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"OPHTHALMIC LENSES"

This invention relates to ophthalmic lenses and in particular to ophthalmic lenses having, at least in part, a progressively varying focal power.

The present invention seeks to reduce the astigmatism and distortion which are inevitably present in an image formed by a progressive multifocal lens and thereby to provide a lens which is easy to use.

References to "vertical" and "horizontal" in the following description are to be understood to refer to directions in the accompanying drawings.

According to the present invention there is provided an ophthalmic lens having a far vision viewing zone in the upper portion thereof, a near vision viewing zone in the lower portion thereof, an intermediate vision viewing zone in an intermediate portion thereof extending from the said upper portion to the said lower portion, and a principal meridian extending across each of the said zones, the curvature of the principal meridian changing between an optical centre of the far viewing zone and an optical centre of the near viewing zone in a predetermined manner so as to give a desired progressive variation of the focal power of the said intermediate vision

viewing zone, wherein an angle subtended by a line normal to the refractive surface of the lens through each point on an intersection between every arbitrary plane as hereinafter defined and the refractive surface of the lens and a plane including the said principal meridian is constant for points in the far vision viewing zone, and for points in the near vision viewing zone, but changes for points in the intermediate vision viewing zone in the same predetermined manner in which the curvature of the principal meridian changes in the intermediate viewing zone, each said arbitrary plane being defined as a plane parallel to the said plane including the principal meridian.

The curvature of the principal meridian may change in a substantially linear manner between the said optical centres.

Preferably the curvature of the principal meridian changes in a smooth or gradual manner adjacent to the said optical centres.

The curvature of the principal meridian may change in a substantially part-sinusoidal manner between the said optical centres.

Each said arbitrary plane may be any plane which is parallel to the said plane including the principal meridian and which intersects the said refractive surface of the lens.

Alternatively, each said arbitrary plane may be any plane which is parallel to the said plane including the principal meridian and which intersects the said refractive surface of the lens at a distance less than a predetermined distance from the said principal meridian.

The refractive surface of the far viewing zone or the near viewing zone may be substantially spherical, or the refractive surfaces of the far and the near viewing zone may be substantially spherical.

An intersection of a plane perpendicular to the said plane including the principal meridian with the far viewing zone of the said refractive surface may have a circular form for a distance of at least 2.5mm from the principal meridian.

The intersection of a plane perpendicular to the said plane including the principal meridian with the near viewing zone of the said refractive surface may have a circular form for a distance of at least 1.5mm from the principal meridian.

The said intersection of a plane perpendicular to the said plane including the principal meridian with the far viewing zone of the said refractive surface may have a non-circular form at distances greater than 2.5mm from the principal meridian.

The said intersection of a plane perpendicular to the said plane including the principal meridian with the near viewing zone of the said refractive surface may have a non-circular form at distances greater than 1.5mm from the principal meridian.

Preferably at least part of the visual centre line of the lens is inclined at substantially 10° to the principal meridian.

According to another aspect of the present invention there is provided a pair of glasses or monocle including an ophthalmic lens such as recited.

The present invention will be illustrated merely by way of example, in the accompanying drawings, in which:-

Figure 1 is a perspective view of a convex surface of a progressive multi-focal ophthalmic lens,

Figure 2 shows the change of focal power along the principal meridian of an ophthalmic lens such as that shown in Figure 1,

Figure 3 illustrates the distribution of astigmitism in the lens shown in Figure 1,

Figure 4 shows the distortion of an image formed by the lens shown in Figure 1,

Figure 5 is a schematic view of an ophthalmic lens according to the present invention,

Figure 6 shows the change of an angle K along an intersection of the lens shown in Figure 5,

Figure 7 is a perspective view of part of the lens shown in Figure 5,

Figure 8 shows the change of the angle K along further intersections of the lens shown in Figure 5,

Figures 9(a) and (b) illustrate the types of distortion produced by lenses,

Figure 10 is a schematic view of a first embodiment of an ophthalmic lens according to the present invention,

Figure 11 shows the change of focal power along the principal meridian of the lens shown in Figure 10,

Figure 12 shows the distortion of an image formed by the lens shown in Figure 10,

Figure 13 illustrates the distribution of astigmatism in the lens shown in Figure 10,

Figures 14 and 15 illustrate the effects of astigmatism in a lens such as that shown in Figure 10,

Figures 16 and 17, 18 and 19, 20 and 21, and 22 and 23 show the distortion of an image formed by, and the distribution of astigmatism in, second, third, fourth and fifth embodiments of ophthalmic lenses according to the present invention,

Figure 24 illustrates the intersection of lines of vision with lenses incorporated in a pair of glasses,

Figure 25 is a schematic view of a sixth embodiment of an ophthalmic lens according to the present invention,

Figure 26 shows the change of focal power along the principal meridian of the lens shown in Figure 25,

Figures 27 and 28 show the distortion of an image formed by, and the distribution of astigmatism in, the lens shown in Figure 25, and

Figure 29 shows how a lens such as that shown in Figure 25 can be cut from a circular glass.

A description of the use, structure,and optical characteristics of a progressive multi-focal lens will now be given in order to aid in the description of the invention.

Progressive multi-focal lenses are designed to provide

a person, particularly a person of advanced age whose crystalline lens has lost some of its control capability, with a lens to compensate for this defect. The lens consists of three zones: a far vision viewing zone, a near vision viewing zone, and an intermediate vision viewing zone which has a progressively varying focal power. These zones are referred to as the far zone, the near zone, and the intermediate zone. Figure 1 shows a perspective view of a convex refractive surface of a progressive multifocal lens. The opposite surface, not shown in Figure 1, is concave and in this invention is assumed to be spherical or cylindrical to compensate for the user's long-sightedness (hyperopia), near-sightedness (myopia), and astigmatism. Figure 1 shows an optical centre axis 1 (referred to as the optic axis hereinafter) which passes through a point O which is a geometric centre of the lens, and a principal meridian curve 2 which is an intersection of a vertical plane 5 including the optic axis 1 and the refractive surface of the lens. Figure 2 shows the change in curvature of the principal meridian curve 2, the ordinate representing distance along the principal meridian curve 2 and the abscissa representing the focal power P of the refractive surface. The focal power along the principal meridian curve 2 is constant in an upper portion of the lens above a point A and in a lower portion of the lens below a point B. Between the point A and the point B, the focal power progressively increases. As Figure 2 shows, the increase is substantially linear except at the

portions of the lens adjacent to the points A and B where it follows smooth curves. Points A and B are referred to as the optical centre of the far zone and the optical centre of the near zone,respectively, and the difference of the focal power between them (shown as ADD in Figure 2) is referred to as the additional power. The focal power of the refractive surface of the lens is proportional to its curvature. Figure 2 shows the change of curvature of the refractive surface, and Figure 1 shows a locus of evolute 3 of the principal meridian curve 2. At each point on the principal meridian curve 2, the curvature in a direction at right angles to the principal meridian curve 2 is equal to that along the direction of the principal meridian curve 2, that is to say, the principal meridian curve 2 is umbilical and each portion of the refractive surface along the principal meridian curve 2 is substantially spherical. This, of course, means that the astigmatism of the principal meridian curve 2 is zero. However, as the principal meridian curve 2 is connected to surfaces having a different curvature it is inevitable that portions of the refractive surface away from the principal meridian curve 2 will be aspherical and hence be astigmatic. As the focal power varies in each portion of the refractive surface, distortion of the image is increased.

Figure 3 shows the distribution of astigmatism of a progressive multi-focal lens,the more closely hatched areas

showing the areas of higher astigmatism. As will be seen, the image deteriorates away from the principal meridian curve 2. Generally speaking, when a lens has more than 0.5 diopters (D) astigmatism this can be perceived and the lens is uncomfortable to use. In the non-hatched portions of Figure 3, the astigmatism is 0.5 D or less. The upper part of the lens from point A is the clear viewing zone of the far zone, the lower part of the lens from point B is the clear viewing zone of the near zone, and the part between the points A and B is the clear viewing zone of the intermediate zone. Figure 4 shows the distortion of an image of a square grid which is drawn with an equal pitch in the vertical and horizontal directions, through such a progressive multi-focal lens. The image of the square grid is distorted, as shown in Figure 4, by the magnification of the lens, i.e. vertical lines are symmetrically expanded downward with respect to the line on a principal meridian curve 2 and horizontal lines are distorted more and more as the lines approach the peripheral portions of the lens. When a user looks at an object through such a lens, and the object moves relative to the visual point, the user follows the object with his eyes and the image will appear to shake thus rendering the lens uncomfortable to use. Watching an object which is moving is designated dynamic vision, and watching a stationary point, as in reading, is designated static vision. Static vision is mainly influenced by astigmatism,

that is to say, comfortable vision is available when the clear viewing zones of the far zone, the near zone and the intermediate zone are large and astigmatism is small within the whole viewing zone. On the other hand, dynamic vision is mainly influenced by distortion of the image, i.e. comfortable vision is available when distortion of the image is small. The quality of static vision and the quality of dynamic vision are not independent of one another, there being a reciprocal relationship therebetween. To have a large clear viewing zone in the far zone and the near zone for comfortable static vision, it is necessary to have a relatively large change of magnification in the side portion of the intermediate zone whereby dynamic vision is rendered uncomfortable. On the other hand, when dynamic vision is comfortable, astigmatism in the side portion of the intermediate zone becomes large so the clear viewing zone of the far zone and of the near zone is restricted in width.

The present invention seeks to improve on the faults described above of progressive multifocal lenses which inevitably have some astigmatism and distortion, and to provide lenses which are comfortable to use in static vision and in dynamic vision. Furthermore, the invention seeks to provide lenses which allow for some selection in the choice as to whether static vision or dynamic vision should be most improved.

Figures 5, 6 and 7 show the structure of a refractive surface

of a multi-focal lens according to the present invention. Figure 5 is a front view and Figure 7 is a perspective view of one part of such a refractive surface. Figure 5 shows a curve C1 intersecting with a principal meridian curve M at a point A which is the optical centre of the far vision viewing zone, and a curve C2 intersecting with the principal meridian curve M at a point B which is the optical centre of the near vision viewing zone. These two curves C1 and C2 divide the refractive surface of the lens into three portions; a far zone 51, a near zone 52, and an intermediate zone 53. The change in curvature along the principal meridian curve M is, of course, similar to that shown in Figure 2, the curvature changing in a predetermined manner so as to give a desired progressive variation of the focal power of the intermediate vision viewing zone. A line M1 is the intersection of an arbitrary plane, which is parallel to the plane including the principal meridian curve M,and the refractive surface of the lens. The intersection of the two curves M1 and C1 is designated A1, and the intersection of the two curves M1 and C2 is designated B1. The angle subtended by a line normal to the refractive surface of the lens at any point on the intersection M1 on the plane which includes the principal meridian curve M is designated K, and the variation of this angle for points along the intersection M1 is shown in Figure 6. The perspective view of Figure 7 illustrates the angle K at various points on the intersection M1.

In Figure 7, P1, P2, and P3 are points on the intersection M1 in the three respective zones, i.e. the far, the near and the intermediate zones. The normal lines at the points P1, P2, and P3 are shown by the reference numerals T1, T2, and T3. The plane which includes the principal meridian curve M is designated 71. The normal lines T1, T2, and T3 subtend angles K1, K2, and K3 on the said plane 71. One of the characteristics of the present invention is shown in Figure 6. Figure 6 shows that the angle K (on the abscissa) is constant in the far zone (the portion above the point A1) and in the near zone (the portion below the point B1), but continually changes in the intermediate zone. Furthermore, the angle K changes along the intersection M1 in the intermediate zone in the same manner in which the curvature of the principal meridian curve M changes. This is true for all such angles K subtended by normal lines through points on intersections between the refractive surface and planes parallel to the plane 71 on the said plane 71. Figure 8 shows the variation of the angle K across the intermediate zone for a plurality of intersections M1, M2, M3 and M4 which are progressively more distant from the principal meridian curve M.

The change in the angle K along the intersections is proportional to the change in the prismatic effect in the horizontal direction, i.e. perpendicular to the meridian curve M, so Figure 8 can be regarded as representing the distortion of a vertical line at each intersection. With the arrangement described above, if

vertical lines are not distorted then horizontal lines will not be distorted either. However, the converse is also true, i.e. if horizontal lines are distorted then vertical lines will also be distorted. The far and the near zones therefore have a normal distortion in which a square grid is distorted to a substantially rectangular form, and the intermediate zone has a skew distortion in which a square grid is distorted substantially to the shape of a parallelogram. As a result, the appearance of shake of an image in the far and the near zone can be reduced.

In the intermediate zone, since a vertical line is distorted according to the same law of change as that which produces the desired curvature between the optical centre A of the far zone and the optical centre B of the near zone on the principal meridian curve, the astigmatism on the principal meridian curve is reduced to zero and the peripheral portions of the lens can be adjusted so as to reduce the astigmatism and distortion of the image as much as possible.

Before the properties of a lens such as that mentioned above are more fully described, it is necessary to first explain the relation between astigmatism and distortion of an image and the prismatic effect. Figure 9 is an image of a part of a square grid seen through a lens. In Figures 9(a) and (b), broken lines show the image without the lens and solid lines show the image with the lens. Figure 9(a) shows a normal distortion, that

is to say the shape of a square grid is changed substantially to a shape of a rectangle whose sides are parallel to the sides of the square. In this normal distortion, there is an amount of prismatic displacement of both the vertical and horizontal lines, the displacement being in directions perpendicular to the sides of the square, and the magnitude of the displacement is constant along each side of the square. The astigmatism of the lens produces the difference in length between the long and short sides of the rectangle. The directions of the maximum curvature and the minimum curvature of the lens are shown by the small arrows in Figure 9(a), the arrows being parallel to respective sides of the square grid. Figure 9(b) shows a skew distortion, that is to say, a square grid is changed substantially to the shape of a parallelogram. In this skew distortion, there is a prismatic displacement of vertical and horizontal lines which although perpendicular to the sides of the square grid is not constant along the sides of the square so that the astigmatism of the lens changes the shape of the square grid to a parallelogram. The directions of the maximum and minimum curvature of the lens are shown by the small arrows and, as will be seen, these directions are not parallel to the respective sides of the square grid. The influence of these two kinds of distortion on the user's vision will now be described. With respect to static vision, normal distortion makes the image stretch or shrink in the horizontal or vertical directions, and when the astigmatism

exceeds the allowed value (0.5D), the image is no longer in focus. On the other hand, skew distortion makes the image stretch or shrink in an inclined or slant direction, and again the image is not in focus when the astigmatism exceeds the allowed value. With respect to dynamic vision, normal distortion changes the speed at which the image is seen to move, and skew distortion makes the moving image appear to shake.

Particular embodiments of lenses according to the present invention will now be described. In these embodiments the focal power of the far zone is assumed to be zero. In practice the focal power of the far zone will not be zero but will have some value which provides a correction for myopia, hyperopia, or astigmatism. Such differences do not impair the advantages of the invention and thus have no effect on the description given below. Each of the embodiments will also be described as having an additional power of 2D but, again, this may be changed in practice to suit individual requirements.

Figure 10 shows a first embodiment of a lens according to this invention. In this embodiment, a boundary line C1 between the far zone and the intermediate zone is a horizontal line which passes through a geometric centre of the lens. However, a boundary line C2 between the intermediate zone and the near zone is made up of two straight lines which diverge away from the boundary line C1 as the peripheral portions

of the lens are approached. Both the lines C1 and C2 are symmetric with respect to the principal meridian curve M. The far zone and the near zone are spherical and, as mentioned above, their additional power is 2D. It is obvious that the spherical surfaces satisfy the object of the invention of providing clear viewing zones in the far zone and the near zone. Figure 11 shows the change of curvature of the principal meridian curve M of the lens. The change in focal power between the optical centre A of the far zone and the optical centre B of the near zone is linear except where the intermediate zone blends into the far and near zones adjacent the points A and B respectively. Where the intermediate zone blends into the far and near zones, the curvature changes as a smooth or gradual curve, as shown in Figure 11.

Figure 12 shows the distortion of an image of a square grid produced by the first embodiment. Because the far zone and the near zone has spherical surfaces, as is the case in the more common single focal power type of lens, they produce only a very small skew distortion. This small amount of skew distortion can usually be neglected. The image of the square grid is magnified by each of the zones by a different amount in dependence upon the relative focal powers of the zones. In the intermediate zone, the angle K, (described above), changes in the manner illustrated in Figure 8 and thus changes between the boundaries of the far and near zones in the same way as the focal power

changes, as is shown in Figure 11. The change of the angle K is approximately proportional to the change in the amount of prismatic displacement produced in the horizontal direction, i.e. parallel to the line C1. Vertical lines of the square grid between the boundary of the power zone and the boundary of the near zone are therefore displaced towards the peripheral portions of the lens in the same manner as that in which the angle K is changed, that is to say, in the same manner as that in which the curvature of the principal meridian curve is changed. In this embodiment, the change of curvature on the principal meridian curve is as shown in Figure 11 so vertical lines of the square grid in the intermediate zone appear as substantially linear diverging lines except at the portions of the intermediate zone adjacent to the boundaries of the far zone and the near zone. In the portions of the intermediate zone adjacent to these boundaries, the lines curve smoothly and gradually. Horizontal lines of the square grid are gradually distorted to diverge as the lines approach the peripheral portions of the intermediate zone.

Figure 13 shows the distribution of astigmatism of a lens according to this embodiment. The portion of the lens which provides distinct vision, i.e. the clear viewing zone, is shown as the non-hatched area in Figure 13. In this area the astigmatism is 1.5D or less. This area includes almost all of the far zone and the near zone and also part of the intermediate

zone adjacent to the principal meridian curve extending from the optical centre A of the far zone to the optical centre B of the near zone. The astigmatic effects of this lens are found in parts of the intermediate zone near to the principal meridian curve and across the whole intermediate zone. In the part of the intermediate zone adjacent to the principal meridian curve, changes in the angle K (described above), which produces a change in prismatic displacement in the horizontal direction, i.e. parallel to the line C1, are made substantially equal to the change of curvature on the principal meridian curve which produces the change of magnification of the image in the vertical direction, i.e. parallel to the principal meridian curve, so that astigmatism is small. This is shown in Fig. 14. Astigmatism is made small by making the magnification c of the image in the vertical direction along the principal meridian curve M, and the magnification d in the horizontal direction, i.e. parallel to the line C1, almost equal to each other. In each part of the entire intermediate zone, the distortion of the square grid in the vertical direction is made substantially equal to the distortion in other directions so that the distortion of the image of the square grid changes gradually. As a result, strong astigmatism is avoided since a small amount of astigmatism is distributed throughout the whole intermediate zone, this being illustrated in Fig. 15. As is evident from Fig. 15(b), the image of a square grid produced by a lens according to this embodiment has less astigmatism than the image shown in Fig. 15(a) which is produced by another type

of lens, and the astigmatism is distributed generally to avoid points of high astigmatism.

In the embodiment described above, a sudden change in the distribution of astigmatism is avoided and thus astigmatism is reduced.

Figs. 16 and 17 show the distortion of an image of a square grid and the distribution of astigmatism produced by a second embodiment of this invention.

It should be noted that Figs. 16 to 23 only show half of a lens or grid since each Figure is symmetrical about the principal meridian curve. In addition, the reference numerals used in these Figures correspond to those used for like parts in the above description, and description of similar parts will not therefore be repeated. In each of the embodiments described, the angle K and the curvature of the principal meridian change in the same manner, at least in part of the lens, as is described above. It will also be seen that the lines C1 and C2 which separate the three zones of the lenses shown in Figures 16-23 do not have the same shape as those described above.

In the embodiment shown in Figs. 16 and 17, the far zone of the lens has a spherical surface and the near zone an aspherical surface. The far zone is the same as that described in the first embodiment, i.e. it produces an undistorted image of the square grid. However, in the near zone, which has an aspherical surface, the image of the square grid changes as the peripheral portions of

the lens are approached. In this embodiment the angle K (which is described above) is, of course, constant along each intersection as it crosses the near zone. Furthermore, as this is true for all intersections parallel to a principal meridian curve, the directions of maximum and minimum curvature are parallel to the directions parallel to and perpendicular to the intersections, this being shown by the small arrows in Fig. 16. The near zone thus has normal distortion. Of course, skew distortion, due to the spherical or cylindrical surface opposite to the refractive surface of the lens, can usually be ignored, as it is in the more common single focal power type of lens.

Fig. 17 shows distribution of astigmatism according to this embodiment. As the surface of the far zone is spherical, there is no astigmatism in this zone and a large clear viewing zone is thus provided. In the near zone, the surface has normal distortion which increases at points more distant from the principal meridian. As a result, and as shown in Fig. 17, when points having the same astigmatism are joined, vertical lines are produced in the near zone. In this embodiment, as the surface of the near zone is aspherical, distortion of the image is small. This is clear from the comparison of Fig. 16 and Fig. 13 from which it is apparent that the areas of high astigmatism in Fig. 13 have been moved further towards the peripheral portions of the lens in Fig. 16. As the near zone has normal distortion, the images it produces of moving objects do not appear to shake. However, although astigmatism is

reduced in the intermediate zone it is increased in the near zone.

Figs. 18 and 19 show a third embodiment of a lens according to this invention. In this embodiment the far zone and the near zone both have aspherical surfaces and so they both have normal distortion as described for the near zone in relation to Figs. 16 and 17. In this embodiment, the distortion of the image is, in general, smaller than that in the second embodiment and, again, as the far zone and the near zone both have normal distortion, the images produced thereby do not appear to shake. The distribution of astigmatism in this embodiment is as shown in Fig. 19. It can be seen that there is some astigmatism in the near and far zones but that the astigmatism in the intermediate zone is reduced, the areas of high astigmatism again being pushed further towards the peripheral portions of the lens. As before, when points of equal astigmatism are joined vertical lines are produced, in this case both in the far zone and the near zone.

Figs. 20 and 21 show a fourth embodiment of a lens according to this invention. In this embodiment, the surfaces of both the far zone and the near zone are again aspherical. On the intersection which is equivalent to a vertical line S and is parallel to the plane including the principal meridian curve, the angle K (described above) is constant across all three zones of the lens. The angle K made by normal lines through points on intersections more distant from the principal meridian curve than S is also constant across the three zones of the lens. The parts

of the lens beyond the vertical line S thus have normal distortion, and the distortion of the image is, in general, smaller than that in the third embodiment. However, astigmatism is larger in regions which are closer to the principal meridian curve than the line S and the clear viewing zone is smaller than that in the third embodiment described above.

Figs. 22 and 23 show a fifth embodiment of a lens according to this invention. In this embodiment, as is shown in Fig. 22, the intermediate zone is curved downward at points away from the principal meridian curve and the angle K (described above) follows a part sinusoidal change, i.e. the change in the angle K and the curvature of the principal meridian across the intermediate zone is no longer substantially linear but, instead, changes in a part sinusoidal manner, as is shown by the image of the vertical lines in Fig. 22. The far zone and the near zone both have aspherical surfaces. In this embodiment, the far zone is enlarged and by changing the angle K in a part sinusoidal manner, astigmatism is concentrated in the region between the lines C1 and C2. The clear viewing zones of the far zone and of the near zone are therefore enlarged.

In the embodiments described above, the far zone and the near zone have normal distortion and as a result, it is possible to reduce the appearance of shake of an image in dynamic vision. On the other hand, by arranging the distortion of the image it is possible to reduce a skew distortion in the intermediate zone

and thus to obtain a smooth distortion curve. The balance between improving characteristics of static vision or of dynamic vision of a lens can be freely selected by varying the combinations of elements such as the shape of the three zones, the law of change of curvature on the principal meridian curve, and the type of curvature, i.e. spherical or aspherical, of the far zone and the near zone.

The embodiments described above have been described as being symmetrical with respect to the principal meridian curve. However, this invention is not restricted to such lenses. It is clear that the present invention is applicable to lenses having three zones, even if these zones, or any one of them, are not symmetrical with respect to the principal meridian curve, and also to lenses in which the spherical or aspherical surfaces of the far zone and the near zone are not symmetrically formed.

Further embodiments of the present invention will now be described with reference to Figs. 24 to 29. These embodiments relate to lenses which not only have the advantages discussed in relation to the embodiments described above but which are also relatively easy to manufacture and relatively easy for an optician to fit correctly to a user.

A progressive multifocal lens has characteristics which a single focal power lens or a bifocal lens do not have. First of all, with regard to the manufacture of the lens, the surface of the lens does not consist entirely of a single spherical surface nor

does it consist of a plurality of separate spherical lenses. Because of this, it is difficult to measure, and control, the accuracy of the shape of a progressively variable focal power lens by optical or mechanical methods. Also, when the lenses are used in glasses, as the width of the intermediate clear viewing zone is relatively narrow, it is necessary to arrange the position of the left and right lenses precisely in front of the user's eyes and to take account of the convergence of the eyes. Fig. 24 shows the change in the line of vision through lenses fitted in a pair of glasses when an object at an intermediate distance is being viewed through the intermediate clear viewing zone. When the line of vision is moved gradually from an object at a relatively far distance from the lens to a relatively near position, the point at which the line of vision passes through the lens gradually moves from a point a to a point b, as shown in Fig. 24, as a consequence of the convergence of the eyes.

The locus of the line of vision between the points a and b is inclined at an angle of about 10 degrees to the vertical. On the other hand, when looking at the object through the far zone or the near zone, especially when gazing steadily at an object, the user's face is moved in front of the object and the line of sight tends to follow the line a-a' or the line b-b', these lines being substantially vertical, as shown in Fig. 24.

In view of this, it is desirable that the astigmatism in the parts of the lens crossed by the lines a'-a, a-b, and b-b' is

very low. The line a'-a-b-b' is often referred to as the visual centre line. In conventional progressive multifocal lenses, an umbilical curve is made to lie along the visual centre line, the surface of the far and near zones being made spherical and the lens being geometrically bisymmetric about a principal meridian curve which is inclined at an angle of about 10 degrees to the vertical, i.e. it follows the line a-b. However, with such an arrangement the left and right lenses are not identical to each other and, therefore, it is necessary to use a pair of symmetric lenses rather than two identical lenses, and each lens has to be cut from a glass which is exclusively either a left or a right glass. This is extremely inconvenient as it entails duplicating all the manufacturing steps and this, of course, makes it difficult to ensure that two lenses of a pair are equally accurately made. Besides the above difficulties, when the far zone and the near zone are spherical, and the intermediate clear viewing zone is extremely narrow, it is necessary to ensure that each lens is aligned with the user's eyes with extreme accuracy.

The embodiments of the invention described below seek to overcome the above defects and to provide a progressive multifocal lens which is easy to use, easy to manufacture, and easy for an optician to fit.

Fig. 25 shows a front view of a sixth embodiment of progressive multifocal lens according to the present invention. In this embodiment, the optical centre A of the far zone is a geometric

centre of the lens and a boundary line C1 between the far zone and the intermediate zone is horizontal. The boundary line C2 between the near zone and the intermediate zone is comprised of two straight lines which diverge away from the line C1 away from the principal meridian M. The far zone and the near zone in this embodiment are provided with spherical zones D and E adjacent the principal meridian curve M, and with aspherical zones D1 and E1 on either side of the spherical zones D and E. In the far zone, the spherical zone or zones D extend for at least 2.5 mm on either side of the principal meridian curve. In the outer zones D1, the curvature in the horizontal direction, i.e. parallel to the line C1, is arranged to gradually increase at points more distant from the principal meridian curve M. On the other hand, in the near zone, the spherical zone or zones E extend for at least 1.5 mm on either side of the principal meridian curve. In the outer zones E1, the curvature in the horizontal direction, i.e. parallel to line C1, is arranged to gradually decrease at points more distant from the principal meridian curve M. In other words, the line C1, or a line parallel to the line C1, which intersects the principal meridian curve at right angles, has a circular form for more than 2.5 mm on either side of the principal meridian curve, and the line C2, or a line parallel to the line C2, has a circular form for more than 1.5 mm on either side of the principal meridian curve. The radii of curvature of the two said circular forms are arranged to equal

that of the principal meridian curve where the lines C1 and C2, or the lines parallel to the lines C1 and C2, cross the curve, e.g. at points A and B. In the far zone, the radius of curvature decreases away from the zone or zones D so that the zones D1 have a non-circular form. In the near zone, the radius of curvature increases away from the zone or zones E so that the zones E1 have a non-circular form.

Figure 26 shows the change in the focal power of the refractive surface (that is to say, the change of the curvature) along the principal meridian curve M for this embodiment. Figure 27 shows the distortion of the image of a square grid when it is viewed through such a lens. The broken lines in Figure 27 correspond to the perimeters of the zones shown in Figure 25. In the portions corresponding to the spherical areas of the far and near zones, the square grid is magnified in correspondence with the focal power of these zones. The portions on either side of the spherical areas have a normal distortion, the direction of the maximum and minimum curvature of which is indicated by the small arrows which, as shown, are parallel to the horizontal and vertical directions. The image in the side portions of the far zone is distorted as it becomes more distant from the principal meridian curve, the image being stretched horizontally. Conversely, in the side portions of the near zone, the image is distorted as it becomes more distant from the principal meridian curve M, the image in this case being compressed horizontally. The

distortion of the image in the side portions of the lens is thereby reduced. Figure 28 shows the distribution of astigmatism in such a lens. In this embodiment, the portion of the lens enclosed by the broken lines is non-hatched, i.e. has no astigmatism. Thus, a clear viewing zone is formed in the spherical portions of the far zone and the near zone, and in areas adjacent to the principal meridian curve in the intermediate zone. The astigmatism in these areas is zero. In the far zone and near zone, astigmatism is increased approximately in proportion with the increase or decrease of the curvature of the portions D1 and E1 on either side of the spherical portions D and E.

Figure 29 shows a circular glass from which a lens for a pair of glasses according to this embodiment is prepared. A lens is cut with a shape such as that shown by the line F and is arranged so that the principal meridian curve M thereof is inclined at an angle of about 10° to a vertical visual line a'-a, the point a being 2 to 3 millimetres above the optical centre A of the far zone on the principal meridian curve M of the lens. The lens shown in Figure 29 is formed so as to be suitable for positioning before a user's right eye, the nose-bridge (not shown) of the glasses being positioned on the right hand side of Figure 29. By inclining the principal meridian curve at about 10° to the line a'-a, the principal meridian curve M lies substantially over the visual centre line a-b (described above), thereby making the lens comfortable to use.

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The important point of this embodiment of the invention is that the visual centre-lines in the far zone and the near zone, namely the line a'-a-A in the far zone and the line B-b-b' in the near zone, fall substantially within the spherical zones D and E, respectively, so that the astigmatism on the visual centre-line in the two zones is substantially zero. In practice the points a' and a are about 12-15 mm apart and the points b and b' are about 10 mm apart, the line a-b being inclined at an angle of about 10 degrees to the vertical. It goes without saying that astigmatism on the visual centre-line which is used frequently and is also used when one steadily gazes at an object, should be reduced to zero in order to avoid fatigue of the eyes. This embodiment satisfies this requirement. Furthermore, with such lenses, the glasses from which the lenses are cut do not need to be exclusively for left or right lenses in order to avoid astigmatism on the visual centre line since a left or right lens can be cut from the same glass by altering the angle at which the lens is cut from the glass. Such lenses are therefore relatively inexpensive to manufacture and it is easier to control the accuracy with which they are made.

As the curvature of the portions of the lens on either side of the spherical portions of the near and far zones is changed, at points more distant from the principal meridian curve, distortion of the image in the peripheral portion of the lens can be reduced, the width of the intermediate clear viewing zone can be broadened,

and the precision with which the centre line a-b is aligned with the principal meridian curve can be slightly relaxed.

The portions of the far zone and the near zone having spherical surfaces can be manufactured accurately with relative ease as the accuracy of such spherical curves can be determined by optical or mechanical methods.

As described above, a progressive multifocal lens according to this embodiment provides a user with relatively good static vision and dynamic vision and also provides a lens which is relatively easy for an optician to fit and relatively easy to manufacture accurately. It is also possible, of course, to form the lens so that either the near zone or the far zone consists entirely of a spherical surface.

* C L M S *

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C L A I M S

1. An ophthalmic lens having a far vision viewing zone in the upper portion thereof, a near vision viewing zone in the lower portion thereof, an intermediate vision viewing zone in an intermediate portion thereof extending from the said upper portion to the said lower portion, and a principal meridian extending across each of the said zones, the curvature of the principal meridian changing between an optical centre of the far viewing zone and an optical centre of the near viewing zone in a predetermined manner so as to give a desired progressive variation of the focal power of the said intermediate vision viewing zone, wherein an angle subtended by a line normal to the refractive surface of the lens through each point on an intersection between every arbitrary plane as hereinafter defined and the refractive surface of the lens and a plane including the said principal meridian is constant for points in the far vision viewing zone, and for points in the near vision viewing zone, but changes for points in the intermediate vision viewing zone in the same predetermined manner in which the curvature of the principal meridian changes in the intermediate viewing zone, each said arbitrary plane being defined as a plane parallel to the said plane including the principal meridian.

* C L M S *

2. An ophthalmic lens as claimed in claim 1 in which the curvature of the principal meridian changes in a substantially linear manner between the said optical centres.

3. An ophthalmic lens as claimed in claim 2 in which the curvature of the principal meridian changes in a smooth or gradual manner adjacent to the said optical centres.

4. An ophthalmic lens as claimed in claim 1 in which the curvature of the principal meridian changes in a substantially part-sinusoidal manner between the said optical centres.

5. An ophthalmic lens as claimed in any preceding claim in which each said arbitrary plane is any plane which is parallel to the said plane including the principal meridian and which intersects the said refractive surface of the lens.

6. An ophthalmic lens as claimed in any of claims 1 to 4 in which each said arbitrary plane is any plane which is parallel to the said plane including the principal meridian and which intersects the said refractive surface of the lens at a distance less than a predetermined distance from the said principal meridian.

7. An ophthalmic lens as claimed in any preceding claim in which the refractive surface of the far viewing zone or the near viewing zone is substantially spherical.

8. An ophthalmic lens as claimed in claim 7 in which the refractive surfaces of the far and the near viewing zones are substantially spherical.

9. An ophthalmic lens as claimed in any of claims 1 to 6 in which an intersection of a plane perpendicular to the said plane including the said principal meridian with the far viewing zone of the said refractive surface has a circular form for a distance of at least 2.5 mm from the principal meridian.

10. An ophthalmic lens as claimed in any of claims 1 to 6 or claim 9 in which an intersection of a plane perpendicular to the said plane including the principal meridian with the near viewing zone of the said refractive surface has a circular form for a distance of at least 1.5mm from the principal meridian.

11. An ophthalmic lens as claimed in claim 9 in which the said intersection of the plane perpendicular to the said plane including the principal meridian with the far viewing zone of the said refractive surface has a non-circular form at distances greater than 2.5mm from the principal meridian.

12. An ophthalmic lens as claimed in claim 10 in which the said intersection of a plane perpendicular to the said plane including the principal meridian with the near viewing zone of the said refractive surface has a non-circular form at distances greater than 1.5mm from the principal meridian.

13. An ophthalmic lens as claimed in any of claims 9 to 12 in which at least part of a visual centre line of the lens is inclined at substantially 10° to the principal meridian.

14. An ophthalmic lens substantially as hereinbefore described with reference to Figures 5 to 29 of the accompanying drawings.

15. A pair of glasses or monocle including an ophthalmic lens as claimed in any preceding claim.