An arrangement is shown in Fig. 19 for a quantitative study of interference by a thin film of dielectric. A metal shield with an aperture one wavelength or less in diameter prevents effects of diffraction around small pieces of dielectric. Ideally, each piece should be many wavelengths wide. The shield makes it possible to deal with small quantities of dielectric.

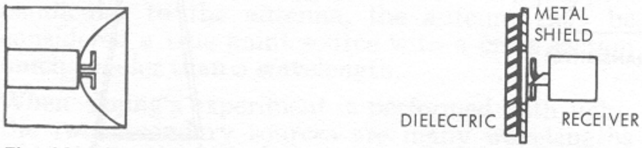

Fig. 19 Arrangement for Study of Interference in Thin Films of Dielectric

Prepare at least twelve sheets of wood 6″ × 6″ × ¼″. (Plywood is satisfactory.) Or, if desired, all items for this experiment can be procured from the *Microwave Index of Refraction Apparatus*, Cenco No. 80424-2. Increase the thickness by steps of one sheet and plot a graph of transmitted intensity against thickness of dielectric. As the thickness of the dielectric approaches zero, transmission approaches 100%. This fundamental fact is observed with light. As the thickness of a soap film becomes a small fraction of a wavelength, the reflected intensity approaches zero and transmitted intensity approaches 100% of the incident intensity. If the reflected intensity approaches zero as the distance

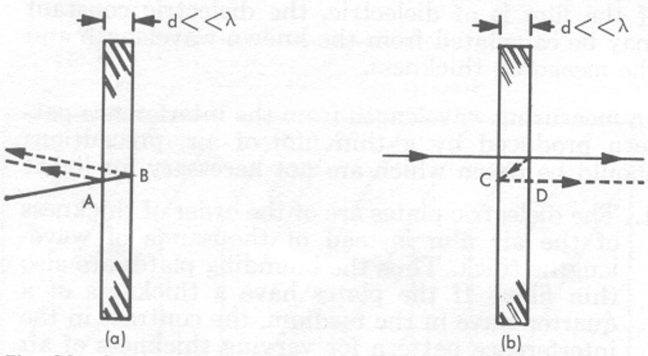

Fig. 20 Interference in Films Thin Compared to Wavelength

AB becomes much less than a wavelength, it must be concluded that the waves reflected from *A* and *B* of Fig. 20a are out of phase. This would be true if one of the two reflected waves underwent 180° phase change upon reflection. In Experiment 4, it was shown that a 180° phase change took place upon reflection for waves incident from air to the more dense substance. Therefore, in Fig. 20 the change of phase in the electric field takes place at *A* and not at *B*. This fundamental fact which is shown experimentally with microwaves has been proven by electromagnetic theory. In Fig. 20b, the reflected wave will not have undergone any changes in phase at *C* or *D*. It should be noted that since the frequency of a wave never changes as it passes from one medium to another, the wavelengths in the media are as the velocities of the wave in those media. Thus if μ is the index of refraction, and λ_a and λ_d are the wavelengths in air and in a dielectric,

$$\mu = \frac{\textit{velocity in air}}{\textit{velocity in dielectric}} = \frac{\lambda_a}{\lambda_d}$$

For present purposes, the wavelength in air may be taken as the same as that in vacuum. Show from Fig. 20b and a consideration of phase relations that the transmission will be a minimum when the dielectric is an odd number of quarter-wavelengths thick and a maximum when it is an even number of quarter-wavelengths thick where the wavelength is that in the dielectric.

From the graph which you have plotted, determine the wavelength in the wood. Making use of the wavelength in air measured by standing wave measurements in Experiment 7, calculate the index of refraction for the wood.

If the material has a higher dielectric constant, the contrast in intensities of the transmitted beam is more pronounced as the thickness is varied. If they are available, stacks of glass sheets may be used and plots made of transmitted intensity against thickness. Different kinds of glass have indices of refraction for microwaves ranging from 2.0 to 2.5. Sheets of transite (asbestos lumber) are also effective. Transite has an index of refraction of about 2.3 but it has a higher coefficient of absorption than does glass.

Using two plates of high dielectric constant such as glass or transite, each with a thickness of a quarter-wavelength in the dielectric, study the interference by thin films of air as shown in Fig. 21. Keep dielectric plate No. 1 close to the metal shield and move plate No. 2 away by steps of two millimeters. Plot a graph of transmitted intensity against thickness of the film and interpret the results. Use this method to determine the wavelength of the radiation.

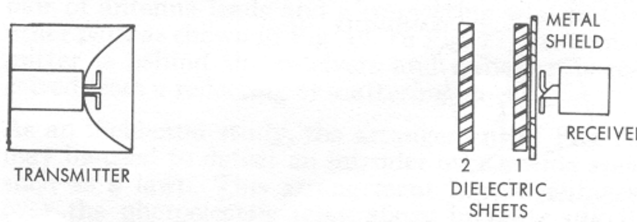

Fig. 21 Arrangement for Studying Interference of Microwaves Caused by a Thin Film of Air between Two Dielectrics

In optics, when two plates of glass are in sufficiently close contact to transmit about 99% of the radiation, the glass plates are said to be in optical contact. For microwaves, two plates of dielectric are in fair optical contact if they are a millimeter apart. How thick would the space be for an equally good optical contact when the waves are from a sodium light and 0.000059 cm long?

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11 michelson's interferometer

Michelson's interferometer is used to measure small displacements of a surface in terms of known wavelengths of light. Since the standard of length has been made the length of the red cadmium line, the interferometer has an added importance.

Michelson's interferometer for microwaves may be set up on the laboratory or lecture table as shown in Fig. 22. The half-reflecting screen may be of chicken wire or square mesh wire with meshes about one-fifth wavelength across. The screen may be held by a wooden clamp in a vertical plane at 45° to the direction of the incident beam. The half-reflecting screen as well as mirrors *A* and *B* should not be smaller than one foot square. Mirrors *A* and *B* may be of sheet metal or window screen, carefully set in vertical planes at right angles to each other. Mirror *A* may be fixed and mirror *B* moved between two guides, one of which may be a meter stick.

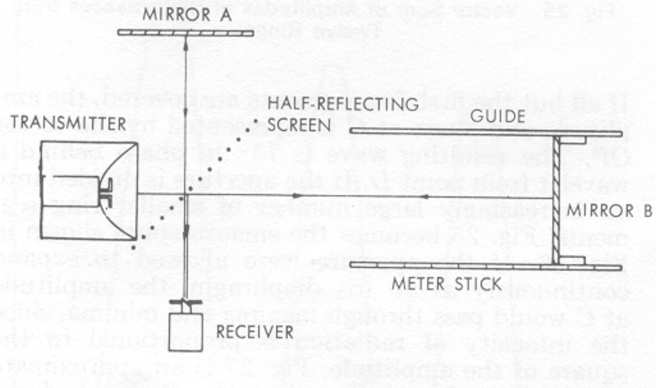

Fig. 22 Michelson's Interferometer for Microwaves

Construct a line from the antenna of the transmitter perpendicular to mirror *B*. From the point of intersection of that line with the plane of the half reflecting screen construct another line perpendicular to the plane of mirror *A*. Set the receiver in a position on that line as shown in Fig. 22 where motion of mirror *B* will produce the greatest variation in the received intensity. The output of the transmitter and the position of the receiver may be adjusted until motion of mirror *B* causes the reading of the meter to vary over half the scale.

What are the conditions for maximum intensity at the meter? What are the conditions for minimum intensity? Locate the position of the mirror along the meter stick for which the intensity at the meter is a minimum. Calculate the wavelength by the method of the weighted mean. To make another independent determination of the wavelength, change the position of fixed mirror *A* and repeat the motion of mirror *B*.

The above interferometer shown in Fig. 22 has its sole value as an introduction to Michelson's interferometer for light. To measure the wavelength of microwaves or the motion of an object in terms of known wavelengths, mirror *A* and the half-reflecting screen may be removed. Radiation reflected back to the transmitter reacts on the oscillator and causes a change in the output of the transmitter. The effect on the oscillator may be observed either by noting the plate current or the output of the oscillator.

Place the receiver in the field of the transmitter but outside the standing wave pattern between the transmitter and mirror *B*. Locate the positions of mirror *B* along the meter stick for which the output intensity of the transmitter is a minimum and calculate the wavelength.

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12 diffraction pattern of a circular aperture

After the wave theory of light had been confirmed by Young's experiment and other experiments involving interference of waves from two point sources, the next victory for the wave theory was the exact explanation by Fresnel of diffraction as observed in the colored fringes at the edge of a sharp shadow, the bright spot and rings observed in the center of the shadow of a small coin and the angular spread of a parallel beam of light passing through a sufficiently small aperture. None of these observations could be explained on the basis of geometrical corpuscular propagation.

Fresnel explained diffraction quantitatively by an extension of Huygen's principle. In Fig. 23, *AB* is a plane wave front of a continuous wave of constant intensity over the front. The intensity at point *C* is to be predicted. *AB* is thought of as made up of an infinite number of point sources. According to Huygen's principle, every point on the wave front sends out secondary wavelets which combine to determine the wave motion at *C*. Fresnel added to Huygen's principle by considering a continuous wave instead of a single pulse front. The wavelets from the many points on the wave front will arrive at *C* in different phases. Thus the amplitude at *C* is not an arithmetic sum of the amplitudes of the wavelets, but a vector sum.

For simplicity, consider a plane wave incident normally upon a circular aperture and predict the intensity at a point *C* on the axis of the aperture. *C* is on the opposite side of the aperture from the source. In this simple case, the theory is identical for both sound and electromagnetic waves. If *C* were off the axis, polarization of the transverse electromagnetic wave would be considered.

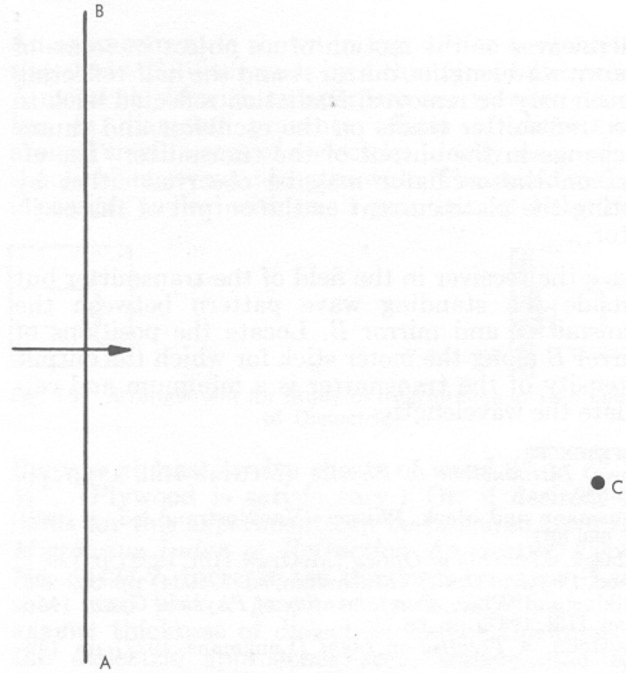

Fig. 23 Wave Front Approaching a Point C

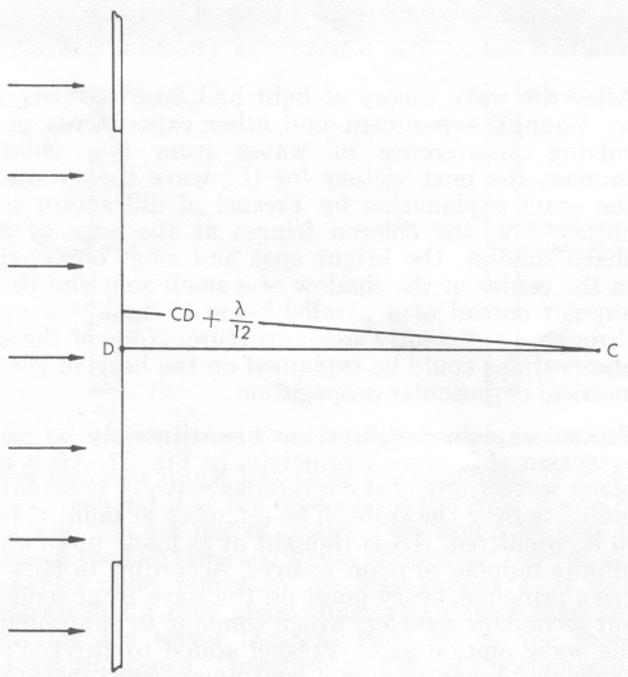

Fig. 24 Geometry for Predicting Intensity of C when a Plane Wave is Incident on a Circular Aperture

For convenience, the wave front in the aperture may be divided into a large number of rings by concentric circles about the center of the aperture. For the present, let the points on the first circle be one-twelfth wavelength farther from C than is D. Likewise, succeeding circles may be chosen so that, if n is the number of circles, each point on the circle is $CD + \lambda/12$ from C.

With rough approximation, assume that the wavelets from a given segment all arrive at C in phase with each other. In Fig. 25, vector 1 represents the amplitude of the wave arriving at C from the center segment and vector 2 represents the amplitude of the wave from the second segment, which is 30° in phase behind that from the first. Kirchoff has shown that, due to a direction factor, the effects from each succeeding segment will be smaller. Thus the vector sum of the amplitudes from the twelve segments is not quite zero.

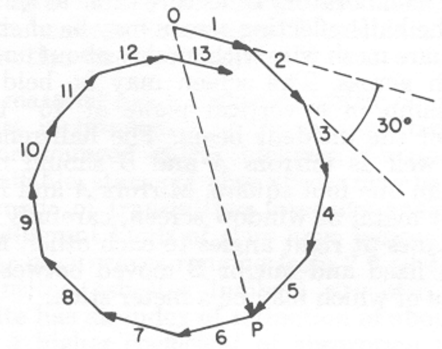

Fig. 25 Vector Sum of Amplitudes of Disturbances from Twelve Rings

If all but the first five segments are covered, the amplitude and phase at C is represented by the vector OP. The resulting wave is 75° in phase behind a wavelet from point D. If the aperture is divided into an increasingly large number of smaller ring segments, Fig. 25 becomes the smooth spiral shown in Fig. 26. If the aperture were allowed to expand continuously as an iris diaphragm, the amplitude at C would pass through maxima and minima, since the intensity of radiation is proportional to the square of the amplitude. Fig. 27 is an approximate plot of intensity at C against the diameter of the aperture.

To make quantitative predictions of the intensity at point C (Fig. 24), the wave front may be divided into convenient zones in the following manner. Construct a series of concentric spheres about point C of diameters $CD + \lambda/2$, $CD + 2\lambda/2$, $CD + 3\lambda/2$ etc., making the radius of each sphere a half-wavelength greater than the preceding one. These spheres will intersect the wave front in circles dividing the front into zones known as Fresnel zones. As seen from Figs. 24 and 25, if the aperture exposes an odd number of consecutive Fresnel zones, the intensity at C will be a maximum; if it uncovers an even number of zones, the intensity will be a minimum.

When Fresnel diffraction is observed with light, the source is a well-shielded carbon arc with a small aperture. The apertures or obstacles which are to produce the diffraction pattern are placed in the beam a few feet from the arc and the diffraction pattern is observed at the far end of the room on a ground glass plate. When microwaves are employed, all the apparatus may be put on one or two laboratory tables and the Fresnel zones drawn on the blackboard in convenient sizes.

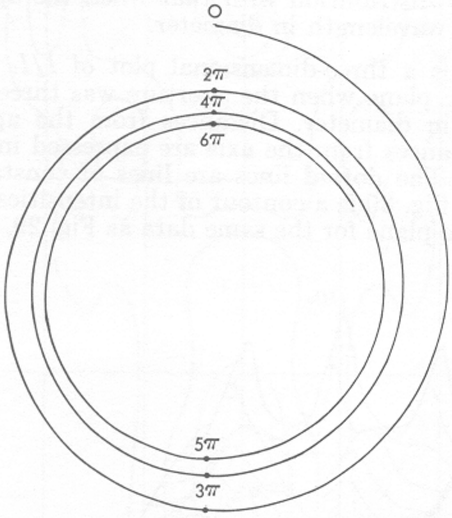

Fig. 26 Spiral for Determination of Amplitude and Phase Diameter of the Aperture

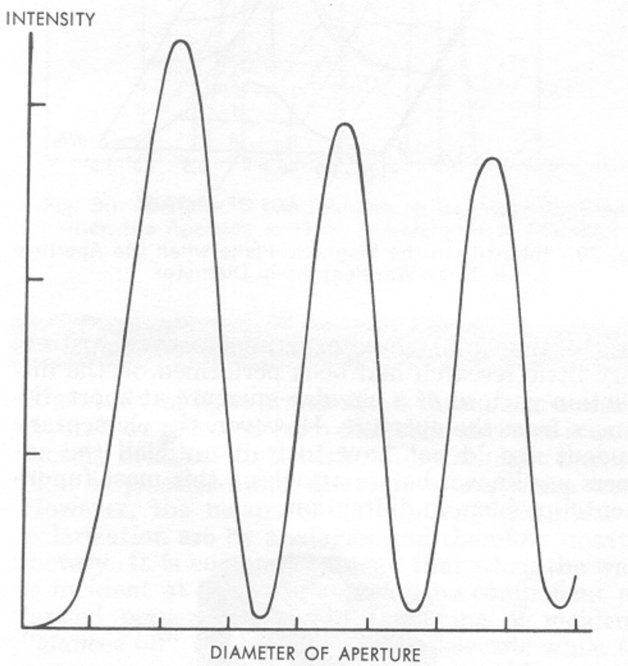

Fig. 27 Variation of Intensity at a Point on the Axis with Diameter of the Aperture

Fig. 28 shows the equipment for studying the diffraction by a circular aperture. Place the aperture about ten feet from the transmitter. With the first and second zone ring and disc removed, move the receiver backward and forward a few millimeters until it indicates a minimum of intensity. Because of standing waves between the source and the shield, the intensity minimum may be reduced somewhat by moving the shield and meter toward or away from the transmitter a few centimeters. When the antenna of the receiver is at an intensity minimum, the center of the antenna should be one wavelength farther from the edge of the aperture than from the center of the aperture. How does this check with the wavelength as found by interference methods?

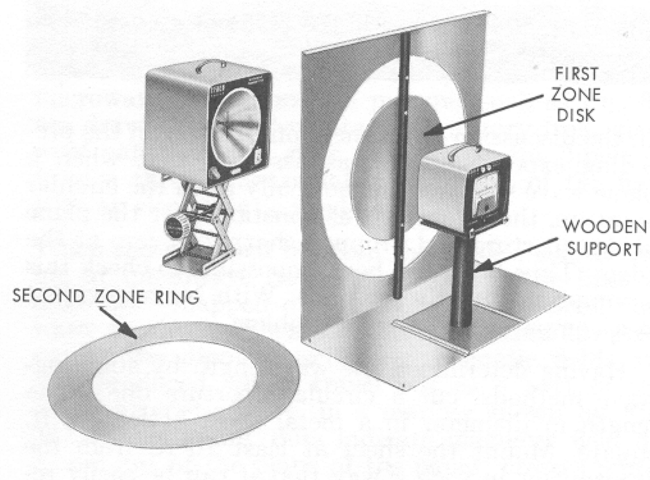

Fig. 28 Arrangement for Studying Diffraction by a Circular Aperture

Cover the first zone. What happens to the intensity? Cover the second Fresnel zone and leave the first one open. The waves from the zones will very nearly cancel at the antenna of the intensity meter. Does the energy from one zone destroy that from the other? Does the principle of Conservation of Energy apply in this case? This question may be answered experimentally. With both zones uncovered, move the receiver slowly along radially outward paths in a plane that includes the minimum point and is parallel to the plane of the shield. A ring of maximum intensity will be found. Is that ring present when only the first zone is uncovered and there is a maximum at the center?

With both the ring and disc removed, move the intensity meter slowly away from the aperture, along the axis of the aperture, to a sharp maximum of intensity. The large aperture is then one Fresnel zone relative to the center of the antenna. Measure the distances from the center of the antenna to the center of the aperture and to the edge of the aperture. What fraction of a wavelength is the difference of those distances?

If a pinhole box camera is five inches long, how large should the pinhole be in order to uncover one Fresnel zone relative to a point at the center of the photographic plate for a wavelength of 0.00005 cm? If a parallel beam of radio waves were projected at the earth, of what wavelength should they be so that the moon would cover one Fresnel zone relative to a point on the earth? The moon is 238,000 miles from the earth and 2160 miles in diameter.

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Born, *Optick* (Springer, 1933) pp. 147-151.

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Baker and Copson, *Huygen's Principle* (Oxford Press, 1939).

13 diffraction pattern in the plane of a circular aperture

In the discussion of Fresnel Zone Theory in the preceding experiment, it was assumed that when a plane wave was incident normally upon the circular aperture, the intensity was constant over the plane of the aperture and dropped sharply to zero at the edges. Thus far it has been impossible to check this assumption directly for light. With microwaves, it is a comparatively simple problem.

Having determined the wavelength by standing-wave methods, cut a circular aperture one wavelength in diameter in a metal sheet at least 2 ft. square. Mount the sheet at least 10 ft. from the transmitter in such a way that it can be easily removed and replaced in order to read the intensity of the undisturbed radiation.

Mount the receiver in a wooden support such as that shown in Fig. 28 so that the center of the antenna will be at the height of the center of the aperture. With the antenna of the receiver positioned vertically facing the source, move the receiver by steps of a half centimeter along the horizontal diameter.

That diameter is the intersection of the plane of the aperture with the magnetic plane. The magnetic plane is a plane through the axis of the aperture perpendicular to the antenna. It is called the magnetic plane because it contains complete magnetic lines. In taking the readings, stand far enough behind the meter so that motion of your body will not cause variations in the reading larger than you wish to tolerate. Plot a graph of I/I_0, the ratio of intensity to intensity of the undisturbed beam against position along the diameter. Is the intensity across the aperture constant as is commonly assumed in Fresnel Zone Theory?

An examination of the surface of the metal shield around the aperture on the side opposite the source will reveal high-frequency currents over portions of the shield which give rise to radiation from the surface. Move the antenna along a line parallel to the diameter in the magnetic plane but two millimeters from the plane of the aperture on the opposite side from the source; that is, far enough so that the antenna will not touch the surface. Plot a graph of I/I_0 against position along the line extending beyond the edge of the aperture to where the intensity is zero. Plot a similar graph for a line two millimeters behind the diameter in the electric plane. Instead of moving the receiver vertically, it is simpler to rotate the transmitter and receiver so that the antennas are horizontal, and then to move the meter horizontally.

Compare the widths of the intensity curves for half maximum intensity for the magnetic and electric planes. Where are the most pronounced currents found on the surface of the shield?

Make the circular aperture two wavelengths in diameter and repeat the measurements. Compare the intensity distribution with that when the aperture was one wavelength in diameter.

Fig. 29 is a three-dimensional plot of I/I_0 in the magnetic plane when the aperture was three wavelengths in diameter. Distances from the aperture and distances from the axis are expressed in wavelengths. The dotted lines are lines of constant intensity. Fig. 30 is a contour of the intensities in the magnetic plane for the same data as Fig. 29.

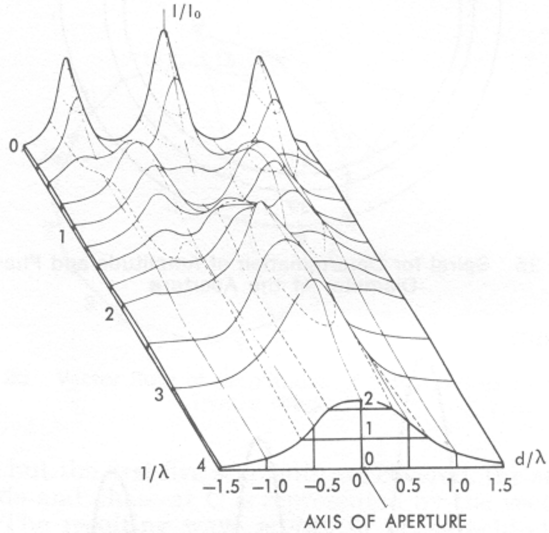
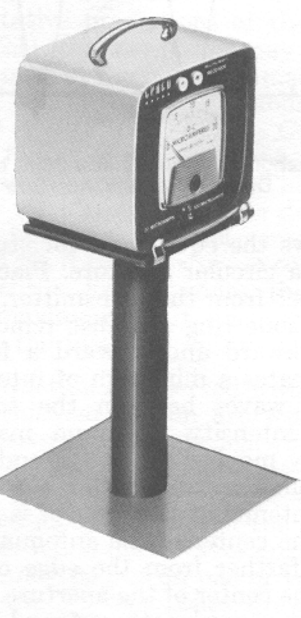


Fig. 29 Intensity in the Magnetic Plane when the Aperture is Three Wavelengths in Diameter

At the time that these experiments were written, very little research had been performed on the diffraction pattern of a circular aperture at short distances from the aperture. However, the elementary student should not have to wait until all the answers are known before attacking this most fundamental problem in diffraction.



Receiver on Wooden Support

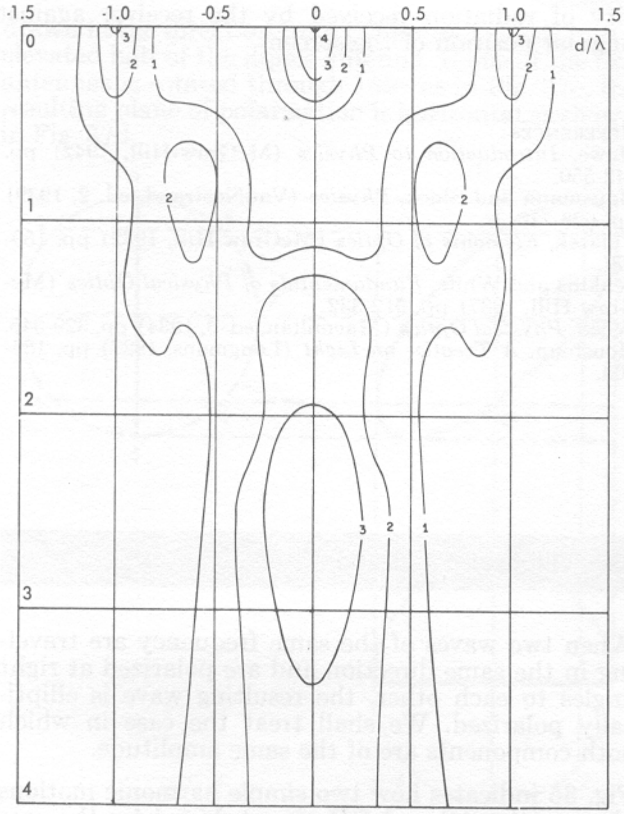


Fig. 30 Contour of the Intensity in the Magnetic Plane when the Aperture is Three Wavelengths in Diameter

14 polarization

The study of light transmitted through tourmaline crystals or reflected from dielectric surfaces is satisfactory evidence to the laboratory student that the light is polarized and therefore a transverse wave. However, the means of determining the plane of polarization are by analogies and therefore unsatisfactory. It is customary to say that when the wave is incident at Brewster's angle, the component polarized perpendicularly to the plane of incidence "glances off" the surface of the dielectric while the component polarized in the plane of incidence "digs in". The skipping stone analogy is an aid to the memory but not an experimental evidence of the plane in which the light is polarized.

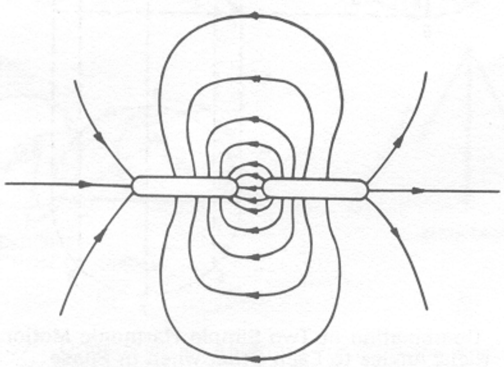


Fig. 31 Electrostatic Field of a Dipole

If the study of microwaves precedes the study of light waves, the student need have only an experimental picture of the electrostatic field around a dipole to determine the plane of polarization of the microwaves. Experimental pictures such as Fig. 31 are drawn in the elementary laboratory from glass wool patterns on a glass plate above the dipole or from a three-dimensional examination of the field with an electrostatic needle.

When the potential between the dipoles is alternating at microwave frequencies, the electric lines of force are "snapped off" in loops which travel outward as waves. When oscillating currents are present in the dipoles, oscillating magnetic fields are also produced which travel out as a part of the electromagnetic wave, in a manner shown by Fig. 32. In this figure, dots indicate magnetic field directed out of the plane of the paper; crosses represent magnetic fields directed into the plane of the paper. *From custom, we shall speak of the plane of the electric field as the plane of polarization.* The antennas of both the receiver and the transmitter are parallel to the field.

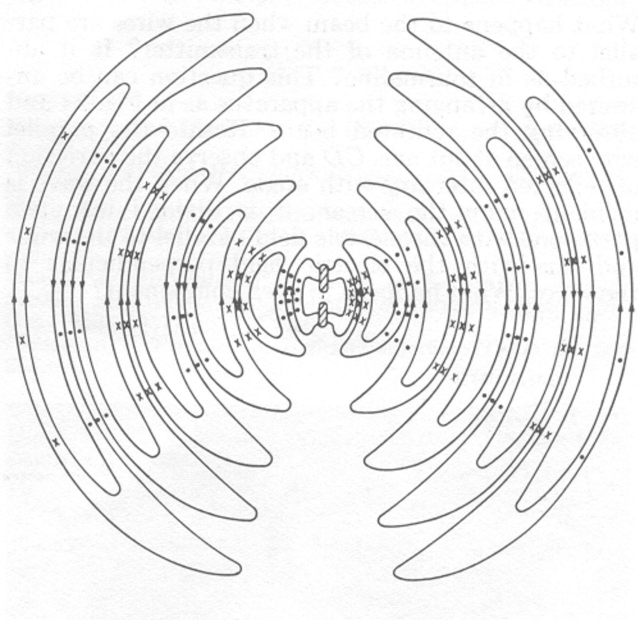


Fig. 32 Radiating Electric and Magnetic Fields from a Dipole with an Oscillating Potential Difference

With the transmitter and receiver arranged as shown in Fig. 33, rotate the intensity meter about axis *AB* by 5° steps through 180°. Plot intensity of radiation against angle on polar graph paper.

Show that the intensity of received radiation should be proportional to the square of the cosine of the angle between the direction of the electric field and the line of the antenna of the receiver. Does the experimental graph check with theory?

A screen of parallel wires about an eighth-wavelength apart may be used in polarization of microwaves much as polaroid is used with light. The parallel wires can be seen, but crystal structure can not.

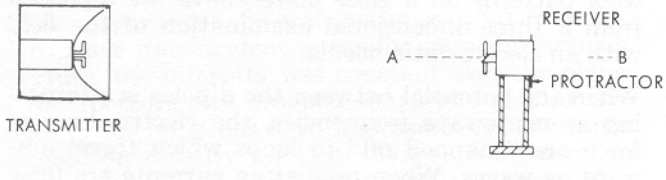


Fig. 33 Arrangement for Studying Polarization of Microwaves

Hold the parallel wire screen in the beam between transmitter and intensity meter with its plane perpendicular to line AB of Fig. 33 and rotate it slowly about axis AB. In what position does it transmit the beam? Compare the variation of intensity with angle with that when the intensity meter was rotated. If the polarizing screen is near the transmitter or receiver, Fresnel diffraction around the screen will be slight. To avoid diffraction effects, use the metal screen as in Fig. 28 and place the parallel wire screen over the first zone aperture.

What happens to the beam when the wires are parallel to the antenna of the transmitter? Is it absorbed as in tourmaline? This question can be answered by arranging the apparatus as in Fig. 34 and observing the reflected beam. Rotate the parallel wire screen about axis CD and observe the variation of reflected intensity with angle. When the wave is incident upon the screen, it is divided into two parts, one with the electric field parallel to the wires and one with the electric field perpendicular to the wires. What happens to each component?

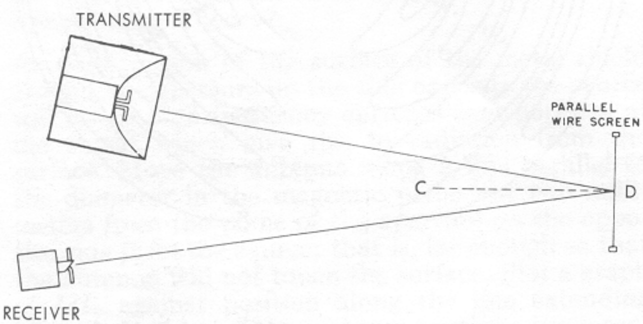


Fig. 34 Arrangement for Studying Reflection from Parallel Wire Screen

Returning to the arrangement of Fig. 33, rotate the intensity meter about line AB until it is set for extinction; that is, its antenna is at right angles to that when the antennas were parallel and the screen about axis AB (Fig. 33) through 360°. How does the number of maxima and minima compare with that when the antennas were parallel and the screen was rotated? Plot a graph on polar paper of intensity of radiation received by the receiver against angular position of the screen.

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Howe, *Introduction to Physics* (McGraw-Hill, 1942) pp. 542-550.
Hausmann and Slack, *Physics* (VanNostrand, ed. 2, 1939) pp. 698-710.
Valasek, *Elements of Optics* (McGraw-Hill, 1932) pp. 150-177.
Jenkins and White, *Fundamentals of Physical Optics* (McGraw-Hill, 1937) pp. 312-332.
Wood, *Physical Optics* (Macmillan, ed. 3, 1934) pp. 329-345.
Houstoun, *A Treatise on Light* (Longmans, 1927) pp. 186-203.

15 elliptical polarization

When two waves of the same frequency are traveling in the same direction and are polarized at right angles to each other, the resulting wave is elliptically polarized. We shall treat the case in which both components are of the same amplitude.

Fig. 35 indicates how two simple harmonic motions along paths AB and CD are combined for the case when the two components are in phase. Fig. 36 is a similar addition when the components are 45° out of phase. If he has never done so, the student should make similar graphical additions when the two components are 90, 135 and 180° out of phase.

If the two secondary sources from Experiment 2 (shown in Fig. 8) are arranged with their antennas at right angles as in Fig. 37a and the faces of the two parabolic reflectors are in the same plane, the resulting plane of polarization is found to be horizontal as indicated in Fig. 37b. The arrows, which indicate relative phase of the two sources, have been

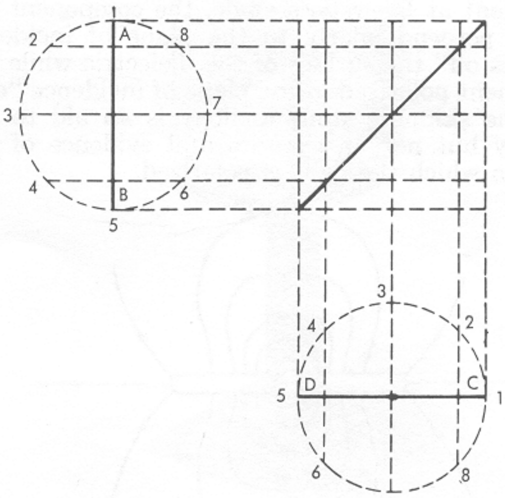


Fig. 35 Combination of Two Simple Harmonic Motions at Right Angles to Each Other when in Phase

drawn in the direction from the grounded half to the elevated half of the dipole antenna. If one of the two antennas is rotated through 180° as in Fig. 37c, the resulting plane of polarization is horizontal as shown in Fig. 37d.

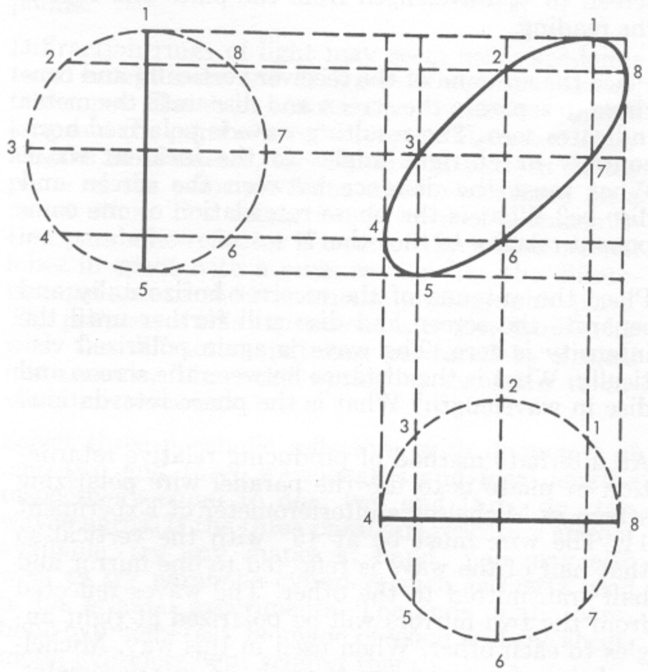


Fig. 36 Combination of Two Simple Harmonic Motions at Right Angles to Each Other, 45° out of Phase

Using the equipment from Experiment 2 arranged as indicated in Fig. 38 but with the rims of the parabolic reflectors in the same plane, check the predictions of the preceding paragraph. If the two coaxial lines are not of precisely the same length, it may be necessary to move one of the sources backward or forward a few millimeters before the resultant beam is plane polarized.

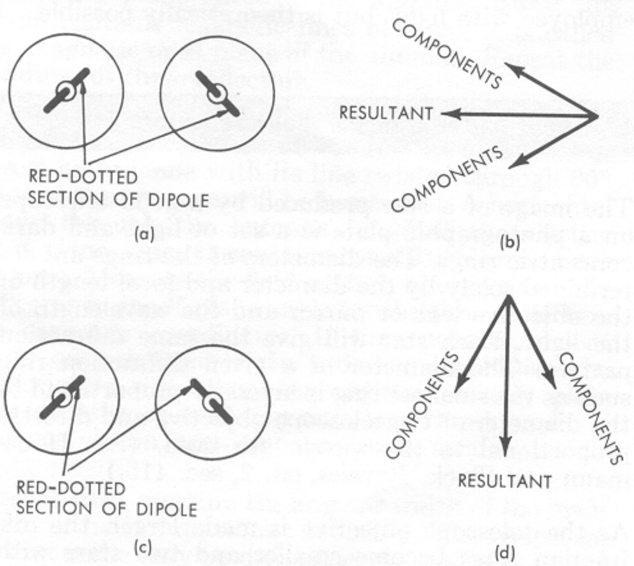


Fig. 37 Orientation of Antennas for Studying Addition of Waves Polarized at Right Angles to Each Other

Next, move one of the two sources an eighth-wavelength nearer the receiver. The resulting wave should be elliptically polarized as predicted in Fig. 36. Rotate the receiver through 360° by steps of 10° and plot the intensity on polar paper. To check with predictions, plot the square root of the intensity, or amplitude, against angle. In like manner, move one source a quarter-wavelength ahead of the other and repeat. Predict and check the results when the difference in distance from the sources to the receiver is increased by steps of a quarter-wavelength. Under what conditions is the polarization circular?

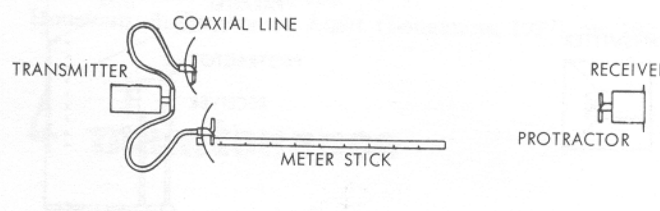


Fig. 38 Arrangement for Production of Elliptical Polarization

References:

Hausmann and Slack, *Physics* (VanNostrand, ed. 2, 1939) pp. 707-710.

Lindsay, *Physical Mechanics* (VanNostrand, 1933) pp. 55-59.

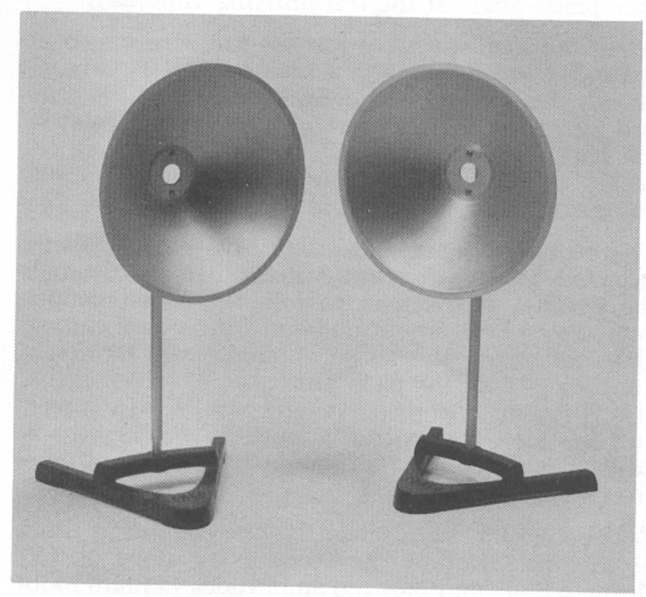
Hoag, *Basic Radio* (VanNostrand, 1942) pp. 171-175.

Valasek, *Elements of Optics* (McGraw-Hill, 1932) pp. 169-172.

Wood, *Physical Optics* (Macmillan, ed. 3, 1934) pp. 346-387.

Jenkins and White, *Fundamentals of Physical Optics* (McGraw-Hill, 1937) pp. 334-352.

Houstoun, *A Treatise on Light* (Longmans, 1927) pp. 204-211.



No. 80429-3 Parabolic Reflectors

16 elliptical polarization by relative retardation

A plane-polarized wave may be divided into two components polarized at right angles to each other, with one component retarded in phase relative to the other, by two methods: (1) by causing the two components to travel paths of different length before uniting; (2) by passing them through a doubly refracting medium in which the two components travel at different speeds. The latter method is employed in the science of crystallography, the engineering study of mechanical strain in models of complex structures, and in electro-optical shutters. The first method will be employed in this experiment because of its simplicity.

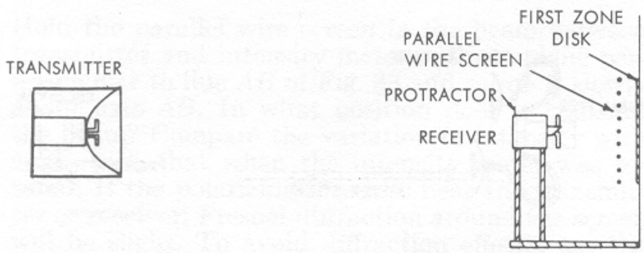


Fig. 39 Arrangement for Production of Elliptical Polarization of Reflected Waves

Fig. 39 is an arrangement for the production of elliptical polarization with one of the components retarded in phase by traveling an extra distance, as done in Experiment 15. The metal disc is the first zone disc of Experiment 12. With the parallel wire screen removed, set the receiver at the diffraction maximum by moving it a few millimeters in the wooden frame. The parallel wire screen from Experiment 14 may be supported by a wooden tripod and clamp in front of the disc with its plane parallel to that of the disc. Rotate the screen until the wires make an angle of 45° with the plane of polarization (the phase angle of the transmitting antenna).

When the incident wave reaches the wire screen, it is divided into two components of nearly equal amplitude, one with electric field parallel to the wire and the other with the electric field perpendicular to the wire. The field parallel to the wire will be reflected and the field perpendicular to the wire will be transmitted.

The component perpendicular to the wires will be reflected by the disc and will again pass through the parallel wire screen to join the other component. Since both waves undergo 180° phase change upon reflection, the phase difference will be determined solely by the path difference in wavelengths. If d is the distance between the parallel wire screen and the disc, the path difference in wavelengths is $2d/\lambda$. The phase retardation of one component relative to the other is $4\pi d/\lambda$.

Set the parallel wire screen $1/16$-wavelength in front of the disc. Rotate the receiver by steps of 15° through 360° and plot the amplitudes (square roots of intensities on polar graph paper. In order that your body will not interfere, read the intensity meter from behind the transmitter. Move the wire screen to $1/8$-wavelength from the plate and repeat the reading.

Place the antenna of the receiver vertically and continue to separate the screen and disc until the meter indicates zero. The resulting wave is polarized horizontally or at right angles to the incident wave. What must the distance between the screen and disc be? What is the phase retardation of one component relative to the other?

Place the antenna of the receiver horizontally and separate the screen and disc still further until the intensity is zero. The wave is again polarized vertically. What is the distance between the screen and disc in wavelength? What is the phase retardation?

An alternate method of producing relative retardation in phase is to use the parallel wire polarizing screen in Michelson's interferometer of Experiment 11. The wire must be at 45° with the vertical so that half of the wave is reflected to one mirror and half transmitted to the other. The waves reflected from the two mirrors will be polarized at right angles to each other. When used in this way, Michelson's interferometer is not really an interferometer, since the two components do not interfere but combine to form an elliptically-polarized beam. If the antenna of the receiver is kept vertical, the intensity will go through the same maxima and minima when mirror B of Fig. 22 is moved toward the sources as it did in Experiment 11 when interference was involved. When this method is used, the receiver may be rotated to follow the major axis of the ellipse. Thus the receiver will be rotated once for every wavelength that the screen is moved, effectively adding a circular micrometer scale to Michelson's interferometer. This method has never been employed with light, but is theoretically possible.

17 field patterns of parabolic reflectors

The image of a star produced by a good telescope on a photographic plate is a set of light and dark concentric rings. The diameters of the rings are determined solely by the diameter and focal length of the objective lens or mirror and the wavelength of the light. Each star will give the same diffraction pattern. The diameter of a given diffraction ring such as the smallest ring is inversely proportional to the diameter of the telescope objective and directly proportional to the wavelength used. (See Hausmann and Slack, *Physics*, ed. 2, sec. 415.)

As the telescope objective is made larger, the diffraction rings become smaller and two stars with smaller angular separation may be resolved. To make the diffraction rings from a "point" source under a microscope smaller, the shorter ultra-violet waves, or the still shorter waves associated with an electron beam in an electron microscope are employed. As the rings become smaller, points closer together on the object may be resolved as separate points.

Diffraction rings of light may seem quite academic to all except users and designers of microscopes and telescopes. However, when the waves are five inches long and the parabolic reflectors are but a few wavelengths in diameter, the diffraction pattern in the plane of the principle focus can be measured on a meter stick. The diffraction pattern of a transmitting parabolic reflector is a set of three-dimensional lobes in space with a cross section like the diffraction pattern of the star on the photographic plate. The purpose of this experiment is to give familiarity with the diffraction patterns produced by optical instruments. The word optical is extended to include microwaves.

Select three parabolic reflectors, with diameters of one, two and three wavelengths and focal lengths respectively equal to one, two and three quarter-wavelengths. If the three parabolic reflectors are not available, try any shapes at hand. You may also wish to try parabolic cylinders such as Hertz used in his original experiments. The ends of the parabolic cylinders may be made of wood and the sheet-metal cylinders bent around them.

Mount the transmitter out of doors facing away from any buildings, at least four feet above level ground. There should be no trees or larger reflecting objects within fifty feet of the transmitter. Using a string, construct on the ground a 180° protractor twenty feet in radius by driving stakes at 5° intervals around the semicircle.

Attach one of the parabolic reflectors to the front of the transmitter by means of a coaxial line and measure the intensity at points above the stakes in the horizontal plane through the antenna. Since this plane contains magnetic lines of force, it is called the magnetic or H plane of the antenna. Repeat the reading for three reflectors.

Rotate the transmitter 90° about the axial line or insert an antenna with its line twisted through 90° so that the antenna will be horizontal. A horizontal plane through the antenna is called the electric or E plane, since it contains complete electric lines of force. Measure the field pattern of each parabolic reflector in the E plane angle for the three reflectors on cartesian coordinates. If time permits, repeat plots on polar paper. In order to emphasize the undesirable side lobes, the engineer usually plots the intensity of radiation on a logarithmic scale. If you can obtain semi-log paper, make such a plot.

In each case, measure the angular width of the main beam at half of maximum intensity. The reciprocal of that angle may be defined as the resolving power of the radiator. Compare the resolving powers of the parabolic radiator in both H and E planes. If radiation were reflected back by an airplane behind a distant cloud and received by a sensitive detector near the transmitter, with which of three transmitters could you determine the direction of the plane most precisely?

If an airplane flew through a side lobe, it might reflect back sufficient intensity to be detected, but the observer would not know whether the plane was in the main beam or one of the side lobes.

REFERENCES:

Hausmann and Slack, *Physics* (VanNostrand, ed. 2, 1939) pp. 689-691.

Valasek, *Elements of Optics* (McGraw-Hill, 1932) pp. 142-145.

Wood, *Physical Optics* (Macmillan, ed. 3, 1934) pp. 267-268.

Jenkins and White, *Fundamentals of Physical Optics* (McGraw-Hill, 1937) pp. 121-126.

Houstoun, *A Treatise on Light* (Longmans, 1927) pp. 182.

4 maintenance

4.1 general notes

Because the Cenco Microwave Apparatus is a well designed and ruggedly built unit, it needs no special care. Operation in accordance with the instruction manual should provide trouble-free service.

4.2 tube replacement

With constant use the transmitter tube may have to be replaced occasionally. The following procedure is recommended:

(1) Remove the back of the case.

(2) Loosen the clamp that holds the tube socket and the tube to the cavity.

(3) Slide the clamp forward onto the cavity tube.

(4) Grasp the tube and socket and pull *straight* back to remove them.

(5) Remove the toroidal contactor from the tube and remove the tube from the socket.

(6) Insert a new tube in the socket.

(7) Place the toroidal contactor around the glass portion of the new tube that has the greatest diameter.

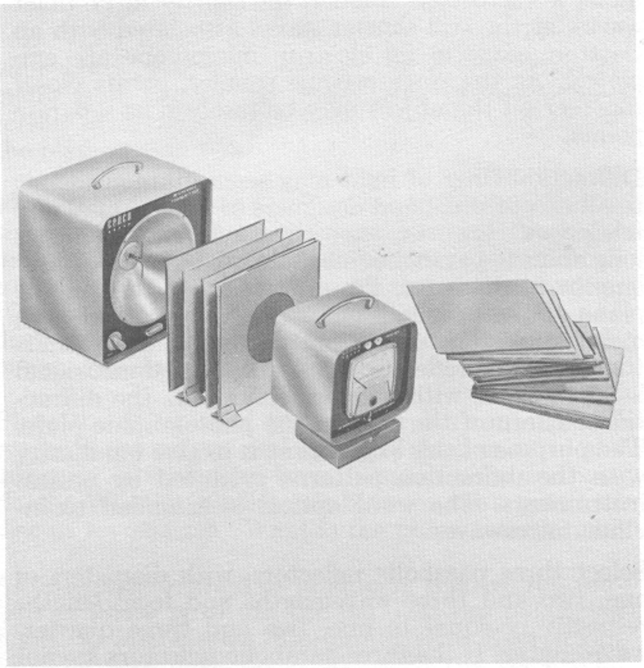
(8) Holding the tube in one hand, *collapse* the toroidal contactor with 3 fingers of the other hand and insert the tube into the cavity as far as possible, maintaining a straight-in direction.

(9) Reposition the cavity spacer ring at the tube-socket end of the cavity and tighten the clamp, half on the tube and half on the ring and cavity.

(10) Replace the rear panel; the transmitter is now ready for use.

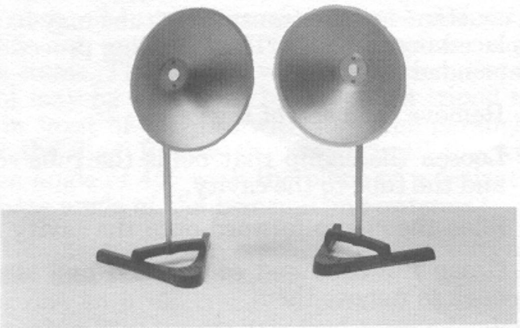
4.3 crystal diode replacement

(1) Remove the clear plastic back from the receiver.
(2) Remove the two nuts that hold the reflector plate to the meter terminals. (See Fig. 4.)
(3) Grasp the half wave dipole antenna and remove the assembly.
(4) Remove the crystal holder and retaining spring.
(5) Using a pair of long nosed pliers, remove the crystal from the half wave dipole.
(6) Insert a new crystal.
(7) Replace the spring and crystal holder, making sure that the crystal-holder lead is positioned around the insulated terminal hole on the left side of the reflector plate.
(8) Replace the dipole assembly on the meter terminals, being careful that the crystal-holder lead terminal engages the meter terminal.
(9) Replace the washers and nuts, tighten securely.
(10) Check to see that the reflector plate is parallel to the front of the case. (It may be necessary to adjust the nuts on the meter terminal.)
(11) Replace the clear plastic back.

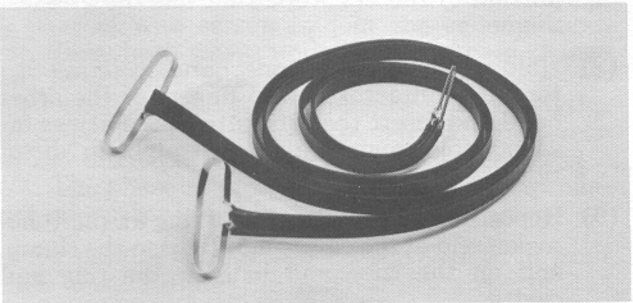


No. 80424-2 Microwave Index of Refraction Experiment

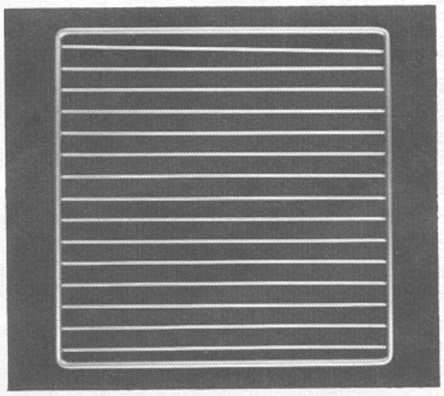
5 replacement parts and accessories



80429-4 REFLECTORS, for use with No. 80429-3 Double Dipole Antenna. Supplied with friction clamp with support rods No. 72165-2 in 72002-1 Support Bases................................PER PAIR $18.25



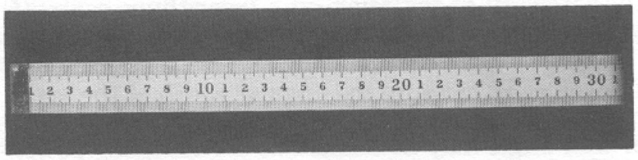
80429-3 DOUBLE DIPOLE ANTENNA, for use with No. 80429-4 Reflectors.................EACH $4.65



80434 GRID, POLARIZATION ANALYZER. The grid consists of parallel wires for demonstrating the polarized nature of the radiation emitted by the transmitter..EACH $2.50

80433 TRANSMITTER TUBE, for replacement in No. 80422 (GE 2C40A)......................EACH $27.50

No. P19336 RECEIVER CRYSTAL for replacement in No. 80422.................................EACH $4.00



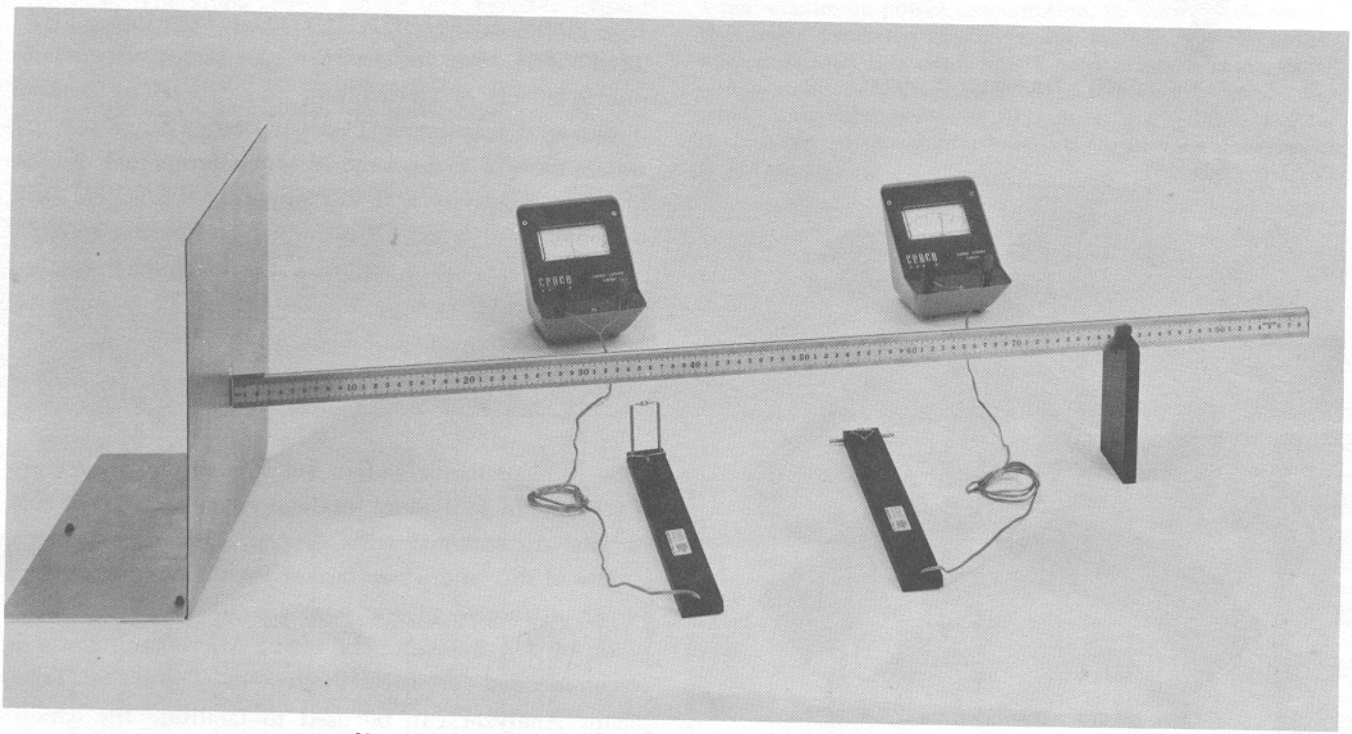
73120 METER STICK, for use with No. 80429-3 Antenna and No. 80429-4 Reflectors....EACH $1.25

P67424 MICROWAVE RECEIVER COMPLETE. The receiver is a crystal detector with a half-wave dipole antenna with leads to a sensitive meter. A switch is provided for shunting the meter from 20 to 100 microamperes. Two banana jacks are located on the receiver front panel for connecting a radio speaker or earphones (see 80785 or 80795) for audible detection. Since the current through the crystal is very nearly proportional to the square of the potential across it, the meter reading is proportional to the intensity of radiation. The metal disk, a quarter wavelength behind the antenna, acts as a reflector. Since the electric field undergoes a change in phase of 180° upon reflection, the reflected wave arrives at the antenna in phase with the incident wave.

Complete with one P19336 Crystal (Type 1N23B) ....EACH $55.00

P67630 MICROWAVE RECEIVER COMPLETE.

No. 82422-2 DC MILLIAMMETER, 0-1 ma. For use with No. 80423, two required. 2% accuracy...... ....EACH $23.50



No. 80423 Accessories with 82422-2 Milliammeters

No. 80423 ACCESSORIES FOR MEASURING *E* AND *H* COMPONENTS OF MICROWAVE FIELDS. For use with No. 80422 Microwave Optics when performing experiment No. 7, *Standing Electromagnetic Waves* ....EACH $27.90

Consists of:

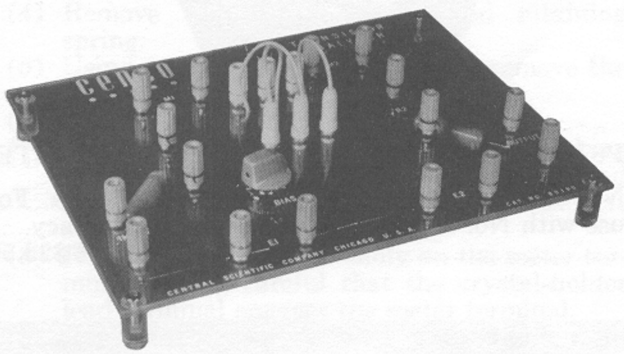
- one Electric Field Probe
- one Magnetic Field Probe
- one Reflector
- one Meter Stick Support
- one Meter Stick

No. 80422 MICROWAVE OPTICS APPARATUS, CENCO, with transmitter tube, but WITHOUT double dipole antenna, reflectors and polarization grid ....EACH $325.00

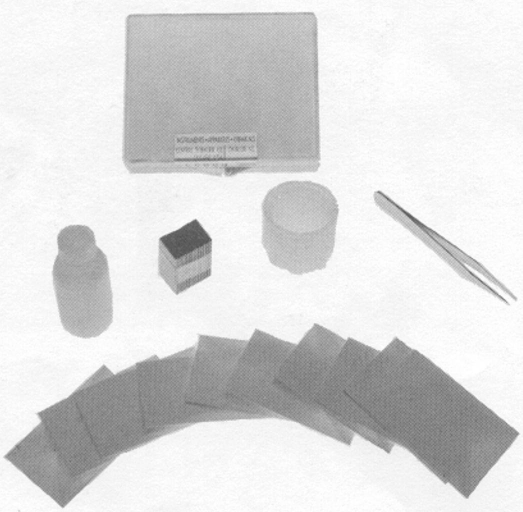
The Microwave Optics Apparatus includes a transmitter with dipole antenna and parabolic reflector; a receiver with receiving dipole, rectifying crystal, reflector plate, and meter; and the manual of suggested experiments. For operation on 115 volt, 50/60 cycle A.C.

PRICES SUBJECT TO CHANGE

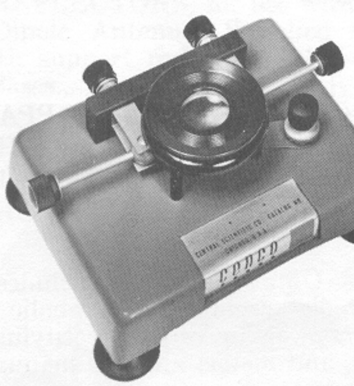
No. 80390 TRANSISTOR ANALYZER. A simple device for demonstrating the basic functions of a transistor — dc current gain, ac voltage gain, and oscillation. The board is designed so that common emitter, common base, or common collector configurations can be quickly set-up by the student using the included instruction book.



No. 80390 Transistor Analyzer



No. 80394 Demonstration Set



No. 80395 Micromanipulator

Consists of a "Lucite" plate, 9 x 11¾ x 3/16 in. thick, provided with binding posts at suitable points for batteries, meters, etc. to enable the user to exercise great freedom in circuit configuration. Supplied without transistor No. 80391 but with detailed operating directions with diagrams. Overall height, 2¼ inches. Approximate weight, 1¾ lbs. (Shipped with Selected Experiment In Physics E94b) and Booklet 315.

Each $39.50

No. 80391 TRANSISTOR. For use with No. 80390 Cenco Transistor Analyzer. Type 2N369 transistor of low frequency and high gain as recommended.

Each $3.95

No. 80394 SEMICONDUCTOR DEMONSTRATION SET. For the study of fundamental semiconductor effects of Germanium and Silicon by making diodes and transistors. Consists of two single crystal wafers each of P type and N type Germanium of high and low resistivity and two single crystal wafers each of P type and N type Silicon of high and low resistivity for a total of 16 wafers. The wafers have a minimum area of 2 sq. cm. The resistance of the high resistivity wafers is greater than 5 ohm-cm and the resistance of the low resistivity wafers is less than 5 ohm-cm.

The semiconductor wafers and the proper solder are packaged in individual, marked envelopes. These materials are supplied with 16 copper plates, tweezers, ottle of flux and a cap beaker for the etching reagent an attractive plastic box, 4⅝ in. long by 3½ in. de by 1½ in. high. The 80395 Micromanipulator is recommended for use with this set. The 80390 Transistor Analyzer can be used to facilitate the experimental set-up and the 16630 Hot Plate can be used to facilitate the assembly.......................... **Each $22.50**

No. 80395 MICROMANIPULATOR. For use with No. 80394 Semiconductor Demonstration Set. Consists of two ball jointed contacts mounted on a non-magnetic metal base with provisions for clamping the semiconductor assembly and binding posts for making the necessary electrical connections. Supplied with Cat. No. 60020 Tripod Magnifier which has ten times magnification. Dimensions: Length, 5 in.; width, 4 in.; height, 2 in..Each $13.75

PRICES SUBJECT TO CHANGE