United States Patent [19]

Schaefer

[11] **3,708,221**

[45] **Jan. 2, 1973**

[54] **ASPHERIC LENS AND METHOD OF MANUFACTURE**

[75] Inventor: **Howard A. Schaefer,** Lancaster, Ohio

[73] Assignee: **Anchor Hocking Corporation,** Lancaster, Ohio

[22] Filed: **April 2, 1970**

[21] Appl. No.: **25,179**

[52] **U.S. Cl.** **350/189,** 240/106.1, 350/211

[51] **Int. Cl.**.....**G02b 3/04,** G02b 3/08

[58] **Field of Search**.....350/178, 189, 190–192, 350/211; 240/106.1

[56] **References Cited**

UNITED STATES PATENTS

3,578,966	5/1971	Levin	350/189 X
1,872,643	8/1932	Bone	350/189
1,955,599	4/1934	Lamblin-Parent	240/106.1 X
2,551,954	5/1951	Lehman	350/190
2,282,167	5/1942	Cullman	350/189 X
1,422,307	7/1922	Salto	350/189
2,072,849	3/1937	Dietrich	350/190 X

Primary Examiner—David Schonberg
Assistant Examiner—Paul A. Sacher
Attorney—Connolly and Hutz

[57] **ABSTRACT**

An aspheric lens is made with an aspheric curvature on its frontal surface wherein the curvature is defined in the X-Y coordinate system by a particular relationship in accordance with the index of refraction, heighth, focal distance and radius of back surface parameters.

11 Claims, 22 Drawing Figures

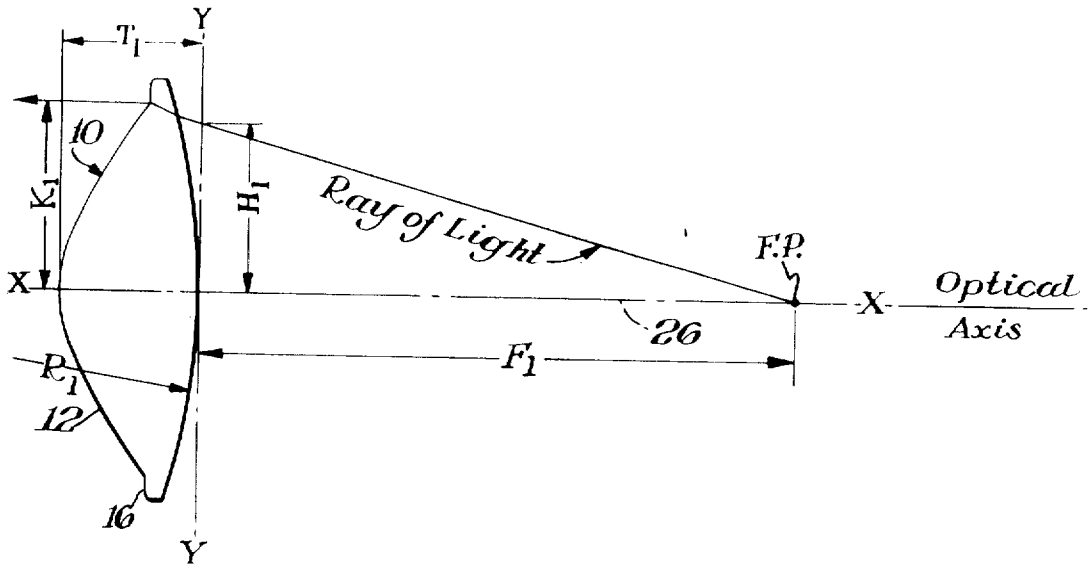


Fig. 1.

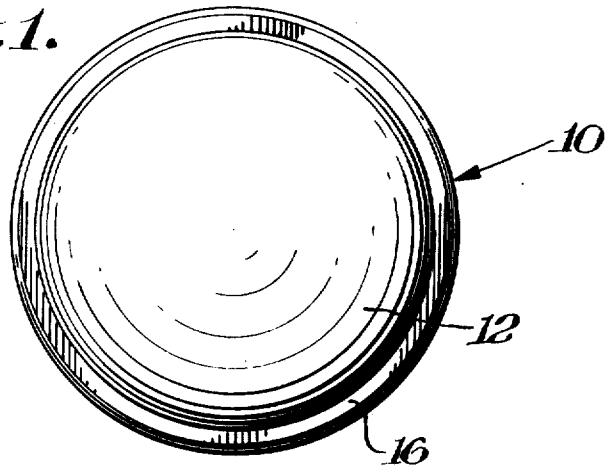


Fig. 2.

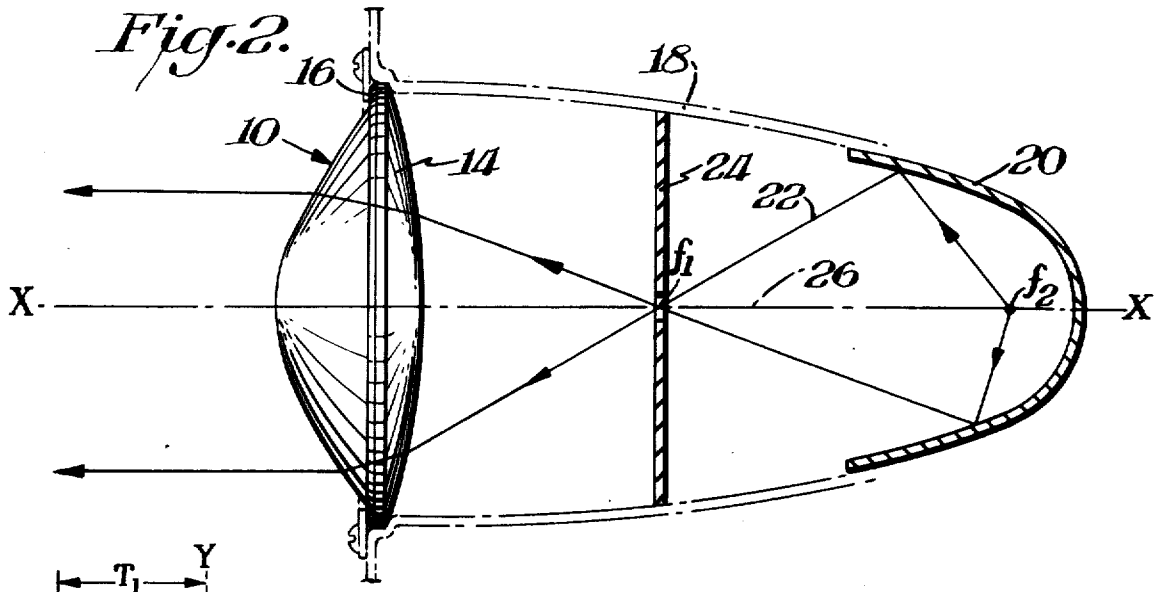


Fig. 3.

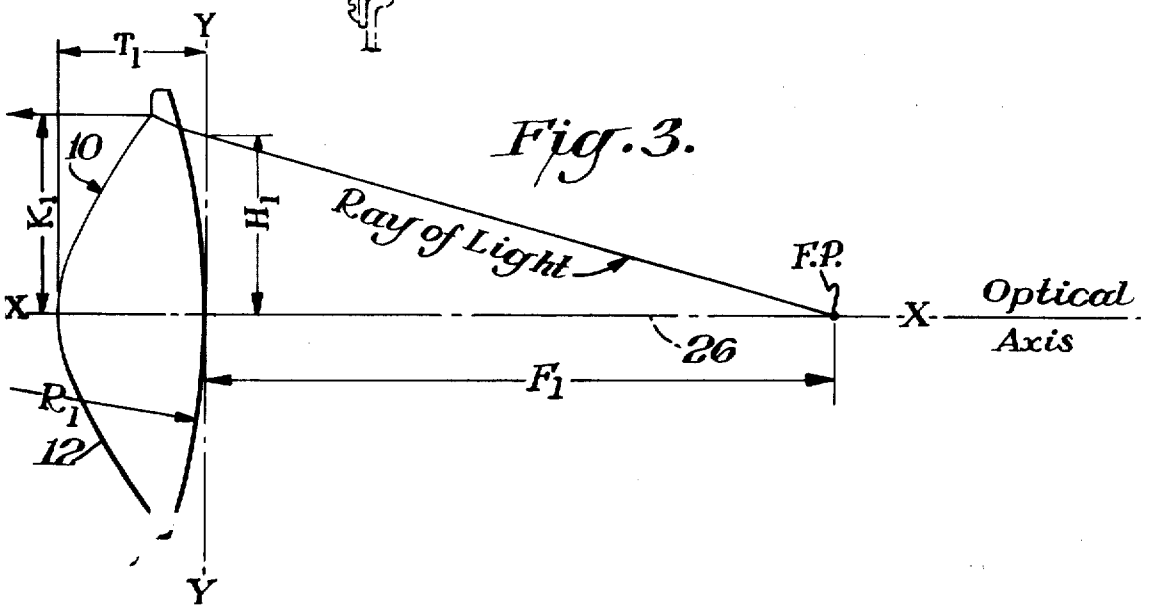


Fig. 4.

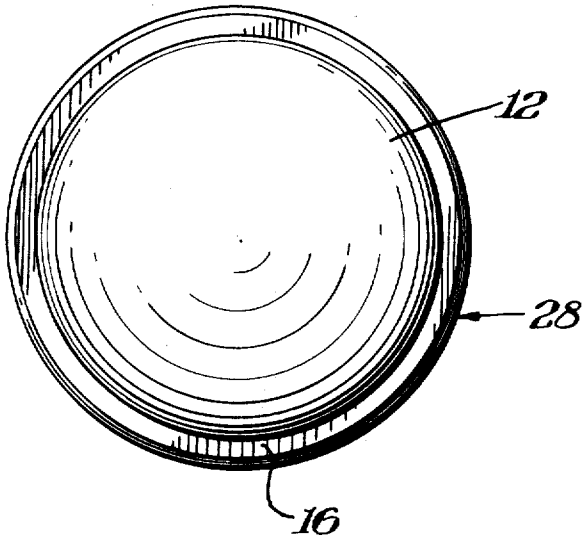


Fig. 5.

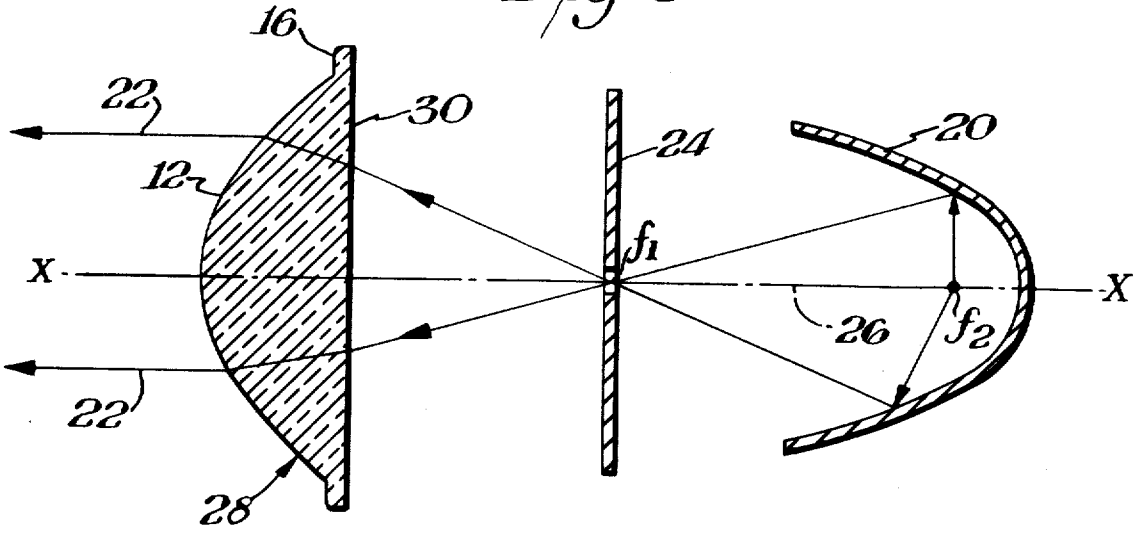


Fig. 6.

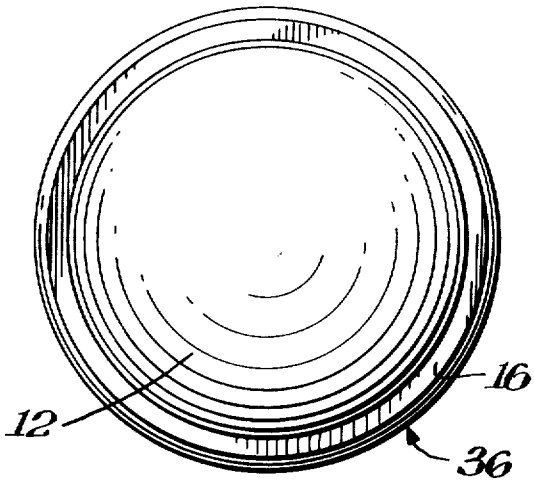


Fig. 7.

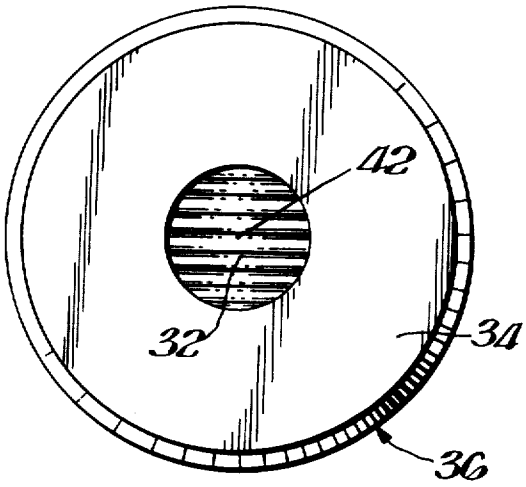


Fig. 8.

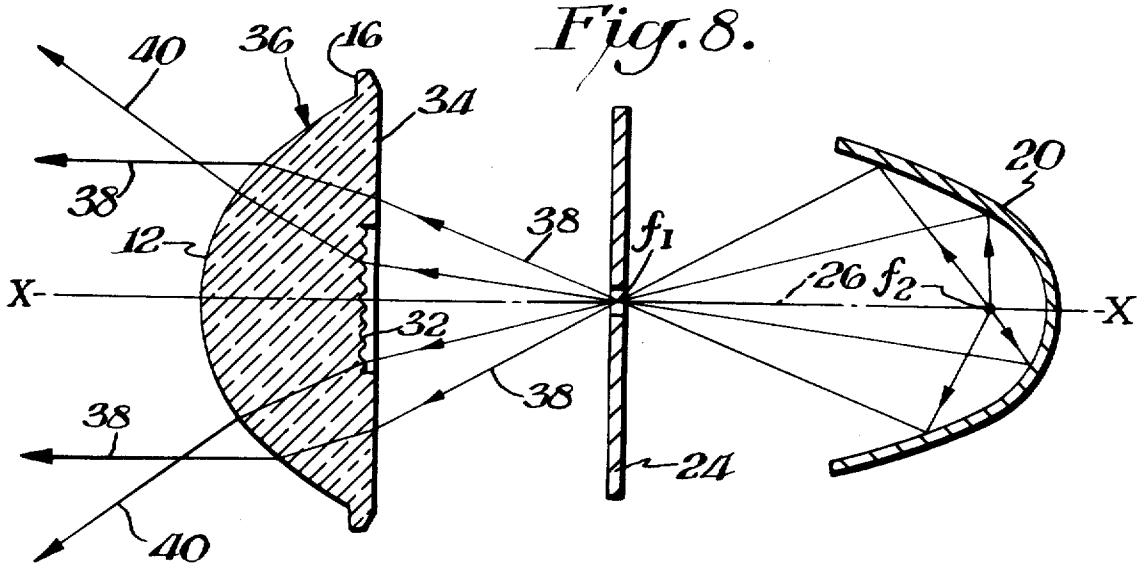


Fig. 9.

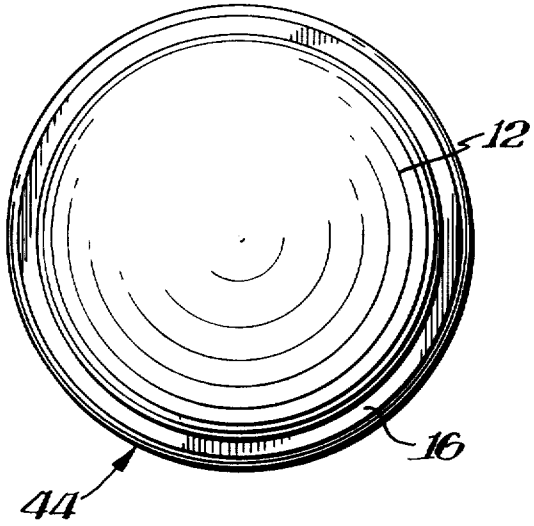


Fig. 10.

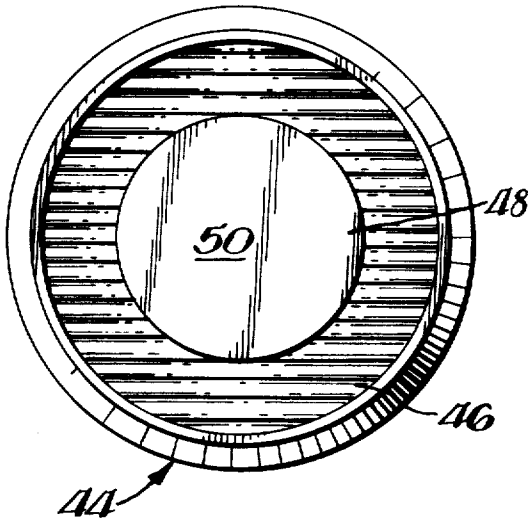


Fig. 11.

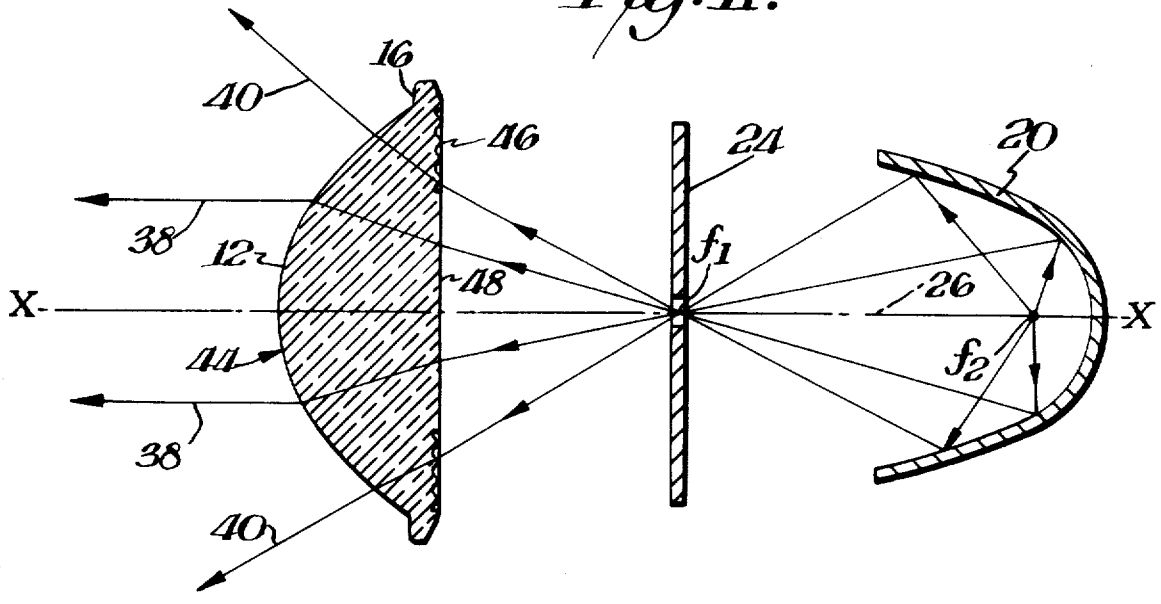


Fig. 12.

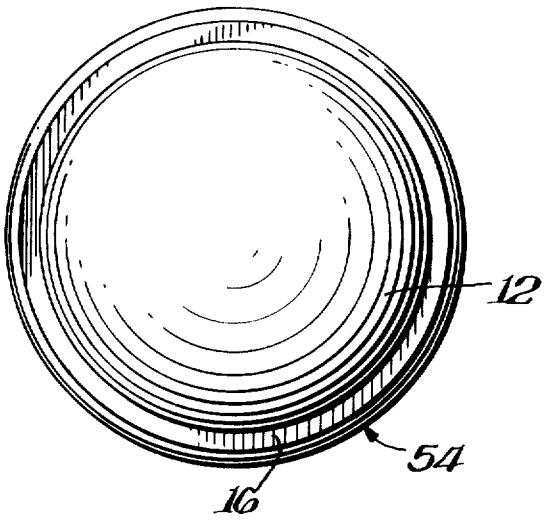


Fig. 13.

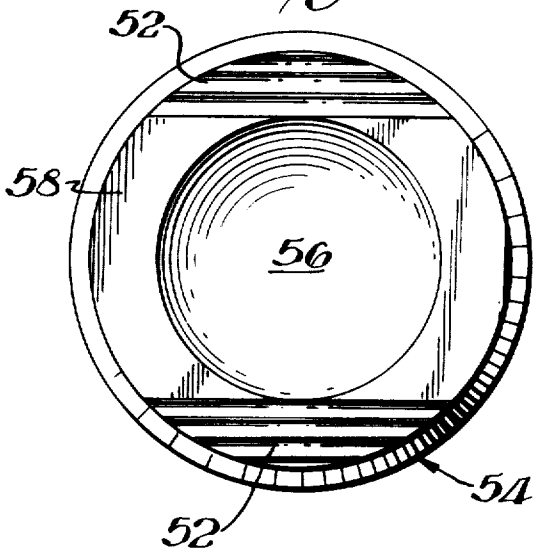


Fig. 14.

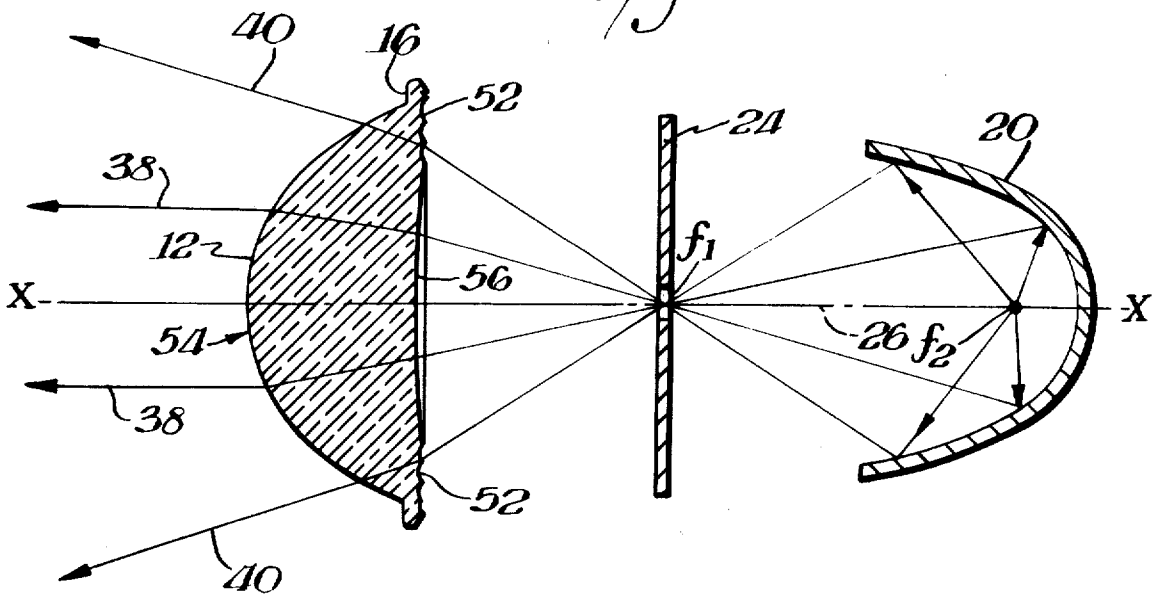


Fig. 15.

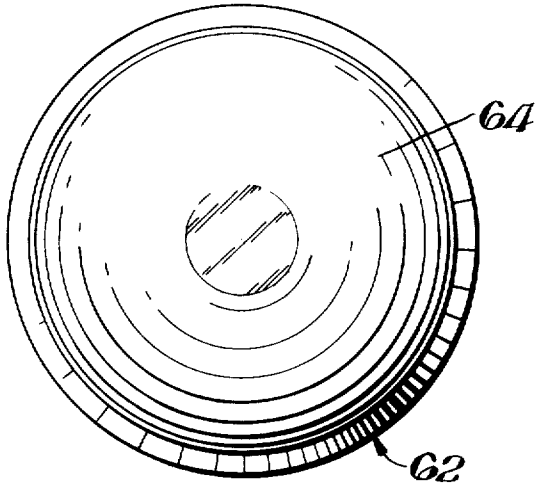


Fig. 16.

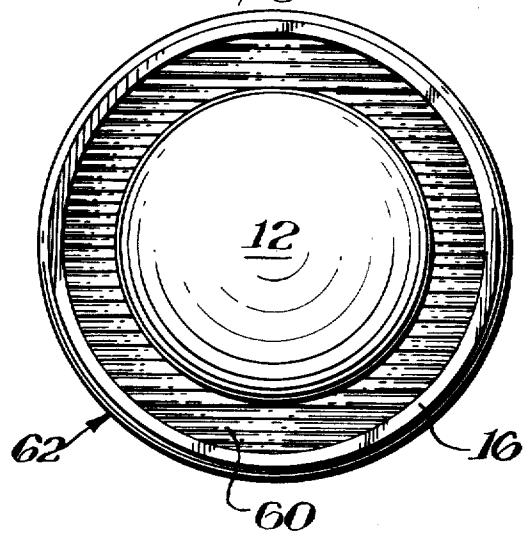


Fig. 17.

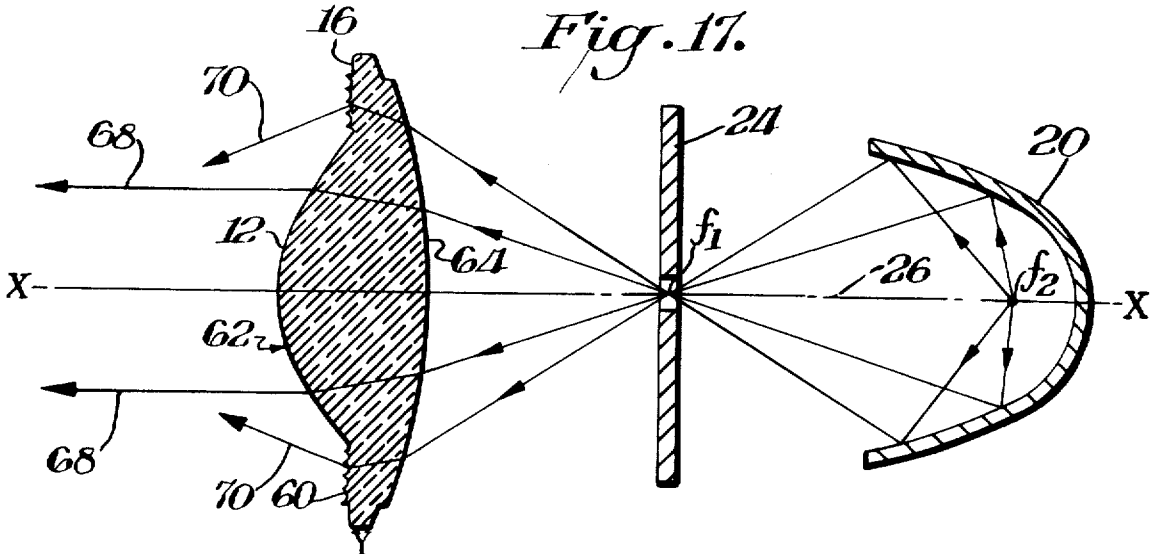


Fig. 18.

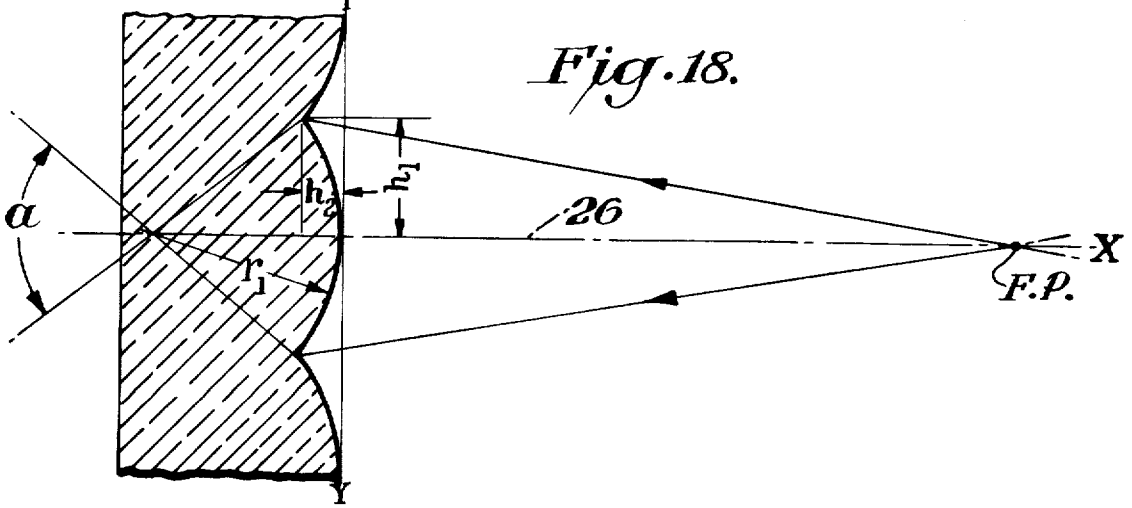


Fig. 19.

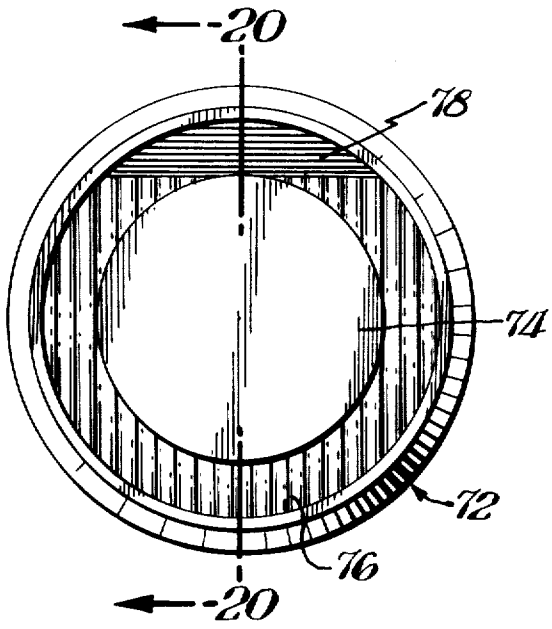


Fig. 20.

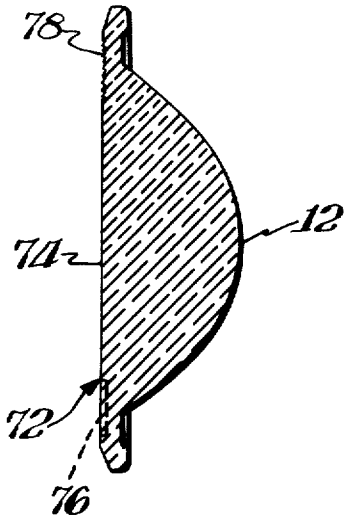


Fig. 21.

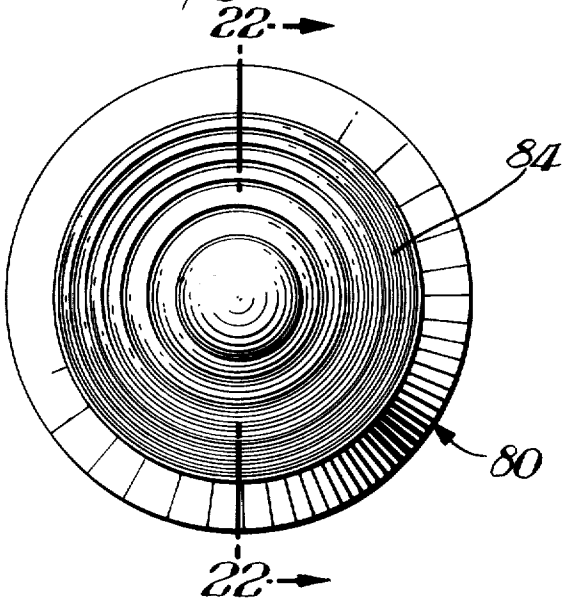
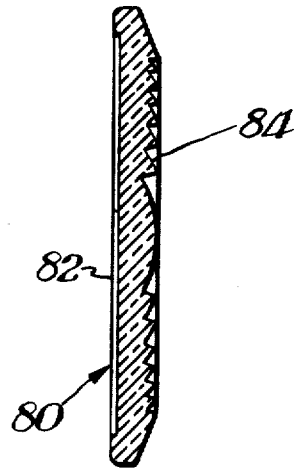


Fig. 22.



ASPHERIC LENS AND METHOD OF MANUFACTURE

BACKGROUND OF INVENTION

Aspheric lenses have been utilized in the prior art as a means of minimizing chromatic aberration. Such lenses, for example, are utilized in the photographic field as exemplified by U. S. Pat. Nos. 2,637,242 and 2,685,821. A further use of such a lens has been in flashlights as exemplified in U. S. Pat. No. 2,282,167. A further early use of such lenses is exemplified by U. S. Pat. No. 1,389,291 which discloses an aplanatic lens incorporated in a vehicle headlight system. This use in a vehicle headlight system has been recently revived wherein the aspheric lens is used as a supplementary source of concentrated light in addition to the high beam and low beam headlights.

The prior art has heretofore constructed such aspheric lenses wherein the back surface is convex in that it is in the form of a spherical segment of constant radius. A difficulty exists with the prior art aspheric lenses in the accurate forming of the aspheric curvature. Where attempts have been made to attain a high degree of accuracy and control over the specific aspheric curvature, the prior art has been forced to increase the time and labor requirements which in turn increases the costs of constructing such aspheric lenses. Because of lack of ready controls the prior art techniques have not been adaptable to mass producing such high quality products.

SUMMARY OF INVENTION

An object of this invention is to provide an aspheric lens with an aspheric curvature having a high degree of accuracy while reducing the time and labor requirements therefore.

A further object of this invention is to provide such an aspheric lens wherein the aspheric curvature may be determined by computer techniques to enable mass production thereof.

A still further object of this invention is to provide an aspheric lens which incorporates flutes for creating auxiliary spread light.

In accordance with this invention an aspheric lens is made with an aspheric curvature on its frontal surface wherein the curvature is defined in the X-Y coordinate system by a particular relationship in accordance with the index of refraction, heighth, focal distance and radius of back surface parameters.

The above indicated formulation can be simplified by eliminating the radius as a variable parameter when the lens is formed with a planar back surface. In further embodiments of this invention auxiliary spread light may be obtained by incorporating parallel flutes in portions of the planar back surface.

In another form of this invention the back surface is made convex as the segment of a sphere while a substantially planar rim surrounds aspheric curvature on the frontal surface. The spread light flutes are then provided in this planar peripheral rim.

THE DRAWINGS

FIG. 1 is a front elevation view of an aspheric lens formed in accordance with this invention;

FIG. 2 is a side elevation view of the convexo-aspheric lens of FIG. 1 schematically incorporated in a vehicle headlight system;

FIG. 3 is a schematic showing of the various parameters utilized in determining the specific aspheric curvature;

FIG. 4 is a front elevation view of a modified form of aspheric lens;

FIG. 5 is a side elevation view showing the ray trace with the plano-aspheric lens of FIG. 4;

FIG. 6 is a front elevation view of a further modified form of aspheric lens;

FIG. 7 is a rear elevation view of the fluted plano-aspheric lens illustrated in FIG. 6;

FIG. 8 is a ray trace of the aspheric lens shown in FIGS. 6–7;

FIG. 9 is a front elevation view of a still further embodiment of this invention;

FIG. 10 is a rear elevation view of the fluted plano-aspheric lens shown in FIG. 9;

FIG. 11 is a ray trace of the aspheric lens shown in FIGS. 9–10;

FIG. 12 is a front elevation view of yet another embodiment of this invention;

FIG. 13 is a rear elevation view of the fluted plano-aspheric lens shown in FIG. 12;

FIG. 14 is a ray trace of the aspheric lens shown in FIGS. 12–13;

FIG. 15 is a rear elevation view of still yet another embodiment of this invention;

FIG. 16 is a front elevation view of the fluted convexo-aspheric lens shown in FIG. 15;

FIG. 17 is a ray trace of the aspheric lens shown in FIGS. 15–16;

FIG. 18 is a schematic illustration of the parameters used for calculating the flute spread for the various fluted aspheric lenses;

FIG. 19 is a rear elevation view of a further modified form of aspheric lens;

FIG. 20 is a cross-sectional view taken through FIG. 19 along the line 20—20;

FIG. 21 is a rear elevation view of still yet another embodiment of this invention; and

FIG. 22 is a cross-sectional view taken through FIG. 21 along the line 22—22.

DETAILED DESCRIPTION

FIGS. 1–2 show a convexo-aspheric lens 10 formed in accordance with this invention and particularly adapted for use in the headlight system of a vehicle. As indicated therein the lens 10 includes an aspheric frontal surface 12 and a convex back surface 14 which is in the segment of a sphere. A peripheral rim 16 adapts the lens 10 to be mounted in a vehicle headlight system which may include for example a housing 18 having any suitable point source of light which may be simulated by utilizing light source f_2 and an elliptical reflector 20 to refocus the light rays 22 to infinity with minimum chromatic aberration. As schematically illustrated in FIG. 2 lens 10 closes the open end of the housing 18. Housing 18 also includes an aperture plate 24 having its aperture at the focal point f_1 with lens 10 being symetrically arranged on the optical axis 26 of the headlight system. The paths of light passing through lens 10 are parallel to the optical axis 26 to an

unusually high degree of accuracy thereby producing a highly concentrated light beam which is particularly effective for lighting a roadway. The housing **18** and its various components are connected in the headlight system as an auxiliary light or as a replacement for either the conventional high or low beams. Any suitable glass composition such as a borosilicate glass may be utilized with this invention while still attaining the high degree of accuracy. It is to be understood, of course, that although the lens **10** is described with particular reference to use in a vehicle other uses are also possible within the scope of this invention where there is a requirement for a concentrated light beam having minimal chromatic aberration and wherein the paths in the light beam are parallel to the optical axis.

In accordance with this invention frontal surface **12** is formed with an aspheric curvature which may be accurately reproduced and controlled through a series of mathematical calculations which particularly lend themselves to the use of computer techniques thereby vastly reducing the time and labor requirements. The formulas used for determining the aspheric curvature are particularly noteworthy in that the many parameters can be varied while still producing a highly accurate relatively low cost mass produced lens with very good light control properties. The parameters which can be varied in accordance with this invention are the radius of back curve, the focal distance to the face of the back curve, the refractive index of the glass, the diameter of the lens and the thickness of the lens.

FIG. **3** schematically illustrates the various parameters which must be considered in forming the lens **10** and which are taken into account in accurately producing and reproducing the aspheric curvature on the frontal surface **12**. As is readily apparent in FIG. **3** the aspheric curvature is a smooth curve with constantly changing radius. As indicated in FIG. **3** the focal point FP lies upon the optical axis **26**. This axis is also designated as the X—X axis of the X-Y coordinate system. Where the optical axis intersects the face of the back curve of the convex back surface and tangent thereto is the Y—Y axis of the X-Y coordinate system. The heighth of the ray of light is indicated as H_1 and corresponds to the Y distance at which the ray of light intersects the Y axis. The various points on the aspheric frontal surface **12** each have a corresponding X and Y value in accordance with the X-Y coordinate system. As later used in the formulas for defining this curvature these X and Y values are indicated as X_1 and Y_1 which represents the variable X and Y coordinates. The maximum thickness of the lens is illustrated in FIG. **3** as T_1 while F_1 represents the focal distance of the focal point FP to the back surface of the lens. K_1 designates the limit of active surface. It is not necessary to continue the aspheric curvature beyond K_1 and thus the remaining portion **16** of the frontal surface may be used for mounting the lens **10** in any suitable housing. The lower computer limit of the X value of K_1 is indicated as L_1 while the upper limit is designated as L_2. The radius of the convex back surface is designated as R_1.

The various points on the aspheric curvature are defined in the X-Y coordinate system by the variable B_1 being equal to $\{X_1[\mathrm{COT}(A_6)]+Y_1-J_1+D_1[\mathrm{TAN}(A_4)]\}/[\mathrm{TAN}(A_4)+\mathrm{COT}(A_6)]$ and the corresponding C_1 being equal to $J_1 + (B_1-D_1)[\mathrm{TAN}(A_4)]$. These formulas represent a shorthand method of computing the aspheric curvature and the designations therein are derived from the following mathematical calculations wherein N_1 is the index of refraction and other parameters have their designations in FIG. **3**; B_1 is the X value of the point being calculated and C_1 is its corresponding Y valve; and wherein X_1 is the X value of the previous calculated point, while Y_1 is the Y value of the previous calculated point and wherein: $G_1 = 4(2R_1F_1 + F_1^2)$; $A_1 = \mathrm{ATN}(H_1/F_1)$; $E_1 = 2(R_1 + F_1) \cdot [\mathrm{COS}(A_1)]$; $E_2 = E_1^2 - G_1$; $M_5 = (E_1 - \sqrt{E_2}) \cdot (0.5)$; $J_1 = M_5 [\mathrm{SIN}(A_1)]$; $D_1 = (J_1 - H_1) \cdot [\mathrm{TAN}(A_1)]$; $A_2 = \mathrm{ASN}(J_1/R_1)$; $A_7 = A_1 + A_2$; $A_3 = \mathrm{ASN}[\mathrm{SIN}(A_7)/N_1]$; $A_4 = A_3 - A_2$; $A_5 = \mathrm{ATN}\{\mathrm{SIN}(A_4)/[N_1 - \mathrm{COS}(A_4)]\}$; and $A_6 = A_4 + A_5$.

In the practical application of these formulas, rough limits L_4 and L_5 are set up for computer usage which in turn sets up rough limits that confine the point K_1 as far as X values are concerned. This locates the limits that the X value of K_1 must fall within, in relation to the X-Y axis intersection located tangent to the back spherical radius. Then the computer is made to refine the calculated curve by use of the fine limits L_1 and L_2 which tie down the X value of point K_1 to any degree of precision desired.

It is understood that for any particular computer run, other variable parameters such as R_1, F_1, N_1, T_1 are given numerical values. This process of calculation of aspheric curves allows one to choose an N_1 (Index of Refraction) of a commercially available glass for the design of aspheric lens with a high degree of accuracy that can be mass produced from conventional glasses.

By utilizing conventional computer techniques and selecting an X dimension with sufficient significant numbers it is, therefore, possible to quickly obtain an unusually high degree of accuracy of for example 10^{-8} with respect to the emitted rays of light being parallel to the optical axis. It is even possible through computer techniques with the inventive manner of forming the aspheric curvature to obtain a degree of accuracy as fine as 10^{-15}.

The aspheric lens illustrated in FIGS. **1–2** is somewhat similar to the conventional aspheric lens in the utilization of a convexo back surface but differs from the conventional lens of course in the specific curvature and the manner of quickly and accurately determining the curvature. FIGS. **4–5**, however, represent a more radical departure from the conventional aspheric lens. As illustrated in FIGS. **4–5** the back surface is made planar. This not only gives more flexibility in thickness requirements (since the back surface is flat rather than convex) but also simplifies the formulas for computing the aspheric curvature. In this respect the radius R_1 is no longer a factor. With the radius thus eliminated as a variable the ultimate formulas for defining X and Y are reduced to $B_1 = \{(Y_1-H_1)[\mathrm{TAN}(A_4)] + X_1\}/\{[\mathrm{TAN}(A_2)][\mathrm{TAN}(A_4)] + 1\}$ and $C_1 = B_1 [\mathrm{TAN}(A_2)] + H_1$; wherein $A_1 = \mathrm{ATN}(H_1/F_1)$; $A_2 = \mathrm{ASN}[\mathrm{SIN}(A_1)/N_1]$; $A_3 = \mathrm{ATN}\{\mathrm{SIN}(A_2)/[N_1 - \mathrm{COS}(A_2)]\}$; $A_4 = \mathrm{ASN}\{N_1 \cdot [\mathrm{SIN}(A_3)]\}$; $B_1 = X$ value of point being calculated; $C_1 = Y$ value of point being calculated; $X_1 = X$ value of previous calculated point; and $Y_1 = Y$ value of previous calculated point. It is to be understood that the formulas indicated above are actually the same as the formulas previously described with respect to the convexo-aspheric lens but appear more

simplified with the radius R_1 being removed as a parameter.

FIG. 5 illustrates the ray trace obtained with the plano-aspheric lens 28 of FIG. 4 wherein the frontal surface includes the aspheric curvature 12 and the back surface is planar as indicated at 30. As in the case of the convexo-aspheric lens 10 the paths of light limited therefrom are parallel to the optical axis 26 to the same unusually high degree of accuracy. It is further noted that with the ray trace of FIG. 5 as well as the various other ray traces of FIGS. 8, 11, 14 and 17 the aspheric lens is shown in cross-section along a section line taken through the center of the lens.

The aspheric lenses 10 and 28 illustrated in FIGS. 1 and 4 are highly effective in producing a concentrated light beam wherein all of the rays of light are parallel to the optical axis with minimal chromatic aberration. For certain uses, however, as for example automobile headlights it is desirable to provide an additional spread light which is less concentrated than the main concentrated parallel beam but sufficiently lights up the surroundings to increase the scope of vision of the driver rather than limiting it to the main concentrated beam of light produced by the aspheric curvature. Accordingly, this invention provides means for creating this spread light. In general this means comprises flutes incorporated in the lens to create the auxiliary light. As later described the flutes are parallel with each flute being rounded or smooth and having for example a cross-section which is a spherical segment.

FIGS. 6–8 show one modification which incorporates flutes 32 recessed in the planar surface 34 of the plano-aspheric lens 36. FIG. 8 illustrates the ray trace resulting from this arrangement. As indicated therein the concentrated light beam is produced from the rays of light 38 passing through the planar portion 34 of the lens 36 while a divergent less concentrated light beam is produced from the paths of light 40 passing through the flutes 32. In the embodiment illustrated in FIGS. 6–8 the flutes are disposed in a central area 42 of the planar surface 34 wherein the center of area 42 lies on the optical axis 26. Although the flutes are illustrated as being recessed the flutes may be substantially co-planar with surface 34 or may extend outwardly from surface 34. Further, although each flute is illustrated as being a mirror image of its adjacent flutes all of the flutes may be convex or all of the flutes may be concave.

FIGS. 9–11 show another modification of this invention wherein the plano-aspheric lens 44 includes parallel flutes 46 arranged in a ring shaped area at the periphery of planar surface 48. As shown in FIG. 10 the planar surface 48 includes a circular area 50 which is free of flutes and which lies on the optical axis 26.

FIGS. 12–14 show still another form of this invention wherein the flutes 52 are incorporated in spaced parallel portions at the periphery of the plano-aspheric lens 54. In the form illustrated in this embodiment the central area 56 of the substantially planar surface 58 is slightly concave.

FIGS. 15–17 show still another form of this invention wherein the flutes 60 are incorporated in a convexo-aspheric lens 62. Lens 62 includes a convex back surface 64 with the aspheric curvature 12 on its frontal surface. The flutes 60 are disposed in a ring shaped substantially planar surface 66 around aspheric curvature 12. FIG. 17 illustrates the ray trace produced with lens 62 wherein the concentrated parallel light beam is obtained from the rays 68 passing through the aspheric curvature 12, while the spread light which is initially convergent is produced from the rays 70 passing through flutes 60.

It is ordinarily undesirable to have flutes of the exit side of a headlight lens since these irregularities may become dirty, damaged, or wet which would lead to distortion. Since, however, the flutes 60 are smooth curvatures the likelihood of distortion is minimized. Moreover, the spherical cross-section of each flute assures a uniform spread of light.

FIG. 18 illustrates the manner of computing the flute spread. Since the intensity of the light beam is not as critical with the spread light, it is assumed that each flute is symetrically arranged with respect to the optical axis 26 having its focal point FP lying on the X—X axis of an X-Y coordinate system. The Y-Y axis is disposed tangential to the flute outer surface at the intersection of the optical axis and the back surface thereof. The half heighth of a flute is designated as h_1 while the heighth of cord or maximum distance the flute extends into the lens is designated as h_2. Each flute has a cross section which is the segment of a sphere having a radius indicated as r_1. The angle in degrees of spread is designated in FIG. 18 as "a." The flute spread may then be calculated as $r_1 = h_1/\mathrm{SIN}(A_4)$ and

$$h_2 = \{r_1 - 0.5\sqrt{[4(r_1)^2 - (2h_1)^2]}\}$$

wherein $a_1 = a\pi/360$; $a_2 = \mathrm{ASN}[\mathrm{SIN}(a_1)/N_1]$; $a_3 = \mathrm{ATN}\{\mathrm{SIN}(a_2)/[N_1 - \mathrm{COS}(a_2)]\}$; $a_4 = a_2 + a_3$; and N_1 = the index of refraction. With the above defined relationship the flutes are formed to provide any specified amount and angular spread of the spread light. The parameters that may be varied include the indicies of refraction, thickness of lens, diameter of lens, focal distance from FP to the back surface of lens, amount of spread light desired, angular spread desired and width of flutes.

FIGS. 19–20 show a further modified form of this invention wherein a plano-aspheric lens 72 is provided similar to the lens 44 shown in FIGS. 9–11. The lens 72, however, includes provision to create a convergent spread light at the upper portion of the lens so that the spread light will not shine into the eyes of the oncoming driver. Thus the planar surface 74 includes two types of flutes. One type of flute is the parallel spherical segmental flute 76 which creates a divergent spread light. At the uppermost portion of the planar back surface, however, fresnel type parallel flutes 78 are provided. Unlike conventional fresnel lenses, the flutes 78 form in cross-section, portions of a continuous aspheric curvature, rather than the conventional spherical curvature or prism type lens. This aspheric curvature would be formed in accordance with the manner of computing the aspheric curvature described in connection with FIG. 3.

FIGS. 21–22 show still another form of aspheric lens. As indicated therein a fresnel type surface is formed on the rear, rather than the frontal surface of the lens 80. The frontal surface 82 is made planar. The fresnel surface 84, unlike conventional fresnel surface, is formed wherein the individual segments comprise portions of an aspheric curvature as previously discussed. By forming the fresnel surface 84 at the rear, the light entering the lens 80 is made parallel to the optical axis within

the lens and remains parallel when emerging therefrom since the frontal surface **82** is planar. This embodiment is particularly advantageous since it renders the emerging path of light independent of its environment beyond the frontal surface **82**. Lens **80** is thus equally adapted for use underwater, in air or any other environment, regardless of the index of refraction of the environment.

What is claimed is:

1. An aspheric lens having a frontal surface and a back surface, said frontal surface having an aspheric curvature which produces paths of light parallel to its optical axis from the rays of light passing therethrough with the emitted light being concentrated and having minimal chromatic aberration, said curvature being defined in the X-Y coordinate system by B_1 being equal to $\{X_1[\mathrm{COT}(A_6)] + Y_1 - J_1 + D_1[\mathrm{TAN}(A_4)]\}/[\mathrm{TAN}(A_4) + \mathrm{COT}(A_6)]$ and C_1 being equal to $J_1 + (B_1 - D_1)[\mathrm{TAN}(A_4)]$ wherein N_1 is the index of refraction, H_1 is the heighth, X_1 is the X value of the previous calculated point and Y_1 is Y value of the previous calculated point, F_1 is the focal distance from the focal point to said back surface, R_1 is the radius of the back surface, $G_1 = 4(2R_1F_1 + F_1^2)$, $A_1 = \mathrm{ATN}(H_1/F_1)$, $E_1 = 2(R_1 + F_1)[A_1)]$, $E_2 = E_1^2 - G_1$, $M_5 = (E_1 - \sqrt{E_2})(0.5)$, $J_1 = M_5[\mathrm{SIN}(A_1)]$, $D_1 = (J_1 - H_1)[\mathrm{TAN}(A_1)]$, $A_2 = \mathrm{ASN}(J_1/r_1)$, $A_7 = A_1 + A_2$, $A_3 = \mathrm{ASN}[\mathrm{SIN}(A_7)/N_1]$, $A_4 = A_3 - A_2$, $A_5 = \mathrm{ATN}\{\mathrm{SIN}(A_4)/[N_1 - \mathrm{COS}(A_4)]\}$, $A_6 = A_4 + A_5$, $B_1 = X$ value of point being calculated; and $C_1 = Y$ value of point being calculated.

2. An aspheric lens as set forth in claim **1** wherein said back surface is convex being the segment of a sphere.

3. An aspheric lens as set forth in claim **2** wherein said frontal surface includes a peripheral substantially planar rim around said aspheric curvature, and said peripheral rim having parallel flutes.

4. An aspheric lens as set forth in claim **1** wherein said frontal surface includes a peripheral substantially planar rim around said aspheric curvature, and said peripheral rim having parallel flutes.

5. An aspheric lens as set forth in claim **1** wherein said back surface is planar.

6. An aspheric lens as set forth in claim **5** wherein a portion of said back surface has parallel flutes to create an auxiliary spread light pattern.

7. An aspheric lens as set forth in claim **6** wherein said flutes are disposed in a circular area having its center on said optical axis of said lens.

8. An aspheric lens as set forth in claim **6** wherein said back surface includes a circular area having its center on said optical axis of said lens, said circular area being free of flutes, a peripheral ring shaped area being around said central area, and said flutes being in said ring shaped area.

9. An aspheric lens as set forth in claim **6** wherein said back surface includes a central area centered on said optical axis of said lens, and said flutes being in parallel portions adjacent to and on two sides of said central area.

10. An aspheric lens as set forth in claim **6** wherein each flute is defined in cross-section by a radius $r_1 = h_1/SIN(A_4)$ and a chord heighth

$$h_2 = [r_1 - 0.5\sqrt{4(r_1)^2 - (2h_1)^2}],$$

wherein N_1 is the index of refraction, h_1 is the half heighth of the flute, a is the degrees spread, $a_1 = a\pi/360$, $a_2 = \mathrm{ASN}[\mathrm{SIN}(a_1)/N_1]$, $a_3 = \mathrm{ATN}[\mathrm{SIN}(a_2)/N_1 - \mathrm{COS}(a_2)]$, and $a_4 = a_2 + a_3$.

11. An aspheric lens as set forth in claim **1** in combination therewith, a housing having an open end, a point source of light in said housing, said lens closing said open end of said housing, and said housing being connected in the headlight system of a vehicle.

* * * * *