CHAPTER VIII

INTERFERENCE SPECTROSCOPES

In the Chapter on Diffraction we have discussed the action of the diffraction grating, and we will now take up the subject of the more recently devised spectroscopes, which should have been treated in the Chapter on Interference, but which has been postponed for the reason that certain points cannot be well understood without previously considering the theory of the grating. We will begin with the Michelson interferometer, which is, perhaps, the best-known type.

The Michelson Interferometer. — Interference fringes were employed by Fizeau and others for the study of the composition of light in a crude way (for example the periodic disappearance of the fringes of sodium light in the case of Newton's rings) but A. A. Michelson was the first to construct an instrument of precision based upon interference, and to study systematically the fine structure of spectrum lines.

By his brilliant invention of the interferometer he opened up a wide field of research and furnished us with an instrument capable of showing in a most beautiful manner the interference phenomena of thin and thick plates, wedge-shaped or plane-parallel, which we have studied with simpler apparatus.

The essential parts of this instrument are four plates of glass arranged as shown in Fig. 186. Plates A and B are cut from the same piece of glass accurately plane-parallel. Both may be transparent or A may be half silvered on the surface opposed to B. Plates C and D are heavily silvered on their front surfaces. Plate D is mounted on a carriage arranged so that it can be moved along parallel ways by means of a screw. The action of the apparatus is as follows: Light from a source S made slightly convergent by a lens falls upon the plate A, the beam being divided into two portions by the half-silvered surface. If the source has a considerable area, such as a flame, no lens is required. One portion is reflected to the mirror D, the other transmitted through B to the mirror at C, which is fixed in position. The mirror D returns the light to A, a portion of it escaping through the half-silvered film and entering the observer's eye, which is located at O, at which point the convergent beam should come to a focus. The light reflected back

from C is in part reflected from the silver film and enters the eye over the same path. If the path-difference is an odd number of half wave-lengths, these two streams will interfere destructively and we shall have darkness. The path-difference between the two rays can be altered by moving the mirror D by means of the screw, consequently the point in question upon the half-silvered surface will appear alternately bright and dark as the carriage is moved along the ways. The plate B is not essential, and its object will be explained presently. We can get a better idea, perhaps, of the action of the instrument in the following way: The mirror C is seen by reflection in the half-silvered film in coincidence with the mirror D,

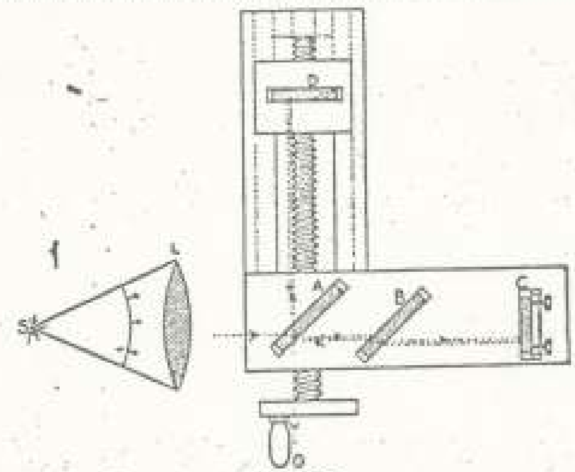

FIG. 186

if the optical paths are the same. The instrument is thus the equivalent of two parallel reflecting surfaces, one real the other virtual, the distance between which can be varied. The phenomena presented by the interferometer are thus similar to those shown by thin films, the difference lying in the fact that in the present case we may make the distance between the reflecting surfaces as great or as small as we please.

The fact that the two beams which interfere are widely separated (at right angles) makes it possible to introduce objects of large area (*e.g.* a tube filled with a gas, the dispersion of which is to be investigated) is of great importance. One of the reflecting planes being a virtual image, results can be accomplished which are impossible with two material reflectors, for one can be brought into exact coincidence with the other, or made to pass through it. If the virtual reflector makes a small angle with the real one, and the distance between them is small, we observe the fringes shown by thin wedge-shaped film (such as are seen in the case of Newton's rings). These are located in the plane of the reflector. By moving the mirror forward or back we can cause the reflecting planes to intersect along a line, and along this line we have the black "central fringe" seen with white light which corresponds to the Newton black spot observed on very thin soap-films. The change of phase occurs at the oblique mirror, one reflection being from a glass-silver surface, the other from silver-air. If the two reflecting planes (the real and the virtual one) are exactly parallel, we have circular fringes (located at infinity) of the type first described by Haidinger. These are best seen with a telescope or with the eye focussed for distance. This type of interference we have already studied in the case of thick plates. We can, with this instrument watch the increase in the diameter of the circular Haidinger fringes as the reflecting planes approach each other, until, when they are practically in contact, the whole field becomes uniformly bright or dark, according to the exact setting of the mirror. This means merely that the central circular spot of the fringe system has become so large that it fills the entire field of view.

The plate B is called the compensator, and is introduced to make the two optical paths symmetrical. In its absence it is obvious from the diagram that one of the interfering beams which enters the eye has traversed the plate A three times, while the other has passed through it but once; the double transit of the latter ray through the compensator makes the two paths optically equivalent. The compensator has also another use, for by turning it slightly we can increase or diminish the optical path, thus compensating for and measuring a change produced in the other path, as, for example, by the introduction of a thin film, the refractive index of which we wish to determine.

Adjustment of Interferometer. — The following directions for the use of the instrument are taken from Mann's *Manual of Advanced Optics*. "Measure roughly the distance from the silver half-film upon the rear of the plate A to the front of the mirror C. Set the mirror D, by turning the worm wheel, so that its distance from the rear of A is the same as that of C from A. This need not be done accurately. It is suggested because it is easier to find the fringes when the distance between the mirror D and the virtual image of the mirror C is small. This distance will hereafter be called the distance between the mirrors.

"Now place a sodium burner, or some other source of monochromatic light, at S, in the principal focus of a lens of short focus. It is not necessary that the incident beam be strictly parallel. Hold some small object, such as a pin or the point of a pencil, between L and A."

A pin-hole in card is preferred by the author, as the vertical and horizontal adjustments can be made with greater precision. It must be removed when looking for fringes of course.

"On looking into the instrument from O, three images of the small object will be seen. One image is formed by reflection at the front surfaces of A and D; the second is formed by the reflection at the rear surface of A and the front surface of D; the third is formed by reflection from the front surface of C and the rear surface of A. Interference fringes in the monochromatic light are found by bringing this third image into coincidence with either of the other two by means of the adjusting screws upon which the mirror C rests. If, however, it is desired to find the images in white light, the second and third of these images should be brought into coincidence, because then the two paths of the light in the instrument are symmetrical, *i.e.* each is made up of a given distance in air and a given thickness of glass. When the paths are symmetrical, the fringes are always approximately arcs of circles as described above. If, however, the first and third images are made to coincide, then the two optical paths are unsymmetrical, *i.e.* the path from A to C has more glass in it than from A to D, and in this case the fringes may be ellipses or equilateral hyperbolae, because of the astigmatism which is introduced by the two plates A and B. It is quite probable that the fringes will not appear when the two images of the small objects seem to have been brought in to coincidence. This is simply due to the fact that the eye cannot judge with sufficient accuracy for this purpose when the two are really superposed. To find the fringes, then, it is only necessary to move the adjusting screws slightly back and forth. As the instrument has here been described, the second image lies to the right of the first.

"Having found the fringes the student should practise adjustment until he can produce at will the various forms of fringes. Thus the circles appear when the distance between the mirrors is not zero, and when the mirror D is strictly parallel to the virtual image of C. The accuracy of this adjustment may be tested by moving the eye sideways and up and down while looking at the circles. If the adjustment is correct, any given circle will not change its diameter, as the eye is thus moved. To be sure, the circles appear to move across the plates because their centre is at the foot of the perpendicular dropped from the eye to the mirror D, but their apparent diameters are independent of the lateral motion of the eye. For this reason it is advisable to use the circular fringes whenever possible.

"To find the fringes in white light, adjust so that the monochromatic fringes are arcs of circles. Move the carriage rapidly by intervals of a quarter turn or so of the worm wheel. When the region of the white-light fringes has been passed, the curvature of the fringes will have changed sign, *i.e.* if the fringes were convex toward the right, they will now be convex toward the left. Having thus located within rather narrow limits the position of the mirror *D*, which corresponds to zero difference of path, it is only necessary to replace the sodium light by a source of white light, and move the mirror *D* by means of the worm slowly through this region until the fringes appear."

A better control of the motion can be obtained by placing a small white gas flame behind the sodium flame. This gives us a white spot in the centre of the field, on which the colored fringes appear when we reach the centre of the system.

"These white-light fringes are strongly colored with the colors of Newton's rings. The central fringe — the one which indicates exactly the position of zero difference of path — is, as in the case of Newton's rings, black. This black fringe will be entirely free from color, *i.e.* perfectly achromatic, if the plates *A* and *B* are of the same piece of glass, are equally thick, and are strictly parallel. If they are matched plates, *i.e.* if they are made of the same piece of glass and have the same thickness, their parallelism should be adjusted, until the central fringe of the system is perfectly achromatic. When this is correctly done, the colors of the bands on either side of the central one will be symmetrically arranged with respect to the central black fringe."

If the instrument is illuminated with sodium light it will be found that the fringes become invisible periodically as the mirror is moved, for reasons which have been given in the Chapter on Interference. It will be found instructive to illuminate the instrument with a lithium flame containing a little sodium, and note the shortness of the periods of indistinctness. In using the instrument to measure the refractive index or dispersion of a gas, the tube containing the gas can be closed with plates of thin plate glass, which, if of good quality, do not much affect the appearance of the fringes. The tube is highly exhausted and the gas then slowly admitted, the shift in the fringe system being determined by counting the number of bands which cross the hair in the telescope used to view them.

The interesting investigation by Johonnott [1] on the thickness of the "black spot" on soap-films, is an example of the many interesting applications of the interferometer. If we know the thickness of a transparent plate we can measure its refractive index by inserting it in one of the optical paths of the instrument and measuring the fringe displacement. The white system must be used of course in conjunction with the sodium or other monochromatic system, as the central fringe is the only one that can be identified. The abnormal displacement of the central band referred to in the Chapter on Interference must also be remembered.

[1] *Phil. Mag.*, 47, 501, 1899.

It is evident now that if the refractive index of a film is known the thickness can be determined. Johonnott found that, by employing a battery of 54 soap-films mounted on frames, it was possible to get a measurable shift of the fringes even when the films were so thin that they refused to reflect light, *i.e.* showed the Newton black.

The thickness was found to vary between .00006 mm. and .0004 mm.

Effects of Surface Films on the Mirrors. — In general the central fringe, with white light, is black: its locus being the intersection of the real mirror with the virtual image of the other. The path-difference being zero in this case, it is obvious that the destructive interference must result from a phase-change due to reflection of the two rays under different conditions, as is the case with the "black spot" of Newton's rings, as we have seen. With the type of interferometer used by Michelson in repeating Fizeau's experiment on the velocity of light in a moving current of water, the central fringe is white instead of black, as no phase-change occurs in this case. One ray is reflected twice from silver (once from the air side and once from the glass side), while the other ray is twice transmitted through the silver. As Zeeman [1] has shown, however, if the silver is modified by the action of chemical vapors, the central fringe may become black. A copper mirror obtained by cathodic sputtering gave a black fringe unless protected by a thin film of celluloid, applied immediately after the sputtering. Gold and silver mirrors give a white central fringe, but curiously enough an alloy of 10% Au–90% Ag gave a black one. In all cases where a very high degree of accuracy is required, it is well to guard against possible deterioration of the metal film with time. Zeeman found that a freshly sputtered silver film gave a white central fringe, midway between two dark ones, but in half an hour it had moved towards one of the dark fringes by one-sixth of the fringe width.

Twyman and Green's Application of the Interferometer to the Correction of Imperfections in Prisms and Lenses. — A very great advance in the method of testing and correcting imperfections in prisms and lenses was made at the firm of Adam Hilger by Twyman

[1] Zeeman, *Zeit. f. Phys. Chemie*, Cohen-Festband, 1927.

and Green. The interferometer is illuminated by plane-waves furnished by a point source at the focus of an extremely well-corrected lens. A screen perforated with a hole .5 mm. in diameter is placed in front of the source, which may be a mazda lamp with opal globe. The first objective is placed in the position L shown in Fig. 187 and a second objective placed at O which focusses the

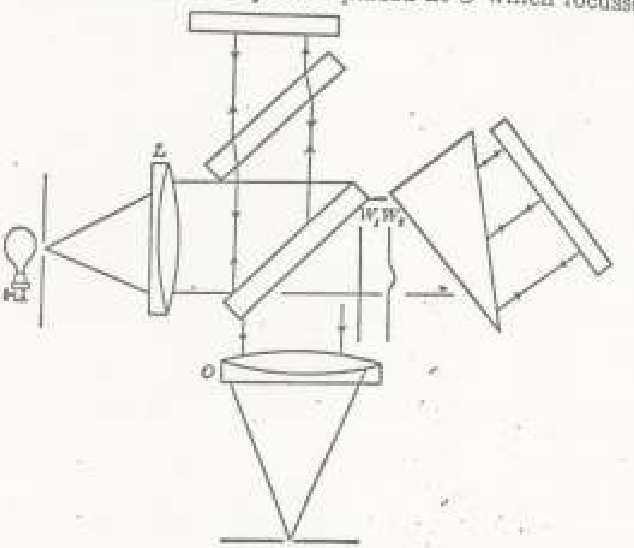

Fig. 187

waves upon a small aperture in a second screen, through which the observations are made. The improvement over the old method of using the interferometer lies in the use of truly plane-waves, and the second objective. If the two uniting wave-fronts are both truly plane, the whole field of view will appear of uniform intensity (or color). If now a prism P is introduced into one path as shown in the figure, any distortions of the plane-wave-front resulting from two transmissions through the prism cause fringes to appear on the uniformly illuminated field. If, for example, there is a globular region in the prism of slightly higher refractive index than that of the rest of the glass, a system of concentric rings will appear, and the area in which they appear is marked on the face of the prism. As Twyman shows [1] this fringe system may be regarded as contour lines of the deformed wave-front, which localize the regions of equal elevation (or depression) like the contour lines on a map.

The fringes would present the same appearance if the wave-front were reversed, the elevations becoming depressions, and we require,

[1] *Phil. Mag.*, 35, 49, 1918.

therefore, some method of distinguishing between the two as we must know whether the bad spot in the prism has a higher or lower refractive index than that of the rest of the glass. This can be done by pressing against the support of the mirror behind the prism, which retards slightl the reflected wave-front and the fringes expand if the deformation is a "valley" in wave-front W_2 as shown in the figure, while if the deformation is a hill, the rings will close in. In the former case the region causing the deformation has a higher refractive index than that of the surrounding glass, and the correction is made by marking the area on the face of the prism and then rubbing away some of the glass from the surface with a very small polishing tool until the field becomes uniform again. In other words the thickness of the prism has been locally reduced to compensate for the local high index of refraction. The prism obviously has been corrected in this case for two transmissions, and would have to be used with the original plane (or uncorrected surface) silvered, the rays being reflected back to the single lens which serves as collimator and telescope (Littrow spectrograph).

For a prism which is to be used in the usual way with a single transmission, the correction would be one-half of that indicated by the interferometer.

The method has been adapted also to the correction of lenses, and practically perfect lenses, prisms and plates can now be made from glass which is not absolutely homogeneous, — and even the best optical glass is not free from defects.

The Twyman and Green interferometer can be [illegible]sted by the following method, which can be used as an altern[illegible]e to the one given for the Michelson instrument (which is mere[illegible] the T. and G. one without the lenses).

Two spots of light are seen on the back of the perforated screen in front of the lamp, caused by the rays which pass through the half-silvered plate after reflection from the two back mirrors, and two similar spots on the screen at the focus of the second objective. The two pairs of spots should be brought simultaneously into coincidence with the two apertures, by tilting the half-silvered plate and one of the back mirrors. The opal lamp is then replaced by a sodium flame or other source of monochromatic radiations and on looking through the eye aperture, the fringes are seen, which can be widened by tilting one of the back mirrors until one of them fills the entire field. If the screens are painted white, it is easier to see the small spots.

There is an essential difference between this method of testing plates and that employed by Fizeau, which was described in the

Chapter on Interference. We are dealing here with two transmissions through, say, a plate of thickness t. The retardation on the other ray is therefore $2\mu t-2t$ or $2(\mu-1)t$, which is the quantity tested. In the Fizeau instrument, in which the light is reflected from the upper and lower surface of a plate, the retardation is simply that of the plate, or $2\mu t$. Plates for echelon gratings, which will be described presently, require the constancy of $(\mu-1)t$, as they are used with a single transmission.

To correct a large plate which is to be cut up into echelon plates, the Fizeau fringes and the fringes obtained with the Twyman and Green interferometer are plotted, by which variations in the refractive index can be found to the sixth decimal place.

Determination of Refractive Index and Dispersion with the Interferometer. — The refractive index of a transparent plate and its dispersion can be obtained by means of white light in combination with monochromatic light of a single wave-length. The determination of the dispersion is based upon the shift between the *true* and the *apparent* position of the centre of the system of fringes formed by white light, which we have just studied. The plate should be sensibly plane-parallel, and should be cut in two, the two portions placed in the paths of the interfering beams in such positions that they cover the same portion of the field. We may illuminate the instrument with a sodium flame backed by a candle flame. The two pieces of the plate should be so arranged that they can be rotated about vertical axes, one of them very slowly and uniformly, the angles of rotation being measured with a mirror and scale. We can set them normal to the rays, by turning them to the point where the direction of motion of the fringes resulting from the increase of path with increasing incidence angle reverses.

Adjust the instrument so that both the white-light fringes and the sodium fringes appear in the field. Then turn one plate through a convenient angle, which is read from the scale. Turn the other plate very slowly, counting the sodium fringes as they pass over the cross hair of the observing telescope until the white fringes again appear and occupy their former position. Let the angle through which the plates have been turned be i, the fringe count $2N$, the thickness of the glass t, its refractive index μ, and the wave-length of the sodium light λ, it can be shown that

$$\mu=\frac{(t-N\lambda)(1-\cos i)+\frac{N^2\lambda^2}{2t}}{t(1-\cos i)-N\lambda},$$

in which the term $N^2\lambda^2/2t$ is negligible. We now restore one plate to its original position, and move the interferometer mirror until

the white-light fringes appear in their former position, counting the sodium fringes as they cross the hair. The number will be greater than $2N$, the difference, which we will call $2N'$, being due to the dispersion.

The Cauchy dispersion formula can be assumed, $\mu=A+B/\lambda^2$, and we have $N'=2Bt'/\lambda^3$, in which t' is the thickness of the glass introduced by the rotation,[1] as was shown in the Chapter on Interference.

Light-Waves as Standards of Length. — Probably the most important use to which the interferometer has been put was the determination of the length of the standard metre in wave-lengths of the monochromatic radiations from cadmium. The invariableness of the wave-length of the radiation sent out from the atoms of a metal, brought to a state of luminescence by electrical discharges in a high vacuum, suggests their adoption as a standard of length. This proposition was first made by Lamont in 1823, and subsequently by Dr. Gould about fifty years ago. At that time the interferometer in its present form was unknown, and the method proposed involved the use of the diffraction grating, the measurement of its width, and the determination of angles, all of which measurements would have entailed no very inconsiderable errors. Michelson suggested the use of his interferometer, and through the efforts of Dr. Gould, who represented the United States in the International Committee of Weights and Measures, was asked to carry out the experiments at the International Bureau at Sèvres in collaboration with Benoit. A very complete description of the method will be found in Professor Michelson's book, *Light-Waves and Their Uses* (Chicago University Press, 1903).

The general principle of the method can be briefly outlined as follows: —

The problem is to measure the distance between the two marks on the standard metre bar in terms of the wave-length of light, or, in other words, find out how many light-waves there are in a beam a metre long.

A bronze bar 10 cms. in length, of the form shown in Fig. 188, was prepared; on the ends of which two silvered-glass mirrors were mounted which could be made accurately parallel by observing the interference fringes, formed in the manner to be described presently. The principle consisted in finding the number of light-waves in a beam whose length was equal to the distance between the planes of the two mirrors, and then to find how many times this distance was contained in the metre. In a length of 10 cms., there are, however, roughly 300,000 light-waves, and the direct

[1] Mann's *Manual of Optics*.

determination of this number by actual count would have involved too much labor and too great a risk of accidental mistakes. Nine other standards similar to the above were therefore prepared, each half as long as its predecessor, *i.e.* of lengths 10, 5, 2.5, 1.25, etc., cms.; the smallest unit had mirrors with reflecting planes only .39 mm. apart. The number of light-waves in this distance was first determined for the red, green and blue radiations from a vacuum tube containing cadmium vapor. This was accomplished by putting the bar with its two mirrors in the place of one of the mirrors of the interferometer; the other mirror was then brought into such a position that the central fringe (white light) appeared in the field of, we will say, the lower mirror. By moving the mirror back the centre of the system could be made to appear in the upper mirror, and by counting the number of fringes which passed during this operation the number of wave-lengths in the distance through which the mirror moved could be determined.

Fig. 188

This first "*etalon*," as it was called, was next compared with the second by mounting the two side by side, in place of the movable mirror of the interferometer. The field of view now consisted of four square areas corresponding to the four mirrors of the *etalons*. The longer of the two (No. II) was fixed in position, while the shorter (No. I) could be moved by turning the screw of the instrument. The reference plane (image of the interferometer mirror seen in the plate) was then brought into coincidence with the front surface of the lower mirrors of the two etalons (the plane of the lower dotted line in Fig. 189), by moving the interferometer mirror until the colored fringes appeared. This mirror, which is usually fixed, in the present type of instrument could be moved along parallel ways. It was then moved back until the reference plane coincided with the upper mirror D of etalon I, the plane R'. The fringes passing during this motion of the mirror were counted, the number of course corresponding with the number previously determined.

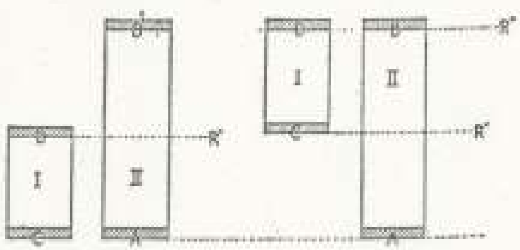

Fig. 189

Etalon I was now moved back until C came into coincidence with the reference plane R' (Fig. 189). The reference plane was now moved to R'', until it coincided with D' in its new position, and was within a few wave-lengths of the plane of B, the number being found by turning the compensating plate. The second etalon was then compared with the third, and so on, until finally the number of wave-lengths in the 10 cm. etalon had been determined. A mark on this etalon was then brought into coincidence with one of the end marks on the metre bar under the microscope, and the etalon was then progressively advanced, its front mirror being brought into coincidence with the plane previously occupied by the rear mirror, the reference plane then moved back and the process repeated. In this way the total number of waves in a length equal to the standard metre was determined. The final results were as follows, for 15° C. and 760 mms. pressure:

Red line 1 m. = 1553163.5λ, *i.e.* λ = 6438.4722*AE*,
Green line 1 m. = 1900249.7λ, *i.e.* λ = 5085.8240*AE*,
Blue line 1 m. = 2083372.1λ, *i.e.* λ = 4799.9107*AE*.

The values given by Rowland for these same lines are

6438.680, 5086.001, and 4800.097.

An idea of the accuracy of the work can be obtained by comparing three independent observations, the first two by Michelson, the third by Benoit:

1553162.7, 1553164.3, 1553163.6.

In addition to recording the length of the standard metre in terms of an invariable unit, this remarkable piece of work has given absolute determinations of three standard lines, which will doubtless stand for a long time, if not forever, as the standards from which all other lines will be measured.

It may be well to point out here that it has been recently shown by Michelson, and proven experimentally by Kayser, that Rowland's coincidence method is not accurate. As a result of small errors of ruling, the second order ultra-violet line of wave-length 2 may not fall exactly upon a first order line of wave-length 4. The use of the grating is thus restricted to obtaining the wave-lengths of lines between fixed standard lines, by interpolation, at least if the greatest accuracy is required. The standard wave-lengths in use at the present time have all been measured by interferometer methods.

The Visibility Curves. — As we saw in the Chapter on Interference, the fringe system formed with Newton's combination of a lens and flat plate, illuminated with sodium light, is not continuous. There are periodic regions of invisibility as we proceed outward from the centre, due to the fact that when the maxima of D_2 coincide with the minima of D_1, uniform illumination results. If now D_1 and D_2 were infinitely narrow lines and single, the fringes would be equally distinct when "in-step," regardless of the path-difference. If, however, this is not the case, the visibility will vary at the different points of maximum distinctness. Suppose, for example, that each line is a close double; with a sufficiently large path-difference, the two components of D_1 will get out-of-step, and we shall have uniform illumination and invisibility entirely independent of the light from D_2. Fizeau and Foucault, who may be regarded as the founders of interference spectroscopy, only recorded the successive recurrences of the fringes as the path-difference increased. Michelson went a step further, and measured the distinctness of the fringes at each reappearance. From these observations he was able to compute the nature of the lines, *i.e.* whether they were single or double, broad or narrow, etc. If J_1 denotes the maximum brightness of a fringe, and J_2 the intensity of the dark region between, Michelson calls

$$\frac{J_1-J_2}{J_1+J_2}=V,$$

the "Visibility" a quantity which represents the distinctness with which the fringes appear to the eye.

If we know the nature of the distribution of the light in the source, *i.e.* whether the lines are single or double, accompanied or not by fainter companions, etc., it is possible to construct a visibility curve in which the values of V are plotted as ordinates and the path-differences as abscissae.

Michelson commenced by calculating the visibility curves which would result from various types of single, double and multiple lines. Examples of such curves are shown in Fig. 190, the intensity curves of the spectrum lines being shown to the left of each. The curves shown are resultant curves formed by the superposition of wave-trains such as would emanate from sources having a distribution of intensity as figured. The visibility curves are obviously the envelopes of the above curves. Michelson next took up the subject of the construction of an intensity curve from a visibility curve, a much more difficult problem. His work along this line was much aided by the invention of his harmonic analyzer, a machine which separates out of a complex curve the simple harmonic curves of which it is formed; in other words, makes a Fourier analysis of it.

As Lord Rayleigh [1] has shown, the rigorous solution of the problem is not possible, for, except in cases where there is symmetry in the group of lines, we may have a large number of different distributions of intensity, all of which give the same visibility curve. It is impossible, moreover, to decide from the visibility curve on which side of the principal line a fainter component lies. Michelson's predictions regarding the structure of many lines have been subsequently verified, however, and he is to be regarded as the pioneer in the field of investigations devoted to the minute study of spectrum lines.

[1] *Phil. Mag.*, 34, 407, 1892.

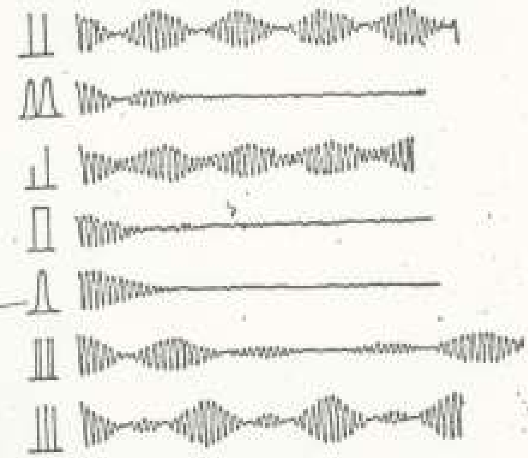

FIG. 190

The method has not been used to any great extent by other observers, partly from the great difficulty of estimating "visibilities" of the fringes, and partly from the difficulty in interpreting the results. Michelson's results were due to his great skill in this respect, which resulted from long experience and familiarity with his instrument. The more modern interferometers show objectively what before could only be guessed at, that is, they actually separate the line into its components just as the prism and grating separate the originally composite light into a spectrum of lines.

It should be noted, however, that the study of line structure by this method gives us practically unlimited resolving-power, and, as pointed out by W. E. Williams in his recent book on *Applications of Interferometry* might still be employed to advantage for examining the hyper-fine structure of a satellite line that could be isolated by a powerful auxiliary instrument. Very large path-differences would be required, and the difficulty of the small size of the rings could be avoided by employing the method of Twyman and Green (small point source at focus of a lens, the light eventually focussed on the pupil of the eye) which gives localized fringes of any size desired, no change resulting as the path-difference is increased.

Michelson's genius gave us the next instrument in the series which we are considering, and we will now take up the subject of