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(54) Title: SPECTACLE LENSES HAVING AN INSIDE-OUT CONICOIDAL FRONT SURFACE

(57) Abstract

Plus and minus power ophthalmic spectacle lenses for the correction of distance vision incorporating a convex aspherical front surface are provided. The front surface (14') of the invention is described mathematically as an inside-out conicoid. The inside-out conicoidal surface (14'), when used in conjunction with a concave spherical or toroidal back surface (12'), provides a lens having improved off-axis optical performance and reduced thickness and flatness characteristics relative to prior art lenses of the same back vertex power and refractive index.

SPECTACLE LENSES HAVING AN INSIDE-OUT
CONICOIDAL FRONT SURFACE

5   ## Field of the Invention:
     This invention relates to the field of ophthalmic
spectacle lenses, and in particular to spectacle lenses
for the correction of distance vision.

10   ## Background of the Invention:
     Spectacle lenses for the correction of blurred
vision of distant objects conventionally employ two
surfaces of spherical form when the eye is free of
astigmatism, or one surface of spherical form and the
15   other of toroidal form when astigmatism requiring

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correction is present. For a given value of back
vertex power, the curvatures of the surfaces comprising
a lens of this type are fixed by the designer using a
predetermined standard of optical performance for
vision through the peripheral areas of the lens
("off-axis performance"). Such lenses are termed "best
form" lenses.

Conventional best form lenses tend to be bulky and
cosmetically unattractive in the higher powers. Table
1 illustrates the point for typical best form
hard-resin lenses (refractive index n = 1.498) having
back vertex powers of +5.00 D and -5.00 D. The
curvatures of the spherical surfaces of these lenses
have been chosen, in the absence of chromatic
aberration, to minimize the sum $|MOE| + |OAE|$, where
MOE is the mean oblique error [arithmetic mean of the
tangential (T) and saggital (S) errors] and OAE is the
oblique astigmatic error (T - S). The table suggests

TABLE I.   CHARACTERISTICS OF BEST FORM LENSES OF REFRACTIVE

           INDEX 1.498 AND 71 MM DIAMETER.   CENTER OF ROTATION

           DISTANCE = 28.5 MM. OBJECT DISTANCE = 10,000 M.

Back vertex power (D)	1.53 power of front surface[1] (D)	Edge thickness (mm)	Center thickness (mm)	Flat plate thickness (mm)
+5.00	9.80	1.0	8.2	14.3
-5.00	3.90	9.8	2.2	14.5

[1] 1.53 surface power is an industry standard defined

by the expression (n-1)/r, where n = 1.53 and r is

radius of curvature (in meters)

that the +5.00 D lens will be bulbous in appearance owing to the
relative strong front surface power (i.e., short radius of
curvature), and the -5.00 lens will seem massive owning to its
relatively thick edge. Both lenses exhibit a large flat plate
thickness. (Flat plate thickness is the separation of two flat
plates held against opposite sides of the lens.)

It is well known that the cosmetic appearance of the best
form lenses can be improved by employing an aspherical surface
of appropriate form in conjunction with a conventionally formed
spherical or toroidal second surface. Davis (U.S. Patent
3,960,442) discloses the basic concept of combining an aspheric
surface with base curve selection to obtain desired design
characteristics while maintaining optical performance. A

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specific lens series of the aspheric type described by
Jalie (U.S. Patent 4,289,387) utilizes a convex
hyperboloidal front surface for plus power lenses, with
the prescription to be formed on the back surface, and
a concave hyperboloidal back surface for minus power

5   lenses, with the prescription to be formed on the front
surface. The use of the hyperboloidal surfaces
provides lenses having reduced edge, center and flat
plate thicknesses relative to those of their
conventional best form counterparts. Moreover, by an

10   appropriate choice of the "conic constant" associated
with the hyperboloidal surface, the off-axis
performance of the aspherical lens series can be made
comparable to that of the conventional best form series.
        The use of a concave hyperboloidal surface for

15   minus power lenses presents a problem for prescription
lens processing laboratories in that most laboratories
lack the machinery necessary to generate, grind and
polish the convex front surfaces of prescription
lenses. The processing problem is resolved by
incorporating a convex oblate ellipsoid on the front

20   side of the lens, rather than a concave hyperboloid on
the back side. Unfortunately, although the off-axis
performance of such a lens can be adjusted by varying
the conic constant of the oblate ellipsoid, the
performance is not, in general, as good as that of the

25   lens with concave hyperboloidal back surface.

Brief Description of the Drawings:
        FIGURE 1 illustrates the first step in the

30   conceptual development of the aspheric surface of the
invention, wherein a lens having a convex spherical
surface and a concave conicoidal surface is placed in
front of the eye, with the convex side facing the eye.

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FIGURE 2 illustrates conceptually the second step in the development of the aspheric surface of the invention, wherein the lens of FIGURE 1 is bent in such a manner that the formerly convex spherical posterior surface becomes a concave spherical posterior surface, and the formerly concave conicoidal anterior surface becomes a convex inside-out conicoidal anterior surface.

FIGURE 3 shows the surface curvature along an axial section of a conicoid of hyperboloidal form.

FIGURE 4 shows the surface curvature along an axial section of an inside-out conicoid of inside-out hyperboloidal form.

FIGURE 5 depicts an axial cross section of a +5.00 D power lens of the invention.

FIGURE 6 depicts an axial cross section of a -5.00 D power lens of the invention.

FIGURE 7 depicts an axial cross section of a +5.00 D power best form lens.

FIGURE 8 depicts an axial cross section of a -5.00 D power best form lens.

Summary of the Invention:

In accordance with the present invention, ophthalmic spectacle lenses are provided for the correction of distance vision incorporating a continuous convex aspherical front surface that affords improvements over conventional best form lenses as well as over existing non-conventional lenses having aspheric surfaces.

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In particular, the present invention provides
ophthalmic lenses of both plus and minus power having
reduced edge and center thicknesses, reduced flat plate
thickness and improved performance, and whose concave
sides can be generated, ground and polished using
standard prescription laboratory machinery. In both
cases (i.e., plus and minus power lenses) the rear
concave surfaces are comprised of any suitable
conventionally shaped surfaces and are preferably
comprised of spherical or toroidal surfaces, which can
be provided either by the manufacturer or by the use of
conventional prescription laboratory machinery.

The invention consists of a lens whose continuous
convex front surface is axially symmetric and is of a
special aspherical form, here referred to as an
"inside-out" conicoid. The mathematical construction
of such a surface is analogous to turning an orange
peel inside out: a lens having a concave conicoidal
surface is mathematically turned inside out, so that
the concave surface is converted into a convex one.
When the conic constant of the concave conicoid that is
turned inside-out is algebraically positive, the
resulting convex inside-out surface is appropriate to
the design of plus-powered lenses. When the conic
constant of the concave conicoid that is turned inside
out is algebraically negative, the resulting convex
inside-out surface is appropriate to the design of
minus-powered lenses. Although the inside-out surface
so formed bears little resemblance to the conicoid from
which it is derived, it is nevertheless uniquely
specified by just three parameters, namely the axial
curvature k_0 and conic constant K of the original
concave conicoid, and the axial curvature k_1 of the

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final convex inside-out surface. Lens thickness and
off-axis performance can be adjusted by adjusting the
values of the parameters k_0 and K.

Description of the Preferred Embodiments:

As already stated, it is an object of the present
invention to provide ophthalmic lenses having reduced
flat plate thickness and improved performance as
compared with the corresponding characteristics of best
form lenses. It is, of course, possible to reduce the
flat plate thickness of a best form lens by replacing
its surfaces with spherical surfaces having reduced
curvatures, the relative values of these reduced
curvatures being chosen in such a way as to give the
same back vertex power as that of the best form lens.
However, the off-axis optical performance of such a
lens will be inferior to that of the best form lens.
However, in accordance with the present invention, the
lost performance can be restored by an appropriate
aspherization of the front surface of the flatter
lens. The present invention incorporates a
particularly advantageous form of convex aspheric
surface for the restoration of lost performance, namely
the inside-out conicoid.

The development of the inside-out conicoidal
surface involves three steps, the first two of which
are illustrated in FIGURES 1 and 2. It should be
understood that the development pictured is presented
as an aid to the teaching and understanding of the
mathematical structure of the inside-out surface, and
is not to be construed as representing a manufacturing
process.

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Step 1. FIGURE 1 shows a lens 10 placed in front
of the eye in an unorthodox manner, with the convex
side facing the eye. The convex posterior surface 12
of this lens is of spherical or toroidal form, whereas
the concave anterior surface 14 is of conicoidal form,
i.e., a surface formed by rotating a conic section
about an axis of symmetry. The relative values of the
axial curvatures of these two surfaces are such as to
give the required back vertex power for correction of
distance vision.

Step 2. The second step, depicted in FIGURE 2, is
to bend the extremities of the lens uniformly towards
the eye until the axial surface curvature of the
anterior surface 14' attains a specified value flatter
than that of the spherical anterior surface of the best
form lens for the given back vertex power. After
bending, the posterior surface 12' is still of
spherical or toroidal form but is now concave. The
convex aspherical anterior surface 14' so formed is the
inside-out conicoid.

Step 3. The third and final step is to adjust the
conic constant, i.e., a constant whose value specifies
the type of conic section (circle, ellipse, parabola,
etc.) of the conicoid that has been turned inside out
until the off-axis performance matches or exceeds that
of the more steeply curved best form lens. It may also
be necessary to adjust the curvature of the concave
spherical or toroidal surface to maintain the required
back vertex power.

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The mathematical form of the inside-out conicoid is readily derived. The derivation begins with the equation of a conicoid. With the vertex of the conicoid at the origin as shown in FIGURE 1, the equation of the conicoid can be written [M. Jalie, The Principles of Ophthalmic Lenses, (Association of Dispensing Opticians, London, 1984), p. 517].

$$y^2 = 2Rx - (K+1)x^2 \qquad (1)$$

where x is the axis of rotational symmetry, y is the radial coordinate, R is the axial radius of curvature, and K is the conic constant (in Jalie's notation, $K + 1 = p$). The types of conicoid corresponding to different values of K are as follows:

$$-\infty < K < -1 \qquad \text{hyperboloid}$$
$$K = -1 \qquad \text{paraboloid}$$
$$-1 < K < 0 \qquad \text{prolate ellipsoid}$$
$$K = 0 \qquad \text{sphere}$$
$$0 < K < \infty \qquad \text{oblate ellipsoid}$$

Solving equation (1) for x gives

$$x = \left\{ R \pm [R^2 - (K + 1)y^2]^{1/2} \right\} /(K + 1) , \qquad (2)$$

where for $R > 0$ (center of curvature to the right of the vertex) the minus sign must be taken, and for $R < 0$ (center of curvature to the left of the vertex) the plus sign must be taken. The curvature $k_c(y)$ of the conicoid along an axial section at aperture radius y is found to be (for either sign of R)

$$k_c(y) = x''/(1 + x'^2)^{3/2}$$
$$= (1/R)/(1 - Ky^2/R^2)^{3/2} . \qquad (3)$$

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Since the conicoid of FIGURE 1 is concave to the left, its axial curvature 1/R and general curvature function $k_c(y)$ are algebraically negative. The general form of this curvature function for the case that the conicoid is hyperboloidal is sketched in FIGURE 3. To obtain the curvature function $k(y)$ of the inside-out conicoid depicted in FIGURE 2, it is only necessary to add a positive constant B to the function $k_c(y)$ defined by Equation (3):

$$k(y) = B + k_c(y)$$
$$= B + k_0/(1 - Kk_0^2y^2)^{3/2} \tag{4}$$

where $k_0 = 1/R$. Let k_1 denote the axial curvature $k(0)$ of the inside-out conicoid of FIGURE 2. Then from Equation (4),

$$k_1 = B + k_0 , \tag{5}$$

and from Equations (4) and (5), the curvature function of the inside-out conicoid at aperture radius y can finally be written

$$k(y) = k_1 - k_0 + k_0/(1 - Kk_0^2y^2)^{3/2} , \tag{6}$$

where

k_0 = axial curvature of concave conicoid prior to being turned inside-out (a negative number in this sign convention)

k_1 = axial curvature of convex aspherical front surface (a positive number)

K = conic constant of the concave conicoid prior to being turned inside out (positive or negative, depending on application).

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The curvature function of Equation (6) is everywhere
positive; the corresponding surface is therefore
concave to the right, as is usual in the case of
ophthalmic spectacle lenses. The general form of $k(y)$
is depicted in FIGURE 4 which replicates the curve of
FIGURE 3 shifted upward by the constant B.

A knowledge of the curvature function $k(y)$ is
sufficient to define the equation of the inside-out
surface itself. It is given by the definite integral

$$x(y) = \int_0^y \tan\theta \, dy \, , \tag{7}$$

where

$$\sin\theta = \int_0^y k(y) \, dy \, , \tag{8}$$

as may be verified by direct substitution into the
general expression for curvature

$$k(y) = x''/(1 + x'^2)^{3/2} \, . \tag{9}$$

Some general rules for selecting the values of the
parameters k_0, k_1 and K will now be given.

Although the curvature k_1 will invariably be
flatter than the front surface curvature of the
corresponding best form sphere, there are practical
limitations to the degree of flatness that can be
attained. For plus lenses, the flatness of the front
surface is limited by such practical considerations as
eyelash clearance at the back surface, reflection of

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light from the back surface, and the ability of
prescription laboratory machinery to generate concave
surfaces of long radius. For minus power lenses, the
only practical restriction on the anterior surface is
that it be convex.

To optimize off-axis performance and achieve the
desired thickness reductions the conic constant K must
be positive for plus power lenses, and negative for
minus power lenses.

To define a particular inside-out surface it is
necessary to specify the value of the "reference
curvature" k_0 appearing in Equation (6). Let k_2
denote the characteristic curvature of the concave
spherical or toroidal back curve of the lens of the
invention. Experience shows that a value of k_0 =
$-k_2$, together with an appropriate choice of the
value of the conic constant K, generally yields the
best off-axis performance. For this case

$$k(y) = k_1 + k_2 - k_2/(1 - Kk_2^2y^2)^{3/2} , \qquad (10)$$

where

k_2 = characteristic curvature of the concave
spherical or torical back surface (a positive number).

Let D denote the curvature of the inside-out
surface at aperture radius y_0, relative to the axial
curvature
$k_1 = k(0)$:

$$D = k(y_0) - k(0) , \qquad (11)$$

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where $k(y_0)$ is given by Equation (10), or more
generally by Equation (6), evaluated at $y = y_0$. For
present purposes, y_0 represents an aperture radius
near the edge of the lens. The curvature "drop" D at
y_0 generally is negative for plus power lenses, and
positive for minus power lenses. The drop D is an
important indicator of the severity of the asphere; the
larger its magnitude, the more severe the asphere.
Suppose that a curvature function k(y) corresponding to
a certain combination of values of k_0 and K has been
found, and that this function yields a drop D at
aperture radius y_0. According to Equation (6) there
exists an infinite number number of pairs of values of
k_0 and K that yield this same value of D. Such pairs
may be found from the formula, obtained by solving
Equation (6) for K, with $y = y_0$,

$$K = [1 - (1 + D/k_0)^{-2/3}]/(k_0 y_0)^2 . \qquad (12)$$

It may happen that one or the other of these pairs of
k_0 and K give better performance for the same drop D
than the original pair.

Alternatively, one can begin the design of a
particular embodiment by choosing a value of D at
radius y_0. A table of pairs of values of k_0 and K
that give the chosen value of D can then be developed
from Equation (12). From these pairs, one pair can be
selected that produces the desired lens thickness and
off-axis performance characteristics.

To facilitate a comparison between prior art
lenses and those of the present invention, it is
convenient to have a figure of merit for off-axis

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performance. The following very simple figure of merit, σ, which neglects chromatic aberration and is restricted to lenses having spherical back surfaces, will be employed for purposes of illustration:

$$\sigma = |MOE| + |OAE| \tag{13}$$

where, as previously noted, MOE denotes the mean oblique power error [arithmetic mean of the tangential (T) and saggital (S) errors] and OAE denotes the oblique astigmatic error (T - S), both errors being measured in diopters (D). Roughly speaking, a σ value of 0.25 D represents the just observable total error. The value of σ varies with viewing angle, and lenses are typically compared for a 30° rotation of the eye from the forward direction.

    FIGURE 5 depicts a plus power lens constructed in accordance with the invention. It may be compared with the plus power best form lens shown in FIGURE 7. The convex, inside-out conicoidal front surface 14" of FIGURE 5 is described algebraically by Equation (6) with K $>$ 0. That is, for plus power lenses, the conicoid that is turned inside-out is an oblate ellipsoid. The concave back surface 12" of the lens is spherical or toroidal depending on whether astigmatism requiring correction is present or not.

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FIGURE 6 depicts a minus power lens constructed in
accordance with the invention. It is to be compared
with the minus power best form lens shown in FIGURE 8.
The convex, inside-out conicoidal front surface 14"' of
FIGURE 6 is described algebraically by Equation (6)
with $K < 0$. That is, for minus power lenses, the
conicoid that is turned inside-out is either a prolate
ellipsoid, a paraboloid or a hyperboloid. As in the
case of the plus lens, the concave back surface of the
lens is spherical or toroidal depending on whether
astigmatism requiring correction is present or not.

By design, all lenses of the invention, whether of
plus or minus power, have reduced flat plate
thicknesses in comparison with best form lenses having
the same back vertex power and refractive index.
Moreover, the center thicknesses of the plus power
lenses, and the edge thickness of the minus power
lenses of the invention, are reduced in comparison to
the corresponding thicknesses of best form lenses, and
even to those of prior art aspheric lenses having the
same axial front surface power. These thickness
reductions translate into improved cosmesis and a
reduction of weight over previously known lenses.
Significantly, the gains in cosmesis and weight are
accompanied by gains in off-axis performance as well.
This will now be demonstrated by way of the examples
presented in Tables II and III.

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TABLE II. COMPARISON OF LENSES OF +5.00 D POWER.

N = 1.498, EDGE THICKNESS = 1.0 MM, DIAMETER = 71 MM.

OBJECT DISTANCE = 10,000 M.

	Best form sphere[a]	Flattened sphere[b]	Prior art asphere[b]	Lens of the invention[b]
K	-------	--------	-1.75	15.4
$530k_0$ (D)	-------	--------	-------	-3.00
Axial convex surf pwr (D)	9.80	7.10	7.10	7.10
Convex surf pwr @ 35 mm	9.80	7.10	4.38	-1.96
Drop D @ 35 mm (D)	0.00	0.00	2.72	9.06
Axial concave surf pwr (D)	-5.00	-2.03	-2.00	-1.99
T error @ 30° (D)	-0.14	0.66	-0.26	-0.13
S error @ 30° (D)	-0.23	0.01	-0.26	-0.20
MOE @ 30° (D)	-0.19	0.34	-0.26	-0.17
OAE @ 30° (D)	0.09	0.65	0.00	0.07
σ @ 30° (D)	0.28	0.98	0.26	0.23
Flat plate thickness (mm)	14.28	9.98	9.11	8.92
Center thickness (mm)	8.17	7.56	6.72	6.54

[a]Center of rotation distance = 28.5 mm.

[b]Center of rotation distance = 25.0 mm.

TABLE III. COMPARISON OF LENSES OF POWER -5.00 D.

N = 1.498, CENTER THICKNESS = 2.2 MM, DIAMETER = 71 MM.

OBJECT DISTANCE = 10,000 M.

	Best form sphere[a]	Flattened sphere[b]	Prior art asphere[b]	Lens of the invention[b]
K	-------	--------	64	-2.8
$530k_0$ (D)	-------	--------	-------	-6.00
Axial convex surf pwr (D)	3.90	0.75	1.60	0.75
Convex surf pwr @ 35 mm	3.90	0.75	10.49	3.27
Drop D @ 35 mm (D)	0.00	0.00	8.89	2.52
Axial concave surf pwr (D)	-9.24	-6.07	-6.93	-6.07
T error @ 30° (D)	0.17	-0.76	-0.04	0.09
S error @ 30° (D)	0.17	-0.10	0.09	0.13
MOE @ 30° (D)	0.17	-0.43	0.03	0.11
OAE @ 30° (D)	0.00	-0.66	-0.13	-0.04
σ—@ 30° (D)	0.18	1.08	0.16	0.15
Flat plate thickness (mm)	14.51	9.75	10.93	9.75
Edge thickness (mm)	9.79	8.85	8.40	8.19

[a]Center of rotation distance = 28.5 mm.

[b]Center of rotation distance = 25.0 mm.

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TABLE II compares a +5.00 D power embodiment of the present invention with three types of prior art lens of the same power: a best form lens with spherical surfaces, a flatter lens with spherical surfaces, and a prior art aspherical lens of the Jalie patent type having a convex hyperboloidal front surface (conic constant -1.75) and spherical back surface. The front surface of the lens of the invention is an inside-out oblate ellipsoid (conic constant 15.4). The lens of the invention can be seen to have a reduced flat plate thickness, reduced center thickness, and somewhat improved off-axis performance relative to the corresponding characteristics of the prior art lenses.

Similarly, TABLE III compares a -5.00 D lens of the invention with the same three types of prior art lens; the prior art asphere in this case incorporates a convex oblate ellipsoidal front surface (conic constant 15.4). The front surface of the lens of the invention is an inside-out hyperboloid (conic constant -2.8). Again, the lens of the invention provides improvement over all three prior art lenses in that it exhibits reduced flat plate thickness, reduced edge thickness, and somewhat improved off-axis performance.

While preferred embodiments have been shown and described, various modifications and substitutions may be made thereto without departing from the spirit and scope of the invention. Accordingly, it is to be understood that the present invention has been described by way of illustrations and not limitation.

What is claimed is:

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CLAIM 1.   An ophthalmic lens, including:
    a continuous convex front surface of aspherical
form; and
    a concave rear surface;
    said continuous convex front surface of aspherical
form being a surface which can be defined
mathematically as an inside-out conicoid.

CLAIM 2.   The ophthalmic lens of claim 1 wherein:
    said lens is a plus power lens.

CLAIM 3.   The ophthalmic lens of claim 1 wherein:
    said lens is a minus power lens.

CLAIM 4.   The ophthalmic lens of claim 1 wherein:
    said convex front surface of aspherical form is
axially symmetric and defined by the curvature function
$k(y)$ at aperature radius y as follows:
$$k(y) = k_1 - k_0 + k_0/(1-Kk_0^2y^2)^{3/2},$$
where
    k_0 = axial curvature of a concave conicoid prior
to being turned inside out;
    k_1 = axial curvature of convex aspherical front
surface, and
    K = conic constant of a concave conicoid prior to
being turned inside out.

CLAIM 5.   The ophthalmic lens of claim 4 wherein:
    k_0 = a negative number; and
    k_1 = a positive number.

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CLAIM 6. The ophthalmic lens of claim 4 wherein:
     K is positive for plus power lenses.

CLAIM 7. The ophthalmic lens of claim 4 wherein:
     K is negative for minus power lenses.

CLAIM 8. The ophthalmic lens of claim 1 wherein:
     said convex front surface of aspherical form is axially symmetric and defined by the curvature of function k(y) at aperature radius y as follows:

$$k(y) = k_1 + k_2 - k_2/(1-Kk_2^2y^2)^{3/2},$$

where
     k_1 = axial curvature of convex aspherical front surface;
     k_2 = characteristic curvature of the concave spherical or torical back surface, and
     K = conic constant of the concave conicoid that is turned inside out.

CLAIM 9. The ophthalmic lens of claim 8 wherein:
     k_1 and k_2 comprise positive numbers.

CLAIM 10. The ophthalmic lens of claim 8 wherein:
     K is positive for plus power lenses.

CLAIM 11. The ophthalmic lens of claim 8 wherein:
     K is negative for minus power lenses.

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CLAIM 12. The ophthalmic lens of claim 1 wherein the conic constant (K) associated with the aspherical form of said convex front surface is defined by:

$$K = [1-(1+D/k_0))^{-2/3}]/(k_0 y_0)^2$$

where

K = conic constant of a concave conicoid prior to being turned inside out;

D = curvature of the inside out surface at aperature radius y_0, relative to the axial curvature k_1;

k_0 = axial curvature of a concave conicoid prior to being turned inside out; and

y_0 = a selected value of aperature radius y.

CLAIM 13. The ophthalmic lens of claim 12 wherein:

k_0 = a negative number.

CLAIM 14. The ophthalmic lens of claim 1 wherein:

said concave rear surface is of either spherical or toroidal shape.

CLAIM 15. A method of forming an ophthalmic lens, including the steps of:

forming a continuous convex front surface of aspherical shape on a lens; and

forming a continuous concave rear surface;

said continuous convex front surface of aspherical shape being a surface which can be defined mathematically as an inside out conicoid.

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CLAIM 16. The method of claim 15 wherein said step of forming a convex front surface includes:

   forming a front surface to define a plus power lens.

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CLAIM 17. The method of claim 15 wherein said step of forming a convex front surface includes:

   forming a convex front surface to define a minus power lens.

10

CLAIM 18. The method of claim 15 wherein:

   said convex front surface of aspherical form is axially symmetric and defined by the curvature function $k(y)$ at aperature radius y as follows:

$$k(y) = k_1 - k_0 + k_0/(1-Kk_0^2y^2)^{3/2},$$

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where

   k_0 = axial curvature of a concave conicoid prior to being turned inside out;

   k_1 = axial curvature of convex aspherical front surface, and

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   K = conic constant of a concave conicoid prior to being turned inside out.

CLAIM 19. The method of claim 18 wherein:

   k_0 = a negative number; and

   k_1 = a positive number.

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CLAIM 20. The method of claim 16 wherein:

   K is positive for plus power lenses.

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CLAIM 21. The method of claim 16 wherein:
     K is negative for minus power lenses.

CLAIM 22. The method of claim 15 wherein:
     said convex front surface of aspherical form is
axially symmetric and defined by the curvature of
function k(y) at aperature radius y as follows:

$$k(y) = k_1 + k_2 - k_2/(1-Kk_2^2y^2)^{3/2},$$

where
     k_1 = axial curvature of convex aspherical front
surface;
     k_2 = characteristic curvature of the concave
spherical or torical back surface, and
     K = conic constant of the concave conicoid that is
turned inside out.

CLAIM 23. The method of claim 22 wherein:
     k_1 and k_2 comprise positive numbers.

CLAIM 24. The method of claim 22 wherein:
     K is positive for plus power lenses.

CLAIM 25. The method of claim 22 wherein:
     K is negative for minus power lenses.

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CLAIM 26. The method of claim 15 wherein the conic constant (K) associated with the aspherical form of said convex front surface is defined by:

$$K = [1-(1+D/k_0))^{-2/3}]/(k_0 Y_0)^2$$

where

K = conic constant of a concave conicoid prior to being turned inside out;

D = curvature of the inside out surface at aperature radius Y_0, relative to the axial curvature k_1;

k_0 = axial curvature of a concave conicoid prior to being turned inside out; and

Y_0 = a selected value of aperture radius y.

CLAIM 27. The method of claim 22 wherein:

said concave rear surface is of either spherical or toroidal shape.
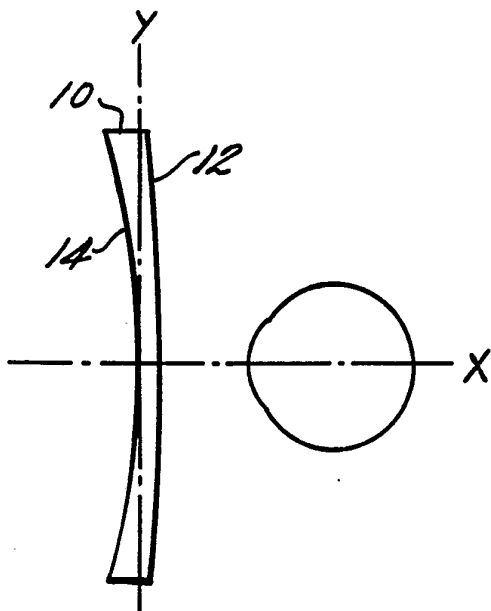
FIG. 1
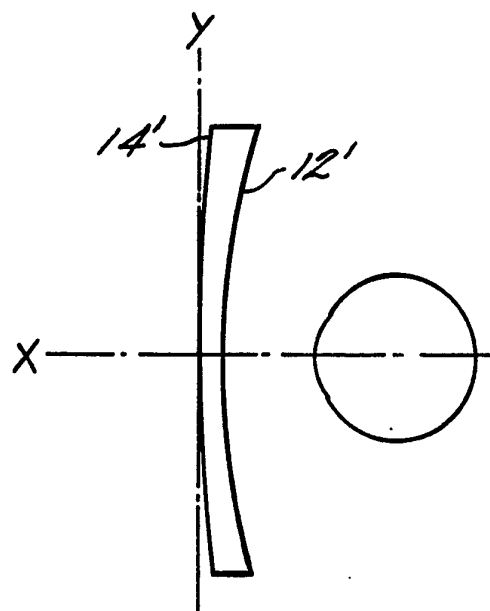
FIG. 2
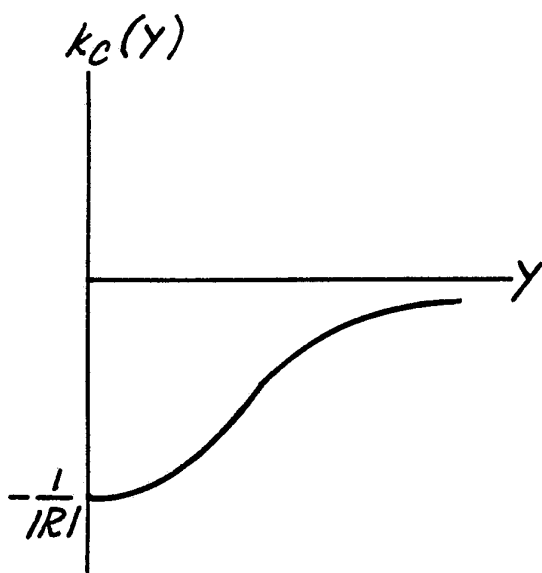
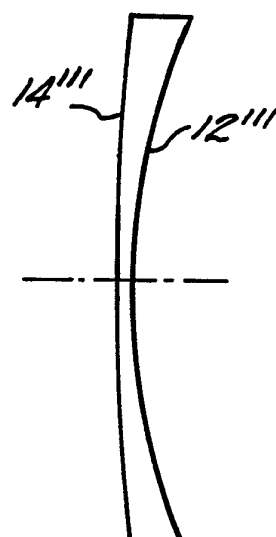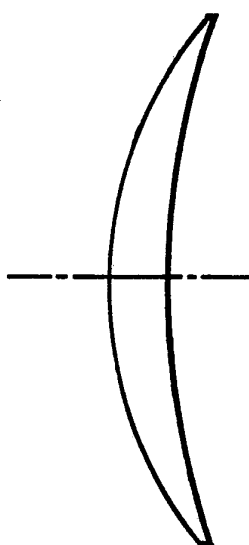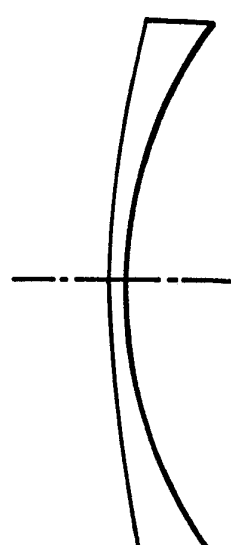
FIG. 3
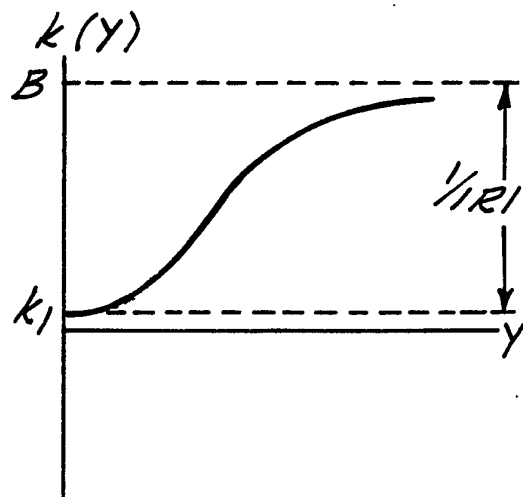
FIG. 4
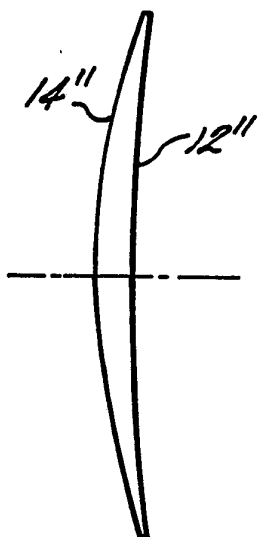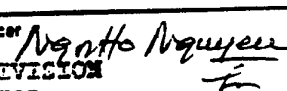
FIG. 5

FIG. 6

FIG. 5

FIG. 6

INTERNATIONAL SEARCH REPORT

International Application No. PCT/US91/09385

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) *

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC(5): G02C 7/02
U.S. Cl.: 351/159, 167, 176, 177

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
U.S.	351/159, 167, 176, 177

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No [13]
A	US, A, 4,418,991 (Breger) 06 December 1983 (See entire document)	1-27
A	US, A, 4,195,919 (Shelton) 01 April 1980 (See entire document)	1-27
X	US, A, 3,950,082 (Volk) 13 April 1976 (See col. 1, lines 29-49 and col. 6, lines 32-52)	1-3 and 15-17

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search

04 May 1992

Date of Mailing of this International Search Report

15 MAY 1992

International Searching Authority

ISA/US

Signature of Authorized Officer

DIVISION

Scott J. Sugarman

Form PCT/ISA/210 (second sheet) (Rev.11-87)