CENCO Physics
Selective Experiments In Physics

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YOUNG'S DOUBLE SLIT EXPERIMENT

OBJECT: To study the interference of light by Young's double slit method, and to measure the wavelength of light.

METHOD: A narrow source of light illuminates a double slit, and the spacing of the resulting interference fringes for approximately monochromatic light is measured with an eyepiece micrometer. The wavelength of light is determined from this measurement, the distance between the two slits and the distance from the slits to the plane of observation.

THEORY: The phenomenon of interference can be produced in a very simple way with the aid of a double slit, as was first shown by Young.

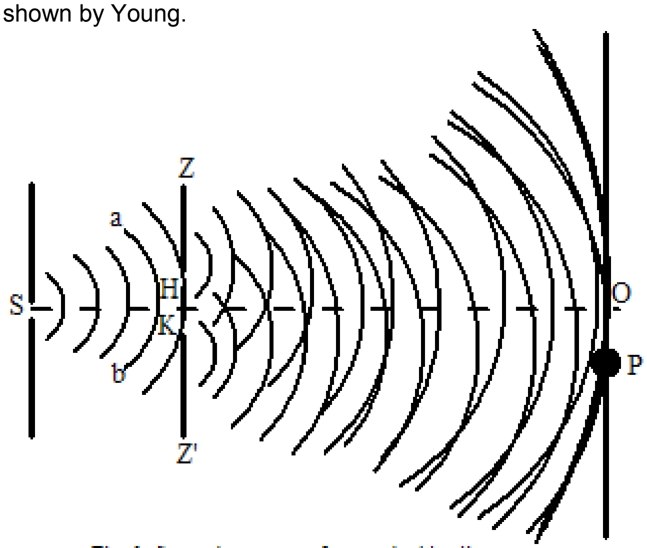

Fig. 1. Secondary waves from a double slit.

Let S (Fig. 1) represent a horizontal cross section of a vertical slit which is emitting cylindrical waves one of which is represented in section by the arc ab. If ZZ' represents a double slit with openings H and K parallel to the slit S, the secondary wavelets emerging from the openings H and K will always be in the same phase. The phase difference between the wavelets arriving at any point P on the screen may then be calculated from the geometry of Fig. 2.

Consider a point P on the screen at a distance *x* from the symmetrical position opposite the center of the double slit. Let

b = distance between the double slits H and K
D = distance from double slit to screen
λ = wavelength of the light used
x = distance OP

Draw PQ parallel to AO; then

$$(HP)^2 = \left(\tfrac{1}{2}b + x\right)^2 + D^2$$

and

$$(KP)^2 = \left(\tfrac{1}{2}b - x\right)^2 + D^2 \qquad (1)$$

Hence

$$HP - KP = 2bx/(HP + KP) \qquad (2)$$

If *b* and *x* are small compared with *D*, one may set (*HP* + *KP*) = 2*D*, hence

$$HP - KP = bx/D \qquad (3)$$

The wavelets from H and K reinforce each other at P if the difference in path *HP* - *KP* is equal to any whole number of wave lengths *N*; that is, there is light at a distance *x* from O if

$$HP - KP = N\lambda = bx/D \qquad (4)$$

The distance *d* between any two successive bright fringes will be

$$d = x_{N+1} - x_N = \lambda D/b \qquad (5)$$

If on the other hand the difference in path *HP* - *KP* equals an odd multiple of half a wavelength, then the waves are 180 degrees out of phase and destructive interference occurs resulting in no light at the point P. The distance between any two dark fringes will be the same as the distance between any two bright fringes. Destructive interference does not mean a loss of energy but its redistribution, concentrating the energy in regions of constructive interference.

APPARATUS:

Experimental Assembly: The apparatus consists of an optical bench carrying in order a fixed or an adjustable slit, a filter, a special holder for the double slit which can easily be rotated about a horizontal axis, an eyepiece micrometer and an adjustable light shield to be placed between the double slit and the eyepiece micrometer.

In addition to this assembly on the optical bench, a light source is required. The number of fringes seen depends on the purity of the source of light. With a small mercury are fitted with a special filter letting through only the green mercury line, the fringes may be followed through the entire field of the view of the eyepiece micrometer. If a tungsten filament using a red glass filter is used, twelve to fourteen fringes may be observed readily. In addition to the above, a comparator is needed for measuring the spacing of the lines of the double slit.

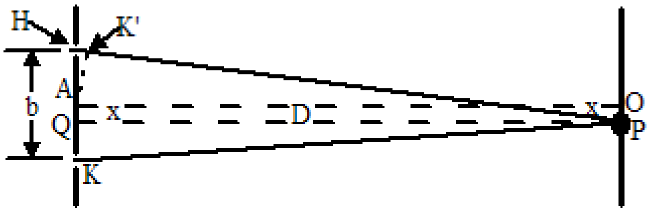

Fig. 2. Illustration of the theory of Young's double slit.

Measuring Microscope:

Description: The instrument consists of a reading microscope securely attached to a block which slides in ways machined in a heavy iron casting. A scale 15cm long, graduated in millimeters, is attached to one edge of the base casting. A vernier attached to the sliding block moves over this scale, its position being read to 0.01mm by means of a magnifier which can be adjusted to center over any part of the vernier. The block carrying the microscope slides freely in the ways provided but can be locked in position by means of a knurled head screw. When locked in position, the block carrying the microscope is adjusted by means of a fine screw, the head of which is shown at the left of the microscope in Fig. 3.

Fig. 3. Measuring Microscope, Universal Type

The microscope is mounted on an arm provided with two joints which permit its use in four different positions with reference to the scale. The base casting is machined at one end as well as at the base so that the measuring microscope may be used in a variety of positions.

Focusing the Eyepiece: Place a piece of plain paper below the objective and move the eyepiece in or out until the cross hairs are sharply defined. Move the head slightly to one side and rest the eye used either by closing it or looking at the floor. Then look quickly into the eyepiece again and see if the cross hairs appear as sharp as before. If they do not appear sharply defined immediately but only after some effort in finding them, make further adjustments until they are sharply seen when first looking into the instrument after the eye has been at rest. This procedure will avoid fatigue of the eye due to excessive use of accommodation.

Focusing the Microscope: Next place a card with some fine figures on it near the plane of the object to be measured and secure an exact focus by sliding the microscope back and forth in its tube. When properly focused, the cross hairs should remain fixed on some point of the image when the head is moved from side to side. If the image moves with the direction of the head and the cross hairs appear to move in the opposite direction, then the image is farther from the observer than the cross hairs. In order to eliminate this apparent motion, it is necessary to push the tube which carries the cross hairs closer to the objective lens without changing the position of the lens itself. Adjustment of the position of this tube will bring the image of the object into the focal plane of the eyepiece. On the other hand, if the cross hairs appear to move in the same direction as the observer, then the image is too near the eye and the microscope tube must be pushed away from the object in order to place the image in the focal plane of the eyepiece.

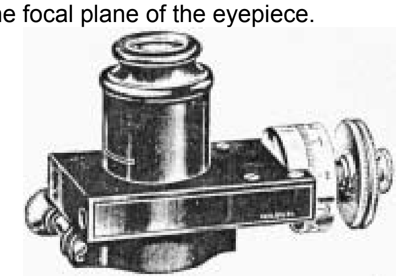

Fig. 4. Eyepiece Micrometer

Eyepiece Micrometer:

Description: The eyepiece micrometer (Fig. 4) consists of a positive eyepiece with a finely-ruled glass scale which is movable in its focal plane by means of a micrometer screw. The scale has thirty divisions, with every fifth division indicated by a numbered line of double length. By means of this scale (Fig. 5), dimensions in the focal plane of the eyepiece may be observed directly with a precision which depends upon the least count of the scale. The length of each interval of the scale (0.2mm) is exactly equal to the pitch of the micrometer screw by which the scale is moved. Fractions of a revolution of this screw are indicated on a drum graduated into a hundred parts.

The drum itself may be so adjusted about the axis of the screw as to set its zero reading in any desire, position.

In use, the scale is moved until one of the millimeter lines coincides with the margin of the object. Then, by noting the part of a revolution necessary to bring another line into coincidence with the opposite side, the fraction a part of the last division is measured in hundredths. The eyepiece micrometer is mounted in position by means of a spring collar which can be tightly clamped by means of a thumbscrew.

Directions for Using the Eyepiece Micrometer: 1. If necessary, rotate the entire micrometer in the mounting until the scale, as seen through the eyepiece, is horizontal with the numerals on the scale upright.

2. Focus the eyepiece on the graduations of the scale.

3. Move the scale until one of the millimeter lines coincides with the left margin of the object to be measured, as shown in Fig. 5.

4. If necessary, adjust the drumhead so that it reads zero when one of the lines of the scale is coincident with the margin of the object in this way.

5. Record the width corresponding to the integral number of divisions covered by the object being measured.

6. Rotate the micrometer screw in the direction of increasing numbers to bring the right margin of the object into coincidence with the first scale ruling which is brought up to it by this motion. Note the fraction of a revolution necessary to effect this last setting, and express the corresponding displacement of the scale in decimal parts of a millimeter. The sum of this displacement and the reading recorded in Part 5 is the width of the object being measured.

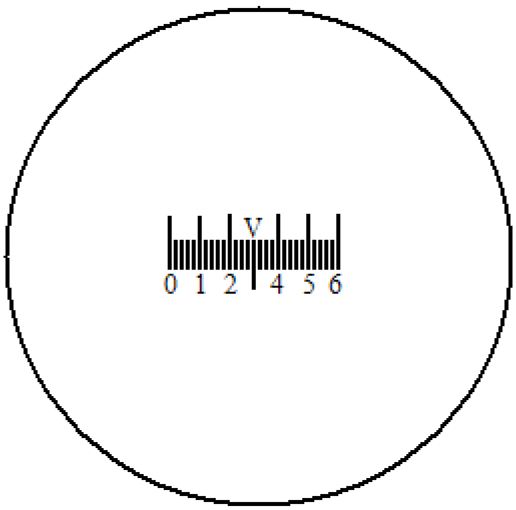

Fig. 5. Reticule of Eyepiece Micrometer showing reference numbers and object to be measured.

7. For the sake of accuracy, repeat the measurement. It is somewhat preferable to initiate the second measurement from a different origin. If it is necessary to turn the micrometer screw in the direction of decreasing numbers in order to employ a different origin, the scale should be moved at least one complete revolution past the position of origin; and the new origin should be brought into position by rotating the screw in the direction of increasing numbers. In this way, errors which might arise from lost motion in the screw may be avoided.

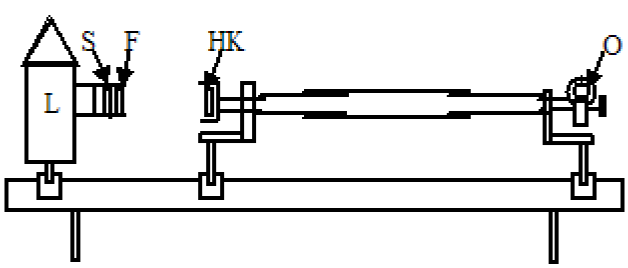

Fig. 6. Assembly for observing interference fringes.

PROCEDURE:

Experimental: Mount the light source L at one end of the optical bench as shown in Fig. 6. The mercury lamp (a) or the incandescent source (b) shown in Fig. 7 should be used. Place a single slit S and a light filter F in the frame of the light source. Next mount the double slit HK and the micrometer eyepiece O (Fig. 4) on the supports of the light shield (Fig. 8).

Set the micrometer eyepiece about 30cm from the double slit and, looking through the eyepiece, rotate the single slit until the fringes are sharply defined. By moving the double slit the laterally the fringe system can be centered in the eyepiece.

Measure the positions of ten or fifteen fringes in the field of view, numbering the fringes in the direction of motion of the movable cross hair. From this measurement determine *d*, the width of a single fringe.

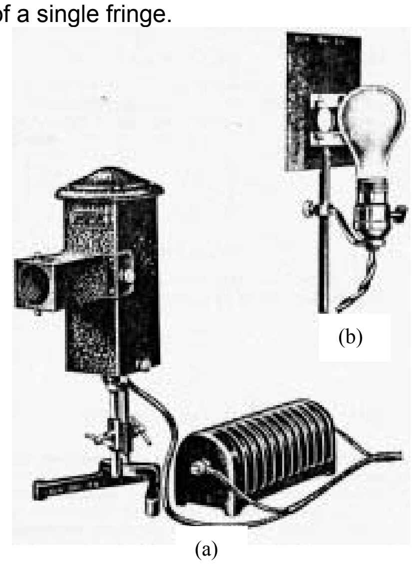

Fig. 7. (a) Mercury Light Source with detachable slit and filter holder. (b) Incandescent Light Source with slit and filter holder (filter holder not in view).

Determine the distance *D* from the double slit to the focal plane of the eyepiece micrometer. The focal plane of the eyepiece micrometer is the front face of the plate to which the eyepiece is attached (i.e., the face toward the incident light).

Change the distance *D* and take two additional sets of measurements for determining the spacing of the fringes. Measure with the comparator the distance HK = b between the centers of the lines of the double slit. The two fibers which constitute the cross hairs should be symmetrically inclined to the direction of the slits.

Interpretation of Data: Using Eq. (5), calculate for each set of measurements the wavelength of the light passed by the filter. Compute the average wavelength and the deviation of each value of the wavelength from the mean value. Compare the average wavelength calculated with the correct value. For the green line of mercury λ=0.000546mm. If the red glass filter is used, ask the instructor for the wavelength transmitted.

QUESTIONS: 1. Given a double slit with a 1mm spacing between the centers of the two openings, find the spacing of the fringes when observed at a distance of 80cm with light having a wavelength of 5893A.

2. At what distance from a double slit, whose elements between centers are 0.8mm apart, will fringes 1mm apart be observed in light having a wave length of 6350A?

3. If the measurement of the slit separation in Question 1 is in error +0.02mm, what percentage change will this make in the result?

4. By using light of wavelength 5461A, it is desired to secure interference fringes with a spacing of 0.5mm when observations are made one meter from the double slit. What separation of the centers of the two slits is necessary?

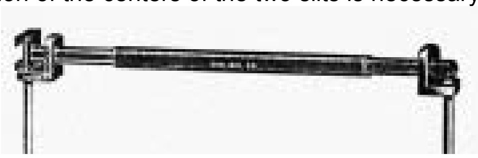

Fig. 8. Apparatus for diffraction measurements with light shield. For use in undarkened room.

MODIFICATION OF YOUNG'S EXPERIMENT

(Optional)

OBJECT: To determine the thickness of a lamina from the shift of the fringes when the lamina covers one opening of a double slit.

METHOD: A thin lamina of known refractive index is placed over one opening of a double slit. From the spacing of the elements of the double slit, the distance from the double slit to the plane of observation, the shift of the fringes produced and the refractive index of the lamina, the thickness of the lamina can be calculated.

THEORY: Suppose that light from the source H (Fig. 9) has to traverse a thin lamina L of a transparent substance before reaching the screen, while light from the source K reaches the screen directly. Let *t* be the thickness of the lamina and *n* its refractive index. If *V* is the velocity of light in air and V_L the velocity of light in the lamina, then

$$V/V_L = n \qquad (6)$$

Before alight wave from H can reach the point P it must travel a distance (*HP- t*) in air and a distance *t* in the lamina. The time required is equal to

$$(HP - t)/V + t/V_L \qquad (7)$$

The time required for a wave to reach P from K is equal to

$$KP/V = (KG + GP)/V = (KG + HP)/V \qquad (8)$$

Hence the time retardation of the waves from K behind those from H is equal to

$$(KG/V + HP/V) - [(HP - t)/V + t/V_L] = KG/V + t(1/V + 1/V_L) \qquad (9)$$

The point P will be the center of the Nth bright fringe if this time retardation amounts to *NT* where *T* is the period of the waves. Thus, for P to be the center of the *N*th bright fringe

$$[KG/V + t(1/V - 1/V_L)] = NT$$

whence

$$KG = NVT + t(V/V_L - 1) \qquad (10)$$

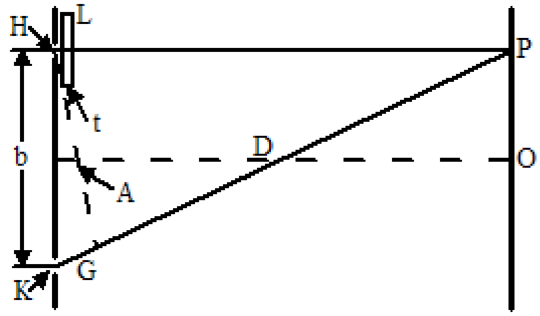

Fig. 9. Double slit with thin lamina over one opening.

In Eq. (4) it was shown that this path difference *HP - KP* (in Fig. 9 = *KG*) is equal to *bx/D*, and since in general $VT = \lambda$,

$$bx/D = N\lambda + (n-1)t$$

or

$$x = D/b[N\lambda + (n-1)t] \qquad (11)$$

This gives the distance *x* = *OP* of the *N*th bright fringe from the point O. Owing to the lamina, the central fringe will be formed a distance x_o from O. In an cases the central fringe is the one at which the waves from H and K arrive after journeys requiring equal times-that is, when *N* = 0.
The displacement of the central fringe due to the lamina L is therefore given by

$$x_o = D(n-1)t/b \qquad (12)$$

giving for the thickness of the lamina

$$t = bx_o/D(n-1) \qquad (13)$$

APPARATUS: This is the same as in the main part of the experiment, with the exception of the double slit which has a thin lamina of known refractive index placed over part of one opening.

PROCEDURE:
Experimental: The apparatus is set up and adjusted as in the main experiment. The central band can be identified by removing the filter and observing in white light.
If a vertical linear source has been used in the preceding experiment, a horizontal slit about 1mm in width should be placed in front of it so that the observations are taken with what is approximately a point source. This will sharpen the transition between the direct and shifted fringes.
Take several measurements of the shift of the central bright band and average them.
Measure the distance *D* with the meter stick and the distance *b* with the comparator.
Repeat the measurements of the displacement of the central fringe for two other distances, D_2 and D_3.

Interpretation of Data: From these measurements and Eq. (13) compute the thickness of the lamina for each of the three distances D and find the average value.