

This invention relates to a contact lens arrangement for observing the interior of an eye and for treating it by light irradiation, mainly in the region of the retina.

The eye, in particular the diaphragm, the crystalline and the
5 retina, may be affected by several diseases. To diagnose the affection, the interior of the eye must be optically inspected in an accurate way.

Several methods of observation are known. The best images to be had are obtained by using a contact lens which, when applied to the eye, causes minimum distortion of the light beam received from the
10 point under observation, or working point, inside the eye, e.g. a Koeppel or a Goldmann lens, described in particular in a publication entitled "Gonioscopie und Goniofotographie", authored by Winfried Müller and Hans-Peter Brandt, and published by Ferdinand Enke in Stuttgart in 1979.

15 A Koeppel contact lens has, for the light beam, a rounded entry surface and a substantially spherical exit surface adapted to be applied to the cornea. A Goldmann contact lens is more particularly designed for observing the retina and has a plane entry surface and a spherical exit surface for the light beam. It may also have one or several re-
20 flecting surfaces acting as mirrors, enabling indirect observation of the interior of the eye.

Ophthalmologists particularly appreciate these kinds of contact lens for observations, especially the second, as they are easy to handle and comfortable in use. However, the quality of the image they
25 produce gradually deteriorates as one moves away from the optical axis of the eye.

While such a contact lens is useful for observing the interior of an eye, it is essential for treating a retina by irradiation. But in this latter case, because the operating conditions are different from those
30 for observation, the lens must meet stricter requirements.

Treating the interior of an eye by irradiation is achieved by focusing on to the affected area, or on to a part of that area, an intense beam of coherent light. This beam can be produced for example by an Nd-YAG or Argon laser.

For the treatment to be effective and harmless, the beam reaching the working point must be accurately focused and strongly convergent or open, i.e. the angle made by the outermost light rays should be wide. The accurate focusing condition is obvious as it enables the working point to be accurately pin-pointed and considerable energy to be concentrated thereon. The strong convergence condition reinforces the previous condition as it enables the working point to be accurately pin-pointed in depth. Besides, the energy density of the beam then decreases rapidly away from the working point, thereby reducing the risk of damage to the healthy parts of the eye. The focusing of the light beam will be better when the spherical aberrations and the astigmatisms of the optical system through which the beam has to travel, i.e. the contact lens and the eye, are slight. However, these flaws usually increase with the diameter or the convergence of the incident beam. These two conditions are thus contradictory and a compromise must be found for each particular use. A Goldmann lens does not solve satisfactorily the problem associated with the width of the angle of the light beam, and even less so that associated with astigmatism. Thus, while such a lens will still be suitable for retina observation, retina treatment by irradiation with such a lens will only be satisfactory at points close to the axis of the eye. For other points of the retina the difficulties increase the further removed they are from the axis.

Various improvements have been made to the Goldmann lens. More effective versions of this lens are thus known. For example, the so-called Abraham lens arrangement consists of a mirror-less Goldmann lens having a plano-convex lens of mineral glass fitted off-centre to its entry surface. This modification enables the angle of the beam to be widened but tends also to enhance the aberrations. Another example is the so-called Roussel lens arrangement, a more recent development described in Applicants' EP-A-0059159. In this lens arrangement the surface that receives the light beam constitutes a wave surface for the beam. As a result, the aberrations are reduced but the width of the angle of the beam is not modified.

It should also be noted that all attempts made to improve the Goldmann lens were aimed at the contact lens itself, without considering the optical properties of the eye it was designed to examine or irradiate. Thus even a flawless contact lens would not enable a light beam to be perfectly focused on a point of the retina remote from the axis of the eye, since, to reach this point, the beam must travel through the different parts of the eye, in particular the crystalline which has an astigmatism that worsens when viewed with a high angle of incidence. This causes the beam to deteriorate. No contact lens, Goldmann or other, takes this phenomenon into consideration. This is a serious flaw in known lenses designed to treat the retina at points situated away from the axis of the eye.

The main object of the invention is to provide a contact lens arrangement for examining and treating by irradiation the various internal parts of an eye, in particular the retina, which does not suffer from the above drawbacks.

To achieve this object, the contact lens arrangement according to the invention for observing and treating an eye with an incident light beam, wherewith the beam travels a distance e within the lens arrangement between an entry surface and an exit surface destined to be applied to the eye, the eye having towards the incident light beam an astigmatism that is defined by a sagittal focal distance S^* and a tangential focal distance T , comprises :

- a main element for focusing the incident light beam on a working point within the eye, said element having a refractive index n and having a plane entry surface and an exit surface forming the exit surface of the contact lens arrangement, the axis of the incident light beam that reaches the entry surface of the lens arrangement being shifted in relation to the optical axis of the main element and being directed perpendicularly to the plane entry surface,

and is characterized in that it further comprises :

- a compensating element having said refractive index n and having an exit surface that is applied to the plane entry surface of the main ele-

ment and an entry surface that forms the entry surface of the contact lens arrangement, the plane that is tangent to the entry surface of the compensating element, at the point where the axis of the incident light beam passes through this surface, forming with the plane entry surface
5 of the main element an angle that is so determined, in dependence on e , S^* , T and n , that the contact lens arrangement has, towards the incident light beam, an astigmatism opposite to that of the eye.

One advantage of the contact lens arrangement according to the invention is that it enables an incident light beam to be accurately
10 focused on one point of the retina in spite of the optic flaws of the parts of the eye the beam goes through.

Other advantages will become apparent from the description that will now be made with the aid of the accompanying drawings which illustrate, by way of non-limiting example, a contact lens arrangement
15 according to the invention. In the drawings :

Figure 1 is a cross-section along a longitudinal plane of symmetry showing, schematically, an eye to the cornea of which a Goldmann contact lens, referred to above, has been applied; and

Figures 2a to 2d illustrate examples of the contact lens arrangement
20 ment according to the invention.

In all of the Figures the same reference numerals bear the same reference numbers.

A schematic view of the eye 1 is shown in Figure 1. It is a solid of revolution having an axis of symmetry aa' and having, from the
25 exterior towards the interior of the eye, a cornea 2 through which light rays enter, an iris 3 whose aperture regulates the amount of light entering, a crystalline lens 4, and a spherical retina 5 having a centre O and through which extends axis aa' at a point F . For the invention to be properly understood, it will be useful first to describe a Goldmann
30 mirror contact lens already known from the prior art, and also shown in Figure 1. This lens, referenced 10, has a plane entry surface 11, a spherical exit surface 12 applied to the cornea 2, and a reflecting surface 13. Other reflecting surfaces, not shown, are provided over

the periphery of the lens. The angle between a reflecting surface and the entry surface depends on the point of the retina being aimed at. This angle may range from 50 to 80°. The straight line that is perpendicular to entry surface 11 and which passes through the centre of curvature C of exit surface 12 defines the axis of symmetry bb' of contact lens 10. In the case of Figure 1, axes aa' and bb' coincide. Lens 10 is so sized that it can be tilted over cornea 2 and hence move, within limits, the point to be observed or to be treated, also termed working point, inside the eye. Axis bb' then pivots about centre C.

10 The field of application of the Goldmann lens is quite broad, as it practically has access to all essential points inside the eye, for both observation and treatment. Whereas the effectiveness of the lens is good for points located close to the cornea 2, it is however poor for those located on retina 5 away from axis aa', for reasons which will
15 be given later.

 An object of the present invention being to provide a modified Goldmann lens enabling observation and particularly treatment by irradiation of any point of retina 5 under good conditions, Figure 1 shows the path of light in a Goldmann lens for two typical points on the
20 retina. The first point, referenced F_x in Figure 1, corresponds to a point close to axis aa' of the eye. To reach this point, an incident light beam X, having an axis xx', must enter Goldmann lens 10 perpendicularly to entry surface 11 at a certain distance from axis aa', and travel directly, without reflection, through lens 10 and eye 1. The second
25 point, referenced F_y , corresponds to a point remote from axis aa'. The angle α formed by axis aa' and the straight line joining point F_y to centre O of retina 5 may exceed 90°. To reach point F_y , a light beam Y, of which only axis yy' is shown, must, after entering lens 10 perpendicularly to surface 11, be completely reflected by surface 13 at
30 a point 14 in order to penetrate eye 1 with an angle of incidence i. To each area of retina 5 remote from axis aa' corresponds a particular slant of surface 13 with respect to surface 11 of lens 10. This is why one and the same Goldmann lens preferably has several reflecting

surfaces with different slants or slopes.

Since the eye is not a perfect optical system, even a flawless contact lens would not enable a light beam to be focused on one point, but at best only within a circle of diffusion having a more or less reduced diameter since the astigmatism of an eye is that much greater when the angle of incidence i of a light beam passing through the crystalline lens is high. To achieve accurate focusing, the contact lens must therefore have an astigmatism opposite to that of the eye.

There are several models of the eye, e.g. the Gullstrand-Legrand model and the Littmann model, which enable its optical properties to be accurately described. As is well known, the eye, like any spherical optical surface, has an astigmatism which can be decomposed into a sagittal part and a tangential part. Each part is defined by its focal distance, measured, for example, from the entry surface of the eye. The focal distance corresponding to the sagittal part is termed S^* and that corresponding to the tangential part is termed T .

Theoretical considerations and tests have shown that it is possible to devise a compensated contact lens arrangement having the required opposite astigmatism by fitting to the entry surface of a Goldmann lens a compensating element of simple shape, which is easy and inexpensive to produce.

The compensating element modifies the point aimed at with a Goldmann lens. This modification is however slight and can be compensated by a slight alteration, of a few degrees, of the slant of the reflecting surface. In practice, it is always possible to make or to find, for each point aimed at, a suitable Goldmann lens. Indeed, there are standard lenses whose reflecting surfaces have a slant, with respect to the entry surface, lying between 50° and 80° .

A first form of embodiment of a compensated contact lens arrangement according to the invention is shown in Figure 2a in longitudinal section along a plane of symmetry of the lens arrangement. In this example, the compensating element is a prism whose intersection with the plane of the Figure is a triangle PQR, right-angled at R, and

having edges perpendicular to the plane of the drawing. This prism is positioned in such a way that, on the one hand, its surface containing points Q and R is applied against the entry surface 11 of Goldmann lens 10 and, on the other hand, point Q lies on the same side, with
 5 respect to axis bb', as reflecting surface 13. The plane of prism 20 containing points P and Q thus becomes the entry surface 21 of the compensated contact lens arrangement.

Figure 2a also shows the path of a light beam Z having an axis zz', the assumption being that Goldmann lens 10 and prism 20 are
 10 made of the same material. The direction of the incident beam is chosen parallel to axis bb' of the contact lens arrangement. Axis zz' of the beam enters prism 20 obliquely with respect to surface 21, at a point z₁ of this surface. The refractive index n of the prism (about 1.5) being greater than that of air (equal to 1), the light rays of beam
 15 Z are refracted as they travel through surface 21. After this refraction, axis zz' passes through entry surface 11 of Goldmann lens 10, again obliquely, at a point z₂. This time however the beam is not refracted as both media on opposite sides of surface 11 are assumed to be identical. Axis zz' then reaches a point 14 on surface 13 where it is
 20 subjected to total reflection, whereupon it enters eye 1 and reaches retina 5 at a point F_z.

In the form of embodiment of the compensated contact lens arrangement shown in Figure 2a, the compensating element is prism 20. As is well known, such a prism has, as regards light beam Z having axis
 25 zz', an astigmatism. This astigmatism depends on the angle q at point Q of triangle PQR and on the distance e, not shown, travelled by the light rays between entry surface 21 and exit surface 12 of the contact lens arrangement of refractive index n.

If $q = \arcsin \left[\frac{(T-S^*)}{(T+e - (S^*+e)/n^2)} \right]^{1/2}$, S* and T
 30 being, as mentioned earlier, the focal distances corresponding respectively to the sagittal and tangential parts of the astigmatism, then the astigmatism of the prism becomes the exact opposite of that of the eye, thus achieving the required correction of the Goldmann lens. If

the material used is a plastic for which n equals 1.5, angle q is roughly 20° for the point F_z aimed at in Figure 2a.

Point z_1 of axis zz' is located between point Q and axis bb' , on surface 21. Length e of the path of the light rays inside the contact lens arrangement being dependent on point z_1 , there is a precise value for angle q for each position of point z_1 . This value makes it possible to achieve optimal focusing of the incident light beam Z at point F_z of retina 5.

The corrected contact lens arrangement in Figure 2a may of course be made in one piece. Also, clearly only that part of prism 20 which receives light beam Z is operative. The remainder of the prism may have any shape. In particular, the angle at point R of the triangle at the base of the prism may have a value other than 90° .

Another form of embodiment, using a prism 25 by way of compensating element, is shown in Figure 2b. This new form of embodiment is similar to that shown in Figure 2a except only that prism 25, having a triangular base $P'Q'R'$, right-angled at R' , is so oriented that points P' and R' lie on the same side, with respect to axis bb' , as the reflecting surface 13 of Goldmann lens 10. The position of prism 25 on the Goldmann lens is thus obtained by a rotation of prism 20 through 180° about an axis parallel to axis bb' .

Prism 25 has an entry surface 26 on which impinges a light beam having an axis zz' . This axis passes through points z_1 , z_2 and 14 to reach retina 5 at point F_z , as in the case of Figure 2a. The different orientation of the compensating prism, however, causes point F_z to be slightly more distant from point F of eye 1 than in the case of Figure 2a if the same angle is used for mirror 13. A different slant of the mirror enables, as in Figure 2b, point F_z of Figure 2a to be reached.

For prism 25 to have an astigmatism exactly opposite to that of the eye, angle q' at point Q' of triangle $P'Q'R'$ must have a well defined value, given by the same relationship as that written for angle q .

The contact lens arrangements of Figures 2a and 2b may also be used in transparency with much smaller angles q or q' but still given

by the same relationship as before. In this type of use, a light beam, having an axis ww' , travels through the contact lens arrangement without being reflected by surface 13 of the Goldmann lens. A point F_w of the retina, located close to the axis of the eye, can be reached. The light beam that has ww' as its axis reaches entry surfaces 21 or 26, shown in Figures 2a and 2b, under the same angle as the beam that has zz' as its axis and, in the contact lens arrangement, it follows a path parallel to the part of axis zz' joining points z_1 and 14.

A second form of embodiment of a compensated contact lens arrangement is shown in Figure 2c. The compensating element here consists of at least a portion of a plano-convex lens 30 having a plane surface and a spherical surface 31. The plane part of lens 30 is applied against the entry surface 11 of the Goldmann lens. The spherical part 31 of the lens constitutes the entry surface of the contact lens arrangement. This surface is defined by the position of its centre of curvature S , with respect to Goldmann lens 10, and by its radius of curvature. A straight line, perpendicular to the plane part of the lens and passing through centre S , defines axis SS' of the lens. This axis is parallel to axis bb' . Certain circumferential parts of lens 30 may be truncated as shown with dotted lines in Figure 2c.

For an incident beam Z , having an axis zz' parallel to axis bb' , optics formulae, known as the Coddington equations and which may for example be found in pages 186 and 187 of a book entitled "Lens Design Fundamentals" by Rudolph Kingslake, published by Academic Press, New York, in 1978, enable the radius of curvature of surface 31 and the distance between axes SS' and zz' (and hence between axes SS' and bb') to be calculated. Several solutions are possible. If the material is plastic, the above radius and distance may measure, e.g., respectively, 42 and 8 mm, point S being located on the side opposite to surface 13 with respect to axis bb' .

An incident light beam Z , having an axis zz' , on reaching the contact lens arrangement parallel to axis bb' , is refracted as it passes through entry surface 31 and is then reflected by surface 13 to reach

point F_z of retina 5, located, in this case, away from the axis of the eye or from point F.

A modified construction using a lens by way of compensating element is shown in Figure 2d. At least a portion of a plano-concave lens 35, having a plane surface and a spherical surface 36, is used in this case. The plane part of this lens is applied against the entry surface 11 of Goldmann lens 10 and its spherical part 36, which constitutes the entry surface of the corrected contact lens arrangement, is defined, as in the previous case, by its centre of curvature S, which lies outside the Figure, and by its radius of curvature. If the same plastic material is used for both the compensating lens and the Goldmann lens, the Coddington equations show that the centre of curvature S of the lens must be positioned approximately e.g. 2 mm away from axis bb' , on the side opposite to that of surface 13, and that its radius of curvature must be about 75 mm long.

The path followed by an incident light beam, shown by its axis zz' , is also shown in Figure 2d. The beam reaches surface 36 parallel to axis bb' , and, after being refracted at point z_1 and reflected at point 14 by surface 13 (the latter having an appropriate slant), reaches retina at point F_z .

The compensating element and the Goldmann lens being made of the same material may be produced as two different components. These two components, once assembled, enable a surface 11 to be physically defined in the contact lens arrangement thus obtained. This surface, however, has no effect on the light rays, as the refractive indices are the same on both sides of the surface. The compensated contact lens arrangement may therefore, just as well, be made in one homogeneous piece within which surface 11 can no longer be located. This one-piece lens arrangement will of course have the same properties as the previous lens arrangement.

CLAIMS

1. A contact lens arrangement for observing and treating an eye (1) with an incident light beam (Z), said beam travelling a distance e within said lens arrangement between an entry surface (21, 26, 31, 36) and an exit surface (12) destined to be applied to the eye, and said eye having towards said beam an astigmatism that is defined by a sagittal focal distance S^* and a tangential focal distance T, comprising :
- a main element (10) for focusing the incident light beam (Z) on a working point (F_z) within the eye, said element having a refractive index n and having a plane entry surface (11) and an exit surface forming said exit surface (12) of the contact lens arrangement, the axis of the incident light beam (Z) reaching the entry surface of said lens arrangement being shifted in relation to the optical axis of the main element and being directed perpendicularly to said plane entry surface, characterized in that it further comprises :
 - a compensating element (20, 25, 30, 35) having said refractive index n and having an exit surface that is applied to the plane entry surface (11) of the main element (10) and an entry surface (21, 26, 31, 36) that forms said entry surface of said lens arrangement, the plane that is tangent to said entry surface of the compensating element, at the point (z_1) where the axis of the incident light beam (Z) passes through said surface, forming with the plane entry surface (11) of the main element an angle (q, q') that is so determined, in dependence on e, S^* , T and n, that said contact lens arrangement has, towards said beam, an astigmatism opposite to that of the eye.
2. A contact lens arrangement according to claim 1, characterized in that the main element (10) is a Goldmann lens having a plane entry surface (11), a reflecting surface (13) and a spherical exit surface (12) defining an axis of symmetry (bb') perpendicular to the plane entry surface (11) and passing through the centre of curvature (C) of the spherical exit surface (12), and in that said compensating element (20, 25, 30, 35), by being applied to said plane entry surface (11), produces in said lens arrangement said opposite astigmatism towards an incident



light beam (Z) having an axis parallel to said axis of symmetry (bb') and which impinges on the contact lens arrangement on the side of the reflecting surface (13).

3. A contact lens arrangement according to claim 2, characterized
5 in that said compensating element is a prism (20, 25).

4. A contact lens arrangement according to claim 2, characterized in that said compensating element is at least a portion (30) of a plano-convex lens having an axis of symmetry (SS').

5. A contact lens arrangement according to claim 2, characterized
10 in that said compensating element is at least a portion (35) of a plano-concave lens having an axis of symmetry (SS').

6. A contact lens arrangement according to either of claims 4 and 5, characterized in that the axis of symmetry (SS') of said compensating element and the axis (bb') of the exit surface (12) of the Goldmann lens
15 are shifted in relation to each other.

7. A contact lens arrangement according to claim 1, characterized in that said main element and said compensating element are united to form a single, homogeneous part.

8. A contact lens arrangement according to claim 1, characterized
20 in that said angle (q, q') is defined by the following formula :

$$\text{arc sin } \left[(T - S^*) / (T + e - (S^* + e) / n^2) \right]^{1/2}.$$

