

Oct. 22, 1968

F. ZANDMAN

3,406,681

METHOD OF DETERMINING STRAIN CONDITION OF THE EYE

Filed May 13, 1963

7 Sheets-Sheet 1

FIG. 1

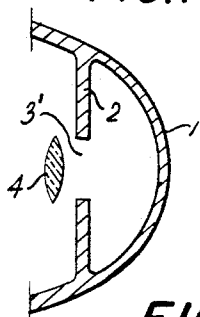


FIG. 2

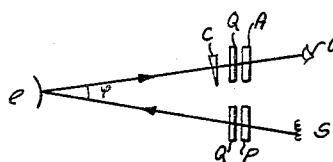


FIG. 3

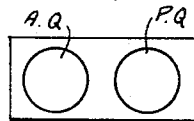


FIG. 5

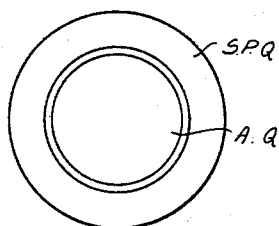


FIG. 4

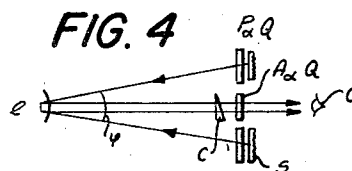


FIG. 6

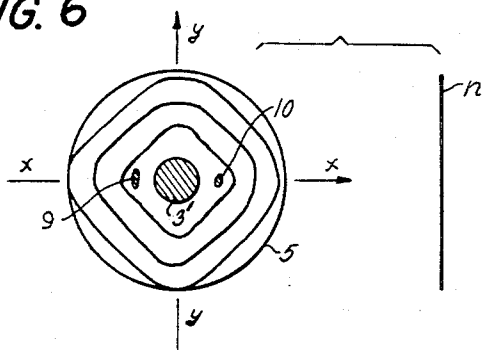


FIG. 7

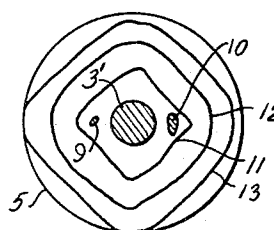


FIG. 8

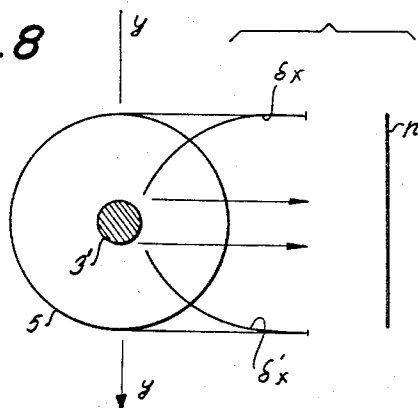
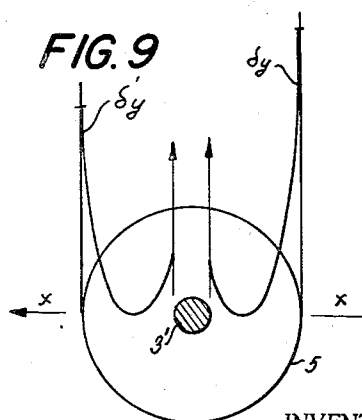


FIG. 9



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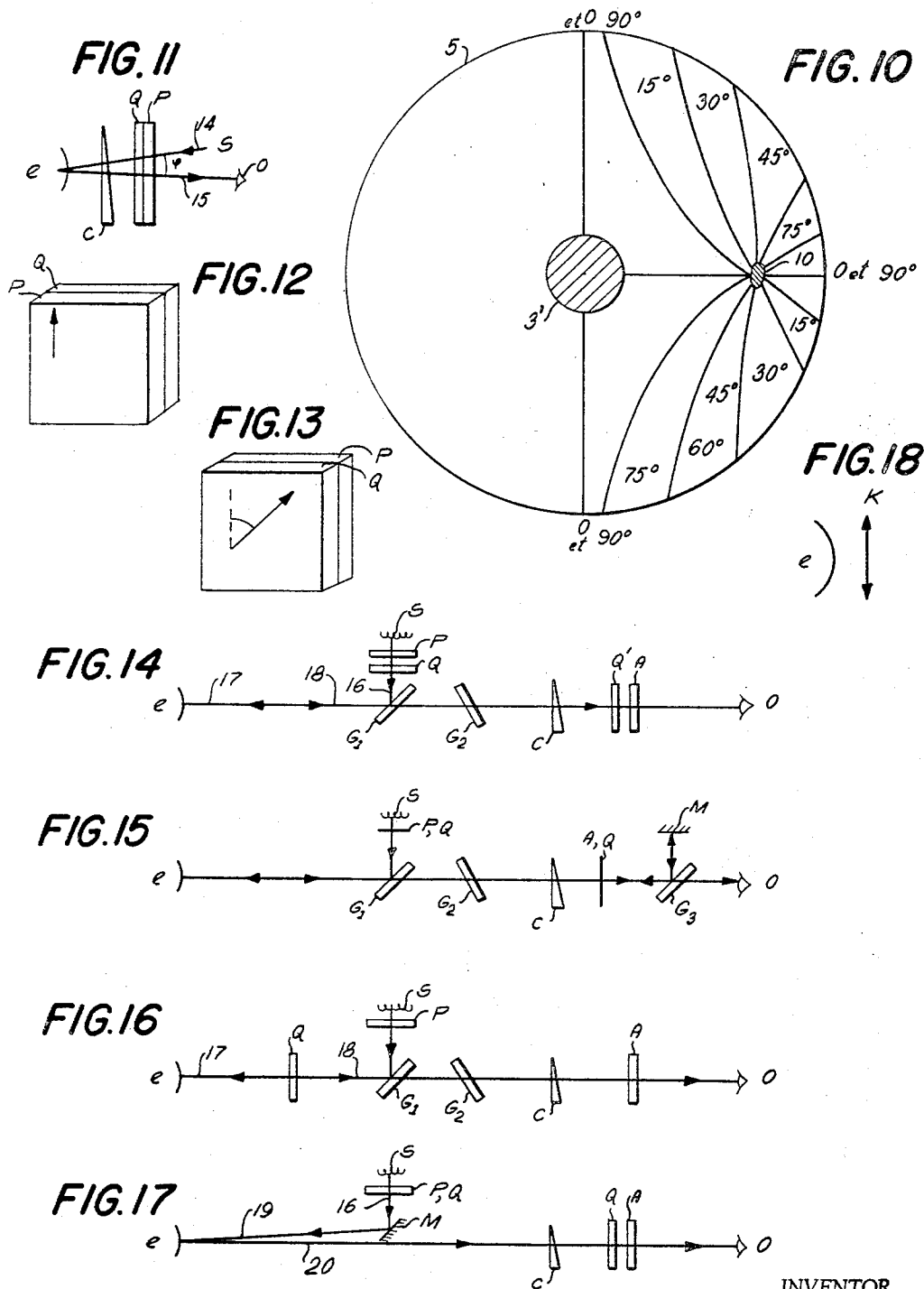
F. ZANDMAN

3,406,681

METHOD OF DETERMINING STRAIN CONDITION OF THE EYE

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7 Sheets-Sheet 2



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3,406,681

METHOD OF DETERMINING STRAIN CONDITION OF THE EYE

Filed May 13, 1963

7 Sheets-Sheet 3

FIG. 19

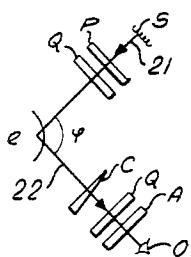


FIG. 20

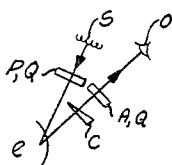


FIG. 21

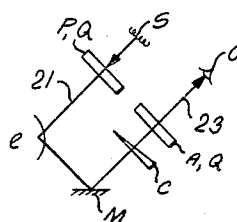


FIG. 22

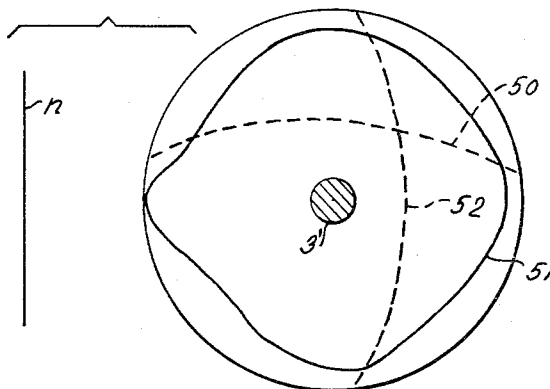


FIG. 23

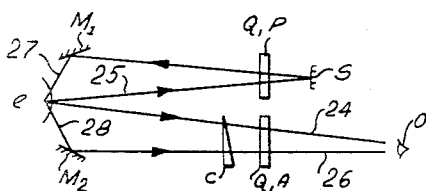


FIG. 25

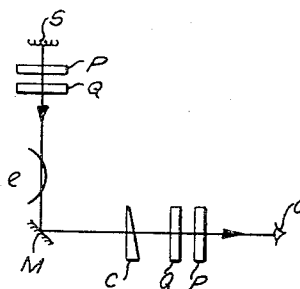
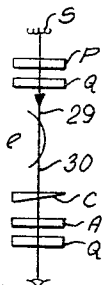


FIG. 24



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3,406,681

METHOD OF DETERMINING STRAIN CONDITION OF THE EYE

Filed May 13, 1963

7 Sheets-Sheet 4

FIG. 26

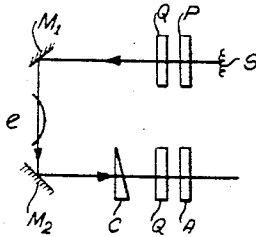


FIG. 27

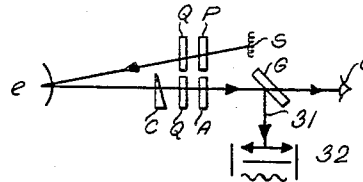


FIG. 30

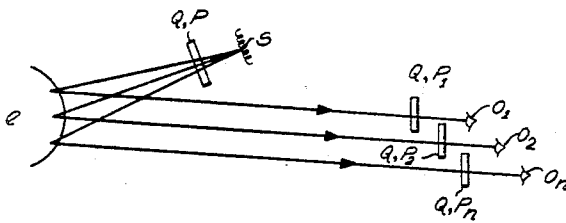


FIG. 28

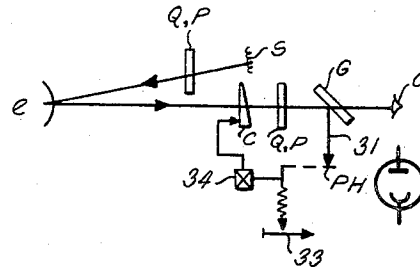


FIG. 31

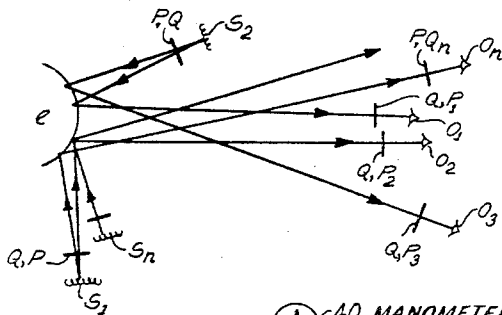


FIG. 29

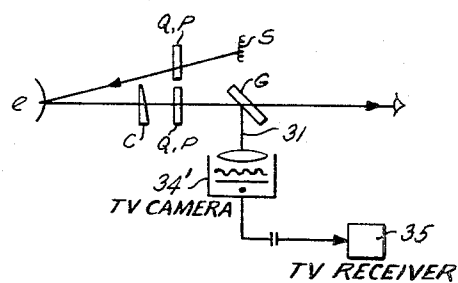
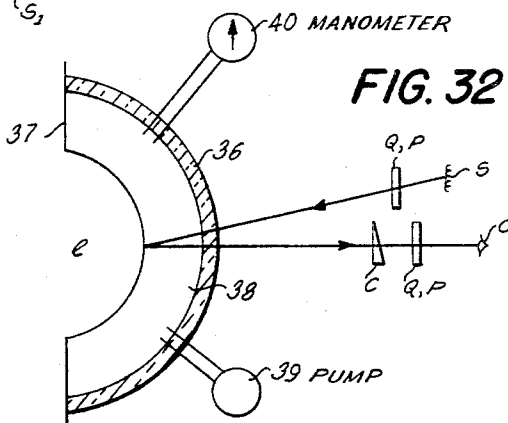


FIG. 32



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3,406,681

METHOD OF DETERMINING STRAIN CONDITION OF THE EYE

Filed May 13, 1963

7 Sheets-Sheet 5

FIG. 33

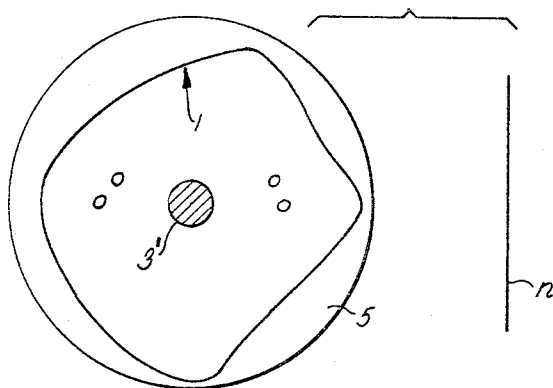


FIG. 34

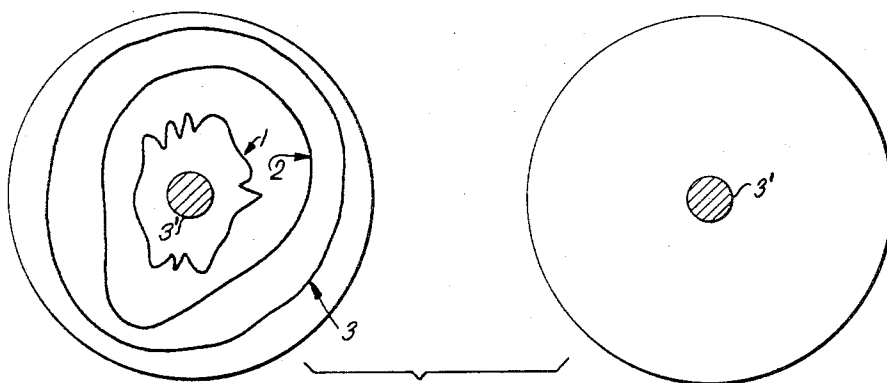
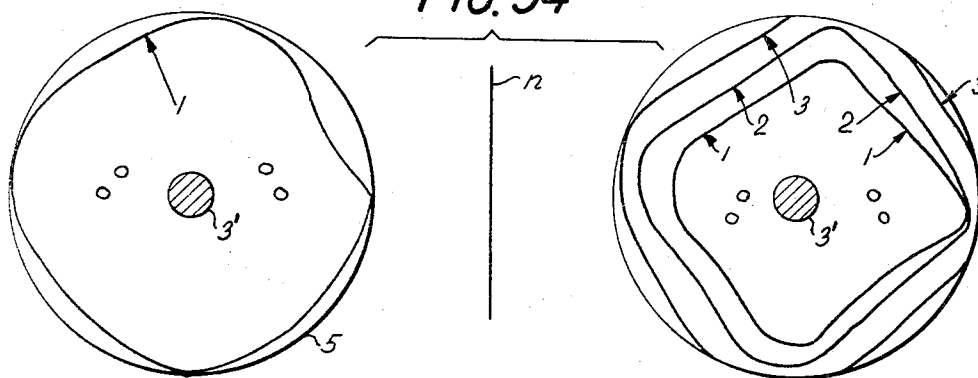


FIG. 35

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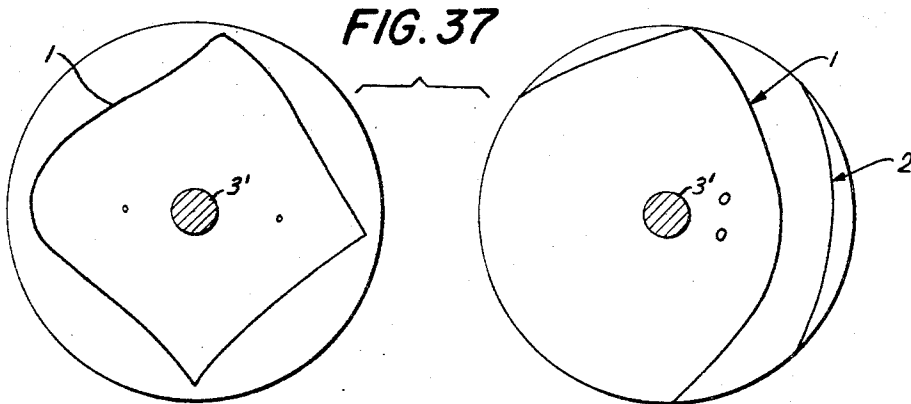
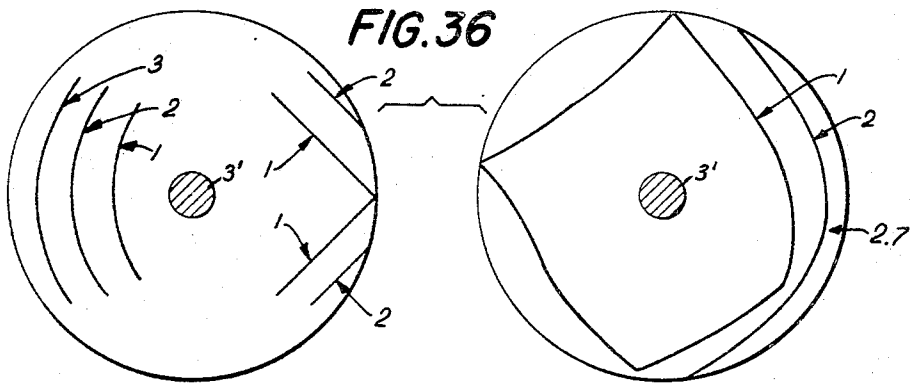
F. ZANDMAN

3,406,681

METHOD OF DETERMINING STRAIN CONDITION OF THE EYE

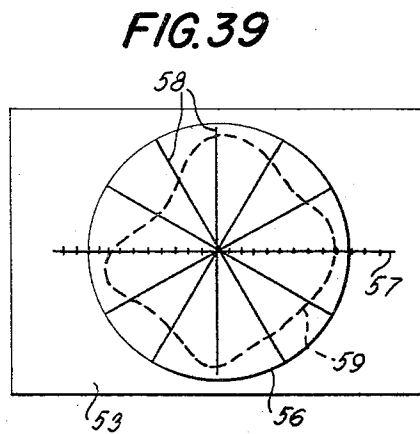
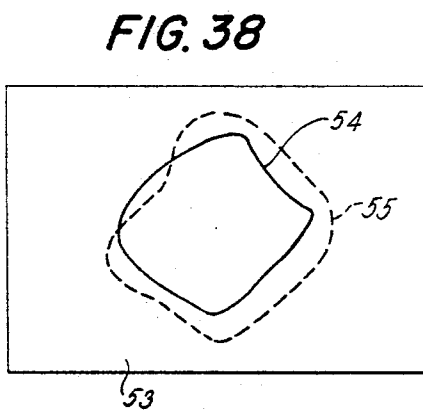
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7 Sheets-Sheet 6



NORMAL EYE OBSERVED
THROUGH A POLARISCOPE

ABNORMAL EYE OBSERVED
THROUGH A POLARISCOPE



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3,406,681

METHOD OF DETERMINING STRAIN CONDITION OF THE EYE

Filed May 13, 1963

7 Sheets-Sheet 7

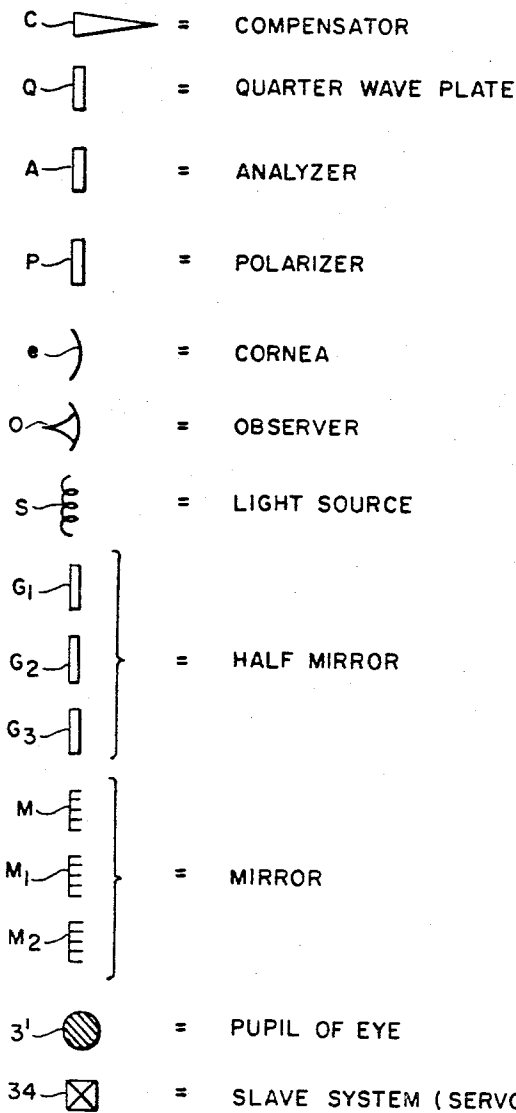


FIG. 40

P, Q₁  = POLARIZER AND QUARTER WAVE PLATE

A, Q₂  = ANALYZER AND QUARTER WAVE PLATE

n  = NOSE

P, Q, S, O- WITH NUMERAL SUBSCRIPTS MEAN CONSECUTIVE OR SEPARATE POLARIZERS, QUARTER WAVE PLATES, LIGHT SOURCES AND OBSERVERS AND THE SUBSCRIPT n MEANS THAT THERE MAY BE ANY NUMBER THEREOF.

FIGS. 6, 7, 22, 33-37 REPRESENT ISOCHROMATIC FRINGES IN NORMAL AND ABNORMAL EYES

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NUMERALS 0, 1, 2, 2.7, AND 3 INDICATE FRINGE ORDERS

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1

2

3,406,681

METHOD OF DETERMINING STRAIN CONDITION OF THE EYE

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Filed May 13, 1963, Ser. No. 279,978

9 Claims. (Cl. 128—2)

This invention relates to the study, determination and measurement of the strain condition of human and animal tissue and more particularly to a method and means for determining and measuring the intraocular pressure of the living eye and hence for diagnosing abnormal eye conditions especially in the case of glaucoma. The invention makes use of polarized light, and takes advantage of the phenomenon of organized birefringence in the eye, with optical axis directions constant throughout the cornea thickness.

Certain transparent materials when subjected to stress or strain exhibit the phenomenon of double refraction or birefringence. They divide an incident beam of light into two beams which travel through such material at different speeds. This phenomenon occurs whether or not the incident light is polarized. This means that one beam will be retarded in respect to the other while traveling through the material. This relative retardation δ , of one beam in respect to the other divided by the thickness t of the material through which the light traveled is called birefringence. In addition, the two beams traveling through this stressed material are polarized at right angles to each other. Their directions of polarization are parallel and perpendicular to the two directions of principal stresses in the material. Those two beams of light will interfere and two sets of fringes or bands (black bands and one color band) will be visible if monochromatic polarized light is used to illuminate the material and an analyzer comprising a further polarization-selective element is used for observation of the material. One set of fringes called isochromatics is related to the stress magnitudes in the material; the other set of fringes called isoclinics is related to the directions of principal stresses in the material. The birefringence results directly from and is directly related to the strain in the material through which the light passes, and is therefore related also to the stress which produces that strain. When white polarized light is used for illumination, isochromatic fringes appear as color bands and isoclinic fringes as black bands. When directions of principal strains (or stresses) vary through the material thickness, isoclinics are not visible. Newmann has shown that relative retardation

$$\delta = (n_1 - n_2)xt = C(\sigma_1 - \sigma_2)xt$$

wherein n_1 and n_2 are the two principal indexes of refraction in a plane perpendicular to the beam of light, t is thickness of material traversed by light, σ_1 and σ_2 are the two principal stresses in a plane perpendicular to the beam of light, and C is the stress optical constant. The same formula can be written in terms of strain as follows:

$$\epsilon_1 - \epsilon_2 = \delta / tk$$

Here ϵ_1 and ϵ_2 are the principal strains and k is the strain optical constant. σ_1 , σ_2 , ϵ_1 and ϵ_2 are secondary principal stresses and strains if the beam of light is perpendicular to a non-principal plane. If the light is traversing the material twice, for example, if a mirror is provided in the back of the transparent material, hence bouncing back the light, the light traverses the material a second time, and then t would be equal to twice the thickness of the material. δ can be determined by sev-

eral methods such as color chart comparison, fringe counting, compensation or photometric method. δ measured under normal light incidence conditions provides the difference of principal stresses or strains. Measurement of δ under oblique light incidence conditions provides additional data so that separate values of principal stresses or strains are obtained. Thus strains resulting from the stresses can be quantitatively determined in birefringent materials such as the cornea of an eye or other birefringent tissues. The technique of stress measurement in birefringent materials is called Photoelasticity. For more details on this subject, reference is made to the "Non-Destructive Testing Handbook," 1959, edited by McMaster, Ronald Press, pages 53-1 to 53-39, volume 2, chapter entitled "Photoelastic Coating Tests." Other literature on photoelasticity where the same phenomenon is described will be found in the bibliography cited at the end of the article. Additional information on photoelasticity is available in "ASME Handbook, Metals Engineering-Design," 2nd ed., 1965, McGraw-Hill Book Co., pp. 554-582, and in the two bibliographies included therein.

It is known that the eye is an extremely delicate organ which makes it difficult in some instance to examine it medically to determine its condition having in mind making a diagnosis or following the progress of a disease. Direct observation with or without magnification provides information only in certain special circumstances and is only of limited use in connection with various diseases notably those of interest in the depth or mass of the eye. This is the case, for example, in glaucoma. For the beneficial treatment of this malady and the study of its progress there has only been available up to now an apparatus known as a tonometer of very delicate manipulation reserved only to specialists for the purpose of making a direct measurement of the compressibility of the eyeball by the application of a known force.

The present invention is predicated on the discovery that the eye cornea possesses the property of organized birefringence or in other words: that the principal strain directions are constant through the cornea thickness as evidenced by the presence of sharp well-defined isoclinics, and that the location of the isoclinic and isochromatic fringes can be observed, recorded and measured for diagnostic purposes or for following the course of a disease which causes changes in the intraocular pressure of the eye as in glaucoma. The invention, however, is useful for determining whether the eye is normal or undiseased and by making a series of observations and measurements over a period of time favorable or unfavorable progress of the condition of the eye can be ascertained. The invention makes it possible both on a qualitative and on a quantitative basis to observe, record and measure the birefringence of the eye and without making any physical contact with the eye since the invention is primarily an optical method and apparatus. The invention thus adds a very important research and/or diagnostic tool to the techniques heretofore available to ophthalmologists and other physicians or technicians specializing in diseases of the eye.

It has now been found that if one observes a human eye or pair of eyes with apparatus designed for the observation and study of birefringence, it can be verified that the phenomenon of birefringence does exist in the eye and can be observed, measured and photographed to obtain information concerning the condition of the eye and to reveal abnormalities rapidly and accurately and to disclose differences between the eyes of the same person.

The invention thus permits the practitioner or ophthalmologist to arrange means entirely novel for him which make it possible to carry out a diagnosis, to follow the

progress of a disease, to judge the effect of treatment and all without harm to the patient which contributes a development of important value to the care and therapy of the eye.

According to the invention, observations and measurements are carried out on the eye analogous to those which have been believed to be restricted heretofore to devices or components in the field of mechanics and hydraulics, notably to those subjected to natural or artificial conditions.

The invention envisions the application in the study of the eye of numerous methods used in the above fields and equally means and components of apparatus utilized in said fields thus enriching to an important extent the armamentarium at the disposal of the ophthalmologist.

In the following description reference is made to the annexed drawings, in which:

FIGURE 1 is a fragmentary sectional schematic view of a portion of a human eye;

FIGURE 2 is a diagrammatic view of the preferred embodiment of apparatus applying the procedure of the present invention;

FIGURE 3 is a front view of the apparatus of FIGURE 2;

FIGURE 4 is a view similar to FIGURE 2 but for a modification into a figure of revolution;

FIGURE 5 is a face view corresponding to the embodiment of FIGURE 4;

FIGURES 6 and 7 illustrate schematically the isochromatic lines observed in the normal right and left eyes when operating in accordance with the present invention in a crossed circular and parallel circular polariscope;

FIGURES 8 and 9 are the relative retardation graphs corresponding to the eye conditions shown in FIGURES 6 and 7;

FIGURE 10 is a schematic view of an isoclinic pattern observed under crossed linear polariscope conditions;

FIGURE 11 is a schematic view of another arrangement of apparatus;

FIGURES 12 and 13 are detail perspective views of a component part of such arrangement of apparatus;

FIGURE 14 is a schematic view of another arrangement of apparatus for carrying out the invention with the ray emerging from the examined eye coincident with the incident ray;

FIGURE 15 is a view similar to FIGURE 14 but for a further modification for self-observation;

FIGURE 16 is a view similar to the two preceding views but for a still further modification;

FIGURE 17 is a view similar to the preceding figures but for still another modification;

FIGURE 18 shows at K a corrective lens interposed in front of the eye to be observed;

FIGURE 19 shows schematically an apparatus arrangement for an additional embodiment;

FIGURE 20 is also a schematic illustration for still another embodiment;

FIGURE 21 is a schematic showing of a still further embodiment;

FIGURE 22 shows schematically an isochromatic pattern observed in the eye when using the present invention and wherein the broken lines correspond to oblique incidence observation;

FIGURE 23 schematically illustrates another form of apparatus;

FIGURE 24 schematically illustrates a different mounting arrangement;

FIGURE 25 schematically shows a further mounting arrangement;

FIGURE 26 shows schematically still another mounting arrangement;

FIGURE 27 schematically illustrates an apparatus according to the invention;

FIGURE 28 is similar to FIGURE 27 but for a modified arrangement;

FIGURE 29 is similar to FIGURES 27 and 28 but for still another embodiment;

FIGURE 30 schematically illustrates an arrangement of apparatus provided for use by more than one observer;

FIGURE 31 is a view similar to FIGURE 30 but for different conditions of observation;

FIGURE 32 is a schematic view of a calibration measuring arrangement;

FIGURE 33 is a front elevational schematic view of the isochromatic fringe pattern of a normal eye;

FIGURE 34 is similar to FIGURE 33 but for abnormal left and right eyes;

FIGURE 35 is similar to FIGURE 34 but showing fringe patterns of other abnormal eyes;

FIGURE 36 is similar to FIGURES 34 and 35 wherein still other abnormalities exist;

FIGURE 37 is similar to FIGURES 34 through 36 but wherein one eye is normal and the other eye is abnormal;

FIGURE 38 is a diagrammatic representation of a scale for measuring the position of the fringe for a normal eye and showing the fringe portion of the examined eye on the scale;

FIGURE 39 is a diagrammatic representation of a composite scale arrangement which is adapted to make both circular and linear measurements and showing the fringe portion of the examined eye thereon; and

FIG. 40 is a table of explanatory legends.

In FIGURE 1 there has been fragmentarily shown in transverse section the anterior portion of the eye comprising the cornea 1 and the iris 2 bordering pupil 3' behind which is the crystalline lens 4. This structure is shown at *e* in FIGURE 2 which is a diagram of an installation for the observation of the birefringence of the eye. The apparatus is provided for the observation of the normal or quasi-normal angle of incidence. Light from source S projects through a polarizer P and eventually through a quarter-wave plate Q which has its optical axis turned 45° from the polarizer axis, the light proceeding thence into the patient's eye *e*. This light passes through the cornea, impinges on and is reflected by the surface of the iris, and the resultant outwardly directed ray of light passes again through the cornea and thence through compensator C, quarter-wave plate Q', and analyzer A, at which point the light may be viewed by an observer or photographed. In this apparatus as well as in the forms of apparatus to be described hereinafter the light source S can be a source of monochromatic or polychromatic light, that is to say, a white light, or even a partially filtered light. It can be generated by an incandescent lamp, a stroboscope or a clear lamp, or an electronic flash or a source of modulated light. Apparatus which may be used in accordance with FIG. 2 is shown and described in U.S. Patent No. 3,062,087, issued Nov. 6, 1962, to Felix Zandman and Jean Avril.

FIGURE 3 shows in face view a polariscope comprising on its left portion an analyzer A and a quarter-wave plate Q and on its right side a polarizer P and a quarter-wave plate Q. The quarter-wave plates can be mounted in such manner that they can be either in an operative or in an inoperative position. The apparatus comprises means known in itself to put it in rotation according to the related movements of the polarizer and the analyzer, an embodiment being that the quarter-wave plates respectively participate correspondingly with the polarizer and the analyzer.

In FIGURES 4 and 5, the arrangement of FIGURES 2 and 3 has been modified into a figure of revolution about the axis of the eye, with the source S, polarizer P and quarter-wave plate Q surrounding the analyzer A which is between the compensator and the observer's eye, whereby observation is made between the polarizer P and light source S through compensator C and quarter-wave plate and analyzer Q and A, respectively.

FIGURES 6 and 7 schematically show the appearance presented by the central portion of the left and right eyes

5

to the observer O through a polariscope in crossed circular and parallel circular conditions. In these two figures the line 5 is the outline or periphery of the iris, i.e., the pigmented portion of the eye, which is relied upon to reflect the incident polarized light back through the cornea toward the observer. The light directed through the polarizer toward the patient's eye is twice refracted by the cornea, first in passing through to the iris, and then, after reflection, in passing outward through the cornea. The images presented to the observer by the patient's right and left eyes, as seen in FIGS. 6 and 7, respectively, include a central area 3' resulting because the rays to the center of the iris pass through the aperture and are not reflected back by the iris. These images also each include a pattern which is generally of the shape of a rounded square having its sides disposed diagonally. Each such image includes two dots 9 and 10—one to the left of spot 3' and one to its right. FIGS. 6 and 7 each show a superposition of three such rounded-square fringe patterns, any one of which is obtainable by angular adjustment of the analyzer A shown in FIG. 2.

FIG. 8 shows a plot of the distances above and below center of the pattern in FIG. 6 of the points of intersection of the Y axis with the rounded square isochromatic pattern as these distances vary with the change of angle of the analyzer. FIG. 9 shows a plot, of the distances to right and left of center, of the points of intersection of the axis with the isochromatic pattern as a function of angle of the analyzer.

FIGURE 10 shows on a larger scale the isoclinic fringes observable with the aid of a linear crossed polariscope with a normal angle of incidence for the respective isoclinic parameters of 15°, 30°, 45°, 60°, 75°, 0° and 90°, 0° being a direction parallel to the median line of the patient's face *n*.

Only the portion of the isoclinic fringe patterns to the right are shown in FIG. 10 in solid line. The corresponding portions to the left are situated equal distances in the opposite direction from the center of the pattern, as shown in dotted lines in FIG. 10.

In the apparatus according to FIGURE 11 there is the same polarizer P and the same quarter-wave plate Q traversed by the incident light ray 14 and the reflected light ray 15, a similar compensator C being eventually traversed by the same incident light ray and the said reflected light ray which impinges on the observer O. This apparatus is less versatile than the apparatus of FIG. 2, being usable for certain isochromatic patterns but not for isoclinic patterns.

In all the preceding and equally in all that follows, it is to be understood that the term "observer" includes the eye or eyes of one or more observers, or a telescope, or a microscope through which observation can be made, or a so-called "zoom" lens, or a combination of the three, or any other system such as a photoelectric cell followed or not by an amplifier which can be attached to a registering device, or an oscillograph or a photographic apparatus, cinematographic apparatus or a television camera, etc.

FIGURES 12 and 13 show schematically the arrangement of the polarizer P and the quarter-wave plate Q as well as their optical axes as related to FIG. 11. FIG. 13, wherein the Q-P sandwich of FIG. 11 is viewed from the position of the patient's eye rather than the opposite viewpoint of FIG. 12, shows the axis of the quarter-wave plate to be at 45° to the vertical axis of the polarizer P (which in this case serves also as an inflexible analyzer).

FIGURE 14 relates to another form of apparatus in which the luminous source S, which can be any of those referred to above, transmits a light ray 16 through a polarizer P and a quarter-wave plate Q which eventually falls on a half-mirror G₁. Then the light rays 17 fall normally or quasi-normally on the eye cornea *e*, traverses the cornea, then is reflected and/or diffused from the iris, traverses again the cornea and is directed toward the half-

6

mirror G₁, another half-mirror G₂ of the same material and thickness as mirror G₁ but not necessarily provided with a semi-reflective surface, and disposed symmetrically with respect to the latter in a plane perpendicular to the direction of the light ray 18, eventually a compensator C, a quarter-wave plate Q', then an analyzer A behind which is the observer O, and which can be any of the types of observing or recording apparatus mentioned above. Element G₂, being perpendicular to element G₁ and disposed at 45° to ray 17, compensates for the shift of the ray due to diffraction of the ray travelling from cornea of eye *e* toward the observer as it enters and then departs from diagonal element G₁.

In the embodiment according to FIGURE 15 the patient can himself ascertain the birefringence which his eye *e* shows due to the interposition of the half-mirror G₃ and the mirror M, the observation being able to be equally followed by the observer O.

In the embodiment of FIGURE 16, a single quarter-wave plate Q is provided and it is traversed by the incident light ray 17 as well as by the reflected light ray 18. In this embodiment as well as the preceding embodiments, particularly those of FIGURES 14 through 16, the polarizer P can be omitted and the half-mirror G₁ oriented at 54° (approximately) to the vertical, thus becoming a polarizer, provided that the source S and polarizer P are shifted to the right to retain the fundamental equality of the angle of incidence (of light from source S) and angle of reflection (of light proceeding along the path to the cornea of eye *e*). Thus, Brewster's angle provides the polarization.

In the installation of FIGURE 17, one draws from the fact that the angle of incidence on the eye, instead of being normal in an absolute manner, can be substantially normal and the light rays 16 are reflected by a mirror M toward the eye *e* at an angle of incidence such that the reflected or diffused light ray 20 misses the mirror M and reaches the observer after passing through a quarter-wave plate Q and an analyzer A and eventually a compensator C.

The function of the quarter-wave plate Q, the axis of which is at 45° to the polarizer axis, is to suppress the isoclinic pattern and hence render more clearly visible the isochromatic pattern.

In all the preceding installations or apparatus arrangements there can be envisioned, complementarily, a lens placed in front of the eye to obtain an angle of incidence as normal as possible in one part or in the totality of the observed surface. Such a lens *k* (FIGURE 18) can be also in contact with the eye through the intermediation of a liquid which can be lacrymal liquid (i.e., a contact lens can be used).

FIGURE 19 shows an apparatus arrangement for the observer with an oblique angle of incidence. The mounting is similar to that which is shown in FIGURE 2, that is to say, the incident light ray from light source S traverses a polarizer P and eventually a quarter-wave plate Q and falls on the eye along a ray which is at a smaller angle to the iris (the surface used for reflecting the ray back through the cornea) than the angle in FIG. 2.

FIGURE 20 relates to a variant of an apparatus for observation under oblique incidence, the said apparatus being identical to that which, in FIGURE 2, is shown disposed for the observation at a normal or quasi-normal angle of incidence but which, in FIGURE 20, is arranged for observation at an oblique angle of incidence.

FIGURE 21 is a variant of the apparatus of FIGURE 20 in which a mirror M diverts the reflected or diffused light ray 23 of the incident light ray 21.

With an installation arranged for the observation at a normal or quasi-normal angle of incidence, one obtains equally the results relative to an oblique angle of incidence when the patient instead of looking in the direction of the incident and reflected light rays looks upwardly, down-

wardly or to the left or to the right, the instrument continuing to be aimed toward the center of the eyeball.

FIGURE 22 shows, for example, in broken lines an isochromatic line 50 observed with an apparatus such as that shown schematically in FIGURE 2, FIGURE 4, FIGURE 11 and FIGURES 14 through 17, but when the patient looks upwardly this line being an isochromatic line with an oblique angle of incidence in a vertical plane; the isochromatic line for normal incidence of light is shown at 51. There is shown at 52 in the same figure the isochromatic line observed when the patient looks toward the left, this line being an isochromatic line at an oblique angle of incidence in a horizontal plane. In this figure the line in the middle of the face or nose is designated by n .

For observation or measurements at a predetermined obliqueness one uses an apparatus shown for the observation at a normal angle of incidence when the patient looks in the direction of the incident and reflected light ray and the patient directs his line of sight toward a predetermined point understood to be distinct from the sensible direction common to the incident light ray and the reflected light ray.

FIGURE 23 illustrates an installation for the simultaneous observation of birefringence with normal and oblique angles of incidence. The light ray 24 resulting from the reflection or diffusion of the light ray 25 furnishes the observation where the measurement follows the normal or quasi-normal angle of incidence, while the light ray 26 furnishes the observation where the measurement is at an oblique angle of incidence, the obliqueness of the light ray 27 for reaching observer O being furnished by mirror M₁ and mirror M₂ which send the light rays 26 back through the compensator C and the analyzer A eventually preceded by a quarter-wave plate Q.

In addition to the above, one could include a regulatable diaphragm 61 arranged to be turned downward to interrupt beam 26 or upward to interrupt beam 24, or turned parallel to beam 26 to permit observation by both beams simultaneously.

The installation of FIGURE 24 also permits the observation and the measurement at an oblique angle of incidence, the incident light ray 29 and the light ray 30 being in prolongation of one another. In FIGS. 24, 25 and 26 there is no reflection at the surface of the iris.

In the variant of FIGURE 25 mirror M permits observation from in front of the patient. In the variant of FIGURE 26 wherein the source of observation is also in front of the patient this arrangement is permitted by virtue of mirrors M₁ and M₂.

In all the forms of apparatus for the observation or measurement at an oblique angle of incidence, the angle of incidence can be either fixed or variable.

Referring now to FIGURE 27 with regard to an embodiment similar to that shown in FIGURE 2 but comprising a half-mirror G behind which direct observation can be carried out as shown at O, the said half-mirror furnishes also reflected light rays 31 which fall on a photographic or cinematographic apparatus 32.

In the embodiment of FIGURE 28 similar to that of FIGURE 27 the light rays 31 fall on a photoelectric cell PH which controls a measuring or observation device 33 such as an oscillograph or oscilloscope. In this embodiment in addition the electric current furnished by the photoelectric cell PH is utilized to control a slave system 34 acting on compensator C to maintain a null balance and thus to furnish directly quantitative information.

In the modification of FIGURE 29 the light rays 31 fall on a television camera 34', a television receiver being shown schematically at 35.

In all embodiments the compensator C can be remotely actuated if necessary.

In all forms of apparatus monochromatic or partially chromatic filters can be mounted in front of light source S or observer O.

In the installation of FIGURE 30 a plurality of observers O₁, O₂ . . . O_n are located behind the polarizers P₁, P₂ . . . P_n eventually preceded each by a quarter-wave plate Q, the incident light ray being derived from a common luminous source S positioned in front of a polarizer P eventually followed by a quarter-wave plate Q.

In the installation of FIGURE 31, observer O₁ and observer O₂ see the light furnished by light source S₂ after diffusion by the iris of the eye e , observer O₂ receives the light rays emanated from source S₁ and after diffusion of the light rays by the iris of the eye the observer O_n receives the light rays emanating from light source S_n after diffusion by the iris of the eye. In all forms of apparatus the polarizer, the analyzer, the quarter-wave plates and the compensator can turn in a suitable plane independently of one another or coupled. The apparatus can also be devoid of quarter-wave plates and compensator.

The invention envisions also the determination of the optical coefficient of stress and/or strain by application of one or the other of the following formulas:

$$\epsilon_1 - \epsilon_2 = \delta / tk \quad (1)$$

$$\sigma_1 - \sigma_2 = \delta / tC \quad (2)$$

In these formulas k is the strain optical constant; C is the stress optical constant; $\epsilon_1 - \epsilon_2$ is the difference between the secondary principal strains; $\sigma_1 - \sigma_2$ is the difference between the secondary principal stresses; δ is the relative retardation of the normal or oblique angle of incidence; and t is the length of the optical path in the birefringent medium.

FIGURE 32 shows an arrangement for determining constants such as C and k . The eye e is surrounded at a distance by a transparent wall 36 disposed in a fluid-tight manner along arcuate opening 37. There can be made present in the interior of chamber 38 a known pressure by a pump 39 and the observation of birefringence in place, for example, of normal or quasi-normal angle of incidence as indicated. The pressure in the interior of chamber 38 being known, for example, by a manometer 40 or only the pressure increase, the observations or measurements made by observer O in the direction indicated above permitting determination of the constants. The changes of the isochromatic patterns may be correlated with different applied pressures as measured by manometer 40 between wall 36 and the cornea. In this manner, for example, one may determine how much change of exterior pressure on the cornea is required to produce a change of 10% in its strain (and the stress producing same) as observed. C and k can also be obtained by applying a known force to a given portion of the eye.

FIGURE 33 shows the main characteristics of the fringe pattern of a normal eye observed in accordance with the present invention and where there are 2 singular points (No. 0) on either side of pupil 3' and a fringe line (No. 1) seen by the observer during the examination of a normal eye with a crossed circular polariscope in quasi-normal incidence. In subsequent FIGURES 34 through 37, observations are made under the same conditions as in FIGURE 33 but for abnormal eyes.

In FIGURE 34 the fringe patterns of the eyes being observed clearly show abnormalities which are due to glaucoma or other eye disease. The fringe pattern of the eye left shows that fringe No. 1 is much closer to the periphery 5 than is the case for the normal eye of FIGURE 33 and, in addition, the fringe line is somewhat distorted. The fringe pattern the right eye shows at least three fringe lines Nos. 1, 2 and 3, thus also indicating an abnormal eye condition.

In FIGURE 35 the fringe pattern of the left eye has 3½ fringes and fringe No. 1 has an irregular zig-zag outline. The right eye has no organized fringe pattern at all.

In FIGURE 36 the fringe pattern of the left eye has an abnormal fringe pattern in portions only and in the other portions there is no organized birefringence, where-

as in the right eye one portion thereof is substantially normal and the other portion shows increased birefringence by the presence of fringe lines Nos. 1, 2 and 2.7.

In FIGURE 37 the fringe pattern of the left eye is normal but the fringe pattern of the right eye shows no organized birefringence in one portion of the eye and an abnormal pattern of fringe lines Nos. 1 and 2 in another portion of that eye. Thus showing that birefringence in the two eyes of one and the same person can have completely different distributions and values.

A linear, circular or curvilinear scale similar to the fringe contour of a normal eye is provided to measure the location of each of the observed fringes and its displacement or variation from normal form and position as explained below anent FIGURES 38 and 39.

FIGURE 38 represents a typical scale wherein a screen or photograph or other base 53 has marked thereon a scale 54 which as will be noted from FIGURE 33 represents the fringe pattern of a normal eye and, consequently, the fringe portion 55 of the examined eye can be superimposed and its variance from 54 determines the extent of abnormality, i.e., the displacement and/or distortion of the fringe portion of the examined eye.

In FIGURE 39 a composite scale is represented on the same screen, photograph or other base 53 but whereon there is a circular graduated scale 56, a linear graduated scale 57 and a radial scale 58 so that when the fringe pattern 59 of the examined eye is superimposed precise measurements can be made and the abnormalities are immediately apparent.

The fringe patterns of FIGURES 34 through 37 are those actually observed in accordance with the present invention in patients who had been diagnosed as having glaucoma in one or both eyes. It will be clear, however, that the present invention makes it possible to observe, determine and measure eye abnormalities whether they result from glaucoma or other eye disease or even from some systemic cause and after having examined a number of eyes both normal and abnormal, the observer is in an excellent position to make a tentative diagnosis or to refer the patient to an ophthalmologist. The fringe patterns can be visualized and recorded as by projecting them on a screen or taking photographs or in any other desired manner so as to have a record. It has not heretofore been possible to accomplish these objectives in a simple, rapid and effective manner and while polariscopes of various designs are per se known, they have never been applied to the observation of eyes or other human or animal tissue for the present purposes. It is also to be understood that the present invention makes it possible to observe both eyes of a patient simultaneously and to make a comparison as well as examining one eye at a time. It is further to be understood that the polariscope arrangements described above and illustrated in the drawings are intended as typical examples and not as an exhaustive compilation of all possible polariscope arrangements.

What is claimed is:

1. A method for investigating the physiological and health condition of the living eye through photoelastic patterns which comprises projecting polarized light through the cornea to the iris to produce reflection of light therefrom, the cornea producing birefringence of the light passing therethrough, and receiving and analyzing in a polarizer the light reflected back through the cornea by the iris, whereby the stresses and strains in the cornea produce birefringence resulting in significant patterns of the received and analyzed light.

2. A method for determining the strain pattern in the frontal portion of the human eye through photoelastic fringe patterns which comprises directing a beam of light

through a polarizer into the cornea of the eye at a preselected angle to cause a portion of the light to reach the iris and be reflected back thereby, the cornea producing birefringence of the light passing therethrough, receiving light emerging from the cornea of the eye as a result of reflection by the iris, and passing the received light through a compensator and an analyzer to present an image wherein the forms and relative positions of the fringes are related to the distribution of strain in the cornea.

3. A method for testing the living eye with respect to its physiological condition which comprises directing a beam of light from a light source through a polarizer and a contiguous quarter-wave plate and thence through the cornea of the eye so as to cause the beam of light to make two traversals through the cornea, one as it enters and the other as it exits from the eye, whereby the strain in the cornea produces birefringence of the light as it enters the cornea and emerges therefrom, said light then being caused to pass successively through a compensator, a quarter-wave plate and an analyzer to render visible to an observer the patterns of birefringence related to the condition of the eye.

4. A method in accordance with claim 3, in which the observed bi-refracting pattern is recorded and the number and relative locations of the thus revealed fringes are measured for diagnostic purposes.

5. A method in accordance with claim 4, in which the bi-refracting pattern is made photographically permanent.

6. A method according to claim 3, in which an external pressure is applied to the eye, whereby the photoelastic results and tonometric effects may be correlated.

7. A method in accordance with claim 1, in which a plurality of beams of light are directed upon the cornea of the eye at preselected different incident angles and the separate reflected and diffused light beams are observed for interpretation.

8. A method in accordance with claim 1, in which an external pressure is applied to the eye, whereby the photoelastic results and tonometric effects may be correlated.

9. A method for investigating the physiological and health condition of the living eye through photoelastic patterns which comprises projecting polarized light through the cornea to the iris to produce reflection of light therefrom, the cornea producing birefringence of the light passing therethrough, and receiving and analyzing the light reflected back through the cornea by the iris whereby the stresses and strains in the cornea produce birefringence resulting in significant patterns of the received and analyzed light.

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