circular fringes at will, one should become acquainted with the behavior of the fringe system when $M_1$ is moved. In particular, observe that the direction of motion of the fringes is reversed as $M_1$ passes through the position of path equality. Then, when the interferometer is adjusted for path equality, substitute a source of white light for the monochromatic one and attempt to obtain colored fringes. It will very likely be necessary to move $M_1$ slowly one way or the other to bring them into view since the condition for path equality is critical.

**I. Calibration of the Interferometer.** Mount the low-
power telescope in viewing position and direct it a little to
one side of the center of the circular pattern. It is some-
what easier to count the fringes that pass the crosshairs
when the telescope is in this position than to count the
fringes as they either appear or disappear at the center.
Obtain several values of the change in reading of the mi-
crometer screw which causes, say, 100 fringes to move past
the crosshairs. To obtain a number of readings expeditious-
ly, take readings of every tenth fringe for about 190 fringes,
and treat the data as follows. Calculate the difference be-
tween the readings for the zeroth and the 100th fringes, the
10th and the 110th, etc., on up to the 90th and the 190th
fringes. From the average of these data and the known
wavelength of the light used, calculate the distance that mir-
ror M₁ moves for each revolution of the micrometer screw
using the equation \( n \lambda = 2d \).

One can check this result for the Atomic Laboratories
M-3 interferometer by careful measurement of the radius \( r \)
of the spindle which moves \( M₁ \) and the length \( L \) of the lever
which rotates the spindle. Except in extreme positions of
the micrometer screw when the cosine of the angle must
be taken into consideration, \( M₁ \) will move a distance equal
to \( r/L \) times the distance the micrometer screw moves.

The motion of the base that supports \( M₁ \) can also be
measured directly by using a micrometer microscope to-
gether with a scale accurately graduated to, for example,
tenths of a millimeter. The scale is attached to one side of
the movable base and the microscope is mounted on one side
in such a position that the scale can be read conveniently.
The micro-
scope should be clamped firmly in position so that it will
not move relative to the instrument while readings are be-
ing taken. With the assistance of a second person, the
number of fringes which pass the field of view can then be
counted while mirror \( M₁ \) moves through successive one-
tenth millimeter steps.

II. Determination of Wavelengths of the Sodium D
Lines. The yellow line of sodium consists of two lines, \( \lambda₁ \)
and \( \lambda₂ \), separated by a few Angstrom units. Therefore, when
a sodium arc is used with a Michelson interferometer, each
line produces a separate fringe system. At certain positions
of the movable mirror the two sets of fringes fall on top of
each other, and sharp fringes are produced. This, of course,
occurs when the two optical paths have the same length.
If \( M₁ \) is then moved either outwards or inwards the two
sets move at different rates and thus gradually get out of
step until, when the mirror has been moved through dis-
cance \( d \) such that

\[
2d = n₁ \lambda₁ = (n₂ + \frac{1}{2}) \lambda₂
\]

they will be exactly interlaced, and the fringe pattern will
be least distinct. (The field of view will be almost uniformly
bright since the two lines are almost equally intense; the
shorter wavelength line is somewhat more intense than the
longer.) As the mirror continues to move in the same direc-
tion, the two fringe systems will again become superposed
when

\[
2d = n₂ \lambda₁ = (n₂ + 1) \lambda₂
\]

Thus, by determining the distance between adjacent settings
for which the fringes are most distinct (or least distinct),
one can calculate the difference between the two wave-
lenghts. From Eq. 1,

\[
\lambda₁ - \lambda₂ = \frac{\lambda₂ - \lambda₁}{2d} = n₂ \lambda₂ - n₁ \lambda₁
\]

or, the difference is given by

\[
\Delta \lambda = \frac{\lambda₁ - \lambda₂}{2d}
\]

where \( \lambda \) is the geometric mean of the two wavelengths.

1. Average Wavelength of the D lines: Adjust the in-

terferometer to give distinct fringes when a sodium arc is
used as the source of light. Obtain a series of micrometer
readings for every 10th fringe that passes the crosshairs
for 190 fringes. (Make a preliminary quick run to make sure
that this number of fringes will remain satisfactorily visible
over the range of motion required.) Average your data as
outlined earlier, and use the calibration obtained in Part I
for calculating the wavelength of the sodium light. Note that
this result should be the mean of the two wavelengths \( \lambda₁ \)
and \( \lambda₂ \).

2. Difference in wavelength between the Sodium D
Lines: Obtain as many settings as the range of the micrometer
screw will permit for the positions of most distinct
fringes and least distinct fringes. Determine the distance
\( d \) from your data and calculate the wavelength difference
between the two lines of sodium, using Eq. 2.

Considerably more data can be obtained with the Atomic
Laboratories instrument by using a micrometer microscope
and a scale accurately divided into, say, tenths of a mil-
limeter, mounted as described in Part I. The ways (Fig. 2)
permit considerably more motion of mirror \( M₁ \), than can be
produced by the micrometer screw. However, the base on
which the mirror is mounted must then be moved by hand
—one hand carefully placed on each side. The scale is read
each time fringes become most distinct and also each time
they are least distinct, and the data are treated as described
for a similar set of data in Part I. If, say, 19 readings are
taken, one can calculate the difference between the zero
and the tenth readings, the first and the eleventh, and so on.
From the final average distance, \( d \) can be determined and
\( \Delta \lambda \) can then be calculated.

QUESTIONS: 1. A student obtains micrometer readings for the
setting of every tenth fringe for 190 fringes as suggested in
Part I. However, instead of treating these data as sug-
gested, he simply takes the difference between successive
readings and averages the resulting differences. Show that

Fig. 4. When a plate of glass is rotated through angle \( i \), the optical path changes from \( AB \) in glass plus \( BC \) in air to \( AD \) in glass plus \( DE \) in air.

he is making use of only the first and the last readings.
(The intermediate readings might as well not have been
taken.)

2. The index of refraction of a gas can be determined by
introducing into one of the arms of an interferometer a gas
cell which has plane glass end windows and a side tube for
changing air pressure. The number of fringes that pass the
field of view is counted as the pressure is changed by one
atmosphere. Calculate this number for a cell of length 2.00 cm when a gas, having a refractive index 1.0003 at the wavelength used, is pumped out of the cell.

3. The index of refraction of a glass plate can be determined by interposing the plate in one of the arms of an interferometer and counting the number of fringes that pass the field of view as the plate is rotated through a measured angle. A certain plate, 0.500 mm thick and having a refractive index of 1.50 at the wavelength used, is inserted and rotated slowly through 30° from its initial position normal to the light. Calculate the number of fringes that pass the field of view. (See Fig. 4. Note that the optical path changes from $AB$ in glass plus $BC$ in air to $AD$ in glass plus $DE$ in air.)

4. An interferometer is used to study the separation of the $D$ lines of sodium. Calculate the number of fringes that pass the field of view for each of the two wavelengths (5890 Å and 5896 Å) when the movable mirror is moved between settings for which the two sets of fringes are superposed.