

SHAPED OPHTHALMIC LENSES

The present invention relates to optical lenses and eyewear including prescription lenses and sunglass lenses, spectacles, lens blanks, sunglasses and safety lenses.

5 It is known in the prior art to manufacture non-corrective eyeglasses such as sunglasses or protective eyeglasses having wrap-around segments designed to shield the eye from incident light, wind, and foreign objects in the temporal vision field of the wearer. Visible light and light in the UV region may enter the eye from angles as high as 100° from the line of sight.

10 It has not been possible, however, in prior art sunglasses or protective eyeglasses, to provide such spectacles with significant through power, whilst maintaining a cosmetically acceptable appearance. The radius of curvature required to provide an ophthalmic lens including a prescription surface is such that the spectacles would produce a bug-eyed appearance, which would be
15 cosmetically unacceptable.

Today, the vast majority of conventional prescription lenses are relatively flat, single vision, Ostwalt section, miniscus lenses which are glazed like window panes into flat outline spectacle frames.

Applicants have developed certain novel optical lens elements including
20 lens elements with a prescription zone, suitable for use in wrap-around or protective eyewear. The element may also include a peripheral vision zone, with no prismatic jump between the zones. These lens elements are produced by design methods for the prescription zone which include temporally rotating a prescription section about a vertical axis through its optical center and/or
25 decentering the optical axis of the prescription section relative to its geometric axes. These lens elements and design method are described in International Publication No. WO 97/35224 (25 September 1997) to applicants, the entire disclosure of which is hereby incorporated by reference. This application describes the use of close fitting prescription shields, visors or dual lens



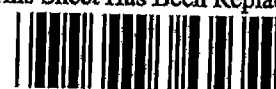
prescription sunglasses by introducing a step change in curvature of the Rx lenses, particularly in the forward visual field of the wearer. However, the technique involves design discontinuities in the optical construction of the lenses, although the visual function is not impaired from the wearer's viewpoint.

5 Applicants had developed certain novel lens elements and eyewear characterised by steeply curved surfaces which are approximately spherical and concentric with the centroid of rotation of the eye. These objects are described in detail in United States Patent Application Serial No 09/223,006 to Applicants, ("Wide field spherical lenses and single design spectacle therefor") filed 30
10 December 1998, the entire disclosure of which is hereby incorporated by reference. These lenses deviate substantially from conventional, relatively flat lens shapes. However, the overall shape of such lenses may be limited by the spherical reference surfaces employed.

Accordingly, it would be a significant advance in the art if an item of
15 prescription eyewear, for example of the wrap-around type, could be provided which would allow for a wide range of selected styling for both horizontal wrap (around the brows) and vertical shape to maximise the fashion appeal. Furthermore, it would be a further significant advance in the art if the lenses could provide good correction to the full visual field from central to peripheral vision, if
20 desired. Even more preferably, it would be a significant advance if this could be achieved without design features that may create fitting difficulties for a practitioner, or features such as a plano extension which are visible to an observer and diminish the appeal of the product unless it is treated as a tinted or reflective sunglass.

25 Further, the range of lens shapes in both the horizontal and orthogonal directions is relatively limited in the prior art. The necessity to provide acceptable optical quality has heretofore limited the range of lens element shapes available, particularly with lens elements having significant through power.

It is accordingly an object of the present invention to overcome, or at least
30 alleviate, one or more of the difficulties and deficiencies related to the prior art.



Accordingly in a first aspect of the present invention there is provided an optical lens element including

a first surface; and

a second surface of complementary curvature;

5 at least one surface exhibiting significant deviation in curvature from a standard optical surface;

the first and second surfaces in combination defining an optical zone exhibiting substantially constant mean through power along at least one meridian.

It will be understood that the optical lens element according to the present
10 invention permits the production of optical lenses with a surface or surfaces of quite radical shape relative to standard ophthalmic lenses, but still providing a lens body for which the mean through power is relatively constant within normal ophthalmic standards. This is despite the fact that the deviating surfaces may exhibit significant optical distortions, e.g. high levels of surface astigmatism over
15 substantial portions of the lens aperture.

Preferably the first and second surfaces are co-varying surfaces such that the optical zone exhibits substantially constant mean through power. More preferably the deviating surface(s) exhibits a substantially smooth change of curvature, at least along a horizontal meridian, across at least a portion of the
20 visual fixation field of the wearer. Thus, the deviating surface(s) may exhibit substantially no visible discontinuity, and more preferably no optical discontinuity.

In a preferred form, the change in curvature results in a change in sagittal depth of at least approximately 2 mm, preferably at least approximately 4 mm, more preferably at least approximately 9 mm.

25 In a preferred form, the optical zone of the lens element functions as a prescription zone. More preferably, the lens element has a mean through power between -6.0 D and +6.0 D, preferably between -4.0 D and +4.0 D.

In a further preferred form, the standard optical surface is of spherical or toric shape, defined at a sphere or fitting point on the surface which passes



through the optical axis.

By the term "good optical quality", we mean optical quality equal to, or greater than, a standard aspheric lens, for example.

By the term "substantially constant mean through power" we mean that the mean through power is constant within ± 0.75 D, preferably within ± 0.5 D, more preferably within ± 0.25 D, in the visual fixation field of the wearer.

Mean through power is the average of F_1' the through power in one principal meridian along a given line of sight and F_2' the through power in the other principal meridian along that line of sight.

$$\text{Mean through power} = \frac{(F_1' + F_2')}{2}$$

RMS Power Error is the root mean squared error of actual lens through powers F_1' and F_2' in the principal meridians, compared with the desired refractive corrections F_1 and F_2 :

$$\text{RMS Power Error} = \sqrt{\frac{(F_1 - F_1')^2 + (F_2 - F_2')^2}{2}}$$

By the term "significant deviation" in curvature from a standard optical surface, we mean that the shape of the surface deviates sufficiently to introduce optical distortions, e.g. astigmatism, to the lens surface. For example, the curvature may deviate from a standard optical shape by at least 1.0 D along the horizontal meridian, preferably 3.0 D along any meridian, more preferably at least 5.0 D, more preferably at least 6.0 D.

By the term "lens element" as used herein, we mean an optical or ophthalmic lens, semi-finished lens, or lens wafer which may be utilised in the formation of an ophthalmic product. The optical lens element may be provided in the form of a semi-finished lens, or lens blank, where the second or back surface of the optical lens element may be finished at a later time.



By the term "visual fixation field", as used herein, we mean a region on the lens surface defined by a set of points which are the intersection of the lens surface and the wearer's line of sight as he or she fixates on objects in the median plane.

- 5 By the term "sagittal depth", as used herein, we mean the distance between the fronto-parallel plane of the lens element and the temporal most edge point. The sagittal depth provides generally a measure of the three-dimensionality of the lens element and lens edge.

- 10 In a particular preferred form the optical lens element includes front and rear co-varying surfaces, at least one of which having a varying surface power such that the mean through power of the lens element is constant to within ± 0.75 D in the visual fixation field of the wearer with the optical axis of the lens element aligned with the visual axis of the wearer, said lens element conforming to the shape of the face of the wearer and having a sagittal depth Z of at least 10 mm,
15 preferably between 10 and 20 mm.

- By the term "co-varying surfaces" as used herein we mean two surfaces which have corresponding points in close proximity which allow substantially constant through-power even though the magnitude of the curvatures may vary substantially. This is achieved by having the curvature changes across the
20 surfaces being nearly equal for each point of a corresponding pair. In this way, the curvatures at corresponding points may be seen to track each other from point to point, even though the physical surfaces may diverge. Co-varying surfaces may be defined by a set of mathematical constraints:

Constraints

- 25 For substantially all corresponding points on the front and back surfaces of the lens lying along lines passing through the center of rotation of the eye in the as-worn position:

$$P_{\max, \text{front}} + P_{\max, \text{back}} \approx F_1 + kA$$

$$P_{\min, \text{front}} + P_{\min, \text{back}} \approx F_2 + kA$$

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for substantially all points on the lens, where $P_{\max}$ is the maximum surface curvature in one principal meridian at a given point, $P_{\min}$ is the minimum surface curvature along the other principal meridian at that point, F_1 is the desired prescription through-power in one principal meridian and F_2 is the through-power in the other principal meridian such that the difference between F_1 and F_2 provides the prescribed cyl correction; A = add in the progressive case ($A \leq 3$ D) and $0 \leq k \leq 1$ (in the case of a plano lens both equations equal zero; in the case where there is no cylinder correction, $F_1 = F_2$; and where the lens is not progressive or varifocal, KA equals zero)

10 and

there exist regions of the lens such that for corresponding points

$$\begin{aligned} |P_{\max \text{ front}} - P_{\min \text{ front}}| &> 0.25D \\ |P_{\max \text{ back}} - P_{\min \text{ back}}| &> 0.25D \end{aligned}$$

and

there exist at least two points P_1 and P_2 on a surface of the lens (typically horizontally spaced points within the useful aperture of the lens) such that

$$|\overline{P_1} - \overline{P_2}| > 3D$$

where $\overline{P_1}$ is the mean surface curvature at P_1 and $\overline{P_2}$ is the mean surface curvature at P_2 .

The optical lens elements of the present invention may be designed to have an optical axis which passes through a sphere point or fitting point of at least one of the surfaces. The surface curvature of the surface(s) varies outwardly from the sphere point.

The lens elements of the present invention may be worn by a wearer with an assumed line of sight: a visual axis substantially corresponding to the wearer's straight ahead gaze directed at an object at infinity. The lens elements may be designed to be glazed and worn so that the optical axis of the lens element is parallel to, and preferably colinear with the line of sight of the wearer.

With respect to the "optical axis" it should be understood that for a lens with



two spherical surfaces, it simply is the line connecting the centers of curvature of the two surfaces. In a practical sense the optical axis is also the line about which the angle of refracted rays of light u' are least deflected from the angle of incidence u . In lenses with covarying surfaces, the definition of an optical axis is not so simple and such a lens might have more than one axis nominally satisfying this definition. For this application we define a primary optical axis as the line passing through the fitting point P. Preferably, for such an axis, the average slope

$$m = \frac{\sum_{n=1}^n u_n}{n}$$

of the rays $r'_1, \dots, r'_n$ in a bundle of refracted rays is minimum. (See Figure 1) We here take a 'bundle' of rays to be all of the rays surrounding the axis within a small circular portion of the xy plane and distributed uniformly such that the sum of all x and y values of the ray points within the plane are equal to zero.

One may usually locate the optical axis of a manufactured lens by identifying the two points on the front and back surface which have coincident normals, for example by using an alignment telescope. These two points define the optical axis and in radially symmetric lenses with covarying surfaces this will be the correct procedure. In ovaliform lenses with spiral curvatures there may not be two such points so the optical axis must be located by finding the line about which bundles of incident and refracted rays has greatest symmetry. This might be done for example using an optical bench with a source of a narrow bundle of rays located at the center of curvature of a spherical mirror and the lens located between the source and mirror. In this method the lens could be tilted and decentered until the returning rays are symmetrically centered upon the source. The optical axis is then defined by the points on the lens surface intersected by the line defined by the chief ray of the source.

In a particularly preferred aspect, the extent of deviation of the deviating surface from a standard optical surface is related to the radial distance from the optical axis of the lens element.

In one embodiment of the present invention, the extent of deviation varies



linearly, sinusoidally or a combination thereof, with radial distance. More preferably, the optical lens element may be generally radially symmetric, and in particular may take the form of a bowl, preferably an oblate or prolate bowl. In a still further preferred form, the deviating surface(s) exhibits no more than 1
5 meridian being circular in section.

In a more preferred form, the lens element is a bowl shape, which is radially symmetric about its optical axis and defined by a pair of rotationally symmetric, co-varying surfaces. An oblate bowl has a flat central portion and becomes increasingly steep away from the optical axis. A prolate bowl is most steeply
10 curved at or near the optical axis and flattens out away from the optical axis toward the edge. The bowl may be defined by a radially symmetric spiral curvature (i.e. a curvature varying monotonically from the fitting point). Optionally the rim or annulus of the bowl may be blended smoothly into a region of reduced or zero power. The bowl shaped lenses have advantages arising from their
15 rotational symmetry. The lenses may be fabricated from two wafer elements as disclosed by applicants in United States patent no. 5,187,505. If an astigmatism correction is provided by the lens, various prescribed cyl axis may be obtained by appropriate rotation, edging and glazing of a common lens blank, thus reducing lens stock requirements.

20 As stated above, the lens element may be of ovaliform shape. This shape may be selected in recognition of the fact that the human face has a strong curvature temporal of the eyes but not in the vertical direction. The ovaliform shape has different overall curvature change in the vertical and horizontal directions. This may be accomplished while maintaining colinearity between the
25 optical axis of the lens and the wearer's line of sight thereby obviating the need for axis tilt or offset.

In the bowl and ovaliform shapes, the lens element surfaces may be described as deviating from a reference sphere defined at a sphere point of the surface. The deviation may be such that the curvature of the lens element surface
30 becomes gradually less than the curvature of the reference sphere. Alternatively, the deviation may be such that the curvature of the surface becomes gradually



more than that of the reference sphere, especially a curvature which would spiral inwardly to a central point if extended. A prolate bowl may for example deviate from approximately 3 to 10 mm from the reference sphere at a location 30 mm from the sphere point.

- 5 Preferably the lens element has a temporal region outside the visual fixation field wherein the mean through power of the lens is gradually reduced.

More preferably along a horizontal meridian of the lens element, the surface powers of co-varying surfaces increase at a location temporal of the optical axis, then decrease in order to bend the lens element around the face of the wearer.

- 10 Alternatively, the surface powers of the co-varying surfaces vary along a vertical meridian and local maxima of surface power occur at locations above and below the optical axis of the lens.

- 15 In a preferred aspect, wherein the optical lens element is of ovaliform shape, and is generally spherical in a central region up to approximately 20 mm, preferably up to approximately 30 mm, sagittal depth, the curvature of the surface along the vertical meridian is maintained within approximately ± 0.5 D of the curvature of the surface along the horizontal meridian. Preferably the curvature along the vertical meridian is maintained within approximately ± 0.3 D of the curvature of the surface along the horizontal meridian.

- 20 Applicants have discovered that for such ovaliform shaped lenses the mean surface power may be permitted to deviate from the reference surface, as required, without generating significant surface astigmatism.

Geometric Description

- 25 The preferred bowl-like lens elements are radially symmetric and may be described in cylindrical coordinates (r, θ, z) where the sagittal depth Z is a function of r alone;

$$Z(r, \theta) = Z(r)$$

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The Sag is expressed in parametric form

$$Z(r) = \sum_{2n=0}^4 A_{2n} * r^{2n}$$

which is of the generic form used to describe a spherical surface. Asphericity as normally introduced in lens design is achieved by selecting the parameters A_{2n} to deviate from the relationship that specifies a surface systematically as spherical, namely

$$A_4 = (A_2)^3, \quad A_6 = 2 * (A_2)^5, \quad \text{and} \quad A_8 = 5 * (A_2)^7$$

For a simple sphere, A_2 is defined by the dioptric base curve D of the sphere and the refractive index n ,

$$A_2 = D / 2(n-1)$$

In the case of a bowl-shaped element of the present invention, however, a target surface may be set by making this parameter itself a systematic function of radial distance;

$$A_2 = P_0 + K(r)$$

wherein the function $K(r)$ is desirably continuous, with well-behaved first or second derivatives according to the shapes of interest.

Surface Power

The tangential power of a surface described in this way is

$$T(r) = (n-1) * d^2Z/dr^2 * [1+(dZ/dr)^2]^{-3/2} \text{ and}$$

the sagittal power is

$$S(r) = (n-1) * dZ/dr * [1+(dZ/dr)^2]^{-1/2} / r.$$

Close to the axis (small values of r), the power equations may be expanded in the following approximate equations;

$$T_{(r \rightarrow 0)} / (n-1) = 2[P_0 + K(r)] + 4r * dK/dr \quad \text{and}$$

$$S_{(r \rightarrow 0)} / (n-1) = 2[P_0 + K(r)] + r * dK/dr$$

which are equal at $r = 0$. Every such surface is therefore spherical at the axis $r = 0$, unless the function form chosen for $K(r)$ has a discontinuity at the axis, so that its derivative diverges.



The two components of power change steadily away from the axis according to the following approximately equations;

$$\begin{aligned} dT/dr_{(r \rightarrow 0)} / (n-1) &= 4dK/dr = 6r * d^2K/dr^2 - 24r [P_0 + K(r)] \quad \text{and} \\ dS/dr_{(r \rightarrow 0)} / (n-1) &= dK/dr = r * d^2K/dr^2 - 8r [P_0 + K(r)] \end{aligned}$$

- 5 For a conventional surface where K is constant or zero, the tangential power changes three times as fast as the sagittal power. For a surface where the first derivative of K dominates the surface form, tangential power changes four times as fast as the sagittal power.

- 10 The particular convenience of this representation is that it allows a complex surface to be seen as the departure from a model spherical or toric form and sets up the mathematical analysis in a form which is familiar in lens design. However it is by no means unique and similar results may be achieved by working with a generalised set of polynomial coefficients A_{2n} above (including odd and even terms).

- 15 It may be seen that the tangential and sagittal powers vary to first order in the same form as the function $K(r)$. If a linear ramp [for example $K(r) \propto r$] is used, the surface powers rise approximately linearly. If a sinusoidal form [$K(r) \propto \sin(\pi r/2r_0)$] is used, the surface powers rise approximately sinusoidally to a maximum at a radial position $r = r_0$. In practice, $K(r)$ needs to be vary with a r over a finite
20 area of a lens surface, for example within a disc or radius r_0 , but there may also be areas where it is constant, for example in the annulus beyond r_0 . In order to set the value beyond r_0 , one needs to compute the exact power changes out to r_0 and then fit the appropriate value of $K(r)$ to the outer region of the lens, smoothing the transition if required.

- 25 In this way, a pair of rotationally symmetric surfaces may be described and analysed to bound a powered lens, both surfaces being reminiscent of the form of a bowl. An oblate bowl has a flat central portion and becomes increasingly steep away from the axis, optionally blending smoothly into a spherical edge or annulus. A prolate bowl is most steeply curved at the axis and flattens out away from it



towards the edge. To zero order, the same function $K(r)$ is applied to both surfaces bounding the lens body and the result is akin to physically bending a powered lens from one notionally spherical shape to another of quite different shape. To achieve best optics off-axis, however, one or other surface has to be
 5 optimised by systematic adjustment of the surface parameters to achieve the best distribution of mean through power and astigmatism, frequently judged by constructing blur and RMS power error plots after ray trace analysis of the lens.

Cyl correction

Lens elements designed as bowls may be provided with one surface,
 10 typically the back surface, that carries the astigmatic correction required to complete an Rx. The considerations explained in the United States patent application 09/223006, referred to herein, apply equally in lenses of a bowl configuration and analogous solutions may be employed to describe the astigmatic correction applied to the mean through power of the powered lens,
 15 such as describing the surface height function of the back surface as

$$Z(r, \theta) = R(r, \theta) - \sqrt{R(r, \theta)^2 r^2}$$

and where

$$R(r, \theta) = \frac{R(r, 0) * R(r, \pi / 2)}{R(r, 0) \sin^2 \theta + R(r, \pi / 2) \cos^2 \theta}$$

is the radial curvature along the meridian at θ , and the values $\theta = 0$ and $\pi/2$
 20 represent the principal meridians.

Selection of surface powers

In respect of the preferred rotationally symmetrical bowl-like lens elements, analysis of selection of surface powers may be illustrated with resort to Morris-Spratt diagrams, whose properties are discussed in detail in the aforementioned
 25 United States patent application serial No. 09/223,006.

Preferably the bowl-like lens elements are generally spherical in a central region with a diameter of at least approximately 30 mm.

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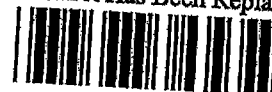


According to the Morris-Spratt diagram, Figure 2 hereto, there is considerable freedom of choice for front surface power available over a range of prescription powers in the general region where the Ostwalt and Wollaston sections of Tscherning's ellipse merge. Generally acceptable optical performance, as judged by RMS blur analysis, can be expected for designs which fall between the two curves A and B in Figure 3. The design scheme for lenses described in the aforementioned United States application fall generally within the oval C in Figure 3. There is another systematic field extending vertically at zero mean through power that is exploited widely in non-prescription eyewear. The optical quality of different design options may be assessed by referring to Figure 4. In a design such as those described in the aforementioned United States patent application serial No. 09/223006, one may elect to set all front curves constant across the Rx range, per line D in Scheme 1. However, there are extended areas in which design parameters may be set. For example in a prescription range from approximately -1.5 to +4 D [outlined area C], we can select curvatures between approximately 7 and 18 D with absolute confidence in the optics of the final optimised lens design. For lenses having a bowl format, the curvature may vary systematically within these limits and can occur follow the same function change for all Rx's in the field. Outlined at A is a more desirable field in which to operate, defining bowls spanning Rx's from -4 to +4 D, while outlined area C extends the minus range to -6 D with the prospect of some compromise in the high minus prescription range for oblate bowls. Prolate bowls with central curvature of 14 D or above are preferred for the high minus Rx range.

Back Surface Curvature

A very important consideration with the optical lens elements of the present invention for wrap around applications is the matter of clearance between the eyelashes and the back surface of the lens, especially in the direction of forward gaze. Lens elements having plus Rx show greatest tendency for so-called "lash-clash", because the back surfaces tend to be flatter as the Rx becomes more positive. For example a +5 D Rx made from a lens with 8 D base curve has a back surface curve of 3 D, whereas a -5 D Rx made from a 2.50 D base curve

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lens has a back surface curve of 7.50 D.

Scheme 2 in Figure 4 shows a sequence of lines along which a design specification would move if selected to match a criterion of constant back surface curve, the numbers 0, 5, 10 and 15 denoting relevant curvatures. In this case, there would be different front curves for every Rx. In Scheme 3 of Figure 4, we show as the curve α , the actual design trajectory of conventional prescription lenses sold by Applicants and their competitors. The rise of front curvature with increasingly positive Rx is not quite as fast as would deliver a constant back surface curve, but does approach this condition. We have found that a similar rise in front curve is necessary for bowl lenses in the plus Rx range to provide adequate clearance around the eyes and eye leashes. Two appropriate design target schemes for the mean front curvature of bowl type lenses are shown as the lines β and γ in Scheme 3 of Figure 4.

Accordingly in a preferred aspect of the present invention there is provided an optical lens element series wherein each lens element includes

- a first surface; and
- a second surface of complementary curvature;
- at least one surface exhibiting significant deviation in curvature from a standard optical surface;
- the first and second surfaces in combination defining an optical zone exhibiting substantially constant mean through power along at least one meridian

each lens element having

- a front surface varying with mean through power required; and
- a common back surface.

Preferably each lens element in this embodiment exhibits plus power.

Preferably each optical lens element is of radially symmetric, bowl-like shape; the varying front surface and common back surfaces being selected by reference to the Morris-Spratt diagrams as herein described.

Alternatively, in this preferred aspect, there is provided an optical lens



- element series wherein each lens element includes
- a first surface; and
 - a second surface of complementary curvature;
 - at least one surface exhibiting significant deviation in curvature from a
- 5 standard optical surface;
- the first and second surfaces in combination defining an optical zone exhibiting substantially constant mean through power along at least one meridian;
 - each lens element having
- a common front surface; and
- 10 a back surface varying with mean through power required.

Preferably each lens element in this embodiment exhibits minus power.

Preferably each optical lens element is of radially symmetric, bowl-like shape; the common front surface and varying back surfaces being selected by reference to the Morris-Spratt diagrams as herein described.

- 15 The front and/or back surfaces may be selected by reference to the Morris-Spratt diagrams, Figures 2 and 3 hereto, as discussed in more detail below.

The lens element series, by providing constant front and/or back surfaces, may permit a reduction in inventories. These inventories may be further reduced by forming the lens element as laminate from lens wafers, as discussed below.

- 20 The lens element series may be of the type described in International Patent Application PCT/EP97/00105, the entire disclosure of which is incorporated herein by reference.

Ovaliform lens elements and spiral bends

- 25 The designer's ability to achieve very extreme shapes with rotationally symmetric bowls is limited by the strict relationship ensuing between tangential and sagittal powers. This becomes more evident the higher the changes imposed on base curvature and the higher the lens mean through power required to suit a



prescription (Rx). There is also the practical issue that the human face has strong curvature horizontally in the vicinity of the eyes, but not vertically. Attractive and useful non-corrective sunglass lenses and shields of wrap around style frequently employ different curvatures vertically and horizontally. In accordance with this aspect of the present invention, it is possible to achieve this object, again maintaining the correct orientation of the powered lenses and providing a high quality prescription and having clear performance gains over the prior art.

In this embodiment, the optical lens element may not exhibit visual symmetry. Rather the first and/or second surfaces may be seen to deviate from toric surfaces, rather than from spheres,

$$Z(r, \phi) = Z(x, y)$$

The Sag is expressed in parametric form

$$Z(x, y) = \sum_{2n=0}^4 A_{2n} * x^{2n} + \sum_{2n=0}^4 B_{2n} * y^{2n}$$

Where, for example

$$A_2 = P_0 + K(x), \text{ and } B_2 = P_0$$

so that there can be produced a changing base curvature in the direction of the Ox axis and the curvature orthogonal to it is held substantially constant. In this case, for example, the Ox axis corresponds to the horizontal axis and Oy is vertical. In an entirely analogous way to the shape changes of a BOWL as described above, an optical lens element of this form remains somewhat flat in the vertical sense but reaches increasingly tightly in the horizontal direction to spiral in towards the temples to wrap around the field of vision and sit snugly against the face.

A useful alternative representation of the above design form is to consider the surface as a distortion of a sphere, whence

$$Z(x, y) = R - \sqrt{(R - z(x))^2 - y^2}$$

where R is the radius of the spherical surface and z(x) is the surface height variation along the Ox axis.

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In a still further alternative aspect of the present invention, the deviating surface may vary in both the orthogonal and horizontal direction. If closer fit against the cheeks is desired, a similar but less aggressive spiral bend may be imposed in the vertical direction also. It is important when designing such spiral bends to ensure that the vertical curvature does not crash into the eye brows while attempting to spiral in to the cheeks. Similarly, it is often desirable to avoid inward bending of the lens at the nasal limit, to create a lens form which is relatively flat from the nasal limit to the line of sight, beyond which the spiral takes effect.

This is achieved mathematically by making the lens asymmetric, as for example if

$$\begin{aligned} A_2 &= P_0, & \text{for } x \leq 0 \\ &= P_0 + K(x) & \text{for } 0 < x \leq x_0 \\ &= P_0 + P_1 & \text{for } x_0 < x \end{aligned}$$

so that the base curvature has a first lower value to the nasal side of the optical axis (line of direct gaze) and a second high value toward the temporal limit, with a smoothly increasing base curvature between the two.

In a still further alternative approach, the lens element may be designed so that its curvature is lowest at the nasal limit and changes continuously across the line of direct gaze, for example;

$$\begin{aligned} A_2 &= P_0 - K(x) & \text{for } x \leq 0 \\ &= P_0 + K(x) & \text{for } 0 < x \leq x_0 \\ &= P_0 + P_1 & \text{for } x_0 < x \end{aligned}$$

In a further aspect, the optical lens element may exhibit an optical extension beyond the central optical zone. Accordingly, in this aspect of the present invention, there is provided an optical lens element including

a first surface; and

a second surface,

the first and second surfaces in combination defining

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a central optical zone; and

an optical zone extension extending from the central optical zone towards the temporal region of the lens and wherein the absolute value of mean through power of the lens smoothly decreases gradually along at least a horizontal meridian across the extension such that unwanted optical astigmatism is significantly reduced.

Preferably the optical lens element includes

a first surface; and

a second surface of complementary curvature

the first and second surfaces in combination defining a central optical zone of substantially constant mean through power;

an optical zone extension extending from the central optical zone towards the temporal region of the lens.

Preferably the first and second surfaces exhibit a substantially equivalent change of curvature in the optical zone extension such that the mean through power remains substantially constant.

More preferably the mean through power decreases to substantially zero across the extension.

In a preferred aspect, the central optical zone may be corrected for forward distance vision. The central optical zone may bear a vertical meridian, optionally decentred relative to the optical centre of the lens element.

The optical zone extension of the optical lens element may also be corrected for distance vision. The optical zone extension may take the form of a channel, preferably a relatively broad channel, in which the curvature decreases smoothly towards the temporal region of the lens according to a predetermined mathematical formula. This allows the lens to wrap around the forward visual field whilst giving direct control over the thickness and physical reach thereof toward the temporal limits.

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In a preferred form, the optical zone extension tapers in width to avoid contact with the wearer's temples.

The wearer is thus provided uninterrupted ability to detect and locate distant objects throughout the channel. Optionally, the vertical width of the channel
5 may decrease in accordance with the reducing need for vertical movement of the eyes towards the temporal extreme of vision. Preferably the lens surfaces are each substantially umbilic over the full length of the horizontal meridian of the lens element, especially within the temporal extension beyond the central optical zone.

The mathematical formula may be such as to cause increasing
10 accentuation of the lens curvature toward the temporal region of the lens. Consequently the optical lens element may wrap around the forward visual field whilst allowing ample clearance between the eye lashes or temples of the wearer and the inner surface of the prescription lens.

The wearer may then be provided with uninterrupted prescription correction
15 for distance vision throughout the optical zone extension.

In a further preferred aspect, the second or back surface of the optical lens element will maintain constant curvature from the centre of the lens to its temporal extreme and the changes in mean through power will be achieved by alteration of the front curve alone.

20 An optical lens element according to this aspect of the present invention is schematically illustrated in Figure 5 below.

The optical lens element has two optical zones, both corrected for distance vision, separated spatially along the horizontal meridian of the lens, 1-1'. The zones comprise firstly an optical zone OZ for forward vision which is intersected by
25 the vertical meridian, 2-2', which meridian may be decentred with respect to the lens blank. The second zone, the optical zone extension, is a broad channel in which the curvature changes smoothly according to a predetermined mathematical formula in order to cause smoothly decreasing mean through power



toward the temporal region of the lens.

The wearer is provided uninterrupted prescription correction for distance vision throughout the channel. Optionally, the vertical width of the channel may decrease compared to that of the central zone CZ in accordance with the reducing
5 need for vertical movement of the eyes towards the temporal extreme of vision.

In a preferred aspect, the optical lens element may exhibit mirror symmetry around the vertical meridian, e.g. line 2-2', in Figure 5. In this embodiment, the finished lens cut-out exhibits a portion of the channel CZ reaching toward the nasal side of the lens.

10 This has several practical advantages:

1. Lens elements may be provided with generally spherical symmetry about the optical axis through the central optical zone, allowing the identification of a surface of rotation wholly within the body of the lens element so that the latter may be made in two separate wafers as discussed below. The
15 lens wafers may be oriented by rotation with respect to each other to provide the desired orientation for a wearer's astigmatic correction. The final lens may be completed by laminating the two parts together.
2. Many fashionable non-prescription sunglasses use dual lenses or unitary lenses that conform to the human face both laterally and vertically by
20 having generally cylindrical (also called toric) shape or generally conical shape. Lens elements with mirror symmetry about the central optical zone meridian may thus provide Rx lenses for left or right eyes from one inventory item for each desired Rx.

In a further preferred embodiment, the central optical zone may be further
25 modified to be of the progressive type.

Accordingly, in this aspect of the present invention there is provided a progressive optical lens element including

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- a first and
a second surface of complementary curvature;
at least one surface exhibiting a deviation in curvature from a standard optical surface,
- 5 the first and second surfaces defining
a central optical zone exhibiting substantially constant mean through power; and
an optical zone extension extending from the central optical zone towards the temporal region of the lens and wherein the mean through
10 power of the lens decreases gradually along a horizontal meridian across the extension;
the central optical zone including
an upper viewing zone having a surface power to achieve a refracting power corresponding to distance vision;
- 15 a lower viewing zone having a greater surface power than the upper viewing zone to achieve a refracting power corresponding to near vision;
a corridor of relatively low surface astigmatism connecting the upper and lower zones, said corridor having a surface power varying from that of the upper viewing zone to that of the lower viewing zone.
- 20 The upper viewing or distance zone may be positioned primarily above the horizontal meridian of the progressive optical lens element.

The lower viewing or reading zone may be positioned below the horizontal meridian of the progressive optical lens element.

- A progressive optical lens element according to this aspect is schematically
25 illustrated in Figure 6 below. The central optical zone CZ of the optical lens element illustrated in Figure 5 is further modified, in this embodiment, to provide a progressive addition lens form.

- This may be provided on the front and/or back surface providing an upper viewing or distance zone portion DP for distance viewing primarily above the
30 meridian 1-1' and a lower viewing or reading zone RP, optionally horizontally insert

relative thereto, connected to the distance portion DP by an intermediate portion IP or corridor of increasing lens power accessible to the wearer in down-gaze below the horizontal median 1-1'.

Alternatively, but less desirably, the reading portion RP may be a physically
5 distinct segment such as a flat top bifocal or trifocal segment giving functionality for near work but lacking optical and cosmetic continuity with the distance portion within the central zone.

In a still further aspect of the present invention, the optical lens element
10 may further include a nasal optical zone exhibiting a change of curvature across substantially the entire width of the zone.

The nasal optical zone may extend from the nasal side of the central optical zone to the edge of the optical lens element. Desirably, the nasal optical zone may be corrected for distance vision. The nasal optical zone may take the form of a channel, similar to the optical zone extension.

15 More preferably, the nasal optical zone may form a broad channel in which the curvature decreases smoothly according to a predetermined mathematical formula.

Consequently the optical lens element may exhibit increasing forward
20 accentuation of the surface curvature of the lens thus causing it to avoid physical engagement or contact with the nasal corner of the eyes or the nasal bridge. The remainder of the optical lens element may maintain close proximity with the facial structure of the wearer. The optical lens element further maintains ample clearance from the inner surface of the prescription lens.

The wearer is provided uninterrupted prescription correction for distance
25 vision throughout both channels. Obviously lenses of this form cannot be made with mirror symmetry about their vertical meridians. However, the physical shapes they offer are especially suited to fashionable prescription visors, wrap around shields, or dual lens renditions of similar fashion and style objectives.



Optionally the central optical zone of the optical lens element in this embodiment may similarly be modified according to the scheme of Figure 3 to exhibit a local progressive addition lens surface or multi-focal lens segment to provide for close or near vision.

- 5 The optical lens elements according to the present invention may accordingly provide one or more of the following features;
1. Full-field wrap around styling with flexible choice of the general shape of the product to appear spherical, conical, cylindrical and the like according to conventional non-prescription sunglass lens design principles whilst
10 nevertheless delivering a comprehensive Rx range to suit at least 95% of wearers,
 2. Wrap style lenses which depart substantially from all prior shape conventions in ophthalmic lens design principles and which represent totally new style options for lenses and frames beyond any of those employed in
15 the non-prescription lens category and nevertheless deliver uncompromised prescription optics,
 3. No abrupt optical changes such as change in curvature or surface slope that may be visible to an observer, thereby allowing use of products as clear dress eyewear, sports goggles and the like if desired,
 - 20 4. "Conventional" base curves in the region of the central optical zone, meaning that the forward base curve is near or below the Ostwald section of Tschering's ellipse, thereby eliminating bug-eyed appearance and facilitating correct fit of the eyewear to the wearer's pupil locations,
 - 25 5. The availability of progressive addition or multifocal correction in the central zone by lens surface alteration functionally identical to rendering those features to a spectacle lens of conventional curvatures near or below the Ostwald section,

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6. Mean surface curvatures consistent with known art for applying anti-reflective coatings, hard coatings or mirrors coatings to enhance the utility and appeal of the products, and
7. Optical design beyond the optical zone extension may preserve accurate
5 recognition of objects in the extreme limits where the human visual can no longer fixate objects but nevertheless depend upon their identification to activate physical response stimuli (especially physical movement and re-orientation of the direction of sight).

10 Optionally, the central curvature may be unusually high, in which case the design between central optical zone and optical zone extension is configured to decrease the curvature smoothly according to a predetermined mathematical function and so overcome physical contact between the rear prescription surface and the wearer's eyes or temples.

15 In a further aspect of the present invention, the curve or shape of at least one surface of the optical lens element may be varied over a significant range, whilst maintaining the power of the lens substantially constant.

Convention in the prior art with respect to spectacles and sunglasses is to employ conic sections as the basis of lens design. That is, lenses have to be overall spherical, cylindrical, conicoidal or toroidal.

20 In contrast, Applicants have discovered a fundamental principle of lens design which allows the specification in the first instance of unusually curved surface shapes that may fit the above definitions or desirably, which are totally new shapes for the category of ophthalmic products.

25 In particular, Applicants have shown the ability to take lenses of known, e.g. spherical or aspheric form, and bend them mathematically by approximately 15 mm at the limit of the visual fixation field (approximately 50° off axis, which corresponds to about 30 mm aperture width in the horizontal direction), thereby wrapping around Rx corrected temporal vision, and retain mean power and near



horizon blur within approximately 0.25D or less.

In this embodiment, the curvatures of the first and second surfaces are smoothly varying functions that allow the surfaces of the optical lens element to deviate substantially from, for example, a conventional conic section whilst
5 providing between them substantially constant mean through power through the lens.

Thus the first and/or second conventional functions may be of a conventional conic type, defined as a conic section of rotation, given by the following equation describing the sagittal depth z of the lens in terms of distance
10 from the optical axis OZ;

$$z(x, y) = \sum_{n=1}^4 A_{2n} r^{2n}$$

where $r^2 = x^2 + y^2$,

$$A_2 = 1/2R, A_4 = p/8R^3, A_6 = p^2/16R^5, A_8 = 5p^3/128R^7,$$

R is the radius of curvature in millimetres,

15 $D = (N-1) \cdot 10^3 / R$ is surface power, or Base Curve, in Dioptres, and
 N is refractive index of the lens material.

The parameter p is an aspherizing coefficient. If $p=1$, the surface is spherical. If $p=0$, the surface is parabolic. For negative values of p , the surface is hyperbolic and for positive values of p it is elliptical. Most lens designers use the
20 representation in terms of p for initial form functions only and prefer to optimise a lens design by direct manipulation of the coefficients A_{2n} .

According to the present invention, Applicants achieve far greater control over surface shape than manipulation of the coefficients allows.

Applicants employ a design approach wherein the curvatures of front and
25 back are smoothly varying functions that allow the surfaces of the lens to depart substantially from a conic section whilst still defining between them smoothly varying mean through power through the lens.



That is to say, the optical lens element according to the present invention is an Rx lens of conventional form within a central aperture which is distorted mathematically so as to change their shape, without discontinuity in mean through power outside that aperture.

- 5 As stated above, the conventional mathematical formulation of the first and/or second surfaces may be modified by addition of a variable function. Thus in this embodiment, the first and/or second surfaces of the optical lens element may be defined by the following formula:

$$z(x, y) = \left[\sum_{n=1}^4 A_{2n} x^{2n} \right] - f(x/R_0) \left[\sum_{n=1}^4 [A_{2n} - B_{2n}] x^{2n} \right] + \left[\sum_{n=1}^4 A'_{2n} y^{2n} \right]$$

- 10 Where the function $f(x/R_0)$ is a conforming function which imposes a second conic section with coefficients B_{2n} on the first surface with coefficient A_{2n} . Preferably, the second (rear) surface of the lens is defined in its entirety by the coefficients B_{2n} .

- 15 The lens is distorted smoothly outside a central aperture $x \leq R_0$ having asymptotically vanishing effect at $x=R_0$ and maximum effect at the lens edges, utilising the conforming function:

$$\begin{aligned} f(r/R_0) &= 0.75 \left\{ 1 - \left[1 + \sum_{n=2}^4 R_{2n} ((r-R_0)/2R_0)^{2n} \right]^{-m} \right\} && \text{for } r > R_0 \\ &= 0 && \text{for } r \leq R_0 \end{aligned}$$

This function and both its first and second derivatives vanish at $r = R_0$.

- 20 Starting at $x = 28$ mm, the front surface of the optical lens element begins to deviate toward the rear prescription surface, thereby reducing the rate at which the difference in front and back Sag depths grows. Simultaneously, the curvature of the front surface increases smoothly and approaches that of the back surface at the outermost horizontal distances on the lens.

- 25 An example of such a design is given in the following Figure 7 below for a six base lens with -3 D mean through power.

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Note the existence of precise control over the surfaces and corresponding mean through powers out to the edge of the lens element, so that the Rx power is constant across the aperture of the central zone and thereafter declines in a smooth fashion without discontinuity in the rate of change of power along the entire axis 1-1'.

In an alternative embodiment of the present invention, where an optical lens element, for example a progressive optical lens element, exhibits unwanted optical astigmatism in a region of the lens, for example towards the periphery of the lens element, the optical zone may simply function to reduce the excessive surface power of the lens.

As stated above, the optical lens element may be a progressive optical lens element. The peripheral optical zone may extend generally along the horizontal meridian of the optical lens element. The peripheral optical zone may appear on opposite sides of the central optical zone generally along the horizontal meridian.

The optical zone extension may correspondingly extend from opposite sides of the central optical zone of the lens element.

The optical zone extension may be represented by a suitable mathematical formula including a conforming function selected to substantially balance the unwanted optical astigmatism of the peripheral optical zone.

Thus, in this embodiment localised surface correction may be applied to a progressive addition lens element near the ends of the horizontal meridian. For example, prior art lenses manufactured by several ophthalmic lens suppliers such as SOLA, Essilor, and American Optical, show intruding ridges of excessive front surface power extending inward from the ends of the meridian in narrowing wedge shaped forms. The effect is that a wearer experiences both growing astigmatism and unaccommodatable power that further decreases the utility of the lens in the peripheral horizon.

If the front surface $Z(x, y)$ near the horizon of such a lens element is



represented in a perturbed form where change is preferably applied to the temporal periphery as follows:

$$z(x, y) = Z(x, y) + f'(y/R'_0) * f(x/R_0) \left[\sum_{n=1}^4 C_{2n} x^{2n} + \sum_{n=1}^4 C_{2n} y^{2n} \right]$$

where

$$f'(y/R'_0) = \left[1 - \sum_{n=2}^4 R'_{2n} (y/2R'_0)^{2n} \right]^{-m}$$

- 5 The required surface modification may be interpreted as the reverse of the design approach in Figure 7.

Direct measurement of lens elements designed according to this aspect of the present invention will provide plots of horizontal and cross powers at the meridian, of form somewhat similar to those created in the worked example for
10 Figure 7. Suitable parameters R_{2n} , C_{2n} and m along the horizontal meridian may be determined by fitting the sagittal power in that direction to an approximately constant value defined by the power at the optical axis of the lens.

The formulation above preferably results in substantially equal cross power correction at the meridian to that applied horizontally. However, the intention is to
15 perturb the lens surface only in an area close to the meridian and matching as far as possible the region of excessive surface power on the progressive lens. Accordingly, the function $f'(y/R'_0)$ is next fitted as closely as possible to the excess power region, attempting at all times to make surface adjustment which introduces no additional astigmatism to the lens surface. Accordingly, it will not be
20 possible to eliminate the excess surface power entirely by such localised surface perturbation.

In a still further aspect of the present invention the optical lens element may be designed such that the first and second surfaces each exhibit a substantially equivalent change of curvature in the optical zone extension such that the mean
25 through power remains substantially constant.

Accordingly, in this aspect, there is provided an optical lens element including a first and second surface, the first surface defining



a central optical zone; and

a optical zone extension extending from the central optical zone toward the temporal region of the lens and exhibiting a relatively smooth change of curvature across substantially the entire width of the zone;

- 5 the second surface being defined by a complementary surface function to substantially balance the variation in the second optical zone of the first surface, the mean through power of the optical lens element remaining substantially constant as the curvatures are varied beyond the central optical zone.

- 10 In a still further embodiment, the second optical zone may include a temporal optical zone displaced laterally along the horizontal meridian of the lens; and an intermediate optical zone extending between the central optical zone and the temporal optical zone.

Accordingly, in this embodiment there is provided an optical lens element including

- 15 a first surface; and
a second surface of complementary curvature,
at least one surface exhibiting a deviation in curvature from a standard optical surface;
the first and second surfaces in combination defining
20 a central optical zone exhibiting substantially constant mean through power; and
an optical zone extension extending from the central optical zone towards the temporal region of the lens and exhibiting a change of curvature in at least the horizontal direction across substantially the entire
25 width of the extension.

- Thus in this embodiment both front and back surfaces are bent together beyond the central optical zone so that the mean through power remains substantially constant and the lens bends more or less steeply. In contrast, other examples herein of constant power lenses apply the bending equations from $R=0$
30 outwards.



If the conforming function $f'(y/R'o)$ for a general lens form of the type described above is either a slowly varying function of y or is set to unity, and the back surface is described by a complementary surface function, both surface will move together, bending away from the mean curve of the central optical zone.

- 5 If required, in a still further embodiment, the optical lens element may further include a third zone in which to thin the extreme limits of the lens by allowing continuous decline of mean through power.

10 In an alternative embodiment, Figure 8 illustrates a further example of the design approach illustrated in Figure 7, for a six base lens of +3 D mean through power.

Again starting at $x = 28$ mm, the front surface of the optical lens element begins to deviate away from the rear prescription surface, thereby reducing the rate at which the difference in front and back Sag depths declines. Simultaneously, the curvature of the front surface decreases smoothly and
15 approaches that of the back surface at the outermost horizontal distances on the lens element.

Note the extension of the temporal edge beyond the limit of a simple spherical lens of the same power and center thickness.

In a further preferred aspect of the present invention this extension may be
20 exaggerated further by increasing the curvatures of front and back surfaces continuously across the optical zone in addition to changing the temporal surfaces at the axis 1-1'. In this embodiment, the first and second surfaces of the optical lens element, for example the front and back surfaces, are defined by the following formulae:

25
$$z_1(x) = S A_{2n} x^{2n} + \{ 1 - [1 + \sum_{n=1}^4 N_{2n} (r/2N_0)^{2n}]^{-m'} \}^* S G_{2n} x^{2n}$$

and,

$$z_2(x) = S B_{2n} x^{2n} + \{ 1 - [1 + \sum_{n=1}^4 M_{2n} (r/2M_0)^{2n}]^{-m'} \}^* S F_{2n} x^{2n}$$



$$-f(x/R_0) \left[\sum_{n=1}^4 [A_{2n} - B_{2n}] x^{2n} \right]$$

wherein the coefficients A_{2n} and B_{2n} are the chosen front and back curvatures at the optical axis.

The features of the consequent lens element design are shown in Figure 9 as lens [2]. Note the considerable temporal reach and length of the modified lens element compared to the spherical lens [1] to which it corresponds.

As elaborated in WO97/35224 to Applicants, the entire disclosure of which is incorporated herein by reference, the use of tilted alignment requires that front or back surface be further modified with atoric correction to eliminate mean power and astigmatic errors.

Corrections to physical shape that are not provided in the physical design are achieved by horizontal displacement of viewing axis and optical axis. This may require prismatic correction to front or back surface, as elaborated in Australian Provisional Application PP2612 to Applicants, the entire disclosure of which is incorporated herein by reference.

The optical lens element according to this aspect of the present invention may be mounted directly in a spectacle frame, for example of the wrap around or shield type. When mounted, the optical lens element may be rotated temporally about a vertical axis through the optical centre thereof ("tilt"), or translated so that the line of sight remains parallel to the optical axis of the lens ("offset"), or a combination of both tilt and offset as described below.

Preferably, the front and/or back surface(s) of the optical lens element include a compound spherical design to provide the desired prescription (Rx) in the prescription zone. More preferably, this prescription zone will extend across the full aperture of the spectacle frames being employed.

In a further preferred aspect the optical lens element in the region from the nasal limit to the optical centre may be generally of the meniscus type.



Alternatively, the nasal region of the optical lens element may be biconvex in shape. The biconvex shape is preferred, particularly for lenses of high power, due to its ease of mounting and improved cosmetics for the wearer.

5 The lens element may be rotated temporally about a vertical axis through the optical centre thereof or the optical axis may be decentred relative to the geometric axis, or the lens element may be both rotated and decentred. Where this is required, a surface correction to at least partially adjust for optical errors, may be applied. Such corrections are described in detail in International application WO97/35224 to Applicants, referred to above.

10 Preferably the front surface is capable of being mounted in a frame of constant design curve of between 8.0 D and 9.0 D or above.

More preferably the front surface of the lens element has a high compound curve extending from nasal to temporal limits, but the vertical or orthogonal generating curve is 6.0 D or below.

15 It will be understood that such vertical curves permit the final prescription lenses, preferably edged lenses, to be adapted to the shape of the wearer's face and so locate closely in a form of the wrap-around type (a so-called "geometrically toric" design for which the vertical curve of the back surface is selected to maintain the desired mean through power or Rx correction provided by the lens. This may
20 be distinguished from a conventional "optically toric" design wherein one surface is rotationally symmetric and the other is shaped to provide the sphere and cylinder components of the wearer's Rx without consideration of the facial form of a wearer).

Alternatively the optical lens elements may be adapted for mounting in a
25 frame of the shield type.

In a still further aspect of the present invention there is provided prescription ophthalmic eyewear, including:

a frame for holding a pair of ophthalmic lens, preferably each of which



lenses have a non-zero mean through power, wherein each lens curves around the face of the wearer toward one of the wearer's temples in an as-worn configuration; and wherein each lens has

- a front surface with a smoothly horizontal varying surface power, and
- 5 a concave rear surface which clears the wearer's eyelashes in the as-worn configuration, and which has a smoothly, horizontally varying surface power providing, in combination with the front lens surface power, a mean through power constant to within ± 0.75 D, preferably ± 0.50 D, horizontally between the primary line of sight through the lens in the as-worn configuration and a peripheral line of sight
- 10 rotated temporally at least 40° from the primary line of site

More preferably the mean through power is constant to ± 0.125 D up to 40° off axis and declining to no more than ± 0.25 D at 50° off axis.

In a still further preferred embodiment of the present invention, there is provided an optical lens element including:

- 15 a first lens surface having a surface power varying radially symmetrically from a sphere point and exhibiting high levels of surface astigmatism over substantial portions of the lens such that the lens would be unusable as an ophthalmic lens if combined with a second standard optical surface; and
- a second lens surface such that the front and rear surfaces define an
- 20 optical body having an approximately constant mean through power and ophthalmically acceptable properties over said substantial portion of the lens element.

- Preferably the lens element is a prolate bowl such that the first surface deviates from a reference sphere defined at the sphere point by at least 3 mm at a
- 25 location 30 mm from the sphere point.

In a further embodiment, the present invention may provide a single vision, prescription ophthalmic lens element having a relatively flat face portion, and a temporal portion curved to conform to the head of the wearer including:

- a front surface with a surface power which increases in temporal direction
- 30 by at least 3.0 D; and



a rear surface with a surface power which increases in a temporal direction by at least 3.0 D so that the lens has a non-zero mean through power constant to within ± 0.75 D, preferably ± 0.5 D, more preferably 0.25 D.

Preferably, the lens element further includes a nasal portion curved to
5 confirm to the bridge of the nose of the wearer.

In a further aspect of the present invention, there is provided a method of making an optical lens element including

a first surface; and
a second surface of complementary curvature;
10 at least one surface exhibiting significant deviation in curvature from a standard optical surface;

the first and second surfaces in combination defining an optical zone exhibiting substantially constant mean through power along at least one meridian;

which method includes
15 providing
a mathematical or geometrical representation of a first surface exhibiting a deviation in curvature from a standard optical surface; and
a mathematical or geometrical representation of a second surface of complementary curvature; the first and second surfaces in combination
20 defining an optical zone exhibiting substantially constant mean through power;

forming a lens mould corresponding to the representations of the first and second surfaces; and

casting an optical lens element from the mould.

25 In a preferred form, when the lens element is radially symmetric, the sagittal depth is given by the formula

$$Z(r, \theta) = Z(r)$$

wherein r , θ , Z , are cylindrical coordinates

$$Z(r) = \sum_{2n=0}^4 A_{2n} * r^{2n}$$

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wherein $A_4 = (A_2)^3$, $A_6 = 2 * (A_2)^5$, and $A_8 = 5 * (A_2)^7$

wherein $A_2 = P_0 + K(r)$

wherein the function $K(r)$ is continuous.

Alternatively when the lens element deviates from a toric surface, the
5 sagittal depth is given by the formula

$$Z(r, \phi) = Z(x, y)$$

wherein r, ϕ are cylindrical co-ordinates

$$Z(x, y) = \sum_{2n=0}^4 A_{2n} * x^{2n} + \sum_{2n=9}^4 B_{2n} * y^{2n}$$

wherein

10 $A_2 = P_0 + K(x), \text{ and } B_2 = P_0.$

In a particularly preferred form, wherein when a surface carries a surface correction, the sagittal depth is given by the formula

$$Z(r, \theta) = R(r, \theta) - \sqrt{R(r, \theta)^2 r^2}$$

and where

15
$$R(r, \theta) = \frac{R(r, 0) * R(r, \pi / 2)}{R(r, \theta) \sin^2 \theta + R(r, \pi / 2) \cos^2 \theta}$$

is the radial curvature along the meridian at θ , and the values $\theta = 0$ and $\pi/2$ represent the principal meridians.

In a further preferred aspect the first and second surfaces further define an optical zone extension extending from the central optical zone towards the
20 temporal region of the lens; the front surface exhibiting an increase in curvature towards the temporal region of the lens such that the mean through power of the lens reduces gradually along a horizontal meridian across the extension such that unwanted optical astigmatism is significantly reduced. In this embodiment, the sagittal depth may be given by the formula

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$$z(x, y) = Z(x, y) + f'(y/R_0) * f(x/R_0) \left[\sum_{n=1}^4 C_{2n} x^{2n} + \sum_{n=1}^4 C_{2n} y^{2n} \right]$$

where

$$f'(y/R_0) = \left[1 - \sum_{n=2}^4 R'_{2n} (y / 2R'_0)^{2n} \right]^{-m}$$

wherein the value of parameters R_{2n} , C_{2n} and m are determined along the horizontal meridian by fitting the sagittal power to an approximately constant value.

In a preferred aspect of the present invention, as stated above, the optical lens element may be formed as a laminate of a back and front lens element, as described above.

It will be understood, in this embodiment, inventories may be reduced by providing a single front lens wafer for a range of complementary back wafers or vice versa. Furthermore, the need to employ the most modern lens finishing techniques as for example to complete an Rx from a semi-finished blank is alleviated.

It will be understood further that any feature described as being included via the front lens element may equally be included by the back lens element and vice-versa.

In a further preferred embodiment, in order to permit introduction of cylinder correction, the mating surfaces of front and back lens elements may be generally rotationally symmetric about their respective optical axes through the central optical zone of the laminate optical article. The lens wafers may be oriented by rotation with respect to each other to provide the desired orientation for a wearer's astigmatic correction. The final lens may be completed by laminating the two parts together.

In a particularly preferred form, the laminate optical article may include an inner layer providing desired optical properties of the type described in International Patent Application PCT/AU96/00805 to Applicants, the entire disclosure of which is incorporated herein by reference.



The optical lens element may be formulated from any suitable material. A polymeric material may be used. The polymeric material may be of any suitable type. The polymeric material may include a thermoplastic or thermoset material. A material of the diallyl glycol carbonate type, for example CR-39 (PPG Industries)
5 may be used.

The polymeric article may be formed from cross-linkable polymeric casting compositions, for example as described in Applicants' United States Patent 4,912,155, United States Patent Application No. 07/781,392, Australian Patent Applications 50581/93, 50582/93, 81216/87, 74160/91 and European Patent
10 Specification 453159A2, the entire disclosures of which are incorporated herein by reference.

The polymeric material may include a dye, preferably a photochromic dye, which may, for example, be added to the monomer formulation used to produce the polymeric material. The variation in depth of colour may be minimised by
15 incorporating a pigment or dye into one or more layers of the optical article.

The optical lens element according to the present invention may further include standard additional coatings to the front or back surface or either of the mating surfaces of wafers for a laminated lens, including electrochromic coatings.

The front lens surface may include an anti-reflective (AR) coating, for
20 example of the type described in United States Patent 5,704,692 to Applicants, the entire disclosure of which is incorporated herein by reference.

The front lens surface may include an abrasion resistant coating. e.g. of the type described in United States Patent 4,954,591 to Applicants, the entire disclosure of which is incorporated herein by reference.

25 The front and back surfaces may further include one or more additions conventionally used in casting compositions such as inhibitors, dyes including thermochromic and photochromic dyes, e.g. as described above, polarising agents, UV stabilisers and materials capable of modifying refractive index.



The present invention will now be more fully described with reference to the accompanying figures and examples. It should be understood, however, that the description following is illustrative only and should not be taken in any way as a restriction on the generality of the invention described above.

5

EXAMPLE 1

Figure 7 illustrates a six base optical lens element according to the present invention with mean through power of -3 D beginning with Rx lens of conventional form within a central aperture and are distorted mathematically so as to change their shape without discontinuity in mean through power outside that aperture
10 based on the following formula:

$$z(x, y) = \left[\sum_{n=1}^4 A_{2n} x^{2n} \right] - f(x/R_0) \left[\sum_{n=1}^4 [A_{2n} - B_{2n}] x^{2n} \right] + \left[\sum_{n=1}^4 A'_{2n} y^{2n} \right]$$

where the function $f(x/R_0)$ is a conforming function which imposes a second conic section with coefficients B_{2n} on the first surface with coefficient A_{2n} . The second (rear) surface of the lens is in this example defined in its entirety by the
15 coefficients B_{2n} .

The lens is distorted smoothly outside a central aperture $x \leq R_0$ having asymptotically vanishing effect at $x=R_0$ and maximum effect at the lens edges, utilising the conforming function:

$$\begin{aligned} f(r/R_0) &= 0.75 \left\{ 1 - \left[1 + \sum_{n=2}^4 R_{2n} \left((r-R_0)/2R_0 \right)^{2n} \right]^{-m} \right\} & \text{for } r > R_0 \\ &= 0 & \text{for } r \leq R_0 \end{aligned}$$

This function and both its first and second derivatives vanish at $r = R_0$.

Figure 7 shows the application of this formulation to a six base lens of -3D mean through power, for which the coefficients are;

$$\begin{aligned} A_2 &= 5.12 \cdot 10^{-3}, A_4 = 1.34 \cdot 10^{-7}, A_6 = 7.02 \cdot 10^{-12}, A_8 = 4.60 \cdot 10^{-16}, \text{ and} \\ B_0 &= 1, B_2 = 7.68 \cdot 10^{-3}, B_4 = 4.52 \cdot 10^{-8}, B_6 = 5.33 \cdot 10^{-11}, B_8 = 7.86 \cdot 10^{-15} \\ R_0 &= 28, R_2 = 0, R_4 = 2.75, R_6 = -2.0, R_8 = 0, m = 2. \end{aligned}$$



Since it is desirable for the temporal extension to be umbilic at least on the horizontal meridian 1-1', the coefficients A'_2 which define the local cross-curve vertically are computed at each value of x from the changing value of the horizontal curvature (surface power) at the axis 1-1'. The remaining coefficients

5 A'_{2n} are determined for chosen values of the asphericity coefficient p , as defined above. This creates an initial surface form to be optimised in terms of astigmatic and mean power errors, taking into account the chosen lens tilt or offset displacement as required to locate the lens in a frame of the wrap around type.

The variation of A'_2 and the mean through power of the lens along the axis

10 1-1' are shown also in Figure 7.

Note the existence of precise control over the surfaces and corresponding mean through powers out to the edge of the lens element, so that the Rx power is constant across the aperture of the central zone and thereafter declines in a smooth fashion without discontinuity in the rate of change of power along the

15 entire axis 1-1'.

EXAMPLE 2

Figure 8 illustrates a six base optical lens element according to the present invention with mean through power of -3 D. The lens element was designed in a similar manner to that described in Example 1 except that the coefficients are as

20 follows:

$$A_2 = 5.12 \times 10^{-3}, A_4 = 1.34 \times 10^{-7}, A_6 = 7.02 \times 10^{-12}, A_8 = 4.60 \times 10^{-16}, \text{ and} \\ B_0 = 4.5, B_2 = 2.56 \times 10^{-3}, B_4 = 1.68 \times 10^{-8}, B_6 = 2.19 \times 10^{-13}, B_8 = 3.59 \times 10^{-11} \\ R_0 = 28, R_2 = 0, R_4 = 2.5, R_6 = -2.0, R_8 = 0, m = 2.$$

The initial form coefficients A'_2 which define the local cross-curve vertically

25 are computed as before at each value of x from the changing value of the horizontal curvature (surface power) at the axis 1-1'. The dependence of A'_2 and the mean through power of the lens element at the axis 1-1' are shown also in Figure 8.



Note the extension of the temporal edge beyond the limit of a simple spherical lens of the same power and center thickness.

EXAMPLE 3

Figure 9 illustrates a modified form of the optical lens element of Figure 8 wherein the temporal extension is further exaggerated by increasing the curvatures of front and back surfaces continuously across the optical zone in addition to changing the temporal surfaces at the axis 1-1'.

In this embodiment, the first and second surfaces of the optical lens element, for example the front and back surfaces, are defined by the following formulae:

$$z_1(x) = S A_{2n} x^{2n} + \{ 1 - [1 + \sum_{n=1}^4 N_{2n} (r/2N_0)^{2n}]^{-m'} \} S G_{2n} x^{2n}$$

and,

$$z_2(x) = S B_{2n} x^{2n} + \{ 1 - [1 + \sum_{n=1}^4 M_{2n} (r/2M_0)^{2n}]^{-m'} \} S F_{2n} x^{2n} - f(x/R_0) \left[\sum_{n=1}^4 [A_{2n} - B_{2n}] x^{2n} \right]$$

wherein the coefficients A_{2n} and B_{2n} are the chosen front and back base curves at the optical axis. In this example the base curves are 6 D and 3 D to give an Rx of +3 D;

$$A_2 = 5.12 \cdot 10^{-3}, A_4 = 1.34 \cdot 10^{-7}, A_6 = 7.02 \cdot 10^{-12}, A_8 = 4.60 \cdot 10^{-16}, \text{ and} \\ B_0 = 4, B_2 = 2.56 \cdot 10^{-3}, B_4 = 1.68 \cdot 10^{-8}, B_6 = 2.19 \cdot 10^{-13}, B_8 = 3.59 \cdot 10^{-18}$$

and the coefficients G_{2n} and F_{2n} correspond approximately to +10D base curves, being

$$G_2 = 8.53 \cdot 10^{-3}, G_4 = 4.65 \cdot 10^{-7}, G_6 = 5.08 \cdot 10^{-11}, G_8 = 6.96 \cdot 10^{-15}, \text{ and} \\ F_2 = 8.00 \cdot 10^{-3}, F_4 = 4.0 \cdot 10^{-7}, F_6 = 5.08 \cdot 10^{-11}, F_8 = 6.93 \cdot 10^{-15}.$$

The conforming coefficients are,

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$$N_0 = 75, N_2 = 0.415, N_4 = 0.45, N_6 = -0.72, N_8 = 1.50, m' = 3$$

$$M_0 = 77.5, M_2 = 0.50, M_4 = 0.40, M_6 = -0.72, M_8 = 0,$$

$$R_0 = 28, R_2 = 0, R_4 = 2.75, R_6 = -2.0, R_8 = 0, m = 2.$$

5 The features of the consequent lens element design are shown in Figure 9a as lens [2]. Note the considerable temporal reach and length of the modified lens element compared to the spherical lens [1] to which it corresponds.

EXAMPLE 4

Figures 10 and 11 illustrate an optical lens element according to the present invention with mean through power of +3 D.

10 The lens element was designed setting up the description of front and back surfaces of a lens so that bending is occurring only in the horizontal plane (x, z);

$$z_1(x) = \sum A_{2n} x^{2n} + [\cos(\pi x / 2R_0)]^m * \sum B_{2n} x^{2n}$$

$$z_2(x) = \sum G_{2n} x^{2n} + [\cos(\pi x / 2M_0)]^m * \sum F_{2n} x^{2n}$$

15 The utility of the design approach is depicted in Figures 11(a) and 11(b), which shows lens cross-sections in the horizontal or (x,z) plane. The section denoted [1] has constant front base curve of 14D, that denoted [2] is the current variable curvature design, and that denoted [3] has constant front base curve of 6D. All three lenses have mean through power of +3D over wide aperture ranges. The variable base design [2] has equivalent capability to wrap around to the
20 temples as the high base design [1] and provides much enhanced physical space for the human eyes to sit behind the lens. The lower curvature design [3] reaches across the field of vision but has relatively much less wrapping tendency. If this is compensated by tilting the lens off axis, the flat rear surface will truncate the space available to the eyes, clashing with the lashes and eye lids.

25 The numerical value of the base curve at the central optical zone CZ is defined by the sum $A_{2n} + B_{2n}$, and that at the temples approaches the A_{2n} value. In the current example, the curvature increases from CZ towards TZ because of the choice of negative B_{2n} .



If, on the other hand, A_{2n} and B_{2n} are both positive, the curvature will trend oppositely, being highest at the CZ, decreasing smoothly toward TZ.

EXAMPLE 5

Figure 12 illustrates an optical lens element according to the present invention with mean through power of +3 D based on an asymmetrical lens design.

An example of an asymmetric optical lens element design with continuous and smoothly varying curvature, and consequently, constant mean through power notwithstanding the design asymmetry can be created using the following mathematical formulae, defining the first and second surfaces of the optical lens element.

$$\begin{aligned}
 z_1(x) &= \sum \alpha_{2n} x^{2n} && \text{for } x < 0 \\
 z_1(x) &= \sum A_{2n} x^{2n} + [\cos(\pi x / 2R_0)]^m * \sum B_{2n} x^{2n} && \text{for } x > 0 \\
 z_2(x) &= \sum \gamma_{2n} x^{2n} && \text{for } x < 0 \\
 z_2(x) &= \sum G_{2n} x^{2n} + [\cos(\pi x / 2M_0)]^m * \sum F_{2n} x^{2n} && \text{for } x > 0 \\
 \text{while} \quad z_1(y) &= \sum \alpha_{2n} y^{2n} \quad \text{and} \quad z_2(y) = \sum \gamma_{2n} y^{2n}
 \end{aligned}$$

where the coefficients are as defined above.

The features of the resultant lens are shown in Figure 12a to 12c.

EXAMPLE 6

Figure 13 illustrates a modified form of the optical lens element of Figure 12.

The horizontal lens section of Figure 12c is reproduced in Figure 13. The lens front and back surfaces are [1] and [2]. An 8D curve [3] is superimposed between nasal and temporal limits. The back surface [2] intrudes approximately 1.5 mm behind the inner curve [3]. This provides satisfactory clearance for the eyes when the lens is mounted in a frame involving an off-axis tilt to achieve the



desired degree of wrap. As elaborated in WO97/35224 to Applicants, the use of tilted alignment requires that front or back surface be further modified with atoric correction to eliminate mean power and astigmatic errors.

EXAMPLE 7

- 5 Figure 14 illustrates a modified form of the optical lens element of Figure 13.

The first and second surfaces of the optical lens elements are defined by the following mathematical formulae

$$\begin{aligned}
 & z_1(x) = 0 \quad \text{for } x < 0 \\
 10 \quad & z_1(x) = \sum A_{2n} x^{2n} - [\cos(\pi x / 2R_0)]^m * \sum A_{2n} x^{2n} \quad \text{for } x > 0 \\
 & z_2(x) = G_0 \quad \text{for } x < 0 \\
 & z_2(x) = \sum G_{2n} x^{2n} - [\cos(\pi x / 2M_0)]^m * \sum A_{2n} x^{2n} \quad \text{for } x > 0 \\
 & \text{while } z_1(y) = \sum \alpha_{2n} y^{2n} \quad \text{and} \quad z_2(y) = \sum \gamma_{2n} y^{2n}
 \end{aligned}$$

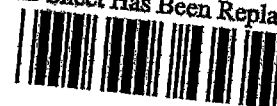
wherein the sign of the variable functions are reversed.

- 15 Applicants have discovered therefore that a lens equivalent to that in Figure 13 below may be created wherein the front surface has zero curvature on the nasal side of the optical axis. That is, the front surface is identical to its own tangent for $x \leq 0$.

EXAMPLE 8

- 20 Figure 15 illustrates a modified form of the optical lens element of Figure 14 in which the surface of the Figure 14 design is displaced increasingly forward in the nasal region.

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The first and second surfaces of the optical lens element of Figure 15 are defined by the following mathematical formulae:

$$\begin{aligned}
 z_1(x) &= [\sin(\pi x / 2R'_0)]^{m'} * \sum B'_{2n} x^{2n} & \text{for } x < 0 \\
 z_1(x) &= \sum A_{2n} x^{2n} - [\cos(\pi x / 2R_0)]^{m'} * \sum A_{2n} x^{2n} & \text{for } x > 0 \\
 5 \quad z_2(x) &= G_0 + [\sin(\pi x / 2M'_0)]^{m'} * \sum B'_{2n} x^{2n} & \text{for } x < 0 \\
 z_2(x) &= \sum G_{2n} x^{2n} - [\cos(\pi x / 2M_0)]^{m'} * \sum A_{2n} x^{2n} & \text{for } x > 0 \\
 \text{while } z_1(y) &= \sum \alpha_{2n} y^{2n} \quad \text{and} \quad z_2(y) = \sum \gamma_{2n} y^{2n}
 \end{aligned}$$

where the various coefficients are as described above, and there being additional parameters R'_0 , M'_0 and m' corresponding to R_0 , M_0 and m .

- 10 According to the choice of parameters, this representation may displace the surface of the asymmetric tangent optical lens element illustrated in Figure 14 increasingly forward in the nasal region to a maximum forward displacement at approximately $x = -1.3 R'_0$. When these designs are set with $R'_0 \approx M'_0 < PD/2.6$ where PD is the pupillary distance for the wearer a pair of left and right lenses is
- 15 created with a point of mirror symmetry corresponding to the center of the nasal bridge.

For the lens element illustrated in Figure 15

$$m' = 2$$

$$R'_0 = M'_0 = 25$$

$$20 \quad B'_2 = -2.56 \cdot 10^{-3}, B'_4 = 1.68 \cdot 10^{-6}, B'_6 = -2.19 \cdot 10^{-11}, B'_8 = -3.59 \cdot 10^{-18}$$

EXAMPLE 9

Figure 16 illustrates a modified form of the optical lens element of Figures 10 and 11 wherein the conforming function is of the "Witch of Agnesi" type.

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The first and second surface of the optical lens element of Figure 16 are defined by the mathematical formulae

$$z_1(x) = \sum A_{2n} x^{2n} + \{ 1 - [1 + \sum_{n=1}^4 R_{2n} (r/2R_0)^{2n}]^{-m} \}^* \sum B_{2n} x^{2n}$$

$$z_2(x) = \sum G_{2n} x^{2n} + \{ 1 - [1 + \sum_{n=1}^4 M_{2n} (r/2M_0)^{2n}]^{-m} \}^* \sum F_{2n} x^{2n}$$

- 5 Figure 16 shows the application of this formulation to the example worked in connection with Figures 10 and 11.

The coefficients A_{2n} and G_{2n} are the chosen front and back base curves at the optical axis. In this example 6D and 3 D;

- 10 $A_2 = 5.12 \cdot 10^{-3}$, $A_4 = 1.34 \cdot 10^{-7}$, $A_6 = 7.02 \cdot 10^{-12}$, $A_8 = 4.60 \cdot 10^{-16}$, and
 $G_0 = 4$, $G_2 = 2.56 \cdot 10^{-3}$, $G_4 = 1.68 \cdot 10^{-8}$, $G_6 = 2.19 \cdot 10^{-13}$, $G_8 = 3.59 \cdot 10^{-18}$
 and the coefficients B_{2n} and F_{2n} correspond approximately to +10D base curves, being

$$B_2 = 8.53 \cdot 10^{-3}, B_4 = 4.65 \cdot 10^{-7}, B_6 = 5.08 \cdot 10^{-11}, B_8 = 6.96 \cdot 10^{-15}, \text{ and} \\ F_2 = 8.00 \cdot 10^{-3}, F_4 = 4.0 \cdot 10^{-7}, F_6 = 5.08 \cdot 10^{-11}, F_8 = 6.93 \cdot 10^{-15}.$$

- 15 The conforming coefficients are,
 $R_0 = 75$, $R_2 = 0.415$, $R_4 = 0.45$, $R_6 = -0.72$, $R_8 = 1.50$, $m = 2$
 $M_0 = 77.5$, $M_2 = 0.50$, $M_4 = 0.40$, $M_6 = -0.72$, $M_8 = 0$,

Note the existence of precise control over the tangential powers out to the edge of the lens, so that the Rx power is constant across the entire lens aperture.

20 EXAMPLE 10

Figure 17 illustrates a modified form of the optical lens element of Figure 16 wherein the conforming parameters are altered without change in the curvature coefficients, whence

- 25 $R_0 = 75$, $R_2 = 0.415$, $R_4 = 0.45$, $R_6 = -0.72$, $R_8 = -3.0$, $m = 2$
 $M_0 = 77.5$, $M_2 = 0.50$, $M_4 = 0.40$, $M_6 = -0.72$, $M_8 = 4.5$,



Note the extensive wrap achieved by changing only the parameters R_8 and M_8 . The Rx power drop commences 25 mm off-axis and equates 0.4D at 30 mm off-axis. It falls to plano at about 41 mm off-axis. Further subtlety in control of this type may be provided by increasing the power series expansions in R_{2n} and M_{2n} to $n = 5$ or 6. The cross curves in the outer region beyond the temporal zone TZ may require further atoric corrective modification to keep horizontal and vertical components of Rx power moving in step with each other, thus avoiding the introduction of high levels of blur and prismatic error in the non-fixated temporal field.

10

EXAMPLE 11

Figure 18 illustrates an optical lens element having Rx of -3 D which is flattened by 9 D between the optical axis and a point 30 mm off-axis.

The first and second surfaces of the optical lens element are defined by the following mathematical representation

15

$$z_1(x) = \sum A_{2n} x^{2n} + \left[1 + \sum_{n=1}^4 R_{2n} (r/2R_0)^{2n} \right]^{-m} * \sum B_{2n} x^{2n}$$

$$z_2(x) = \sum G_{2n} x^{2n} + \left[1 + \sum_{n=1}^4 M_{2n} (r/2M_0)^{2n} \right]^{-m} * \sum F_{2n} x^{2n}$$

The coefficients $A_{2n} + B_{2n}$ are the chosen front curve at the optical axis (16.5 D) and $G_{2n} + F_{2n}$ is the back curve, in this example 19.5 D for an Rx of -3 D;

20

$$A_2 = 5.97 \cdot 10^{-3}, A_4 = 2.13 \cdot 10^{-7}, A_6 = 1.52 \cdot 10^{-11}, A_8 = 1.35 \cdot 10^{-15}, \text{ and}$$

$$G_0 = 1, G_2 = 8.53 \cdot 10^{-3}, G_4 = 4.65 \cdot 10^{-7}, G_6 = 5.08 \cdot 10^{-11}, G_8 = 6.93 \cdot 10^{-15}$$

The coefficients $B_{2n} = F_{2n}$ correspond approximately to +10D base curves, being in this example;

$$B_2 = 8.1 \cdot 10^{-3}, B_4 = 5.32 \cdot 10^{-7}, B_6 = 6.99 \cdot 10^{-11}, B_8 = 1.15 \cdot 10^{-14},$$

and the conforming coefficients are,

25

$$R_0 = 27.5, R_2 = 0.5, R_4 = -0.03, R_6 = 0.03, R_8 = 0.08, m = 2$$

$$M_0 = 30, M_2 = 0.5, M_4 = -0.03, M_6 = 0.03, M_8 = 0.08,$$



The curve marked [1] in Figure 18 denotes the location of the front surface if the curvature were to be held constant at 16.5D. It is seen that the front surface of the lenses according to the current invention are moved approximately 7 mm outward, opening out the lens as it wraps around the eyes from an aperture of 23 mm to 30 mm as desired. It is also seen from the Rx tangential power plot that the mean through power error is less than 0.3 D across the lens aperture.

EXAMPLE 12

Bowl shapes

Examples of some bowl-shaped lens profiles are given in Figures 19, 20 and 21 for plano lenses having a 8 D base curvature at the optical axis, increasing via a range of functions to 16 D toward their outer edge. These are compared with prior art spherical surfaces of 8 and 16 D curvature (Figures a and e in each case). To achieve wrap of an 8 D lens around the visual field, it is necessary to decenter the lens so that the forward line of sight is parallel to the optical axis, but not coincident with the axis or tilt the optical axis with respect the forward line of sight and apply atoric corrections to shapes allow for power and prism errors thus introduced. A lens element of high curvature such as 16 D may be mounted so the optical axis coincides with the line of forward gaze of each eye but the curvature is so extreme that lenses cannot actually reach beyond the temples to enclose the visual apparatus. Bowl-shaped lens elements designed according to this method achieve the desired physical wrap and can also be fitted with correct alignment of the optical axis. They also provide greater volume in which to fit an Rx power correction between the front of the lens and the approximately spherical volume defined by the limits of the eye lashes, this being approximately 18 to 23 mm in radius from the center of rotation of the eye. In each case, Figures (b) to (d) illustrate the result on the lens designs of the 3 different selected illustrative tangential power profiles.

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EXAMPLE 13

Figures 22(a) and (b) respectively illustrate a plan, side or top view of a 10.0 D base spherical lens (prior art) and an optical lens according to the present invention being a 10.0 D to 16.0 D base variable curvature, rotationally symmetric spiral oblate lens corresponding to the optical lens described in Figure 19(d) above.

In Figure 22 the dotted lines represent the front surfaces of the lenses and the solid lines represent the back edges of the lenses.

The spiral optical lens according to Figure 22(b) may be contrasted with a comparable prior art spherical lens of Figure 22(a). It will be noted that the lens according to the present invention exhibits a radical shape, with significantly increased curvature and sagittal depth, but still permitting mounting in a frame suitable for the prior art spherical lens.

EXAMPLE 14

15

Spiral bends

In this example axial symmetry is not maintained and the co-varying surfaces are treated as deviations from toric surfaces, rather than from spheres.

$$Z(r, \varphi) = Z(x, y)$$

The Sag is expressed in parametric form

20

$$Z(x, y) = \sum_{2n=0}^4 A_{2n} * x^{2n} + \sum_{2n=0}^4 B_{2n} * y^{2n}$$

Where, for example

$$A_2 = P_0 + K(x), \text{ and } B_2 = P_0$$

so that there can be produced a changing base curvature in the direction of the Ox

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axis and the curvature orthogonal to it is held constant. In this case, for example, the Ox axis corresponds to the horizontal axis and Oy is vertical. In an entirely analogous way to the shape changes of a bowl as described above, a lens of this form remains somewhat flat in the vertical sense but reaches increasingly tightly in
5 the horizontal direction to spiral in toward the temples to wrap around the field of vision and sit snugly against the face.

Designs and optical analysis of lenses designed according to this scheme are given in Figure 23.

Figures 23(a) to (e) illustrate the general shape of the front surface (Figure
10 23(a)) and back surfaces (Figures 23(b) to (e)) of the lens elements configured as spirals. The back surfaces are respectively plano (Figure 23(b)) or have surface powers of -3 D, -2 D and +2 D (Figures 23(c), (d) and (e)).

In each design the curve marked (1) is the reference sphere and the curve marked (2) is the spiral surface of the lens, thus illustrating the degree of
15 deviation.

In Figure 24(a) to (c), plots of the RMS power error for spiral lens designs according to the present invention are provided which illustrate a spiral lens design of -3 D mean through power optimized at 0 degrees (a) a prior art aspherical design (b) and a spiral lens optimised at 45 degrees (c).

20 In the spiral lens designs the design in the left hemisphere is a spherical design and in the right hemisphere is a spiral design.

EXAMPLE 15

Figure 25(a) illustrates the general shape (sagittal depth) of a front surface of a lens element according to the present invention and substantially corresponds
25 to the surface in Figure 23(a) below. Figure 25(b) illustrates the surface power profile of the deviating surface in Figure 25(a). In this case the reference sphere has a curvature of 8 D.



The deviating front surface has a curvature of 8 D at the centre and linearly ramps up to 12 D over 27 mm along the "x" axis. It continues with 12 D to the edge. The resulting curvature and sag along the x axis of the surface are shown in Figure 25(a) below. Also shown is the sag of an 8 base sphere for comparison.

- 5 The curvature gradient increases the sag by a little over 5 mm and increases the slope from 37 to 53 degrees at 40 mm out. The curvature in the y direction was kept constant at 8 D. The formula used for the surface depth was

$$z(x, y) = R - \sqrt{(R - z(x))^2 - y^2}$$

- where $z(x)$ is the one x direction height described above and R is the 66.25 mm
10 radius corresponding to 8 D. The following sphere power plot Figure 26 shows the vertical contours for this design. The contour interval is 1 D.

All subsequent contour plots will also have a range of ± 40 mm, or about 56 degrees of eye rotation.

Plano lens

- 15 To make a plano lens element, a back surface was selected that had the same form as the front, but with the central curvature slightly adjusted to give zero through power. The resulting RMS power error is shown below. For comparison Figure 27(c) is a spherical plano lens element with an 8 base spherical front and appropriate spherical back. The contours are at 0.1 D intervals.

- 20 The plots in Figures 27(a) and (c) show that the deviating surfaces cause only a slight increase in the error at extreme eye rotation angles on the right side of the lens. The left hemisphere of the accentuated surface is an 8 base sphere so performs substantially identically to the spherical lens. Even without optimization this provides a plano lens that performs essentially as well as a
25 spherical lens with an 8 base front. Optimization was performed by adding some aspherical corrections to the back surface. The optimization procedure is described in more detail in Example 16 below. After optimization (Figure 27(b))



the performance is nearly perfect everywhere except for the extreme right edge of the lens. Of course optimizing the back of the lens with the spherical front would give the performance shown on the left, spherical half of the lens.

EXAMPLE 16

5

Optimized minus two lens

A lens element was designed with an Rx of -2 D using a deviating front surface. The back surface consisted of three components; 1) the sag of the front surface 2) a spherical correction to give the proper Rx at the center and 3) an aspherical correction surface. The aspherical correction consisted of two separate
10 10th order polynomials, one for the left hemisphere and one for the right. The "left hand" polynomial coefficients were adjusted by hand to minimize the RMS power error along the negative half of the x axis. Separate coefficients were similarly determined for the right half optimizing along the positive x axis. The final correction surface used was a linear superposition of these function multiplied by
15 smoothly varying functions of angle ($\theta = \tan^{-1}(y/x)$). The right side polynomial was multiplied by $\cos^2\theta$ out to ± 90 in the right hemisphere only. This has the effect of giving the polynomial full influence along the positive x axis and smoothly tapering it to zero along the y. The opposite function, $\sin^2\theta$ in the right hemisphere, was used for the left side polynomial so that it has full effect on the left hemisphere
20 and disappears along the positive x axis.

Figure 28(a) below shows the RMS power error for a lens with the back surface design as described above. For comparison Figure 28(b) is from a design with a spherical 8 base front and an optimized asphere on the back. The left side polynomial from the accentuated lens was used for this asphere since, again, that
25 lens is spherical in the left hemisphere.

At first glance the result is surprising. The power error along the positive x axis is actually smaller than that along the negative (spherical front) axis, and therefore also less than for the optimized asphere. Figure 29 below compares the RMS power error along this axis in detail.

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The error at 0 degrees, along the positive x axis, is lower for the complex lens than for the spherical lens out to well past 30 mm.

Figure 28(c) and Figure 29 also illustrate the RMS power error at 45 degrees up from the x axis for the accentuated lens. This error is significantly higher than for the aspherical case, which is constrained to have the same error along all axes. $\sin^4\theta$ and $\cos^4\theta$ terms were added to the angular ramping functions for the left and right side polynomials respectively. The new coefficient was adjusted of the left side function to minimize the error at 45 degrees (it does not affect the 0 degree error). Then the coefficient of the $\cos^4\theta$ term was until the errors at 0 and 45 degrees were roughly equal. The result is shown in Figure 30 below. Surprisingly the curves cross just at the level of the optimised asphere.

In summary, it is possible to design a back surface that gave optical performance essentially equal to a lens with a spherical front of similar complementary curvature. It showed that the performance along one preferred axis could actually be made better than the equivalent spherical front - aspherical back lens. It suggests that the angular averaged RMS error may not be significantly lower than the sphere-asphere combination.

EXAMPLE 17

Bowl shapes.

Figures 31(a)-(c) illustrate the general shapes of lens elements configured as bowls. It will be understood that lens blanks may be made in the bowl forms shown in Figures 31(a)-(c). When edged, the bowl may have a non-circular rim which is adapted to the spectacle frames or mountings desired.

A spherical bowl 500 has an edge or rim 502. It will be understood that the lens elements disclosed in the above-mentioned United States Application Serial No. 09/223,006 may have the general shape shown in Figure 22(a). Such lens elements may be characterized by a generally constant radius of spherical curvature of 35 mm or less, centered on the centroid of rotation 504 of the eye in



the as worn condition. An optical axis of the lens O-O is shown intersecting the centroid of rotation 504. The spherical bowl 500 is radially symmetric about axis O-O. When worn, it may require no optical axis tilt or offset from the visual axis of the wearer.

5 The bowl shapes of Figures 31(b) and 31(c) are also radially symmetric about their respective optical axes O-O. Figure 31(b) illustrates an oblate bowl 510. It is characterized by a relatively gentle instantaneous spherical curvature at a sphere point 512 located at about the intersection of the optical axis O-O with the lens element. The curvature becomes steeper radially outwardly from the axis
10 O-O. The effect is illustrated by a reference sphere indicated in cross-section by dashed line 514. The reference sphere has the same curvature as the instantaneous curvature of the lens element at the sphere point 512. As shown in Figure 31(b) the lens element gradually deviates from the reference sphere as radial distance increases. Examples of various changes in curvature which may
15 be used are illustrated in Figures 19-21.

 The shape of a lens made from the lens element of Figures 31 may be characterized by a sagittal depth Z. The depth may be measured from the fronto-parallel plane 513 (a plane perpendicular to the axis O-O at the sphere point 512) and a point 514 which represents the most radially distant temporal edge point of
20 the edged lens. In preferred embodiments of the present invention this distance may be on the order of 20 mm at a 30 mm radial distance as illustrated more explicitly in Figures 19-21.

 The value ΔZ represent the perpendicular distance or deviation of the lens element from the reference sphere. It will be understood that ΔZ will have its
25 maximum value in the edged lens at the radial distance corresponding to point 514. In the oblate bowl examples of Figures 19-21, ΔZ is shown to range from approximately 3 to 10 mm from the reference sphere at a location 30 mm from the axis O-O.

 Figure 31(c) illustrates a prolate bowl-shaped lens element 520. It is
30 characterized by a relatively steep instantaneous spherical curvature at the sphere



point 512. In contrast to the oblate bowl of Figure 31(b) the curvature becomes less steep radially outwardly from the axis O-O. In a preferred embodiment, the bowl of Figure 31(c) may take the form of one of the lens objects described in United States Application Serial No. 09/223,006 such that it has steeply curved spherical shape in a visual fixation region approximately bounded by a cone whose cross-section is indicated by rays 522 and 524. At the edge of the visual fixation region the curvature begins to gradually change to produce a temporal extension, in accordance with the preceding disclosure, in the lens region between ray 524 and the temporal edge point 514.

10

EXAMPLE 18

Ovaliform lens elements and spiral bends

Figures 32(a) and (b) are, respectively, top and side views of an ovaliform lens 600 with a spiral bend in the horizontal direction. The lens is illustrated as having an optical axis O-O, which, preferably, is colinear with the wearer's visual axis. The temporal-most edge point of the lens is indicated at 602. The shape of the lens in the horizontal plane of Figure 32(a) is characterized by a spiral bend (i.e. a monotonic curvature increasing in at least the temporal direction). For illustration purposes, this curvature increase is continued beyond the lens edge point 602 and is indicated by the spiralling dashed line 604.

20 The eye 606 and eyelashes 608 of the wearer are also shown in Figure 32(a). A line 610 represents a cross-section of a three dimensional surface which contains the frontal-most possible locations of the eyelashes and lids. This surface 610 preferably lies completely behind the rear surface of the lens to avoid eyelash/lid clash.

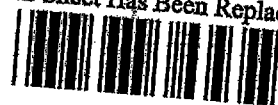
25 Figure 32(b) is a side perspective view in partial cross-section of the lens 600 and eye 606 of Figure 32(a). Figures 32(a) and (b) illustrate that the vertical curvature of lens is different than the horizontal curvature of the lens. The lens is not radially symmetric and better described as an ovaliform shape than as a bowl.



The vertical shape of the lens 600 is characterized by bends 612 and 614 located above and below the axis O-O, respectively. The change in vertical curvature may be tailored to avoiding eyelash/lid clash and providing protection for the eye above and below the optical axis O-O.

- 5 It will be understood that the invention disclosed and defined in this specification extends to all alternative combinations of two or more of the individual features mentioned or evident from the text or drawings. All of these different combinations constitute various alternative aspects of the invention.

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CLAIMS

1. An optical lens element including
a first surface; and
a second surface of complementary curvature;
- 5 at least one surface exhibiting significant deviation in curvature from a standard optical surface;
the first and second surfaces in combination defining an optical zone exhibiting substantially constant mean through power along at least one meridian.
2. An optical lens element according to Claim 1, wherein the first and second
- 10 surfaces are co-varying surfaces such that the optical zone exhibits substantially constant mean through power.
3. An optical lens element according to Claim 1, wherein the deviating
- 15 surface(s) exhibits a substantially smooth change of curvature, at least along a horizontal meridian, across at least a portion of the visual fixation field of the wearer.
4. An optical lens element according to Claim 3, wherein the deviating
- surface(s) exhibits substantially no visible discontinuity.
5. An optical lens element according to Claim 4, wherein the deviating
- surface(s) exhibits substantially no optical discontinuity.
- 20 6. An optical lens element according to Claim 1, wherein the change in curvature results in a change in sagittal depth of at least approximately 2 mm.
7. An optical lens element according to Claim 6, wherein the change in curvature results in a change in sagittal depth of at least approximately 4 mm.
8. An optical lens element according to Claim 1, wherein the optical zone is a
- 25 prescription zone having a non-zero mean through power between -6.0 D and +6.0 D.

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9. An optical lens element according to Claim 1, wherein, when mounted, the optical axis of the lens element is parallel to the line of sight of the wearer.
10. An optical lens element according to Claim 9, wherein the optical axis is colinear with the line of sight of the wearer.
- 5 11. An optical lens element according to Claim 1, wherein the standard optical surface is of spherical or toric shape, defined at a sphere or fitting point on the surface which passes through the optical axis.
12. An optical lens element according to Claim 11, wherein the extent of deviation of the deviating surface from a standard optical surface is related to the
10 radial distance from the optical axis.
13. An optical lens element according to Claim 12, wherein the deviation varies linearly, sinusoidally or a combination thereof, with radial distance.
14. An optical lens element according to Claim 1, wherein the deviating surface(s) exhibits no more than 1 meridian being circular in section.
- 15 15. An optical lens element according to Claim 14, wherein the optical lens element is of ovaliform shape.
16. An optical lens element according to Claim 12, wherein the optical lens element is generally radially symmetric.
17. An optical lens element according to Claim 16, wherein the shape of the
20 optical lens element approximates that of a bowl.
18. An optical lens element according to Claim 17, wherein the shape of the optical lens element approximates that of an oblate or prolate bowl.
19. An optical lens element according to Claim 12, wherein the shape of a horizontal section through the optical lens element is generally that of a spiral.





20. An optical lens element according to Claim 1, wherein the deviating surface(s) varies along a horizontal meridian, but the curvature of the surface along the vertical meridian is substantially constant.
21. An optical lens element according to Claim 1, wherein the deviating
5 surface(s) varies along the horizontal and vertical meridians.
22. An optical lens element according to Claim 21, wherein the curvature of the surface along the vertical meridian is maintained within approximately ± 0.5 D of the curvature of the surface along the horizontal meridian.
23. An optical lens element according to Claim 1, wherein the front and/or back
10 surface bears a surface correction to at least partially adjust for optical errors.
24. An optical lens element according to Claim 23, wherein the back surface of the lens bears a surface correction to at least partially adjust for optical errors.
25. An optical lens element according to Claim 1, wherein the lens element is adapted for mounting in a frame of the wrap-around or shield type, such that the
15 lens is rotated temporally about a vertical axis through the optical centre thereof.
26. An optical lens element according to Claim 1, wherein the lens element is adapted for mounting in a frame of the wrap-around or shield type, such that the lens is decentred to displace its optical axis from the line of sight, while maintaining parallelism between the two.
- 20 27. An optical lens element according to Claim 25 or 26, wherein the lens element is both decentred and rotated temporally about a vertical axis through the optical centre thereof.
28. An optical lens element including front and rear co-varying surfaces, at least one of which having a varying surface power such that the mean through
25 power of the lens element is constant to within ± 0.75 D in the visual fixation field of the wearer with the optical axis of the lens element aligned with the visual axis of





the wearer, said lens element conforming to the shape of the face of the wearer and having a sagittal depth Z of at least approximately 10 mm.

29. An optical lens element according to Claim 28, wherein the mean through power is constant to within ± 0.5 D in the visual fixation field.

5 30. An optical lens element according to Claim 28, wherein the lens element has a non-zero mean through power between -4.0 D and +4.0 D.

31. An optical lens element according to Claim 30, wherein the lens element has a temporal region outside the visual fixation field wherein the absolute value of mean through power of the lens is gradually reduced.

10 32. An optical lens element according to Claim 28, wherein the lens element is a prolate bowl, at least one of whose surfaces has a sphere point on said optical axis, and whose back surface is designed to minimize eyelash clash.

33. An optical lens element according to Claim 28, wherein the lens element is ovaliform at least one of whose surfaces has a sphere point on said optical axis.

15 34. An optical lens element according to Claim 28, wherein along a horizontal meridian of the lens element, the surface powers of co-varying surfaces increase at a location temporal of the optical axis, then decrease in order to bend the lens element around the face of the wearer.

35. An optical lens element according to Claim 28, wherein the surface powers
20 of the co-varying surfaces vary along a vertical meridian and local maxima of surface power occur at locations above and below the optical axis of the lens.

36. An optical lens element including
a first surface; and
a second surface,

25 the first and second surfaces in combination defining
a central optical zone; and





an optical zone extension extending from the central optical zone towards the temporal region of the lens and wherein the absolute value of mean through power of the lens smoothly decreases gradually along at least a horizontal meridian across the extension such that unwanted optical astigmatism is significantly reduced.

37. An optical lens element according to Claim 36, wherein the optical lens element includes

a first surface; and

a second surface of complementary curvature

at least one surface exhibiting a deviation in curvature from a standard optical shape;

the first and second surfaces in combination defining a central optical zone of substantially constant mean through power.

38. An optical lens element according to Claim 36, wherein the mean through power decreases to substantially zero across the extension.

39. An optical lens element according to Claim 36, wherein the optical zone extension takes the form of a channel in which the mean through power decreases relatively smoothly according to a predetermined mathematical formula.

40. An optical lens element according to Claim 36, wherein the optical zone extension tapers in width to avoid contact with the wearer's temples.

41. An optical lens element including

a first surface; and

a second surface,

at least one surface exhibiting a significant deviation in curvature from a standard optical surface;

the first and second surfaces in combination defining

a central optical zone; and

an optical zone extension extending from the central optical zone

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towards the temporal region of the lens and wherein the first and second surfaces exhibit a substantially equivalent change of curvature in the optical zone extension such that the mean through power remains substantially constant.

- 5 42. An optical lens element including
 a first surface; and
 a second surface of complementary curvature;
 at least one surface exhibiting a significant deviation in curvature from a
standard optical surface;
- 10 the first and second surfaces in combination defining
 a central optical zone exhibiting substantially constant mean through
power along at least one meridian;
 a temporal optical zone displaced laterally along a horizontal
meridian of the lens; and
- 15 an intermediate optical zone therebetween wherein the mean
through power of the lens varies gradually along a horizontal meridian
across the zone.
43. An optical lens element according to Claim 42, wherein the intermediate
optical zone takes the form of a channel in which the mean through power
- 20 increases relatively smoothly according to a predetermined mathematical formula.
44. An optical lens element according to Claim 43, wherein the intermediate
optical zone takes the form of a relatively broad channel.
45. An optical lens element series wherein each lens element includes
 a first surface; and
- 25 a second surface of complementary curvature;
 at least one surface exhibiting significant deviation in curvature from a
standard optical surface;
- the first and second surfaces in combination defining an optical zone
exhibiting substantially constant mean through power along at least one meridian
- 30 each lens element having





a front surface varying with mean through power required; and
a common back surface.

46. An optical lens element series according to Claim 45 wherein each lens element exhibits plus through power.

5 47. An optical lens element series according to Claim 45, wherein each optical lens element is of radially symmetric, bowl-like shape; the varying front surface and common back surfaces being selected by reference to the Morris-Spratt diagrams as herein described.

10 48. An optical lens element series wherein each lens element includes
a first surface; and
a second surface of complementary curvature;
at least one surface exhibiting significant deviation in curvature from a standard optical surface;
the first and second surfaces in combination defining an optical zone
15 exhibiting substantially constant mean through power along at least one meridian;
each lens element having
a common front surface; and
a back surface varying with mean through power required.

20 49. An optical lens element series according to Claim 48 wherein each lens element exhibits minus through power.

50. An optical lens element series according to Claim 48, wherein each optical lens element is of radially symmetric, bowl-like shape; the common front surface and varying back surfaces being selected by reference to the Morris-Spratt diagrams as herein described.

25 51. Prescription ophthalmic eyewear, including:
a frame for holding a pair of ophthalmic lens, wherein each lens curves around the face of the wearer toward one of the wearer's temples in an as-worn configuration; and wherein each lens has





a front surface with a smoothly horizontal varying surface power, and
a concave rear surface which clears the wearer's eyelashes in the as-worn configuration, and which has a smoothly, horizontally varying surface power providing, in combination with the front lens surface power, a mean through power
5 constant to within ± 0.75 D horizontally between the primary line of sight through the lens in the as-worn configuration and a peripheral line of sight rotated temporally at least 40° from the primary line of site.

52. Prescription eyewear according to Claim 51 wherein each ophthalmic lens has a non-zero mean through power.

10 53. Prescription eyewear according to Claim 51, wherein the mean through power is constant to $\pm .50$ D.

54. Prescription eyewear according to Claim 51, wherein the mean through power is constant to $\pm .125$ D up to 40° off axis and declining to no more than $\pm .25$ D at 50° off axis.

15 55. A method of making an optical lens element including
a first surface; and
a second surface of complementary curvature;
at least one surface exhibiting significant deviation in curvature from a
standard optical surface;

20 the first and second surfaces in combination defining an optical zone exhibiting substantially constant mean through power along at least one meridian;
which method includes
providing

25 a mathematical or geometrical representation of a first surface exhibiting a deviation in curvature from a standard optical surface; and

a mathematical or geometrical representation of the profile of a second surface of complementary curvature; the first and second surfaces in combination defining an optical zone exhibiting substantially constant mean through power;

30 forming a lens element corresponding to the representations of the first and



second surfaces.



56. A method according to Claim 55, wherein, when the lens element is radially symmetric, the sagittal depth is given by the formula

$$Z(r, \theta) = Z(r)$$

5 wherein r, θ, Z , are cylindrical coordinates

$$Z(r) = \sum_{2n=0}^4 A_{2n} * r^{2n}$$

wherein $A_4 = (A_2)^3$, $A_6 = 2 * (A_2)^5$, and $A_8 = 5 * (A_2)^7$

wherein $A_2 = P_0 + K(r)$

wherein the function $K(r)$ is continuous.

10 57. A method according to Claim 55, wherein when a surface carries a surface correction, the sagittal depth is given by the formula

$$Z(r, \theta) = R(r, \theta) - \sqrt{R(r, \theta)^2 - r^2}$$

and where

$$R(r, \theta) = \frac{R(r, 0) * R(r, \pi/2)}{R(r, \theta) \sin^2 \theta + R(r, \pi/2) \cos^2 \theta}$$

15 is the radial curvature along the meridian at θ , and the values $\theta = 0$ and $\pi/2$ represent the principal meridians.

58. A method according to Claim 55, wherein, when the lens element deviates from a toric surface, the sagittal depth is given by the formula

$$Z(r, \varphi) = Z(x, y)$$

20 wherein r, φ are cylindrical co-ordinates

$$Z(x, y) = \sum_{2n=0}^4 A_{2n} * x^{2n} + \sum_{2n=0}^4 B_{2n} * y^{2n}$$

wherein

$$A_2 = P_0 + K(x), \text{ and } B_2 = P_0.$$

59. A method according to Claim 55, wherein, when the lens element includes
25 an optical zone extension in which unwanted optical astigmatism is significantly reduced, the sagittal depth is given by the formula



$$z(x, y) = Z(x, y) + f'(y/R_0) * f(x/R_0) \left[\sum_{n=1}^4 C_{2n} x^{2n} + \sum_{n=1}^4 C_{2n} y^{2n} \right]$$



where

$$f'(y/R_0) = \left[1 - \sum_{n=2}^4 R'_{2n} (y/2R'_0)^{2n} \right]^{-m}$$

wherein the value of parameters R_{2n} , C_{2n} and m are determined along the horizontal meridian by fitting the sagittal power to an approximately constant value.

60. An optical lens element including:

a first lens surface having a surface power varying radially symmetrically from a sphere point and exhibiting high levels of surface astigmatism over substantial portions of the lens such that the lens would be unusable as an ophthalmic lens if combined with a second standard optical surface; and

a second lens surface such that the front and rear surfaces define an optical body having an approximately constant mean through power and ophthalmically acceptable properties over said substantial portion of the lens element.

61. An optical lens element according to Claim 60, wherein the lens element is a prolate bowl such that the first surface deviates from a reference sphere defined at the sphere point by at least 3 mm at a location 30 mm from the sphere point.

62. A single vision, prescription ophthalmic lens element having a relatively flat face portion, and a temporal portion curved to conform to the head of the wearer including:

a front surface with a surface power which increases in temporal direction by at least 3.0 D;

a rear surface with a surface power which increases in a temporal direction by at least 3.0 D so that the lens has a non-zero mean through power constant to within ± 0.75 D.

63. An ophthalmic lens element according to Claim 62 wherein the mean through power is constant to within ± 0.75 D.

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64. An ophthalmic lens element according to Claim 62, further includes a nasal portion curved to conform to the bridge of the nose of the wearer.

65. An optical lens element substantially as hereinbefore described with reference to any one of the examples.



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