

The Truth About Base Curves

By

***Phernell Walker, II, A.B.O.M
V.P.of Retail Development & Education,
Budget Optical's of America, Inc.***

**Submitted for completion of
The American Board of Opticianry
Master in Ophthalmic Optics Program**

INTRODUCTION

The Dictionary of Visual Science defines the base curve as *1*) In ophthalmic lenses, the standard or reference surface in a lens or series of lenses, classified by (varying) nomenclature as having a given base curve.

2) In a toric surface, the curve of least power¹. Although both definitions are correct, the optical industry has adopted the first definition to describe the base curve. In simpler terms, the base curve is the single front surface of a lens, measured in diopters over the distance portion of a lens.

Opticians should consider the patient's current lens material's true surface power and the new prescription, when designing new lenses. Otherwise, a resulting magnification change, increased marginal astigmatism and induced aniseikonic symptoms could occur. Manufacturers offer multiple base curves and refractive indices. Calculating the most appropriate base curve goes beyond the common myth, “keep the same base curve” and standardized base curve charts.

In this paper we will explore both the implications for visual acuity, and the practical applications of proper base curve selection.

¹ D. Cline, B.S., O.D., H.W. Hofster, O.D., Ph.D., J.R. Griffin, O.D., M.S.E.D., Dictionary of Visual Science, Third Edition, 1980, pp. 150-151

HISTORICAL PERSPECTIVE

Correcting refractive errors (Myopia, Hyperopia, and Astigmatism) dates back to about 1000 A.D. In the beginning, lenses were simply biconvex (both surfaces are convex) or biconcave (both surfaces are concave). These lenses corrected refractive errors, but also produced aberrations. Aberration is the failure of a mirror or lens to bring light rays to a single focal point, producing a defective image.

The first group of aberrations are aberrations produced as a result of the lens material and/or the lens form. The first group of aberrations includes transverse chromatic aberration, also known as chromatism or color distortion¹ⁿ. All ophthalmic lenses are composed of a series of prisms. Not only will prisms refract light, but a prism will disperse light into its natural component colors which consist of Red, Orange, Yellow, Green, Blue, Indigo and Violet (Roy G BIV)³. Chromatism is present in all lenses and is measurable away from the optical center. The amount of chromatic aberration in a lens is described as the Abbe Value or V value. The Abbe value is the reciprocal of the lens material's V value. Abbe values will generally range between 20 and 60. Higher abbe value materials will disperse white light into its natural component colors less and conversely the lower abbe value materials will disperse white light more⁴. Examples are listed below:

| <u>Lens Type</u> | <u>Refractive Index</u> | <u>Abbe Value</u> |
|------------------|-------------------------|-------------------|
| CR-39 | 1.498n | 58 |
| Crown Glass | 1.523n | 58 |
| H.I. 54 | 1.54n | 47 |
| Polycarbonate | 1.59n | 31 |
| H.I. 60 | 1.60n | 37 |

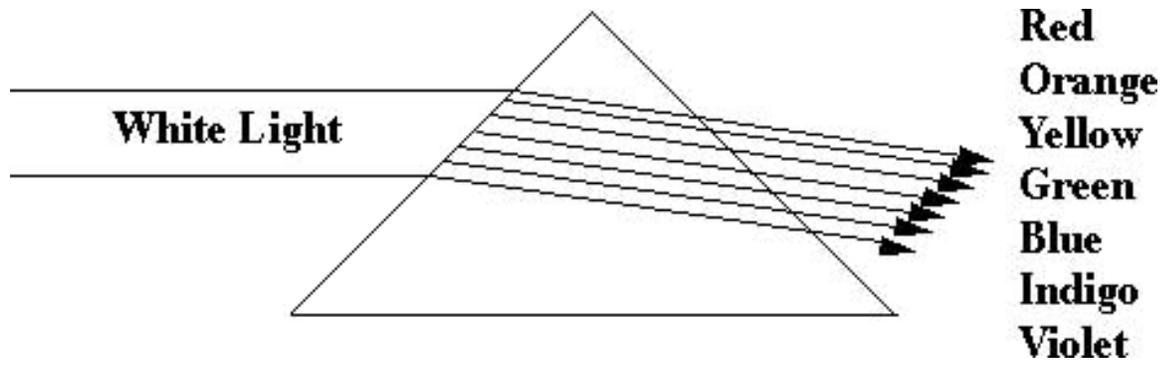
The viewer sees chromatic aberration as color fringes around objects (Fig. 1).

² M. Jalie, F.A.D.O., *The Principles of Ophthalmic Lenses*, Third Edition, 1990, pp. 366-367

³ M. Di Santo, A.B.O.M., *Technical Options for Professional Services*, 1993, p. 205

⁴ J. Bruneni, *Perspectives on Lenses*, Fifth Annual Edition, 1995, pp. 3-4

Figure 1



In 1804, William H. Wollaston used a non-mathematical approach to reduce marginal astigmatism by examining the image formation by different forms of lenses. The result was the "Periscopic" lens, a lens form in which oblique rays have the same amount of refraction on each surface⁵.

In 1843, the Petzval surface was introduced. To correct marginal astigmatism the surface had a radius of curvature equivalent to the product of the lens' focal length and refractive index. $RPS = \text{Index of refraction} * \text{Focal length}$. This focused the sagittal and tangential axes at the same point⁶.

In 1855-56, Ludwig von Seidel published five independent types of aberrations. The five aberrations are:

- SI Spherical aberration
- SII Coma
- SIII Marginal Astigmatism
- SIV Curvature of field
- SV Distortion

Spherical aberration occurs when broad peripheral light rays focus at a different point than paraxial rays (Fig. 2). Considering the pupil is between 3 to 5 mm. in diameter however, spherical aberration is not important since only a small portion of the lens is used at a given time⁷.

Coma occurs when broad light rays pass obliquely through a lens. The axial light ray does not intersect at the same point as the peripheral rays (Fig. 3). Coma creates a comet like image also known as a comatic flare. Coma is given little attention by lens designers, since the pupil's small diameter also alleviates the peripheral rays⁸.

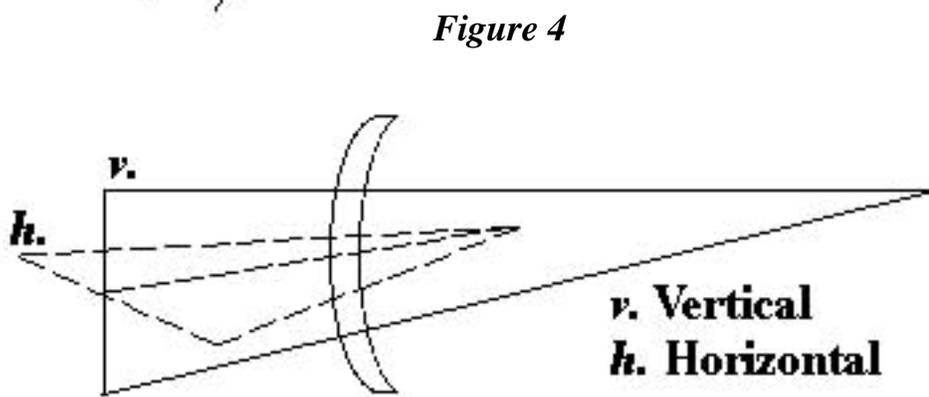
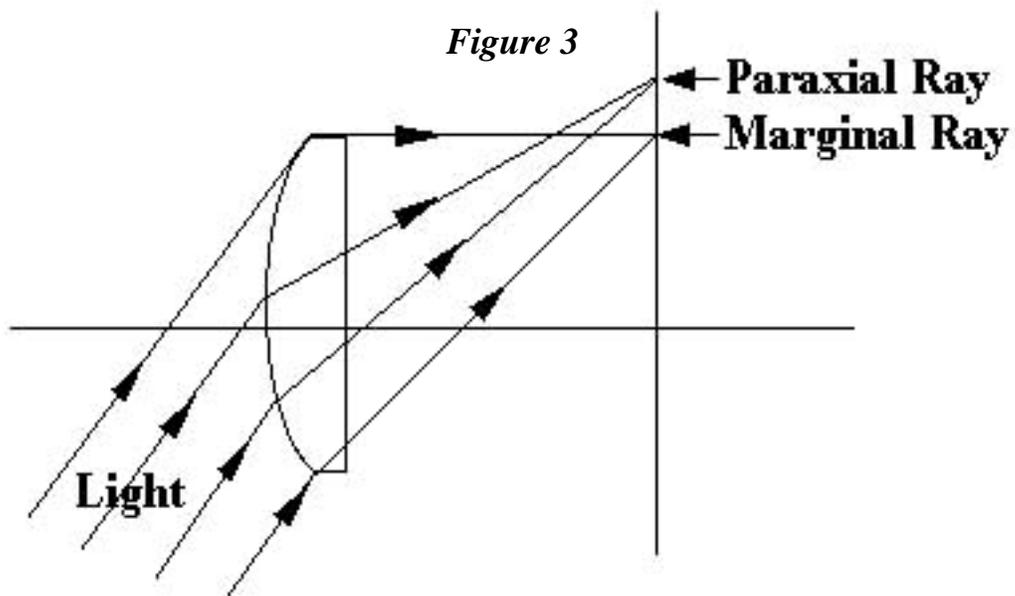
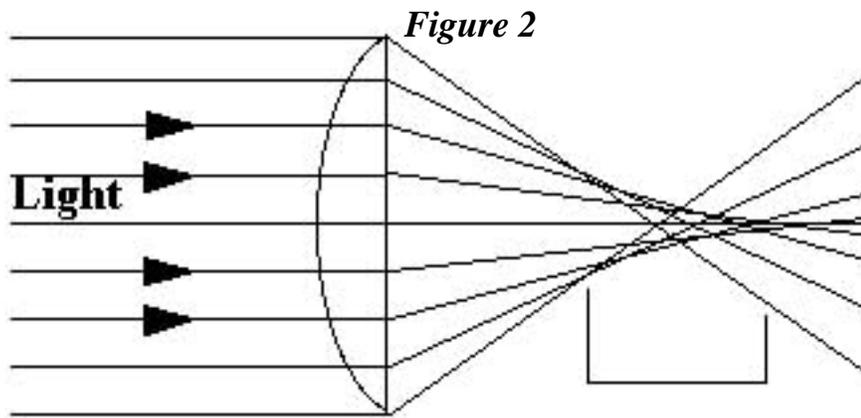
Marginal astigmatism is the result of narrow parallel light rays that pass obliquely through a lens. The oblique rays in the opposing meridians focus at two independent locations. The difference between the two focal points creates the amount of astigmatic error produced (Fig. 4). If the error is inconsequential the brain will ignore the image. Since marginal astigmatism involves narrow light rays, the pupil's 3 to 5 mm. diameter does not limit the entrance of the oblique rays into the eye. Consequently, marginal astigmatism has the greatest effect in the reduction of image quality. Since marginal astigmatism has the most effect in the reduction of image quality, many lens

⁵ M. Jalie, F.A.D.O., The Principles of Ophthalmic Lenses, Third Edition, 1990, pp. 436-437

⁶ M. Jalie, F.A.D.O., The Principles of Ophthalmic Lenses, Third Edition, 1990, p. 437

⁷ W.H.A. Fincham, F.I. McPhil, M.H. Freeman, B.S., Ph.D., Optics, 9th Edition, 1980, pp. 380-393

⁸ M. Jalie, F.A.D.O., The Principles of Ophthalmic Lenses, Third Edition, 1990, pp. 381-383



designs have evolved in the hopes of reducing this aberration. Hyperopic patients can accommodate and neutralize marginal astigmatism, but myopic patients cannot. Consequently, myopes are more likely to notice changes in their base curves⁹.

Curvature of field is the inherent curvature of the image in the image plane and is a residual of a curved lens (Fig. 5). An unequal vertex distance at the periphery causes curvature of field. Since both the eye and a lens have independent constant focal plane radius' which oppose each other, the result is a blur at the periphery of the lens¹⁰.

Distortion occurs as a result of unequal magnification across a high powered lens. Plus lenses produce more magnification on the corners of a square than the sides; this phenomenon is known as pincushion distortion (Fig. 6). Minus lenses produce more minification for the corners of a square than the sides; this is known as barrel distortion (Fig. 7)¹¹.

In 1867, a variation of the "Periscopic" lens was introduced by the German firm of Nitsche and Gunther. Minus lenses used a +1.25 base curve and plus lenses had a -1.25 ocular curve¹².

By the end of the nineteenth century, third order equations for point focal lenses were introduced. Dr. Marius Tscherning adopted the theory that there are two lens forms for each dioptric power, thus freeing any oblique astigmatism. A Parisian oculist, F. Ostwalt, first presented this theory in 1898. Using this theory, Dr. Tscherning developed methods to further correct marginal astigmatism. The results of his work produced equations that, when plotted in a graph, produce a curve in the form of an ellipse. In 1904, Dr. Tscherning published his work and these ellipses became known as the Tscherning ellipse. This new lens design enabled the optician to select from a multiple of base curves as opposed to previous mono-base curve designs. Having a series of base curves allows the optician to control marginal astigmatic error when designing various prescriptions. Today's patients are self conscious about the thickness and weight of their lenses. Although flatter base curves will produce thinner lenses flatter curves will accentuate marginal astigmatism¹³.

⁹ W.H.A. Fincham, F.I. McPhil, M.H. Freeman, B.S., Ph.D., *Optics*, 9th Edition, 1980, pp. 395-401

¹⁰ M. Di Santo, A.B.O.M., *Technical Options for Professional Services*, 1993, p. 207

¹¹ M. Jalie, F.A.D.O., *The Principles of Ophthalmic Lenses*, Third Edition, 1990, pp. 400-402

¹² M. Jalie, F.A.D.O., *The Principles of Ophthalmic Lenses*, Third Edition, 1990, p. 437

¹³ Frank Ervin, O.D., *The Masters Review*, 1994, pp. 5-9.

Figure 5

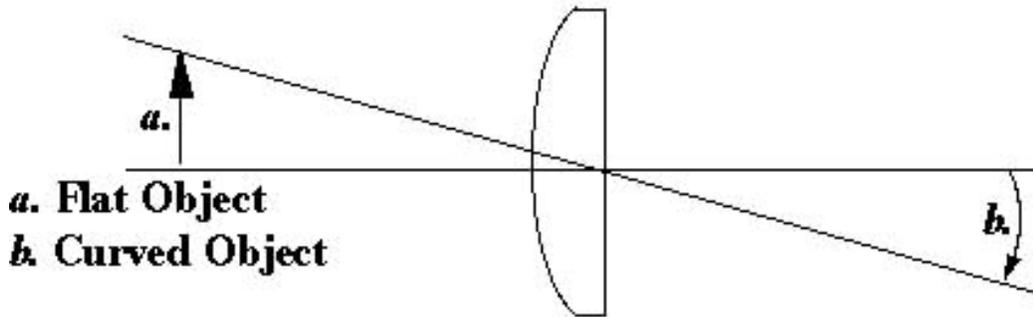


Figure 6

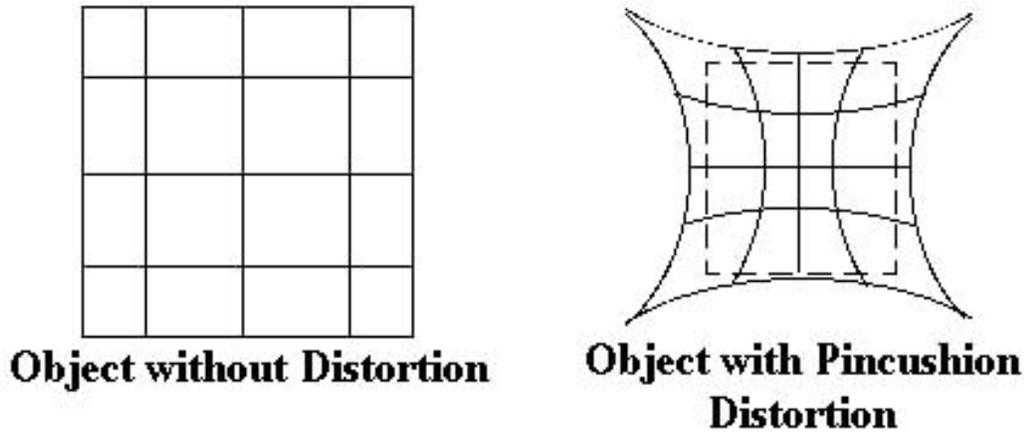
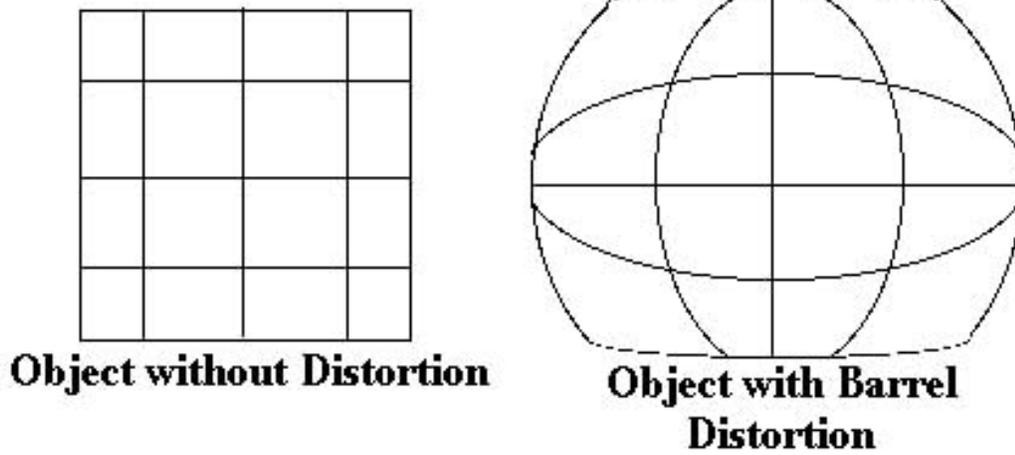


Figure 7



PRACTICAL ASPECTS OF BASE CURVE SELECTION

The base curve is the basis for all other curves on the lens. Curvature is responsible for the lens' dioptric power. By algebraically adding the base curve to the ocular curve (back curve), the dioptric power can be achieved. Any series of curves can produce dioptric power. Unfortunately the wrong combination of curves will increase a combination of aberrations¹⁴.

Laboratories stock semi-finished and finished lenses. Semi-finished lenses, also known as lens blanks, have the front surface polished and need to have the remaining prescription ground into the back surface of the lens. Once a semi-finished blank's back surface is polished with the appropriate curves, the lens becomes a finished lens¹⁵. Depending on the lab, finished lenses can be used for single vision prescriptions up to plus or minus six diopters. Base curves can range from plano (zero surface power) up to plus 16 diopters, and even some minus values. The lower the number the flatter the base curve and conversely the higher the number the steeper the base curve. As the blank size increases, the radius of curvature increases. A long radius of curvature will produce a flatter base curve and plate height (as the lens rests on a flat surface the height from the surface to the lens). Best-form lenses are designed with the concept of keeping the ocular curve no steeper than seven diopters or flatter than four diopters¹⁶.

The axiom, "patients become adapted to a particular base curve" is not completely accurate. A more accurate statement would be, "patients become acclimated to the combined curves and the vertex of the ocular curve"¹⁷.

Patients also notice changes in magnification. Noticeable effects in magnification occur if the base curve is altered one diopter or more. Placing a patient in a base curve which is too steep will cause objects to appear larger, distorted and increase roving ring scotoma (lens defect which decreases the viewers visual field). Of course, placing a patient in a base curve that is too flat will cause objects to appear smaller but may not affect the patient's acuity¹⁸.

¹⁴ M. Di Santo, A.B.O.M., Technical Options for Professional Services, 1993, pp. 50-52

¹⁵ M. Di Santo, A.B.O.M., Technical Options for Professional Services, 1993, pp. 22-26

¹⁶ M. Di Santo, A.B.O.M., Technical Options for Professional Services, 1993, p. 50

¹⁷ M. Di Santo, A.B.O.M., Technical Options for Professional Services, 1993, p. 52

¹⁸ Randall Smith, A.B.O.M., Review Course for the Master's Optician Examination, 1996

When designing lenses for patients with anisometropia (a condition where the refractive error of one eye is different from the other eye by one diopter or more in the primary meridian) do not use standardized base curve charts. Standardized base curve charts are designed on a monocular principle. In anisometric patients however, this is not practical since both eyes are used in unison. A large difference between each base curve may induce aniseikonia. Aniseikonia occurs when the ocular image of an object as seen by one eye differs in size or shape from that seen by the other eye. In extreme cases, the two images can not be fused into a single impression. A 3 to 5 percent difference in magnification results in loss of binocularity, yet surprisingly fusion can still be present. The difference becomes clinically significant at 5 percent or greater. Above 5 percent, the patient losses binocularity and diplopia exists¹⁹. The following example shows how aniseikonic symptoms could be inadvertently induced:

Patient prescription

O.D. +1.25 D.S.
O.S. +3.50 D.S.

Lens material CR-39, 1.498n

Vertex distance 12mm.

A 72mm finished lens blanks would have the following base

curves and thickness: O.D. 6 b.c., 3.1 mm. c.t.
 O.S. 8 b.c., 5.9mm. c.t.

The difference in magnification can be calculated using the following formula:

$$\text{Percentage} = (M_t - 1)100. \quad M_t = M_s \times M_p$$

$$M_s = 1 / (1 - (t)(D_1)) / n$$

M_s = Magnification due to shape factor

D_1 = Front curve in diopters

t = Center thickness in meters

n = Lens material's refractive index

$$M_p = 1 / (1 - D_v(h))$$

¹⁹ M. Polasky, O.D., Aniseikonia Cookbook, 1974, pp. 2-5.

M_p = Magnification due to power factor

D_v = Lens' dioptric power

h = Vertex distance in meters

O.D. $M_s = 1/(1 - (t)(D_1)/n)$

$M_s = 1/(1 - (0.0031)(6)/1.498)$

$M_s = 1/(1 - 0.0186/1.498)$

$M_s = 1/(1 - 0.0124)$

$M_s = 1/0.9875$

$M_s = 1.0126$

$M_p = 1/(1 - D_v(h))$

$M_p = 1/(1 - 1.25 \times 0.012)$

$M_p = 1/(1 - 0.015)$

$M_p = 1/0.985$

$M_p = 1.0152$

$M_t = (M_s)(M_p)$

$M_t = (1.0126)(1.0152)$

$M_t = 1.0279$

Percentage of Magnification = $(M_t - 1)100$

Percentage of Magnification = $(1.0279 - 1)100$

Percentage of Magnification = $(0.0279)100$

O.D. percentage of magnification = 2.79%

O.S. $M_s = 1/(1 - (t)(n))/1.498$

$M_s = 1/((1 - 0.0059 \times 8)/1.498)$

$M_s = 1/(1 - 0.0472/1.498)$

$M_s = 1/(1 - 0.0315)$

$M_s = 1/0.9684$

$M_s = 1.0326$

$$M_p = 1/(1 - Dv(h))$$

$$M_p = 1/(1-(3.50)(0.012))$$

$$M_p = 1/(1 - 0.042)$$

$$M_p = 1/0.958$$

$$M_p = 1.0438$$

$$M_t = (M_s)(M_p)$$

$$M_t = (1.0326)(1.0438)$$

$$M_t = 1.0778$$

$$\text{Percentage of Magnification} = (M_t - 1)100$$

$$\text{Percentage of Magnification} = (1.0778 - 1)100$$

$$\text{Percentage of Magnification} = (0.0778)100$$

$$\text{O.S. percentage of magnification} = 7.78\%$$

The magnification of the right lens would be 2.79% and 7.78% in the left lens, which is a difference of 4.99%. This much of a difference in magnification between the two eyes will induce aniseikonic symptoms that include: Asthenopia, Diplopia, Headaches, Nausea and Suppression of one eye²⁰. By simply changing the base curve and thickness to (8 b.c., 5.9 ct.) in the right lens, which is the same as the left lens, magnification in the right lens would be 4.83%, a difference of only 2.95% which is below our 3% threshold. The example above is just one of many methods that can be used to reduce aniseikonic symptoms. For more information on reduction of aniseikonic symptoms, consult any aniseikonia references.

Since the manifestation of aspherical lens designs (non-spherical surfaces to further reduce marginal astigmatism), some opticians forget the importance of base curve basics and rely on asphericity to correct mechanical defects. Although CR-39 is still the most commonly used lens material in today's lenses, few manufacturers offer aspherical lens designs in CR-39. Most manufactures do offer aspherical curves in refractive indices higher than 1.530n. Each manufacturer designs their aspheric lens based on their theory of lens design. Consequently, when selecting the most appropriate base curve for aspherical lenses, it will be necessary to consult

²⁰ Frank Ervin, O.D., The Masters Review, 1994, p. 82

with the specific lens manufactures base curve suggestions. Since CR-39 is the most commonly used lens material for today's lenses and most manufactures do not offer aspherical curves for CR-39, the following procedure should be used to select the most appropriate base curve when designing non-aspherical lenses.

- 1) Using a lens measure (lens clock), measure the patient's current base curve in two primary meridians 90 degrees apart. Make sure your lens measure is calibrated before measuring the lenses.
- 2) Record the measurements as references.
- 3) Ascertain if the patient is comfortable with the view through their current lenses.
- 4) If the new prescription is within one diopter of the previous prescription and the patient is comfortable with the view through the lenses, keep the base curve the same.
- 5) If the new prescription has changed one diopter or more, it may be necessary to change the base curve²¹.
- 6) As the refractive index increases, the surface power also increases. Consequently, it will be necessary to compensate for the increase in surface power. When designing lenses with a higher refractive than 1.50n, Flatten the base curve using the following chart²²:

| Current | New n. | Flatten |
|----------------|---------------|----------------|
| 1.50n. | 1.55n. | 7.5% |
| 1.50n. | 1.60n. | 15.0% |
| 1.50n. | 1.65n. | 20.0% |
| 1.50n. | 1.70n. | 25.0% |

- 7) If the glasses will be worn at a maximum vertex (down the nose) flatten the base curve two diopters.
- 8) If the glasses are half eyes, flatten the base curve two diopters²³.
- 9) Position the frame to a minimum vertex distance.
- 10) Increase parabolic angle of the frame when flattening the base curve.
- 11) Decrease the parabolic angle of the frame, without creating negative parabolic angle, when increasing the base curve.

²¹ M. Di Santo, A.B.O.M., Technical Options for Professional Services, 1993, p. 52

²² Randall Smith, A.B.O.M., Review Course for the Master's Optician Examination, 1996

²³ M. Di Santo, A.B.O.M., Technical Options for Professional Services, 1993, pp. 50-52

Designing the most optically precise lenses for the patient can be both challenging and exciting. It is also important not to forget about the patient's expectations and cosmesis. While correcting one problem, be careful not to induce another problem, or combination of problems. By following the processes and procedures discussed in this thesis, my method will consistently provide optimal lens designs for your patients. Now you know the Truth about Base Curves. I wish you the utmost success in designing your new lenses.

BIBLIOGRAPHY

Bruneni J., Perspective On Lenses: Fifth Annual Edition, (Optical Laboratory Association, 1995)

Cline D., B.S., O.D., Hofster H.W., O.D., Ph.D., Griffin J.R., O.D., M.S.E.D., Dictionary of Visual Science, Third Edition (Chilton, 1980)

Di Santo M., A.B.O.M., Technical Options for Professional Services, (Bell Optical Lab Inc., 1993)

Ervin, Frank, O.D., The Masters Review, (National Academy of Opticianry, 1994)

Fincham W.H.A., McPhil, F.I., Freeman M.H., B.S., Ph.D., Optics 9th Edition (Butterworths, 1980)

Jalie M. F.A.D.O., The Principles of Ophthalmic Lenses, Third Edition (Hazell, Watson and Viney LTD, Aylesbury, Bucks, 1990)

Polasky, M., O.D., Aniseikonia Cookbook, (Polasky, M., 1974)

Smith, Randall, A.B.O.M., Review Course for the Master's Optician Examination, (Review notes September 26, 1996, Anaheim, California)

Illustrations for Figures 1-7 by Chris Mellon, B.B.A., A.B.O.C.

Director of Marketing, Budget Optical's of America, Inc.